CHALMERS
UNIVERSITY OF TECHNOLOGY

# The Impact of Sustainable Materials on Construction Innovation

## The Case of Timber in Gothenburg

Master's thesis in Design and Construction Project Management

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# Abstract

The global climate challenges and growing discrepancy between the availability and demand for natural resources have driven many industries to alter their practices. The construction industry is highly responsible for climate impact and natural resource usage. The pressure for the industry to change is apparent but lacking the required innovation capability as a major obstacle. At the same time, the call for new sustainable solutions provide great business opportunities for organisations.

The aim of the study is to analyse the drivers and barriers for implementing sustainable materials into construction projects in Gothenburg, Sweden. The case of timber structures in multi-storey buildings represents a material that has recently been reintroduced to the Swedish construction industry. The theoretical basis is constructed upon current research on the topics of sustainability, socio-technical systems, resource analysis and construction innovation. The research involves three steps. Firstly, the perspectives of a diverse set of stakeholders are provided. Secondly, the case studies of twelve construction projects formulate the context of timber construction in Sweden. Thirdly, four in-depth perspectives are summarised from Gothenburg stakeholders that represent the public sector, private sector and academia.

The results show the political pressure for implementing timber constructions in Gothenburg due to the associated sustainability benefits. However, the activities of various stakeholders hinder the progress. Similar innovations in other regions have required strong strategic orientations by municipalities, timber industry firms and property developers. The ensuing networks of organisations have provided the resource bases for successful innovation projects. In addition, stable relationships enable the industry to seek benefits from advancing the processes of timber construction, such as standardisation and prefabrication. The successful introduction of sustainable materials into construction requires intense collaboration between the public sector, private sector and academia.

The findings of the research provide a framework which can explain and guide the enabling processes for sustainability transitions in the construction industry. Furthermore, with certain adaptations, the research methodology and process could be applied to other industries due to its suitability for explaining pressures on existing systems. Apart from further research, the results are applicable for regional policy-making and strategy formulation of existing and starting businesses.

**Keywords:** *construction innovation; multi-storey timber building; resource analysis; socio-technical system; sustainable construction material; timber.*

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David Esteban & Ivo Jaanisoo

Gothenburg, June 2016

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# List of Abbreviations

| | |
|---|---|
| 4R: | Four Resource model for business network analysis |
| AoA: | Areas of Advance |
| ARA: | Activity-Resource-Actor model for business network analysis |
| CBBT: | Centrum för byggande och boende med trä (Centrum of Timber Construction and Housing) |
| CLT: | Cross Laminated Timber |
| EU: | European Union |
| LCA: | Life Cycle Assessment |
| LCC: | Life Cycle Costing |
| LVL: | Laminated veneer lumber |
| MLP: | Multi-level perspective |
| OECD: | Organisation for Economic Co-operation and Development |
| SDG: | Sustainable Development Goals |
| SI: | System innovations |
| SME: | Small and medium-sized enterprises |

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# 1 Introduction

The increasing attention on global sustainability issues affect the attention of policy-makers to improve their governance (OECD, 2015). A way of leading the world towards sustainable practice is to affect the functioning of the markets. Innovation is a common topic among the authorities, researchers and entrepreneurs, as the social desires and technical capabilities are providing an increasing amount of opportunities for inventions and the subsequent innovations (Fagerberg, 2005). Examples of economic benefits enjoyed by sustainability-focused pioneers are turning the heads of other organisations to adopt the strategic positions for catching the effect of “first mover advantage”. As an example, for green innovation, it is becoming an accepted entrepreneurial understanding that the green products can be sold for higher prices, improve brand reputation, increase productivity and be at an advantageous position for tightening regulations (Chen, 2008).

From an ecological perspective of sustainability, the construction industry is considered to be providing a high worldwide impact (Qi et al., 2010). The measurement and management of ecological impacts during the operating cycle of buildings is becoming a standard practice. Respective international standards have been established in the last decades and they are being continuously improved. Additionally, other processes such as material manufacturing, construction assembly, renovation and recycling are receiving attention. Many of the sustainability transitions require an even broader perspective within the topics of land use, freshwater use, biodiversity and human health aspects. This is being considered when improving the current tools and methods for assessing life cycle impacts of various products (Finnveden et al., 2009). Arguably, the arguments for timber as a sustainable material strengthen when the scope of assessment is enlarged.

The environmentally-motivated technical innovations rarely happen without the social changes that drive or enable the transition (Rohracher, 2001). Additionally, the holistic feasibility studies of sustainable constructions should bring together the three pillars of sustainability, the social, ecological and economic dimensions. Therefore the aspects of cultural preservation, workplace safety, profitability to the supply chain actors and other process-related questions should be given some weight in the sustainable construction evaluation (Shen et al., 2010).

The construction industry in research has been treated as an outlier from other sectors in terms of improvements in technological and social perspectives. The low innovation capability has been attributed to several issues, such as heavy reliance on product-related services, high entry barriers, high institutionalisation, path dependency, project-based environments etc. (Dubois & Gadde, 2002b; Gann & Salter, 2000; Winch, 1998). The issue has been in attention by national and international bodies of governance which has evolved into policy actions. The European initiative to replace prescriptive with performance-based regulations was one of the results that has lifted the negative pressure on creativity in construction (Blayse & Manley, 2004). As a consequence, the business landscape has changed but with considerably less momentum than expected.

Multi-storey buildings with timber structure became a regular sight in North European cities during the $18^{th}$ and $19^{th}$ century. Large city fires in the respective neighbourhoods led the authorities to ban multi-storey timber construction, due to the lacking capabilities of using the technology in a safe manner. After approximately a century of non-utilization, the technical and regulatory awareness had become sufficient to enable multi-storey timber structures with the performance-based constraints. In Sweden, the market response shows large regional differences when re-adopting the technology. In some areas, there is almost no interest to build multi-storey buildings in timber (Bengtson, 2003). Proposed reasons to the tendency align mostly with the mentioned barriers about construction innovation (Bengtson, 2003; Mahapatra & Gustavsson, 2008).

National programmes that encourage timber promotion rely on the sustainability values of timber in the social, economic and ecological dimensions (von Platen, 2004). Therefore, the challenge, reflected in the present study, is to observe the changed situation at the output and demand level of new constructions which are affected by the increased attention on sustainability and enabling policies for construction innovation. The research rests on the hypothesis that the adoption of sustainable materials in a wider scale faces barriers and unexploited opportunities which are engrained to the industry. It is crucial to highlight these drivers and barriers in order to manage their impact on the transition towards a sustainable society.

## 1.1 Required Attention Areas in Construction Research

The literature used for supporting the study has been reviewed in terms of further research recommendations. The recommendations reflect deficiencies in earlier studies and consequently provide opportunities of creating knowledge that is useful to the industry.

From the perspective of construction innovation, there is much to be researched about the influences and subsequently the societal consequences of the innovation. This is especially suitable for the construction industry due to its high relation to societal well-being (Blayse &

Manley, 2004). Managing the knowledge of innovation drivers is also important to companies that aim to improve their market positions and product quality (Bossink, 2004). That is especially the case for construction clients that determine the “rules of the game” (Pitt et al., 2009). Additionally, the isolated view of resources can provide an objective perspective on how the value of a construction product can depend on its connections to other resources which are consciously managed by the relevant stakeholders (Håkansson et al., 2009).

Regarding the major drivers of construction product innovation, sustainability is prevalent in recent literature. However, the aspect of sustainability is often defined from an ecological dimension with only indirect attention to the economic and social sustainability (von Geibler et al., 2010). Such deficiencies are also apparent in construction innovation literature in the context of Sweden. Wood as a construction material is widely researched in Sweden but the reasons for its application could be further elaborated (Bengtson, 2003; Mahapatra & Gustavsson, 2008, 2009). This could expand the understanding of respective barriers and opportunities while simultaneously providing knowledge of regional differences.

## 1.2 Aim of the Thesis

The aim of the thesis is to analyse the drivers and barriers for implementing sustainable materials into the construction projects in Gothenburg, based on the case of timber. Thus, the study intends to explore benefits and negative aspects of using sustainable materials in the construction industry, as well as identifying the challenges that need to be overcome in order to improve sustainability conditions of the industry. The aim is relevant to various stakeholders but the primary focus is on municipalities, researchers, property developers, construction contractors and timber building manufacturers.

## 1.3 Disposition

This thesis is structured in 7 different chapters which are defined according to the purpose of the research. The disposition of the chapters and a brief description of its content is provided in Table 1.

*Table 1. Disposition of the thesis*

| Chapter | Content |
|---|---|
| **1** | Introduction |
| **2** | Methodology of Defining the Project Aim |
| **3** | Theoretical Framework |
| **4** | Research Methodology |
| **5** | Empirical Findings |
| **6** | Analysis |
| **7** | Concluding Discussion |

*Chapter 1:* The chapter includes the introduction of the topic. The purpose of the thesis is described as well as the problem statement that motivated the authors to carry out the research.

*Chapter 2:* The process of identifying the research aim is described. The process follows the methodology established by Challenge Lab in order to identify the sustainability-related issues of Gothenburg.

*Chapter 3:* The literature from earlier research is summarised that supports the analytical framework. The analytical framework at the end of the chapter summarises the research questions that derive from the studied literature.

*Chapter 4:* The strategies, methods and writing process of the thesis are described. In addition, a justification is provided for the choice of measures within the study.

*Chapter 5:* The interview data for Swedish perspectives, Gothenburg perspectives and the data of case studies is presented.

*Chapter 6:* The data of the earlier chapters is combined and analysed to answer the research questions stated in the analytical framework.

*Chapter 7:* The chapter presents the conclusion made by the authors, based on the research aim. Further implications beyond the present study are provided and recommendations for further research conclude the paper.

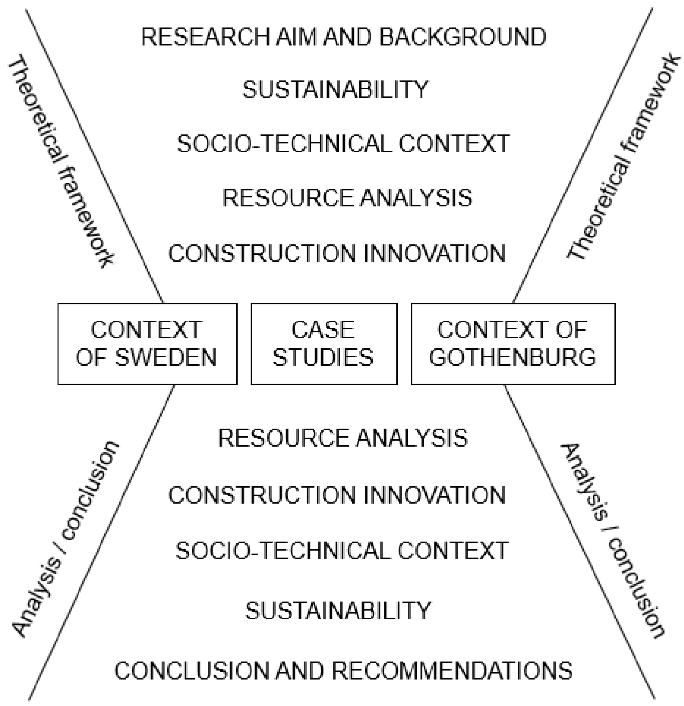


*Figure 1: Structure of the study*

# 2 Methodology of Defining the Project Aim

*The present chapter describes the journey of the authors from thorough understanding of the current societal challenges until defining the aim for a specific research. First, the chapter describes the research group Challenge Lab which provided the crucial resources for the study. Secondly, the theoretical basis for specifying the research aim is presented. Last but not least, the group work process is described for resolving a research aim which is currently the most relevant to the authors and the society.*

## 2.1 Challenge Lab

Challenge Lab is a neutral space created for Master's degree students in order to carry out their thesis projects within the frame of sustainability transitions. Throughout the Challenge Lab process, the students are able to identify the current regional challenges that must be overcome in order to achieve a sustainable future. By providing unique abilities of self-management and leadership to students of different disciplines, these challenges are faced from an integrative perspective. Its core aspect is the internal and external collaboration through collective strategic development, dialogues and research. The dimension of sustainability provides a basis for a transformative strategy as the solutions are sought from areas with insufficient considerations towards the various aspects of sustainability. Challenge Lab, simultaneously an integrative and a transformative force, could be treated as a driver in our society because of its direct and indirect influence on the societal decision making instances (Holmberg, 2014).

In order to create a neutral arena, Challenge Lab gathers students with various backgrounds and experiences, who work together towards the common goal of becoming change agents for a sustainable future. Being a change agent implies that the students will be able to challenge the current complex systems of society in a global context. To achieve this, the change agents are provided with several tools which enhance their leadership skills as well as the awareness of their own values and strengths. Change agents must be able to recognise their own values and capabilities which is enabled by self-leadership workshops. The main strength of being a change agent is their potential to bring together people from different levels of society to encourage a process of co-creation towards a sustainable future. The reason for such potential is the neutral profile of students as they are not representing the interests of a certain organisation. Additionally, the diversity of Challenge Lab students and their wide approach towards the societal issues may generate discussions that are uncommon but important to observed networks. For these reasons, it is easy to establish trust between students and various groups of stakeholders. The co-creation process is usually characterised by openness and sincere attitude (Holmberg, 2014).

According to Brown & Wyatt (2015), the selection of people from various backgrounds is also important in design thinking which is a method utilised in the Challenge Lab setting. Stimulating empathy among a diverse set of people can create a collaboration atmosphere that is open, optimistic, experimenting, curious and encouraging to learn from practical experience.

Through continuous interaction with the public sector, private sector and academia, the students are able to identify the current challenges that are hindering the transition towards a desirable sustainable future. This interaction is depicted as a triple helix which symbolises the collaborative engagement of the three stakeholder groups. The development of innovative solutions is carried out by identifying leverage points in the current systems with the support of the backcasting method. Together with the triple helix interaction, Challenge Lab employs three different components constituting the knowledge triangle: research, education and innovation (Figure 2). Students are seen as the most potent stakeholders that can unite the triple helix and knowledge triangle to solve complex challenges in collaboration. In Challenge Lab, the students initiate challenging dialogues among the respective stakeholders which often provide fruitful results due to the non-threatening nature of students. The mission statement of Challenge Lab connects the vision and means of its application in practice. Framed by Holmberg (2014), the mission is as follows:

*"The Challenge Lab mission is to:*

- *Strengthen the educational dimension in the knowledge triangle within the Areas of Advance.*
- *Provide a natural hub for the triple helix actors within the five regional knowledge clusters, where all parties are drawn because of the students, as they all have a stake in the students.*
- *Build trust within the clusters through students. A defining feature of students is that they are simultaneously non-threatening and challenging, a feature crucial to the kind of change society greatly needs, positioning the students to be powerful change agents.*
- *Give the students the opportunity to develop unique skills in working across disciplines and from a challenge-driven perspective."*

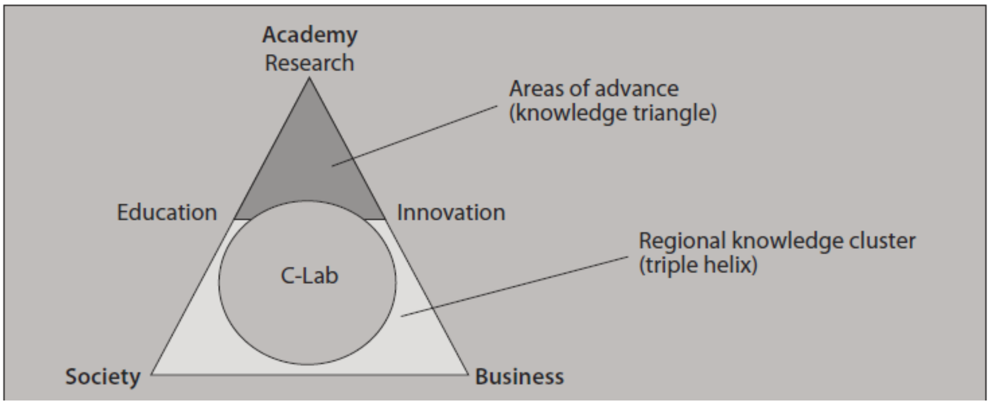


*Figure 2: Challenge Lab at the centre of the regional knowledge cluster (Holmberg, 2014)*

The Challenge Lab process consists of two phases in which different methods and tools are applied. During phase one the students work together to identify current sustainability challenges. Consequently, different strategies are generated to overcome them by employing the backcasting method. The result is a specific aim for the Master's theses that are to be carried out afterwards. Phase two aims to take the outcomes of phase one to develop them further. The result is a set of Master's theses that provide transformative and integrative impacts to the society. In the following section the backcasting method is explained, as well as the main tools that are implemented during phase one.

## 2.2 Theory of Defining the Project Aim

Backcasting is a method that helps to envision a desirable future and provides different strategies for pursuing its achievement (Robinson, 1990). The main feature that distinguishes the method is its scope of attention that spans from a future end-point to the present situation. According to the author, this method facilitates the identification of requirements needed to reach a desired goal. Instead of forecasting the future by its likelihood, backcasting intends to present the consequences of alternative scenarios which are defined based on externally set criteria.

According to Dreborg (1996), it is important to consider the context when backcasting is applicable. He suggests that the method should be used for complex societal topics with a long-term focus. Holmberg (1998) adds that backcasting constitutes an important tool when large societal changes are required as well as when the current trends do not help to overcome the problems.

Holmberg (1998) discusses the suitability of the backcasting method in order to achieve a path of sustainable development. He defines four steps in an orderly manner to align the method with a strategic planning for sustainability (Figure 3): (1) Define a framework for sustainability; (2) Describe the current situation in relation to the framework; (3) Envisage a future situation; and (4) Find strategies for sustainability.

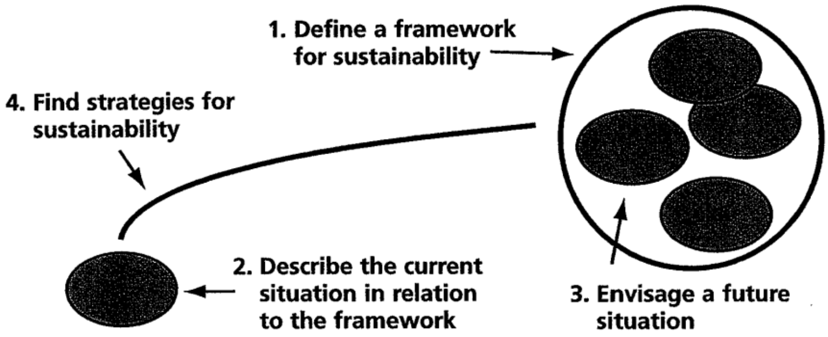


*Figure 3. Steps in strategic planning for sustainability (Holmberg, 1998)*

### 2.2.1 Step 1: Define Criteria for Sustainability

The first step of the backcasting method is to establish the criteria for a sustainable future based on four dimensions: ecological, societal, economic sustainability and individual well-being. According to Holmberg and Robèrt (2000), the criteria should be established in such a way that the ecological, societal and economic dimensions create the conditions for guaranteeing the fulfilment of well-being (Figure 4). In order to formulate the criteria for each of these dimensions, it is necessary to acknowledge certain aspects which have great influence over them and can be divided into two categories: inside-out and outside-in. **Inside-out** refers to the characteristics that originate from the individual, which affects its behaviour and the way the environment is perceived. **Outside-in** includes all the external factors that create impacts on the individual and have to be assimilated.

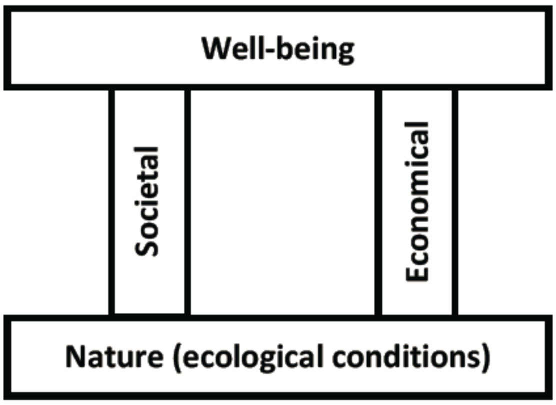


*Figure 4. Dimensions for a sustainable development (Atkisson, 2012)*

**Inside-out perspective**

Before defining the criteria, it is necessary that the individual is aware of his or her own values and strengths, providing a tool to visualise a conceivable sustainable future. Besides, being able to recognise personal values and strengths facilitates the individual to exercise his or her self-leadership capabilities. By following the guidance of Stewart et al. (2011), the individuals are therefore empowered to identify what needs to be performed, for what reason it is done and in which way it should be approached. That provides foresight and confidence throughout the whole Master's thesis writing process.

**Outside-in perspective**

After identifying the individual aspects that contribute to criteria selection, some of the external factors must be considered. Among these considerations are the principles for sustainable development defined by Holmberg et al. (1996) which aim to set the boundaries for societal growth without affecting the ecological environment. These principles are taken as a basis to elaborate criteria for the other dimensions.

Human needs are the second external consideration to be taken into account for criteria development. According to Max-Neef et al. (1992) human needs are the crucial aspects that are strongly connected to human evolution. The authors have identified nine different needs which are necessary to achieve individual well-being. Those are subsistence, protection, affection, understanding, participation, idleness, creation, identity and freedom. It is important to consider that the principles should not affect the planetary boundaries. This means that the envisioned future should operate without affecting systems and processes on Earth (Rockström et al., 2009).

### 2.2.2 Step 2: Describe Present Situation in Relation to Sustainability Criteria

The objective of the second step is to analyse the present situation by considering the principles established during the first stage (Holmberg, 1998). Therefore, during this phase, the current attributes of society are examined in order to see their alignment with the criteria. The outcome of step two will serve as a starting point both for the phases three and four.

One of the main tools that can be used to analyse the present situation is a dialogue. Isaacs (1993) states that dialogues enable to create a space in which different parties meet to exchange ideas, experiences, proposals and assumptions with the purpose of creating a common goal and understanding. Another benefit of dialogues is that they incentivise the emergence of new ideas from the collective thinking that is created. Hence, dialogues constitute an instrument to create trust among the actors and incentivise co-creation.

### 2.2.3 Step 3: Envision Future Solutions

The point of departure in step three is the analysis of the present situation at step two. The present situation description is compared with the principles from step one in order to define the breaches between them. From this result it is possible to envision a variety of future options. According to Holmberg (1998), this is performed by focusing on the desired outcomes rather than current issues. Furthermore, during step three it is necessary to consider all the potential restrictions and boundaries that could be encountered for the different envisioned futures.

At this stage of backcasting, another method is introduced, called design thinking. Brown (2008) defines design thinking as the alignment of current needs with actually feasible conditions in order to create a product. The three overlapping spaces (instead of orderly steps) that constitute design thinking are inspiration, ideation and implementation. Inspiration is the problem or opportunity that provokes the particular design thinking process. Ideation follows where the gathered information is analysed and turned into ideas that utilise the challenges or opportunities apparent from the synthesis. The final space, implementation, implies that the ideas with the most potential are selected and developed further into specific action plans (Brown & Wyatt, 2015). The design thinking process is based on iteration and learning by doing which is an ongoing process during all the phases in Challenge Lab (Figure 5).

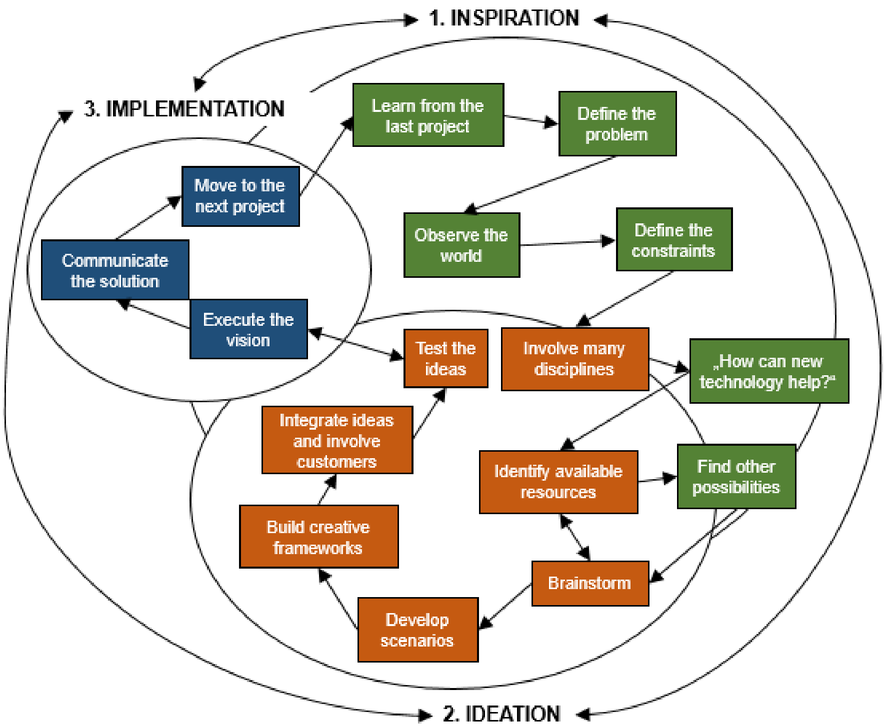


*Figure 5. Process of design thinking (adapted from Brown, 2008)*

### 2.2.4 **Step 4: Finding Strategies Towards Sustainability**

According to Holmberg (1998), the fourth step of backcasting aims to find the strategies that could transform the present situation into the desired sustainable future state. Moreover, it is essential to verify that these strategies are aligned with the criteria established during step one. In parallel, possible contradictions between strategies and criteria should be avoided. Another necessary aspect is the feasibility of the identified measures, referring to their attainability with currently available resources.

The theory described above is used as a guideline during the initial phase of Challenge Lab. The results of the application in order to define the project aim are explained in the following sections.

## 2.3 Results of Defining the Project Aim

The structure of Challenge Lab and backcasting method have been used to reach the research question of this study. The point of departure is the universal understanding that there is a need for scenario-based collaboration in order to steer society towards a sustainable state. The four backcasting steps defined by (Holmberg, 1998) were utilized to understand the current challenges within the Västra Götaland region in Sweden.

### 2.3.1 **Step 1**

The future sustainability criteria-setting is done as a guideline to achieve the Challenge Lab vision. The students decided to keep the vision of Challenge Lab team of the previous year in order to maintain continuity to Challenge Lab on a long-term basis. Therefore, the statement for the desired future is as follows:

> *"A sustainable future where we, approximately 10 billion people, are able to meet our own needs within the planetary boundaries without compromising the ability of our future generations to meet theirs".*

**Inside-out perspective**

The student group at Challenge Lab followed both, the inside-out and outside-in approaches to obtain a balanced understanding of the desired societal state. The inside-out perspective was strongly supported by self-leadership workshops and consequent work in order for the students to have a better understanding of their own individual attributes. The personal strengths and ambitions provided a basis for effective and efficient work as a group. At a later phase of Challenge Lab, the combination of different strengths was helpful to create diverse and supportive partnerships. Open discussions were held for interpreting the four pillars of sustainable development – ecological, social, economic sustainability and individual well-being.

**Outside-in perspective**

The outside-in perspective incorporated scientific literature search as well as learning about international political objectives. For the goals of sustainability, three major political institutions were identified: international agreements, European Union policies and policies by Swedish government. Regarding the former, the agreements on 17 Sustainable Development Goals (SDG) by the world leaders at the UN Climate Conference in September 2015 have been a fundamental reference point. As inferred by Robinson (1990), there is a need to predict the desired future in order to shape our behaviour towards those imagined outcomes. Therefore, the recent high-level agreements on SDGs provided a reliable guidance to follow in strategic decisions.

The European Union welcomes the SDGs and is committed to actively finance the research and development among other measures towards an achievement of the goals. Sweden is proactive in many of the measures by EU Commission, especially considering climate change. The goal of becoming carbon neutral as a country by year 2050 is unique and exemplary to the whole world.

From the inside-out and outside-in perspectives, a set of criteria were developed within the four pillars of sustainability:

**Ecological criteria**

The criteria for ecological sustainability have been in focus for a wide array of researchers. The criteria are adopted from Holmberg et al. (1996) and are stated as follows:

*Human activities affecting nature's function and diversity are done in such a way that they:*

- *do not increase the concentration of substances from the lithosphere in the ecosphere;*
- *do not increase concentration of human made substances in the ecosphere;*
- *do not systematically deteriorate the resource base; such as fresh water, fertile land, and biodiversity through manipulation, mismanagement, or over-exploitation.*

**Well-being**

The concept of well-being is a recurring theme in research for sustainable development. Max-Neef et al. (1992) and the follow up study by Cruz et al., (2009) has provided the theme with a framework of individual needs that should be defined and measured. These needs, reflected in the criteria below, are supposed to be universally acceptable as well as their deterrence should be universally unacceptable. The Sustainable Development Goals adopted by the General Assembly of United Nations support the well-being criteria primarily by discussing the issues of poverty, hunger, health, education and sanitation (Assembly, 2015). The criteria of well-being, derived by Challenge Lab, are:

> *"The goal of the society and economy, lying on the nature as its fundament, is to serve the human wellbeing, where:*
>
> - *Everyone has the right to human basic needs; health, security, future security, food, water, sanitation, recreation, shelter, energy;*
> - *Human life includes: subsistence, protection, affection, understanding, participation, idleness, creation, identity, freedom;*
> - *Everyone should have access to the same opportunity and the freedom to build a meaningful life;*
> - *Everyone should have access to the same opportunity and freedom to explore and express your "inner-self" and to be your values without limiting others' freedoms or harming others;*
> - *Social and economic inequalities are not justified unless they are to the greatest benefit to the least-advantaged members of society."*

**Economic Criteria**

The pillar of economic sustainability is considered to be a support towards attaining personal well-being while using our natural resources in a sustainable manner. The starting point is the work by Cruz et al. (2009) who refer to Aristotle in breaking down the understanding of economics. One constituent of economics is chrematistics as the art of acquisition and the other half is stated as oikonomy which describes the (re)creation of value with the resources at hand. The latter is also referred to as the "art of living and living well" which is also what defines the sustainability criteria. Anand and Sen (2000) mention the necessity to treat human capital as the end to sustainable human development rather than means to maintaining and expanding the material prosperity. Therefore, the notion of value in the Aristotelian definition of oikonomia could be the well-being of the human being and its natural environment. Additionally, to the static manner of treating economics there is a need for certain adaptability to unforeseen events, called resilience. Arguably by Simmie & Martin (2010), the resilience of an economic system should not only concern the return to an initial state. Economies are dependent on continuous changes of knowledge and thus should react to shocks by obtaining new capabilities, therefore the return after a shock should be to an advanced state. The Sustainable Development Goals adopted by the General Assembly of United Nations support the economic criteria primarily by discussing the issues of sustainable production and consumption, sustained economic growth, resiliency in infrastructure and innovation as well as energy that is renewable and efficient (Assembly, 2015). The criteria are as follows:

> *"The economic system is an instrument that enables individuals to meet the other criteria (society, wellbeing, nature) efficiently and effectively, as such:*
>
> - *The function of the economic system is driven by the other criteria and not the other way around;*
> - *It enables further use of resources and avoids dissipative use of materials;*
> - *It ensures an equitable distribution of resources;*
> - *It has an inherent mechanism of maintaining and serving societal infrastructure and institutions that permits human wellbeing to be met over time;*
> - *It has the ability to change and to adapt when facing shocks and disturbances."*

**Societal Criteria**

In addition to individual well-being, there is a need to set the criteria for the preferred coexistence among the individuals. Raworth (2012) illustrates the safety and equity of people to be carried between two boundaries that are environmental ceiling and social foundation. The latter includes the directions agreed upon at the UN Conference on Sustainable Development in June 2012. The Sustainable Development Goals adopted by the General Assembly of United Nations support the societal criteria primarily by discussing the issues of gender equality, urban environment sustainability, peace, justice and ongoing collaboration in the goal development (Assembly, 2015). It is also important to build resiliency into the development process in order to maintain the desirable goals for sustainability even after unforeseen disruptions. Adaptable management is the key, considering that societal environments are subject to high complexity and consequent unpredictability (Pisano, 2012). The societal criteria by Challenge Lab are:

> *"The societal system is an instrument for individuals to live together within the other criteria with respect to the following conditions:*

*It enables the well-being, empowerment and productiveness of every individual while adhering to the ecological principles by:*

- *equitable accessibility to education and health care;*
- *gender and social equity;*
- *equal human rights;*

*Its governing mechanisms (and societal institutions) are built on transparency, accountability, mutual trust, adaptability and recognition of diversity."*

### 2.3.2 Step 2

The criteria-setting is followed by interactions with individuals who are involved in complex decisions affecting the sustainability transitions in the Västra Götaland region in Sweden. Several multi-stakeholder dialogues were carried out in order to identify the current situation and set several shared common goals as well as capture newly emerging ideas. The summaries of the dialogues below refer to the aspects in broad relation to the current study. Additional elaborations are omitted from the summaries.

**Dialogue 1: The integrative role of academia**

Chalmers University of Technology, the location of the current study, has gone through a structural change in order to better match the scientific excellence with global challenges. The result is a matrix organisation with departments integrated by profiles of excellence. These profiles called Areas of Advance (AoA) are created by necessity for nationwide responsibility in terms of solving the sustainability challenges of today and the future (Svanström et al., 2012). The dialogue elaborated further on the interrelation of the knowledge triangle – integrating academia, business and the public sector.

Through the dialogue it was possible to observe new opportunities that have arisen from an interdisciplinary collaboration across university departments. Completely new branches of study have appeared both in basic and applied research. The balance in resource allocation constitutes one of the main difficulties that AoA have to face, especially because of political priorities and strong driving forces from certain industries.

The area of built environment attracts relatively little amount of research when compared to other industries. Among the possible reasons are a project-based nature and limited investment capacity for basic and applied research. In addition, developing the built environment requires a substantial amount of stakeholder involvement in a long-term perspective. That is rarely the case in the construction sector. Besides, there is a lack of interdisciplinary collaboration within the existing stakeholder networks. By improving the mentioned issue, the industry could be able to open towards more creative solutions for a sustainable future.

**Dialogue 2: Urban Development and Transportation in a Densely Inhabited City**

Gothenburg is on the threshold of major developments that aim to improve societal, economic and ecological sustainability along with individual well-being. Despite the strong political visions, some guidance is needed in order to ensure its proper implementation. Therefore, the academia in terms of research and student initiatives could provide the needed creative platform. Additionally, the long-term goals should be communicated as clearly as possible, to attract the attention of a wide array of stakeholders.

Regarding built environment, the industry is seeking for economically sustainable solutions. For instance, it is beneficial to property owners that their investment is adaptable to various types of uses that might be required during the lifetime of the building. Public infrastructure and facilities should, at the same time, attract as many people as possible to share the development and maintenance costs over a larger number of tax-paying citizens. However, the social and well-being benefits of a dense city are not inherent. The collaborative thinking towards environmentally sustainable and socially inclusive communities within the planned environments need to be intensified. Ideally, the private sector should be motivated to be aligned and even steer the sustainable transformations to secure consistent returns from their investment with low long-term risk. Still, business cases for solutions benefiting all dimensions of sustainability are not frequent.

**Dialogue 3: Innovations in our built environment**

Collaborative efforts, discussed in the previous dialogues, might end up with innovation projects that could promote creative and collaborative thinking further. As an example, the use of materials in the construction industry is strongly dependent on the product suppliers. Interaction between the property developers and material producers is almost non-existent.

An example of innovative materials is structural timber which is not commonly used in multi-storey buildings. It should be tried harder to utilise the renewable sources of materials such as the biomass. There is a lack of knowledge among professionals and people in general about the benefits of timber as a construction material. The private sector dealing with forestry and timber component manufacturing could show more initiative in the innovation projects, similarly to some other regions in Sweden. There is already a large capacity of research in Sweden that supports the industry towards utilising timber as a structural material.

### 2.3.3 **Step 3**

Data received from the dialogues initiated the ideation process of design thinking. Brainstorming sessions were held to map the topic areas of interest within the themes of each dialogue. The topic areas were synthesised with the result of eleven key themes. A decision had to be made to choose only the three most actionable themes. This stage stands for a group agreement on the most critical challenges in Västra Götaland, based on the inspiration process according to design thinking as well as steps one and two of backcasting method. Several discussions were held to narrow down the amount of topics. It required compromises but also agreements over leaving some topics out of further discussions. Additionally, the topics varied in terms of scope which enabled the group to generalise some while specifying other common themes. Eventually, three themes were selected, called “hot topics”:

- Value chains of sustainable materials in the construction industry;
- Sustainability challenges in modern densely built cities;
- Sustainable transportation strategies.

The next activity was to expand the 'hot topics' and understand them from different perspectives, using the relevant methods. The perspectives for analysis were as follows:

Who are the stakeholders?

The people were identified from dialogue sessions or personal contacts that could be interested in the respective topics. It was a preference to seek for stakeholders from the groups of triple helix – the private sector, public sector and academia. For the sustainable construction material topic, the identified stakeholders were chemical industry, construction clients, city developers and construction contractors.

What is the relation to sustainability criteria?

The previously established sustainability criteria were matched with proposed topics. It was important to identify how the research on a particular topic could be carried out on the basis of economic, ecological and social sustainability as well as the well-being criteria. For the sustainable construction material topic, the criteria had clear interconnections, especially in terms of ecological and economic sustainability. The social sustainability and well-being criteria were expected to require further research.

Where is the transformative potential?

It was identified, whether and where the existing systems have to be disrupted. For the sustainable construction material topic, the potential was found at the procurement level. Decision-making stakeholders and the respective activities required attention.

Where is the potential for being integrative?

For cross-disciplinary changes, the integrative action is particularly important. This implies the involvement of stakeholders not only for initial inspiration but also for the ideation and implementation processes. For the sustainable construction material topic, major potential was acknowledged due to the amount of various stakeholders that are engaged in every project. On the other hand, these stakeholders are rarely in long-term networks which may need to be challenged.

What are the socio-technical challenges?

When addressing the socio-technical challenges, the path dependent characteristics of the specific industry were observed. This required attention on the levels of current policies, scientific support, available technology, industry networks, markets and culture. For the sustainable construction materials, the paths were distinguishable. During the stakeholder dialogues, a major discrepancy was mentioned in terms of awareness between the demand-side and output-related stakeholders. The construction networks are often disjointed and therefore it is difficult for the stakeholders to initiate and maintain continuous change processes.

Firstly, attention was directed towards the path dependent characteristics of the specific industry. Secondly, the top-down and bottom-up pressures to excite changes in these path dependent characteristics were looked into.

How to understand the topic on a multi-level perspective?

On a multi-level perspective, the socio-technical systems are being affected by top-down and bottom-up pressures. In the sustainable construction material topic, it was clear that the legislative pressure is increasing that forces the industry to take actions towards improving their activities ecologically, economically and socially. The bottom-up pressures originate from innovative projects and construction systems that are not common in the current industry. The application of sustainable materials may be considered an innovation that is challenging the current path-dependent industry.

What part of value chains might require intervention?

During the analysis, various locations of the value chains were identified where intervention could provide results towards a sustainable built environment. It was actually the interaction of various parts of value chains that need more awareness of the capabilities and desires of each other. The demand-side stakeholders should be aware of the producers and the other way around.

**Topic constellations and voting**

The further analysis ensued with another brainstorming session which ended up with constellations of perspectives around the “hot topics” each of which could be the departure point for a research project. As an example the topic “Value chains of sustainable materials in the construction industry” generated the following perspectives:

- Clusters and cooperation;
- Culture;
- Innovation environment;
- Logistics;
- Markets;
- Procurement;
- Product development;
- Regulations;
- Reusing and recycling;
- Test-beds (could also be considered as a separate topic).

A democratic process of voting was carried out to select the topics and perspectives that had the highest interest from all the members of Challenge Lab. The highest voted topics and perspectives were brought along to further selection. Additionally, the team members and stakeholders identified during the previous exercise were allocated to most popular topics and perspectives. A map was generated with the constellation of topics, perspectives, Challenge Lab members and stakeholders. The map became a guide to the team, helping to choose research partners and topics of study. Authors of the current study were planned to be involved in the research of sustainable building materials from the possible perspectives of value chains, organisational networks, logistics and test beds for innovation.

### 2.3.4 **Step 4**

The final step of backcasting, and in the utilised form, initiating the implementation stage of the design thinking method, took the authors to develop the partnership and coordinate further activities. Partly still at the ideation phase, the topics and perspectives were reconsidered on the basis of individual strengths, skills and ambitions. The high extent of analytical skills, diverse background in the construction industry and the ambition to improve the sustainability profile of the industry led the authors towards an in-depth research of construction material sustainability. The university supervisor was engaged to the project and explorative dialogues were held with stakeholders knowledgeable in the topic area.

The knowledge and experience of the authors in the construction industry and the insights from stakeholders led the discussions towards peculiarities of the industry, especially the relatively low innovation capability. Extrapolating to construction materials and considering the desire to not disturb the ecological criteria in step one, the attention was pointed towards sustainable construction materials and their introduction to the existing construction business networks. Possible alternatives to choose were materials from recycled products and from renewable sources. Additional thoughts were put on other kinds of sustainable materials that could be developed with extensive business networks spanning across the chemical and construction industry. Eventually, the materials from renewable sources were chosen for research, with the example of timber as a reintroduced construction material to structural systems of multi-storey residential buildings.

# 3 Theoretical framework

*In this chapter, the existing literature is reviewed in order to prepare a basis for the empirical findings and the analysis. Firstly, a description of sustainability in the context of the industry is explained. Secondly, the socio-technical systems are presented, being followed by resource analysis as a tool to make sense of the complex topic. Furthermore, the aspects of construction innovation are provided. The chapter ends with the analytical framework which summarises the research questions that derive from the studied literature.*

## 3.1 Sustainability in the Construction Industry

The Brundtland Report (Brundtland et al., 1987) defines sustainability as "meeting the needs of the present without compromising the ability for future generations to meet their own needs". Additionally, in order to achieve a sustainable societal development, it is necessary to be able to address the three different dimensions – societal, economic and environmental - as shown in Figure 6. According to Morelli (2013), these three pillars of sustainability are mutually dependent and cannot exist without each other. Thus, sustainability cannot be reached if one of these dimensions is not fulfilled.

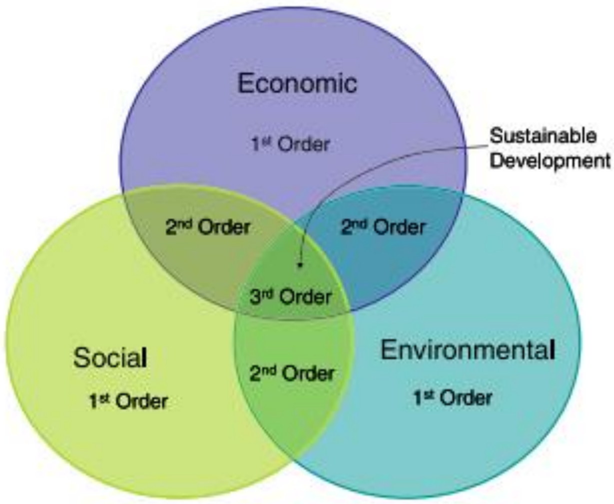


*Figure 6. Sustainable development (Edum-Fotwe & Price, 2009)*

Construction industry is known for its sizeable impacts on the three different levels of sustainability mentioned above, which are often permanent and considerable (Ortiz et al., 2009). The increasing concern for sustainability in recent years by governments and general population has changed the way the topic is approached by industry stakeholders. Progressively more companies and researchers are focusing on developing and improving the traditional construction processes in order to make them more sustainable through all the stages. However, the slow learning characteristic of the construction industry hinders the possibility to adapt its processes to the requirements needed for sustainability. Additional reasons for a slow adaption of green innovations in the construction industry are framed by Gluch et al. (2007) on the basis of ecological sustainability:

1. A disbelief that a green market is available for respective products and services;
2. Lack of collaboration between construction process stakeholders;
3. Lack of monitoring of ecological goals which disorientates the actors;
4. Belief by stakeholders that the policies and legislations will solve the problems;
5. Lack of understanding of influence by the banks to support environmental actions;
6. Lack of collaboration among the firms, academia and environmental organisations.

Furthermore, to achieve sustainability in the construction industry, it is reasonable to identify the principles that should be followed in a societal, economic and ecological context. Hill and Bowen (1997) propose several principles for each of the dimensions mentioned above, which are stated as follows.

### 3.1.1 Social Principles of Sustainable Construction

The social principles for a sustainable construction are the ones that aim to ensure that a society with justice and equity is possible. One of the principles described by the authors is that construction should help to increase the living quality of the population. This can be achieved by providing secure and comfortable structures which facilitates the fulfilment of the basic human needs, such as health, shelter and education. Another principle highlights the importance of construction in developing cultural diversity through adequate planning.

On the other hand, other principles relate more to the working environment created during the construction process. For instance, a construction project must ensure the safety and well-being of its workers. At the same time, means must be available for training and developing the skills and capabilities of workers to create a quality product and reduce the risks during the process. Additionally, equal employment opportunities must be ensured in order to be aligned with a society of equal and fair distribution of benefits.

### 3.1.2 Economic Principles of Sustainable Construction

Economic principles aim to fundamentally reduce the use of natural non-renewable resources. This is achieved by the process of transforming the resources into products through the selection of suppliers and contractors based on their environmental performance. In addition, they try to establish a context where economy is more equitable through a better distribution of resources.

Economic sustainability in the construction industry involves the creation of new jobs that favour unprivileged communities, especially for the people in the surroundings of the project. Job creation can provide a chance for the construction industry to contribute towards a society where resources are better distributed.

A second principle can be realised by pricing the resources based on the real social and environmental cost of each product. Thus, the use of resources would be more efficient and more practices and regulations towards sustainability could be created.

### 3.1.3 **Ecological Principles of Sustainable Construction**

The ecological principles are based on the idea that construction should not affect the ecosystem in a negative way. For instance, the production of artificial substances should be at a slower pace than the nature is capable to assimilate them. As another example, the principles emphasise the importance of reducing the implementation of resources that have a larger impact on the environment.

Additionally, the industry should aim to improve the quality of life while supporting the environmental ecosystems. This means that renewable resources must be prioritised over non-renewable ones, by maximising their usage. Moreover, the reuse and recycling of materials is part of the principles established towards a sustainable construction.

### 3.1.4 **Sustainable Construction Materials**

The construction process of any building or structure involves the implementation of many materials which characteristically differ from each other. The choice of these resources will have a direct impact on sustainability in every stage of the construction process and operation of the building. Dainty and Brooke (2004) point out that around 15% of the materials in a construction project are disposed as waste, showing the importance of working towards the optimization of material use. Yao (2013) underlines that the optimisation and sustainability of construction materials is achieved through waste reduction and recycling of materials after the building reaches the end of its life cycle. Therefore, organisations and professionals involved in the construction industry have an important role to play in order to improve the way construction materials are used, through a better utilisation as well as reusing and recycling of those resources.

### 3.1.5 The Measurement of Construction Process Sustainability

The increasing pressure towards a sustainable construction have created the necessity to improve each phase of the process. However, to be able to define if the sustainability is truly being accomplished, certain measurements are needed for the three dimensions of sustainability: ecological, economic and societal. As stated by Edum-Fotwe & Price (2009), the ecological dimension counts with more consideration than the others by authorities and general public. Therefore, the knowledge and development about their measurement tools are also diverse.

In recent years, there has been an increasing concern to reduce the ecological impacts caused by the construction industry (Ding, 2008). Hence, some tools and methods to measure the sustainability impact on the environment have been developed. One of the main challenges is to create a standardised tool or method that could be able to include needs of everybody while also evaluating the construction process performance. Ding (2008) also argues that the need for this tool is growing since the ecological issues are becoming more critical.

**Life Cycle Assessment**

A common method used in the construction industry is Life-Cycle Assessment (LCA). Ayres (1995) defines LCA as “a methodology used to evaluate all the ecological impacts of a product from the initial extraction and processing of raw materials to final disposal”. This means that in order to be able to measure the LCA of one product, it is necessary to involve all the parties that participated during its life cycle as well as standardising the way they collect the data.

According to Ortiz et al. (2009), LCA could be seen as an essential tool for achieving ecological sustainability in the construction industry. However, its application must be done not only to fulfil the ecological demands but to increase the efficiency and attractiveness of the products. Besides, Bribián et al. (2009) recognise other benefits in the implementation of an LCA analysis, such as improved competitiveness and the construction of ecologically sustainable buildings. On the other hand, it is known that the collection of LCA data represent the main challenge to be overcome since they are not always available or they frequently lack of quality (Halog & Manik, 2011). The authors consider that the current methods to measure the ecological impacts are deficient since the LCA method is overly simplified. Besides, they point out that these procedures can be used for the convenience of companies and business as usual and they usually avoid approaching the real causes of the environmental problems.

**Life Cycle Costing**

As stated before, the economic aspect is usually the most relevant one inside the construction industry. In order to introduce the economic sustainability dimension into the analyses, some other tools have been developed such as the Life Cycle Costing (LCC). Through this analysis, all the costs during the whole life cycle of a product are considered. LCC requires a structure where all the costs for each step of the product life cycle can be stated as well as the involvement of all the organisations that have been part of it (Halog & Manik, 2011).

**Social Life Cycle Assessment**

In the case of social sustainability an available measurement tool is the Social Life Cycle Assessment (SLCA). SLCA aims to measure the impact during the life cycle of a product on society. However, to measure the actual social impacts is not an easy task since many of them cannot be quantified. Therefore, there exists no standardised and widely accepted method to measure the social impacts of a product (Halog & Manik, 2011).

**Summary**

In this section, three tools are presented for measuring the sustainability impacts on each of the three sustainability dimensions. Nevertheless, there are many other methods that can be used to analyse the life cycle impact of a product. The ones exposed here exemplify the benefits as well as the challenges that must be overcome in order to reach a standardised sustainable construction measurement method.

### 3.1.6 Summary and Research Question Regarding Sustainability

In the current chapter, the drivers and barriers of the transition towards a sustainable construction industry are studied. The conscious steering of the industry towards a sustainable state might need to be guided by the principle “If you can’t measure it, you can’t manage it” (Drucker, 2009). Therefore, the questions to be answered should relate to the definition of sustainability in its ecological, economic and social perspective. Furthermore, the criteria and means for measurement should be defined that fit into the construction industry, possibly in a location-related context. To sum up, the question to be analysed is:

*What is needed to establish coherent sustainability criteria for construction materials?*

## 3.2 Innovations in a Socio-Technical Context

To understand what innovation is, it is firstly important to understand the difference between inventions and innovations. The former is the initial emergence of a new creation while the latter implies the wide-scale application of the novel idea. A varying time lag is often described between the two, commonly spanning a decade or more. Arguably the preconditions needed for a successful innovation can be completely different from what characterises the work of inventors. Throughout history, it has been evident that often the major technological advances do not directly proceed into serving a function in society. A successful innovation requires certain established aspects in the processes of supply as well as market demand. More specifically, a variety of knowledge, experience, resources, finances, user requirements and other aspects could be needed (Fagerberg, 2005).

Another characteristic of innovations is its interrelation to other innovations that are needed for its application. Looking again at the historical examples, there are an abundance of technological breakthroughs that were only possible because of other concurrent innovations that supported their functionality. The implied complexity and multidisciplinary nature is the reason why innovation researchers seek for a broader systems perspective instead of single inventions or innovations that do not represent interlinked actors, activities or resources (Fagerberg, 2005).

The exploration of trying to improve and create new processes and products could be considered a characteristic of the mankind and human nature (ibid.). The research on innovation, on the other hand, is a rather recent phenomenon, increasing its popularity only in the recent decades. Due to the early steps in research and the nature of innovation to be present in many contexts of human activity, the theories and models to follow are especially diverse. Focusing on a specific direction is paramount in order to apply the acquired knowledge.

### 3.2.1 Innovations for Sustainability Transitions

There is a high current attention of international organisations and policy-makers on innovations for ecological sustainability. Green Growth established itself as a topic of interest during the last economic crisis when new strategies were required to re-establish the economic growth on national levels. Aligned with economic interests, the increasing understanding of ecological and social sustainability issues define the limits that account for the well-being of each individual (OECD, 2009). International focus on Green Growth[1] together with sustainable innovation strategies is helping to gather the policy domains into holistic discussions over the economic, ecological and social aspects. Innovation in this respect is attributed to the economic domain as a driver of growth. It is important to note that innovations are often technical in nature, but only rarely is technology the driver of the scope of change needed for acting on global sustainability issues (OECD, 2015). The changes are usually triggered by other mechanisms that are described in the following section.

### 3.2.2 **Socio-Technical System Innovations**

Recent literature has established the notion of socio-technical systems (ibid.). Socio-technical systems are characterised by a cluster of elements that involve technology, science, regulation, user practices, markets, cultural meaning, infrastructure, production and supply networks (Geels & Kemp, 2007). Major changes at the interconnections of these clusters are arguably needed in order to tackle the transition towards a sustainable society. An example of an abrupt change is the 80% carbon emission decrease over the next generation (Smith et al., 2010).

A redefinition of the functions of society and the ways of fulfilling its needs could open up opportunities for completely unexplored socio-technical systems. The subsequent innovations of the production and consumption principles could bring along shifts from one system to another. The novelty of the innovation object is therefore not as important as the redefined use and functionality that has become accessible to the society. Such a perspective expects a research focus on dynamics and change instead of the economic performance of the innovation. System innovations (SI) elevate the functional user needs as the core object of analysis. The supply-side and demand-side actors create, maintain and improve the socio-technical systems as a result of their interactions (Geels, 2004). OECD (2015) underlines three central characteristics of SI:

1. "*Fundamentally different knowledge base and technical capabilities that either disrupt existing competencies and technologies or complement them, resulting in new combinations.*
2. *Changes in consumer practices and markets.*
3. *Changes in infrastructure, skills and other elements, including policy and culture."*

[1] Economic growth that aims at sustainable solutions, especially considering the ecological dimension (OECD, 2015).

The focus of attention in socio-technical research is on the co-evolution of the form and the function (Geels, 2004). Corresponding value to the present study is to understand the societal needs towards the construction products on the domain of sustainability. This can be observed by past initiatives as well as current opinions from the user representatives. The fact that OECD countries are successfully implementing SI in a range of areas can ensure a possibility that the present analysis would be highly applicable in nature (OECD, 2015).

### 3.2.3 The Role of Research and Development

Concerning earlier applications, the public sector activities in terms of system innovations as represented by the initiatives of OECD (ibid.) are useful to follow. It is observed that the existing public support systems are also divided into the supply side and the demand side. The former relates to intangible and tangible resources as innovation inputs while the latter concerns the markets in the form of standards and regulations that the public authorities can affect. However, there are additional areas of attention in innovation policy instruments. The spillovers of knowledge from universities and financial support for supply-side R&D are considered extremely important (Aschhoff & Sofka, 2009). Therefore, the present study aims to expand the limited view of innovation production and consumption by involving the resources possessed by the public sector and academia.

### 3.2.4 Multi-Level Perspective

Multi-level perspective (MLP) has attracted the attention of sustainability research because of its broad problem framing potential at a large-scale level of socio-technical systems. As dynamics between the systems are arguably the sources of sustainability challenges, the level of analyses could not be more limited (Smith et al., 2010). In presenting the MLP, Geels (2004) argues about the typical studies on science and technology as picturing the empirical environment as a complex reality that offers limited possibilities to study in a structured manner. Studies on innovation from an economic perspective, however, tend to overcomplicate the analyses by combining various societal and technological factors that do not have much in common. The MLP, in contrast, provides a framework to analyse the socio-technical innovations as the interlinkages of actors, rules (replacing the term institutions by the author) and socio-technical systems. Developing from that, the transitions from one socio-technical system to another have been described as aligned dynamics on three different levels: 1) Socio-technical regimes; 2) Technological niches; and 3) Landscape developments (Figure 7).

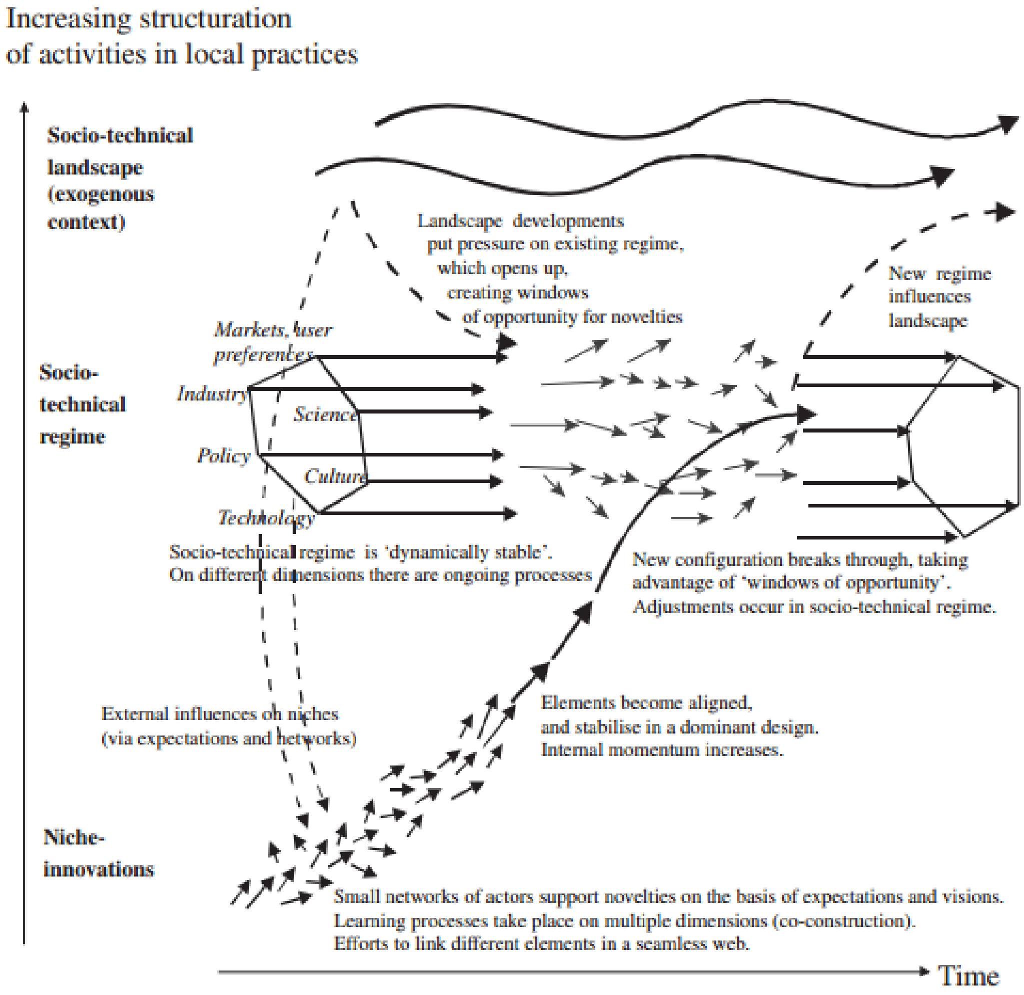


*Figure 7: Multi-level perspective (Geels, 2004)*

**Socio-Technical Regimes**

Focal to MLP is the level of socio-technical regimes which are the stable and dominant ways of fulfilling societal functions. It is represented by clear sets of rules and corresponding actor relationships. Their coordinated activities within and between their social groups as sub-regimes constitute the rather well structured socio-technical regimes. As shown in Figure 7, these sub-regimes are technological, science, policy, socio-cultural and user as well as market regimes (Geels, 2004). In terms of innovations, the regimes are characterised by incremental changes as a result of path dependence and lock-in. Revolutionary changes, such as the socio-technical innovations discussed above, are arguably not possible at the regime level, but appear at another environment, as called the niche level in the MLP. Pressures from other levels may enact dynamics in regimes that affect their stability and therefore offer chances for niche developments to offer a challenge. The result can be changes in existing regimes or the replacement of one regime for another (Smith et al., 2010).

**Niche Innovations**

A source of pressure to existing regimes could originate from socio-technical niches. These are less organised and stable spaces of development; however, their existence is enabled by a certain protective element. This can be a research project, experimentation by a non-dominant cultural movement, pioneering initiatives at lead markets or similar. Niches are however constrained by the existing institutional environment, the socio-technical landscape (see below) and other kinds of constraining influence that are subject to regimes and projected by the regimes. Their ability to compete with the regimes lies at the convincing and network-developing capability on different levels. To be successful and establish themselves beside or replacing the regime, they need social legitimacy in the form of cooperation from the powerful actors at existing regimes. The experimenting actors at socio-technical niches prioritise the social and ecological qualities over the quality of production or service which makes them more forgiven by users on the future performance in relation to regime members (Smith et al., 2010).

**Socio-Technical Landscapes**

Additional pressure to regimes and niches appears from the macro-level, called socio-technical landscape. The dynamics in landscapes are not directly influenced by either the regimes or niches but result from broader processes spanning societal functions. These processes can be changes in environmental situation, demographics, social situation, political and cultural developments etc. The broad scope is what inspires the regime and niche actors with the considerations to societal needs. For regimes, the landscape level dynamics can act as a source of reinforcement or uncertainty. The changes can trigger quick reactions, creating instability within the regimes. This offers gaps in socio-technical systems that the niche developments could fulfil (Smith et al., 2010).

An example of landscape pressure is the concern for sustainability. Regarding the ever improving understanding and developments in sustainability policies, the regimes find themselves under performance requirements that were hardly considered during their early development (Smith et al., 2010). Such fundamental questioning over "doing the right thing instead of doing things right" is not easily applicable in many established regimes and provides opportunities for the much less constrained niche actors.

### 3.2.5 The Hinders of System Innovations: Path Dependence and Lock-in

Path dependence has been under discussion by scholars in a variety of disciplines. As an expanded but still evolving term, it is currently used to explain self-reinforcing mechanisms and processes that are a result of some historically established structures. The structures could have been evolved by chance, due to certain events in sequence. Thus in research, the “historical accidents” are often relied upon, as their existence can have clear impact on the current situation (Martin & Sunley, 2006).

Path dependence and lock-in, the characteristics of existing regimes, are a powerful incentive for incremental innovations in socio-technical systems, leading to particular paths or trajectories (Figure 8). Change processes are stable and predictable, almost counteracting the potential for system-wide innovations. According to Geels (2012), the examples of lock-in mechanisms are:

> *“Shared beliefs that make actors blind for developments outside their scope, consumer lifestyles, regulations and laws that create market entry barriers, sunk investments in machines, people and infrastructure, resistance from vested interests and low costs because of economies of scale.”*

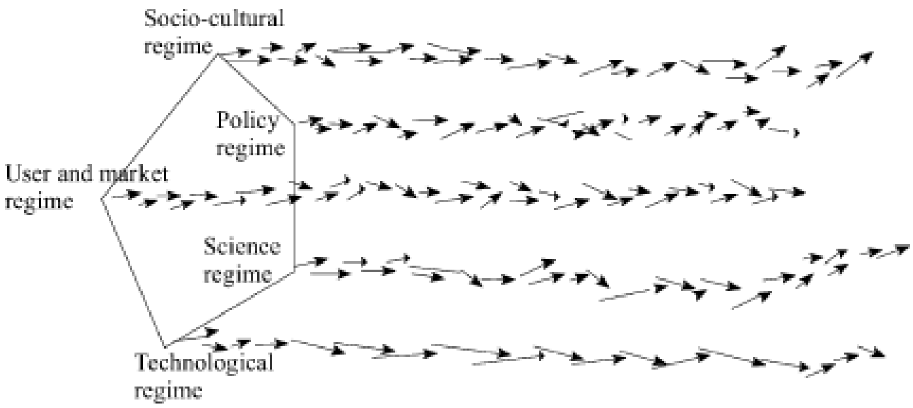


*Figure 8: Alignment of trajectories in different regimes*

Thus the lock-in effect differs from path dependence by explaining the mostly economical inertia that keeps the systems from changing. Path dependence can describe the reasons that lead to the lock-in effect. It is argued that path dependence is still lacking some definition as it offers little to understand the changes from one path to another. To consider the changes, the aspects of path creation and path destruction, that co-exist with path dependent phenomena, are suggested in a „path as process“ approach (Martin & Sunley, 2006). The authors of the present study take notice that MLP has similar characteristics to the approach, assuring its applicability on the innovation research.

**Regional Path-dependence**

Martin and Sunley (2006) provide another dimension of discussion to path dependence. They bring in the phenomenon of place dependence which implies that the physical colocation of actors could impact path dependence to a similar scale as other historical reasons. The possible implications of finding place-specific causes are related to the organisational interactions which often take place in the context of regional economies. In such case, it is hypothesized that the change of the business networks to become more open and co-operative could reduce the location related path dependence. The new technological-institutional regimes valuing international and collaborative development could provide environments where the regimes would be more open for changes from internal and external resources.

The issue with place dependence in evolutionary economics is that the relation of path dependence to regional aspects is complicated due to the complex nature of business networks. Furthermore, it is not only that path dependence is shaping the economic activity within regions but the other way around as well. The regional governance agents, local firms and industries consciously shape the regional economy to increase participation in the specific technological developments. Especially the actors of emerging technological niches thrive on local inputs in terms of knowledge and other resources and use it to their advantage (Martin & Sunley, 2006).

Regarding lock-in in a regional context, a positive and negative path could be distinguished. It is often important for regional governance to introduce some amount of lock-in to create stability for forming long-term networks. However, as the systems mature that have been the subject of lock-in, the phenomenon may become suboptimal and harm the regional innovation capability and economy as a whole (Martin & Sunley, 2006). The authors summarise it shortly:

> *"The 'strong ties' that were previously a source of cumulative economic success become a source of weakness."*

Examples by the authors emphasise some successful technological development clusters to have greatly benefitted from the permanent knowledge and networking related organisations such as universities and science parks. Other firm- or network-specific motivations can create paths that influence the regional economy. Thus, the purposeful human agency, structural preconditions and contextual influences should not be neglected when discussing path dependence. The current reasoning with a limited view on "historical accidents" is not sufficient to explore the phenomenon in a conclusive and credible way (Martin & Sunley, 2006).

### 3.2.6 **The Governance of System Transitions**

The changes or shifts in socio-technical regimes depend on the availability and coordination of comprising resources (Smith, et al., 2005). The authors consider regime changes to be the function of two processes. First of all, there are shifting selection processes that describe the changes at a socio-technical landscape and niche level, for example triggered by the global concerns towards sustainability. The second process concerns the internal and external resources to the regime that can respond to different pressures from niches and landscapes. Smith et al. (2005) refer to the latter feature as "adaptive capacity" of the regime which is inspired by literature on vulnerability and resilience from ecological studies. It is argued that the higher the external pressures to the regime, the more is required from resources "defending" the regime, facilitating its adaptability.

As explained above, the mobilisation of resources for change can originate from inside or outside the regime; in niches inside or outside an existing regime. According to this framework, the success of a niche is dependent on its suitability to selection processes, such as sustainability requirements, and its ability to combine the resources needed to respond to the selection criteria. When resources are internal to an incumbent regime, the conditions for major structural changes such as system innovations are weak. Therefore, the suggestion for governance, that evaluates the current regime to navigate between insufficient resources for a sustainable transformation, is to channel attention towards the enabling resources outside from the regime (Figure 9). It can regulate the context of selection and the resource base for adaptability which indirectly shape the transformation processes (Smith et al., 2005).

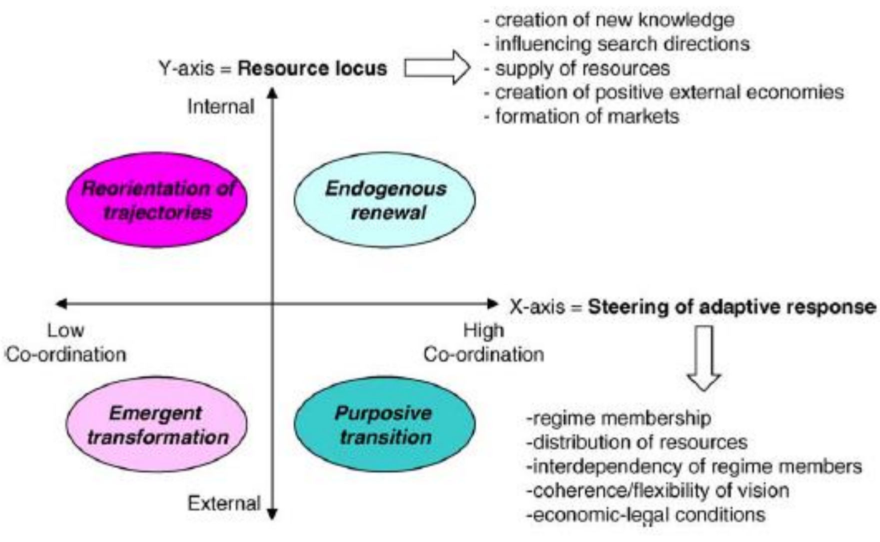


*Figure 9: Transition contexts as a function of degree of coordination to selection pressures and the locus of adaptive resources (Smith et al., 2005)*

The attention of researchers cited in earlier sections concern additional perspectives to socio-technical systems such as the issues of agency and power. The resource perspective navigates around these topics by attaching into more objective and measurable aspects. The following strengths of the resource focus are relied upon in the present thesis.

1. The resource perspective is more easily observable than the questions of agency as the latter may involve high complexity in terms of time and relationships;
2. The resource perspective is neutral and offers the students a possibility to extract information with a little amount of defensive reactions, in comparison to the observations of competing market actors;
3. The resource perspective offers a tangible and objective basis for analysis that would be inspiring for new kinds of cross-disciplinary dialogues in other contexts.

### 3.2.7 **Summary and Research Question about Socio-Technical Systems**

The chapter has provided a background of innovations which are triggered by the current societal needs and available technological opportunities. Large-scale innovations such as the transition of industries to a sustainable state require changes that affect the way how societal functions are fulfilled. Often a cross-disciplinary approach is needed which challenges the existing systems by introducing resources not familiar to them. Such pressure can originate from “top-down” such as through regulations or “bottom-up” as through innovative prototypes. Additionally, the role of research and the associated knowledge can catalyse the change processes. To sum up, the question to be analysed is:

*How can the regional governance shape the local economy to adopt sustainable construction materials?*

## 3.3 Resource Analysis for System Change

To analyse the resources required for a system change, the questions should be asked on the analysis structure. The present study takes inspiration from the literature about business interaction and relationships, known under the label of Industrial Marketing and Purchasing. The focus of study in the field is to understand business interactions that have become permanent for one reason or another. Close cooperation between organisations, that work towards similar goals, is a standard practice and is a source of co-evolution in terms of technical as well as social matters. Stable relationships between buyers and sellers has shown to be the main source of innovation for both parties (Håkansson et al., 2009).

A systematic way to observe the interactive landscape is the Activity-Resource-Actor (ARA) model which divides the interactions into the three layers as implied in the name of the model. In a similar manner to the motivation in the previous section, the links between actors and activities are related to the issues of agency, thus being not in the scope of the present work. The resource layer, however, provides an opportunity for independent study where the interactions are attributed to the sharing of tangible or intangible economic resources. The former could be raw materials, components, plants or equipment whereas the latter could comprise knowledge, creativity and ability. The used resources, possessed by interacting organisations, are likely to adapt to each other and possibly generate novel resource combinations. The latter could be the trigger or a result of innovative processes (Håkansson et al., 2009).

Resources are characterised by heterogeneity. That refers to a difference in its provided value which depends on combinations with other resources. Such combination can differ in terms of the depth of relation of a certain resource to another. It can also differ in evolutionary terms, as the constellations of interrelated resources develop over time in adapting to each other and the environment. A path of evolution can be observed which is also referred to as path dependence (Håkansson et al., 2009).

### 3.3.1 The 4R model

As implied in the previous sections, economic resource combinations could be analysed either within a specific company, called resource collections, or across company boundaries, called resource constellations. According to the 4R model, the constellation perspective, as interactions of resources between various companies, is central in determining the usefulness of a resource in focus (Figure 10). In contrast to the ARA model, the 4R model decouples the resources from established business relationships. That enables the freedom to observe the interplay between resources and their impact from such interaction, independent to their ownership (Håkansson et al., 2009). The types of resources, according to the model, are described in depth by (Baraldi et al., 2012) as presented in the following sections.

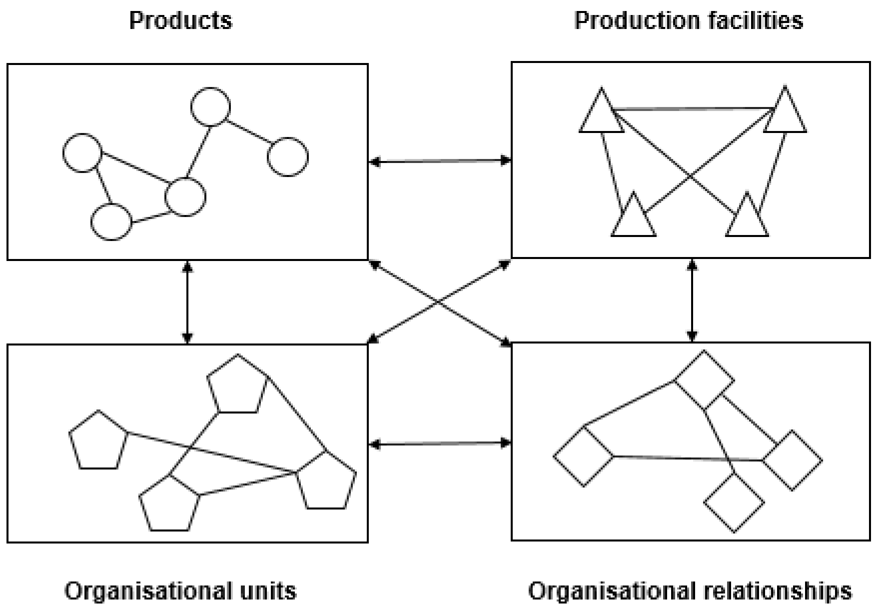


*Figure 10: The 4R model and the interplay between resources (Håkansson et al., 2009)*

### 3.3.2 The Resource Categories

**Products** are a technical resource that represents a combination of goods and services exchanged by organisations. Products are also subject to product development which is a driver of interactions between all other resource categories (Håkansson et al., 2009).

**Facilities** are also a technical resource used to enable the processes that deliver products to the market. This category relates also to the social resources because facilities are controlled by them. It is important to delimit the facilities to tangible objects as a source of confusion can appear when incorporating the skills which are used to control facilities (Håkansson et al., 2009).

The first social resource category is **organisational units**. Here, the intangible resources are considered such as knowledge, identity, routines and reputation. The organisational units can refer to firms or other organised groups of people that organise, manage and control the technical resources. Even a single person could belong to this category (Håkansson et al., 2009).

Another social resource category and the final one in 4R method is the level of **organisational relationships and networks**. Here, knowledge retention and expectations between organisational units are considered important. The value of this level is to connect organisational units and their technical resources into a single enabling as well as limiting context (Håkansson et al., 2009).

### 3.3.3 **Expected Results of the 4R Model**

The aim of the present study is to develop maps of resource combinations to support the argumentation of drivers and barriers of a specific socio-technical innovation. With the 4R model, the resources that have been instrumental in an innovative process as well as the limiting resources can be defined. Baraldi et al. (2012) infer that the result can be used to help innovation processes by identifying resources that need to be developed and related to other resources in order to provide more value for the end-users of the innovative product. Basis for a systematic resource prioritisation and development arrangement for a business or a governing party is the expected result.

### 3.3.4 **Summary and Research Question about Resources**

The resource perspective presented in the chapter provides an objective way to analyse system innovations. The value of resources depends on their relation to other resources and the environment where they are situated. Therefore, an analysis of resources could provide knowledge that is decoupled from the actors and respective subjective ambitions. To sum up, the question to be analysed is:

*How to provide an environment that attracts the important resource combinations for sustainable construction materials?*

## 3.4 Innovation in the Construction Networks

Innovation in the construction industry can be monitored on many levels. One way to understand the variety is to differentiate between incremental and radical innovations. Here the question concerning resources is whether they are already existing and within the organisation or appear during the innovation process. Secondly, the innovations can be structured into modular, architectural and system innovations, respectively implying a broadening scope. Modular innovations concern a certain component, architectural a combination of components and the system innovation describes multiple innovations in an integrated system (Blayse & Manley, 2004).

There are many permanent and temporary organisations involved and thus the organisational networks in the construction industry are complex (Figure 11). The outcomes of a construction process involve many different products and services that may not be explicit after the process has been completed. The most important participants to drive innovation are construction clients and manufacturing firms. The clients have a strong word in the selection process as they determine the requirements and standards being used. Manufacturers, as very stable actors in the supply side, are able to drive product innovation due to their ability to run research and development programmes. Their production processes are not contingent to temporary projects which also enables a continuous learning environment (Blayse & Manley, 2004).

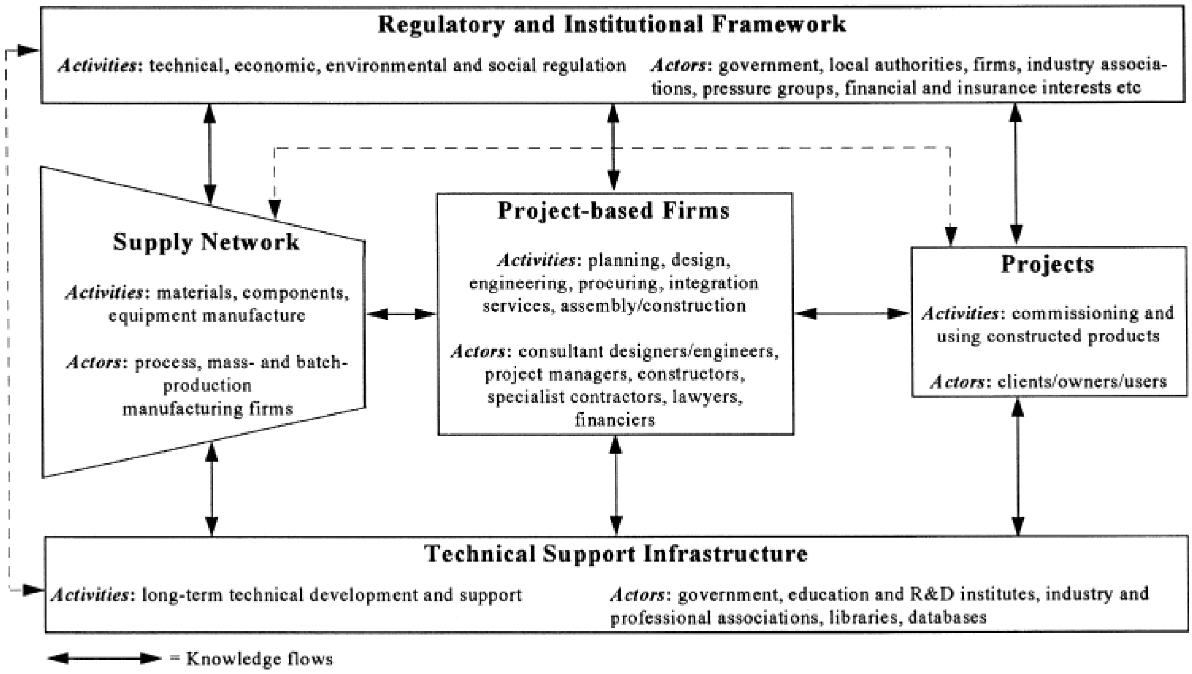


*Figure 11: Participants in the building and construction project system (Gann & Salter, 2000)*

### 3.4.1 **Networks in Construction**

A supply network is defined by Christopher (1998) as a network of several organisations that collaborate in order to add value to products and services which are delivered to the customers. Each of the parties involved in the supply chain perform different activities and processes which increase the value of the final product. Therefore, a supply network involves a joint actor coordination where sharing information and collaboration are crucial to achieve a successful product.

In the construction industry, traditional supply networks differ from other industries mainly because of its unique characteristics (Vrijhoef & Koskela, 2000). Dainty et al. (2001) mention factors that distinguish the industry such as inconsistent demand, unpredictability of building site conditions and the involvement of many people with various knowledge and skills. The temporary nature of construction projects as well as short-term relationships among the actors imply that networks in the industry are usually created for each project and disappear after the product is delivered. However, in order to increase the value creation of the product as well as the transfer of knowledge, Bystedt (2012) establishes that it is necessary to create a long-term relationship beyond the project. In Figure 12, a traditional supply chain in construction is illustrated.

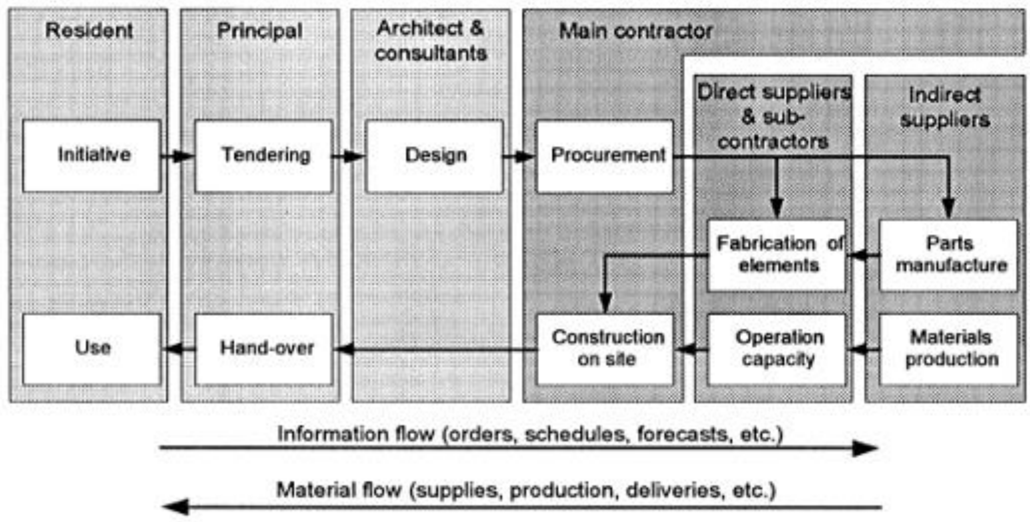


*Figure 12. Typical configuration of a traditional construction supply chain (Vrijhoef and Koskela, 2000)*

**Temporary and Permanent Networks**

According to Dubois & Gadde (2000), in the construction industry two types of networks can be identified. Firstly, there are temporary networks formed for the completion of each specific construction project. These networks count usually with a considerable interdependence among the actors. Secondly, the permanent networks are distinguished, in which products and processes are likely to be more standardised. Within this network, the interdependence among the authors is low. Therefore, it is likely that there is a lack of coordination and collaboration in the permanent networks.

Vrijhoef & Koskela (2000) explain that one of the main reasons for the above-mentioned is that each product from the construction process constitutes a unique outcome that is most likely not going to be repeated. Hence, supply networks in the construction industry tend to be unstable and broken. This means that there are frequently different supply networks, depending on the phase of the project that is being carried out. Additionally, Dainty et al. (2001) add that the recent increase in subcontracting has made the networks even more fragmented.

**Increasing Trust by Long-Term Relationships**

To counteract these issues, Akintoye et al. (2000) explain that it is necessary to establish an environment of collaboration among the involved organisations by creating a “temporary multiple organisation". However, to be able to create integration in the industry, it is required to overcome the lack of trust among the construction companies. Same is necessary against the rejection of new practices and procedures (Dainty et al., 2001). They state that the lack of trust and adversarial relationships are common because of a belief from most of the small suppliers that the supply procedures tend to favour profitability of the big contractors. According to Zuo et al. (2009), by creating long-term relationships, it is possible to increase the trust. Therefore, the parties will be more open to share risks which can lead to an important improvement of the supply procedures.

**Complexity and Customer Involvement**

Another particular characteristic of construction supply networks is the fact that the final product is produced at a fixed location, where the project is going to be delivered to the customer. Therefore, there is no necessity for distributing the final product. Besides, the client has the power to define the specifications of the product and, because of this reason, he or she has great involvement during the construction process (Akintoye et al., 2000).

The high degree of involvement of the customer as well as the large amount of suppliers that take part of a construction project generate a very complex supply network. There the main contractor is the core actor with direct relationships with the client and main suppliers. von Geibler et al. (2010) say that these contractors, that have the power to establish boundaries and parameters, are known as lead agents since they are the main forces of coordination and control in supply chains. Among the lead actors, two types of firms can be identified: those involved with the production and the ones that contribute with knowledge. However, the construction process has increased its dependence on subcontractors, making it necessary to introduce a change in the way the traditional construction supply networks work, where price is usually the main driver for their selection (Vrijhoef & Koskela, 2000).

### 3.4.2 Resources for Innovation in Construction

As explained in earlier sections, the tangible and intangible resources in a construction project are complex, diverse and controlled by many different stakeholders. Landscape pressures such as changes in social and political requirements affect the resource requirements by influencing the source technology developments and their respective increases in costs (Gann & Salter, 2000). Additionally, the organisational units and networks differ greatly in terms of the context. On a project level, the organisations are tightly coupled, meaning that they collaborate closely because of their high dependence on resources that the supply network actors possess (Figure 13). Beyond projects, the interdependence is much less pronounced which has also both affected and been reinforced by the increased standardisation of products and services. Outside individual projects, the system is considered to be loosely coupled. Industry-wide reliance on standardisation and consequent low level of product customisation has discouraged alternative couplings that could exceed the timeframe of single projects. Loose coupling between permanent firms  is considered to be a major hindrance of innovation in the industry (Dubois & Gadde, 2002b).

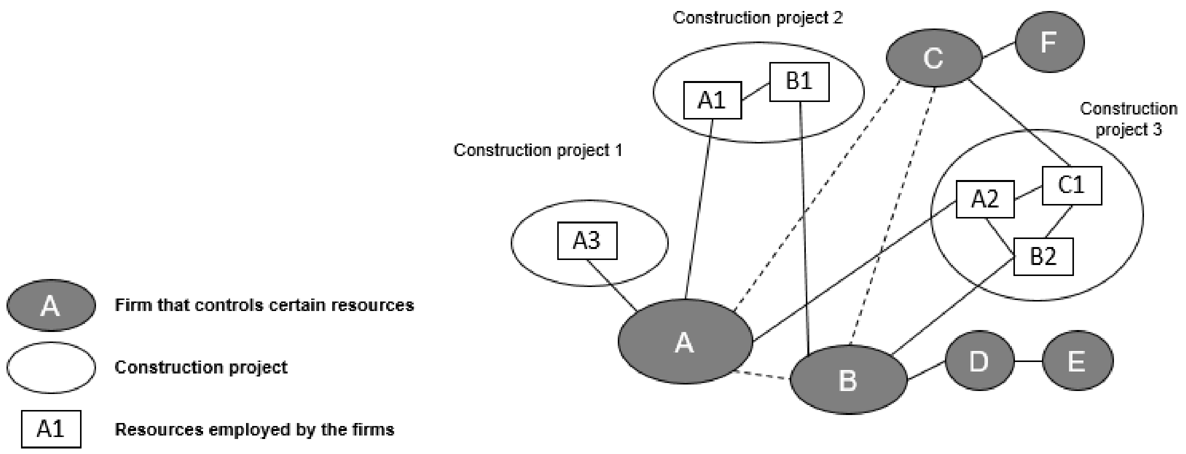


*Figure 13: A construction project in its context (adapted from Dubois & Gadde, 2000)*

**Products**

The change in European approach towards construction codes, from prescriptive to performance-based regulations, has enabled more innovative approach towards product and service definition (Blayse & Manley, 2004). Institutionally, however, there are differences in national contracting systems that show signs of lock-in or the opposite. For the former, Sweden is brought forward as an example, where there is a tendency to stick to certain technologies. In Denmark and Great Britain, on the other hand, the explorative nature prevails which can deliver excessive innovation that do not get diffused on a construction firm level (Winch, 1998). The character of construction product development is different to products in other sectors as the project-based innovations rarely happen in a controlled environment of a single firm. Winch (1998) divides the innovation drivers into two, top-down and bottom-up moments, affecting the firm or a project (Figure 14). The first represents a selection pressure of requirements, standards and other steering mechanisms while bottom-up emphasises the problem-solving and learning aspects, appearing from unforeseen events at a project level. Both of the drivers are considered crucial for construction innovation.

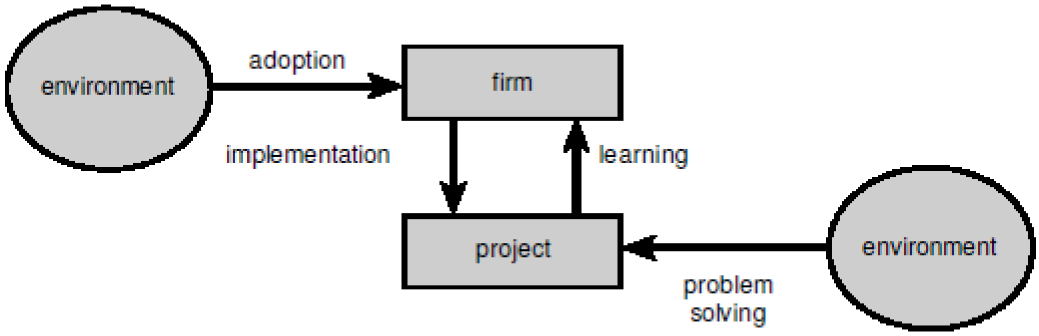


*Figure 14: A model of construction innovation processes (Winch, 1998)*

In order to add location-specific context to construction innovation literature, Winch (1998) explains the phenomena of exploitation and exploration traps. The former is a result of institutional lock-in where innovations are not encouraged for which Sweden is a good example. Exploration trap haunts the countries where the technologies are continuously re-invented from one project to another, similarly to the situation in Denmark.

**Facilities**

In physical terms, the construction facilities are dependent on the character of construction products and services which are heterogeneous in terms of their interlinkages, development aspects, user impact and other properties. All those characteristics are enabled by the supply network actors, using respective plants and equipment. "The construction factory", according to Vrijhoef and Koskela (2000), is different from regular manufacturing by being established around the eventual construction product and serving only the completion of that product. The authors establish a model that differentiates the construction site operations from the rest that happen earlier in the more permanent facilities within the supply chain (Figure 15). The proposed roles for improvement in each of the interfaces are:

1. Role 1: Concentrating on the material flow between the supply chain facilities and the construction site, compared to the traditional focus on construction sites only;
2. Role 2: Focus on improving a specific supply chain process for a construction product such as prefabricated elements of certain kind or elevators;
3. Role 3: Consider transferring activities from the building site to the facilities of the supply chain which can be achieved by industrialisation or more specifically prefabrication;
4. Role 4: The priority here is less tangible as it recommends a further integration of the activities on site and at the supply network facilities. A more permanent supply chain is sought for than is usually the case in construction. Postponing certain interior

design elements from production, pre-engineered buildings and design-build project delivery forms are considered examples in the category.

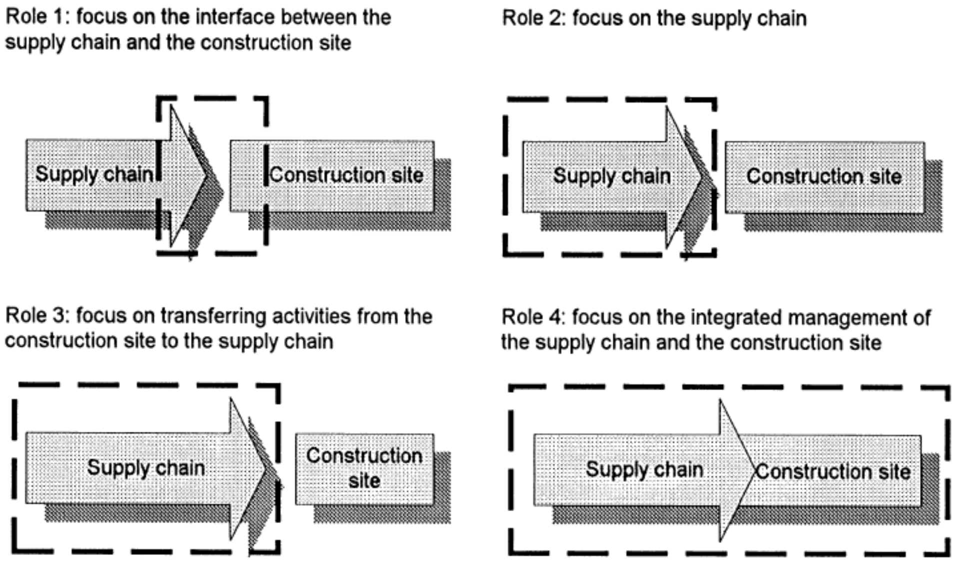


*Figure 15: The four roles of supply chain management in construction (Vrijhoef & Koskela, 2000)*

Apart from regular building sites, some of the assembly of building parts can be performed at specialised facilities. Such pre-fabricated production has a marginal impact on the energy spent and carbon emitted, compared to the production of materials. Thus, the construction sustainability arguments that depend on materials should rather account for the early phases of activities in supply networks (Sathre, 2007).

**Organisational Units**

Organisational units in construction could be observed from the project and permanent firm levels. The project level can be explained by the construction contract types. Unfortunately, there is a low amount of coherence in terms of classifying various contracts but some common types could be distinguished. Firstly, the **Design-Bid-Build** contracts imply that the design and construction providers are separately hired by the construction client. Therefore, the client maintains a high level of control and risk for the project. Secondly, in the **Design-Build** contracts, the control and risk is transferred to a construction contractor at the design stage. The client can provide requirements regarding the scope of work and outcome but the contractor provides the detailed design. This creates opportunities for innovation as the contractor can account for its production capabilities and knowledge when performing the design. Thirdly, **Construction Management** could be seen as a contract type or a way to set up work by the contractor. This involves a management firm from the early design stage as well but the control is maintained by the construction client. The construction management firm advises the client during design and hires the project team during construction. In some cases, where the contractors rely heavily on subcontractors, the Design-Build and Construction Management may behave in the same manner. Furthermore, the **Owner Builder** is distinguished from the Construction Management by having the project management competence in-house, thus retaining the associated risk and control. All in all, the mentioned contracts differ in prescribing the responsible parties for detailed design and defining the amount of contractors handled by the client at any phase of the project (Borg & Lind, 2014).

The firm level is distinguished from the project level due to the ongoing and repetitive process. The ensuing potential to establish routines is crucial in order to bring innovations to the industry. Gann & Salter (2000) stress the importance of researching construction innovation as a coordinated system of project-based firms, projects and other supporting infrastructure. According to the authors, the characteristics for a project-based firm in construction are:

1. The design and construction processes are organised around projects;
2. Typically, one-off or highly customised products are produced;
3. The firms operate in supply networks that involve many organisations.

The networks beyond construction projects are considered to be loosely coupled. The nature of loose couplings results in creative adaptations to local contexts at a project level. The paradox however is that the same structure, allowing the loose coupling system to thrive, is not effective in diffusing the local innovations to future projects. In fact, the highly standardised system, reflected by the strong community of practice, has an opposite effect. Such a system is often reluctant to accept innovative solutions that do not follow the usual practice (Dubois & Gadde, 2002b).

A study involving the impact of sustainability challenges on construction innovation in the Netherlands show that some organisations started to use a sustainable innovation strategy in their contracts as a competitive advantage. By broadening their scope of risk, the sustainability aspects became more relevant than in traditional organisations, being treated as an order qualifier for the future. External technical knowledge was used as reference for stimulating the knowledge build-up of their employees (Bossink, 2004).

**Organisational relationships and networks**

According to Dubois and Gadde (2002b), the level of inter-firm relationships is almost inexistent from the construction industry. There is a strong community of practice which acts as a connecting interface of organisations that do not have strong ties with each other. Kadefors and Bröchner (2014) describe the current Swedish construction industry to be less integrated than the manufacturing industry. There have also been substantial changes in relation to governmental support due to the adaption to frameworks of the European Union. Some trends in the Swedish construction industry collaboration are identified as follows (Kadefors & Bröchner, 2014):

1. Increasing focus on collaboration between the industry and universities which is initiated by the organisational and financial inputs from the business;
2. Concentration on the large trends of societal advances such as international competitiveness; integrative and sustainable urban development;
3. Collaboration in research across the country.

Not surprisingly, Blayse and Manley (2004) find the main strategies for construction innovations within the scope of organisational networks. Some of the propositions are client leadership enhancement, material manufacturer involvement in R&D programmes, countering the temporary coalitions through integration across several projects, reliance on complementary external knowledge bases and promoting innovative procurement systems that enhance cooperative problem solving.

Bystedt (2012) offers a practical solution to the missing inter-firm relationships whereby the collaboration could be enhanced by moving towards a more industrialised perspective resembling manufacturing industry. That requires more integrated work between different supply network links. Especially important is the competence of subcontractors to be aware of requirements within the entire system, from client satisfaction to the specifics of its trade.

### 3.4.3 Timber Structures as a Sustainable Innovation in Sweden

Construction industry in Sweden is characterised by structures of concrete and steel, especially for multi-storey buildings. The reason goes back to the end of 19$^{th}$ century when large fires in the principal cities of the country led to the prohibition of multi-storey timber buildings. This prohibition remained for more than 100 years until the construction regulations changed in 1994 (Mahapatra & Gustavsson, 2008).

During the prohibition period, the construction development in Sweden was based on concrete, with gradually reducing knowledge about wood in construction. Thus, most professionals and organisations involved in the industry have great skills and knowledge about the processes and products of concrete and steel. As a result, the current situation in Sweden shows established networks of actors and products which work with traditional resources. Therefore, Mahapatra and Gustavsson (2008) state that the introduction of timber into multi-storey buildings can be considered an innovation.

**Timber as a Modern Construction Material**

There exist some prejudices and misbeliefs about building with wood among the industry and population. Gold and Rubik (2009) point out that the main misconceptions about the material are: lack of resistance, quality of the material and the deficient characteristics against fire. They argue that these misbeliefs about timber are hindering the increased use of wood inside the construction sector.

A challenge is to tackle the common belief of the high flammability of timber constructions since it is embedded in the collective consciousness (Gold & Rubik, 2009). In addition, banks and insurance companies might further hinder the development of the material since they consider timber buildings as a risk (Mahapatra & Gustavsson, 2008). All these misconceptions prevent the spread of knowledge about the real benefits of building with timber.

Among the main benefits related to timber construction is the reduction of process complexity. Mahapatra and Gustavsson (2008) claim that with lower complexity of the buildings, construction would be faster reducing the costs in a long-term.

Timber construction involves some drawbacks that have to be taken into account. Despite the construction period being shorter, the time taken to produce the elements could be long. The fabrication requires many steps, especially if it is necessary to mount different layers. Additionally, for being an organic material it is important to consider its relative humidity as moisture can cause severe damage to the structural system. Another problem of wooden structure is the weak noise isolation at high frequencies that wood provides, causing discomfort to some users (Selvarajah & Ehrnström, 2011).

**Timber as a Sustainable Material**

The renewable nature of timber make it a considerable sustainable alternative to the traditional construction materials (Gold & Rubik, 2009). Therefore, awareness and interest for the use of timber has increased in the industry. The implications of using wood in the construction industry can cover the ecological, economic and social dimensions of sustainability.

Considering the ecological dimension, the use of wood brings several long-term benefits, particularly concerning the reduction of $CO_2$ emissions and wastes (Sathre, 2007). The author measured the positive effects of timber construction in comparison with concrete structures.  The result was a lower amount of emissions during the entire life cycle of the material, from the production until the operation of the finished building.

On the other hand, the use of timber has some negative ecological implications. Wood requires more land to grow the material which means that large amounts of biomass are required for production. However, the positive ecological implications of the implementation of timber in the construction industry are greater than the negative ones (Sathre, 2007).

In a societal context the impacts of timber buildings are well regarded. According to Gold and Rubik (2009), a wooden structure produces mostly positive feelings among the people since it promotes ecological friendliness and more aesthetical buildings. This is supported by a survey in Sweden were 84% of respondents said that they prefer to live in an apartment made of wood. In addition, timber improves the working conditions during construction works since it produces less noise. Using prefabricated structures can expand the aforementioned positive effects. For instance, having a prefabricated structure results in a cleaner construction site as well as fewer deliveries contribute to a reduced traffic congestion risk (Mahapatra & Gustavsson, 2008).

**Requirements for the Increased Application of Timber**

In order to be able to increase the use of timber and achieve the associated sustainability advantages some aspects are required to be accomplished. As stated by von Geibler et al. (2010), a collaboration among different stakeholders is needed, especially private organisations, government, professionals, academia and the users in general. In the case of the government, they have the responsibility to ensure that every material has the same opportunities to compete, generating rules that are equal for everybody (von Platen, 2004).

Gold and Rubik (2009) point out that most of the professionals and organisations involved in the construction industry are in agreement over the sustainability benefits. However, they frequently prefer the use of other materials. One reason for this is the lacking knowledge in working with the material. The current knowledge among the professionals and construction companies is dominated by traditional materials, influencing the selection of the material and the way they perceive the introduction of new alternatives (Mahapatra & Gustavsson, 2008). Therefore, investments in the educational system as well as in developing the skills of current professionals are required. The creation of knowledge would provide a platform for timber structure to be developed.

Another aspect to take into consideration is the involvement of established construction companies in the introduction of new materials. These companies might perceive the introduction of alternative materials as a financial risk since they are already consolidated in the market of concrete and steel. Moreover, the activities of construction companies include the construction of structures not suitable to the use of wood. To utilise the equipment for a diverse set of structures, it would be suboptimal to construct the structures in different ways.

Therefore, flexible-use materials such as concrete and steel would be the preference for large contractors (Bengtson, 2003).

As most of the decisions in the construction industry are based on economic aspects, Sathre (2007) argues that establishing a taxation to the use of non-sustainable materials should provide opportunities. In that case the choice of timber and other sustainable materials would be seen as an economic benefit rather than a risk. All in all, the collaboration of parties from the government until the final users of constructed buildings is needed to scale up the use of timber and other sustainable construction materials.

### 3.4.4 **Summary and Research Question about Construction Innovation**

The chapter has demonstrated the opportunities and challenges regarding the innovation capability of construction networks. As described a chapter earlier, the construction industry is considered to be different from other industries and represents low levels of change. In recent times the change is happening due to various pressures and thus it is important to understand which resource combinations have enabled the newfound flexibility. To sum up, the question to be analysed is:

*How are the resource combinations associated with multi-storey timber building projects changing the innovation capability of the industry?*

## 3.5 Analytical framework

The theory of the present study follows the multi-level perspective model by Geels (2004). Chapter 3.2 Innovations in a Socio-Technical Context provide a summary of the relevant literature which provides a basis for the thesis structure. The levels have been represented by the chapters as follows (see also Figure 16):

1. The socio-technical landscape in the study is illustrated by the societal consciousness and actions towards a sustainable built environment. The corresponding actions create dynamics within existing regimes and provide opportunities for niches to affect the regimes. Chapter 3.1 Sustainability in the Construction Industry contains the relevant findings.
2. The socio-technical regime in the study is considered to be the traditional construction industry in its current form. The challenges of the industry are explained in Chapter 3.4 Innovation in the Construction Networks.

3. The niche innovations in the present study are exemplified by wood as a renewable and relatively sustainable construction material. Many permanent and temporary organisations have appeared in Sweden for building structures from the material which may have an impact on the dynamics in the construction industry at present. The niche innovations are elaborated in further chapters of the thesis on the basis of Chapter 3.3 Resource Analysis for System Change.

The analysis on the empirical material is based on the research questions, developed from each of the chapters of the reviewed literature. The questions are as follows:

1. What is needed to establish coherent sustainability criteria for construction materials?
2. How can the regional governance shape the local economy to adopt sustainable construction materials?
3. How to provide an environment that attracts the important resource combinations for sustainable construction materials?
4. How are the resource combinations associated with multi-storey timber building projects changing the innovation capability of the industry?

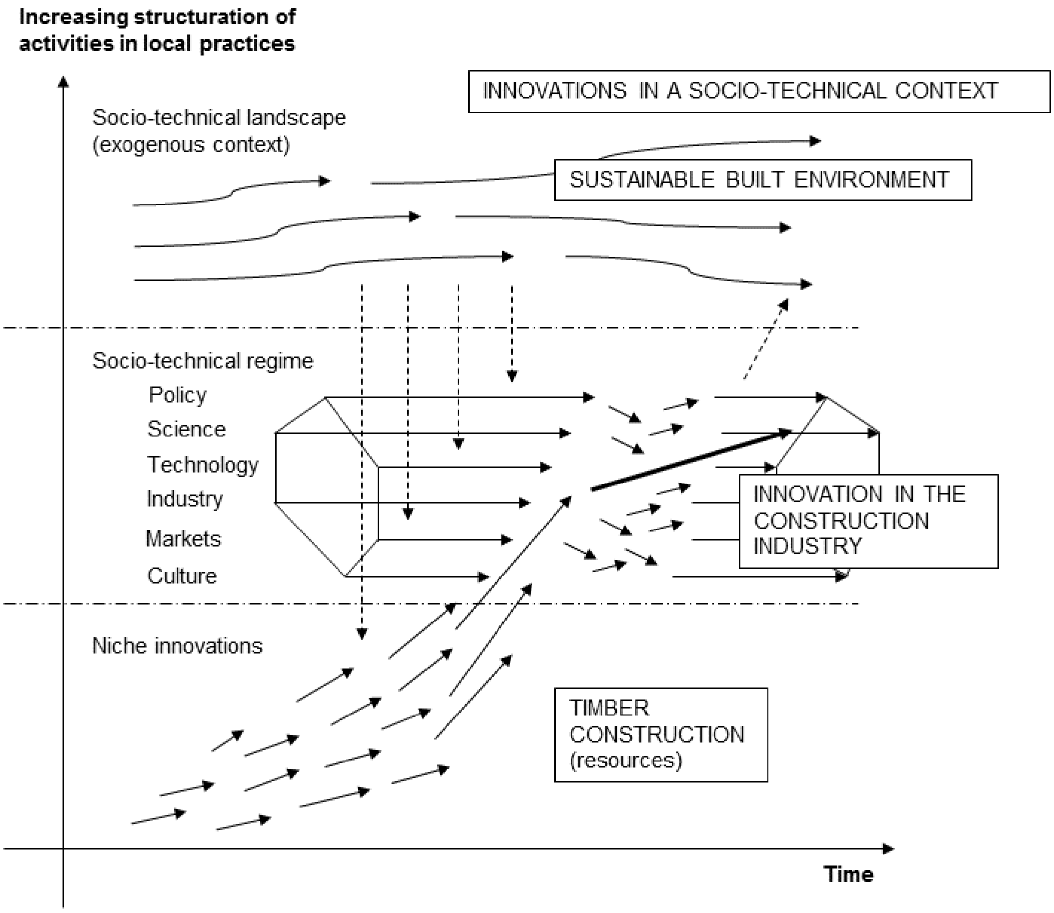


*Figure 16: Structure of the theoretical framework on the basis of a multi-level perspective (adapted from Geels, 2004)*

# 4 Research Methodology

*The present chapter provides an overview of the research from the aspects of literature study, empirical material and its analysis. Additionally, a justification of the chosen methods is described in order to establish validity for the thesis. The result is aimed to be a credible support for future research and other purposeful actions towards encouraging sustainable actions in the society.*

## 4.1 Research Approach and Theoretical Review

The theoretical composition of the study relies on the most cited authors that have written on the following topics: *sustainable development; sustainability transitions; sustainable construction materials, innovation in construction, construction supply networks, economic resources, timber construction, multi-storey timber buildings, wood in construction* etc. Existing models for observing system innovations are described and used as the basis for empirical research, analysis and eventual interpretations, which hints towards a deductive nature of the study. However, the Challenge Lab process and overall explorative approach during the research, involving parallel activity with purpose adjustment, literature study and empirical data implies an abductive approach. A part of abductive logic and a useful process to use in case study research is *systematic combining* which describes a simultaneous development of theoretical, empirical and analytical material (Dubois & Gadde, 2002a). In the following, a description of the systematic combining is given which aligns with the actual experiences during the present study (Figure 17):

> *"…The evolving framework directs the search for empirical data. Empirical observations might result in identification of unanticipated yet related issues that may be further explored in interviews or by other means of data collection. This might bring about a further need to redirect the current theoretical framework through expansion or change of the theoretical model." (Dubois & Gadde, 2002a)*

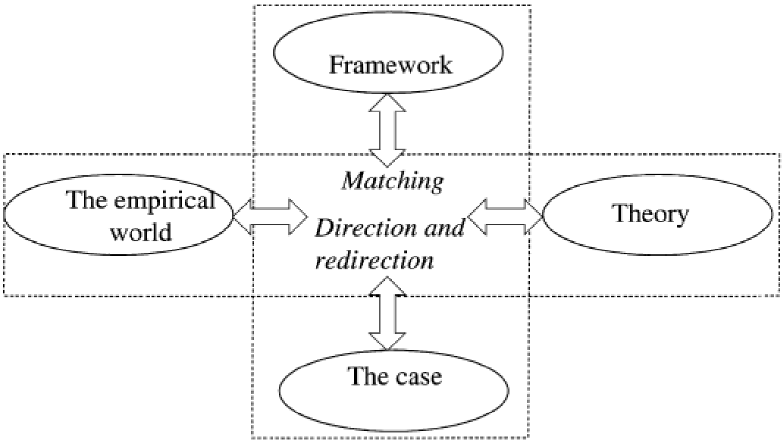


*Figure 17: Systematic combining (Dubois & Gadde, 2002a)*

Inspiration for structuring the empirical part of the research is gathered from literature that is also used to support the main content of the theory section. Bengtson (2003) is influential in combining the data of conducted construction projects with the qualitative data from interviews with relevant stakeholders. The author has also utilised the Actor-Resource-Activity (ARA) model which is a precursor to the 4R model used in the present study. Hemström (2015); Mahapatra and Gustavsson (2008); and Orstavik (2014) have all taken examples from the Multi-level perspective (MLP). Orstavik (2014), in addition, has successfully combined the ARA model with MLP. He concluded that on the context of construction innovation, the combination of the models is useful and can provide applicable results.

## 4.2 Research Process

The research has been carried out in 17 weeks, as a coordinated work by two students of Chalmers University of Technology at the MSc programme of Design and Construction Project Management. The work was predicated on an extensive process of exploring the societal challenges and defining the aim of the project which is described in Chapter 2: Methodology of Defining the Project Aim. The rest of the project duration was distributed among literature study, interviews, case study, analysis, conclusion and final adjustments. The weekly progress has been as described in the following:

1. Week 1-4: Defining the project aim and describing the preceding work;
2. Week 5-8: Literature review on the relevant theories, and interviews with industry professionals around Sweden;
3. Week 9-11: Exploring and describing cases and carrying out in-depth interviews;
4. Week 12-15: Analysing and concluding the data;

5. Week 16: Preparing for the presentations and correcting the work based on feedback;
6. Week 17: Finalising the thesis and submitting to the university staff for final approval.

## 4.3 Empirical Material

The empirical support of the research is a natural development from the present state of the current literature as well as the existing opportunities and constraints that have formed the work process. In order to fulfil the goals, set at the problem statement, the empirically gathered data needed to provide knowledge about the projects that have been completed in Sweden but also to represent the situation in Gothenburg. According to Yin (2013), the method of case studies is used to observe how a set of decisions have been implemented as well as to understand the reasons and consequences of them. Case study method has established a stable presence in qualitative research during the last decades. After conducting the cross-case synthesis from the multi-storey timber building projects in Sweden, the authors were prepared to carry out a broader analysis from the interview data with local stakeholders in Gothenburg.

### 4.3.1 Quality of the Chosen Method

Case study is appropriate to be used for investigating current phenomena in their context especially when it is difficult or inappropriate to distinguish a phenomenon from its context. The inquiry of case studies is especially fitting to situations which are technically distinctive but involve many variables of interest. Additionally, it is suitable where the sources of evidence are diverse and where earlier research can support the data collection and analysis (Yin, 2013).

The chosen methodology is structured into three steps. Firstly, the interviews with Swedish stakeholders were carried out for the researchers to understand potential focus areas. It was considered important to involve the stakeholders from the three general groups, the public sector, private sector and academia. The analysis of the perspectives provided a basis for the following parts of the empirical material. The case studies of Swedish construction projects were used to construct a context for the situation in Gothenburg. Due to the importance of time and location in resource analysis, the focus was on finding as diverse projects as possible in terms of the location of stakeholders and year of production. Many different patterns were found which could explain the perspectives of stakeholders and the current situation in Gothenburg. To explain the latter, in-depth interviews were carried out with influential stakeholders active in the region. The focus was again to combine the views of the public sector, private sector and academia to obtain a balanced view over the current situation.

All in all, the dedication into certain sections of the work prior to concluding the findings offers assurance on the validity, reliability and most of all the usability of the study:

1. It has been important to channel efforts towards defining the suitable research aim on the basis of current international, regional and local issues as well as individual capabilities of the authors. Consequently, the authors could feel confident in targeting the right stakeholders and they would likely find the topic relevant enough to collaborate.
2. The analytical framework based on the multi-level perspective and 4R method enabled to establish a boundary between the traditional construction industry and the innovative developments. The consideration helped the authors to be focused on the timber construction niche throughout the whole work but retain the sustainability aspects and traditional construction industry in the context. The latter has provided a platform for objective analysis and avoided the authors to develop a limited perspective when mainly observing the niche organisations.
3. The three-stage empirical framework mirrors the focus in earlier sections by building up the knowledge of the authors, learning about actual cases in Sweden and eventually gathering the current perspectives of local stakeholders. The interview guides for the latter were tailored to the Swedish and international perspective. Therefore, the authors were enabled to focus on the respective drivers and barriers that the local stakeholders might not have been aware of.

### 4.3.2 Mitigating Potential Risks with the Chosen Method

According to Yin (2013), there are some concerns that have decreased the credibility of case studies in research which are addressed in the present study. It is said that the case study approach might become less structured than other research methods due to a comparative lack of guidance from scientific texts. This concern is mitigated by following a set of highly cited books on research design and more specifically, case studies as a research method. It is also discussed that the case studies are sometimes confused with deliberately exaggerated cases for teaching purposes and also used for generalised conclusions from non-representative samples. The way to avoid such issues is to retain full objectivity during the gathering of empirical data and when analysing and drawing conclusions from the data.

It is not recommended to aim case studies to provide statistical evidence but rather contribute to theoretical models that have been used in similar contexts.

Eventually, other more general steps are necessary for the purposes of research validity and reliability. Relevant strategies directly implemented in the present study are triangulation, bias clarification and peer debriefing (Creswell, 2013). *Triangulation* of the data is facilitated by the use of different interview sources that help to converge the streams of data. Additionally, the use of two types of interviews and the mapping of actual project attributes helps to identify the empirical similarities and differences as well as discuss the anomalies on the basis of existing literature. Using different sources of data has another positive impact within the abductive logic which is the exploration of aspects unknown to the researchers (Dubois & Gadde, 2002a). That is especially useful to postgraduate students, represented by the authors, whose purpose with the research is to explore and learn from research experience. Empowering the students to redirect their study amplifies the creative potential and motivation to seek for current problems that require input from their research.

All in all, securing a good case study is not a clearly defined endeavour because the method lacks a unified formal definition. Therefore, in addition to previously mentioned measures, the authors of the present study use their personal judgements to be objective, professional and striving towards high-quality results. The judgements are continuously supported by the supervisors from the Chalmers University of Technology and Challenge Lab, the institutions under which the research is being conducted.

**Bias Clarification and Peer Debriefing**

*Bias clarification* is necessary due to the professional background of the present authors which may be hindering a fully objective analysis. *Peer review* as a requirement from the university is used to ensure that the chosen approaches resonate with other people than the authors.

The development of the research question and further work on the study has been shaped by the background of both of the authors. In fact, the research format encouraged the problem statement to be partly derived from author engagement. Interest and experience with sustainable construction has been an important point of departure. Despite being an important driver of motivation, the personal beliefs can provide observations with too much emphasis on a certain individual perspective (Creswell, 2013). The involuntary bias is acknowledged, especially during reflective situations during the research.

Peer debriefing is another validity strategy which is set as a requirement from the research institution. The strategy is needed to make sure that the account resonates with other people than the researcher (Creswell, 2013). The peers are selected from similar backgrounds to the authors in order to provide in-depth interpretations on specific details.

### 4.3.3 Initial Interviews for Understanding the Swedish Context

Before and during the early process of literature review, it was considered necessary by the authors to conduct unstructured and semi-structured interviews with the representatives of public sector, business and academia. The prerequisite for interviewees was their involvement in earlier or future construction projects of timber or research involvement to timber construction in Sweden. The results from initial interviews prepared the authors in a short time frame with knowledge about the existing situation, concerning the current research as well as the actual examples from the market.

By conducting interviews with the public sector representatives it was aimed to understand what motivates the sector to drive timber construction and how is it carried out. The interviewees were relevant professionals from different public institutions of Gothenburg and Växjö as well as authorities of national associations that currently encourage the use of wood as a construction material.

The aim of performing interviews within the private sector was to understand the business perspective regarding the current and future possibilities of timber construction. The participants of these interviews were professionals at management positions in the private sector enterprises with experience and knowledge about timber buildings.

Finally, interviews with researchers from universities provided the understanding of the educational and research dimensions in relation to wood as a sustainable construction material. In addition, the goal was to recognise what research has been done in recent years and how academia collaborates with the public and private sector on the topic of timber construction. The interviewees belong to different Swedish universities in several regions of the country.

### 4.3.4 Case Studies for Obtaining Resource Data in Sweden

Secondary data from existing documentation as well as supporting interview data was used to obtain information from construction projects in Sweden. The 4R model was used to categorise the identified resources on Swedish multi-storey projects of timber structure. The result of simple and objective observations provided a strong basis for the subsequent interviews in a clearly established structure. Besides, it provides an understanding of the used resource combinations that have been applied in getting the buildings built. According to Yin (2013), The benefits of documented data is their stable and unobtrusive nature as well as their specific orientation to a broad range of details, events and contexts. The projects are chosen for their variety in terms of location, time, used resources, and are presented in a chronological sequence.

The authors of the present study have kept in mind that there are also weaknesses to the documented sources, such as their availability and accessibility, biased selectivity if the material is incomplete and reporting bias. It is important to acknowledge that the documents have been written for a specific purpose to a specific audience other than the authors of the current study. The previously mentioned aspects were critical to be considered during the information retrieval process as well as when carrying out the eventual analysis. A proper mitigation action is used, which is a good sense of source credibility and complementing the findings with personal reflections from the interviews.

### 4.3.5 In-depth Interviews for Obtaining the Gothenburg Perspective

The initial interviews and data from the case studies provided a structured basis for the in-depth interviews. The structure implies resource-themed interview agendas with a back-up of insightful source material that enabled the interviews to hastily proceed into specific matters. This is important, considering the scope and time limitations that have constrained the authors, however the limitations are also the case for interviewees of the study.

Interviews are considered to be some of the most important sources of qualitative evidence and thus it is common in case study research. The in-depth interviews expect a structured approach but usually develop in a fluid manner, depending on the expected and unexpected streams of information being retrieved. It is important to follow the interview guide but at the same time be creative in posing unbiased questions based on the new material that appear from the conversation. These two non-conflicting approaches are known as “Level 1” and “Level 2” questions which can complement each other in fulfilling the desired line of inquiry (Yin, 2013).

The main goal of the interviews was to corroborate the findings that the authors have gathered from earlier sources as explained in previous sections. It was necessary for the authors to remain unbiased and even naïve to prompt fresh commentaries. Inspired by Yin (2013), leading questions were avoided as that would have undermined the unbiased and corroboratory purpose of the interviews. Following the advice of the author, the “Why” questions were substituted with “How” questions as much as possible. This was to excite less defensiveness and enable more applicable results to be retrieved.

The results were collected through interviewing four different people from various sectors: a project manager of a medium-sized timber construction company in the west region of Sweden; a business manager of a medium-sized construction company which is owned by a large Swedish contractor; a timber researcher with experience in Japan, Switzerland and Sweden; and a project manager from the municipality.

Furthermore, recording devices were utilised to reduce the probability for transcribing errors as well as to provide more freedom for the interviewers for establishing a relaxed atmosphere. The sole reliance on written notes were considered to distract the questioners as the physical presence of laptops and notebooks would have reduced the attention from the fluid conversation.

## 4.4 Analysis of Empirical Material

The general strategy of the analysis was to rely on theoretical propositions that are developed for construction innovation and sustainability transitions. The abductive approach was also shaping the data collection, firstly to understand if the research questions were appropriately postulated and how the case of timber structures in multi-storey housing can be considered a socio-technical system innovation. Thereafter, the 4R resource model by Håkansson et al. (2009) provided a structure for the chosen analytic technique. Based on Creswell (2013), the analytic technique is called *explanation building* which is a specific type of *pattern matching*. It implies that the observed phenomena are related to certain causal links or to the questions of “how” or “why” they have taken place. This is helpful to generate ideas for further studies and propose recommendations for future policy actions.

Explanation building is iterative in nature as the comparison of findings to the initial statement and consequent revision of the statement is often a repetitive process until the conclusion is satisfactory to the research objective. The iteration has been reflected by the different case study sources as explained in the previous chapters which sequentially elevate data of increasing depth. Yin (2013) warns for potential shortcomings of an iterative analysis which are drifting focus from the research question and an unwanted selective bias. To reduce the threats, the original problem statement has been continuously reviewed. Also the bias clarification and peer debriefing, described in the previous section, provide awareness to the unscientific tendencies to refrain from presenting some key data because of personal preferences.

All in all, the authors have done everything within the scope and time limitations that ensure a high applicability of the results for further research and policy or strategy formulation. The four principles that are common to a high-quality social science research are strictly followed (Yin, 2013):

1. Care is taken to present that all the relevant and available evidence has been taken into consideration in the eventual interpretation;
2. As much as possible, the rivalling interpretations are presented. Considering the limited research background of the authors, all the interpretations are likely to be undiscovered but the acknowledgement of that is reflected in the suggestions for future studies;
3. The authors have made sure that the analysis addresses primarily the most significant aspects of the case study. Less relevant issues to the problem statement, that have appeared before or during the research, are not included to the analysis;
4. The authors use their own background and expert knowledge to guide the case study. This was much enabled by the "Phase I" of the current thesis where the statement of the problem was partly derived from individual strengths of the authors.

## 4.5 Delimitations and Limitations

The analysis performed in the following report is based on information related to Swedish construction industry, including relevant actors from the Gothenburg region. In addition, timber was selected as the sustainable construction material to be studied since the associated modern technologies have been implemented in the industry for the past 22 years. Additionally, the available information is broad, compared to other alternative materials. Moreover, regarding the innovation, the resources were emphasised, leaving aside the agency issues regarding the exerted power over those resources.

In order to maximise the quality of the study, the scope is limited to observing construction projects where the project teams have completed their work. Due to this reason, some of the issues appearing during previous stages of the project could be forgotten or ignored by the actors involved. Besides, the time constraint hindered the possibility of involving a wider array of actors into the analysis, however the most crucial decision makers have been targeted and interviewed for this study. Therefore, the secondary stakeholders to decision making such as users, architects and subcontractors are not in focus of the study.

# 5 Empirical findings

*The following chapter is structured into three sections where the empirical findings from the interviews and case studies are presented. The first section includes the data from several interviews performed to different actors from various regions of Sweden. The second section gathers the main information about the resources used in several multi-storey buildings in Sweden. The final section summarises the main findings of more in-depth interviews performed with four stakeholders from academia, private and public sector.*

## 5.1 Perspectives of Timber Construction in Sweden

In the following section the information gathered from the initial interviews is presented. The data is divided into three different perspectives: Public Sector; Private Sector and Academia. Each of these sections summarise the main ideas exposed by the interviewees.

### 5.1.1 Public Sector Perspective

Timber construction is perceived by the public sector as an important alternative to the traditional construction materials for multi-storey buildings, especially because of its positive implications regarding sustainability. Therefore, there is a national effort to promote different strategies to increase the construction with the material. However, there seems to be an uneven growth between the regions in Sweden. Cities like Växjö have taken a leading role in the development of wooden multi-storey buildings, to the extent of establishing ambitious goals such as having 50% of the new buildings with timber as a main material. On the other hand, bigger cities like Gothenburg have been struggling to consolidate a market for timber constructions.

**Timber Construction in Visions and Implementation Strategies**

Among the main motivations to stimulate the construction with timber are the sustainability benefits that have been identified. For this reason, local public institutions are currently setting ecological, social and economic requirements for the new developments in order to encourage them to select alternative materials. Nevertheless, concrete and steel are still the preferred materials of the construction companies as they perceive that these materials represent a less risky option, especially on the economical aspect. Despite this, one representative of a public institution in Gothenburg pointed out that "*building with timber is politically perceived as an advantage*". Therefore, these kinds of structures are likely to be chosen for future developments. The increasing importance that sustainability has among the construction sector is the main reason why the different public authorities tend to favour timber construction over concrete and steel.

The city of Gothenburg currently has an ambitious plan for the development of the city for the next 35 years, in which a great importance is given to the reduction of carbon footprint. Due to this, great efforts are being made to measure the real impacts of the implementation of different materials and construction principles, through methods such as LCA and LCC. The main issue lies in the fact that only a few large companies are capable of performing these assessments, which are not completely standardised. Because of this, the public sector has not been able to set specific requirements for construction material emissions since this constitutes an unfair competition for medium and small organisations, hindering even more the introduction of sustainable materials such as timber.

As mentioned above, the situation differs within the different regions of Sweden. For instance, in Växjö, large contractors have taken an important role in the new developments of the city. They have been involved in multi-storey buildings done with timber and are actively involving local small and medium organisations to be part of these developments. Their main challenge was voiced by a public authority of Växjö: "*the consultants and engineers must be convinced about the viability of using timber".* To be able to overcome this challenge, the city has counted on the support of universities and programs such as CBBT[2] and Trästad Sverige[3] which has helped to increase knowledge about the material.

**Requirements for Improving the Situation for Timber Construction**

In the same way, in Gothenburg, it is necessary to increase the knowledge among the industry about timber construction. In order to achieve this, strengthening the collaboration with academia is seen as a key priority. The Gothenburg public sector is aware of this and the local politicians express the desire to promote timber construction in the city. As a consequence, there is a need to specify, what is timber construction. Determining that requires a collaboration with researchers and private sector stakeholders.

To sum up, the perspective from the public sector indicates a desire to increase the implementation of wood and other sustainable materials in the construction industry. However, public institutions have not found the way to promote its use without incurring in an unfair competition towards organisations with lacking resources. At the same time, public

[2] A foundation that initiates and finances the research and development of timber construction (Westerlund, 2012).
[3] A network of public and private stakeholders that aim to spread knowledge of modern timber construction (Westerlund, 2012).

sector perceives that there is a lack of collaboration with academia to overcome the challenges that timber construction involves.

### 5.1.2 Private Sector Perspective

Timber construction in the private sector is perceived as an alternative that does not provide the same economic benefits as building with concrete and steel. Contractors and subcontractors do not have enough knowledge about the material and, therefore, they tend to charge more because of the perceived risks. Because of this, some of the companies involved in timber construction are trying to consolidate their own actor networks by trying to work together with the same organisations throughout their projects. Most of these organisations consist of small or medium size companies. Large companies argue that they were pioneers in multi-storey timber buildings but they did not perceive the expected results in terms of profit, customer perception and quality.

**Economic and Sustainability Considerations**

In recent years, the local governments seem to have increased their interest in multi-storey timber buildings, mostly because of sustainability advantages of the material. However, according to one representative of a medium-sized timber construction company in the region of Gothenburg "*it is not easy for small and medium-sized companies to get lands to develop".* As a consequence, most of the land in Gothenburg is developed by large contractors that prefer to use concrete and steel as main materials resulting in the slow progress of the city regarding timber construction. In order to change the trend, a change in the educational systems is needed, as currently most of the knowledge provided is about concrete and steel. Moreover, currently there are not enough organisations in Gothenburg with the knowledge and capabilities to supply for a bigger demand for multi-storey timber buildings.

The private sector promotes their use of the material as follows. The most described sustainability advantages relate to the ecological dimension. For instance, the low emissions of carbon during material production and transport are in focus. In the social dimension, the conditions of workers in factories and under the weather screen are more controlled and secure compared to regular building sites. Additional motivations relate to low amount of traffic due to prefabrication and low noise from timber component assembly.

As explained above, one of the main reasons of the slow growing of the timber construction market is the alleged lack of economic benefits. However, according to some of the interviewees this is not entirely true. Building with timber is faster which results in an economic benefit on a long term. Moreover, the possibilities to prefabricate the timber elements reduce the costs of the construction processes since it requires less workers and time for its completion.

One of the biggest challenge that the organisations dealing with timber construction have to face is the difficulty in measuring sustainability. Assessments such as LCA and LCC demand the collaboration and support of several actors. Therefore, small and medium size companies claim that they lack the competence or networks to carry out these analyses. Also the evaluation procedure of different calculations can become complicated. In addition, there is not a current joint cooperation with the academia and private companies in the region of Gothenburg regarding the assessment tools for construction materials.

An example of a project where this problem is acknowledged, involves a proactive approach by the construction client. The life cycle assessment of the whole building is ordered by the client whereas the results are transformed into simple prescriptive requirements. Thanks to the process, the client is aware of the parameters that are the most significant in order to reduce the climate impact. For example, the prefabricated concrete in the project should include a low amount of clinker in the cement, a low amount of cement in the concrete mix and a high level of recycled steel in the reinforcement. These simple guidelines ensure that contractors would behave in the most ecologically advantageous manner and the smaller firms would not be disadvantaged by the complicated calculation requirements.

**Differences Among the Firms**

All in all, there seem to be different perspectives inside the private sector regarding timber construction. Big companies prefer to keep implementing traditional materials as they have provided them satisfactory results in economic and quality terms. On the other hand, some small and medium organisations have been trying to introduce their knowledge about timber construction into the market, though the development of projects in different regions of Sweden.

### 5.1.3 Academia Perspective

The main function of academia is to create knowledge about timber as a construction material as well as quantifying its sustainability benefits. However, in order to be able to apply the knowledge it is necessary to communicate it to the different stakeholders. According to one researcher of timber construction: "*communication with the industry is the main issue, therefore, trust must be developed between academia and the industry and this* *requires a lot of time".* Thus, there is a need to have a communication platform that unites the private and public sector with the academia.

**Varying Regional Competence of Universities**

Regions of Sweden such as Växjö and Skellefteå that count with a strong presence of the forest industry are in a different situation from Gothenburg. Forest industry in these regions has financed timber research in local universities such as Linnaeus University and Luleå University of Technology. The result is a promoted development of the material which, in turn, has encouraged local authorities to establish ambitious goals towards sustainable construction. This is possibly one reason why most of the researchers of wood as a construction material are located in the cities mentioned above and have decreased considerably in cities such as Gothenburg, Stockholm or Lund in the past 20 years.

In the case of Gothenburg, where the forest industry is not represented by large enterprises, there is a lack of collaboration to promote the material since construction organisations do not perceive the associated benefits. Despite the public sector intentions to promote the use of wood, the dominant organisations in the construction market have preferred to put their efforts into making traditional materials more sustainable instead of using alternative resources. Some academics state that this is not feasible in a short term arguing that "*there is still a lot to be done in order to use traditional materials in a more sustainable way".* On the other hand, there is the belief in the academic sector that through research it is possible to "*make any material more profitable"* since, clearly, the economic factor is the main driver for the private sector.

**Perspectives on the Sustainability of Timber**

Regarding the economic factor, the challenge to overcome from the academic perspective is the data of the private sector which is not shared with researchers, therefore making it difficult to measure sustainability. In order to obtain economic sustainability when using timber, it is important that the raw material exploitation is done in a sustainable way. This means that some regions could not have a benefit from increasing the use of timber since they cannot supply an excessive use of timber. This factor indicates that it is not economically sustainable for some regions to seek for renewable construction materials that they cannot produce.

From an ecological perspective the main tool to measure the impacts of the material is LCA. However, this method can be applied in several different ways and be adjusted according to the decided boundaries and interests of the stakeholders. Hence, the application of LCA can currently be used by concrete, timber and other material promoters to favour their own benefits. Therefore, relying on a LCA to decide between materials is not viable.

In terms of social sustainability, the use of wood can provide better working conditions in terms of security, noise, weather conditions and disturbance to the community. At the same time, it is important to take into account the social aspects during the operation phase. Timber provides comfort and aesthetics for the users, however, this can be achieved with traditional materials as well.

As stated above, one of the main tasks for the academia is to quantify the sustainability aspects in order to be able to show the real impact of changing towards a timber building construction. Nevertheless, a joint collaboration with the private and public sector is needed to prioritise each of these aspects. Although this collaboration seems difficult to achieve because of the different interests of the parties, it is allegedly not impossible as "*communication is more about the people, not the organisations. If there is interest from the people, changes will happen".* The opinion was provided by a researcher with international experience in timber research.

**Technical Challenges**

Another important characteristic to be taken into account is the technical aspect. From the academic perspective, timber products and processes fulfil all the technical requirements in order to be used as a construction material. However, one aspect that hinders the implementation of wood is the moisture regulation in Sweden. According to one interviewee this regulation is too conservative in comparison with other countries which have extensive experience in timber construction. Due to such conservative regulations, the cost of multi-storey timber buildings is higher than it should be which discourages potential investors. Additionally, Swedish construction market is built around concrete, including sound measurements and fire testing, making necessary to introduce a wider change in the system.

**The Integration of Academia and Industry**

Overall, the opinion of representatives of the academy is that they have the task to create the knowledge about the benefits of using timber as a sustainable material. However, in some regions they are having problems in transferring their knowledge to the industry. In order to improve the communication among the parties, it is necessary to exchange information. Successful knowledge sharing between the industry and academia requires a low amount of protective attitude. The competitive nature of the industry may affect the companies to avoid sharing crucial information that might be valuable to the society at large.

Therefore, a collaboration with high levels of trust is needed. For example, regarding the available tools to measure sustainability, they seem to be currently underdeveloped because of the lacking data exchange and insufficiently standardised processes.

## 5.2 Examples of Multi-Storey Timber Buildings in Sweden

The following section includes the observations gathered from several multi-storey timber buildings in Sweden. The projects and their locations are presented in a chronological sequence from the year of completion as follows:

1. Orgelbänken, Linköping, 1996;
2. Wälludden, Växjö, 1996;
3. Inre Hamnen, Sundsvall, 2005;
4. Kv Rya, Rydebäck, 2007;
5. Kv Hyttkammaren, Falun, 2008;
6. Kvarteret Ekorren, Skellefteå, 2009;
7. Limnologen, Växjö, 2009;
8. Askim Torg, Gothenburg, 2012;
9. Strandparken, Sundbyberg, 2013;
10. Hjortronstället, Sundbyberg, 2014;
11. Solbacka Strand, Norrtälje, 2014;
12. Trädriket, Gothenburg, 2015.

### 5.2.1 Orgelbänken, Linköping

The project Orgelbänken was an explorative project initiated by Skanska, a large Swedish contractor. The project was to mimic a similar building system popular in the USA. In the USA, the timber-structured buildings were on average about 30 percent cheaper than concrete and 20 percent cheaper than steel. Orgelbänken was an effort to understand if the considerably lower production costs in the USA compared to Sweden were related to the technology. The building was completed in 1996 and became the first multi-storey building of timber to be built after the technology was allowed by the regulations (Bengtson, 2003).

**Products**

The building:
A four-storey building with 36 apartments.

The structural system of Orgelbänken is a light timber frame with load-bearing wooden studs and joists and OSB particleboards for stabilisation. Due to stringent sound and fire requirements in Sweden, the partition elements were covered with more gypsum boards than in the cases in the USA. Additionally, the particleboards were imported because of lacking knowledge at available Swedish sources. These were major elements that drove the material costs considerably higher than expected (Bengtson, 2003).

**Facilities**

The building was planned to use the construction methods of the USA as much as possible. The framing was completely assembled on the building site. The work of carpenters was made simple and interesting because they were not dependent on the lifting of heavy elements. Besides, the skills and education of the workers was at a high level which contributed to high levels of productivity. This was also enabled due to the fact that the workers were given authority to plan their work. The actual productivity at the building site compared to the planned work decreased the respective costs by approximately ten percent (Bengtson, 2003).

**Organisational units**

The project organisation consisted of the construction contractor Skanska including their engineering department and a local production unit, the property developer Stångåstaden. A large architect office FFNS Arkitekter[4] was involved as well. The contract was design-build which left the design and construction responsibility to Skanska. However, they required an untraditionally close dialogue with their customer and other parties. It was necessary because of unclear desires of clients and facility administrators about the required materials, noise protection, and construction process in general. Empowerment of employees, as mentioned in the previous section, was another consideration for combining the creative input of all parties. (Bengtson, 2003).

**Organisational networks**

The research that was required for developing the innovative construction system in Sweden was funded by the following group of companies: Skanska, FFNS, Stångåstaden, Swedish housing federation Sabo and a timber research organisation Trätek. Study visits by project representatives were conducted to USA where the architectural opportunities, engineering, installations and production processes were observed. The recorded knowledge, among

[4] FFNS Arkitekter was later reorganised to form a large consultancy firm Sweco

other studies, was used to educate the carpenters on working practices and to plan the project.

As previously mentioned, Skanska decided upon an integrated approach when interacting with partners. Bengtson et al. (2010) consider that decision to be one of the main reasons why Orgelbänken was economically and technologically more successful than another concurrent project Wälludden. However, there were negative experiences with supplier interactions. Neither the contractor nor the local plasterboard producer were aware of their available cooperation opportunity. After Orgelbänken, the engineering department of Skanska became more thorough in looking for local material producers. There were also cost increases due to less experienced partners increasing the prices of their work such as the case of the installation firms (Bengtson, 2003).

*Figure 18: Project Orgelbänken in Linköping (Google Maps)*

### 5.2.2 **Wälludden, Växjö**

The project Wälludden was the result of an ambition of Södra, the largest society of Swedish forest owners, to explore the opportunities of multi-storey timber construction. The goal was to demonstrate the economic, technical and aesthetic opportunities that the technology could provide. The decision to start with the research was taken in 1991 and the project was completed in 1996. The building is located in the city of Växjö (Bengtson, 2003).

**Products**

The buildings:
Phase I: One five and one four-storey building;
Phase II: Two three-storey and three two-storey buildings.

The structural system of the buildings is light timber-frame, inspired by similar constructions in the USA. The architectural proposal was regarded due to simplicity and clear association with the utilised building technique. The approach was careful, for instance the façade was not designed to contain wood due to unfamiliarity to future residents (Bengtson, 2003).

**Facilities**

To produce the timber frames, an effort was made to apply prefabrication of building components, similarly to the production processes of Swedish single-family housing. The factory was located close to the construction site and its purpose was to simplify the production of building elements as well as their transportation (Bengtson, 2003).

**Organisational Units**

Trähus Sydöst was established as an equally owned property development company by Södra Timber and Skanska Sydöst. Skanska was in charge of the construction process in which they use their regular suppliers that had been used for other constructions as their approach to the supply network. This was motivated by the interest of Skanska for evaluating the project performance after it was completed. According to the architect of the project, the primary interest of Skanska with the project was to seek for new possibilities for making revenues (Bengtson, 2003). In terms of design, the architectural drawings and descriptions were performed by a small architect office from Stockholm Tina Wik Arkitekter that have experience with many different construction systems (Tina Wik Arkitekter, 2016).

**Organisational Networks**

Apart from the focal organisation, the research support was obtained from Lund's Technological University and the timber-research organisation Trätek (today known as SP Trä). Bengtson et al. (2010) considered the management decision to use regular supply networks as difficult to understand, because the majority of turnover in construction projects is usually affected by the products and services provided by others. Mahapatra and Gustavsson (2008) add that the project coordination was actively led by the architect but the contractor did indeed not initiate any wider collaboration, such as supplier-initiated efforts for development. Moreover, the one-off nature of the project was disadvantageous to the supply itself as the requested low amount of timber in certain dimensions was not optimal for their production and delivery.

*Figure 19: Project Wälludden in Växjö (Tina Wik Arkitekter, 2016)*

### 5.2.3 Inre Hamnen, Sundsvall

Inre Hamnen was a test project partly funded by Byggkostnadsforum (BKF) which was started as a response to the decision of Swedish government to investigate the possible solutions to an alarming increase of construction costs. BKF was active from 2001 to 2007 and supported more than 100 projects with more than 100 million SEK in total. The goal was to find construction systems and practices that would lower construction costs of apartment buildings by bringing the current research and practice closer together. Inre Hamnen was the project that had to demonstrate the economic feasibility of residential constructions built from solid timber elements. The project was in progress from 2004 to 2005 (von Platen, 2009).

**Products**

The buildings:
Five six-storey buildings of 94 apartments in total.

From the beginning of project planning, Inre Hamnen was planned to be built from timber. The structural system is cross laminated timber (CLT) panels by Martinsons. Additionally, the CLT technology is used for the exterior facades. The sought benefits of timber were a more slender construction of the foundations due to the low weight of structures and short construction time because of the “dry assembly” relative to concrete (Boverket, 2006).

**Facilities**

The CLT panels used for the partitions and façade elements were prefabricated, about 400 km away from the construction site. The degree of prefabrication was however medium, considering that the installations, plasterboards and other fittings were still to be installed on site (Boverket, 2006).

The chosen timber structure was thoroughly economically evaluated in comparison to a hypothetical concrete structure and to a timber structure with a higher degree of prefabrication. The latter was evaluated due to suggestions from experts that evaluated the economic, social and technical aspects of the project. The evaluation was ordered by the contractor NCC that is rather known for concrete structures. As a conclusion to the project, the traditionally constructed concrete structures would have been economically more feasible but a timber structure with a higher level of prefabrication would have been the cheapest solution, especially when considering the long-term perspective (Mahapatra & Gustavsson, 2009).

**Organisational Units**

The project was initiated by Mitthem AB, a property developer fully owned by the municipality of Sundsvall (Mitthem, 2016). The aim of the project was to set the cornerstone for establishing the profile of Sundsvall to be the “capital of wood”. As a development project, the role was to develop the technology, methods and their economic implications. As a result, the proactive nature of the construction client was regarded due to clarity in requirements, involving the facility managers, considering the right materials, right people and being focused on the end customers (Boverket, 2009).

The project planning started a couple of years earlier than construction. A local real estate development consultant Framtidsporten AB was given a task to gather different developers and other parties to joint dialogues over the principles and financing of the project. Several of the co-financing stakeholders entered with the assurance that the Swedish Forest Industry (Sveriges Skogsindustrier) association would take the leading role in financing the project. The project team was arranged by NCC with one of the goals being systematic research and documentation for improvement possibilities of the planned constructions. The development budget from project co-financing stakeholders was used to work out and immediately apply new solutions, based on improvement proposals during the project planning and construction period (Boverket, 2006).

Apart from the structural choices and continuous improvement strategy, the ambition was also to involve all the project participants early to thoroughly plan the floor plans, building site organization, quality management, manufacturing, delivery, assembly and installation works. The contractor NCC, manufacturer Martinsons and architectural firm White acknowledged that the chosen timber construction can only provide the planned benefits if all the stakeholders were involved during the thorough planning process. A reflection study was however pointing out that the chosen design-build contract form might have caused quality issues due to missing responsibility of subcontractors to care for aspects not directly included in their contracts. The Inre Hamnen project did not represent such an issue due to high and early commitment of key parties (Boverket, 2006).

**Organisational Networks**

As mentioned in the previous sections, the project benefitted largely from a clear strategy set by the municipality. The first initiative from the government was aimed to reduce the costs of new apartment buildings and the municipality included the local economic benefits by presenting the city as the "capital of wood". The financial support of project development by BKF, Sveriges Skogsindustrier and other parties helped to provide an environment which was more accepting for risks from applying technologies that were new to some project participants and the region. The eventual economic analysis by an external consulting firm was very thorough and provided learning points for similar projects to follow. Another study by Luleå Technical University provided clear requirements for improving the degree of prefabrication in following projects. Martinsons AB took the study as a basis to continue developing its CLT-based construction system. Other follow-up studies were conducted as well by various research institutions (Boverket, 2006).

*Figure 20: Project Inre Hamnen in Sundsvall (Mitthem, 2016)*

### 5.2.4 **Kv Rya, Rydebäck**

In the project Kv Rya, timber structure was considered from an early planning phase. The detailed decision for construction design came after the detail plan and general design of the building was ready. The architect drawings at the detailed plan were made for concrete buildings but could be roughly followed. The decision to use timber construction was the result of a design-bid-build tender where a suggestion by the construction client Derome Förvaltning AB was to use timber structure. Derome is a large group of companies related to Swedish forest industry and therefore they aimed at presenting a possibility to build high quality apartments from wood. Other materials were allowed but in spite of this the construction start delayed for one year due to the problem of finding a suitable contractor. Eventually, the principles of another completed project by Derome were followed and local contractors constructed the building. The project was completed in 2007. The building comprises 28 apartments and a restaurant area (Selvarajah & Ehrnström, 2011; Stehn et al., 2008).

**Products**

The building:
One five-storey building

The chosen structural system was based on a specific glued plywood material Kerto-wood which performs well for load bearing purposes. The material is also called laminated veneer lumber (LVL). Glue laminated beams and steel rods were also part of the structure. For some walls timber frame was used with plywood board cover in case of required additional structural support. Many interior walls were also constructed from light steel studs to avoid surface alignment issues (Axelson, 2008; Selvarajah & Ehrnström, 2011). There were registered issues with impact sound insulation which was not sufficiently considered during the design process (Rosenkilde et al., 2008). Another issue was related to the airtightness due to construction details which were unfamiliar to the construction firm because of such problems would not have been the case with concrete partitions (Selvarajah & Ehrnström, 2011). The structure of timber was planned to be the economically most feasible option for the project. It is interesting to note that wood in the constructions was not presented by the property developer as a selling argument. Pleasant architecture was still pursued and the argument was to show that a regular apartment building can also be built of timber (Stehn et al., 2008).

**Facilities**

An issue which was mitigated to some extent due to previous project experience was moisture. Temporary roof constructions were used but the situation could have been even better if more building components would have been produced at a factory (Stehn et al., 2008). For the fifth storey, a local prefabrication facility was created to speed up the production of non-load bearing wall elements and the roof (Rosenkilde et al., 2008). The timber frame system was considered simple and effective to enable various degrees of prefabrication and the participation of small local firms. Some of the operations were complicated due to large-dimensioned massive boards that were applied to facades for resisting horizontal shear loads. It was also a challenge to protect the construction material from moisture. It was not clear in the beginning of the project how much of the elements were to be prefabricated. That created issues in building site logistics which were not corrected. An earlier more in-depth planning would have provided more efficiency during the construction process (Rosenkilde et al., 2008).

**Organisational Units**

The project delivery form was design-bid-build which means that the design documentation was prepared before tendering for contractors. The architectural design was made by a small architect office at Helsingborg, Jais Arkitekter AB that were later involved in a school building project in Växjö in 2010 which was built from a wooden column-beam system. Derome led the process of design and the building was to be operated by a subsidiary of the same firm. The design was made by the same engineers that were involved at another similar project of Derome in Mölnlycke, therefore some learning from feedback was applied to the improved design. The engineering works were carried out by Tyréns Byggkonsult AB. Some knowledge of weather protection was offered by the research institute SP that used the project Inre Hamnen in Sundsvall as a reference. The construction works were completed by a small construction firm Byggmästar'n i Skåne AB but the coordination of work and quality assurance was the responsibility of Derome. There was a clear division of works, dependent on the structural material. A construction manager responsible of timber works was specifically appointed and the work teams were split between carpenters working with wood and other workers (Selvarajah & Ehrnström, 2011).

**Organisational Networks**

Project Kv Rya was planned in a relatively small scale by Derome. Their interest was to promote a possibility to provide multi-storey housing with timber structures. Tyréns, the engineering consultant, did not initially recommend the use of timber as a cheaper alternative in relation to concrete. Additional risk of unproven technologies was part of the assessment. Eventually the construction firm was found and the project was carried out in a satisfactory quality standard. From external actors, there was a study by the Swedish research organisation SP, analysing the technical aspects of the design and construction process (Axelson, 2008; Rosenkilde et al., 2008; Stehn et al., 2008).

*Figure 21: Project Kv Rya in Rydebäck (Jais Arkitekter, 2016)*

### 5.2.5 Kv Hyttkammaren, Falun

The project Hyttkammaren was commissioned by a municipality-owned property developer Kopparstaden. Their purpose was to expand their properties into central Falun and the choice of wood as a construction material was motivated by the image of the city which is known for being surrounded by Swedish forests. A suitable site was found in coordination with the city planning agency of Falun. However, there was an issue regarding the existing detail plan which was very detailed and made with traditional construction methods in mind. The city planning agency allowed Kopparstaden to develop a new and less prescriptive detail plan which was carried out by a large consultancy firm Sweco. One reason for the allowance was a longer perspective by the city planners to attract a higher variety of construction methods to the city, including timber construction. Some examples of the changes in the detail plan are limits to roof pitch and building height. The latter was expressed in the amount of stories instead, allowing for freedom in interpretation. The first idea of the timber building appeared in 2004 and the tender competition was carried out in 2006. The building was handed over in 2008, consisting of 46 apartments in two buildings.

**Products**

The buildings:
One four-storey and one five-storey building

Since the tender competition was for a design-build contract, the winning proposal involved a certain architectural design, structural system and a construction process. The proposed structural system was to be provided by KLH, an Austrian manufacturer of cross-laminated timber. There were intense dialogues among the project team and the respective authorities about fire safety, noise protection and moisture. Regarding fire, the lacking knowledge of team members and insufficient standards contributed to a safe approach towards the constructions. Therefore, much of the façade was clad by fire impregnated boards and fire gypsum was used in many locations indoors. In terms of noise protection, the challenge was for the manufacturer KLH to deviate from their standard constructions to the Austrian market. The reason was that the regulations in Sweden for sound transmission were stricter, regarding lower sound frequencies. Due to insecure solutions, there was a need to calculate a better floor construction and test its validity. The latter was finally accomplished after some tests with room-sized floor prototypes. For moisture issues, a temporary roof construction was used during the assembly and other precautions were taken to protect the structural timber as well as the rest of the materials (Stehn et al., 2008).

The construction system, delivered by the Swedish subsidiary of KLH, has been used in one other more than two-storey residential building in Sweden. The building is located close to Gothenburg and was carried out by 2014 in line with the project Trästad 2012. The project Åsbovägen constructed by Fristad Bygg has involved pleasant and modern architecture that makes timber visible to the users. It is also important to note that the leading people at KLH Sweden are employees of Fristad Bygg (Fristad Bygg, 2014; KLH Sverige, 2016a).

**Facilities**

The structural system is based on a tested and certified cross-laminated partition element system by an Austrian timber product company KLH. For the project Hyttkammaren, the 30 truckloads of elements were transported from Austria by their subsidiary firm in Orsa, located in North Sweden. The building site assembly was carried out together by the personnel from KLH and workers from HMB Construction, the contractor of the project. The personnel from HMB learned fast and in the middle of project assembly they were entrusted to finish the work without further assistance from KLH. As a reflection, the fastening of the elements was very simple but difficulties appeared later when fitting piping and other installations. No holes or pathways were prepared, thus the work had to be done at the building site. The eventual suggestion to the designers and the factory for next projects was to prepare the holes and pathways for installations (Stehn et al., 2008).

**Organisational units**

The project was led by HMB Construction, a local contractor in Falun. Their design-build delivery included the architectural design by Mondo Arkitekter and the structural system by KLH, an Austrian timber product manufacturer. From the beginning of the project, the cooperation between the developer Kopparstaden and the city representatives was close due to both being unfamiliar to the system. The refining of the detail plan exemplifies such joint efforts. After the tender competition, HMB showed plenty of efforts to integrate the team, for example by running weekly planning and technical meetings. In retrospect, they realised that they could have done even more work with the integration aspect. Some delays did happen due to everybody being unfamiliar to the capabilities and working patterns of other team members. A considerable benefit, emphasized by HMB, was the weather protected building site which contributed to a pleasant and quality-focused working environment. The main contractor and subcontractors were generally content with the process and outcomes of the project as well as implications to future activities. Many new ways of working were found and a number of improvement suggestions for future projects were determined. The major suggestion of a higher prefabrication level with installation pathways in the panels were provided to the construction client (Stehn et al., 2008).

**Organisational networks**

Knowledge, funding and other support for a successful project were mostly attained internally from the project team. The main actors were local to Falun, apart from the wood manufacturer and provider KLH which is from Austria. According to the available information, the appearing technological issues related to fire, sound and moisture were solved by the team actors. Respective timber related development was actively led by KLH (Stehn et al., 2008).

*Figure 22: Project Kv Hyttkammaren in Falun (KLH Sverige, 2016b)*

### 5.2.6 **Kv Ekorren, Skellefteå**

Kvarteret Ekorren represents the ambitions of the timber construction industry in Skellefteå. There are a number of companies in the area that are dependent on the local forest industry. Despite the small size of the municipality, there were several municipally funded timber buildings built in the nineties such as a sports hall, a library and a student union building. The local resources and experience were relied upon, to design and produce the buildings at Kvarteret Ekorren. There are 54 apartments in total and the project was in production from 2006 to 2009 (AIX Arkitekter, 2012; Setra, 2015).

**Products**

The buildings:
Two apartment buildings of three to five storeys, depending on the section.

The building structures are made of timber volume elements, based on the concept Plusshus[5] by a Swedish construction company Setra AB. The applied system Trälyftet is patented by Setra and involves solid wood elements for multi-storey constructions (Setra, 2015). The volume elements are transported to the building from nearby manufacturing facility, run by Setra. The architectural principle was to expose wood as much as possible on the interior and exterior of the buildings (AIX Arkitekter, 2012).

**Facilities**

The Plusshus construction system is a combination of volume elements and floor/wall elements that are prepared in a production facility of Setra, close to Skellefteå. The company describes their decision of choosing wood in their industrial process because of a possibility to apply high levels of prefabrication. The result of the method is work safety for material and employees as well as consistently high quality. Wood provides good thermal insulation and it has a long service life. Due to its low weight to capacity ratio, the transportation costs and foundation dimensions could be reduced. Additionally, prefabrication helps to shorten the construction time and the related costs. The construction system and facilities are certified and are being continuously monitored by self-evaluation as well as by the research institution SP (Setra, 2015).

**Organisational Units**

A housing association was the customer of the project. The project team was created by Setra, in the form of a trades contract (ByggfaktaDOCU, 2012).

[5] Plusshus facilities were bought by Derome in May 2016 (Derome, 2016).

**Organisational Networks**

The project is one of the representatives of the ambitions by Skellefteå municipality to be at the frontier of timber construction in Sweden. It was indirectly influenced by the national programme Trästad 2012 which was aimed at educating the municipalities and property developers about the benefits and possibilities of timber construction. Skellefteå, due to its ambitions and experience, started a local programme after Trästad 2012 commenced. The local programme called Trästad Skellefteå was directed towards increasing the scope and involving private sector to engage further with the planned actions of the municipality. The resulting timber building strategy is inspired by the three pillars of sustainable development. Apart from improving the sustainable and cultural development of the local communities, the goal is also to improve the involvement of local SMEs to future building projects (Ingmar, 2015; Westerlund, 2012).

*Figure 23: Project Kv Ekorren in Skellefteå (AIX Arkitekter, 2012)*

### 5.2.7 Limnologen, Växjö

The project Limnologen was initiated as a result of a town planning strategy for the city of Växjö which was in progress from 2002 up to the final decision in 2005. The strategy involved the development of Välle Broar, an area in the centre of the city, which had a requirement to be constructed from wood or wood-based materials. In the rest of the city, wood was a construction material that had to be demonstratively considered as an alternative in all of the building projects. There were multiple reasons for the strategy such as regional economic dependence on the local forest industry, environmental policies, need for a distinct profile of the city, existing research capacity and lowering the costs of properties owned by the city. The timber construction strategy became to influence the

Swedish national programme “Mer Trä i Byggandet” which has the aim to promote timber construction in the whole country (Serrano, 2009).

Limnologen became the landmark of Välle Broar as the tallest timber building in Sweden up to the present day. It was in production from 2006 to 2009 and was led by a property development firm Midroc. An important aspect with the Välle Broar area was the conclusion of Växjö municipality that their power to influence the use of construction material was possible when they owned the land before obtaining respective building permissions. Fortunately, the managing director of Midroc had a will to further negotiate with the municipality which ended up with several floors taller buildings than initially planned. A key enabler was also the CLT-element producer Martinsons that had demonstrated their ability to provide reliable structural systems for tall timber buildings (Serrano, 2009).

**Products**

The buildings:
Four eight-storey buildings with 134 apartments in total. All the first storeys are with a concrete structure.

The structural system of Limnologen is based on elements which are glued together from wooden blocks at production facilities (Serrano, 2009). The material is called cross-laminated timber (CLT) which became available as a construction material approximately 20 years ago. By today, the material has become accepted in the design of tall timber buildings. It has been used in structures up to nine floors in height and research has shown its applicability to buildings as tall as 150 metres where more than 80% of the components can be made of wood (Kuilen et al., 2011).

CLT elements are used in load-bearing partitions such as outer walls, inner walls and floors. In some locations, a timber column-beam system combination is used to complement for the structural stability of the buildings. Between apartments, a timber frame is used for the wall constructions. The CLT elements in the floors are additionally combined with a timber frame to accommodate the piping, fulfil sound transmission requirements and for other reasons (Serrano, 2009).

**Facilities**

The structural components for the project Limnologen were built by a large contractor NCC and a CLT-element manufacturer Martinsons. The latter was mainly responsible for erecting all the floors except the first which was made of concrete. The wooden component manufacturing took place approximately 1200 km away from the building site, at a manufacturing facility in North Sweden (Serrano, 2009)

The assembly at building site was carried out by around 10 workers at a pace of one floor per 10 working days. The moisture concerns from weather required a fully covered construction site which was also accompanied by an on-site crane underneath the temporary roof. The covered building site was well regarded of the workers because of a stable working environment. The weather protection was however costly and time-consuming to elevate. It was also not optimal for the logistics as the transported elements could not be lifted directly from trucks to the constructed buildings. Some issues during the assembly were related to the one-off nature of the project such as missing or damaged material, dimensional errors and mounting errors (Serrano, 2009).

**Organisational Units**

The project involved numerous participants. First and foremost, the project was initiated by the developer Midroc Property Development. The project team was put together by the sister company Midroc Projects AB in the form of trades contract (Stehn et al., 2008). Midroc was not experienced with high-rise timber constructions from before, therefore trusting relationships were needed with other project parties. Regarding timber components, the availability of a Swedish CLT producer Martinsons was the key for Midroc to consider applying the technology at a larger scale. It was vital for Midroc to utilise a system which was capable of fulfilling the fire and sound requirements for residential buildings as Martinsons had proven (Serrano, 2009). The construction works were carried out by a large number of small subcontractor firms that complicated the project management process. The borders of responsibility became complicated and the coordinating became time consuming for everybody involved. A careful planning and follow-up ensured a well completed project in the time and cost constraints but the subcontractors reflected that similar projects could involve fewer different participants in the future (Rosenkilde et al., 2008).

Another important source of knowledge was sought through the architectural competition where a requirement was to have earlier experience with timber. The eventual invitations were sent to two firms which had to develop their proposals. A local company ArkitektBolaget won the competition which is engaged in sustainable architecture and especially timber constructions. In addition, the engineering consultant company Tyréns was involved for carrying out calculations and a feasibility study for the structural system. A rough comparison of different materials regarding the economic feasibility regarded timber frame as three to four percent more expensive option than concrete. This involved the contingency considerations due to complicated structural requirements because of the building height and site conditions. From a broader perspective, timber was to provide a faster construction process which reduced the respective costs. Eventually, because of the offered price and verification of their capability, Martinsons was selected by Midroc to take the primary responsibility for manufacturing and assembling the structure (Serrano, 2009).

**Organisational Networks**

Due to the fact that all the involved parties in the project were considered to have little experience with tall buildings of timber, the knowledge from other sources needed to be used. An example is a fire meeting with eight experts in the field that was arranged when four storeys of the first building were erected. Similar meetings were held to manage the moisture protection issue during construction. A high number of checks, audits and samples were made in Limnologen, by representatives of the timber research organisation SP Trätek (renamed to SP Trä) and Linnaeus University in Växjö.

For the purposes of presenting the renewed image of the city with projects such as Limnologen, the municipality was active in promoting the Välle Broar area for Swedish and international audience. Already during the first years after completion, there had been thousands of visitors triggered by relevant interest. Another spin-off from the success was an organisation founded by Växjö municipality and Linnaeus University. It was named "Centre for Building and Living with Wood" (CBBT) and the goal was to act as a research and development organisation as well as a funding body to respective research. In addition to the previously named, the foundation comprised of firms and other organisations related to timber manufacturing and construction in Sweden.

The projects such as Limnologen have managed to make the parties from academia, private and public sector to have a joint understanding about the technical challenges and solutions. The follow-up projects and respective organisational networks that developed needed less and less pressure from the municipality to consider timber as a structural material. The level of discussion entered from the question "if" to "how" and long-term aspects came to the forefront, such as timber structure effect on health, maintenance costs for stairwells and similar (Ingmar, 2015).

*Figure 24: Project Limnologen in Växjö (Midroc Property Development AB, 2016)*

### 5.2.8 **Askim Torg, Gothenburg**

The residential building at Askim Torg, Gothenburg, was planned to be a replacement for an existing two-storey building which was demolished. The existing foundations were considered sufficient to withstand the weight of a timber-framed multi-storey residential building. The basement floor was preserved as well for the use of the new buildings. The fact that the substructures did not require reconstruction and the column-beam system by Moelven Töreboda AB provided a quick construction, the timber building was considered to be economically a better alternative compared to concrete or steel structures. The building involves 65 apartments and was constructed from 2011 to 2012 (Moelven Töreboda AB, 2013; Tellnes et al., 2013)

**Products**

The buildings:
Two six-storey residential buildings

The structural system is timber column-beam system where Kerto LVL is used for load-bearing floor partitions. The utilised construction system Trä8 is developed by Moelven Töreboda AB together with the research by Luleå University of Technology. Apart from the timber sections, the elevator and stairway shaft are made of reinforced concrete. There is also a façade where steel beams and steel struts are used (Tellnes et al., 2013).

**Facilities**

The columns, beams and prefabricated floor elements were prefabricated by Moelven and transported to the building site from the factory in Töreboda, approximately 200km away from the building site. The construction system provides a very fast erection of the structural system and enables the fast establishment of a rain tight roof partition. After that the construction of internal partitions can continue with lesser precautions for weather protection. The construction system Trä8 had previously been used at another construction project in Växjö (Johannesson, 2016; Tellnes et al., 2013). The buildings at Askim Torg were the first six-storey buildings to be accomplished by the system Trä8. The duration for their building site assembly was eight weeks in total (Moelven Töreboda AB, 2015).

**Organisational Units**

The project team was created by the local property developer and manager Hökerum Bygg AB in the form of a design-build contract (ByggfaktaDOCU, 2015a). The architecture was developed by an architecture firm Arkitekthuset Jönköping AB whose references involve buildings of many different types and materials. Moelven Töreboda AB, the developer of the structural system prefabricated the elements, delivered them to the construction site and did the assembly works at the building site. Hökerum Bygg considers the experience a good lesson to understand the benefits of the material (Moelven Töreboda AB, 2013; Tellnes et al., 2013). In other projects, Hökerum Bygg prefers the use of prefabricated concrete for similar benefits than prefabricated wooden construction. It provides them the possibility to build safely, in a fast way and avoid moisture in the construction (Hökerum Bygg, 2016).

**Organisational Networks**

The further knowledge and promotion in relation to the project was carried by the contractor Moelven that had developed a structural system together with Luleå University of Technology. By today they have applied the system in several other projects (Moelven Töreboda AB, 2015). There has been one Norwegian follow-up study on the carbon emissions during the material production, transporting and construction which demonstrated considerable savings of emissions in comparison to equivalent concrete structures (Tellnes et al., 2013).

*Figure 25: Project Askim Torg in Gothenburg (Arkitekthuset, 2016)*

### 5.2.9 **Strandparken, Sundbyberg**

The project Strandparken is special due to the lack of involvement of the municipality in deciding upon a timber structure (Sundbybergs stad, 2010). Folkhem Produktion AB, the property owner and land developer, is a small private company that is active in the Stockholm area. Recently they strategically decided to be only involved in buildings with timber structures. The project called Strandparken at Sundbyberg near Stockholm is their largest achievement up to this date. The project is designed by a famous Swedish architect office Wingårdh Arkitektkontor AB. The buildings contain 124 apartments in total. The project was in progress between 2012 and 2013 (Sveriges Träbyggnadskansliet, 2015).

**Products**

The buildings:
Four buildings of eight floors.

Strandparken is promoted as the first eight-storey building which is entirely built with modern timber construction. The focus on promotion and architectural design have resulted on carefully developed solutions which elegantly demonstrate wood in the interior and exterior. Apart from the load-bearing structure which is CLT from Martinsons AB, the façade is from cedar shingles and wood is widely exposed in interior details as well (Sveriges Träbyggnadskansliet, 2015). When choosing the structural system, another option was considered by a German manufacturer Kaufmann Holzbau GmbH. The system would have resulted in a composite structure of timber beams and columns with concrete panels completing the system. A functional study recommended to decide upon the latter provider because of a potential to acquire knowledge of a timber construction system that has not been applied in Sweden (Selvarajah & Ehrnström, 2011).

To justify the timber construction strategy, Folkhem has developed a list of "ten truths about timber buildings" which primarily aim at exemplifying the benefits of timber structures in comparison to concrete. These are as follows (Folkhem AB, 2016):

1. 2200-ton difference of carbon emissions between structural systems of concrete and solid wood, based on the example of one building in the Strandparken project;
2. Production of a timber building is twice as fast compared to concrete building;
3. The construction of timber buildings is a quiet process;
4. Timber buildings due to their low weight require less intensive groundworks;
5. Wood as a construction material does not emit toxins that may be the case for concrete during its post-curing process which can take many years;
6. Wood as a construction material is low-weight and requires less from transportation;
7. Wood is an abundant national resource. The whole Swedish forestry provides the equivalent of timber for a single Strandparken building during one minute of growth;
8. Wood is a completely renewable material if the forests are rightly taken care of;
9. Wood is durable, even as a façade material like cedar shingles on the facades of Strandparken. Their lifetime in Swedish climate is estimated to be around 100 years;
10. Timber buildings are fire safe. Considering that steel structures and the steel reinforcement in concrete structures distort during fire, the timber structures char but do not deflect.

Based on the project Strandparken, Folkhem has acquired an environmental product declaration for their building concept. The focus of the declaration is life cycle analysis which regards all the processes from raw material supply to the disposal of building components after demolition (EPD International, 2015).

**Facilities**

Strandparken buildings are constructed from CLT wall and floor elements which are manufactured and transported from North Sweden, about 700km away from the building site. The producer and assembler of CLT elements is Martinsons that has been involved in numerous other multi-storey timber projects in Sweden. For site assembly, they are using a combined system of temporary roof and a mounted crane called Extoler (Figure 26) which they have developed based on the experience of earlier projects (Selvarajah & Ehrnström, 2011). The cedar shingles on facades are shaped and delivered by a Swedish timber building component provider Moelven Wood AB (Sveriges Träbyggnadskansliet, 2015).

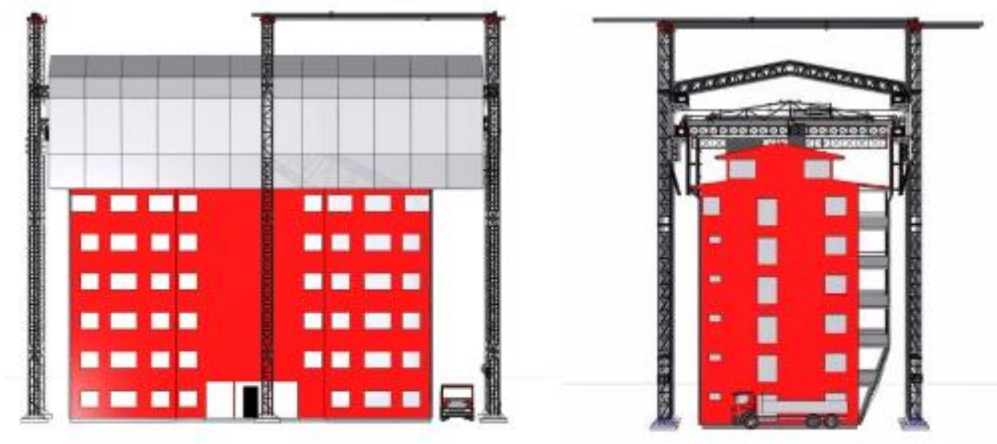

*Figure 26: Extoler system: Assembly under the temporary roof with a mounted crane (Selvarajah & Ehrnström, 2011)*

**Organisational Units**

The project team was organised by Folkhem and the project has been used as a reference object to promote their business. The project delivery form is trade contracting (ByggfaktaDOCU, 2015d). As in many other Swedish projects, the structural system production, delivery and assembly is achieved by Martinsons. The architectural design was developed by Wingårdhs, a famous Swedish design office (Sveriges Träbyggnadskansliet, 2015).

**Organisational Networks**

The project team consisted of partners that had earlier experience with timber construction. Therefore, the collaboration with other parties during the early project phases are not known, apart from an evaluation study for the use of structural timber (Selvarajah & Ehrnström, 2011). The follow-up activities, however, are involving many organisations such as LCA calculations for an environmental product declaration by Tyréns consultants and overall promotions of tall timber buildings by Sveriges Träbyggnadskansli (Sveriges Träbyggnadskansliet, 2015). Furthermore, during the construction of Strandparken, Folkhem signed a contract with Rikshem, one of the largest property owners in Sweden, to provide 4000 new apartments at the Stockholm region until the year 2020 (Rikshem AB, 2014). Deliveries by Martinsons, the CLT system provider, are part of the agreement (Martinsons, 2014).

*Figure 27: Project Strandparken in Sundbyberg (Martinsons, 2014)*

### 5.2.10 Hjortronstället, Sundbyberg

Hjortronstället is a multi-storey timber construction project at Sundbyberg, near Stockholm. Unlike other areas with traditions and visions related to timber construction, the vision of Sundbyberg does not explicitly involve aspects of timber construction. The current vision however mentions the keywords of sustainable development of living environment involving severe reductions of carbon emissions and a growth of the area with new homes, workplaces and well developed infrastructure (Sundbybergs stad, 2016). Project Hjortronstället with 112 new apartments was in construction and development from 2012 to 2014 (Lindbäcks Bygg, 2016a).

**Products**

The building:
Two apartment buildings of five-storeys.

The structural system for Hjortronstället is prefabricated volume elements where timber frames are used for load-bearing purposes. The construction system is based on the standards of a large volume element manufacturer Lindbäcks Bygg. There is a limitation to the width of volumes to 4 metres due to freight transportation limitations on Swedish roads (Giang & Moroz, 2013).

**Facilities**

The buildings are prefabricated to a high degree. The volume elements were manufactured in North Sweden about 900km away from the building site. Volume elements imply that the partition elements are combined at a factory to finished room modules. The installations and much of the internal finishing apart from final assembly is completed before works at the building site. The volume elements are transported from the factory to building sites by truck (Giang & Moroz, 2013).

**Organisational Units**

The project for the buildings was initiated by the volume element manufacturer Lindbäcks Bygg, as a design-build contract (ByggfaktaDOCU, 2015b). The architectural design was created by a small architectural firm Hermansson, Hiller & Lundberg who have lately also collaborated with Folkhem, a property developer at Stockholm that has taken a strategic approach to concentrate on timber structures in the future (HHL, 2016).

**Organisational Networks**

The basis for a construction system of Lindbäcks Bygg was developed as a coordinated effort with Luleå University of Technology. The cooperation still ensues in relation to specific development projects and follow-up studies. Lindbäcks Bygg has also prioritised long-term relations with upstream and downstream stakeholders in their supply network. Long-term framework agreements with Martinsons and Rikshem are examples of both directions (Brege, Stehn, & Nord, 2014; Lidelöw et al., 2015). It is not clear to the authors of the present study, whether any additional stakeholders apart from the above-mentioned were involved in project Hjortronstället.

*Figure 28: Project Hjortronstället in Sundbyberg (Lindbäcks Bygg, 2016a)*

### 5.2.11 Solbacka Strand, Norrtälje

Solbacka Strand is a building of assisted living, comprising 54 apartments for elderly people additionally to various kinds of common rooms. The project was started in 2013 and finished in 2014 (Constrera AB, 2016b). The project was ordered by Svenska Vårdfastigheter, a company that is specialised in building and operating assisted living homes for the elderly (Svenska Vårdfastigheter AB, 2016).

**Products**

The building:
A four storey building of assisted living

The construction is allegedly unique because it is the first time in Sweden when the construction system of an assisted living home is volume elements. The structural system is timber frame. The energy use requirement for the building is Miljöklass Silver according to respective standards in Sweden (Constrera AB, 2016b). The construction system of Kodumaja is certified according to the requirements of European Assessment Document which has approved the methods of attaining required mechanical stability, fire resistance, sound insulation, environmental impact and energy performance (Sintef Certification, 2015).

**Facilities**

The volume elements are manufactured in the Southern part of Estonia, around 200km by car and 400km by sea away from the construction site. The modules are finished to a high degree, with installations and most of the finishing ready before delivering them to the building site. The benefit of the method is to reduce the construction time to a significant degree (Constrera AB, 2016b).

**Organisational Units**

Svenska Vårdfastigheter have hired the project development, management and contracting function from a project development firm Castor Projekt. For Solbacka Strand, Castor Projekt sourced the project management function from Constrera AB that provided a project delivery form which they call Open Construction (Castor Projekt AB, 2014; Constrera AB, 2016b). This implies a project management service whereby Constrera manages the design, production and delivery together with the guarantees for staying within the estimated time and cost (Constrera AB, 2016a). An Estonian volume element manufacturer Kodumaja provided the manufacturing and assembly services as a subcontractor (Constrera AB, 2016b). The architectural design was created by a small consultancy firm Konsultfirman Christian Rasmusson Holmberg (ByggfaktaDOCU, 2015c).

**Organisational Networks**

As previously mentioned, Svenska Vårdfastigheter represent themselves as a highly specialised construction client that has focused on homes of assisted living. Their strategic orientation has been cemented by their long term relations with leading care home managers, environment institutes, specialised architects, ethnologists, scientists and the representatives of end-customers (Svenska Vårdfastigheter AB, 2016). It is also observed that the coalition of Castor Projekt, Constrera and Kodumaja has continued their cooperation with a building of similar function at the other side of Stockholm (Castor Projekt AB, 2015; Constrera AB, 2015).

*Figure 29: Project Solbacka Strand in Norrtälje (Constrera AB, 2016b)*

### 5.2.12 Trädriket, Gothenburg

The project Trädriket has been a result of a political and entrepreneurial interest. The developer Derome Mark & Bostad was invited to buy the respective land if they managed to demonstrate that they could build the buildings from timber. The result is a building of 50 apartments in the new city development area of Gothenburg (Derome Mark & Bostad, 2016).

**Products**

The building:
One residential building of 6 storeys with the first storey in concrete.

The structural system of Trädriket is timber frame which are prefabricated at a manufacturing facility of A-Hus, a sister company of Derome (Elinstallatören, 2016).

**Facilities**

The manufacturing facility of the timber elements is situated at Kungsbacka, approximately 50km away from the building site. The wall and floor elements are produced in the factory with final assembly at the building site (Elinstallatören, 2016).

**Organisational Units**

The project has been following a very integrated system as the property owner, manufacturing firm, construction firm and the facility management is handled by companies of the same corporation. Subcontractors were used for the assembly on site due to uneven demand for workforce across projects (Elinstallatören, 2016).

**Organisational Networks**

The project was helped by the sustainability-oriented mind-set of the city development company Älvstranden Utveckling who had a task by the municipality to invite Derome to buy the respective land. When the project was completed, the local politicians in power were invited to inaugurate the new buildings at a promotional event (Derome Mark & Bostad, 2016).

*Figure 30: Project Trädriket in Gothenburg (Fredblad Arkitekter, 2016)*

## 5.3 Perspectives of Timber Construction in Gothenburg

In this section the information is presented from the in-depth interviews with representatives from the public sector, private sector and academia. The section is divided into the main topics originating from the analytical framework of the study: sustainability, socio-technical system innovations, resources, and construction innovation.

### 5.3.1 **Sustainability**

Sustainability is considered by all the interviewees as the main aspect for which timber construction should be regarded. However, the view of each of the parties regarding its implementation differs, considering the perceived benefits compared to the possibilities with materials.

**Demand for Sustainable Timber Construction**

In recent years, due to political pressure, the municipality has been trying to promote the implementation of wood as a construction material. The argument is that wood is more sustainable than traditional materials such as concrete and steel. Nevertheless, it has not been easy to incentivise the private sector to provide timber constructions since there are several other drivers needed to be considered for them to promote the change. Another aspect to be taken into account is that the public sector cannot obligate the market to build with a specific material. Therefore, in new city development areas a series of functional requirements are stated related to ecological and social aspects. The main problem with these requirements is that they are based on a ten-year-old program. Therefore, the environmental expectations are not challenging the national standards and are rather easy to fulfil. If the requirements are met by more than one proposal, the municipality gives priority to the projects that provide more organisational diversity to the existing market.

The interest from the municipality is also perceived by the private contractors. For instance, an interviewee from the private sector affirms that they were selected to develop one project because of their expertise in implementing timber constructions. According to the private sector interviewees, the demand for timber construction is growing in Gothenburg and they expect that the trend continues in the following years.

**Supply of Sustainable Timber Construction**

The perspective of the private sector regarding sustainability issues in construction seems to be aligned with the perceptions by the municipality. Unlike the municipality that prioritises the ecological and social aspects, private companies consider the economic benefits most crucial. Construction companies consider economic sustainability very important, especially the opportunities that modern materials can provide regarding the speed and simplicity of the construction process. Nevertheless, traditional materials such as concrete provide a broader possibility of lowering costs since the associated expertise, equipment and general set up is already embedded in the market. Therefore, timber specialised companies are focusing on increasing their competitiveness. This is not an easy task, as claimed by a representative of one of the firms, due to the weather related complications with the specific equipment for multi-storey timber buildings. Gothenburg is known for a rainy and windy climate which requires systems that are less needed in the rest of Sweden.

**Wider Perspectives of Sustainable Timber Construction**

Despite the social and ecological advantages of timber construction being clear to the parties, the actual practice is not happening in Gothenburg at the same rhythm with others regions of Sweden. International and Swedish timber researchers have usually been an important part of the industrial development. However, in Gothenburg they have not managed to establish a cooperation arena. Similarly to the public sector, the researchers regard wood because of it being a sustainable material. As stated by the interviewees, they wish to collaborate to make the material more attractive and economically feasible.

Regarding the measurement and control of sustainability, private companies are not capable of measuring the entire life-cycle of the materials since they do not have the required resources. Instead, they channel their efforts to assure conformance to regulations for their materials and processes regarding the sustainability dimensions. Researchers consider that an increased collaboration with the private sector is needed in order to assess the entire life-cycle of various building materials. Currently the required data is not retrievable due to corporate interests.

### 5.3.2 Socio-Technical System Innovation

An innovation in a socio-technical system level requires the involvement of several dimensions such as technology, science, regulations, user practices, markets and supply networks (Geels, 2004). This means that in order to consolidate multi-storey buildings in the current construction market the collaborative involvement of the three actor groups of the triple helix is needed.

According to the interviewees, there is a great interest from the politicians to promote the use of timber as a construction material. However, the public sector cannot favour the implementation of one material over another, especially if both are fulfilling the established requirements. Because of this, the most effective tool for the municipality is to use its role as land distributor to enhance wooden buildings. From the private sector perspective, they do not perceive a barrier from the authorities to develop multi-storey buildings with the material in question. However, many of the current regulations hinder the interest of construction companies to build with wood. Because of fire regulations, costs increase considerably with tall buildings, therefore timber construction companies have limited the amount of storeys in Gothenburg to not more than five.

From a market perspective, public sector and academia believe that some representative projects are needed to create awareness among the users and organisations in the construction sector. The municipality considers such projects to be important for showing alternative construction systems to existing firms in the industry. Similarly, researchers think that these “test projects” are needed in order to make benefits more visible to the private sector.

Another important issue to consider is regarding the technical aspects. Companies from the private sector seem to be struggling with some issues related with multi-storey timber buildings. Both interviewed representatives from the private sector mentioned the same problem regarding the rigidity of wooden buildings which can affect the elevators. The latter shows an example of some of the technical issues that need to be overcome in order to make timber a more cost competitive material. To achieve this, collaboration is necessary between the private sector and academy since most companies do not have the resources to carry out their own research. Besides, the drawbacks of lack of collaboration are mutual as reflected in the quote by a timber researcher: “*Researchers struggle because of not knowing how to communicate and it is necessary to share the knowledge in order to tackle the issues”.*

### 5.3.3 Resources for Timber Construction

According to the 4R model, two general kinds of resources could be identified which are characteristically technological and organisational. Technological resources are divided into products and facilities, and organisational resources are organisational units and organisational networks (Håkansson et al., 2009).

**Technological Resources**

Regarding the products, the public sector does not have a particular interest in a specific timber building system since their concerns emphasise the fulfilment of functional requirements. Therefore, it is up to the construction companies to decide which product is more convenient to them. Thus, construction organisations select the timber system that provides them the respective benefits such as fast construction processes, simplicity of assembly, in-house production and reduction of errors. In the cases of the interviewees one of the companies uses prefabricated elements because of their in-house production and the second one implements frame structures mostly because of its simplicity.

Another aspect of the product to be taken into account is the type of building that is being done (i.e. apartments, villas, commercial facilities etc.). As specified by one of the private representatives, the municipality is limiting the amount of villas that can be built due to the current lack of housing in Sweden. Because of this, the construction of multi-storey timber buildings is growing and the companies are currently producing new systems and processes that will accelerate the construction processes and increase their building capacity.

Concerning the increasing demand, construction companies agree that they do not have enough production capacity to satisfy the demand. One of the companies represented in the interviews mentioned that they rejected some projects in the region because of the lack of capacity. Hence, the company is working in changing the construction system that they use. On the other hand, the second company plans to increase their capacity by demanding more from their existing as well as some new potential suppliers.

**Organisational Resources**

The municipality argues that they do not have any role in helping the construction companies to improve their capacity, but instead they have to focus on raising the interest from other companies to enter the local construction market. By increasing the number of companies the municipality aims to have a diversity of small, medium and large enterprises developing and building the city, as long as they have the experience for the kind of projects. By having several companies in the construction market it will be easier to face the challenges related to new developments in the city. According to the representative of the public sector, it is not enough to invite a diversity of construction companies. Similar necessity exists for the inclusion of consultancy companies as well. One possible way to enhance the participation of consultants is through creating “spin-off” companies from universities as it is done in Switzerland and Italy. According to the timber researcher, these “spin-off” companies can promote knowledge sharing among relevant parties and Improve competitiveness of wood as a construction material.

Another important aspect to be considered is regarding the relationships among the actors in the timber construction market. Construction companies try to maintain their relationships with different subcontractors through their different projects since this results in an improved construction process and lower costs. However, the interviewed companies prefer to establish short contracts per project or year since short agreements make them economically more secure than long term relationships.

In order to consolidate the construction of multi-storey timber building in Gothenburg a collaboration is needed, as specified by the representatives of academia and public sector. The municipality needs to increase its knowledge about construction processes and techniques, therefore a stronger collaboration with universities is required. It was stated several times during the interview "*The Municipality always has to be neutral and cannot go towards favouring just the timber industry".* For this reason, it is necessary to increase the interest of the private industry as well as the collaboration between them and the universities. Nevertheless, according to one of the private sector organisations, they do not collaborate with the academia but only with their clients since they are the ones who express what their needs. In spite of this, they agree that new materials and techniques should be tested in order to improve the quality and such a collaboration could be beneficial.

### 5.3.4 Construction Innovation

To be able to introduce an innovation in the construction industry, it is necessary to create an environment of continuous learning (Blayse & Manley, 2004). For this reason, it is important to understand how the different parties try to keep the knowledge they acquire through various projects.

In the case of the public sector, the knowledge-keeping is department based. This means that the evaluation and learning from the projects may differ from one department to another since no standardised process is established. The private sector handles the knowledge management in a different way. Construction organisations try to maintain relationships with the same subcontractors through their different projects in order to preserve the knowledge and experience which result in an improvement of the construction processes. Additionally, they consider important to build similar projects to be able to transfer the knowledge between them. On the contrary to the public sector, one of the interviewees expressed that they always share the knowledge among departments to avoid further recurrence of mistakes. Another mean that the private sector implements to keep a continuous learning process is involving their customers through customer satisfaction surveys. Having the perspective of the clients, they are able to provide what the users ask for. It also enables the firms to increase their own learning for future projects.

# 6 Analysis

*This chapter analyses the empirical findings based on the analytical framework. The resource combinations are a result of the pattern finding and explanation building process which analyse the observed case studies. Furthermore, the research questions are used to provide wider implications to the empirical findings. Eventually, the context of Gothenburg is included which precedes the concluding discussion on the main research question.*

## 6.1 Analysis of Resources for Modern Timber Construction

The application of timber structures entail opportunities that can affect the way how the societal needs are satisfied. As mentioned in the previous section, the material provides sustainability implications that are neither limited to only the operational cycle of the building, nor the material production or transportation. The consequences of utilising the material in building structures can change the logistical setup of building sites, thus affecting the transportation issues in areas around emerging properties. Employment conditions can be affected because of high potential degree of prefabrication and quick processes at building sites. The effect to the value chains of local forest industries can be substantial, offering more output opportunities for the renewable material that is widely available and requires to be renewed anyway. Last but not least, carbon emissions can be positively affected when considering the sectors of construction, forestry and transportation in combination (von Platen, 2004).

As a consequence, the present study considers the timber structures in multi-storey constructions to be an enabler towards socio-technical transformation from the current to another system which has the opportunities to become sustainable in social, economic and ecological dimensions. The following sections provide an analysis of resources that have been and could be prevalent for planning, designing and constructing multi-storey timber buildings in Sweden.

The results from empirical findings are summarised in the following chapters which are structured to represent the technological and organisational resources from each project observed. This determines respective patterns that are supported by existing arguments in the research literature.

### 6.1.1 **Products**

It is a trend in the whole Europe to develop innovative forest based products that have high added value in terms of fulfilling societal demands of energy, employment and environmental aspects. Wood as a construction material can fulfil the objective which is why it is on the agenda of many national and international support programmes (Sathre, 2007)

Considering single-family housing, timber has been prevalent as a structural material because the restrictions for wood as a structural material affected only multi-storey constructions. Largely for that reason, the timber buildings produced in recent years constitute between 80 to 90 percent of all the new detached housing. The opportunities in terms of existing knowledge and experience should be considered in the future multi-storey buildings in Sweden (von Platen, 2004).

*Table 2: Technological resource patterns of the case projects*

| Project | TECHNOLOGICAL RESOURCES | | | | | | | | | Time |
|---|---|---|---|---|---|---|---|---|---|---|
| | Products | | | Facilities | | | | | | |
| | Structural system | | | Prefabrication mode | | | Transport | | | |
| | Frame | CLT | Beam-column | On-site | 50/50 | Factory | <50 km | ... | >250 km | Year of handover |
| Orgelbänken | Skanska | | | ■ | | | ■ | | | 1996 |
| Wälludden | Skanska | | | | ■ | | ■ | | | 1996 |
| Inre Hamnen | | Martinsons | | | ■ | | | | ■ | 2005 |
| Rya | (local) | | | ■ | | | ■ | | | 2007 |
| Hyttkammaren | | KLH | | | ■ | | | | ■ | 2008 |
| Ekorren | | Plusshus (Setra) | | | | ■ | | ■ | | 2009 |
| Limnologen | | Martinsons | | | ■ | | | | ■ | 2009 |
| Askim Torg | | | Moelven | | ■ | | | ■ | | 2012 |
| Strandparken | | Martinsons | | | ■ | | | | ■ | 2013 |
| Hjortronstället | Lindbäcks | | | | | ■ | | | ■ | 2014 |
| Solbacka strand | Kodumaja | | | | | ■ | | | ■ | 2014 |
| Trädriket | A-Hus (Derome) | | | | ■ | | | ■ | | 2015 |

**Implications of the Products (Table 2)**

Regarding the observed projects, the products in the strict sense are the buildings that the research focuses on. Therefore, the opportunity for analysis in terms of distinctive patterns are oriented towards the application of wood as a structural material. In terms of structure, timber offers a variety of options which are explained by Stehn et al. (2008) in the Swedish context (see also Appendix B). First of all, there is the timber frame system which is a typical technology for single-family housing and lower multi-storey buildings. Secondly, the solid wood partitions are gaining popularity as the technology is rather recent and improvements to the systems are still frequent. The final observed type of structures is the column-beam system which can either complement earlier mentioned systems or constitute a system of its own. The columns and beams could be made of glue laminated wood or/and plywood which offers more specific differentiation opportunities.

The potential implications of the differences in the use of timber during the short amount of time are firstly that the application possibilities are evolving fast and are not limited to the context of Sweden. As an example, the cross-laminated timber, that is highly regarded for its structural properties, is only a couple of decades old but is already implemented into structures that expect high levels of reliability. Similar agility could be seen with construction systems such as Trälyftet by Setra and Trä8 by Moelven.

**Relations of Products to Other Resources**

Timber frame has been applied in various contexts of facilities. The level of prefabrication for timber frame has been varying and according to the empirical study, the capabilities of firms providing factory-made constructions have been increasing. Solid wood and beam-column structures have been applied in a consistent manner, with an average level of prefabrication and based on a product system that has been developed earlier by a certain producer.

In terms of organisational resources, the different system categories are not specific to a certain region in Sweden. The timber frame structure has been used in a variety of combinations. It could be assumed that the technology is familiar to many firms and workforce that have been active in the single-family housing construction. Solid wood structures and column-beam systems have been contracted by a variety of property developers. The construction systems for solid wood structures have been developed and certified in advance by the respective production firms, Martinsons, Setra and Moelven, all of which are subsidiaries of large firms in the Swedish forest industry. The available data from case projects shows that the solid wood systems were beginning to be introduced in Sweden in early 2000s. This implies a fast progress from invention to an innovative product, considering that Kuilen et al. (2011) claim the technology to be developed in the 1990s.

### 6.1.2 Facilities

Much of the argumentation for the benefits of timber construction are related to the transition of construction assembly from building sites to factories. This provides opportunities to develop routines similar to manufacturing industries due to smaller risks from unknown or uncontrollable environment in terms of resources and activities (Mahapatra & Gustavsson, 2008). Industrialised processes are characteristically proactive because of being owned by a network of integrated actors (Bystedt, 2012).

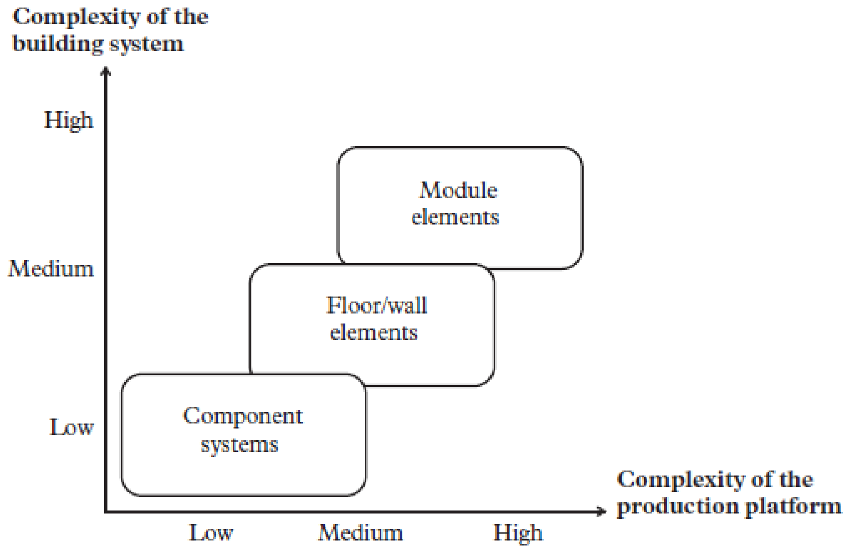


*Figure 31: Prefabrication mode as the degree of complexity of building system and production platform (Brege et al., 2014)*

The prefabrication mode affects the complexity of the building system as well as having an impact on the complexity of the production processes (Figure 31). The three different product categories in the observed projects are component systems, floor/wall elements and volume elements. According to Brege et al. (2014), the level of fabrication could be interpreted in percentages. The component system implies less than 20% work in the factory, volume elements less than 20% at the building site and the floor/wall elements approximately a 50/50 distribution.

**Implications of the Facilities (Table 2)**

The level of prefabrication has been low for product systems that were being introduced to Swedish construction. This was the case for a pioneering timber frame technology after a regulation change that was explored by Skanska in the project Orgelbänken. The system was based on the examples of a popular system in the United States. The situation was similar for a timber company Derome whose project Kv Rya was a follow-up to a pioneering project with the industrialised timber-frame system for multi-storey housing in 2003. Interestingly, wood as a construction material was purposefully not emphasised in either of the projects. Stehn et al. (2008) cite a representative of Derome by whom the structural material is not what the customers would be interested. Their focus instead is on the room layouts, furnishing, appliances etc. and the industrialised construction method that is enabled by the structural properties of timber. For a construction client, the focus is on economic benefits and the reduction of risks regarding the introduction of an unfamiliar technology to the market. The risk aspect was especially important for Skanska during the early projects Orgelbänken and Wälludden (Bengtson, 2003).

**Relations of Facilities to Other Resources**

The level of prefabrication enabling the assembly of floor/wall panels and volume elements impacts all product categories, with some reservations to the column-beam system where the volume elements have not been observed. In terms of organisations, it can be seen that a medium or high level of prefabrication is expected by the clients that are usually not involved in timber construction or construction works. Location wise, the increased level of prefabrication shows that the production of structures can take place more than 1000 km away from the construction site, either in Sweden or a foreign country. Judging from the respective reference material, the observed construction systems are adaptable to requirements in various countries. In neither of the observed projects with some levels of prefabrication, there had been only limited cooperation among the organisations in the project teams. This could imply that loss of knowledge through the loose coupling beyond projects is reduced by standardised methods, similarly to what was observed by Kadefors (1995).

### 6.1.3 Organisational Units

According to Mahapatra and Gustavsson (2008), the century of restrictions for multi-storey timber structures had an effect on the industry which became path dependent and locked in to other technologies such as based on concrete and steel. Bengtson (2003) observed the initial exploration of multi-storey timber structures by large incumbent contractors, primarily to seek for cost reductions. The consequence was mainly opposite and thus the endeavours were short-lived.

Construction industry is characterised by having a great amount of companies available in the market, however, most of them have no more than four employees (Mahapatra & Gustavsson, 2008). The large number of small companies hinders the possibility to introduce new alternative materials since they do not count with the resources needed to promote such a change. That is why some of the large companies have been the first ones in approaching the introduction of timber as a construction material.

| Phase 0<br>Concept and idea | Phase 1<br>Prototypes | Phase 2<br>Strong niches | Phase 3<br>Mass market |
|---|---|---|---|
| - Choice of technology<br>- Choice of production platform<br>- Choice of business platform | - Technology development<br>- Production and process development<br>- Business development | - Technology certification<br>- Concept preparation<br>- Established market position | - Technology certification<br>- Concept development<br>- Strategic business development |

Year: 5 10 15 25

*Figure 32: Development of timber construction firms (translated from Stehn et al., 2008)*

By today, there are many multi-storey buildings completed all around Sweden with the modern timber constructions. After the initial trials by incumbent contractors, the timber building manufacturers and material suppliers started to carry out long-term investments to develop the technological capabilities and knowledge among the market stakeholders. The output has become increasingly integrated in nature, as the timber construction providers take much responsibility for carrying out the projects compared to two decades ago. Long-term relations have been created among the subcontractors and designers as well. The phases of business development in the respective companies is illustrated in Figure 32. The implications are that within the approximate duration of 25 years the timber construction firms have developed from innovators in terms of the technological platform to mass-market firms with certified technology as well as well-defined development processes (Stehn et al., 2008).

*Table 3: Organisational unit resource patterns of the case projects*

| Project | ORGANISATIONAL RESOURCES – Organisational Units | | | | | | Project location | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Construction client background | | | Contractor / contract type | | | Sweden | | | |
| | Construction firm | Forest industry | Property developer | DB | DBB | Other | North | Stock-holm | Centre | West / South |
| Orgelbänken | Skanska | | | Skanska | | | | | | |
| Wälludden | | Södra | | Skanska | | | | | | |
| Inre Hamnen | | | Mitthem | NCC | | | | | | |
| Rya | | Derome | | | Derome | | | | | |
| Hyttkammaren | | | Kopparstaden | (local) | | | | | | |
| Ekorren | | Setra | | | | Setra | | | | |
| Limnologen | | | Midroc | | | Midroc | | | | |
| Askim Torg | | | Hökerum | | | Hökerum | | | | |
| Strandparken | | | Folkhem | | | Folkhem | | | | |
| Hjortronstället | Lindbäcks | | | Lindbäcks | | | | | | |
| Solbacka strand | | | Svenska Vårdfastigheter | | | Constrera | | | | |
| Trädriket | | Derome | | | | Derome | | | | |

**Implications of the Organisational Units (Table 3)**

Regarding the project teams for the construction of multi-storey residential buildings of timber, three main categories of initiating organisations could be determined. Initially, the large construction enterprises, Skanska and NCC, explored the opportunities provided by structural timber. Especially the former became deeply involved in the pilot projects right after the regulation change that allowed the technology to be used. It is worth to mention that a strong driver was provided by a highly engaged project manager of Skanska (Bengtson, 2003). Lindbäcks Bygg is a contractor that became the first construction company in Sweden to utilise industrialised building concepts for multi-storey timber buildings. To fulfil the aim, they have developed their construction systems and facilities that are located in North Sweden. Similarly to other large contractors, they also develop their own properties (Lindbäcks Bygg, 2016b).

Secondly, the large companies from the forest industry such as Södra, Derome and Setra have been active in starting up projects in order to provide higher value products with their regular business. For these actors, there are different levels of engagement. When some firms such as Martinsons, Moelven and KLH have focused on delivering construction systems then Derome and Setra have also assumed the roles of property developers in addition to their project management and manufacturing capabilities. Södra explored a property management and contractor role in project Wälludden with a joint venture with Skanska. Lindbäcks Bygg as a contractor has also taken roles in property development and facility management, integrating the required resources within the company.

In the case examples, regular property developers have been active in initiating the timber construction projects. There is a considerable variety among the developers regarding ownership and strategic orientation. The developers Mitthem and Kopparstaden are owned by their respective municipalities where wood products are considered to be important for the local economy. The private enterprises Midroc and Hökerum Fastigheter are not as much tied to regional politics, neither is timber included in their strategic goals. The project by Midroc provided the developer the benefits of close relationships with the municipality and a promotional project. The benefits of Hökerum were related to the savings from not having to reconstruct foundations due to the low weight of the timber structure. The private enterprises Folkhem and Svenska Vårdfastigheter have explicitly mentioned timber as part of their strategies. The former has expressed that they will only build from timber in the future, whereas the latter states it as a preference. Both justify the decision with the ecological, economic and social benefits (Folkhem AB, 2016; Svenska Vårdfastigheter AB, 2016).

The following is a summary of the observed firms in the chronological order by projects and the primary motivation that has impacted their decisions to carry out the projects:

1. Skanska – Exploring economic benefits, based on their American projects;
2. Södra – Exploring added value opportunities to their wood products;
3. Mitthem – Fulfilling the municipal strategy;
4. Derome - Exploring added value opportunities to their wood products;
5. Kopparstaden – Fulfilling the municipal strategy;
6. Setra - Exploring added value opportunities to their wood products;
7. Midroc – Promotional project and improved relationships with the municipality;
8. Hökerum – Savings on costs due to the light weight of a reconstructed building;
9. Folkhem – Fulfilling the corporate strategy;
10. Lindbäcks - Fulfilling the corporate strategy;
11. Svenska Vårdfastigheter - Fulfilling the corporate strategy.

All in all, the motivations could be divided into: 1) experiments for economic benefit, and 2) longer term goals which are guided by the economic, environmental and social benefits of the material and technology.

Noteworthy for the analysis is the type of contracting that shows a reliance on Design-Build or Design-Bid-Build contracts for projects that could be considered early pioneers and are characteristically more explorative. In other projects, the construction clients have either retained the risks of design and construction or transferred it to a project management firm. The latter is either a subsidiary of the client organisation or in one of the cases a separate agent.

**Relations of Organisational Units to Other Resources**

The observed relation of organisational units to products shows that the established construction systems could be applied by construction clients and contractors from different backgrounds. A certified and tested system could be an enabling factor for a successful coordination of stakeholders that do not have earlier experience in working with each other which align with the suggestions by Kadefors (1995). However, the clients tend to retain their control over the project progress with respective contract forms and project management units. Apart from construction contractors themselves, it is only the municipality-owned property developers that have decided upon the design-build delivery where contractors take the sole responsibility for delivering a project.

The observed project teams comprise organisations that have some or no experience in collaborating with each other. A reason for the tendency is likely to be the experimental nature of the projects at the respective areas and regarding the required organisational capabilities. From the knowledge management perspective, the lack of earlier experiences could hinder a smooth process due to unforeseen issues. This is important to be considered when the project success is being evaluated. On the other hand, if similar project teams would continue working in similar projects, the problems could be proactively avoided and new opportunities might emerge.

### 6.1.4 Organisational Relationships and Networks

In order to generate innovations in the construction sector the networks of knowledge-sharing organisations are highly valuable. In the case of timber, most of the networks that can be found are either on a local or regional level. The development that has been done in a regional level is mostly because of the involvement of the forest industry, which has promoted the use of timber through the collaboration with academia and private sector (von Platen, 2004). The author also argues that there is a potential opportunity for increasing the material application on a national level, which can be achieved by connecting the national strategy to regional programmes.

Contribution to the success of multi-storey wood-frame structures is attributed to the inter-firm level knowledge creation, incentives for starting firms and encouraging the development of new actor networks (Mahapatra & Gustavsson, 2008).

*Table 4: Organisational network resource patterns of the case projects*

| Project | ORGANISATIONAL RESOURCES Organisational Networks | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Source of the initiative | | | Network | | | Earlier cooperation | | |
| | Client | Political | Supplier | Local | National | Inter-national | Much | Some | Little |
| Orgelbänken | | | ■ | | | ■ | | | ■ |
| Wälludden | | | ■ | | ■ | | | ■ | |
| Inre Hamnen | | ■ | | | ■ | | | | ■ |
| Rya | | | ■ | ■ | | | | | ■ |
| Hyttkammaren | | ■ | | | | ■ | | | ■ |
| Ekorren | ■ | ■ | | ■ | | | | ■ | |
| Limnologen | ■ | ■ | | | ■ | | | | ■ |
| Askim Torg | ■ | | | | ■ | | | | ■ |
| Strandparken | ■ | | | | ■ | | | ■ | |
| Hjortronstället | ■ | | | | ■ | | | ■ | |
| Solbacka strand | ■ | | | | | ■ | | | ■ |
| Trädriket | | ■ | | ■ | | | | ■ | |

### Implications of the Organisational Networks (Table 4)

The organisational networks identified in the case projects represent a diversity in terms of initiative source, network scope and the earlier cooperation of stakeholders. The further analysis of resource constellations provides a basis for pattern identification, as presented in the following sections.

### Implications of the Organisational Resource Constellations

The location-specific organisations associated with the case projects in Sweden are presented in Figure 33. The organisations are fairly evenly distributed across Sweden which is partly intentional as the authors sought the projects for a wide resource diversity. The resource constellations spanning across the observed projects, their actors and the municipalities are presented in Figure 34, Figure 35 and Figure 36. There are several links between the projects at the level of national timber construction strategy, the education and research institutions as well as business networks and the earlier or later cooperation of some actors.

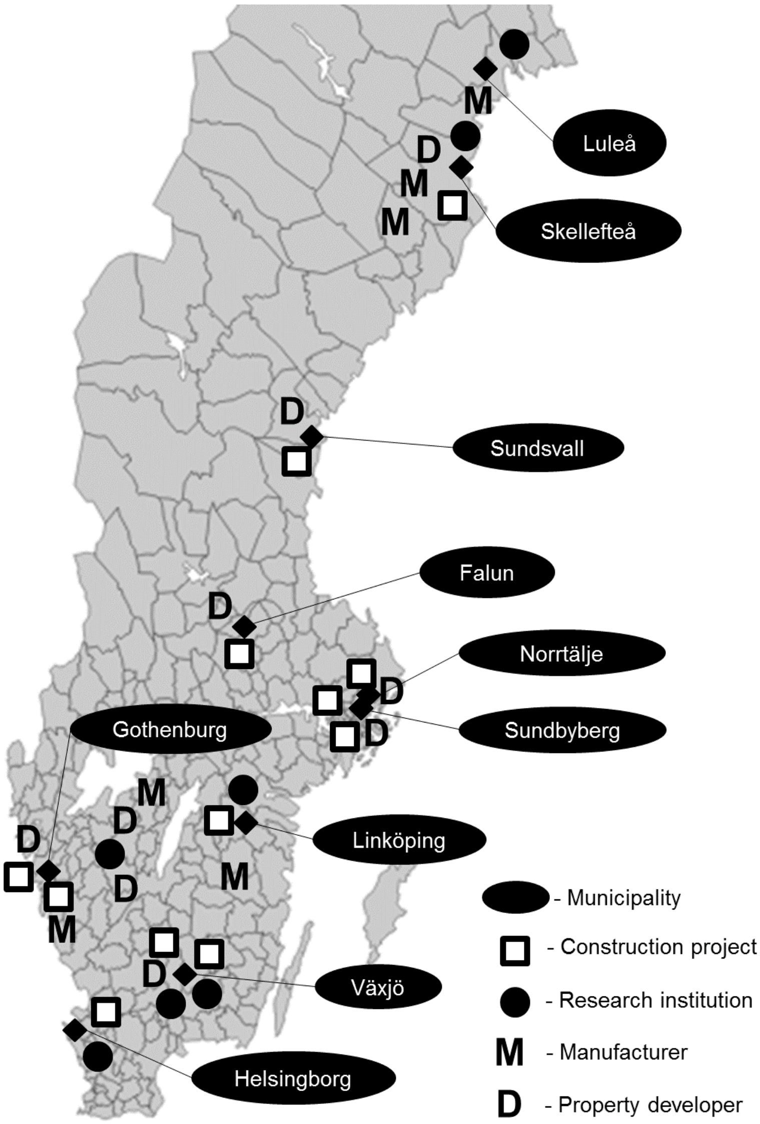


*Figure 33: Location-specific organisations related to timber construction in Sweden*

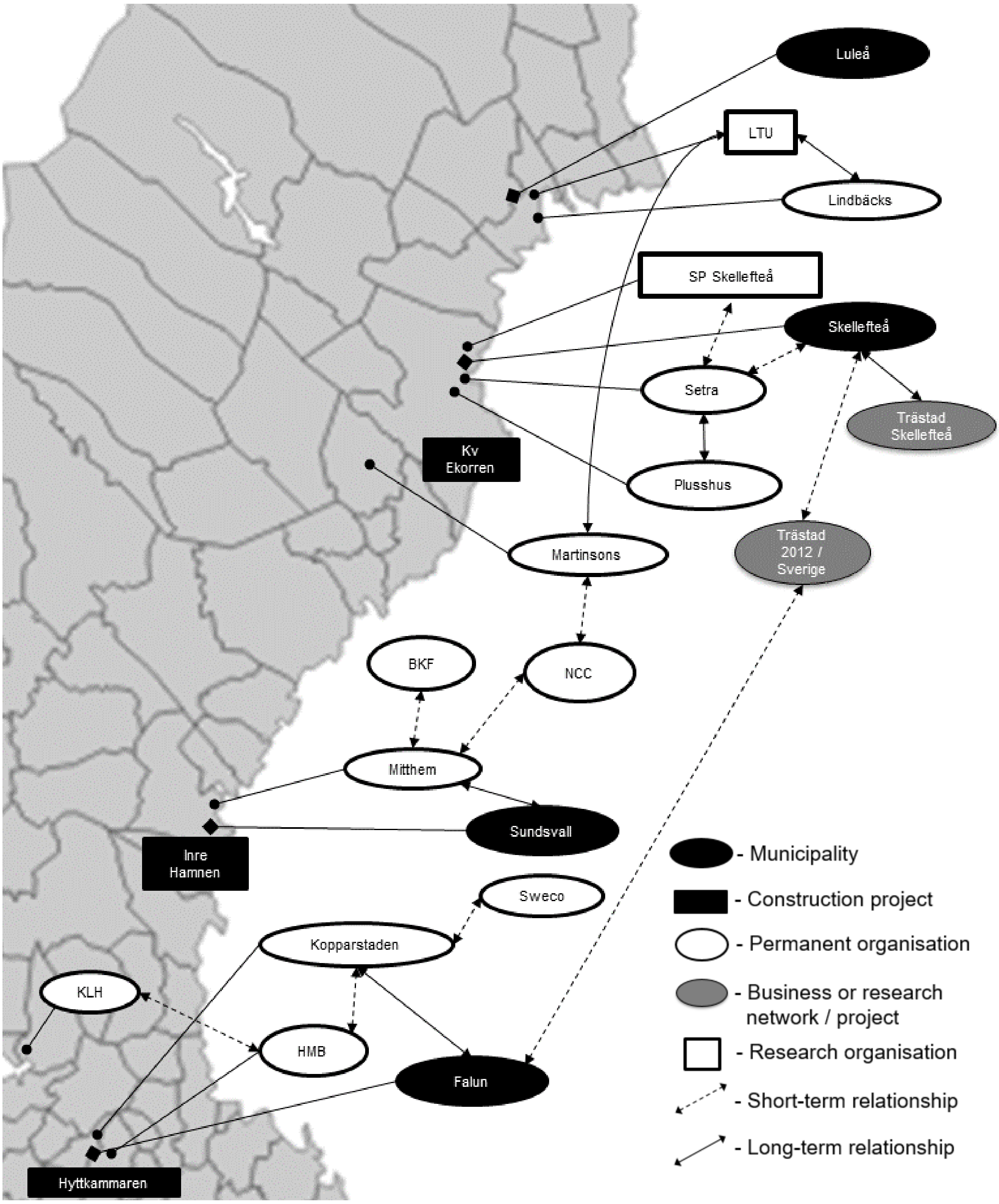


*Figure 34: Organisational resource constellations in North Sweden*

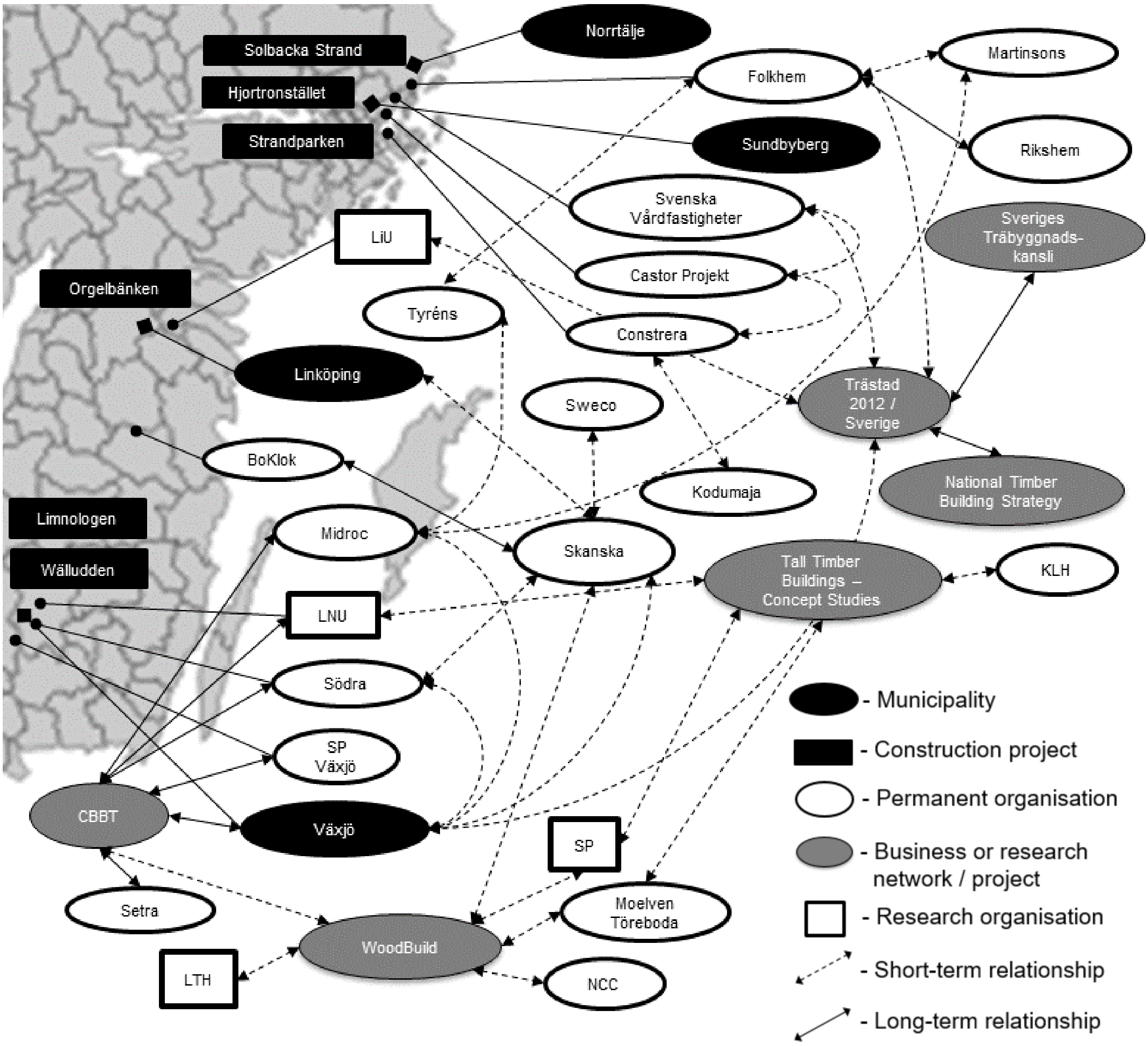


*Figure 35: Organisational resource constellations in East and Central Sweden*

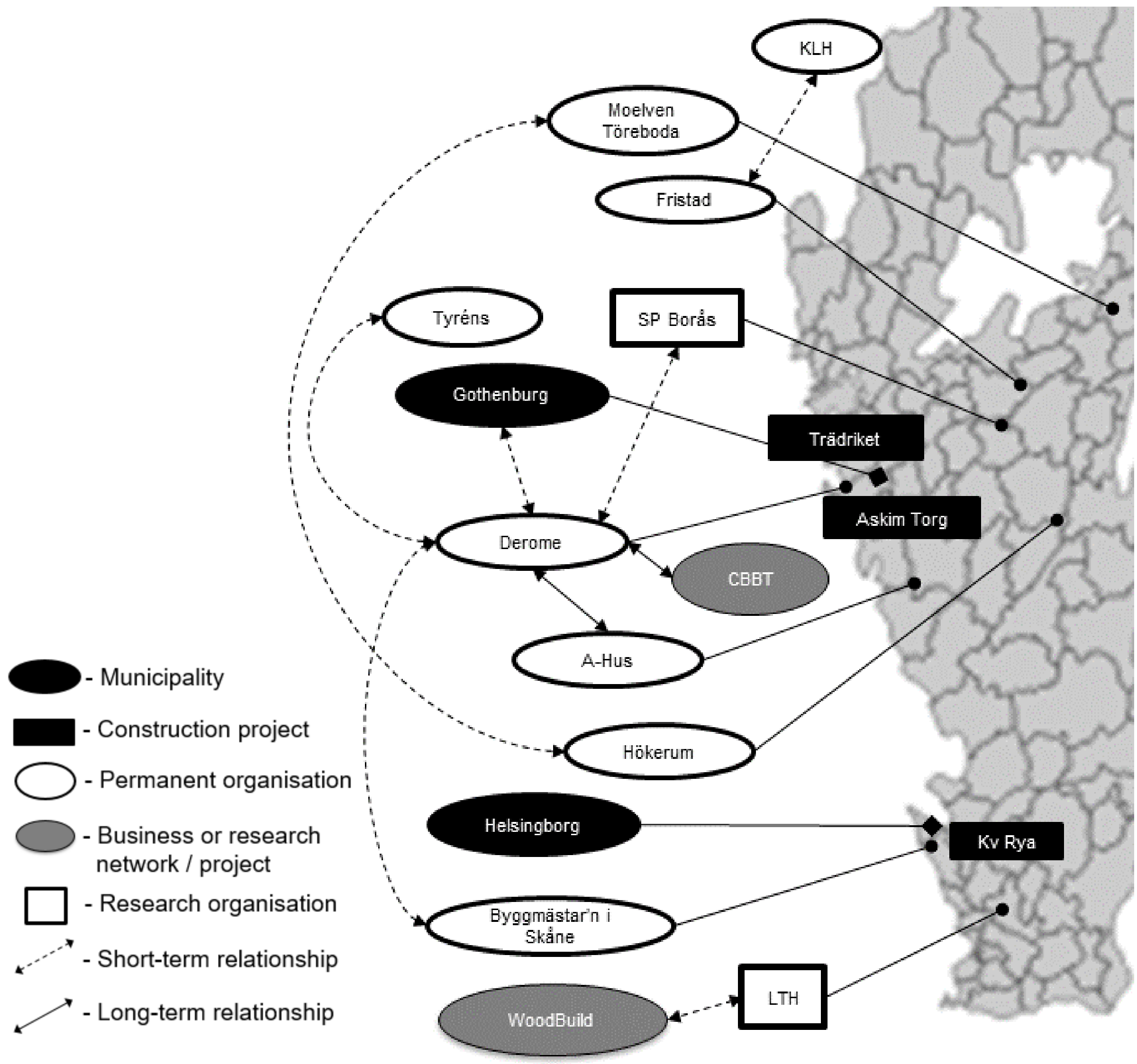


*Figure 36: Organisational resource constellations in West and South Sweden*

The explored resource constellations in the case projects highlight a number of aspects that may have benefitted certain projects to be started or that may have resulted from the success of these projects. The observations are as follows.

**The regional influence** on the construction activity can be noted, especially due to organisations that depend on a certain location such as research institutions and timber construction manufacturers. The direct cooperation between these actors is noted to take place in North Sweden between Luleå University of Technology and two manufacturers, Lindbäcks Bygg and Martinsons. Some impact to the industry regarding the case project has been provided by SP, Linneaus University and Lund University. Surprisingly, the projects at the large city regions, such as in Gothenburg and the Stockholm area were not associated with nearby research institutions in relation to the observed projects. The lack of respective collaboration of research and the industry is also noticed from the opinions of industry professionals within the present study.

**Nation-wide and international networks** are developed on a project basis to attain desired resources. Therefore, the location-specific research institutions and manufacturers are not limited to their physical situation but enhanced by the reach of networks. Some nation-wide networks have been developed above the level of projects which may be enabled by the stable nature of the stakeholders.

**Long-term organisations** such as CBBT and Sveriges Träbyggnadskansli are partly the result of the national timber building strategy and also the success of pilot projects in regional or national context. It is expected that their activities concerning the support of research and promotion can accelerate the production of multi-storey timber buildings. Therefore, the permanent organisations can be the result of temporary ones and vice versa.

**Long-term contracts** between key organisations in the industry have been a consequence of some observed projects. This can result in higher trust between industry actors and confidence to develop high-investment technologies. Additional network connections can appear such as product certifications through consultancy firms or research organisations and framework agreements with public sector organisations. Some examples are the long-term production contract between Folkhem, Rikshem and Martinsons and a continued production relationship of Svenska Vårdfastigheter, Constrera and Kodumaja.

**Municipality involvement** in the projects is varying which has implications on the research organisation involvement as well. The political interests and the realisations of the objectives can vary. The city of Växjö and cities in North Sweden have been proactive in terms of the projects but also in communication with the research organisations. Political pressure to utilise timber exists also in Gothenburg which has resulted in one project but no collaboration with the local technical university. Based on the examples of other municipalities, the higher attention to organisational networks could increase the speed of desired innovations.

#### Relations of Organisational Networks to Other Resources

At the observed projects, certain patterns could be identified regarding the source of the initiative, network scope and earlier experience between the actors involved. The commissioning of the projects has been either by construction clients, supplier organisations from the forest industry or from public sector initiatives. It is interesting that in the chosen projects, only the earliest projects were driven by suppliers that were seeking to improve their technology and bring it to the market. In these projects, the prefabrication level has been low which can further suggest the explorative nature of the projects. In several municipalities, the projects have been initiated because of the interest from local politicians. Some of the municipalities were or were going to be part of the Trästad 2012 programme (Sundsvall, Falun, Skellefteå and Växjö). The programme has evolved from the national timber construction strategy, developed by von Platen in 2004 (Westerlund, 2012). It could also be pointed out that the production of the buildings with political background has been carried out by companies that had already developed their timber construction technology. The respective projects, producers and the municipalities are:

1. Inre Hamnen; Martinsons; Sundsvall;
2. Kv Hyttkammaren; KLH; Falun;
3. Kv Ekorren; Setra; Skellefteå;
4. Limnologen; Martinsons; Växjö;
5. Trädriket; A-Hus (Derome); Gothenburg.

As mentioned in the previous chapter, it is the construction clients from the private sector that have been in the driving role for creating organisational networks. In all such cases the level of prefabrication has been relatively high, with three projects involving volume elements and other three projects a well-developed construction system by Martinsons or Moelven. The structural timber itself has been used in different ways, either as a frame, a glue-laminated product or a beam-column system. Therefore, in terms of organisational networks, the level of prefabrication could be seen as a more determining aspect instead of the exact way how wood is used in the structure.

To compare with the organisational units in the project level, a similar pattern can be seen as in the previous chapter regarding the risk allocation. It is noticeable that the projects started by private sector stakeholders involve contracts where the design and construction responsibility is not completely transferred to contractors external to the founding organisation. It could be deduced that a relatively high level of integration has been sought for. Neither of the observed project teams has had earlier multiple cooperation experiences within the team and the respective municipalities. Thus the interest of the clients to have a control over the process could be understood.

### 6.1.5 **Resource Situation in Gothenburg**

By the results from case studies and interviews, the three construction systems, timber frame, solid wood and a beam-column system have been used in Gothenburg or nearby regions. The degree of industrialisation has been varying but according to interviews with local suppliers, the tendency is to increase the level of fabrication to volume elements. The mentioned reasons are a potential to provide higher quality products and the fact that volume elements are feasible for multi-storey housing production. The latter is especially the case for a manufacturer that has concentrated on detached home production where volume elements are less superior to floor and wall panel system.

The organisational networks in Gothenburg differ from other observed regions by having a limited amount of relations to universities. Neither of the interviewed company representatives expressed any corresponding long-term cooperation. A building material researcher from the local technical university, Chalmers University of Technology, and other respondents in earlier interviews were neither aware of similar relations. Furthermore, the cooperation possibility is limited by the fact that the research of wood as a building material in the university is funded and resourced by a low degree.

Regarding other organisations, some minor development projects have taken place between the firms and the research institution SP that has a timber research department close to Gothenburg, in Borås. Long-term collaboration between firms is not popular as can be judged by the observed firms and projects in Gothenburg.

## 6.2 Analysis of Construction Innovation

Project-based nature of construction projects creates an environment where short-term relationships are established only for the execution of a project. In order to create more valuable products Bystedt (2012) claims that it is necessary to ensure knowledge sharing and transfer through projects. Therefore, the introduction of sustainable materials such as timber to the construction industry requires the establishment of strong long-term relationships Having long-term relationships enables the possibility to transfer knowledge between projects and therefore it facilitates the improvement of construction processes which can make certain materials more competitive. In the construction industry it is usual to have strong relationships among the actors on the project level but it ends with the conclusion of the project (Dubois & Gadde, 2000). However, in order to create a new network, this collaboration should be maintained in a long-term period.

Additionally to long-term relationships, trust is needed to introduce innovation in the construction industry. Dainty et al. (2001) claim that in order to consolidate new construction practices and procedures there needs to be trust among the parties. The latter can be seen in some regions of Sweden such as Växjö, where the strong relationship between the industry and academia has helped the development and establishment of multi-storey buildings in the region.

All the parties should perceive individual benefits in order to decide upon innovative practices. A clear example of this is the situation in central Gothenburg where resources are available in order to consolidate timber as a construction material. However, some of the private sector stakeholders do not see direct economic benefits which is one reason why the development of timber buildings has been slower than other regions.

The final identified aspect is the availability of resources. It is important that the resources available can satisfy the demand without compromising any of the three sustainability dimensions. For example, in Växjö, the availability of timber related products, manufacturing organisations, collaboration networks and other resources have accelerated the process of building with timber. On the other hand, the lack of similar arrangements in Gothenburg together with the existence of strong networks of traditional materials have prevented a fast development of the material.

To sum up, five key factors have enabled construction innovation with regard to the use of timber in the industry. These factors are:

1. Strong long-term relationships among the parties;
2. Existing knowledge within the region;
3. Trust within and between project organisations and permanent firms;
4. Perceived benefits to each stakeholder before starting the project;
5. Availability of resources within the region.

## 6.3 Analysis of Socio-technical Systems

In terms of system perspective, the situation of the Swedish construction industry is going through fundamental changes. The incremental sector-specific innovations are happening but fundamental changes to the industry are expected due to broader landscape pressures and increasing technological possibilities originating from outside the existing regimes. According to the multi-level perspective by Geels (2004), the regimes and innovative platforms as niches are both subject to the constraints and opportunities that the environment is providing. In the present study, the boundary between regimes and niches have not been clearly identified because of the following reasons. The stakeholders that might be attributed to the regime level, such as the large international construction firms Skanska and NCC, have been seeking for benefits with timber construction. Secondly, the universities and other research organisations are generating knowledge that apply to materials that might be considered both, traditional and innovative. Despite the overlaps, the niche level can be delineated in terms of projects, stakeholders and research units that are mainly devoted to timber construction. In the following section, the landscape- and niche-level impacts are described that point increasing amounts of pressure to the existing socio-technical regimes.

### 6.3.1 Changes to Existing Socio-technical Regimes

The focus of the present study has been oriented towards the resources that primarily originate from outside the regimes of traditional construction industry. The existing regimes, often path dependent in nature as written by Geels (2012), are showing patterns of change. According to the author, the regimes are characterised by path-dependent trends at the levels of policy, science, technology, industry, markets and culture. Each of these paths in the construction industry context represent new dynamics that have appeared in the recent decades.

**Changes in Policy**

In terms of policy, the performance based regulations that replaced prescriptive building regulations in Sweden, opened up the possibility of considering alternative construction materials to the traditional steel and concrete. The regulation change took place in 1994 in order to reform the European construction industry to be more innovative (von Platen, 2004).

**Changes in Scientific Support**

Scientifically, the research of wood in multi-storey building structures has been especially active after the regulation change. The key stakeholder has been SP[6]. The research institute has attained a leading international role regarding fire protection of timber constructions and is actively researching the sound and durability related aspects of wood constructions (SP, 2016).

**Changes in Available Technology**

The enabling regulatory environment, research and other aspects are possibly a large influence on the technological developments. According to the case examples observed, there are a number of certified and tested technologies that are available in the Swedish market. Furthermore, due to increasing demand for apartment buildings in the future, the investments for improving the respective technologies are being improved.

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[6] SP Technical Research Institute of Sweden is a leading International research institute. The subsidiary dealing with timber construction has been renamed from Trätek to SP Trä. Recently, the subsidiary has been reorganised to form a department of Sustainable Built Environment (SP, 2016).

**Changes in Industrial Capability**

The firms that provide the technologies are establishing increasing amounts of presence. These companies are increasing their network connections with stakeholders in academia, public sector and the rest of the private sector. Furthermore, collaborations are not only region-based but span across the whole Sweden and involve international organisations. Aside from project-based collaborations, there are long-term contracts appearing for technology development and application. According to the claims from the case studies, the knowledge obtained from successes or mistakes are often used to improve the product and construction system.

**Changes in Market Demand**

The markets in terms of available demand are changing mostly due to long or short term economic benefits. There is some difference between the private commissioners or the ones tied to the public sector. The organisations as well as the rest in the respective supply chains are interested in providing the requested value for low costs. The clients not related to the forest industry are increasingly finding wood to provide economic benefits that the traditional materials would not be capable of. The more specific motivating aspects have led to the following requests in the Swedish construction market which are seen in the observed cases within the present study:

1. Orgelbänken – A large international contractor Skanska tried to mimic a cheaper construction system that they used in the United States in order to lower construction costs in Sweden.
2. Inre Hamnen – The partial funding for the project originated from a governmental programme to research the potential for reducing construction costs in Sweden.
3. Kv Hyttkammaren – The municipality was willing to change the detail plans to attract a higher variety of construction systems into the city.
4. Kv Ekorren – The municipality took a leading role in order to attract more local firms to participate at the construction market.
5. Limnologen – There is no specific motivating factor of the property developer to choose a more expensive structure compared to concrete by economic assessment. It could be assumed that due to the large size of the firm, they were more risk-prone to test the construction system provided by Martinsons. Additionally, the high timber construction interest from the municipality must have provided a closer relationship with local stakeholders in the context of future projects as well. Furthermore, the promotional nature of the project must have been interesting for the company as well.

6. Askim Torg – The contractor chose a timber construction system because of a low construction cost.
7. Strandparken – The private property developer involved a famous architect office to develop well-functioning and aesthetically pleasing buildings. The eventual economic benefit is the promotional impact to the company and long-term agreements with Rikshem, Martinsons and certain municipalities to provide a large amount of apartment buildings in the future.
8. Solbacka Strand – The property developer is engaged in low-energy buildings and low-emitting construction materials such as timber. The exact economic benefit of choosing the material is not clear.

All in all, the municipalities seek for a variety in construction systems, especially which can provide opportunities for a diverse set of firms, including the local SMEs. Some of the clients are exploring timber for its opportunities regarding the construction cost reduction. The latter is often related to industrialised production which often includes certified and tested systems, therefore providing reliability and fast assembly.

**Changes in Culture**

The understanding of wood as a construction material for multi-storey buildings might have improved, as could be inferred by the approaches of construction firms. The explorative projects by Skanska and Derome were in fact explicit in terms of using timber only as a replacement to a traditional structural material. The opportunities for providing any additional benefits to the users were not explored. In most of the other projects, however, there were different levels of effort directed towards aesthetic and functional design by using the advantages of wood. It is apparent that some organisations focus on the cultural aspect in order to attract the attention of people that would like to live in the buildings. The culture in that sense is tied to the sustainability benefits which are promoted by the respective organisations, either municipalities, property developers or manufacturers.

### 6.3.2 Path Dependence and Lock-in of the Timber Construction Industry

It is likely that the existing resources and developing relationships of those that manage the resources are creating new effects of path dependence and lock-in. Considering the increasing complexity of manufacturing facilities for industrialised timber buildings, the economic reasons for not disrupting their flow could be a reason why new markets would not be observed if a continuous demand already exists in their existing target market.

Based on Martin and Sunley (2006), the necessity by regional governance to introduce some lock-in should not be neglected. There is a fine line between providing assurance of long-term stability and turning into the path of technological and economic stagnation. Regarding timber constructions, many municipalities are interested for political reasons but the material cannot be explicitly demanded. In some cases, the considerations of alternative construction materials could be asked for. Furthermore, the municipality can have a stronger influence when distributing land to developers. This is enabled when the municipality has ownership of the land where the sustainable building stock is desired to be built. Despite the requirements for sustainable materials, the hindering aspects of detailed plan and unwillingness of the property developer could not provide the expected results. As examples, in the case of the project in Falun, the detailed plan was due to its high level of detail too specific and thus favouring traditional construction methods. The land at a future timber building development area in Växjö was owned by a private developer and the city did not have any other selection option apart from allowing the buildings to be built taller than initially expected by the detail plan. Instead, it was the recognition for an ambitious project and available technological resources convinced the property developer to choose timber over the traditional and secure solutions.

### 6.3.3 Socio-Technical Systems in Gothenburg

In terms of the top-down pressure, there is political interest, similarly to many other regions in Sweden. National programmes to reduce construction costs or introduce sustainable materials are popular in many regions but according to the available information, their extent in Gothenburg is low. The city is progressive in terms of strategies for sustainable built environment, especially concerning a large scale development plan at the heart of the city. A local timber construction firm was invited to one of the early developments because it was able to express the capability to build what was required by the detail plan. Timber construction stakeholders that were observed in other projects of Sweden have only had limited or no presence in Gothenburg. This is an interesting aspect considering the claims from the city representatives of aiming for a diverse set of construction firms into the city.

For the niche actors, there may be strategic issues that limit their presence in the city. From the interviewed firms with local presence, one of them concentrates their efforts on building detached houses to the neighbourhoods further from the city centre. This has limited their choice of technology. The requirements by municipalities for added multi-storey housing from single-family housing developers has changed the focus of technological development. Thus they are working to replace the floor and wall panel production to volume element system with high preparation level in the factory. Another firm concentrates on similar locations but builds low-cost housing to predetermined standards which are aesthetically not accepted in the central areas of the city. The choice of remote locations is also motivated by the low price of land which is consequently reflected into low prices for the customers. Therefore, the path dependence can be seen at a company level as well and there is considerable effort needed to reduce such limitations, if strategically possible.

## 6.4 Analysis of Sustainability

Construction industry in Sweden is traditionally based on the use of concrete and steel (Mahapatra & Gustavsson, 2008). In recent years, timber construction has been promoted by politicians and public authorities because of being a material that carries several sustainability benefits in comparison with more traditional materials, such as concrete and steel. However, the growth of the timber construction market has been uneven in the different regions of the country. This disparity lies mainly in the presence of several actors related to the forest industry which often establish relationships with other parties. These relationships seem to increase the knowledge available among the industry which in turn creates an enabling environment for timber construction.

By summarising the empirical data, it could be seen that there is a common understanding regarding the social and ecological benefits of timber construction among the public sector, private sector and academia. Nevertheless, the three parties seem to be in different positions about the economic aspect. Morelli (2013) claims that these three dimensions are dependent on each other, therefore there cannot be a sustainable development supported by timber construction until all of the dimensions are fulfilled. In the following sections the three dimensions of sustainability are discussed.

### 6.4.1 Ecological Sustainability

As mentioned above, the different actors involved in the development of timber as a construction material agree on the ecological benefits that it carries over other building materials. As defined by Hill and Bowen (1997), in order to have a sustainable construction from the ecological perspective, it cannot affect the ecosystem in a negative way. Building with timber provides opportunities for low carbon emissions during the construction process as well as during fabrication of the material. These benefits are acknowledged by the public and private sector and representatives of academia. Additionally, wood constitutes a renewable material which is an advantage from the ecological point of view, especially in Sweden where the resource is available.

The ecological sustainability benefits are the main drivers for the promotion of timber since there is a great concern towards reducing the environmental impacts caused by the construction industry (Ding, 2008). However, currently the industry is not relying upon standardised tools or methods which can quantify the sustainability aspects of using a certain material. Because of this, methods such as LCA can be adjusted in order to favour the interests of the actors involved. Besides, only organisations with a wide range of resources are able to perform these assessments. Therefore, the calculations may favour the materials and construction systems which are typical for the large firms in the industry that can hinder the introduction of alternative resources. Due to this, there is a need for developing a standardised method which can determine the convenience of each material from an ecological perspective. In order to achieve this, a stronger collaboration between academia and private sector is required since currently the knowledge is not shared in a sufficient manner.

The introduction of timber as a construction material for multi-storey buildings opens a bigger possibility to standardise processes and introduce more prefabrication for the construction elements. Standardisation in the construction industry might result in a reduction of environmental impacts by the construction process since it will be simpler and faster than bespoke solutions. Prefabricated elements can also counteract the issue of waste in the construction industry that is expressed by Dainty & Brooke (2004). In addition, the carbon emissions during the transportation process will be reduced because of the possibility of fewer deliveries due to higher level of assembly at the factory.

### 6.4.2 Social Sustainability

Similarly to the ecological dimension, most of the stakeholders are aware of the potential social benefits when implementing wood as a construction material. The social dimension is considered by Hill and Bowen (1997) to be ensuring a good quality of life among other people. The implementation of wood can result in better working conditions as well as less disturbance to the surrounding community. At the same time, wood as a construction material fulfils all the requirements and standards that are needed to have quality buildings in operation.

Most of the social benefits that timber buildings represent derive from the level of prefabrication that the kind of construction allows. Prefabricated elements are usually produced in a controlled environment where the working conditions are more adequate than on traditional construction sites. Additionally, multi-storey timber buildings require on-site weather cover and other specific equipment that benefit the working environment during assembly. In both cases, the weather impacts are reduced while the safety and well-being of the workers are increased. Another important aspect refers to the reduction of the disturbance to the surrounding community since prefabrication implies a faster construction process and less frequent deliveries to and from the construction site.

In order to measure the social impacts of a construction material or system there is a need to define a method for assessment. Among the three dimensions, social impacts are probably the most difficult to measure since they cannot be quantified. However, unlike the ecological impacts the social ones are harder to manipulate since better construction environment implies a clear social benefit.

### 6.4.3 Economic Sustainability

There seems to be a disagreement regarding the economic benefits that the use of wood as a construction material can entail. Construction organisations might not perceive an economic benefit in changing their traditional methods because of a short-term view caused by the project-based nature of construction projects (Dubois & Gadde, 2002b). For instance, the implementation of some equipment needed during the construction process can increment the costs of the project preventing the visibility of long-term benefits to the organisation. Additionally, the project-based nature implies that the knowledge and learning is lost between projects, therefore the implementation of new methods and materials is seen as an economic risk.

Mahapatra and Gustavsson (2008) claim that timber can reduce the complexity of the construction processes making them faster and reducing costs in the long term. It is important to consider that the long-term costs are enabled by consolidated networks where the knowledge and learning can be transferred through the different projects. An example of the influence of knowledge in the economic aspect can be seen in Växjö where timber construction is well developed since the interaction among the diverse set of actors is high. Hence, stronger and continuous relationships among the actors create an environment where the knowledge can be preserved resulting in greater profits in future projects.

As mentioned above, timber increases the possibilities of prefabrication which can also simplify the construction processes. The claim is supported by Mahapatra and Gustavsson (2008) who highlight the possibilities of having economic benefits through timber construction. Prefabrication also implies having a standardised process which in turn can reduce failures in construction processes. Stehn et al. (2008) present several areas where the timber construction has significant economic benefits compared to steel and concrete constructions:

1. Costs of the foundation and rest of the substructure can be reduced by 30-50% due to the low weight of constructions;
2. Measured by surface area, a truck can transport about four times more timber partitions than concrete panels;
3. The timber elements can be lifted with a crane that costs eight times less than the crane needed for concrete assembly;
4. Changes to completed construction elements are five to ten times less costly than for the equivalent concrete elements;
5. It is easier to attach piping and wiring to the construction elements at factories, especially for the volume elements, which reduces costly work at the building site;
6. The direct and indirect costs of drying concrete constructions are avoided;
7. Timber is more suitable for assembly in winter as the material does not require warming up or protection from freezing;
8. The demolition and material disposal can be simplified, especially for solid wood structures;
9. From a wider perspective, timber is easy to recycle and the raw material can be found close to the building site or factory.

Coherently to the ecological aspects, there is a lack of standardised measurement methodology for quantifying the economic benefits of a particular material. Furthermore, construction companies prefer not to share their economic data with researchers which complicates the life-cycle cost measurements of a specific material.

### 6.4.4 Gothenburg Context

Multi-storey timber buildings in the context of Gothenburg are considered to bring several advantages regarding social and ecological sustainability. However, the private sector is not perceiving wood as profitable as other traditional materials and are not strategically oriented towards challenging the status quo. A proposed reason is the lack of industry knowledge, reflected by little cooperation between the relevant stakeholders and universities. This is contrasting to several other regions in Sweden where the collaboration is strong. In addition, the academic sector has been struggling to find a way to share knowledge among the private and public sectors without much impact to increasing collaboration. In spite of this, the municipality shows a desire to promote construction with timber because of political pressure. Due to this, the public sector has a position where they are open to the introduction of new actors which could create new networks and facilitate the introduction of new materials. However, there is a need to update the public requirements since they were established a decade ago and are easy to fulfil with any material and system that corresponds to the national building regulations

In the region, there are not many construction companies specialised into timber construction with the argument being an economic disadvantage compared to traditional materials. The firms are currently trying to tackle this challenge by developing new methods that could improve the construction process and reduce costs. The introduction of new methods might entail the creation of new construction networks and would possibly increase the interest of the private sector in timber construction.

# 7 Concluding Discussion

*This chapter provides a concluding discussion that results from the previous chapters in the thesis. Firstly, the general remarks are provided about the application of sustainable construction materials. Secondly, the drivers and barriers for applying sustainable construction materials in Gothenburg are presented. Thirdly, the conditions are described that are the most suitable for attracting resources for innovation. Last but not least, the recommendations are provided for future research.*

The application of sustainable construction materials can be a counterintuitive practice, considering that direct economic benefits may not reflect the long-term value to the users and society. The difficulty of argumentation for sustainable construction materials is amplified further by the vagueness in how to measure various consequences with regard to choice of material, and application of such measurement techniques. This thesis shows that despite these barriers, the ambition to increase the use of sustainable materials in the form of timber in the construction industry seems promising. This is enabled by the drivers that could be utilised to improve the competitiveness of timber as a sustainable material. The combination of respective drivers and barriers identified in the thesis are presented in the following table:

*Table 5. Drivers and barriers for applying sustainable construction materials in Gothenburg*

| BARRIERS | DRIVERS |
|---|---|
| 1. Large investments needed to develop knowledge and technology; | 1. Sustainability awareness by international organisations; |
| 2. Loose relationships among the organisations; | 2. Sustainability awareness by the Swedish Government; |
| 3. Competitiveness with aesthetics and flexibility; | 3. Sustainability awareness by the municipality; |
| 4. Perceived risk on financial return and customer satisfaction; | 4. Wide stakeholder awareness of ecological and economic sustainability benefits; |
| 5. Lack of awareness regarding technology; | 5. Some stakeholder awareness of social sustainability benefits; |
| 6. Design requirements are system-specific; | 6. Potential to standardise and prefabricate; |
| 7. Research and education focus on traditional materials; | 7. Available national business networks; |
| 8. Lack of economic data sharing; | 8. Available national research networks; |
| 9. Researchers lack awareness of the industry situation; | 9. Potential to apply resources from outside the region; |
| 10. Industry reliance on short-term benefits; | 10. Widely available raw material; |
| 11. Sustainability measurement tools not used in a standardised way; | 11. Available products and technology within the region; |
| 12. The demand-side lack of awareness of the industry capabilities; | 12. Large experience of firms with single family housing of timber structure. |
| 13. Limited production capacity in the region; | |
| 14. Lack of driving stakeholders. | |

It is important to stress that the presented list of drivers and barriers is highlighting the main observed aspects with sustainable construction material application in Gothenburg which is based on the case of timber. However, other enabling and limiting factors could be found when observing different stakeholders and materials at various points of time. This represents the dynamic nature of drivers and barriers wherefore the decision making should rely on the most recent data that account for specific organisations within the network.

Successful implementation of sustainable construction materials requires availability and mobilisation of resources that are possessed and controlled by various stakeholders. The value in these resources can be realised if the resources are appropriately combined. The following sections discuss seven enabling conditions for successful resource combining with regard to sustainable construction materials in relation to existing barriers and the stakeholders to be addressed. A pervading theme with several of the conditions is the awareness by various stakeholders of sustainable products and services. In multiple observed cases the demand-side stakeholders struggled to define the aspect of sustainability as well as the producers did not market their products as sustainable products. In addition, when the lack of attention from these stakeholders towards research input has been low, the cooperation between triple helix stakeholder groups is hindered. That interrupts a stable regional communication and development in order to continuously improve upon the sustainability-related understanding and performance. In Gothenburg, such limitations in relationships are visible and should be acted upon. The enabling conditions are presented as follows, in the order of responsible stakeholders: the municipality, private sector and academia.

**Condition 1: Agreement over Regional Sustainability Vision**

Stakeholder: Municipality

Some local governments of Sweden have been especially proactive in terms of sustainable development, for example, the cities of Växjö and Skellefteå. This has provided a stable foundation for attracting various stakeholders that together form networks that align with the objectives of sustainable societal development. The location-specific nature of nation-wide networks is a strong resource that can spur sustainable construction even if the location lacks other important resources, such as manufacturing or research facilities. Additionally, the local industry is more willing to invest into advanced technologies if the municipality behaves in consistent with their predefined long-term goals.

The regional sustainability vision-setting requires the collaborative efforts of the public sector, private sector and academia. Together this constellation ensures focus on the functional requirements of the society and how to accomplish that with available resources.

By matching the functions, resources and stakeholders' commitments, opportunities are obtained for finding new ways to organise the built environment and developing new technologies.

**Condition 2: The Suitability of Design Requirements to Various Materials**

Stakeholder: Municipality

In some cases, the requirements for new buildings in detailed plans are hindering the competitiveness of timber buildings. For example, if limitations with regard to height of the building height could be more flexible or stated in another way, such as by relating them to the amount of storeys, timber would not have to be excluded as a possible material for construction. There is a need for more open discussions within the industry to identify additional "grey" areas where alternative materials and technologies cannot compete with the existing ones as a consequence of too narrow requirements. In addition, timber structures require different design considerations in comparison to steel and concrete wherefore such conditions must be addressed in the early phase of property development.

**Condition 3: National Sustainable Construction Networks**

Stakeholder: Municipality and private enterprises

The participation at national sustainable construction networks can enlarge the knowledge base of the members with regard to availability and applicability of the necessary resources, including both technological and organisational dimensions. However, the neutrality position of municipalities could hinder such commitments since certain material providers should not be set to a competitive disadvantage. This can reduce the interest of the networks that aim to collaborate with public authorities which hinders the introduction of innovation to the industry. A more neutral image of timber networks could be pursued by establishing a specific department for the built environment instead of for one particular material, as it was done by the Technical Research Institute of Sweden (SP). Figure 37 illustrates the potential for long-term relations and continuous cross-organisational learning through coordinated networks which are not limited to temporary construction projects.

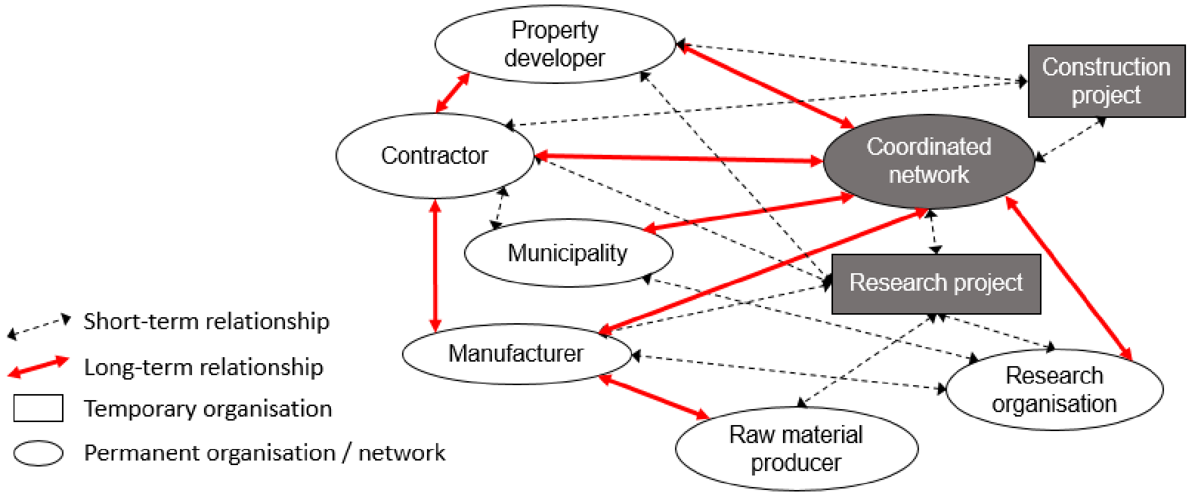


*Figure 37: Illustration of organisations and long-term relationships enhanced by permanent networks*

**Condition 4: Simple Criteria for Sustainability Requirements**

Stakeholder: Municipality and property developers

The complexity of life cycle assessment as an indicator of sustainability may hamper the willingness of construction clients to require the analysis results in the calls for tender requests. Without the measured performance within the ecological, economic and social criteria, the procuring organisations does not a have power to prioritise a more sustainable offer from another. It would be beneficial to the procuring organisation to carry out the analyses based on early design. Support could be obtained from consultancy firms that have the skills and knowledge to carry out life cycle assessments. As a result, the attention could be directed towards aspects which are the most crucial to improve the sustainability profile of a project. Based on the information, certain technical prescriptions could be provided to the contractors. The options may be limitations to the content of cement in concrete, recycled steel for reinforcement or wood as a structural material.

**Condition 5: Research Support to Develop and Maintain Knowledge**

Stakeholder: Municipality, the industry and research organisations

The project-based nature of the construction industry makes it difficult to transfer knowledge from one project to another, which in turn hampers the innovative capabilities of the involved organisations. Research organisations are an important resource of knowledge and they maintain and make sense of the local experiences within a specific field, across project boundaries and also across regional network contexts. Additionally, the research organisations can be a source of spin-off firms which may challenge the path-dependent characteristics of established processes.

Several successful manufacturers of timber constructions have developed their technologies in cooperation with research organisations. These types of arrangements provide benefits for both parties: the manufacturers can learn from other international practices through the research organisations' international connections, and the researcher organisations receive real life data that is crucial for further research. Additionally, in the case of universities, there is an opportunity for impacting the educational system. Thus, the skills of current and future workforce could be improved thanks to current knowledge from the industry.

**Condition 6: Increased Standardisation, Prefabrication and Integration**
Stakeholder: Manufacturing firms

Several manufactures have been successful in expanding their scope of production because of their consistent development of resources, i.e. products, facilities, organisational units and organisational networks. For instance, the timber products have become more standardised and certified, the off-site facilities have been improved as well as organisations seek for higher value from the products and services. However, this evolution implies increased lock-in effects within the timber construction regime which might result in the reduction of collaboration and knowledge sharing with other organisations and stakeholders outside the network. As such, this would start to hamper innovation initiatives which is counterproductive to accepting new initiatives towards a sustainable built environment.

Timber provides a wide possibility to standardised construction processes as well as the prefabrication of the buildings. Therefore, timber buildings have a positive effect in the three sustainability dimensions. Standardised processes tend to improve conditions for the construction workers and attain a low disruption to the surrounding community. In addition, long-term economic benefits can be obtained since prefabricated construction provides a faster alternative to on-site building. Spreading the knowledge of timber and other sustainable construction materials may have a positive effect on the respective demand and supply processes. For example, the material producers would be aware of the opportunities to sell sustainable materials and the construction clients would be prepared to request for these materials. Stable networks between these groups of stakeholders may create a process where a collaboration could be established for the production of sustainable solutions to specific product types.

**Condition 7: Clear Sustainability Performance of Products and Services**
Stakeholder: Manufacturing firms, contractors and property developers

The thesis has shown that in addition to the economic benefits, the focus on sustainable evolution can provide long-term stability to the company as well as a proactive position towards future sustainable regulations. This proactive position should be aligned with international agreements and political decisions in order to reduce the risk that might be implied in an abrupt change of current regulations. Furthermore, the promotion of social, economic and ecological sustainability in relation to the provided products and services can activate the creation of new business and networking opportunities. Some examples from timber construction are the employee-friendly work environment in manufacturing facilities, low-noise building sites, reduction of material deliveries and the application of renewable materials that are provided by local businesses. Considering the growing concerns about sustainability, the development of skills and knowledge about sustainability factors can result in new business opportunities for many different stakeholders within the construction industry.

## 7.1 Recommendations for Future Research

The thesis has covered the Swedish context in terms of multi-storey timber construction with the focus on decision-making stakeholders. However, also other stakeholders, such as architects, engineers and building users, have an important influence on the application of sustainable construction materials. Therefore, future research needs to investigate the influence of the mentioned stakeholders on construction innovation.

The findings in this paper consist of broad implications to the sustainable construction industry. Therefore, the work could be continued with more in-depth studies on the basis of a certain organisation, region or a sustainability dimension. In addition, this study covers a Swedish context, wherefore researching other national contexts may enlarge the understanding of construction innovation due to the advent of sustainable materials.

The methodology could be fitting for the research of other sustainable construction materials or processes than the construction of timber structures. With consideration to the project-based nature of construction and resulting adaptations, the methodology may be useful for observing other industries.

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# Appendix A – List of Interviews

Cluster Manager, regional chemical and material cluster, 2016-02-22, Gothenburg;

Project Manager, medium-sized timber building manufacturer and property developer, 2016-02-24, telephone interview;

Researcher of timber construction networks, Uppsala University, 2016-02-25, e-mail interview;

Associate Professor of the built environment, Linnaeus University, 2016-02-25, e-mail interview;

Project Manager, building physics research group, Chalmers University of Technology, 2016-03-02, e-mail interview;

Environmental Strategist, city development firm at Gothenburg Municipality, 2016-03-03, e-mail interview;

R&D Manager, medium-sized timber building manufacturer, 2016-03-07, Kungsbacka;

Former Head of Sustainability and Development, city development firm at Gothenburg Municipality, 2016-03-09, Gothenburg;

Professor in Timber Engineering, Linneaus University, 2016-03-11, e-mail interview;

Project Coordinator, Växjö Municipality and member of CBBT foundation, 2016-03-11, telephone interview;

Environmental Consultant, large national consultancy firm, 2016-03-15, e-mail interview;

Assistant Professor of building physics, Chalmers University of Technology, 2016-03-16, Gothenburg;

Director, national timber building council, 2016-03-17, Skövde;

Sustainability manager, large-sized international contractor, 2016-03-30, telephone interview;

PR Representative, city development firm at Gothenburg Municipality, 2016-03-31, telephone interview;

Researcher and Lecturer of building physics, Chalmers University of Technology, 2016-03-31, Gothenburg;

Team Leader, national research institute, 2016-04-07, telephone interview;

Project Manager, Gothenburg Municipality, 2016-04-12, Gothenburg;

Researcher of timber technology, Chalmers University of Technology, 2016-04-19, Gothenburg;

Business Manager, medium-sized timber building manufacturer, 2016-05-03, Gothenburg;

Project Manager, medium-sized timber building manufacturer and property developer, 2016-05-03, Gothenburg;

Researcher of timber technology, Chalmers University of Technology; Project Manager, Gothenburg Municipality, 2016-05-04, Gothenburg.

# Appendix B – Timber Construction Systems

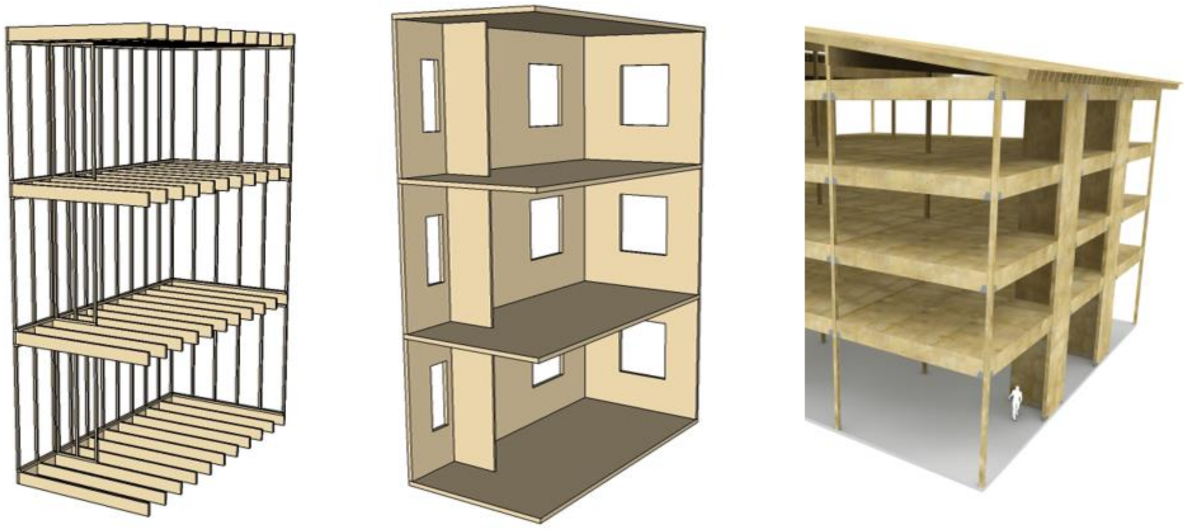

*Figure: Three types of timber structures in Sweden: a) timber frame b) solid wood c) column-beam system*

# Appendix C – Interview Guide: Manufacturer 1

*Translated from Swedish by the authors*

Interviewee: Business Manager, medium-sized timber building manufacturer
Date: 2016-05-03
Location: Gothenburg

1. **Introduction by the facilitator and the interviewee**
2. **How does wood as a construction material affect sustainability in the construction process?**
3. **There are many advantages with timber. Why doesn't the holding company (a large international contractor) base the rest of their residential production on timber structures?**
4. **Why is there little demand for timber housing in Gothenburg?**
5. **What is the aim of the company regarding the multi storey building of timber in Gothenburg?**
6. **How do you measure how the different sustainability dimensions have been fulfilled?**
7. **Which kind of top-down drivers and barriers are there for timber as a structural material for multi-storey buildings in Gothenburg?**
8. **How much can the different building concepts be adjusted?**
9. **Do you have your own architects for concept buildings?**
10. **Which structural systems do you use (timber frame / CLT / column-beam)?**
11. **How many of your products are constructed in the factory?**
12. **Are you going to increase the capacities if the demand increases?**
13. **Is there enough capacity in the company to fulfil the demand in Gothenburg?**
14. **How long away from Gothenburg or Sweden is it sensible to prefabricate the multi-storey buildings in timber. Are there any economic limitations?**
15. **How does wood as a construction material affect the contract forms or organisations in general around the construction? Is it different from usual projects of the holding company?**
16. **How does wood as a building material affect the relations between organisations in order to seek for financing, knowledge, advertising or similar?**
17. **Do you work together with universities or others to develop your products?**
18. **Do you have any long-term relationships with the key companies in the supply chain?**
19. **How is knowledge and experience retained from one project to another?**
20. **Do you think that the company is different from the rest of construction-site based holding company, considering the continuous development?**
21. **What is your personal opinion about the driving forces in Gothenburg for timber constructions?**

# Appendix D – Interview Guide: Manufacturer 2

Interviewee: Project Manager, medium-sized timber building manufacturer and property developer
Date: 2016-05-03
Location: Gothenburg

1. **Introduction by the facilitator and the interviewee.**
2. **What is the purpose of your organisation concerning multi-storey timber buildings in Gothenburg?**
3. **How long have you been active in timber construction?**
4. **How can timber affect the social dimension of sustainability?**
5. **How can timber affect the economic dimension of sustainability?**
6. **How can timber affect the ecological dimension of sustainability?**
7. **How is the sustainable criteria measure in your organisation?**
8. **What are the top-down drivers and barriers towards the use of timber as a structural material for multi-storey buildings?**
9. **What are the bottom-up drivers and barriers towards timber projects?**
10. **What type of building is the organisation focusing on?**
11. **How was the process of changing from villas to multi-storey buildings?**
12. **What construction systems are you using? Why?**
13. **Is there enough capacity to build for the growing demand in Gothenburg? Why?**
14. **How does the type of product affect the facilities and construction processes?**
15. **How does the type of product affect the project organisation?**
16. **How does the type of product affect relationships with other organisations for funding, knowledge, promotion or other support?**
17. **Do you have long-term contracts with key companies within the supply chain?**
18. **How is the knowledge and experience preserved after completing the construction processes?**
19. **What is your personal opinion about the driving forces in Gothenburg for timber constructions?**

# Appendix E – Interview Guide: Municipality and Academia

Interviewee 1: Researcher of timber technology, Chalmers University
Interviewee 2: Project Manager, Gothenburg Municipality
Date: 2016-05-04
Location: Gothenburg

1. **Introduction by the facilitators and the interviewees.**
2. **What is the purpose of Gothenburg municipality concerning multi-storey timber buildings?**
3. **What is the purpose of researchers concerning multi-storey timber buildings?**
4. **How are or could the three dimensions of sustainability (social, economic, ecological) be measured for building materials?**
5. **How can the political pressure towards using timber construction be transformed into real projects?**
6. **How can the public sector and university affect the markets so that companies would be capable of providing what is required by the politicians?**
7. **How can prototype projects become part of the mainstream?**
8. **How could the existing capacity of companies be improved to fulfil the growing demand in Gothenburg?**
9. **Which differences are expected for timber building projects regarding the size or experience of firms involved?**
10. **Which new networks or collaborations are expected for timber building projects?**
11. **How does the city preserve knowledge and experience from one construction project to another?**
12. **What is your personal opinion about the driving forces in Gothenburg for timber constructions?**