CHALMERS
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Analyzing the Potentials of 3D-Printing in the Construction Industry

Considering implementation characteristics and supplier relationship interfaces

Master's thesis in Supply Chain Management

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ABSTRACT

Construction companies are often referred to as late adopters of new technologies and have shown to lag behind other industries when it comes to implementing innovative technologies. Moreover, the construction supply chain is a complex matter that contains project based material flows. The construction company NCC has the vision of renewing the construction industry by offering the most qualitative sustainable solutions. One innovative technology that has gotten a lot of attention lately is Additive Manufacturing, a technology known for its ability to manufacture customized products with increased functionality from digital 3D models. This master thesis was set out to give insight into the potential for implementing additive manufacturing in the construction industry. It also aims at invigorating the technology by looking at what positive effects it could have on construction supply chain related issues. This was achieved by studying relevant literature in the areas of additive manufacturing, the construction industry and supply chain management. Furthermore, an empirical study was conducted at NCC, investigating its internal processes. Interviews were held with both people acting in the additive manufacturing industry and with internal employees at NCC. The analysis shows four clear factors that need to be acclaimed and understood in order to facilitate an implementation of 3D-Printing in the construction industry. These are; Importance of having a collaborative approach, Incentives are needed for investing in the 3D-Printing technology, Lack of standards in 3D-Printing technology and Low maturity level of the 3D-Printing technology in the construction industry. Moreover, the analysis reveals that in order for additive manufacturing to be successfully implemented interactive supplier interfaces need to be established to facilitate the collaborative approach. Lastly, the analysis shows that there are several matches between the benefits with additive manufacturing and critical construction supply chain characteristics, pointing at the technology as a possible catalyst for better construction supply chain performance.

Keywords: Additive manufacturing, 3D-Printing, Construction industry, Construction supply chain, Supplier interface, Partnering.

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1 INTRODUCTION

1.1 Background

The construction industry plays a vital role in the world we live in today. Everything around us such as infrastructure and buildings are designed and created by construction companies, making them a necessity in today's society. Many of the solutions in our lives we take for granted e.g. water supply, electricity, waste handling, houses, roads, bridges and we seldom think about the companies behind these solutions (Håkansson & Ingemansson, 2013). Historically there has been a general opinion and perception about the construction industry as conservative. Construction companies are often referred to as late adopters of new technology and the industry is commonly characterized as a regressive industry (Winch, 2003). However, the characteristics of a construction project require an organization that fully masters projects with short time-frames and limited available space (Wallén, 2013). Nevertheless, a construction project is a complex process and is occasionally referred to as a process with low productivity and high degree of non-value adding activities as a result of troubled material flows, thus the industry is blamed for its inefficiency (Dubois & Gadde, 2002).

One new way of producing products and components in a flexible way that has developed fast over the past years is additive manufacturing. One of the technologies, that has gotten significant attention is 3D printing (further referred to as 3DP). 3DP is not only the fastest; it is also the least expensive amongst comparable alternatives (Petrick & Simpson, 2013). Today, 3DP can produce products for commercial use that hold quality measures comparable with products produced with conventional manufacturing technologies (Petrick & Simpson, 2013). Petrick and Simpson (2013, p.12) also states that; "The rise of 3DP and Additive manufacturing will replace the competitive dynamics of traditional economies-of-scale production with an economies-of-one production model, at least for some industries and products". Even though 3DP has been around, in some form, since the 80´s, it is not until now the technology is reaching its full potential when it comes to versatility and price (Goldberg, 2014).

3DP has countless benefits when it comes to manufacturing, clearly underlined by Bogue (2013) who argues that 3DP may change the fundamentals of how products are developed and produced. The author also points at the fact that 3DP is a technology that is suitable to use in a very wide spectrum of industries, and is today an important manufacturing method when producing everything from vehicle and aircraft parts to orthopedic implants and jewelry. An industry, where 3DP is vaguely examined, is the construction industry. Since 3DP is a relatively young technology, there are few studies about its applicability and implication for the construction industry which indicates that this subject is yet quite unexplored. 3DP might be a possible method for construction companies to embrace in the future in order to become more efficient and create better supply chain performance and add more customer value.

Even though the construction industry is not yet comfortable with 3DP as part of the daily business, initiatives are taken in this sector all around the world. Construction companies initiate full-scale projects, aiming at increasing the knowledge of 3DP by showing its benefits and how far the development of the technology has reached (Skanska and Loughborough University, 2014).

NCC, one of the largest construction companies in Sweden, has a vision of being pioneers in the construction industry and to offer the most sustainable solutions to the market. NCC conducts extensive research in several focus areas together with customer, suppliers and universities in order to make the construction industry more efficient and sustainable (NCC, 2015a). 3DP is a relatively young technology but a lot of industries have already started to understand its potential. NCC envisages an opportunity to investigate the possibilities of using 3DP as a catalyst to achieve successes within several of their research focus areas. By being a fast mover, NCC can create an edge against its competitors when or if the 3DP technology gets its breakthrough. Hence, this master thesis is set out to give NCC initial insight into 3DP implementation and its possible implications on supply chain related issues.

1.2 Purpose

The purpose of this master thesis is to investigate the potentials of 3DP in the construction industry. Moreover, the purpose is also to invigorate the 3DP technology by demonstrating its possible positive effects on construction supply chain related issues.

1.3 Problem Analysis

According to Vrijhoef and Koskela (2000) the on-site productivity, in the construction industry, has not increased in parity with the growth in labor- and material costs. This highlights the fact that the industry have been struggling in finding new ways to increase the overall performance of a construction project (Vrijhoef & Koskela, 2000). A common problem for construction projects is the large risk of delays which can be related to the characteristics of a construction project. Furthermore, a construction project is quite unique compared with other manufacturing processes. In most manufacturing processes, the products runs through a factory but in a construction project the ‘factory’ is set up around the product (Vrijhoef & Koskela, 2000). The main contractor then uses other companies in the fulfillment of their obligations which results in many different companies at the same site which can result in a complex network of actors. The argumentation is supported by Hartmann et al., (2009) and Vrijhoef and Koskela (2000) who argues that the majority of the on-site work is carried out by subcontractors. This puts high demand on the main contractor’s ability to coordinate all different actors and relationships in order to perform a well-functioning project (Håkansson & Ingemansson, 2012). Consequently, the importance of a supply chain perspective with a focus on a construction firm’s supplier relationships is further reinforced.

There are strong arguments in the literature about the inertia in the construction industry to adopt new technologies. One of the explanations to this can be due to the project orientated character of the industry. Dubois and Gadde (2002) describe a construction project as a complex situation with a lot of local adjustments because of the interdependencies and the sequencing among activities. A lot of innovation and technical development is done decentralized in respective project, often on production site, which creates a situation where experiences and knowledge transfer, between projects, are hindered. According to Dubois and Gadde (2002) a short-term, project based, perspective can lead to sub optimizations and can also hamper innovation and technical development. This is because innovative solutions are created inside the project boundaries and is seldom transferred to the central organization, illustrated in Figure 1.1.

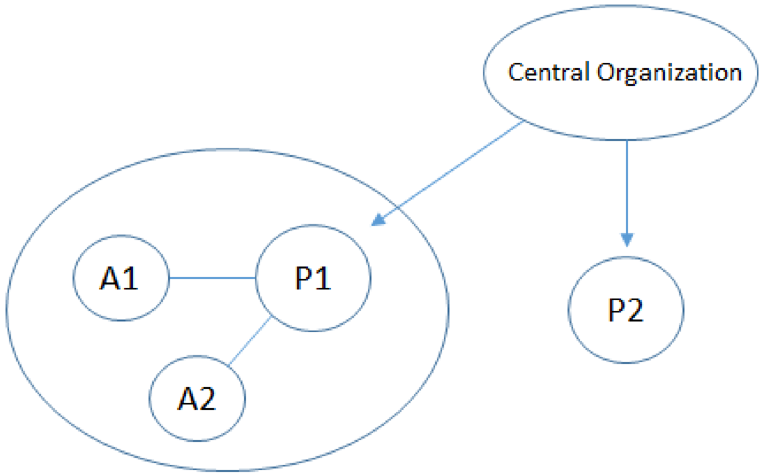

Figure 1.1 - Project boundaries in construction industry.

It is argued that the construction industry have failed to implement technologies which have been successfully implemented in other industries such as just-in-time, total quality management and supply chain management (Dubois & Gadde, 2002). Vrijhoef and Koskela (2000) suggest that supply chain management can be a mean to improve the total performance of a construction project. The construction industry differs a lot from other industries, especially when it comes to standardization of activities, which is much more present in other industries, e.g. automotive industry, in order for companies to gain volume-oriented economies of scale (Christopher, 2000). Standardization is present in the construction industry, but more related to standardized components instead of standardized activities (Dubois & Gadde, 2002). The construction industry is a more project-oriented industry, where each project is customized to its surroundings and conditions (Winch, 1998). A construction project can be described as: "The physical substance of a house is a pile of materials assembled from widely scattered sources. They undergo different kinds and degrees of processing in large number of places, require many types of handling over periods that vary greatly in length, and use the services of a multitude of people organized into many different sorts of business entity" (Dubois & Gadde, 2002, pp.622). Since most construction projects are unique, construction companies need to be flexible and customize the construction process to each project in order to meet those ever-changing conditions.

As can be seen in Figure 3 and as mentioned earlier a construction company needs to be able to handle a lot of different flows and actors in order to make a construction project as efficient as possible. Hence, it is important for the main contractor to take a holistic view of the supply chain in order to understand the complexity and coordinate actors, material and information flows. Moreover, Vrijhoef and Koskela (2000) and Dainty et al. (2001) present figures showing that a clear majority of the gross work done is performed by subcontractors and a majority of the material used is prefabricated by external suppliers. As a consequence, the main contractors are becoming more and more reliant on other actors in a construction project supply chain which highlights the importance of the holistic approach; an illustration is to be seen in Figure 1.2.

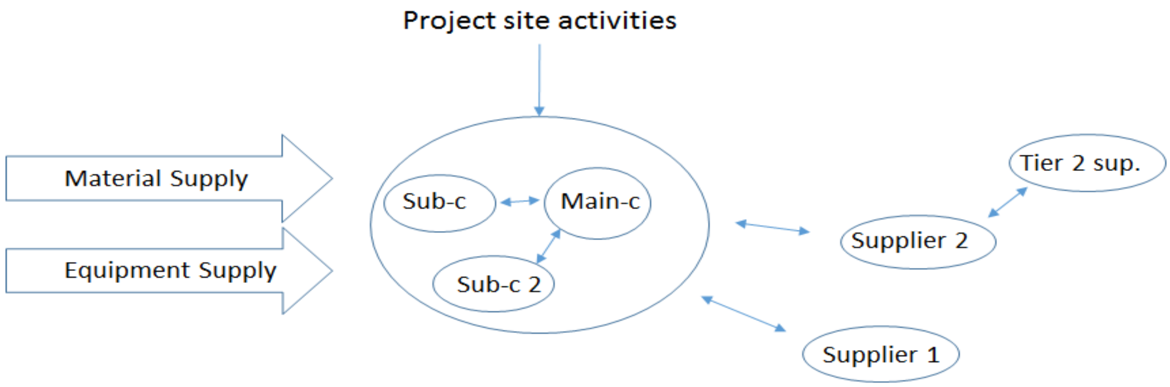

Figure 1.2 - Construction project supply chain complexity

In order for a company, regardless industry, to implement new innovative technologies, a lot of factors need to be in place to secure successful implementation (Mellor et al., 2014). According to several authors 3DP is an upcoming technology with large potential in a wide range of industries (Bogue, 2013; Goldberg, 2014; Petrick & Simpson, 2013). However, little has been written about the potential for successful implementation in the construction industry. As researchers in the area of manufacturing technologies predict that 3DP is going to have its big breakthrough in the relatively near future, many take on a proactive approach to research in the area. Mellor et al. (2014) have, amongst others, embraced this and developed a framework for the implementation of 3DP technologies. The authors have identified several dimensions influencing implementation possibility, regardless industry. The supply chain dimension is highlighted as one important dimension to consider, which is particularly interesting for this thesis. The supply chain dimension referred to the link that exists between two different actors within a chain. A generic supply chain consists of several links which together generates the complete chain. This implies that this thesis will focus on the links between different actors in the chain. Hence, possible effects that 3DP implementation will have on the internal organization is considered as non-priority for this study. An illustration of this link can be seen in Figure 1.3.

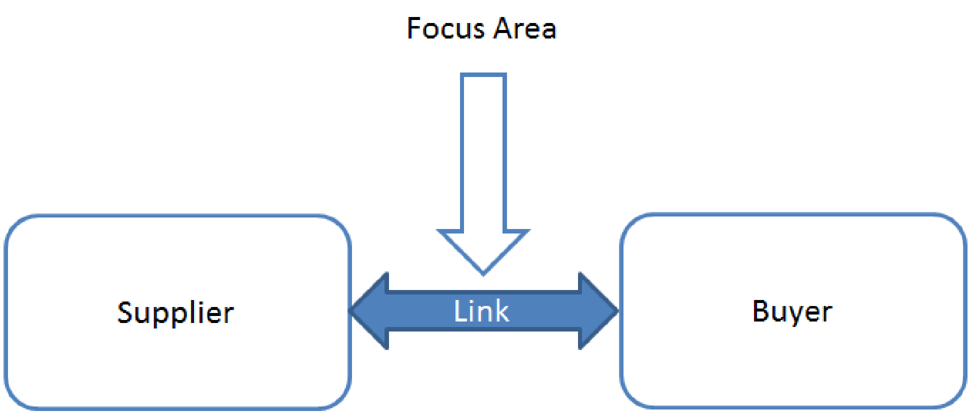

Figure 1.3 – Focus area of the thesis

Implementing new technologies into the construction industry will most likely not be a simple walk in the park and a lot of factors will determine the future for 3DP in the construction industry. As previously mentioned, the supply chain perspective is highlighted as important for successful 3DP implementation. Moreover, a construction company, like NCC, is heavily dependent on its sub-contractors and suppliers. Consequently, the relationship perspective is important in order to fulfill the purpose of this thesis. Furthermore, there is also a need for getting an understanding for construction industry related supply chain issues and how these might be affected by the usage of 3DP. Hence, to fulfill the purpose of this thesis the following three research questions are formulated.

RQ1: What characterizes the supplier relationship needed in order to support successful 3DP implementation in the construction industry?

RQ2: Which factors are the most eminent regarding 3DP's possibilities to get a foothold in the construction industry?

RQ3: What problem areas characterize a construction supply chain and how can 3DP contribute to improvements of the same?

1.4 Delimitations

This master thesis aims at investigating the implications and possibilities of 3DP in NCC´s business area of house building. Hence, other business areas e.g. construction of roads and infrastructure will be out of the scope, even though the implications may be similar in these areas as well.

In order to usurp sufficient knowledge about 3DP as a manufacturing technology, empirical data considering 3DP was mostly gathered from companies acting in non-construction related industries, this was due to the fact that the technology is yet quite unexplored in the construction industry. Furthermore, the term 3DP is a synonym to 'additive manufacturing'. In turn, the term 'additive manufacturing' consists of several similar techniques with different characteristics, including 'Selective Laser Sintering (SLS) and 'Stereo lithography' (SLA) etc. In the scope of this thesis 3DP will be treated as a family name for several similar manufacturing techniques. Consequently, analysis of individual technologies and their applicability will not be included in the scope of this thesis. Lastly, financial calculations related to e.g. increase costs related to investments needed, for a possible 3DP implementation will be neglected due to the limited time frame.

2 LAYER-BY-LAYER MANUFACTURING

Since the purpose of this master's thesis is to give insight into how well prepared the construction industry is for embracing the 3D-printing technology and its possible effects on construction supply chain related issues, it is important to get an understanding for the technology. Therefore the following section will consist of a literature review, investigating additive manufacturing with a focus on 3DP technology. The focus will be on market related factors rather than a deep technical description.

2.1 Additive manufacturing

Previously in this report 3DP has been used as the form of expression for a family of manufacturing technologies. However, there is an expression that is used by many authors as the overall name for layer-by-layer manufacturing technologies, namely additive manufacturing (AM). The expressions 3DP and AM are, however, often used interchangeably explained by Petrick and Simpson (2013, pp.13) who says; "The terms 3DP and AM are often used interchangeably, as both refer to the layer-by-layer creation of physical objects based on digital files that represent their design." and "The term additive manufacturing has come to represent the use of 3DP to create final parts and metallic components, differentiating from the more traditional subtractive manufacturing processes.". Hence, during this chapter, both AM and 3DP will be used representable for similar manufacturing methods. This is done in order to be able to incorporate a wider range of academic articles highlighting resembling issues.

In order to understand the logic behind different AM technologies, following illustration presented by Kulkarni et al., (2000) shows one way to distinguish between some AM technologies, based on type of bonding method:

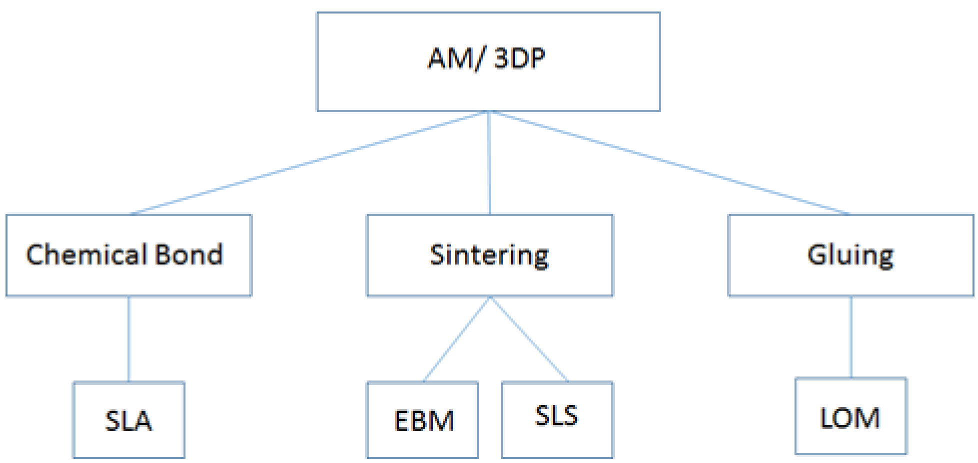

Figure 2.1 – A selection of AM/3DP technologies based on bounding method, adopted from Kulkarni et al., (2000)

Due to the ongoing globalization of the business world of today, mass production has been focused to emerging markets where the cost for production is considerably lower than in e.g. United States and Europe (Mellor et al., 2014). In order to cope with this fact, companies are forced to develop and use efficient and highly value adding manufacturing technologies in order to be able to compete at home (Mellor et al., 2014). One group of methods that has been given a lot of attention last decades is the additive manufacturing (AM) technologies. AM is an advanced set of manufacturing technologies that allows companies to produce highly customized, low volume, series of products with complex geometries in a variety of materials (Mellor et al., 2014). AM can be used to produce products with complex geometry such as internal passageways and undercuts which are difficult or even impossible to create with conventional manufacturing methods (Bogue, 2013).

A commonly used definition of AM, retrieved from Mellor et al. (2014, pp.194) is; “The process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining”. The family of AM methodologies consists of several technologies that has been developed simultaneously and share, therefore, many fundamental characteristics (Kulkarni et al., 2000). The most popular, available today, are; Stereo lithography (SLA), fused deposition modeling (FDM), selective laser sintering (SLS), laminated object manufacturing (LOM) and 3-D printing (3DP). Mellor et al. (2014) highlights a number of general benefits that derives from the unique characteristics of AM production.

First of all there is no tooling needed for production, resulting in a significant reduction of ramp-up time and production expenses. It is economically viable to produce small batches or one-off products. There is a possibility to quickly and lately in the process change product design. The product can be optimized for its specific function e.g. optimized cooling channels or specific geometric measures optimized for area of use. There is a large potential for waste reduction. AM can contribute to the simplification of the supply chain through shorter lead-times and lower inventories. Finally, AM entails complete design customization i.e. if a geometry can be designed in a CAD program it can be manufactured using AM technologies.

The general benefits are summarized in the following list:

- No tooling needed
- Enables economies-of-one production
- Late design changes
- Function optimization
- Waste reduction
- Shorter lead-times and reduced inventories
- Total design freedom

Many of the abovementioned benefits have been achieved in several different industries and in a wide range of stages in the product development life cycle. One example is from the aerospace industry where it is claimed that 90 percent of the material needed for a specific titanium part can be saved, using AM technologies, compared to using conventional manufacturing methods (Mellor et al., 2014). Furthermore, Berman (2012) claims that between 95-98 percent of waste materials can be reused when using 3DP as manufacturing method.

2.2 Commercial 3DP

3DP is constantly developing and is spreading along with its maturity. There are, however, industries and situations where it has been given more reliance. In the context of this thesis it is important to understand the underlying reasons for adopting and implementing 3DP into the manufacturing strategy. The following section will give insight into some areas of use where 3DP has been accepted as the prevailing manufacturing method, and highlight the most significant reasons for implementing the technology in that particular context.

Prototyping

When 3DP was in its cradle, it was most used for prototyping. Many designers and new-product planners want to examine, touch and hold an item before committing to a large investment (Berman, 2012). Unlike traditional methods for prototypes like wood and clay, the 3DP technology can be used in order to create functioning prototypes with moving parts and different materials. Furthermore, 3DP can also be used to produce different versions, e.g. different versions for different markets, quickly without costly retooling (Berman, 2012). There are several benefits to gain when using 3DP for prototyping according to Berman (2012). First of all, 3DP makes it easy to duplicate and change product variants since it costs the same to produce two different variants as it costs to produce two identical variants, meaning that the economies of scale rationale of serial production does not apply (Berman, 2012). Less expensive material such as plastics, resins and recycled paper can also be utilized with 3DP which means that less expensive prototypes and mockups can be produced. Cost and time needed for prototype development can also be reduced since there is no need for tools and dyes when using 3DP (Berman, 2012). This is also supported by Bogue (2013) who argues that 3DP can produce a component directly from a CAD design without the need for specialized and costly manufacturing equipment. One manager at Black & Decker mentioned that it would normally take 3-5 days to get a prototype back from the service bureau compared with an on-site 3D printer which can produce a prototype in just a few hours (Berman, 2012). An example of a 3D printed drill can be seen in Figure 2.2. 3DP can also be utilized by start-up companies in order to generate a cheap and less risky route to the market, especially when a product requires extensive market testing before full-scale production (Bogue, 2013).

Aircraft industry

The aircraft industry is often mentioned in the literature as one industry which has embraced the 3DP technology (Bogue, 2013; Berman, 2012; Campbell et al., 2011) especially when it comes to metal 3DP (Petrick & Simpson, 2013). Today, 3DP is utilized in the aircraft industry for low volume products with special demands and requirements. One example of such component is the environmental control system duct in the F-18 fighter aircraft (Campbell et al., 2011). Since 3DP can produce complex components without the need for assembly the aircraft manufacturer of the F-18 were able to reduce the number of involved parts, in the environmental control system, from sixteen to just one (Campbell et al., 2011). The technology most used in the aircraft industry is EBM (electron beam melting) since it can produce light and strong products in titanium aluminide e.g. turbine blades for aircraft engines (Bogue, 2013), Figure 2.3.

Furthermore, 3DP is so far most used for rapid prototyping but Airbus has started to use the technology for commercial usage. A certain cabin bracket, in the model A380, have been manufactured with 3DP, making the Airbus A380 the first commercial plane to use 3D printed parts (Bogue, 2013). According to Airbus (2014), 3DP can result in lighter parts, with shorter lead times, less material usage and significantly reduce the total environmental footprint of production. When printing components for an aircraft, a weight reduction of 30-55 percent can be achieved and at the same time reduce the total raw material needed by up to 90 percent, compared with conventional manufacturing techniques (Airbus, 2014). Spare parts is another large area of interest for Airbus. Out-of-production spare parts can be produced cost-effective on demand with a lead time of only one day with 3DP (Airbus, 2014). Furthermore, Airbus is developing a 3DP facility which can print entire wings and the plan is to print entire planes in 2050 (Ehrenberg, 2013).

Medicine industry

3DP has also been utilized more and more in the development of medicine appliances, especially for hearing aids and orthopedic implants. Laser sintering is used by Siemens and Phonak in order to quickly fabricate customized hearing aids (Campbell et al., 2011). By using 3D scans of impressions of the ear canal, a customized 3D printed hearing aid can be produced, that fits perfectly in the patients ear (Campbell et al., 2011). Berman (2012) does also mention the usage of 3DP for medical applications such as hearing aid molds. Since all ear canals are unique, 3DP is the perfect manufacturing technology to use since each hearing aid can be customized to fit a patient's ear canal perfectly, which is a necessity for optimal performance. An example of a 3D printed hearing aid can be seen in Figure 2.8 Also, 3DP is used for orthopedic implants made from titanium. Since 3DP can be used in order to create almost any geometric structure, this feature is perfect for when replacing damaged parts of human bones. Complex geometry with different pore sizes and 'cage-looking' structures has been shown to be the perfect shape for bone tissue to grow into. Such architecture with porous implants has a great effect on implants integration with newly grown bone (Li et al., 2007). One example of this porous and 'cage-looking' structure can be seen in Figure 2.5.

Locations difficult to access

Another area where 3DP is being examined as manufacturing method is in locations which are difficult to access and one example of this is in the naval industry, more specifically in the US Navy. The US Navy is investigating the possibilities to deploy 3D printers on board their aircraft carriers in order to make the fleet more ready with less vulnerable supply chains. If there is a part needed which does not exist in the inventory, a 3D printer could just print out the wanted part on demand (Stinson, 2014). The US Navy has already installed a 3D printer onboard the USS Essex and it is believed that the future of logistics is 3DP. The amount of spare parts and supplies could significantly be reduced by the use of 3DP, since each part needed can be printed on demand directly on the ships (Stinson, 2014). By printing the parts directly, the lead time for ordering spare parts can be reduced from months to instant (Osborn, 2014). The potential of 3DP in the naval industry is high and Osborn (2014) states that: "The logistics of the future will be more about delivering the right design file to the right printer, in the right location, to produce the right part, tool or system at the right time. This can increase the speed of execution, improve readiness, decrease costs, and avoid shipping parts around the world. Eventually we'll be able to embed sensors, electronics, communication capabilities, and microprocessors in unmanned aerial vehicles printed from 3-D printers".

In order to summarize some of the contexts, mentioned in the literature, that has embraced 3DP as manufacturing method, table 2.2 was created. Table 2.2 includes the context, which products are produced in that particular context and what the main reasons for using 3DP were.

Table 2.1 - Industries, products and reasons for using 3DP

Context	**Products**	**Main reason for using 3DP**
Prototyping	Mockups, conceptual parts	Visualization, function ensuring, early design changes, cost and time reduction.
Aircraft industry	Turbine blades, ducts, brackets	Complex geometries, lighter products, reduced material usage
Medicine industry	Hearing aids, bone replacements	Uniquely designed products, complex porous structures
Locations difficult to access	Spare parts, emergency parts	Less inventory, shorter lead times, decreased costs

Table 2.2 – Commercial examples

	
Figure 2.2 – 3D printed drill (Stratasys, 2015)	Figure 2.3 – 3D printed titanium turbine blades (Sevenson, 2014)
	
Figure 2.4 – 3D printed unique hearing aids (Russell, 2015)	Figure 2.5 – 3D printed porous ‘cage structure’ titanium ball (Arcam, 2015)

2.3 Advantages

The following section will present a summary of 3DP and AM advantages, found in literature, gathered in table 2.3. The summary consists of both advantages expressed by experts that have implemented 3DP in their specific industries, and advantages highlighted in general 3DP and AM technology literature. As discussed previously, 3DP and AM are treated as similar technologies, hence the specific advantages are regarded as equivalent. The advantages captured from specific industries derive from the main reason for implementing 3DP in that particular case, and are thereby seen as an advantage.

Table 2.3 – Summary of 3DP advantages

References	Advantages
Mellor et al. (2014) "Additive manufacturing: A framework for implementation"	• No tooling is needed • Reduced production ramp up time • Facilitates small production batches • Possibility to quickly change design • Allows product to be optimized for function • Possibility to reduce waste • High potential for simpler supply chains • Shorter lead times • Reduced inventories • Design customization
Berman (2012) "Prototyping"	• Good visualization tool • Enables function ensuring • Possibility for early design changes • Cost and time reduction
Campbell et al. (2011); Bouge (2013); Airbus (2014) "Aircraft industry"	• Ability to manufacture complex geometries • Lighter products • Reduced material usage
Li et al. (2007); Campbell et al. (2011); Berman (2012) "Medicine industry"	• Ability to create unique design features • Ability to create complex structures
Stinson (2014); Osborn (2014) "Locations difficult to access"	• Less inventory needed • Shorter lead times • Decreased costs

2.4 The future for 3DP

3DP has according to D'Aveni (2015) reached a point where the usage of the technology is on the tipping point to be a mainstream manufacturing method. Studies made in the area of 3DP usage point at the fact that around 11% of large manufacturing companies have implemented 3DP for volume production of products or parts. The author argues that this number means that the technology will soon have its real breakthrough as the numbers for mainstream usage is defined at 20%. Moreover, the author argues that because of the impending breakthrough, managers must engage in 3DP on a strategic level in order to find its potential and strategic fit of the own organization.

D'Aveni (2015) presents three different levels of strategic questions that managers must face and deal with in order to be prepared to catch the train. Firstly, companies need to think about how they can redesign their offerings in accordance to the benefits that can be achieved by the 3DP technology. The authors mentions several examples where product offerings have been redesigned to give increased customer value by offer something unique that have been facilitated by the new technology. These examples reaches from decreased fuel costs as a result of significantly lighter aircraft parts to applications where the product design can be optimized and continually upgraded by the customer.

Secondly, D'Aveni (2015) claims that, the operations strategy for companies using 3DP technology, will have to change. The operations strategy includes how the company will buy, make, move and sell their goods. The author further emphasizes that apart from a reduction of direct costs, bigger gains are to be find when broadening the scope and consider the total cost of manufacturing and overhead. Moreover, D'Aveni (2015) highlights that it is important that managers think about and decide upon in what setting 3DP should be implemented, including sourcing strategy and logistic hinterland.

Thirdly, the 3DP technology will require new digital platforms in order to facilitate integration across designers, makers and movers of goods. This is something that companies need to consider on a strategic level and it is important to understand what implications these platforms will generate. According to D'Aveni (2015) these platforms will orchestra printer operations, quality control, real-time optimization of printer networks and capacity exchanges. The author further argues that providers of these platforms will prosper on the rise of the technology by establishing standards and creating an ecosystem where the technology can blossom.

According to D'Aveni (2015) there is no doubt about the potential of additive manufacturing. The author predicts that within five years the technology is so developed that it will compete with traditional manufacturing on all levels. It is not unlikely that the technology will be developed to such degree that in the near future, the industry will have access to fully automated, high-speed; large-quantity additive manufacturing systems that are economical even for products of more standardized type. It is D'Aveni's (2015) opinion that companies need to carefully consider how they should take advantage of the technology, because the technology is on its way and it leaps and bounds. D'Aveni (2015) argues that it is the companies that see the potential of the technology today that will be the winners in the future by stating:

"Smart business leaders aren't waiting for all the details and eventualities to reveal themselves. They can see clearly enough that additive manufacturing developments will change the way products are designed, made, bought and delivered"

3 THEORETICAL FRAMEWORK

This chapter captures and summarizes relevant literature that together with the empirical illustration will form the basis for the analysis and facilitate fulfillment of the purpose. The theoretical framework consists of five areas, supply chain management, supplier relationship, construction supply chain, innovation and technical development and implementing additive manufacturing.

3.1 Supply Chain Management

Supply chain is a metaphor used in order to describe all the individual firms, personnel and physical infrastructure required to deliver and offer products to customers (McKeller, 2014). When people are asked to answer where their new t-shirts come from they might reply; “From the store”. That is not the whole truth. The store is just the final point in a long chain of supply that begins with the raw materials extracted from the earth. Almost nothing we use in our daily life is the result of a single individual’s or organization’s efforts (McKeller, 2014). A typical supply chain includes many different actors e.g. manufacturers, transporters, wholesalers, distributors, retailers, trades people etc. and all is therefore a reason, to provide customers with products or services. This amount of different actors creates a complex network of different flows and connections, as can be seen in Figure 3.1.

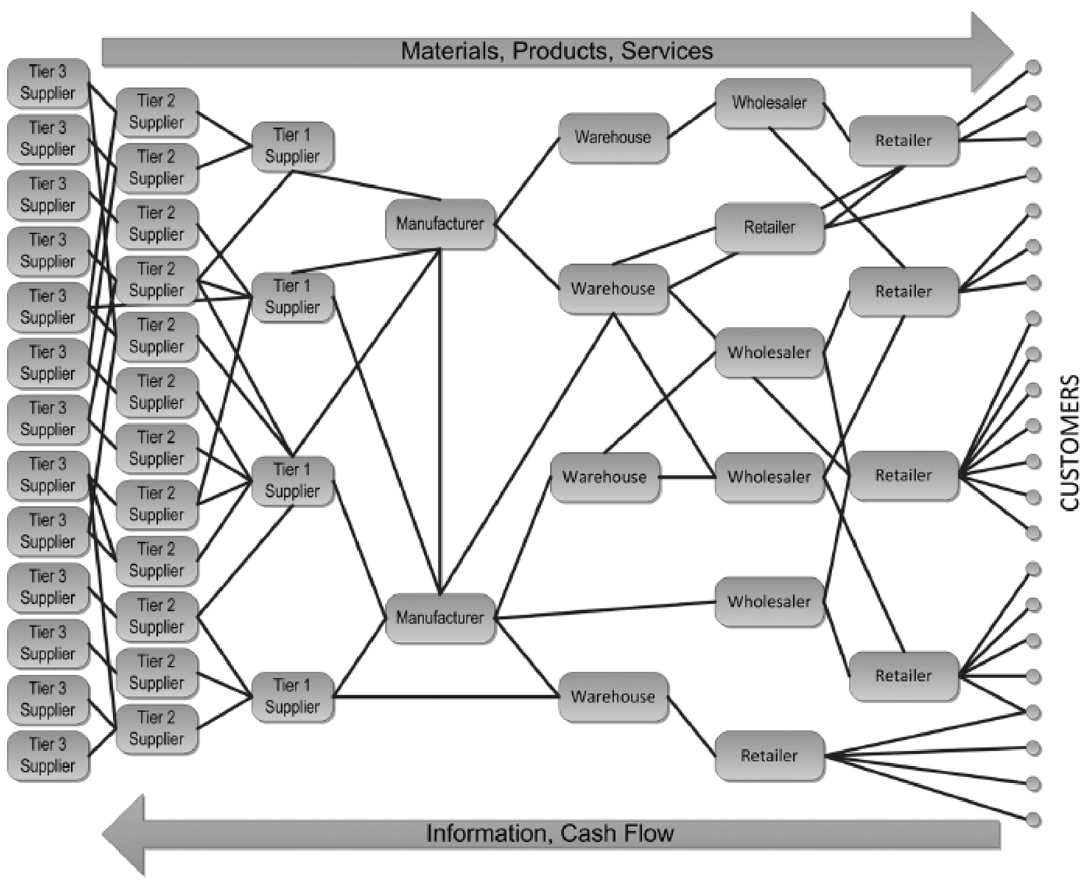

Figure 3.1 - A complex supply chain network (McKeller, 2014)

The concept supply chain management was born when companies wanted to understand what was required in order to meet customers demand. The original idea with supply chain management was that it should be used in order to identify and eliminate waste and excess cost (McKeller, 2014). Supply chain has been defined in many ways but one commonly used definition is the one retrieved from Christopher (2012):"A network of connected and interdependent organizations mutually and cooperatively working together to control, manage and improve the flow of materials and information from suppliers to the end user". When supply chain management was introduced it enlightened new issues and made companies aware of an extended enterprise and a complex network of distributors, retailers, suppliers and other internal and external organizations (McKeller, 2014). This revelation disclosed the fact that it was not sustainable for a company to only focus on one internal element, such as logistics. Instead, supply chain management made it obvious that a company must promote collaboration between both the internal and external members of the chain and hence meeting the need for integration and collaboration became one of the key areas of supply chain management (McKeller, 2014).

Dell Incorporated, a manufacturer of computers, is often described as a pioneer within the field of supply chain management. In the 1990s, Dell became market leaders in the computer industry when they started to sell their computers directly to the customers, making them a make-to-order manufacturer instead of a make-to-stock manufacturer which most of their competitors were. The efficiency of Dell's supply chains become legendary and were quickly imitated by other computer manufacturers who also wanted to reduce inventories and reduce lead times from weeks to days, as was the case for Dell. Another good example, where supply chain management has been used successfully, is the case of the apparel company Zara. Zara has been able to react fast to changes in demand through their control of upstream and downstream supply chains. Zara's control has made it possible for the company to postpone the last design, regarding style, color and product mix, making it easier for them to follow the trends and give the customers what they want (McKeller, 2014).

The attention given to the importance of being able to manage one's supply chain, in order to create competitive advantage, has been extensive over the last decades. Lambert and Cooper (2000) emphasizes this fact by calling the phenomenon a paradigm in modern business management. The fundament of creating competitive advantage lies in the ability of any organization to differentiate itself against its competitors. Secondly, the organization needs to be able to create business processes that enable the company to operate at lower costs, thus generate profit (Christopher, 2012). Today we live in a world of globalization. This generates an even more complex situation to manage where economics, financial, trade and communication are globally integrated. The globalization has led to an increase in cross-border financial flows, significant movement of entire industries to offshore locations and an increase in international commerce (McKeller, 2014). The globalization is a key driver for supply chain planning and design where the amount of global commercial activities has rapidly increased the last years. In many cases the manufacturers, suppliers, retailers and customers are located far away from each other, making the ability to manage the resulting complex supply chain a challenge. It is a necessity for companies to manage lead times, inventories and product introductions across complex and global network of suppliers in order to meet customers' ever-changing demand for variations in products and immediate delivery (McKeller, 2014). Many are the researchers pointing at supply chain improving activities as a mean for companies to stay competitive (Christopher, 2012; Chopra and Meindl, 2013; Lambert and Cooper, 2000; Blanchard, 2010).

Moreover, the underlying goal of managing the supply chain is to be able to coordinate the material and informational flows, created by the network of involved members, as an integrated system rather than a series of interdependent activities (Christopher, 2012). If this is managed correctly, the chances are greater that the customer perceives better service, by getting a high quality product to a competitive price, yet at lower costs for the focal company. According to Blanchard (2010) there are several characteristics that, regardless type of industry, applies as characteristics that defines a top-performing supply chain. These are beneficial to bear in mind when approaching supply chain improvement activities. Firstly, the company should have a clear supply chain strategy, to support supply chain related decisions, which are reflecting the overall strategy of the company. The supply chain itself should be quick and adoptable in order to be versatile and applicable in today's dynamic business environment. Moreover, the supply chain should be transparent, have clear KPIs and enhance a culture where the involved participants are held accountable. In order to secure future performance, the supply chain activities should be focused on continuous improvements and the focal company should be aware of the strengths and weaknesses of the supply chain by being involved in benchmarking activities. Finally, the supply chain should have an end-to-end perspective with a global rather than local focus.

The international center for competitive excellence has identified seven supply chain key business processes (Cooper et al., 1997). These are processes that need to be included in the strategic way of working with supply chain related improvements. The processes are presented in the following list:

- Customer Relationship Management
- Customer Service Management
- Demand Management
- Order Fulfillment
- Manufacturing Flow Management
- Procurement
- Product Development
- Commercialization

Customer relationship management includes all work related to the identification of the most important customers, the development of the relationship with these customers and the generation of special offering programs directed towards the same (Cooper et al., 1997). Moreover, customer service involves the activities aiming at keeping the best possible information available for the customer during the whole process of ordering, manufacturing and delivery. It is important that the customers have easy access to all the information needed during the process, preferably via digital platforms (Cooper et al., 1997). It is important to have a clear linkage between the flow of material and the actual customer demand, by Cooper et al. (1997) referred to as demand management. In-depth forecasting of the customer demand entails large cost saving potential. Order fulfillment includes all activities that aim at providing accurate and timely delivery of the product, including transportation and delivery time planning. The ultimate goal is to exceed the delivery expectations of the customer (Cooper et al., 1997). Furthermore, there is important to have the right product, both in relation to product mix, but also the right product to the customer. This also contributes to the possibility to create more flexible manufacturing processes. Cooper et al. (1997) refers to this as manufacturing flow management. Procurement is much more than just price negotiations and contract agreements. Cooper et al. (1997) argues that the procurement process is predominantly about managing supplier relationships and trying to build collaborations fruitful for all parties involved. The procurement process is, moreover, an important support process to several of the other processes. Lastly, both product development and commercialization are processes that support the most fundamental part that contributes to the success of the company, namely the product offered to the market. The aim is to deliver the best possible product to the market in the shortest time possible (Cooper et al., 1997). As a general note the author argues that many researchers have agreed upon the flow of information as key for the efficiency of the supply chain. The issue concerns both the type of information and the frequency with which the information travels amongst the channel members. Supply chain management is a familiar concept in many industries, such as automotive and retail industry and has been successfully in these. As mentioned earlier in this report, Dubois and Gadde (2002) argue that the construction industry has fallen behind with the implementation of supply chain management. The following section will therefore highlight relevant literature about construction supply chains and characteristics of these.

3.2 Different interfaces between a buyer and supplier

All companies producing something have relationships with suppliers, supplying the focal company with raw materials and services which is utilized by the focal firm in order to satisfy their final customers. A trend has occurred regarding the closeness of the relationship where the nature of the relationship has moved from 'arm's-length' towards relationships of a more collaborative nature (Araujo et al., 1999). The shift is a result of the benefits that can be gained by moving towards more collaboration. Today, a company's competitive advantage doesn't only rely on the internal resources but rather on the mix of internal resources and the access to external resources from suppliers. One example of this way of looking at a company's competitive advantage is General Motors corporate strategy, which "looks at competitiveness in terms of how well the company uses the resources of suppliers" (Araujo et al., 1999, p.498). Araujo et al., (1999, p.498) summarizes this by stating "control of resources as well as access to resources controlled by other parties defines a firm's competitive position". This highlights the fact that a company is heavily dependent on the relationship it has with its suppliers and how these relationships are managed.

Different relationships generate different interfaces between the focal firm and its suppliers. Araujo et al., (1999) categorizes different interfaces based on, to what extent the supplier and customer are aware of each other's context, in other words, being aware of the industry and business context in which the counterpart acts. Their categorization of interfaces ranges from not being aware of the other's context at all, to being fully aware. Following list shows the different interfaces identified by Araujo et al., (1999):

- Standardized interfaces
- Specified interfaces
- Translation interfaces
- Interactive interfaces

The next section will elaborate around and describe the different types of interfaces identified by Araujo et al., (1999).

3.2.1 Standardized interfaces

The first interface between a company and a supplier is standardized interface. In this situation the supplier provides a range of standardized products. This can be seen as a classic arm's length relationship where price act as the main coordination device (Araujo et al., 1999). The customers choose products that suit their needs from, for example, a product catalogue. This type of interface can be seen as the simplest one with the least costs for its maintenance. The buying firm doesn't need to invest anything regarding knowledge about the design or manufacturing process of the products. The low cost for setting up and maintaining the interfaces is the same for the supplier who can gain economies of scale in production and marketing since the interface will be identical for many different customers. However, lack of direct contact between the customers and suppliers might create problems regarding development of new products (Araujo et al., 1999).

3.2.2 Specified interfaces

Specified interface is an interface where the supplier and customer comes closer to each other compared with standardized interfaces. The products produced by the supplier are specified by the customer and one can say that the supplier produce products on the behalf of the customer. Traditional subcontracting or outsourcing is good examples of this type of interface. When having specified interfaces, the customer specifies the geometrical dimensions and material for the product and the supplier just produce the product out from the specifications provided by the customer. The buyer uses the supplier in order to extend its own production capacity (Araujo et al., 1999). In contrast to standardized interfaces, the supplier both requires specifications of the products as well as production schedules. Hence, specified interfaces entails more interdependencies between the supplier and buying firm since production scheduling requires some coordination (Araujo et al., 1999) which on its hand will require more investments from both involved parties.

3.2.3 Translation interfaces

When a customer provides a supplier with product functionality instead of fully specified dimensions and properties, as in specified interfaces, the interface is of translational nature. In this case the specification is based on how the product should perform in the user context (Araujo et al., 1999). In a translation interface, the supplier has a higher degree of freedom since it is up to the supplier to translate the functionality, specified by the customer, into e.g. geometrical dimensions and material choices. In this interface, the supplier takes on a greater responsibility in the relationship (Araujo et al., 1999), compared with standardized and specified interfaces. This type of interface requires more investment from both involved parties since more investments need to be made on coordination in order to ensure that the supplier fully meets the customers' requirement.

3.2.4 Interactive interfaces

The last interface described by Araujo et al., (1999) is the interactive interface and is the interface between a buyer and a supplier with the highest level of collaboration. Instead of specifying product properties and functions, the supplier and buyer jointly develop the product (Araujo et al., 1999). The supplier and buying firm might discuss different variants of the product and possible trade-offs between them based on their joint set of resources. This interface enables both firms to consider productivity consequences and the benefits that can be provided to specific third parties e.g. the buyers' customers.

Araujo et al., (1999, p.500) argues that these four types of interfaces differs in the terms of "(1) the costs associated with the use of the respective interface; and (2) the benefits provided by them differ in terms of (a) productivity and (b) innovativeness". Different interfaces will bring different benefits and costs with it and it is important to balance the benefits against the investment required to establish and maintain the interfaces (Araujo et al., 1999). How the different interfaces affect the productivity and innovativeness will be described in more detail in next section.

3.2.5 The supplier interfaces' effect on productivity and innovativeness

According to Araujo et al., (1999) the costs for developing and maintaining different interfaces for the suppliers will be reflected in the prices charged to the customers. Standardized interfaces generate the best opportunity for the customers to take advantage of large-scale production operations from the supplier. In other words, standardized interfaces is the least expensive interface for both involved parties since suppliers can gain economies of scale when producing standardized parts where they can use the same interface towards many different customers and the investment from the customer is negligible. Specified interface reduces the possible production gains that can be achieved since when specifying a product, the supplier will be limited to these specifications. Economies of scale and scope can be achieved when having translation interfaces (Araujo et al., 1999). When specifying the function of a product, instead of fully specified geometrical dimensions and material choices, the supplier will have more degrees of freedom which might be beneficial for the suppliers from a productivity point of view. Interactive interfaces involve both parties to a greater extent and according to Araujo et al., (1999) this type of interface can have effects on the cost structure for both parties.

When it comes to innovativeness, Araujo et al., (1999) defines innovativeness out from the learning effects originating from the different type of interface. Araujo et al., (1999) describes two types of learning effects where the first is direct, situated, and joint learning takes place when the supplier and customer interacts with each other. The other one is to which extent the customer can benefit from learnings the supplier has gained from interacting with other customers. Standardized interfaces do not provide any opportunity for learning whatsoever.

However, there might be indirect effects on a standardized interface since the suppliers can streamline their operations which might create more efficient processes which in its turn can result in lower price for the customers. Furthermore, both specified and translation interfaces implies small opportunities for direct learning from the interfaces.

Nevertheless, translation interfaces will foster indirect learning since the supplier is give more freedom when producing the products which might enable suppliers to reuse knowledge gained from other interfaces (Araujo et al., 1999). Lastly, interactive interfaces foster great opportunities for learning for both suppliers and customers where joint learning can take place when developing products in collaboration (Araujo et al., 1999).

In summarize one can say that a buying company needs a variety of interfaces (Araujo et al., 1999). Interactive interfaces will foster productivity and innovativeness gains through joint learning but are complex to manage and need substantial investments. This means that a buying firm can only have a limited number of interactive interfaces since they need heavy investment. On the other side of the spectrum, accessing resources through a standardized interface might provide customers with costs benefits that can only be attained when suppliers have many different customers for the same type of product. In this case the suppliers can gain economies of scale as mentioned earlier in this chapter. In summarize, all findings from Araujo et al., (1999) can be seen in table 3.1.

Table 3.1 - Consequences of Different Types of Supply Interfaces from a Customer-Based Perspective (Araujo et al., 1999, p.505)

Interface Category	**Characteristics**	**Customer Benefits Productivity**	**Customer Costs Productivity**	**Customer Benefits Innovativeness**	**Customer Costs Innovativeness**
Standardized	No directions No specific connection between user and producer contexts.	Cost benefits from supplier economies of scale and scope, as well as learning curve effects.	Adaptation to standardized solutions may create indirect costs elsewhere	None	No direct costs. Allows only indirect feedback to suppliers based on sales figures.
Specified	Precise directions given by customer on how to produce.	Supplier can pool together similar order; economies of scale and scope can be attained.	Supplier's resource base "locked in." Limited possibilities to influence specifications.	Minimal (supplier can propose changes to blueprints).	Supplier used as capacity reservoir. Development of supplier resources may suffer.
Translation	Directions given by customer based on user context and functionality required.	Supplier can propose efficient solutions that improve its own and well as the customer's productivity.	Supplier may reap benefits that are not shared with customer.	Supplier has some leeway to propose innovative solutions.	Supplier may not know enough about customer context to innovate radically.
Interactive	Joint development based on combined knowledge of use and production.	Open-ended exchange allows full consideration of direct and indirect costs for both parties.	Investments in knowledge of how best to make use of existing resources.	Supplier learning about user context opens up the gamut of solutions offered.	Requires investments in joint development and learning.

3.3 Construction supply chains

The construction industry is one of the late adopters when it comes to structured supply chain improvement initiatives (O'brien et al., 2008). The manufacturing industry has for a long time put large emphasis on supply chain optimization. O'brien et al. (2008) argues that the construction industry can learn from several initiatives taken in the manufacturing industry, hence the authors elevates the value of transferring manufacturing supply chain practices to a construction project context. By doing so, construction companies can increase project efficiency and reduce project costs. Furthermore, O'brien et al. (2008) argues that many researchers point at the fact that the construction supply chain is a complex and currently ineffective matter. Hence, the authors highlight the need for a structured approach to construction supply chain (CSC) management.

There is a substantial difference between regular manufacturing supply chains and construction supply chains. O'brien et al. (2008) summarizes construction supply chain characteristics in a matrix where it is compared with the characteristics of a regular manufacturing supply chain. This is done in order to better understand the difficulties of applying supply chain management practices directly to the context of construction. The characteristics are shown in table 2.1, which is retrieved from O'brien et al. (2008).

Table 2.1 - Differences between Manufacturing- and Construction supply chains

Characteristics	**Manufacturing Supply chain**	**Construction Supply chain**
Structure	Highly consolidated High barriers to entry High Interdependence Predominantly global markets	Highly fragmented Low barriers to entry Transient locations Low interdependency Predominantly local markets
Information flow	Highly integrated Highly shared Fast SCM tools	Recreated several times between trades Lack of sharing across firms Slow Lack of IT tools to support SC
Collaboration	Long term relationships Shared benefits, incentives	Adversarial practices
Product demand	Very uncertain Advanced forecasting methods	Less uncertain
Production Variability	Highly automated Environment standardization, production routes are defined – lower variability	Labor availability and productivity, tools, open environment, lack of standardization and tolerance management, space availability, material and trade flows are complex – higher variability
Buffering	Inventory models (EOQ, safety inventory, etc.)	No models Inventory on site to reduce risks Use of floats (scheduling)
Capacity planning	Aggregate planning Optimization models	Interdependence planning Infinite capacity assumptions Reactive approach

As a complement to the CSC character compilation done by O'brien et al., (2008), Segerstedt and Olofsson (2010) have done research aiming to introduce and highlight special characteristics of a construction supply chain. The authors summarize their findings in the following points;

- Converging at the construction site where the object is assembled from incoming materials
- Temporary producing one-off construction projects through repeated reconfiguration of project organizations separated from the design
- Typical make-to-order supply chain, with every project creating a new product or prototype.

Poor on-site performance in the construction industry is often caused by lack of appropriate planning activities (O'brien et al., 2008). There is for example often lack of production planning, which includes decisions about right amount of material and where to put buffers in the system in order to secure smooth production flow. Moreover, O'brien et al., (2008) claims that construction project managers often puts too little emphasis on planning that concerns off-site activities and variability in delivery. In order to compensate, managers tend to increase the amount of on-site material inventory in order to secure uptime and reduce the risk of delays in production. However, this common practice leads to high tied up capital, which are in most cases unnecessary. Furthermore, production sites are often very limited to a certain area, hence high amount of material on production site entails troubling on-site material handling activities (O'brien et al., 2008).

Another common way of working which can cause false project time frames is the development of optimistic schedules. The schedule does often not include time buffers to protect against delays caused by uncertainties from off-site manufacturing and delays from late delivery of materials. Furthermore, there is a lack of long-term orientated supplier and subcontractor relationship in the construction industry (Olsson, 1998). O'brien et al., (2008) is taking the argumentation forward by saying that change is needed and that general contractors and construction project owners need to understand the importance of supplier and subcontractor collaboration in order to achieve project goals. Another aspect brought up by O'brien et al., (2008) concerning CSC complexity is the fact that subcontractors are very often involved in several construction projects simultaneously; hence subcontractor resource availability has been an important performance factor for main contractors in order to secure project performance. Summarized, these are characteristics that contribute to the complex and problematic matter of a construction supply chain;

- Insufficient attention on production planning
- Insufficient attention concerning off-site activities including material delivery
- Overcompensation of material
- High tied-up capital
- Troubled on-site materials handling
- Optimistic scheduling
- Need for more long-term relationships
- Need for subcontractor resource availability analysis

The construction project supply chain is as previously mentioned a complex matter. One of the clearest reasons for that is the large number of parties involved in a construction project (O'brien et al., 2008). The structure of the supply chain with regards to involved parties does look different for every individual construction project. Hence, there is important to be aware of the stakeholders involved and the network of relationships that occurs around a particular project, in order to organize effectively. The network of parties often reaches outside the actual construction site and looks different at various stages of the project (O'brien et al., 2008).

The flow of material in a construction project is always converging to the construction site (O'brien et al., 2008). As previously mentioned in this report, traditional construction projects often lack structured coordination and planning activities especially on production site. The demand for material is often unstable due to lack of reliable off-site production systems. Large orders are sent directly from factors to the construction site and smaller orders are delivered from warehouses, managed by distributors. It is hard to foresee and estimate the quantity of smaller orders since activities in construction projects are heavily interdependent on each other, which may result in delays (Dubois & Gadde, 2002). The lack of coordination between supply chains cause a large amount of waste and is therefore a major contributing factor to inefficiency in a construction project (O'brien et al., 2008). A construction project supply chain is illustrated, in a conceptual manner, in Figure 3.2.

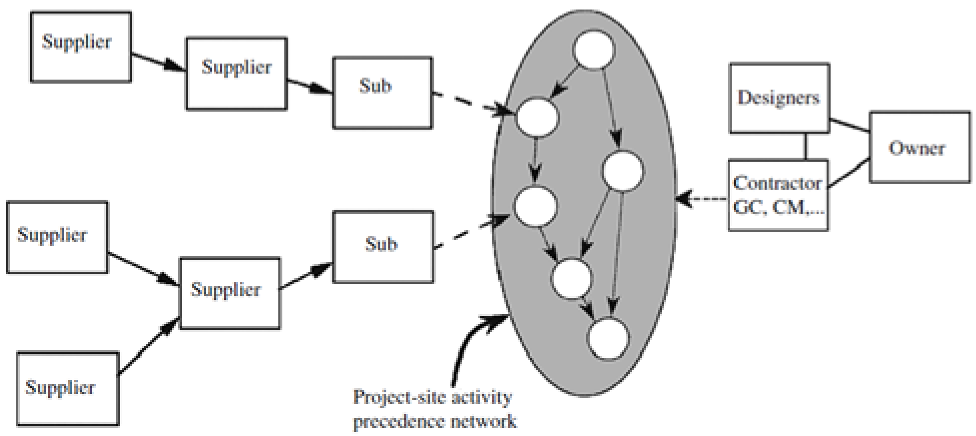

Figure 3.2 - Conceptual view of project supply chain (O'Brien et al., 2008)

As can be seen in Figure 3.2, project activities take place both on and off site. Although material and information flows are converging to production site, a large share of project activities are carried out in various planning and execution stages off site. Such activities are often carried out by actors with high influential power like project owners, construction object designers and the main contractor. Off-site activities are by many authors highlighted as key activities for assuring high quality and performance measures (O'brien et al., 2008).

3.4 Relationships and partnering in the construction industry

As mentioned previously, the construction industry has the last decades faced criticism regarding poor performance, due to an ignorant approach to modern business processes introduced successfully in other industries (Dubois & Gadde, 2010). The authors continue with stating that many of those processes where aimed at the supply side of the company e.g. the way the supplier relationships are managed. Many authors have highlighted the importance for companies in the construction industry to handle supplier relationships with more strategic weight, due to its large impact on performance and efficiency (Dubois & Gadde, 2010). Holmen et al., (2003) mentions that construction firms are much more unexperienced regarding working in long term supplier relationships. Moreover, the main focus of the attention has been directed towards the nature of the relationships i.e. the need for more collaborative and long term supplier relationships, identified as ‘Partnering’ (Dubois & Gadde, 2010). Dubois and Gadde (2010, pp.256) presents a definition of the partnering approach, formulated as follows; “A long term commitment between two or more organizations for the purpose of achieving specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizational boundaries. The relationship as based on trust, dedication to common goals, and an understanding of each other’s individual expectations and values”.

Several authors in this field of research have agreed upon possible benefits resulting from a partnering approach, including;

- Reduced project cost and time due to early supplier involvement
- Improved quality as a result of increased and joint learning contributing to innovation and process improvements.
- Improved client satisfaction
- Greater stability helping companies with planning and resource allocation activities.

According to Andersson and Görgulu (2014) several partnering initiatives are undertaken by the largest construction firms in Sweden. The authors state that the majority of the initiatives undertaken are considered successful meaning that predetermined goals aiming at improvements are reached. As an example, the partnering collaboration between NCC and Telge Fastigheter did achieve a Strategic Partnering Achievement Award by the US-based International Partnering Institute, for successful and efficient collaboration leading to improvements the important measures of time, cost and quality (Andersson & Görgulu, 2014). In this case the partnering structure was between a main contractor and the owner of the housing project, thus on the selling side of the main contractor. According to Bygballe (2010) partnering initiatives often follows a structure where the main contractor creates partnership arrangements on the selling side of the company in order to reach the above mentioned possible benefits. Partnering does, however, require extensive investments from involved parties, both in relation to time invested in the relationship and financial means. Moreover, there is an uncertainty regarding how to transfer the concept of partnering into concrete initiatives. These facts contribute to the realization that the approach is not yet accepted throughout the industry (Dubois & Gadde, 2010). It is nevertheless safe to say that the nature of supplier relationships play an important role for the development of the industry.

3.5 Innovation and technical development in the construction industry

Innovation has been defined in many ways in the literature e.g. “a process that involves the generation, adoption, implementation and incorporation of new ideas, practices or artefacts within the organization” (Wan et al., 2005, p.262) or “the actual use of a non-trivial change and improvement in a process, product, or system that is actually used and which is novel to the company developing or using it (Slaughter, 2000, p.2).

The construction industry plays a vital role in today’s society, constructing buildings, roads and all kind of infrastructure around us. Construction innovations can be a mean for construction companies to develop a competitive strategy in the long-run (Slaughter, 2000). Over the recent decades, there has been a major change in energy supply and consumption in almost all countries (Håkansson & Ingemansson, 2012). Despite these changes and trends in today’s society the construction industry is still perceived as conservative and is often criticized for its lack of innovation (Dubois & Gadde, 2002; Holmen et al., 2005; Håkansson & Ingemansson, 2012; Winch, 1998; Yusof et al., 2014). However, innovation is not one general concept that fits all, and its implication might look different in different industries. It has been discussed in the literature if it is fair to compare innovation in the construction industry with innovation in for example the automotive industry. Håkansson and Ingemansson (2012) states that one reason for the construction industry's bad reputation regarding innovation might be: "the way the concept *innovation* is generally defined and measured is simply not suitable for the construction business" (Håkansson & Ingemansson, 2012, p.41)

The development and performance in the construction industry regarding productivity, quality and product functionality have been low compared with other industries (Koskela & Vrijhoef, 2001). Winch (1998) argues that one reason for the lagging behind other industries might be the low degree of innovation in the industry. However, the author argues that the problem is not that there has been no innovation; instead the industry might be a lively source of new ideas. The problem is that most innovations regard product enhancement and not process improvement (Winch, 1998). The author also argues that the reason for the relatively low level of innovation can be derived from the structural features and characteristics of a construction project. Some examples of such structural features of a construction project are immobility, complexity, durability, costliness and a high degree of social responsibility. These features in combination with decentralized decision-making and informal coordination hinder systematic optimization and innovative evolution (Koskela & Vrijhoef, 2010). The decentralized decision-making and informal coordination can be connected to the organizational structure of a construction company. This organizational aspect can be one of the reasons for lack of renewal and innovation in the industry (Håkansson & Ingemansson, 2012). The authors also argue that the dominant use of project organizations might be one of the critical aspects of why innovation is perceived as low in the construction industry. Since most construction projects consist of smaller, distinct project where each project is handled in a specific way, led by a specific manager with a specific budget, it might be hard to promote innovations and transfer of such innovations to future projects (Håkansson & Ingemansson, 2012)

Furthermore, another reason to the low degree of innovation might be the adversarial characteristic of relations in the construction industry, with lack of collaboration between involved parties (Holmen et al., 2005). Since construction projects is large, complex and long-lasting with temporary alliances, most innovation initiatives are focused on a single project which creates discontinues in the development of knowledge and how this knowledge is transferred from one project to another (Håkansson & Ingemansson, 2012). Holmen et al. (2005) also argues that it is hard for innovations to transfer from one project to another since the construction industry is characterized by an organization shifting coalitions around unique projects. It has also been shown that even for projects focusing on creating technological innovations it is hard to achieve consistent innovations due to the frequent switching of cooperation partners (Holmen et al., 2005).

According to Winch (1998) the construction industry is remarkably different compared with other industries when it comes to innovation. Innovation in the construction industry is seldom implemented in the construction firm itself, but implemented in the project upon which the firm is involved in (Winch, 1998). As mentioned earlier a construction project involves a main-contractor who uses sub-contractors in order to fulfill all its obligations. A construction project can therefore be seen as a project with collaborative engagement from all firms within the project. The implications of this collaborative engagement mean that all innovations in a construction project have to be negotiated with one or more actors within the project coalition (Winch, 1998). This is also supported by Håkansson and Ingemansson (2012) who argues that there has to be potential benefits for all involved actors in order for each one of them to contribute to a new solution, which is a necessity for all innovation processes, in order to become successful.

A construction projects involve a considerable amount of problem-solving since the general repertoire of technologies and techniques always adapts to the specific construction situation. This is done in order to meet client's need in interaction with the constraints of the site. This means that there might be some degree of innovation in a construction project but more of a problem-solving characteristic. In order for problem-solving to become an innovation the solution must be learned, codified and applied to future projects (Winch, 1998).

3.5.1 Factors influencing innovation in the construction industry

When Blayse and Manley (2004) presented their paper about innovation in the construction industry they wanted to identify the main factors driving or hindering construction innovation. Their findings and opinions were in line with what has been discussed previously in this report. The construction industry is according to Blayse and Manley (2004) one of the most important industries in modern economies but there is still lack of innovation within the industry. According to the authors the construction industry has significant impact on the economics and the higher the level of innovation is in the industry, the more likely it is that it will increase the economic growth.

Blayse and Manley (2004) identified six different factors that influence innovation in the construction industry. First of all, it is important to understand that a construction project involves many different participants, Figure 2.3, and as previously mentioned, it is of high importance for active networking between all of these (Blayse & Manley, 2004).

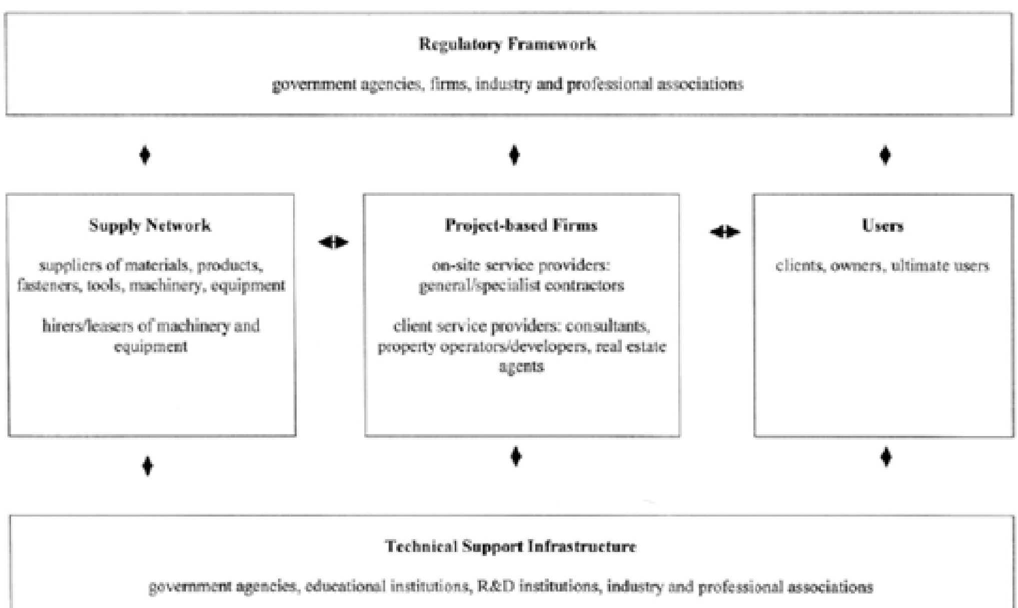

Figure 2.3 - Participants in the building and construction project system (Blayse & Manley, 2004)

3.5.2 Enablers and disablers for increased innovativeness

Clients and manufacturing firms

The first factor influencing innovation in the construction industry is *Clients and manufacturing firms*. Clients have significant impact on innovation since it is the client who demands the final requirements of a construction project. The clients can put pressure on project participants to improve lifecycle performance of buildings, project flexibility and overall characteristics of a project (Blayse & Manley, 2004). According to the authors the more demanding the clients are, the more likely it is that the level of innovation increases. It is also believed that manufacturing firms have significant impact on the degree of innovation. These firms often provide construction project with innovative components and building products. Manufacturing firms have also, according to the authors, better opportunities to build up knowledge bases and virtuous cycles of learning since their activities are not project based in the same way as it is for a construction company (Blayse & Manley, 2004).

Structure of production

The second factor identified by Blayse and Manley (2004) is *Structure of production*. Since most construction projects are of one-off nature it is associated with discontinuities in knowledge development and knowledge transfer both within and between organizations. Due to the one-off characteristic, incentives for innovations are seldom raised since it is most likely that innovations will not be transferred to other projects, therefore hindering implementation of innovations in a construction project. Furthermore, construction projects are expected to be highly durable and according to Blayse and Manley (2004) this generates two other negative consequences. First of all the expected durability of a building results in companies using tried and tested techniques and technologies in order to make sure that the building becomes durable. Secondly the durability puts pressure on suppliers to keep stock of spares far into the future, hindering manufacturers to change product ranges. Structure of production does also involve the hierarchy in a construction project and it is believed that one factor hindering innovation might be traditional management approaches. One study that investigated the construction of the Channel tunnel, between France and England, showed that the French management 'model', where managers were much more autonomous and flexible compared with the English 'model', resulted in a higher level of innovation (Winch, 2000). Another factor associated with structure of production is the fact that the construction business is dominated by smaller construction companies. These smaller firms have limited resources to undertake innovation in the same extent as a larger player could (Blayse & Manley, 2004).

Industry relationships

The third factor is *Industry relationships* which relates to the relationship between participants in a construction project. These relationships are characterized by 'loose couplings' due to the one-off characteristic of a construction project where temporary coalitions are created and then dissolved when the project is finished. Nevertheless, a construction project can be an 'experimental workshop' where innovations can be promoted and developed. However, such innovations are rarely 'codified' and will therefore most probably get lost for future projects according to Blayse and Manley (2004). Tighter couplings, between actors and firms, would probably enhance the possibility to transfer innovations from one project to another (Blayse & Manley, 2004).

Procurement systems

Procurement systems are the fourth factor influencing innovation in the construction industry according to Blayse and Manley (2004). They argue that a procurement system that favors speed and urgency or is based on price competition is most injurious for innovation. A higher level of innovation occurs when more innovative procurement methods are used such as partnering alongside fixed cost contracts, which can be used in order to improve communication and learning. In order to move towards more innovative projects, construction companies need to shift from competitive tendering to partnering and alliancing on the supply-side in order to share gains/risks and those companies that are innovative needs to be rewarded for taking such risks. Such reward systems could foster innovative companies to further adopt new ideas and capture learnings from problem solving activities and transfer these to other projects. Moving away from tendering towards more partnering will, according to Blayse and Manley (2004), increase the productivity, reduce costs, reduce project times, improved quality and also improve client satisfaction.

Regulations/Standards

The fifth factor influencing innovation is *Regulations/standards.* According to Blayse and Manley (2004), regulatory policies have strong influences on technological changes and might hamper (or push) innovations. Sector-specific knowledge related to market conditions, advanced practices and technologies, organizational competencies, industry structure, competition and technical infrastructure is important for regulators to possess in order to come up with regulations which are fair to the market (Blayse & Manley, 2004). Lack of knowledge of the regulators can result in fossilization of practices since requirements are based upon old technologies which can hinder implementation of new technologies into the industry. However, the authors argue that if regulations are designed in an appropriate and strategic way, this can have positive effect on innovations where existing technologies are codified and demand for new practices and technologies are created. By setting requirements that are too strict for today's technologies, regulators can force the industry to develop new technologies i.e. high standards can induce a higher demand for new technologies which otherwise would not be commercialized by the industry (Blayse & Manley, 2004).

Organizational resources

The sixth and last factor influencing innovation in the industry according to Blayse and Manley (2004) is *Organizational resources* and involves five sub-categories; 'culture of innovation', 'absorptive capacity', 'innovation champions', 'knowledge codification' and 'innovation strategy'. Even if all external conditions is favoring innovation it is equally important for a company to have attitudes and processes in place in order to enhance innovation (Blayse & Manley, 2004). In order for a company to successfully create innovations, a culture that encourages innovation is a necessity. Blayse and Manley (2004) summarize 'culture of innovation' into three factors that needs to be in place in order for a company to become more innovative, these are:

- Not penalizing new ways of working if they do not succeed
- People should be able to questioning ways of working without fear of penalty if they are unsuccessful
- Shared perception that participants are all striving to achieve a greater understanding of each other's goals

Moreover, in order for a company to enhance innovation it needs to have ‘absorptive capacity’ i.e. a company needs some in-house technical competence in order to absorb results of research conducted elsewhere. ‘Innovation champions’ is also mentioned as an important factor for innovations and can be expressed as follows: “Innovations need champions. Ideas are carried by people, and ideas are the rallying point around which collective action mobilizes” (Blayse & Manley, 2004, p.151). Furthermore, innovation champions need to possess technical knowledge and authoritative power in order to overcome the uncertainty of construction innovations and the authoritative power can enable them to challenge innovation resistance.

As mentioned previously in this thesis, construction companies struggle to transfer knowledge and learning between different projects (Gann, 2001). Therefore, it is important for construction companies to attempt to codify knowledge and learnings in order to facilitate transfer between different projects, referred to as ‘knowledge codification’ by Blayse and Manley (2004). They states the following when it comes to ‘knowledge codification’: “it is important that firms integrate project experiences into continuous business processes to ensure coherent organization” (Blayse & Manley, 2004, p.151). Furthermore, the last sub-category of the sixth factor, organizational resources, is ‘innovation strategy’ and refers to the overall strategy of a construction firm. Most construction firms do not have the resources or incentives to maintain and develop research programs, which results in the importance of construction firms to adopt innovations developed elsewhere (Blayse & Manley, 2004). A construction company needs to combine elements such as; absorptive capacity, culture, knowledge codification etc. into a formal innovation strategy.

The review conducted by Blayse and Manley (2004) shows that innovation in the construction industry is most usefully considered within a wide product system perspective. This perspective involves contractors, clients, manufacturers, regulators and technical support providers. Together with these actors Blayse and Manley (2004) identified six different elements which significantly affect the degree of innovation in the construction industry. These six are summarized in the following list:

- Clients and manufacturing firms
- Structure of production
- Industry relationships
- Procurement systems
- Regulations/standards
- Organizational resources

When searching through the literature it becomes clear that most authors share the same opinion about the lack of innovation in the construction industry. This lack of innovation is most often referred to as a consequence of a construction project’s characteristics such as one-off nature, many involved subcontractors and adversarial relationships.

3.6 Implementing additive manufacturing

As researchers in the area of manufacturing technology predicts that AM is going to have its big breakthrough in the relative near future, many take on a proactive approach to research in the area. Mellor et al. (2014) have, amongst others, embraced this and developed a framework for the implementation of AM technologies. The authors claim that both external forces and internal factors drive the consideration for implementing AM as a manufacturing strategy. Moreover, five categories of factors influencing implementation possibility are identified, these are; strategic factors, technological factors, organizational factors, operational factors and supply chain factors. Moreover, the authors present three clear external forces with large impact on the ability to successfully implement AM technologies. The external forces can be seen as drivers as well as barriers for implementation but are nevertheless factors hard to control by the focal firm. Hence, the focus of the construction company should be on the internal factors, with the external forces in mind.

Strategic factors
Investing in comprehensive AM technologies is expensive and needs thereby to be clearly linked to the market and specific products suitable for being manufactured with the technology in question (Mellor et al., 2014). Well known authors in the AM management field have proposed three fundamental product characteristics that need to be fulfilled in order for the product in question to be suitable for AM production, the list is retrieved from Mellor et al. (2014, p.196);

- Products with a degree of customization
- Products with increased functionality through design optimization
- Products of low volume

Moreover, it is important that the implementation decision is preceded by careful consideration and strategic alignment with overall business strategy, manufacturing and R&D.

Technological factors
It is emphasized by Mellor et al. (2014) that the technology benefits derived from a potential AM implementation need to be clearly linked to the company's business strategy, in order to gain competitive advantage. However, it is equally important that the company understands the trade-offs or potential sacrifices, a new manufacturing technology could entail. The authors underline some of the predominant factors, important to bear in mind. Regardless the fact that the range of available materials is constantly growing, it is still limited. The machine and material costs are still substantially high and the manufacturing process in itself is relatively long. Furthermore, there is still a lack of technical standards, which is considered a barrier for implementation across industries.

Organizational factors
According to Mellor et al. (2014), previous research carried out in the area of new manufacturing technology implementation point at the structure of the organization as the key factor for successful implementation. The authors continues with stating that companies that goes through manufacturing implementation processes without first conducting organization structure rearrangements, tend to not be as successful as those who do. Moreover, implementing AM technologies will influence the culture of the company (Mellor et al., 2014). The usage of AM and similar technologies pushes designers to change the way that they think of, and create, design, which have a large impact on the culture of the firm. Hence, the authors highlight the need for a skilled and experienced workforce to conduct the implementation and the initial phase of AM usage.

Operational factors
As mentioned previously Mellor et al. (2014) argue that AM technology will force product design to change. This will not only apply to organizational factors, but operational factors as well. The additive characteristics of AM manufacturing technology imply that the majority of regular design constraints disappear or weaken in significance, meaning that product designers are given

greater design freedom. This, in turn, forces companies to develop and use new designing tools and practices to include in the operational strategy. Moreover, another area of operations that according to Mellor et al. (2014) will change is the production planning and quality control. According to the authors, more standardized ways of working is under development, however research in this area is still limited. Lastly, AM manufacturing is still dependent on supportive post manufacturing processes such as, heat treatment and support material removal. Implementation has proven to be most successful in environments where these kind of supportive processes are already available, or under development (Mellor et al., 2014).

Supply chain factors
AM implementation will influence two different supply chains. Firstly, it will add a new supply chain to the system, the supply chain between the focal company and AM technology vendors. Moreover, it will also have direct implications on the regular manufacturing supply chain already existing, hence influencing existing customers and suppliers (Mellor et al., 2014). Implementation of AM technologies will, in order to reach full potential, require extensive organizational changes. Researchers claims that one of the major changes need to be aiming at restructuring supplier relationship to a more long-term and collaborative nature. Moreover, studies shows that the implementation process is more successful when the focal company has support from the AM equipment vendors. It has been discovered that the level of complexity of the technology innovation are closely connected to the level of vendor support needed in order to succeed. AM is considered complex and the support needs therefore to be intense in both support frequency and depth, hence vendor support is looked upon as a key factor in this particular case (Mellor et al., 2014). Furthermore, in the industry of AM technology, equipment suppliers are often also the raw material supplier e.g. plastics or metallic powder. This fact probably derives from the current immaturity in the business creating a lack of specialized material suppliers. Lastly, since AM manufacturing enables tool free manufacturing the opportunity for changing the manufacturing location, according to market demands, occurs, resulting in the possibility for shorter distribution channels (Mellor et al., 2014). The implementation factors are summarized by Mellor et al. (2014), illustrated in Figure 3.3.

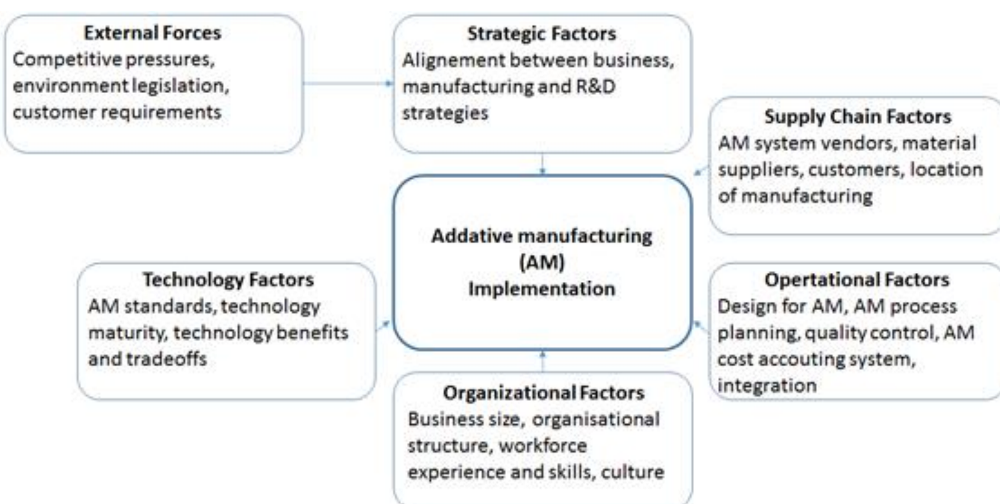

Figure 3.3 - Summary of AM implementation factors.

4 METHODOLOGY

This chapter covers the methods used to complete this master thesis study. The methods are described in detail and study specific suitability argumentations are done to ensure that the reader is familiar with the choices that have been made.

4.1 Research Strategy

The authors of this study sense a need to understand 3DP and the drivers that pushes companies in various industries to implement the technology for production applications. As previously mentioned, one crucial area of a construction project is being able to handle the complexity of the actors involved as well as the material and informational flows that exist. Hence, this thesis takes the construction supply chain as the viewpoint of the study. Based on the focus of the thesis a case study research strategy was applied.

It is, according to Denscombe (2003), important that the chosen research method is well suited for the context in which the study is going to take place. According to Dubois and Gadde (2014, p.1279) case studies are recommended because they "emphasize the rich real-world context in which the phenomenon occurs". Denscombe (2003) stresses the fact that a case study approach enhances the ability to investigate different kinds of processes and how they are linked to each other. The author also point at the fact that a case study is suitable in studies where there is advantageous to make detailed observations, with an in-depth focus, rather than studies with quantitative nature. A suitable way to describe the case study approach is; "The aim is to illuminate the general by looking at the particular" (Denscombe, 2003, pp.53). Researchers using a case study strategy do, however, according to Denscombe (2003) often seek to generalize the findings in some way. This argumentation applies in this particular case, since the findings is supposed to act as a basis of information, to use, in order to increase knowledge in the field. No study, irrespective of the method used, can provide findings that can be universally transferred to other contexts (Malterud, 2001). However, the ambition is that the findings from the case study could be looked upon as representative for the construction industry and facilitates possible future implementation of 3DP.

The purpose of the thesis called for a case study approach where the theoretical framework had the opportunity to gradually evolve along with the empirical findings and the development of knowledge in the field. Hence, the case study of this thesis has followed the research approach presented by Dubois and Gadde (2002), called 'systematic combining'. The research approach enables researchers to develop and adjust research issues and analytical frameworks as the empirical findings mature (Dubois & Gadde, 2002). It enables researchers to let theory, empirics and in-depth case analysis to evolve simultaneously and to go 'back-and-forth' in order to increase understanding for a particular phenomenon. Moreover, this way of conducting case study analysis is according to the authors particularly useful in situations where new theories are created, hence suitable in the context of this study. The cornerstones of the systematic combining approach are illustrated in Figure 4.1.

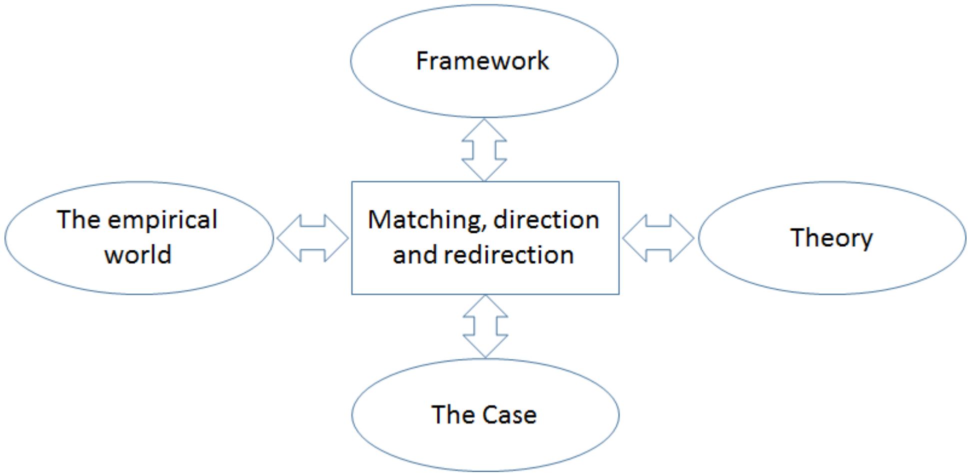

Figure 4.1 - Systematic combining cornerstones (Based on Dubois & Gadde, 2002)

The box in the center in Figure 4.1 represents the process where input from the four major sources are matched with each other and combined, a process that is more or less ongoing throughout the whole research process. Moreover, as multiple sources give new input to the research, the researchers might need to redirect further analysis (Dubois & Gadde, 2002). Furthermore, it is important to possess knowledge about and set boundaries in the empirical world. One important decision to make is how many cases that should be studied in the research project conducted. Multiple cases give a better chance to base the analysis on comparison. However, studies of more complex nature where interdependent variables are going to be analyzed benefit from taking a one case approach (Dubois & Gadde, 2002). Hence, this study had one case as the standing point, with possible extension if needed.

Moreover, Dubois and Gadde (2002) argue that one important benefit that comes from the systematic combining approach is that the evolving case can be used as a tool. However, it is in the end important to be clear about the purpose and the scope of the case in order for it to be used, by other researchers, as a framework for discussion. When it comes to the theoretical framework the authors argues that even though the researchers is set out to discover new things, the findings must be related to theory, hence the theoretical framework plays an important role. The researchers should not be constrained by existing theory, yet a theoretical framework is needed for confirmation and inspiration. Based on that argumentation, the framework is allowed to be developed over time (Dubois & Gadde, 2002).

4.2 Theoretical framework

In order to increase the knowledge in the area of 3D printing, in the construction industry, and to reach the academic originality of a master thesis, a literature research was needed. The aim of the literature research was to collect secondary data i.e. data originating from articles and reports written by researchers (Denscombe, 2003). Secondary data was accessed through databases with high academic credibility such as *ProQuest*, *ScienceDirect* and *Emerald Insight*. In order to search in these databases, search engines as *Google Scholar* and *Chalmers University of Technology's* own search engine were used. To find relevant articles and reports to this master thesis key phrases were used such as; *'Construction Supply Chains', '3D printing', 'Innovation in the construction industry', '3D printing in the construction industry' 'Partnering in the construction industry'*. One problem that arose during the literature review was that it was hard to find credible sources about 3DP and much information was to be found on different 'fan web pages'. This highlights the fact that much literature about 3DP is undifferentiated which generates an oblique picture about 3DP's future penetration as a manufacturing technology. Thus, the researchers had to be careful when selecting literature references for the theoretical framework in order to secure credibility.

4.3 Empirical findings

Ones the theoretical framework was finished an empirical study was conducted as well. The primary data was collected through interviews with relevant experts in the field of 3DP and with internal employees at NCC. The methods used will be presented in the following section.

4.3.1 Data collection

Interview as a research tool is, according to Denscombe (2003), often used when qualitative data collection is needed. In comparison with e.g. questionnaires, an interview gives the researcher the opportunity to collect in-depth data through prepared interviews with predetermined people who possess good insight in the research focus area (Denscombe, 2003). This thesis, with a case study strategy, requiring data collection of qualitative nature; interviews were therefore conducted in order to get insight into 'real' circumstances during a construction project. The interviews were held with people on different executive levels and different positions in order to get a broad picture of the construction project environment.

In order to guide the interviewees in the right direction, semi-structured interviews were chosen as the most appropriate interview structure. When using semi-structured interviews, predefined questions are combined with explanations and elaborations around a certain subject (Wilson, 2014) which means that the respondent can talk freely about a predetermined subject (Denscombe, 2003). Semi-structured interviews does also require less training regarding interview technique since the interviewer has a set of specific questions to fall back to (Wilson, 2014). This was believed beneficial for this thesis since the authors does not have any significant training in interview techniques. Semi-structured interviews do also have the possibility of discovering unknown matters (Wilson, 2014) which is suitable for this thesis because of the still unexplored scope. Therefore, it was believed that semi-structured interviews can raise problems to the surface, which have not been considered or perceived as problems before. Furthermore, according to Wilson (2014) semi-structured interviews allows for some broad comparison between different interviews which is believed necessary for this thesis since this is more qualitative oriented. Moreover, due to the qualitative approach, the focus of the data collection will be on fewer interviews with deep character rather than more interviews.

The different interviews were held with people from two different contexts. Firstly, interviews were held with people possessing expertise in the field of 3DP. The people came from different industries as well as from research centers and universities. The basis for these interviews was to collect information about what underlying reasons there are for companies choosing 3DP as manufacturing method and how the 3DP industry looks at the specific benefits that can be achieved. The second part of the interviews was held with internal employees at NCC. This was done in order to map the internal conditions at NCC and to get input about in what internal context a 3DP implementation could be suitable. The intention was also to get information about how 3DP can be used to simplify and increase the performance of some branch specific supply chain related problem areas.

4.3.2 Interviews

The following section contains information about the different interviews conducted in this thesis. The most relevant findings from the interviews are to be found in chapter 5, Empirical Illustration. Interview 1-3 comprise information regarding different industrial perspectives on 3DP. These can be seen as non-related to NCC and its operations. The reason for choosing these three was that they, combined, contribute with different angles of the 3DP industry. Interview 4-7 comprise information about NCC and its operations and was conducted with employees acting in business areas relevant for this thesis.

Interview 1

In order to get a deeper understanding about 3DP and its characteristics the Swedish company Company A was contacted. The interview with Company A were held at Chalmers University of Technology in Gothenburg and revealed relevant information for the scope of this thesis. The interviewee works in the sales organization at Company A and had good insight into Company A's business relationships. The interviewers had an open approach in order for the interviewee to have the chance to speak freely about predefined questions.

Interview 2

To collect additional information about 3DP and its implication the Swedish company Company B was contacted. The interview with Company B was held at its office in Gothenburg and revealed relevant information for the scope of this thesis. The interviewee is responsible for 3DP research and consulting at Company B and has good insight into the technology. The interviewers had an open approach to the interview in order for the interviewee to come through with uncolored information and knowledge grounded in reality.

Interview 3

In order to widen the scope of the 3DP industrial background an university was contacted. Both Company A and Company B have a commercial agenda with their businesses, hence a university was chosen as the third source due to its disconnection from economic gain. An interview was held over the phone with a researcher in the field of 3DP. The interviewee is an experienced researcher in the field of 3DP. The interview had an open approach where the interviewee could speak freely about predefined questions.

Interview 4

To gain knowledge about how NCC works with its suppliers on an operational level. Therefore, the interview was held with a NCC employee with insight into processes regarding housing development and development of construction methods. Furthermore, the interviewee has good knowledge about NCC's suppliers and what its relationship might look like. The interviewee is stationed in NCC's office in Malmö but was on a visit to the office in Gothenburg when the interview was held. Therefore, the interview was held face-to-face at NCC's office in Gothenburg.

Interview 5

In order to get an understanding for how NCC work strategically with purchasing and supplier management an interview was held with a NCC employee responsible for development of strategic purchasing at NCC. Due to the fact that the employee is stationed at the NCC headquarters in Solna, the interview was held over the phone.

Interview 6
To gain knowledge about the concept partnering an interview was held with an NCC employee, responsible for 'strategic partnering' at NCC. Since the interviewee is stationed at NCC's headquarter in Solna, the interview was held over the phone. The reason for choosing this particular employee was that the authors wanted to collect information about how NCC works with partnering on a strategic level. The interview was of more open structure where the interviewee could speak freely about predefined questions.

Interview 7
The seventh interview was held at the NCC office in Gothenburg. In order to deepen the knowledge of the partnering concept at NCC more operational insight was needed. Therefore, an interview was held with a NCC employee that works as project manager and has been involved in several partnering projects at NCC. The interviewee possesses good knowledge of operational aspects of partnering.

4.3.3 Data analysis
Since data from the interviews were of qualitative type there was a need for 'translating' and understanding this data. In order to do this the 'Grounded Theory' method was chosen. According to Zarif (2012), the grounded theory method can enable the creation of a theory that can later be used in order to explain a phenomenon. The grounded theory provides the researcher with the ability to analyze specific cases and use the conclusion from these cases in a general manner (Denscombe, 2003). To conduct a grounded theory, a number of steps need to be performed (Denscombe, 2003). First of all, the researchers should write short memos when getting acquainted with data collected from literature studies. The collected data should also be coded, using a set of variables e.g. name. The codes should then be categorized by finding links between different codes and group these codes together. When the codes have been categorized, the researchers should reduce the number of categories and also reduce the number of codes that could not be grouped. The reason for this is that a vast number of categories would hamper the researchers. In order to do this the researchers should group the categories with strong connections into one larger category and those without strong connection should be grouped into a category with a wider scope. The described process should be looked upon as a continuous cycle where the researchers analyzes and collects data (Denscombe, 2013; Zarif, 2012).

4.4 Reflection on quality
In order to secure the match between research objectives and research results it is important to reflect upon the validity concept. The validity concept concerns two issues. Firstly, how well the result of a research study can be transferred to an environment different from the one of the particular research study conducted. Secondly, the validity expression examines how god the match is between theory and the empirical findings (Bryman & Bell, 2011). In order to secure validity, meetings where frequently held together with supervisors at both Chalmer and NCC. This way, the researchers ensured that the aim of the study was maintained within reasonable limits and that the development of the problem definition and research questions stayed healthy and in in line with the desired results.

Other initiatives were taken in order to strengthen the validity of the empirical study. To ensure objectivity the interviews were always conducted with both researchers present. This way the data were not influenced by the personal opinion of the interviewer but kept objective. Moreover, to degree possible, the interviews were recorded and transcript in direct connection to the interview. This way the data could be precise which facilitates more qualitative analysis and higher validity. Moreover, the researchers were fully in charge of what suitable persons to interview. This way, the interviewees could be chosen based on what specific type of information needed which also contributed to a data collection well rooted in reality.

3DP is still quite unexplored in the construction industry; therefore the initial approach of the thesis was relatively vague and broad. The host company wanted to have a wide perspective of the subject and learn as much as possible about 3DP and its applicability in the construction industry. This made it hard for the authors to find a concrete angle of the subject and therefore a lot of time were spent in the initial phase to explore the subject and what issues the authors could give insight into. The angle emerged as the authors learned more about the subject and what important issues to consider in order to understand 3DP's implication for the construction industry. Consequently, the authors believe that this thesis has developed to something valuable and usable for all involved actors with a satisfying degree of quality.

In order to increase the generalizability of the thesis a decision was made to not only focus on the NCC specific partnering concept, but also include the more general interface categorization of supplier relationships. The framework presented by Araujo et al., (1999) is general and applicable regardless industrial context. Therefore, some of the results and findings of this thesis could be applied to other industries, not just the construction industry, which increases the generalizability.

4.5 Overall Work Process

NCC has a strong interest in the 3DP technology, therefore, several different interesting angles, that could help NCC understanding the technology in a better way, were presented and discussed as starting points for this master thesis. Since the angle was open, it had to gradually be refined as our knowledge in the field increased and the background and theoretical framework was constructed. Consequently, time was spent in the initial phase on the problem definition in order to make sure that the thesis was heading in a direction that was relevant.

The first step was to interpret the master thesis outlines and to formulate a preliminary purpose, in order to be able to formulate research questions. In parallel with formulating research questions an initial literature review was conducted to gather basic information about the subject and grasp the underlying factors for initiating the thesis. The gained knowledge resulted in a formulated background and introductory chapter to include in the initial planning report. A lot of the initial formulating in the planning report was performed together with supervisors from NCC and Chalmers. This was done in order to make sure that the formulated purpose and problem analysis were in line with what was expected from NCC as well as the academia. It was also important to ensure that the master thesis was of such magnitude that it could be performed during the time allocated for the work in the spring of 2015.

After finishing and conducting the planning report to supervisors and the examiner at Chalmers the theoretical framework was developed in combination with initial data collection. Since a systematic combining approach was used during this phase, the theoretical framework was developed and expanded along with increased knowledge in the field and deepened problem knowledge.

The empirical illustration of the thesis is built on interviews held with both internal and external sources from the 3DP industry and within the organization of NCC. The interviews were performed with an open approach, where predefined questions were asked and discussed together with the interviewee. The analysis of the thesis is of qualitative nature. The interviews were analyzed and relevant information was processed together with the theoretical framework in order to create logical assumptions. Lastly, conclusions were drawn, based on the analysis and a discussion were held, highlighting important outcomes and prospects for further studies.

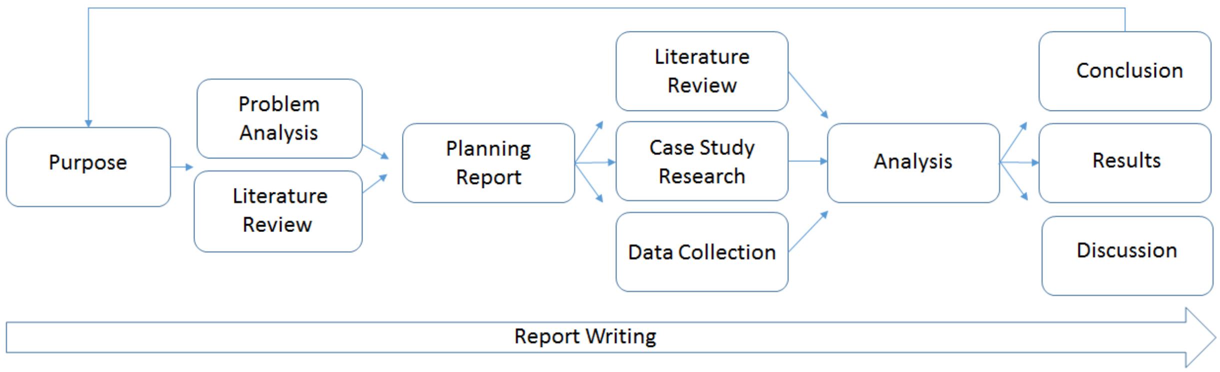

Figure 4.2 - Master thesis process outlines

5 EMPIRICAL FINDINGS

The empirical findings of this thesis derive from interviews held with individuals acting in two different contexts. Firstly, input from interviews held with people with good insight in to the 3DP industry in Sweden is presented. These interviews were held in order to get relevant information about 3DP characteristics and what potential benefits the technology can bring with a focus besides increased product performance and productivity gains. Moreover, underlying forces for 3DP usage and implementation across industries were also captured by the external interviews. Secondly, input from interviews held internally at NCC is presented. The interviews were held in order to be able to build a case around NCC's potential for 3DP implementation by mapping internal processes about how suppliers are managed in general and in the concept of partnering.

5.1 Industrial perspectives

This section contains input from interviews held with representatives from companies acting within the 3DP industry. The interviews comprises a 3DP machinery manufacturer, a research center and consultancy firm as well as university conducting research in the field of 3DP.

5.1.1 Company A: 3DP Machinery manufacturer

Company A is a company acting within the additive manufacturing industry and was founded in 1997, specialized in additive manufacturing with EBM (Electron Beam Melting) technology. The initial development of the company was performed in collaboration with Chalmers University of Technology in Gothenburg. Company A develops machinery for additive manufacturing, mostly for titanium based materials used in the orthopedic and aerospace industry. Company A offers a complete portfolio of EBM machines, auxiliary equipment, software, metal powders, service and training to support its customers.

According to the interviewee, Company A has chosen to specialize in titanium material since they are considered "necessary" expensive. By "necessary" expensive the interviewee means that titanium is expensive enough to have large potential for decreased costs related to material savings. 3DP is described as a more suitable manufacturing method when using expensive materials such as titanium.

Company A have two major selling points for their products related to either performance or production. Either a machine is sold and used for its performance where a geometric shape can be manufactured that is not possible in any other way than additive manufacturing. The other case is when the machine is sold and used on the basis of production where the time for development of a product can be shortened significantly. When developing new products in titanium, a lot of time is spent on production of molds. If a mold is manufactured incorrect, it is first noticed when the finished titanium part is inspected meaning that the company needs to start over again with the molds and will lose weeks in development time. If the molds are manufactured in a 3D-printer instead, an incorrect mold can be replaced immediately by just producing a new mold in the printer. Another major benefit with 3DP, mentioned by the interviewee, is that a company can produce a part directly in the printer without the need for any molds. The part will most likely be little more expensive but it can be tested and evaluated immediately.

Another possible advantage that can be achieved by using 3DP is that the production can be moved closer to the place of usage. The interviewee mentions one extreme possible area of use for 3DP namely the space industry. Instead of shipping parts into the space with rockets, which is extremely expensive, a printer can be sent up to e.g. a space station where it can produce parts on demand. An example of this, where a 3D-printer have been placed locally, is the case with the Canal-house in the Netherlands where parts are produced at the construction site which reduces the total amount of transportation which is beneficial from an environmental point of view.

The sales process is mentioned by the interviewee as a long process and no interface between Company A and a customer is of standardized type and as the interviewee expressed;

"3DP is not a Press-and-Play operation and a lot is required in order to make sure that the machine fits the application and the application fits the machine"

When a customer buys a machine from Company A it is often delivered with a 12 month service agreement. This service agreement includes daily communication between Company A and its customer where Company A support its customers, helping them to tune their machines in the best way for their particular operations. Company A also provides different educational packages to its customers where the most advanced package includes joint development of machines and materials between Company A and the customer. According to the interviewee this package is sold if the customer requires its own material, not supported by Company A today. In this case Company A place its own people at the customer's site where they jointly develop materials and machinery that can satisfy the customer's need. This is something that Company A appreciate since Company A can gain knowledge and experience in areas which have earlier been unknown. It can increase their overall knowledge in the business which might strengthen their market position. However, when producing and introducing a totally new product into the market a lot of work is required in order to validate the product which often takes time according to the interviewee who states that;

"We have daily communication with our customers, supporting them with knowledge and information about how to run their operations in the best way"

The interviewee argues that today it is the specialists who possess the power in the market of additive manufacturing and it is mentioned that the specialists are the ones with the deepest knowledge and understanding. In order for another company to seize this knowledge a close interaction between the specialists and the buying firm is necessary. However, the interviewee mentions that the situation might be different in the future when additive manufacturing becomes more and more recognized as manufacturing method. In order for 3DP to become a recognized manufacturing method economic issues need to be considered. In many cases the 3D-printed part is much more expensive to manufacture compared with conventional methods. One example is the fuel-nozzle for an aircraft engine that is much more expensive to manufacture using 3DP technology, but in the long run, engines containing these nozzles will consume 15% less fuel. This results in a case where the economic gain is localized at the end of the chain, by the aircraft owner, who needs to purchase less fuel, rather than in the manufacturing stage.

Another possible advantage with 3DP, mentioned by the interviewee , is the reduction of spare part inventory needed, which is also mentioned shortly in the theoretical framework. He mentions that for example an automotive manufacturer can invest in a number of 3D-printers that can print spare parts on demand. Once a part is removed from the inventory, a 3D-printer starts to produce the exact same part immediately which will reduce the amount of tied up capital for the company.

5.1.2 Company B: Institute for industrial research within manufacturing

Company B is a combined research center and consultancy firm that provides consultancy services and research knowledge within the area of manufacturing and product development. Company B is a part of the Company B group and holds several knowledge areas within, material- process-, product- and production technology. One of the knowledge areas that has received significant attention recent time is the area of additive manufacturing. Company B is currently in an expanding phase regarding additive manufacturing and is looking into further investments in the area. Company B offer companies, interested in 3DP implementation, initial testing, evaluation and consultation.

In the position as an expert in the area of 3DP the interviewee sees many benefits with the technology, as long as it brings new functionality to the table. The interviewee puts large emphasis on the fact that the potential lies at those product where there is a potential for increased functionality. It does not necessarily have to be direct increased functionality, of the product, but also increased functionality in the chain of production. An example mentioned is when a product can be manufactured in a way so that several steps in the assembly process can be cut out of the process, resulting in shortened total production time and thereby decreased costs. An example mentioned by the interviewee is how the toy manufacturer Lego produces their molds with 3DP instead of conventional methods. The production of the mold itself is more expensive but the total lead time is reduced drastically together with the total production cost.

Furthermore, in order for companies to take the leap and start using, or outsource manufacturing, of a new relatively unexplored technology like 3DP, decision makers must feel confident in the technology and make sure that it will bring great benefits to the table. Early in the process a lot of the attention is directed towards testing and validity. Company B has therefore, together with suitable partners, started an initiative where a 3DP forum is established, creating an environment where companies can share knowledge and help each other develop within 3DP. The interviewee states that joint learning and development can be a key factor for successful usage of 3DP. The forum will partly consist of a center where companies can get their applications printed and tested together with support and input for further development. The interviewee mentions that this could be a way to push the development forward and to get more companies to open their eyes to the technology. Moreover, the interviewee argues that the perception is that the earlier Company B gets involved in the implementation process the more they can contribute with their knowledge and thereby facilitate a successful process.

More specifically the interviewee claims that the main reason for the low usage of 3DP in the construction industry is partly due to the fact that there is no 3DP machinery equipment, specially developed for the construction industry, available on the market today. The machines available are still under development which creates an uncertainty amongst the industry about the area of usage and the reliability of the technology. Furthermore, construction companies needs to find a partnership with a supplier to jointly develop a 3DP suitable application, in order for the implementation to gain a foothold. Moreover, a close relationship with a third party, consisting of a 3DP machinery supplier or a 3DP contractual manufacturer, is necessary. This will result in a small network of involved parties where sharing of knowledge and joint development can take place.

Lastly, the interviewee once again highlights the importance of looking at 3DP usage with a holistic view. The product printed will, according to the interviewee, most probably be more expensive to manufacture using 3DP technology compared to conventional technologies. The gains will be found elsewhere in the production chain.

5.1.3 University A: Researching 3DP

University A has long experience from research within the area of 3DP and comprises three campuses located in Östersund, Härösand and Sundsvall, in the middle of Sweden. Researchers at University A have conducted research in the field of 3DP since 2000. The research has been up scaled during the years but the interviewee claims that research in this field has gotten too little attention in recent years. This fact has created a situation where Sweden, from being at the forefront, has lagged behind US and the rest of Europe, in the area of 3DP research. The interviewee continues with arguing that the manufacturing industry in general lack competence and knowledge in the field of 3DP. Furthermore, the technology will affect every manufacturing company, regardless industry, in the future.

The interviewee says that the vast majority of their research today is directed towards developing new functional materials that in turn increases the number of applications. The interviewee believes that in order for the technology to expand, the number of materials suitable for 3DP need to increase. This argumentation is particularly important in the construction industry where the usage of old conventional materials is high. The interviewee argues that new materials, suitable for the construction context, needs to be developed in collaboration with suitable partners.

There is, according to the interviewee, still a large problem in the 3DP industry. There is a lack of standards linking different 3DP methods and applications together which complicates upscale usage of the technology amongst companies and industries. New programs and software needs to be developed in order to support new actors that lack experience in the field. Another problem mentioned by the interviewee is the lack of incentives for taking an additional cost derived from more expensive production, using 3DP. Disputes can occur between the involved parties regarding the possible higher cost for production. In some cases, it is hard to find common incentives which might hinder increased usage of the technology.

Moreover, it is also important to build relationships between different industries. The interviewee mentions one example where a company within the metal powder industry works closely with the Swedish 3DP machinery manufacturer Company A, in order to jointly develop the technology further. Furthermore, the interviewee states that an interesting collaboration could be between the Swedish pulp and paper industry and the construction industry since both industries, to some extent, handles similar raw materials. Something that could drive 3DP usage in the construction industry is a collaborative initiative between these two industries where both parties have something to gain from the collaboration.

5.2 Empirical findings from NCC

This section is created in order to paint the picture of a construction industry example. It is created around a number of interviews held with people with good insight into relevant business areas at NCC. It aims at illustrating the potential for 3DP implementation by mapping how NCC is working with their suppliers. A concept where this way of working is facilitated is construction partnering, which is a concept where NCC is at the forefront. Therefore, NCC's supplier relationships and partnering concept will be studied with the aim to illustrate a context where supplier collaborations and introduction of innovations has proven to be successful. Moreover, this way the following citation is fulfilled "The aim is to illuminate the general by looking at the particular" (Denscombe, 2003, pp.53), in order to be able to draw generalizable conclusions.

5.2.1 Supplier relationships at NCC

As earlier mentioned in the theoretical framework a construction company, such as NCC, is heavily dependent on its suppliers. The majority of gross work done in a typical construction project is performed by suppliers and subcontractors which requires a good relationship between NCC and its suppliers. According to one interviewee at NCC, NCC strives to only use contractual suppliers and not different suppliers for every unique construction project, in order to create deeper and closer relationships with its suppliers. It is desired that purchasers should only use suppliers which can be found in their internal agreement database since these suppliers are 'quality' verified and meets what is required from NCC. A supplier ends up in the supplier base if it meets both technical aspects and more 'soft' aspects e.g. the supplier should be environmentally sustainable. This is done to make sure that the suppliers follow NCC's codes of conduct. According to one interviewee, NCC strives to only have between 2-5 suppliers per product, to choose from, in order to reduce the total number of suppliers used. However, traditionally in the construction industry, most construction companies procure on the basis of best price. Procuring on the best price and at the same time evaluate each suppliers in how well they meet NCC's requirements is a tedious process. Therefore, if possible, purchasers at NCC should always strive to purchase from suppliers who are in the supplier database. When choosing suppliers from the database, purchases does not need to consider non-technical aspects and can focus more on price, quality and delivery time instead, according to the interviewee. Members in the database are suppliers who NCC seeks to have a long term relationship with and where both parties can develop together towards common goals.

One short example of a successful close relationship is between NCC and a window supplier. The underlying issue to the cooperation concerns incorrect deliveries. If a pallet of windows is shipped to the wrong site, it does not only delay one construction site, it will also affect another construction site in a negative way by confusing or hindering that particular site. According to the interviewee, NCC has developed, together with the supplier, a better and more precise material flow by adding barcodes to the windows. The supplier attaches small barcodes on each window, containing exact information about where the window should be placed. When the windows arrives to the construction site, the site manager scans the codes and knows thereby exactly on which floor and in which room the window should be placed. This has resulted in a much more smooth flow since the windows are placed in the exact right place in the right time. This can be seen upon as a successful close collaboration between a buyer and supplier where both parties, together have developed a successful solution.

One thing that characterizes the construction industry, according to the interviewee, is the lack of repetition. Due to the lack of repetition it is difficult for innovations to get a foothold in the industry. It is argued that most people in a construction project differ from project to project. This hampers innovative learning, since even though an innovation is successful in one project, and would most likely be successful in another; it is rare that such innovations are reused. This is something that NCC is aware of and tries to work more with repetition where the majority of human resources are reused between different projects. Using the same suppliers and subcontractors to a greater extent is argued to facilitate survival and transfer of innovations. One example where an innovative solution has survived and transferred is the case with facades with pre-mounted windows. Pre-mounting windows require more activities of the supplier but require fewer activities at the construction site. In this case, the supplier considered the required investments as economical viable and NCC could justify the higher price by highlighting the fact that the building process became smoother when not mounting the windows afterwards.

Nevertheless, it is argued that different supplier have different incentives for making required investments. Most likely, larger supplier may consider a large investment as advantageous since economic gains can be achieved in several relationships compared with smaller supplier which might just have one or a few relationships according to the interviewee. Furthermore, the interviewee mentions that it is important to re-focus and not just look at the local expense account. By improving the relationship between the buyer and supplier, the quality of the final product can be higher and in the long run even the total costs might be lower. The interviewee mentions an illustrative example with, the visualization technologies BIM and VDC as two very interesting technologies. The initial investments for these are high but this cost is repaid multiple times since the technologies can significantly simplify the construction process.

According to the interviewee, NCC differentiates its purchases dependent on product segments and when in the construction process the purchase takes place. Furthermore, NCC bases its purchases on the maturity level of the specific market, available suppliers and how familiar NCC is with the particular product purchased. However, the never-ending endeavor for purchasers is to minimize costs. The interviewee mentions that NCC has all kinds of different purchasing situations ranging from office supplies to strategic products. However, it is argued that it is NCC's overall goal to have a closer approach to its suppliers, especially in the case of strategic products. These products are often titled strategic or 'heavy' products since they have a significant effect on the progression of a project and it is desired to have close collaboration with suppliers of these products in order to get the products on right time. NCC strives to get an understanding of the cost structure of its suppliers and the goal is to, in collaboration with its suppliers, reduce these costs as much as possible.

According to an interviewee there has been a change in the perception of the industry. Some years ago, a construction company was only seen upon as a producer of buildings and infrastructure compared with today where construction companies are much more customer oriented. The interviewee mentions that approximately 80% of a construction company's expenses can be derived from purchases. Earlier, the construction companies only focused on getting as low price as possible from its suppliers. Today the situation is different where construction companies are more focused on generating as high value for the customer as possible. This comprises closer collaboration with suppliers where more strategic and prolonged relations can take place. The interviewee argues that NCC pursues the key-competence of the suppliers by removing agents and intermediaries. By doing so, a closer relationship can be achieved with a higher degree of trust and understanding for each other. It is beneficial for both parties to create a closer collaboration according to the interviewee. By involving the supplier early in a project, a solution can be developed jointly and a higher customer satisfaction can be gained in the end.

One interviewee mentions one short example where NCC have developed a close relationship and collaboration with their supplier of work wear. The clothes are tested and evaluated in real situations by NCC workers and the collaboration resulted in an economically favorable situation for both parties. The supplier gets input from NCC and can continue to evaluate and develop the clothes based on the data i.e. they do not need to spend resources themselves on testing and evaluation. The incentive for the supplier is that they can promote the new clothes to the market, based on the fact that the clothes are tested by real construction workers in the field. This can be seen as a successful collaboration where both involved parties gains something valuable from the relationship. Another benefit that can be derived from a closer relationship is the facilitation of repetition, according to the interviewee. NCC strives to cut of its ‘tail’ in order to ease up for reuse of suppliers. If it is possible to use the same suppliers for different projects, complaints and aftermarkets are much easier to handle according to the interviewee.

When one of the interviewees was asked to reflect upon 3DP in the construction industry and possible areas of use for the technology, the interviewee mentioned concrete molds as one possible area. It is argued that customers want customized products and by producing concrete molds with 3DP, any geometry of concrete can be created. However, the interviewee said that this is a hypothetical thought but argued that it would be beneficial if this was possible to do, instead of the traditional way with carpenters, who carve up the molds today. It is believed that this area of use is not unlikely if the technology continues to evolve.

5.2.2 NCC Partnering

Partnering is a concept that NCC has developed and refined together with customers during several years. Partnering holds three different fundamental key factors that gives involved parties the opportunity to engage and contribute with their respective expertise. These are, common goals, common organization and common economics, the cornerstones of NCC partnering is illustrated in Figure 5.3. The involved key stakeholders work jointly towards the common goals set, regardless company affiliation, the involved parties contribute with expertise towards the project’s best. The partnering concept has reached large success within NCC partly due to the fundamentals in NCC’s business culture, influenced by the corporate values of honesty, respect, trust and pioneering spirit. The partnering concept is influenced by close collaborations with both customers and suppliers and is characterized by early involvement and frequent meetings.

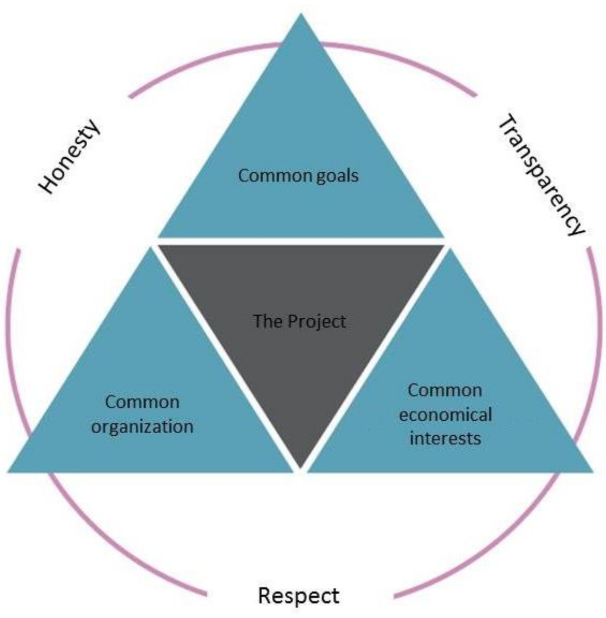

Figure 5.3 - The cornerstones of partnering at NCC, Adopted from NCC (2015b)

There are a lot of gains that can be achieved by using the partnering concept. Through early stakeholder involvement different competences can be introduced early in the projects which save both time and money. By letting all the participants be involved from the beginning and jointly form the goals and processes of the project, the clients' expectation can easily be met. This results in higher quality, a safer project and better overall project environment. Moreover, the partnering concept of NCC also stretches over time and over construction project boundaries, called strategic partnering. This extension of regular partnering facilitates a longer perspective where the same project team develops and executes projects over time which results in an optimization of the project organization's learning curve. Partnering does however demand investments from involved parties and the individual economic gain for each involved participant can be leveled out in order to generate economic gain for the project as a whole.

According to one interviewee at NCC, the general perception is that partnering is only collaboration between NCC and the client of the project, which earlier was the truth. However, the concept has developed a lot and today the concept also contains a collaborative approach to suppliers as well. NCC is currently observing the potential for supplier collaboration initiatives and is working with methods to further incorporate this strategy into the partnering concept. Furthermore, the interviewee mentions that one of the goals with a partnering strategy is that innovations that can increase project performance shall get the opportunity to be discovered and implemented by having open communication with key suppliers of the project. There is however a quite substantial resistance, from the construction industry, against these new ways of working. Processes and ways of working that have been developed and used for hundreds of years is hard to change and the benefits needs to stand out for itself in order for the community to accept them. Nevertheless, there is a paradigm shift in the industry today where companies are forced to find new ways to refine operations as a result of increased competition and lowered margins.

In October 2013 a strategic partnering project started between a municipality in southern Sweden and NCC. The construction goal was to build five buildings divided in five different projects using the same partnering declaration. Apart from the client, eight external strategic suppliers were included in the partnering declaration. The way that the suppliers were chosen for this project was completely through interviews and questionnaires based on 'soft-values' in a rigorous process. The interviewee emphasized the importance of choosing partners that really understand and are mature for the partnering layup and will contribute to the best for the project. According to the interviewee, suppliers that perform well will most likely be chosen again for further projects which create good incentives for the suppliers to engage in the partnering concept. Moreover, NCC sees the opportunity to create longer relationships of collaborative nature with suppliers involved in strategic partnership projects. The interviewee mentions that one problem that the construction industry is struggling with is how to transfer knowledge and innovations between projects. By using the same suppliers for several projects in for example partnering layups, this problem can be reduced. This is, according to the interviewee one of the great benefits with partnering in general and strategic partnering in specific.

When the interviewee gets the opportunity to freely reflect upon in which context that 3DP can be successfully implemented, a partnering project in mentioned due to the fact that the relationships in such layup are heavily built on trust and transparency between involved parties. Moreover, to further specify the context, the interviewee mentions that it would be advantageous if the product or application is of standardized nature. In those cases, the processes and parties, involved to produce the product, are known and a platform for a discussion about implementing an innovative and quite advanced technology is already established.

6 ANALYSIS

The purpose of this master thesis is to investigate the potentials of 3DP in the construction industry. Moreover, the purpose is also to invigorate the 3DP technology by demonstrating its possible positive effects on construction supply chain related issues. The analysis of this thesis is going to be based on two separate supply chain related areas, Figure 6.1. Firstly, the analysis will aim at the interplay between successful 3DP implementation and supplier relationships. Hence, this dimension of the analysis will answer upon RQ1 and RQ2 and can be found in chapter 6.1, 6.2 and 6.3. Secondly, the analysis will focus on how 3DP can improve critical construction supply chain characteristics in order to increase construction performance. This dimension will therefore answer upon RQ3 and can be found in chapter 6.4. Consequently, the analysis of the two dimensions will fulfill the purpose of this thesis.

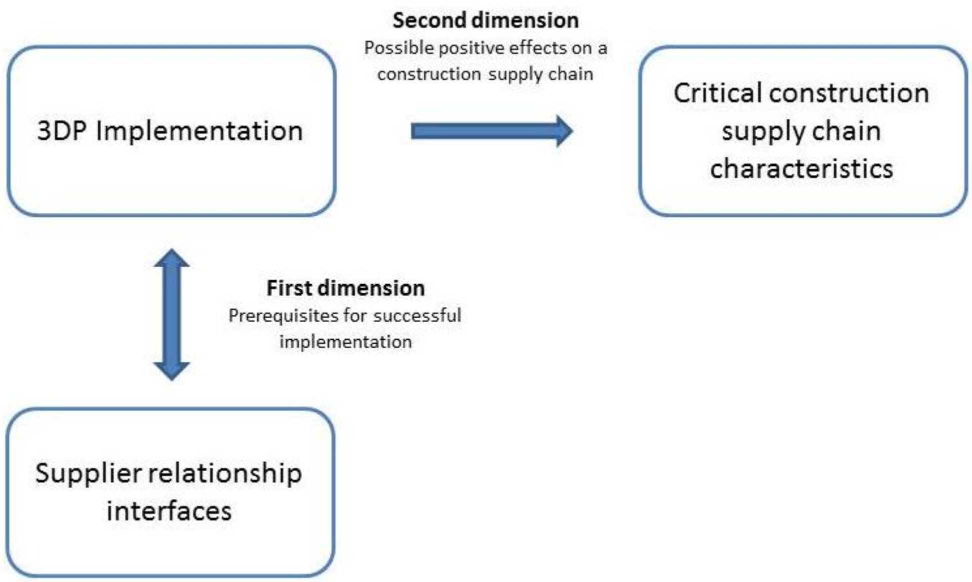

Figure 6.1 – The two dimensions of the analysis

6.1 Characteristics necessary for successful 3DP implementation in the construction industry

The first step of the analysis was to determine the most significant 3DP characteristics suitable for this context. The characteristics are defined as characteristics necessary for successful 3DP implementation i.e. the chance for a successful implementation is heavily dependent on these characteristics. Nevertheless, it needs to be highlighted that the intention was not to find all factors influencing a successful implementation rather the ones related to the purpose of this thesis. The characteristics found are summarized in the following list and will be further elaborated around in detail:

- Importance of having a collaborative approach (Collaboration)
- Incentives are needed for investing in the 3D-Printing (Incentives)
- Lack of standards in 3D-Printing technology (Standards)
- Low maturity level of the 3D-Printing technology in the construction industry (Maturity)

6.1.1 Importance of having a collaborative approach

The most significant characteristic found in both literature and the empirical illustration is the importance of having a collaborative approach to all parties involved in a potential 3DP initiative. A collaborative approach holds many different perspectives and is not a predefined expression. However, the authors have categorized similar statements, pointing at the collaborative direction, into the same category, even though the different sources do not state the exact same thing. Hence, these statements or findings can, to some extension, be derived from and connected to the characteristic 'collaboration'.

As can be read in the theoretical framework, Mellor et al., (2014) mention five different categories of factors influencing implementation possibilities for additive manufacturing, the most relevant for this thesis is 'supply chain factors'. Mellor et al., (2014) argue that major changes aiming at restructuring supplier relationships is necessary. Supplier relationships should be developed to a more long-term and collaborative nature and studies have shown that an implementation process is more successful when the focal company has support from the AM equipment vendors. Furthermore, Mellor et al., (2014) states that the level of complexity of the technology is close connected to the level of vendor support needed.

Another relevant finding described in the theoretical framework is from chapter 3.5, Innovation and technical development. Innovation is argued to have a hard time getting a foothold in the construction industry. Blayse and Manley (2004) identified six different factors that influence innovation in the construction industry and one factor, particularly interesting for this thesis, is 'industry relationships'. Blayse and Manley (2004) argue that due to the one-off characteristics of a construction project, transfer of innovation is rare in the construction industry. To overcome this barrier, much more tight couplings between actors and firms need to be established. We share Blayse and Manley's (2004) opinion that tighter couplings would enhance the possibility to transfer innovations from one project to another and thus also create a higher potential for 3DP to succeed in the construction industry.

Collaboration is also mentioned as one key-factor for a successful implementation of 3DP in the empirical illustration. In chapter 5.1, 'Different industrial perspectives on 3DP', all the different interviewees mention collaboration as one cornerstone for 3DP to be successful. The interviewee representing Company A, mentions that 3DP is not a Press-and-Play operation and requires daily communication between the buyer and the vendor. Today it is the specialists who possess the deepest knowledge and understanding for the technology and therefore it is important to establish a close collaboration with these in order to seize this knowledge. It can be argued that this would be the obvious answer from a company with commercial interests in 3DP machinery. Nevertheless, it seems relevant and important to consider since the argumentation is supported by actors with less economic interests such as Company B and University A. It is expressed by the representative from Company B that joint learning and development can be a key factor for successful usage of 3DP. Company B has also created a forum for 3DP where companies can try the technology and get support from specialists in the field. This type forum is one way of connecting different stakeholder with different backgrounds, interesting in the technology and supports the fact the implementing 3DP is not a 'one man show'.

The need for collaboration in the construction industry becomes even more reinforced when considering the fact that there seems to be no supplier of 3DP machinery, specially configured for construction industry applications, operating commercially today. It is believed that development of such machinery cannot be performed by the construction companies themselves and it is absolutely necessary to create a network of stakeholders in order to develop and find the perfect application for 3DP in the construction industry. Joint development of materials, suitable for the construction industry, is also of high importance. The representative from University A mentions that one possible underlying factor for 3DP not getting a foothold in the industry can be the lack of development of new materials. The construction industry is conservative and there is a jargon that you should only use the same materials that have always been used. This is believed to hinder the advent of the technology; therefore a collaboration where new materials are developed is necessary.

The need for collaboration is found in both the theoretical framework as well as the empirical illustration which points to its importance. All actors asked in the empirical illustration, that has insight into the 3DP industry, mention collaboration as important for 3DP implementation. Therefore, collaboration between suppliers in a 3DP initiative is assessed as one very important issue to reflect upon when considering 3DP. The suppliers could be both existing suppliers that will be affected by 3DP implementation, and suppliers of 3DP related services e.g. machinery equipment supplier, material supplier, 3DP consultancy services.

6.1.2 Incentives for investing in the 3D-Printing

Incentives are mentioned several times in the empirical illustration as an important driver for implementation of investment heavy technologies like 3DP. In general, dual incentives need to exist in order for companies to engage in initiatives that requires large resource investments. The parties involved need to be sure that there is an individual gain that can be generated from the initiative.

The interview with Company A revealed input that point at the importance of mutual incentives when engaging in 3DP manufacturing. The interviewee mentions that, when Company A from time to time engages in developing new applications together with their customers, their own learning process is fostered. Apart from pure commercial incentives, the fostered learning process in an important incentive that Company A can apply elsewhere in their operations. Moreover, the representative from Company A argues that, in order to see the economic gain from using 3DP as manufacturing technology, one need to take a holistic perspective. Economic gains will most probably not be found in direct connection to the production, rather elsewhere in the chain. This argumentation highlights the fact that clear incentives exists but are not maybe recognized by the customers. It is therefore important for the focal company to show them, in order for the customer to accept possible increased product prices. In conclusion, the input from Company A highlight that it is important to create and show the incentives both upstream and downstream the supply chain. This argumentation is supported by the representative from Company B who also highlights the fact that it is important to look at 3DP usage with a holistic view. This strengthen the argumentation that it is important to be able to show the economic gains for the customers in order to motivate a possible higher product price and create an incentive for investment.

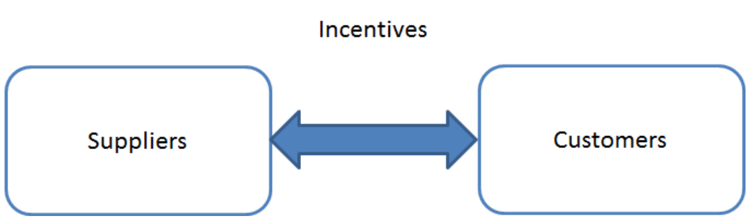

Figure 6.2 - Incentives to both to suppliers and customers

The interview with the University A also revealed interesting input in the area of incentives. The interviewee argues that one large problem that hampers 3DP implementation and usage is the lack of incentives for taking additional cost for production e.g. investments in new machinery equipment. According to previous argumentations incentives do exists but there is a perception that companies, engaging in 3DP initiatives, need to highlight the incentives for involved parties in a better way.

Argumentations pointing at incentives as an important driver for 3DP development are also to be found in literature. We believe that 3DP is to be looked upon as an innovative technology. According to Blayse and Manley (2004) incentives have an important role when trying to implement innovations in the construction industry. The authors point at the fact that, due to the one-off nature of the industry, clear incentives are hard to identify amongst involved actors. Moreover, our opinion is that many construction firms do not have incentives enough to create large research programs on their own. Hence, joint developing initiatives are a necessity for successful innovation implementation. Håkansson and Ingemansson (2012) supports this approach by stating that it is important in the construction industry that all involved actors sees potential benefits, for innovations to get a foothold. Furthermore, D'Aveni (2015) writes about the importance of redesign the product offerings in accordance to the 3DP potential, so that incentives are created for customers to pay a higher price for 3DP products that can generate higher value. The author also highlight the importance of having a broad scope and consider the total manufacturing costs in order to see the 3DP benefits and create incentives for the customers.

In summary, incentives are important in order for 3DP implementation and utilization to be successful. Incentives must be created and shown to the customer side of the company in order for the customers to accept higher product prices. Moreover, incentives must be created towards the supplying side in order to foster joint development and investment required for implementing the technology and finding the right applications.

6.1.3 Standards in 3D-Printing technology

Since 3DP is a quite new technology and it is still in its cradle, the lack of standardized ways of using 3DP can be seen upon as one distinct characteristic that influences the degree of utilization of the technology. As mentioned in the theoretical framework, Mellor et al., (2014) identified 'operational factors' as one important factor that affects the implementation of additive manufacturing. Companies who are interested in implementing 3DP into their business are forced to develop and use new designing tools and practices since there are no standardized ways of working with this technology. However, Mellor et al., (2014) mention that more standardized ways of working are on their way but research in this area is limited. It is therefore believed that in order for the technology to get a foothold in the construction industry, the technology needs to be developed further. This is also supported by D'Aveni (2015) who argues that in order for the technology to become a mainstream manufacturing method, new digital platforms need to be established in order to facilitate integration across designers, makers and movers of goods. D'Aveni (2015) further states that these digital platforms are needed in order to orchestrate printer operations, quality control, real-time optimization of printer networks and capacity exchanges. Consequently, we believe that there needs to be an international standard, regarding the working process of the technology, to facilitate its advent into the construction industry and to secure product quality. These standards should be developed jointly by the construction firms together with the expertise in the field of 3DP.

The need for development of digital platforms and software is also supported in the empirical study where the representative from the University A states that there is a lack of standards linking different 3DP methods and applications together. This complicates the up scaled usage of the technology amongst companies and industries according to the interviewee. It is believed as essential to develop and make both software and interface more user-friendly. This can facilitate for new actors that lack experience in the field, to enter the field of 3DP. Some actors do not dare to try the technology since it is believed to be too technologically complex today.

As can be seen in this section there is a need for further development of the technology, supported by both the theoretical framework as well as the findings in the empirical study. The technology needs to reach a higher degree of standardization before it can get its real breakthrough and especially for the construction industry. There is an obvious lack of customized platforms and software for the construction industry.

6.1.4 Maturity of the 3D-Printing technology in the construction industry

As mentioned previously, 3DP is still a new manufacturing technology. There exist parts and products that are printed and used for commercial purposes. However, a lot is still to be developed in order for the technology to get its real mainstream breakthrough. In the context of the construction industry, the maturity level is particularly low. There are examples of successful initiatives around the world but most of these are in a conceptual stage. 3DP maturity level is a clear factor that influences the possibility for successful implementation in the construction industry today. The empirical study of this thesis points at the maturity level as still quite low for the particular context. The interviewee at the Mid Swedish University clearly states that the research in the area of 3DP has received too little attention in Sweden in general. Moreover, the interviewee claims that the knowledge and competence of 3DP is too low, amongst the whole manufacturing industry, which inhibits the spread of the technology. This argumentation corresponds particularly well with the situation in the construction industry.

Furthermore, according to the interviewee at Company B, there are none, or at least very few, available 3DP machinery manufacturers that can provide equipment specially developed to meet the demands of the construction industry. In addition, Company B is taking initiatives to increase the awareness of 3DP in general which also indicate that increased knowledge and competence are needed. Company A argues that the machinery equipment suppliers are the ones that, so far, possess the vast majority of the knowledge in the field, making them the torchbearers of the industry. This fact highlights the importance of having a collaborative approach to the suppliers as well as pointing at that the maturity level of the industry is still on the rise, not least in Sweden.

The four factors will further be referred to as, Collaboration, Incentives, Standards and Maturity and can be seen in Figure 6.3.

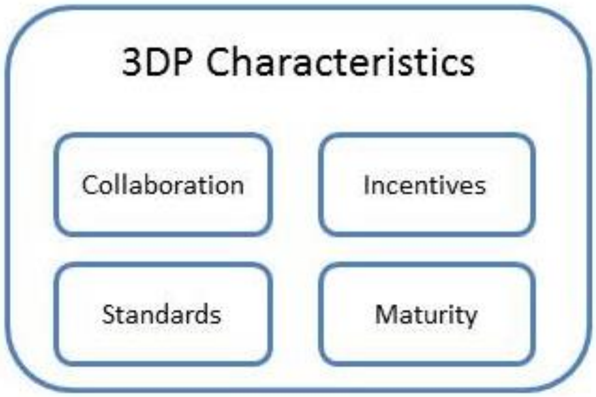

Figure 6.3 – 3DP Characteristics necessary for successful implementation in the construction industry

6.2 3DP and NCC Partnering

The next step in the analysis was to analyze how well NCC Partnering is consistent with the 3DP characteristics necessary for successful implementation. This was done in order to highlight how well suited the partnering way of working is for an implementation of the technology. This section follows the same logic and order as the previous and the concept partnering is elaborated around in detail with the four different characteristics. There is a clear connection between the partnering concept and the characteristics ‘Collaboration’ and ‘Incentives’. However, ‘Standards’ and ‘Maturity’ is assessed to have weaker connections to the partnering concept. Nevertheless, all four characteristics are discussed in following sections, focusing on the ones with the strongest connection. The input to this analysis is based upon the findings captured in chapter 5.

6.2.1 Collaboration

As mentioned earlier in this section, collaboration is of high importance in order for 3DP to become successful. As can be read in chapter 5, NCC is striving to only use contractual suppliers and not different suppliers for every unique construction project. This is done in order to achieve a deeper and closer relationship with their supplier which is in line with what was described in the previous section as a necessity for a successful 3DP implementation.

Purchasers at NCC should as far as possible only use suppliers from their internal database since these suppliers are ‘quality’ checked and are suppliers who NCC seeks to have a long term relationship with. It is also stated that NCC’s overall goal is to have a closer approach to its suppliers. This further enlightens NCC’s strive towards creating more close and collaborative relationships with its suppliers.

Moreover, construction companies of today are more focused on creating as high value for its customers as possible. One of the interviewees mentioned that when moving away from just focusing on getting as low price as possible, which was the case back in the days, construction companies can instead focus on more strategic and prolonged relationships. As one interviewee mentions, NCC pursues key-competence, capturing the suppliers’ expertise in respective field by removing agents and intermediaries, hence moving closer to its suppliers. By doing so a higher degree of trust and understanding can be achieved which could facilitate the possibilities for implementing 3DP.

When investigating the empirical findings it becomes obvious that NCC is striving towards a more close collaboration with a reduced number of suppliers. This is looked upon as consistent with the partnering concept, which facilitates collaboration and can generate increased value for the customer. The interviewee that worked strategically with partnering mentioned that the partnering concept should enhance innovations with great potential and create a forum for discussion regarding implementation of new technologies. Hence, implementation of an innovative technology such as 3DP could very well fit in this context.

Moreover, the partnering concept consists of three conceptual cornerstones, common goals, common organization and common economic interest. It is obvious that, in order for the all of the cornerstones to be fulfilled, high collaboration within the partnering declaration is a necessity. Consequently, there is a strong connection between the cornerstones of partnering and stakeholder collaboration, which was the most prominent of the 3DP characteristics found in previous analysis. All these three cornerstones are believed as facilitators for 3DP implementation since they are in line with the analysis of 3DP characteristics and especially the characteristic ‘collaboration’. Also, the partnering declaration is built upon honesty, transparency and respect which is believed a necessity in order for an implementation of 3DP to be successful.

6.2.2 Incentives

As mentioned in previous chapter, dual incentives play a vital role for the implementation and investment into 3DP technology. It is mentioned earlier in this thesis that it can be hard to motivate investments into the technology if the perspective on 3DP is too narrow. It is essential to have a more holistic perspective when investigating the possible benefits that can be gained with 3DP. Mentioned in chapter 5, it is important to re-focus and not just look at the local expense account. Therefore it is believed that partnering is consistent with the characteristic ‘incentives’ since partnering is all about sharing of goals, organizations and economic interests. In a perfect partnering declaration, no one should take advantage of another part and the question of who should bear the costs does not even exist. The involved parties share the same economic interests and therefore it is a joint decision about if an investment should take place or not. Due to the transparent characteristics of a partnering declaration, creation and visualization of incentives for investing in e.g. 3DP technology, is enhanced. Hence, in a partnering declaration the individual risk for taking on investments are reduced. This does not create an incentive by itself; however, it reduces the risk and facilitates implementation.

Furthermore, 3DP requires investments from all parties involved. The partnering concept is built upon a repetitive approach where NCC strives to use the same supplier for many different projects. This creates an incentive for suppliers, involved, to invest in the relationship in order to be attractive for reuse. Furthermore, another incentive related to this issue is the fact that the costs for an initial investment can be spread out over many different projects. Hence, it becomes easier for a supplier to defend required investments since such investment can bury fruits when used for more than just one project. Consequently, it seems safe to say that partnering is well harmonized with the characteristic ‘incentives’.

Clients in the construction industry of today are most likely becoming more and more environmental aware. In a partnering declaration the clients have a large impact on the project and consequently large impact on its environmental footprint. A strong initiative for using 3DP is that factors are pointing at 3DP as a sustainable manufacturing method for the future. Hence, the clients can put pressure on the construction firms to start using more sustainable manufacturing methods and solutions, creating incentives for investments into 3DP. This reasoning recurs in the theoretical framework, chapter 3.4.2.

6.2.3 Standards

There seems to be no direct connection between the absence of standards in the 3DP industry and how NCC works with construction partnering. In order to be able to upscale the usage of 3DP, common standards are believed to be necessary. Initiatives taken in the direction of finding a common way to connect different functions within 3DP manufacturing, e.g. design, production, logistics, is the next step in 3DP development. The standards need to consist of both software, linking different 3DP methods together, as well as standards regarding 3DP business processes. An establishment of an environment where highly skilled people, from different industrial backgrounds, can work jointly towards the above mentioned goal could contribute to an acceleration of the process. Such environment could be a partnering declaration specially designed for the purpose of developing a construction industry specific standard for 3DP production processes.

6.2.4 Maturity

There are several similarities between the categories maturity and standards and in the same way there seems to be no clear connection between the maturity of 3DP and how NCC works with construction partnering. As mentioned in chapter 6.1.4 the technology is still quite unexplored as manufacturing method, especially in the construction industry. There are some initiatives taken but most of these are still on a conceptual level. However, this is pointing at the fact that there is an interest in the construction industry about the technology and it is believed that the technology will get its breakthrough in the construction industry when the maturity level has increased. As for the standards, a partnering declaration aimed at solving this issue could be one way to make the technology more mature in the construction industry.

6.3 Supplier interfaces in NCC Partnering

One of the fundamentals of NCC partnering is to create more long-term supplier relationships in order to achieve increased project performance and deliver more customer value. There are different ways of categorizing supplier and buyer relationships. One way is to focus on the level of involvement that exists in the interface between the buyer and the supplier, i.e. to what extent the supplier and buyer are aware of each other’s context. As previously mentioned in the theoretical framework, Araujo et al (1999), defines the level of interaction in terms of four different interfaces between a customer and its suppliers. The following section will elaborate on these four interfaces and their suitability for 3DP implementation. The analysis is done in order to be able to draw more general conclusions regarding 3DP implementations.

6.3.1 Translation and Interactive interfaces

Translation interfaces have a more collaborative approach compared to standardized and specified interfaces but is, however, not to compare with an interactive interface. However, a translational interface has the potential of becoming an interactive interface if required resources are allocated.

The interviews at NCC regarding the partnering concept have revealed input that points at the concept as an advantageous platform for 3DP implementation. According to the interviewees, the relationships to the suppliers used in a partnering project are of collaborative nature. One of the interviewees states that a partnering project holds more collaborative relationships with a long-term nature, than a regular construction project. The supplier interface that is characterized by these types of relationships is the interactive interface. Hence, one can say that a partnering project, most likely, comprises a majority of interactive interfaces. In an interactive interface the supplier and buyer jointly develop products that are optimized for the sake of all actors in the relationship. Moreover, it lies in the definition of such interface that there should be a joint discussion about product trade-offs in relation to the resources of the involved parties.

6.3.2 Standardized and Specified interfaces

As can be read in the theoretical framework the standardized and specified interfaces are characterized by arm's-length relationships where price is the main coordination device. The supplier strives towards standardization and economies-of-scale, while the buyer focuses on getting as much value as possible out of the transaction. According to the literature regarding 3DP and the empirical illustration of this thesis, the main reasons for using 3DP as manufacturing method, are amongst other things, full customization and economies-of-one. This is in total contradiction to what characterizes the standardized and specified interfaces; it is therefore obvious that these types of interfaces are not well suited for 3DP today. The suppliers that falls into these categories of interfaces are most likely not willing to change manufacturing methods. It can be assumed that these suppliers lack incentives for changing their operations since their products are of more standardized nature and its associated operations are optimized towards mass production and reduction of production costs.

6.3.3 Potential for implementation of 3DP

Hence, NCC Partnering is a suitable environment for 3DP implementation. Moreover, the relationships in NCC Partnering can be classified as interactive. Consequently, there is a connection between NCC partnering, interactive interfaces and at least two of the characteristics for 3DP implementation, illustrated in Figure 6.4. The figure contains three areas that together create a basis for the first dimension of the analysis, hence answering upon RQ1 and RQ2.

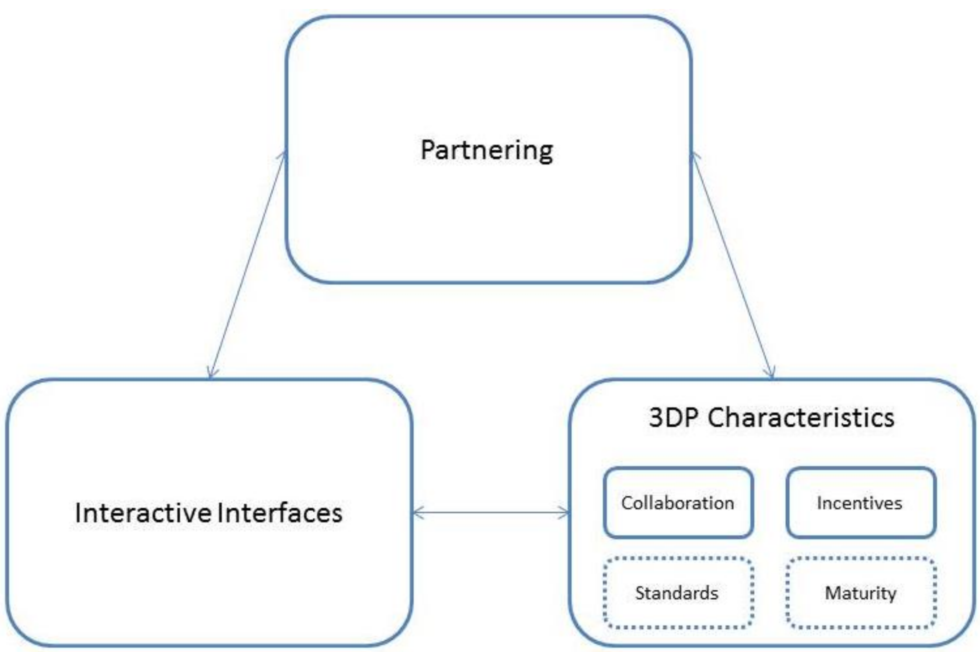

Figure 6.4 – Areas that together creates a basis for implementation of 3DP

6.4 Advantages with 3DP in the construction industry

The second dimension comprises the interplay between 3DP and the critical construction supply chain characteristics (CCSCC), found in literature. In order to be able to discuss possible positive effects and answer upon RQ3 an analysis was done, comparing the benefits with the CCSCC. The comparison was done with the goal of finding matches between the 3DP characteristics and the CCSCC. The matches are based upon a qualitative analysis where we assessed the possible matches out from previous observations. The comparison can be seen in table 6.1.

Table 6.1 – Connections between 3DP advantages and critical construction supply chain characteristics

	Characteristics	Insufficient attention on production planning	Innsufficient attention concerning off-site activities including material delivery	Overcompensation of material	High tied-up capital	Troubled on-site material handling	Optimistic scheduling	Need for more long-term relationships	Need for subcontractor resource availability analysis
3DP advantages									
No tooling is needed		0	0	0	1	0	0	0	0
Reduced production ramp up time		1	1	0	0	0	1	0	0
Facilitates small production batches		0	0	0	1	1	0	0	0
Possiblitity to quickly change design		0	0	1	1	0	0	0	0
Allows product to be optimized for function		0	0	1	1	1	0	0	0
Possibility to reduce waste		0	0	1	1	0	0	0	0
High potential for simpler supply chains		1	1	1	1	1	1	1	1
Shorter lead times		1	1	1	1	0	1	0	0
Reduced inventories		1	1	1	1	1	1	0	0
Design customization		0	0	1	1	0	0	0	0
Good visualization tool		1	1	0	0	0	1	0	0
Possibility for early design changes		1	0	0	1	0	1	0	0
Cost and time reduction		0	0	0	1	0	0	0	0
Lighter products		0	0	0	0	1	0	0	0
Reduced material usage		0	0	1	1	0	0	0	0
SUM		6	5	8	12	5	6	1	1

Several of the benefits are similar and were therefore merged together, resulting in a reduction from 22 to 15 3DP advantages. Moreover, as can be seen in the matrix the two categories 'Need for more long-term relationships' and 'Need for subcontractor resource availability analysis' have gotten very few matches. This is not because of their respective irrelevance but rather that the 3DP advantages are of a much more concrete nature which makes a connection hard to see. However, these categories are as important as the others, but are more of organizational nature, regarding how a construction supply chain should be constructed, and discussed elsewhere in this thesis. The categories with the highest aggregated matches will be further discussed.

6.4.1 3DP effects on CCSCC

In order to better understand the underlying reason for the matches done in the previous section; this section will consist of discussions regarding the different matches and its significance for enhanced critical construction supply chain characteristics.

The category that got the most matches was 'High tied-up capital'. High tied-up capital in the construction industry can be derived from various sources, O'Brien et al., (2008) does however emphasizes that it is a common problem. By looking at the 3DP benefits one can see that many of them can contribute to decreased tied-up capital. The fact that there is no tooling needed, that lead-times are shortened and that the material waste are minimized, as examples, contribute to lower inventories and thereby lower tied-up capital. Moreover, the fact that 3DP can facilitate total product customization and possibility to early design changes, could ultimately lead to a need for decreased purchased material and parts, hence decreased tied-up capital.

Moreover, due to the fear of project delays it is not unusual that there is a presence of overcompensation of material. Since a construction project is sequenced, where different activities need to be performed in the right sequence, it is important to have material ready when it is needed. Therefore, managers do not order the precise amount of material but rather they compensate and order more than needed, if something happens with the delivery. To further complicate the situation, materials are often ordered world-wide which results in long lead-times leading to that the managers cannot afford to reorder and wait for a new delivery if incorrect deliveries occur. As can be seen in the matrix, 3DP benefits are matched several times with 'overcompensation of material'; it is believed that 3DP can be used in order to overcome this issue. 3DP can be used in the construction industry in order to shorten the lead-times which can result in a decrease of overcompensation of material since products and materials can be reordered and delivered almost immediately if there are any incorrect deliveries.

Since a construction project is heavily dependent on getting the right products in the right time and sequence, there is often time buffers built-in in the process. However, these time buffers are often not considered when scheduling and therefore the scheduling becomes incorrect and often of an optimistic nature. The reason for the non-match between the scheduling and the actual time needed is due to the presence of delays. These delays can be derived from off-site manufacturing and late delivery of materials. However, it is believed that the characteristics of 3DP can be used in order to enhance this issue. Since 3DP can be used in order to produce products directly on site, it removes the risk of uncertainties and delays since the products are produced on demand directly on site. Still, there can be delays of material to the 3DP but it is believed that by using 3DP, and thereby reducing a number of intermediaries, the risk of delays will decrease. This means that the schedules for a project can be more correct and non-optimistic since it is easier to foresee and calculate the possible delays if the products are produced in-house. The same logic applies to the insufficient on-site production planning. O'Brien et al. (2008) argues that poor on-site performance in the construction industry is often caused by lack of appropriate planning activities. Several of the 3DP benefits can be derived to simplified production planning with shorter lead-times and simplified supply chains as the most prominent. Finally, a construction site holds many complex logistical problem areas which contribute to troubled material flows. Several of the 3DP benefits contribute to a less complex construction site, especially through small batch sizes and reduced inventories.

7 CONCLUDING DISCUSSION

The purpose of this master thesis was to investigate the potentials of 3DP in the construction industry. Moreover, the purpose was also to invigorate the 3DP technology by demonstrating its possible positive effects on construction supply chain related issues. The analysis of the thesis gives input that fully or to a satisfying extent answers the pre formulated research questions in chapter 1.3.

The construction industry is suffering from inefficiencies regarding the construction supply chain. The construction supply chain is a complex matter, characterized by difficulties both related to planning activities and logistical aspects. A list of characteristics that contribute to the special character of the construction supply chain, formulated by researchers in the field, and summarized by the authors of this thesis is presented as follows:

- Insufficient attention on production planning
- Insufficient attention concerning off-site activities including material delivery
- Overcompensation of material
- High tied-up capital
- Troubled on-site materials handling
- Optimistic scheduling
- Need for more long-term relationships
- Need for subcontractor resource availability analysis

From our analysis, there is a match between several of the construction supply chain characteristics and the benefits of using 3DP. A lot of the benefits of 3DP, especially in other industries, are related to optimization of product functionality. However, we have, by doing the above mentioned comparison, found several benefits related to construction supply chain improvements. This fact emphasizes, that 3DP not only contributes to better product functionality, but also to increased performance related to other important business areas.

Furthermore, the construction industry is perceived as a conservative industry with inertia to adopt new innovative technologies which can be derived from the characteristics of a construction project. Transfer of knowledge and innovative solutions is hindered due to the one-off nature of a construction project. A short-term, project based perspective can lead to sub optimizations, hence, innovative solutions and technologies have a hard time getting foothold in the construction industry.

3DP is an innovative technology and encounters the previously mentioned construction industry related problems. This might be one reason why the technology has gotten less attention in the construction industry compared to other industries. However, initiatives are taken, where use of the same suppliers and subcontractors for several projects, has facilitated the transferability of innovations from one project to another. Such initiatives are looked upon as a catalyst for an innovative technology such as 3DP to get a foothold in the industry. This study shows that NCC strives towards moving closer to its suppliers and sees the potential with collaborative relationships, which the partnering concept is a clear example of. The partnering concept seems to enhance transfer and implementation of innovations, such as 3DP, and is assessed as a forum where stakeholders can move closer to each other. It is our opinion that it is in such contexts, similar to the partnering concept, where 3DP can be successfully implemented. Therefore the authors' opinion is that NCC is headed in the right direction regarding collaboration.

The argumentation above is based upon findings in the analysis of this thesis. The authors have identified four factors that are believed to be crucial for the development of 3DP in the construction industry. The factors are identified through analysis of the empirical study consisting of interviews with both NCC internal professionals but also with experts, with different backgrounds, in the field of 3DP. The four factors are;

- Importance of having a collaborative approach (Collaboration)
- Incentives for investing in the 3D-Printing technology (Incentives)
- Standards in 3D-Printing technology (Standards)
- Maturity of the 3D-Printing technology in the construction industry (Maturity)

The purpose of this thesis was not to give NCC concrete recommendations on how to proceed in its commitments to upscale the usage of 3DP in its operations. However, as the result of the thesis was compiled, several interesting findings, were found, pointing at what next steps NCC could take in order to move closer to an implementation. In order for the 3DP initiative to take off, it is our opinion that a lot of initial attention needs to be directed towards finding suitable partners for a joint development project. It can be looked upon as a partnering project with the sole purpose of trying to develop a 3DP application for the construction industry, consisting of partners and suppliers that possess excellence in the field of both construction and 3DP. In a later phase, NCC needs to identify an appropriate pilot product that is suitable for 3DP. This should be done in order to be able to measure and benchmark the technology against more conventional technologies and thereby highlight the gains that can be achieved. By 3D printing a real product, NCC can also make calculations on saving/costs that can occur in the value chain and it can also reveal what complications NCC can encounter if 3DP is used. This way, a more quantitative analysis, regarding the effects that 3DP might have on a construction supply chain, can be performed.

Other thoughts that have crossed our minds during this period is regarding how implementing such innovative technology as 3DP can foster innovativeness and strengthen NCC's brand image generally. We believe that, in order for NCC to fulfill its endeavor of being leading in renewing the construction industry with sustainable solutions, the company should embrace 3DP. Not only for its potential for increased construction efficiency and quality, but also for the purpose of reinforcement of NCC brand image and innovative position in the industry. The NCC employees that we have met during our time at the company showed go-ahead spirit and curiosity for new technology in general and 3DP in specific. We believe that, the general innovative spirit at NCC could benefit from an implementation of 3DP. Moreover, it could strengthen the brand image by showing initiatives aiming at renewal of today's construction methods to all stakeholders on the market.

The aim of this thesis has been on the relationships to the supplying side of a construction firm, and their contribution to the development of 3DP. For further studies, it would be interesting to investigate the downstream side of the focal firm as well i.e. customer relationships and customer involvement. By doing so, knowledge and input from the customers can be seized, helping the focal company to develop product offerings based on the 3DP technology in order to create the incentives needed for up scaled 3DP usage.

In conclusion, we see two main approaches for the construction industry in general and NCC in specific to take in order to move closer to an implementation of 3DP. A construction company, interested in 3DP technology, can take a passive approach waiting for the technology to develop.

According to the authors, the technology is not yet developed to a satisfying degree for the construction industry. There are clear gaps in relation to both the development of machinery equipment, designed for construction purposes, and standards, connecting the 3DP technology with internal processes. Hence, waiting for a higher maturity level is motivated.

Or, a proactive approach can be taken where the company contributes to the development of the 3DP technology. In such case, the environment suitable for such initiative should be characterized by high collaboration between upstream and downstream actors in the value chain, hence in interactive interfaces. It is important that the initiative is done together with actors possessing excellence in the 3DP field and together with these develop the technology further and identify possible construction applications. It is our opinion that a lot is still to be developed regarding the technology and that the time horizon for the real breakthrough in the construction industry is still relatively far away. Hence, we believe that there is still a lot of time to create as good prerequisites as possible in order to be prepared.

Moreover, this study highlights that NCC have, through the partnering concept, created an environment characterized by factors that facilitates 3DP implementation. Thus, we recommend that NCC undertakes a proactive approach in order to follow the vision of renewing the construction industry by offering the most qualitative sustainable solutions.

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