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School of Electrical Engineering
Master's Programme in Computer, Communication and Information Sciences

Jarkko Aaltonen

Digitalizing and Industrializing Construction Process – A Case Study

Master's thesis

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Supervisor: D.Sc Jan Holmström
Thesis Advisor: M.Sc. Otto Alhava

AALTO-YLIOPISTO
TEKNIIKAN KORKEAKOULUT
PL 12100, 00076 Aalto
http://www.aalto.fi

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Työn ohjaaja(t): DI Otto Alhava

Tämä tutkimus esittelee yleisen kuvauksen teollistumisesta ja digitalisoinnista rakennusalalla ja putkiremonttisektorilla, sekä viitekehyksen organisaation teollisen maturiteetin mittaamiseen.

Teollistuminen rakennusalalla pyrkii tekemään tuotannosta tehokkaampaa luomalla toistettavia työsuoritteita tuotantolaitoksissa, suunnittelutoimistoissa ja rakennustyömaalla aktiviteetteja koordinoimalla. Teollistumisen ytimessä on työmaan aktiviteettien uudelleensijoittaminen erikoistuneisiin tuotantolaitoksiin (esivalmistus) ja digitaalisiin yksikköihin (suunnittelu).

Tämän tutkmuksen kaksi pääasiallista teoreettista kontribuutiota ovat i) uusi viitekehys teollisen maturiteetin mittaamiseen rakennusalalla ja putkiremonttisektorilla, sekä ii) yksityiskohtainen kuvaus tapaustutkimuksen yrityksen nykyisestä teollisen maturiteetin tasosta. Teollisen maturiteetin viitekehys määrittelee organisaation teollisen maturiteetin nykytilan kuudella eri tuotannon osa-alueella. Näillä kontribuutioilla on myös johtoryhmän relevanssia, sillä niiden hyödyntäminen mahdollistaa digitalisaation avulla korkeampaan teollistumiseen tähtäävän muutosprosessin arvioimisen ja suunnittelemisen.

Tutkimuksen empiirinen näyttö osoittaa, että nykyinen teollistumista koskeva kirjallisuus on saattanut painottaa liiaksi teollistumista yleisen tason konseptina ja ei ole huomioinut teollisen maturiteetin mittaamiseen käytettävän viitekehyksen arvoa organisaation teollistumisen mittaamiseen. Tutkimuksessa rakennetun viitekehyksen avulla organisaatiot rakennusalalla pystyvät lähestymään teollistumista strategisemmin ja osoittamaan kehityskohteita saavuttaakseen korkeamman teollistumisen tason.

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AALTO UNIVERSITY
SCHOOLS OF TECHNOLOGY
PO Box 12100, FI-00076 AALTO
http://www.aalto.fi

ABSTRACT OF THE MASTER'S THESIS

Author: Jarkko Aaltonen

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Supervisor: D.Sc Jan Holmström

Instructor(s): M.Sc Otto Alhava

This thesis presents an overall description of industrialization and digitalization in construction industry and pipe repair sector and a framework to assess organization's industrial maturity.

Industrialization in construction industry strives to make production effective by repeating work processes in factories, design offices and at building sites by the coordination of different activities. In the core of industrialization is the relocation of activities from on-site to specialized off-site factories (e.g. pre-assembly) and to remote digital units (e.g. designing).

The two theoretical contributions of this study are i) the new framework for industrial maturity measurement in construction industry and pipe repair sector and ii) the detailed description of case company's current industrial maturity. The industrial maturity framework defines organization's current industrial maturity in six different process categories related to production. These contributions also have managerial relevance as they can be utilized to evaluate and plan a transformative process towards higher industrialization with digitalization as an enabler.

The empirical evidence of this study proposes that the existing literature on industrialization might focus too strongly on industrialization as a concept and has not considered the potential of a framework to assess the level of industrialization. By having a framework to assess the current status, organizations can approach industrialization in a more strategic manner, focusing to enhance the weakest areas in the organization.

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Contents

1 Introduction

This chapter presents the background and motivation for the research, it's problem statement, research design and target audience.

1.1 Background and motivation for the research

Construction industry and pipe repair sector have been characterized for a long time as fields with severe problems. The industry has been lacking in it's approach to reach industrialized practices while other industries such as automobile industry have reaped the benefits of modern and industrialized manufacturing methods. The most notable deficiencies in the construction industry are low productivity, poor safety, inferior working conditions and insufficient quality to name a few (Koskela, 1993).

Industrialization is not a new concept in the construction industry as principles such as on -and off-site production, standardization, pre-assembly and modularization have been established for a long period of time (Gibb, 2001). However, in order to truly industrialize construction industry, a product-, and ultimately customer-oriented approach is required. Emphasis has to be shifted towards development of a more sophisticated pre-planning and design practices to reach higher industrial maturity. (Girmscheid, 2005)

Construction industry, in regards to other manufacturing industries, has limitations due to the requirement to produce location-dependent physical artefacts. Production in the industry has been defined by project-based approaches, on-site labor and ad-hoc execution. The industry in itself therefore has complexities, which have made applying substantial industrialized approaches more difficult. (Koskela, 1992) One of the main aspects in industrializing the construction industry, is the evolution from ad-hoc and project-based approaches to product and product-service offerings. Relocation of on-site execution to off-site production and the increment of pre-design and design, enables organizations to convert towards product and product-service offerings. (Ballard & Howell, 1998)

Digitalization has a major role in industrialization. Industrializing an outdated industry's practices is enabled by modern technology. The adoption of digital technologies in everyday life has a remarkable influence on the manner in which goods and products are consumed. Products are increasingly examined and compared on the Internet via mobile services and digitalized means. (Lehdonvirta, 2012) In addition to bringing consumers closer to organizations via digitalized means, digitalization also enables innovations in product design. Digital design encompasses the product's full life cycle and emphasizes the pre-design of products and thus decreases the variabilities in manufacturing. (Zhou, 2013)

As a starting point for an organization to evolve it's current practices regarding industrialization, knowledge of industrialization as a concept and it's paradigms are essential. In this thesis, the literature review captures the main aspects of industrialization and showcases the methods, which have potential to enable industrialization in construction industry. Knowledge of industrialization as a concept, allows organizations in a traditional construction industry to have a base from which to apply suitable approaches which have already been successfully utilized in other industries.

As knowledge is gathered, organizations have to comprehend the knowledge and establish a current state in which the organization is located regarding it's practices. In order to enable industrialized and digitalized methods, a measurement framework has to be constructed to identify the current state. Current literature regarding construction industry, and especially pipe repair sector, is completely lacking in a framework to measure the state of industrialization for an organization.

In this thesis, such a framework is established specifically for pipe repair sector by applying a measurement concept named maturity model. Maturity models are highly useful methods in determining the state in which the organization is currently at. Maturity models were traditionally constructed for software development and for organizations in ICT industry (Mettler & Rohner, 2009). However, maturity models have since gained exposure also in applications for other industries. Maturity models are also beneficial in identifying the gap between the actual state in which the organization is at, and the intended state to which the organization is striving for. The maturity model constructed in this thesis identifies stages for organizational evolution in specific domains, and showcases required actions, with exemplifications, which the organization has to apply in order to reach higher industrial maturity.

1.2 Problem statement and research questions

The described background drives the goal of the thesis as developing new knowledge and comprehension to industrialize and digitalize traditional construction industry and pipe repair sector. Industrialization (e.g. mass production) and industrial paradigms (e.g. lean manufacturing) have been proven to be applicable, profitable and productive concepts in multiple different industries (Womack et al., 1990). Construction industry has been lacking in the development in comparison to other industries, due to industry's cultural constraints and complexities (Koskela, 1992). Pipe repairs have attributes which create even more complexities in comparison to e.g. traditional building construction, due to the requirement to minimize any inconveniences for the residents of an estate during repair projects (Sivonen, 2011).

Production practices in pipe repair have not reached defined industrialized methods, which would enable a well-functioning production system to deliver pipe renovations for customers in a cost-efficient and timely manner with minimal invasion. The industry is competitive in regards to producing customers pipe renovations in a swift and less invasive manner, as customers have become more demanding due to getting accustomed to other industries' industrialized and digitalized services. (Luomala, 2017) The current digitalized methods allow industrialized practices to take place, and enable great possibilities for organizations willing to take the leap towards higher industrial maturity. Higher industrial maturity enables higher customer satisfaction and delivery of products and product-services with higher margins.

This thesis is constructed based on three research questions presented below. The basic problem for the development of industrialized pipe repair is the lack of description of industrialization as a concept in construction industry, which leads to the following research question:

Q1: What is industrialization and what are the characteristics and consequences of industrialized construction and pipe repair?

Development towards industrialized pipe repair requires a framework to define the current state of industrialization the organization is at. The lack of such a framework for measuring the maturity of the organization's industrial practices in pipe repair industry is a related issue to the conceptual problem, which leads to the following research question:

Q2: What are the most important aspects in pipe repair in order to measure the industrial maturity of the current practices?

This thesis applies a method of a qualitative single-case study. In order to understand the case company's industrialized maturity and opportunities for further development, current state of industrialization in the case company has to be assessed. Assessment is conducted by applying the maturity model constructed in this thesis, which leads to the following research question:

Q3: What is the current industrial maturity of pipe repair in the case company?

1.3 Research design

This thesis emphasizes the review of current literature regarding industrialization in construction and pipe renovation industries in order to create a comprehensive industrial measurement framework. Literature review is conducted by defining the concept of industrialization in general, conceptualizing attributes of industrialization in construction industry and examining digitalization as an enabler for higher industrial maturity. In addition, this thesis also adopts elements of a qualitative single-case study as a research method.

The focus of the study is in constructing a framework for industrial maturity measurement for the case company context. By applying the industrial maturity framework, the case company maturity is examined and identified. The case company was chosen as it was considered to be highly suitable for the research setting. The case company is a medium sized organization, which operates in Finnish construction industry including business sectors such as pipe repair, house-building and building construction. The case company has been described as a modern construction company, which strives to push boundaries by establishing digitalized and modern methods in a non-modern and traditional industry. Case company has also gained exposure in mainstream media for introducing a swift and less invasive pipe repair business concept named, which is the focal point of this thesis.

Current literature on industrialization in pipe repair sector is minimal and a measurement method to define the maturity of the industrialization for the sector is non-existent. The lack of research on the subject enables an opportunity for this thesis to introduce new insights into organizations in this traditional business sector. In addition, this thesis may have a profound impact on the case company and especially on the production methods practiced in the case company.

1.4 Target audience

This thesis is written as an academic assignment for the degree of Master of Science. The research contributing to industrialization and digitalization of construction industry and pipe repair sector is considered an applied science. The purpose is therefore to contribute to the development of the field in academic and industry environments. This thesis is written especially for the case company, but also for researchers and people related to the case company which are interested in developing construction industry and pipe repair sector. Hopefully the substance presented in this thesis can provide direct impact on the development of the industry, and inspiration and encouragement for further research on the subject.

2 Methodology

This chapter describes the case company's relevance for the research and the methodological decisions made and used in the research project based on a methodological frame of reference.

2.1 The case company and relevance for the research

The case company for this single-case study is a Finnish company in construction industry. The case company is founded in 2002 and the company's original focus was on concrete construction until 2009. Since then, the case company has transitioned towards other construction sectors such as pipe repair, house-building and building construction. The case company has grown rapidly in 2010s. In 2009 the case company's revenue was €15M, and six years later in 2015 it's revenue reached €135M and it employed over 200 personnel.

The case company is an interesting and well-suited case for this study regarding industrialization and digitalization in construction industry due to it's modern approach. The case company has established itself as a company in construction sector which emphasizes the importance of digitalization. The case company has conducted plenty of research to offer higher value to customers by applying service business principles in it's construction projects.

This thesis focuses especially on the case company's subdivision and it's business concept, which operates in property pipe repairs and pipe renovations. Case company stands out in contrast to traditional pipe repair concepts. The main features in the case company are less invasive on-site operations due to higher levels of pre-planning and much shorter evacuee time for property residents during the pipe renovations. In traditional pipe renovations, the evacuee time is estimated to be approximately 12 weeks. In the case company's process, the evacuee time has been decreased to as low as 2 weeks. The first case company's 2 week pipe renovation was successfully performed in November 2017.

Due to the case company's groundbreaking approach to offer customers less invasive pipe repairs, it is an interesting research topic regarding opportunities further industrialization and digitalization can offer. Construction industry and pipe repair sector has not evolved in the same pace as other manufacturing industries, which allows the case company to be a forerunner in offering swift and less invasive pipe renovations by applying industrial principles in it's production practices.

2.2 Research approach

This thesis conducts a single-case study focusing on qualitative analysis. According to Yin (2009), case studies are especially suitable for further comprehension in individual settings. The case company's business and context are unique in comparison to other manufacturing industries. Therefore a single case study is applicable for the use in this research context, as industrialization manifests itself in different fashions in differing industries. In order to produce comprehensive theories, multiple studies focusing on the same phenomenon under different conditions have to be performed. Single-case studies are the essential to expand and generalize theories (Yin, 2009).

In addition to the previously mentioned case-study approach, Groop et al. (2017) present a five-step methodological approach in knowledge creation through engagement and design. In this thesis this problem framing and solution development process is applied in the manner which supports the research's scope. Step 1 in the methodological approach is the framing of the wicked problem by distinguishing the most important undesirable effects in the construction industry. Step 2 considers the framed undesirable effects in relation to each other by performing semi-structured interviews and conference sessions to describe the relations between each undesirable effect. Step 3 considers the problem solving, and how the understanding gained from the undesirable effects can be constructed into a Current Reality Tree. Step 4 interventions the design propositions to address the core problems from additional perspectives. Finally step 5 evaluates and observes the outcomes and intended and unintended effects of the proposed design.

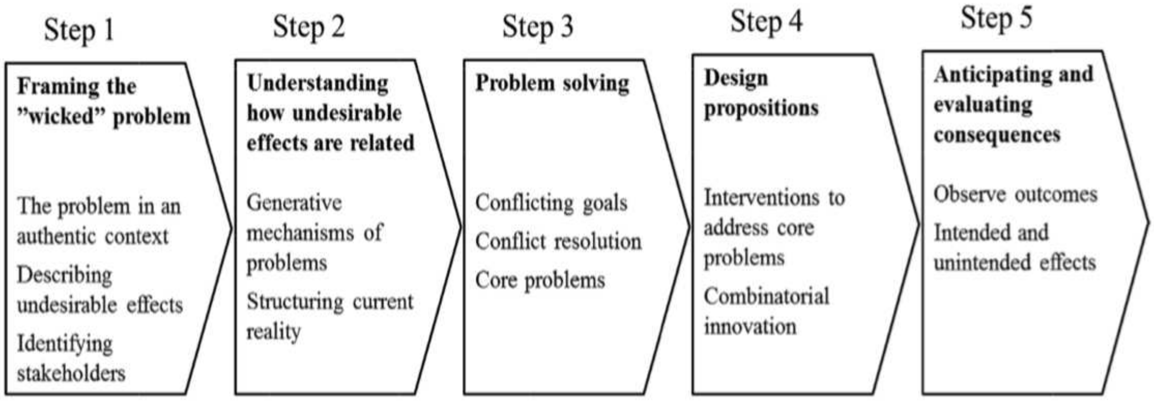

Figure 1: Process of problem framing and solution development (Groop et al., 2017)

This thesis examines steps 1 and 2 by performing a comprehensive literature review to illustrate the core problem and the undesirable effects related to the core problem by distinguishing main aspects regarding industrialization in construction industry and pipe repair sector. Step 3 is applied for this thesis' purpose as the creation of the maturity model, which showcases a comprehensive overview of the current state in the organization's industrial maturity. Step 4 addresses the evaluation of the constructed design and includes interventions from the case company in order to enhance the proposed design. As the constructed design, maturity model, is applied in the case company context, step 5 is considered to observe the outcomes the proposed maturity model delivers.

As the initial establishment of a maturity model based on a comprehensive literature review to identify industrial maturity in several domains is the main purpose of the research, limitations are apparent and should be accepted in this thesis' scope. As presented by Lahrmann et al. (2011), further research and development of maturity model should be embraced after the initial establishment to iterate the model for the purposes of the organization.

2.3 Data collection

The aim of this study is to describe the concept of industrialization, introduce digitalization as a method to reach higher levels of industrial maturity, develop an industrial maturity model and to measure the state of industrial maturity in the case company. Hence, it is important to conduct the study in close relation to the case company.

Data collection was performed in two phases. In the first phase, namely pre-data phase, video conference calls and virtual workshops were conducted in which multiple case company executive personnel participated and gave feedback on the research and the maturity model development and evaluated the initial maturity model design. In addition, participants in pre-data sessions offered potential interviewees within the case organization to conduct further interviews. In the second phase of data collection, namely main data phase, case company personnel were interviewed to verify the maturity concept's sufficiency and to assess the level of industrialization in the case company.

Data collection for main data consisted of semi-structured interviews, in which each process category of the maturity model is evaluated in the context of the case company with a person related to the specific category in the case company. As presented by Yin (2009), interviews are a suitable method for focusing directly on case study topics and offer insight in the case context. The interviews were guided conversations in which the aim was to focus on specific process category in order to measure the maturity of the case company's industrialization in a comprehensive and process category-specific manner.

The main data consists of five approximately 60 minute discussions. Table 1 showcases the participants, their positions, motivation and date and duration for conducted interviews in pre-data and main data phases.

Table 1: Summary of research data collection

Participant	Position	Data phase	Motivation	Date	Duration
H1	Executive	Pre-data	Case company motivation	21.3.2018	0:58
H2	Executive	Pre-data	Establish the research	10.4.2018	1:00
H3	Executive	Pre-data	Define the research	4.5.2018	0:55
H4	Executive	Pre-data	Research status	8.6.2018	0:50
H5	Executive	Pre-data	Evaluation of initial framework design	9.8.2018	1:05
H6	Director, Project development and planning guidance	Main data	Concept verification & Maturity analysis	20.8.2018	0:55
H7	Development coordinator	Main data	Concept verification & Maturity analysis	20.8.2018	1:15
H8	Quality engineer	Main data	Concept verification & Maturity analysis	21.8.2018	0:45
H9	Site supervisor	Main data	Concept verification & Maturity analysis	22.8.2018	1:00
H10	Site technician	Main data	Concept verification & Maturity analysis	24.8.2018	0:55

The process for conducting pre-data discussions was initiated by the case company CTO. Afterwards the responsibility for setting up each conference call shifted to the case company CDO and the researcher. Each session consisted of 4-8 people including the case company personnel and two professors related to the research project. In addition to previously mentioned, the sessions also included the case company business partner's CBO. The business partner provides strategic and development services for the case company as a collaborator since 2017.

The interview process for main data was performed in a short time-frame. Each participant was contacted via telephone or email to set up an agreeable date for the interview session. Each participant received the developed maturity framework and short introduction to the research prior to the interview. All the interview sessions took place via videoconference or in the case company headquarters in Vantaa.

Each interview session consisted of questions related to the specific process-category at hand. All the interviews were in Finnish language and all the questions for interviewees were constructed to support the iteration of maturity framework and the assessment of the case organization's industrial maturity as presented in chapter 6.

2.4 Data analysis

According to Dubois and Gadde (2002), the aim of the data analysis process is to develop further understanding through a systematic process combining theoretical knowledge and case-specific insights. Theoretical knowledge is represented in answering the first research question regarding industrialization by reviewing existing literature. The first research question therefore works as a basis for the data analysis process. Theoretical knowledge supports the second research question related to the development of case-specific industrial maturity measurement model. The third research question applies the gathered knowledge and assesse the case organization's industrial maturity.

As presented by Eisenhardt (1989), data analysis for a case study focusing on qualitative analysis is an iterative process. The most notable remarks in pre-data phase discussions were written down by the researcher and further analyzed after each session. Conference call for session five was also recorded with the permission of the participants in order to further analyze all the responses afterwards. All the conducted interviews in main data phase were recorded with the permission of the participants in order to further analyze the responses afterwards.

By conducting the pre-data phase, the second research question was further established to support the first research question and findings in the literature review. After analyzing the pre-data sessions, especially session five, researcher identified the most notable responses regarding the maturity model evaluation of design and further modified the maturity model content to support the case context.

In main data phase, the researcher conducted the maturity analysis for each process category. Analysis for maturity was performed by fitting the responses gathered in each interview session in relation to the pre-defined indicators for maturity measurement. After analyzing the interviews, researcher identified the most notable responses regarding the theme of the interview topic. The third research question was answered concerning the industrial maturity of the case company.

In addition to the presented maturity model and analysis performed by applying the maturity model, most notable and suitable quotations regarding maturity model evaluation of design and industrial maturity measurement are documented in this thesis. These quotations showcase observations and remarks related to the research of industrialization in the case-specific context.

3 Literature review

This chapter describes the literature review for the research and the attributes regarding industrialization and digitalization.

3.1 Industrialization

Industrialization is defined as the process of converting to a socioeconomic order in which industry is dominant. Through industrialization, the mechanical components were obtained in production and entrepreneurship began to obtain a larger role. (The Editors of Encyclopaedia Britannica) One of the traditional industrialization's main features was the use of 'craft producing', which required highly skilled workers and simplistic tools to produce end-products one at a time (Womack et al., 1990). Craft production however had massive drawbacks such as requirements for high workforce skill level, low production volume and a non-scalable business model which required concentration in a single city.

The definition differs quite a lot if we look at it from a more modern point of view. The modern industrialization can be thought to have started by Henry Ford and Ford's model T automobile. Automobile industry is one of the trend-setters for the modern industrialization and can be viewed as one of the main drivers for evolvement of industrialization as we know it today. One of the main features in automobile industry, started by Ford's model T, is the introduction of mass production in manufacturing. Mass production allows a standardized and a simpler manufacturing process which requires lower skill level from workforce to produce outputs. (Womack et al., 1990) Womack et al., (1990) state, that the end result from a mass production is a cheaper product for a consumer, but without the customization varieties which traditional craft producing would enable.

As we look more in-depth into the main features of modern industrialization, principles such as standardization, interchangeability, repetition and modularization are apparent. Standardization is defined as the development and application of standards that permit large production runs of component parts that can be readily fitted to other parts without adjustment. Standardization allows clear communication between suppliers, relatively low cost and manufacturing on the basis of interchangeable parts (The Editors of Encyclopaedia Britannica). The main advantage in standardization is not the repetition of the work, but rather the clear flow of the work in which work passes on free of errors (Johnson & Bröms, 2000). Encyclopaedia Britannica defines interchangeability and interchangeable parts as identical components, that can be substituted one for another. This allows production of large numbers of identical parts with lower costs.

Standardization and interchangeability introduced another important principle for industrial production, modularization. Modularization is a principle of design that divides a mechanical system or structure into standardized elements, modules, which can be interchanged. Modularization is based on common interfaces between interchangeable modules, which enables manufacturing of different versions of any machine or structure with relative ease and at low cost. (Johnson & Bröms, 2000)

Product modularization enables a step-by-step development and automation of the assembly system. Reduced lead-times, reduced amount of work in progress, reduced number of vendors and improved assembly ergonomics are some of the main advantages modularization enables. Modular design is also an excellent base strategy for continuous product renewal and development of the production system. (Erixon, 1998) Scania, a manufacturer of heavy trucks, is one of the innovators in applying modular design system in truck manufacturing. Practical example of Scania's modular design system is that any engine will fit on any truck's chassis. The customization for customers is still however possible, by having divided each module into smaller sub-modules. This approach allow small changes to be made in the sub-modules, without disturbing the modular design principle and therefore additional configurations based on the customer requirements. Scania famously has had highest margins on revenue and more stable profitability for a longer period than any other truck maker in the world. (Johnson & Bröms, 2000)

3.2 Industrialization of construction industry

Even though this thesis' focus is on industrializing production and manufacturing regarding pipe renovation and pipe repair, scientific literature on industrialization in pipe repair field is currently quite narrow. This chapter will combine literature from construction industry including sub-fields such as industrialized house-building in addition to pipe repair to gather a more comprehensive view of the industry. In general, construction field has plenty of common procedures which are applicable also to production and manufacturing in pipe repairs (Sivonen, 2011).

Regarding construction industry, the definition for industrialization should be revisited and defined in a more suitable manner. Industrialization in construction industry is described as a streamlined process promoting efficiency and economic profit (Bjornfot & Stehn, 2004). According to Koskela (2003), the definition is presented as following;

"Industrialization can be seen as a structural means for eliminating, or at least drastically reducing, on-site activities in construction."

According to Eccles (1981), 'Construction' is presented as following;

"The erection, maintenance, and repair of immobile structures, the demolition of existing structures, and land development."

During the 1940s, building and construction industry experienced a rise in demand as apartment building increased in many countries in Europe. During the 1950s the building industry started to swift towards a more automated and technologically developed industry from the first industrialization concept, craft production. (Lessing, 2006) Building industry obtained multiple industrialization principles in the 1960s which were most notably mass production, standardization, limited variation of production and coordination of people (CIB, 1965).

According to Lessing (2006), industrialized building was defined in the 1965 with the following presentation;

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

The main feature in industrialized building was the use of specialized off-site factories for building parts production instead of manufacturing parts on building site. By having specialized factories for manufacturing and standardized and prefabricated part production, the industry gained much more cost-efficiency in production. (Lessing, 2006)

In 2000s, industrialization has been established as the go-to solution in the construction industry whenever current practices have become insufficient. Industrialization principles in the construction industry, such as applying on- and off-site production technologies, standardized products and elements and modules, are however not by themselves enough because of the industry's fundamental structural deficits (Girmscheid, 2005).

Girmscheid (2005) states, that the success of industrialization in construction industry is not only dependent on the production-related measures, but rather a combination of product-oriented and customer-oriented approach in which all the production and planning processes are in place.

3.2.1 Industrial paradigms

Based on the literature regarding industrialization in construction industry and pipe repair sector, previous attempts to industrialize the industry have been focusing mostly on the aspect of replacing manual labor workforce with machinery and the automation of recurring processes. Industrialization however includes a multitude of other processes which need to be intact beyond this simplistic view, in order to reach an actual industrialized concept. Industrialization of production can be achieved by applying process-oriented work preparation and production cycles, and by optimizing machinery and plant for both on-site and off-site production (Girmscheid, 2005).

Lean Approach

According to Lessing (2006), lean paradigm is applied in Japan's industrialized house building industry by applying modular unit housing production systems which combine aspects of customization and standardization to achieve competitive pricing. The main factors contributing to this approach are that design and production processes are implemented in a highly efficient manner. Construction industry has for a long time had attributes of lean production such as JIT's (Just-In-Time) elimination of waiting and wasted time and TQM's (Total Quality Management) elimination of defects and errors in production, without a systematic process or philosophy incorporated. The Lean Production philosophy however has much more to offer when it is implemented as the production philosophy rather than only as features.

The core of the lean production philosophy is the categorization of two aspects in production systems, which are conversions and flows (Bjornfot & Stehn, 2004). Conversion activities refer to information and material which add value to the production while flows such as inspection, waiting and moving are non-value adding activities and should be minimized. The main difference in lean production to conventional production is the approach of categorizing activities in such a manner, that non-value adding activities can be reduced or diminished and efficiency of production is increased by increasing the amount of value adding activities through continuous improvement and new technology. (Freire & Alarcón, 2002).

In construction, the information conversion refers to design development or design process and material conversion associates with production process (Bjornfot & Stehn, 2004). In order to apply leanness to construction, processes should be streamlined in such a way that product requirements are applied in design, development and assembly (Koskela, 2003).

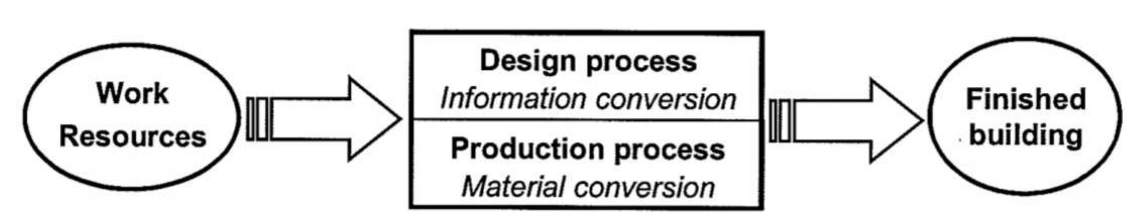

Figure 2: Lean approach manages conversions in construction (Bjornfot & Stehn, 2014)

According to Bertelsen and Koskela (2004), lean construction is divided into product strategy and process strategy. Product strategy refers to the approach which transitions as much activities to off-site manufacturing from construction site. Construction site transforms to a final assembly site. Process strategy on the other hand considers construction in a more traditional manner, in which large-scale products are built on-site, and off-site manufacturing supports on-site production. If this categorization is reflected regarding manufactured house-building or to pipe repairs, product strategy approach to reduce activities on-site is especially well fitting.

Six Sigma

The Six Sigma project-driven management's goal is to improve the organization's products, services and processes by reducing defects in the organization. Six Sigma has two viewpoints, which consider the organization from a statistical and a business viewpoint. From a statistical point of view, having a certain level of defects or by measuring the success rate of production are considered. Sigma as a term is used to represent the variation in the production process on average. The fundamental metric for Six Sigma is to measure the organization's level of sigma capability, and the improvement achieved by applying statistical tools and techniques. (Antony et al., 2003) From a business strategy standpoint, Six Sigma considers the improvement of business profitability and the effectiveness and efficiency all organization's operations have in meeting and exceeding customers' needs and expectations (Kwaka & Anbarib, 2004).

Pande et al. (2000) defines Six Sigma as;

"A comprehensive and flexible system for achieving, sustaining and maximizing business success. Six Sigma is uniquely driven by close understanding of customer needs, disciplined use of facts, data, and statistical analysis, and diligent attention to managing, improving, and reinventing business processes."

According to Pande et al. (2000), by enabling Six Sigma philosophy to management processes, the benefits include cost reduction, productivity improvement, market-share growth, customer retention, cycle-time reduction, defect reduction, cultural change and product/service development to name a few.

Agile Project Management

In construction industry, agile approach is often referred to as Agile Project Management (APM). In relation to agile production, APM enables in construction industry more than just the agility in customization of the products (Naim & Barlow, 2003). APM has a lot of potential to contribute especially to the pre-design and design phases. APM revolves around project planning, execution and methods of control and organizational learning (Owen et al., 2006).

According to Owen et al. (2006), APM considers each construction phase separately, namely pre-design, design and construction phase.

Pre-design phase

Pre-design phase includes three areas of consideration: concept development, planning covering procurement strategy and the preparation of a brief (Best & de Valence, 1999). Pre-design phase can be further categorized into the agile principles which support APM.

As opportunities and risks regarding the opportunities emerge constantly, **attitude to chaordic change** is characterized.

Management style and work group structure requires a non-hierarchical decision making and requires frequent mutual communication between workforce.

Customer involvement is essential as requirements are captured in the pre-design phase.

Nature of planning is not beneficial to be implemented as formal planning in the early phases of successful projects.

Development approach requires an iterative and incremental approach to include customer involvement.

Requirements capture includes stable requirements, volatile requirements and evolving requirements, all of which need to be categorized.

According to Owen et al. (2006), applying the prior principles ensures structured but flexible pre-design approach which seizes opportunities and encourages creativity.

Design phase

Design is the intermediate phase in which the pre-designed concept is transformed into specifications to guide construction operations and includes two main issues: the integration between design and production and dynamic process to capture requirements. (Kagioglou et al., 1998). Design phase can be further categorized into the agile principles which support APM.

Organizational attitudes and practices are essential as the design teams often change. Design process is highly interactive and design teams should have some characteristics which guide design process from project to project (Crawford and Benedetto, 2000; Kamara et al., 1997).

Design planning often includes a number of methods focused detailing the requirements in the beginning. Planning should however continue throughout the whole design phase (Howell et al., 1993).
Execution should be either sequential when product delivery is at the end, or iterative which results to frequent value delivery for clients depending on the project (Kamara et al., 1997).
Control and learning refers to the use of different metrics related to the construction design. The relations between different metrics is however not well understood and should have more cohesion.

Construction phase

According to Koch (2005), construction workforce is one of the most poorly prepared in terms of professional qualifications and has one of the lowest comparative salaries. Based on this premise, the cultural problem arises as APM philosophy requires that workforce is multi-skilled and teams are self-managing.
In addition, the construction industry traditionally is based on the use of sub-contractors and short-term casual workforce, creating another obstacle in implementing APM philosophy which requires strong loyalty and continuity from workers. (Howell & Koskela, 2000).

APM has some implications also in the construction phase, at least regarding planning on which managers can respond quickly. APM is however most suitable for planning in the production phase rather than on construction execution, because of the mentioned cultural limitations in the industry (Owen et al., 2006).

Supply Chain Management

Construction industry differs a lot from other industries because of the aspects construction requires such as one-of-a kind products, temporary project-based organizations and site production (Koskela, 1992). As the construction company managing the project contributes only 25 percent of the execution, and the rest 75 percent is up to suppliers and subcontractors, managing an efficient supply chain is vital for a successful organization. (Dubois & Gadde, 2000). According to Lessing (2006), by applying proven

SCM disciplines from automotive industry, the construction process can be much more efficient. SCM results in reduction of waste of materials, smoother process and reduced working time on-site as a product of better planning and efficient collaboration between partners through an improved information flow.

In order to reap the benefits of SCM principles in construction industry, supply of materials and components, supplier involvement and methods for storage of materials must be integrated early in the design phase. Vrijhoef and Koskela (2000) defined four roles in which SCM can contribute in construction industry;

Role 1: Nurture the relationship between the site and suppliers to ensure material and labor flow to the site, which reduces costs and duration of the on-site activities. Improve the interface between site activities and supply chain.
Role 2: Focus on the supply chain to reduce logistics, lead time and inventory -related costs.
Role 3: Transfer activities from on-site to earlier phases of supply chain to gain benefits of better working conditions which off-site production can offer. Improve the prefabrication and eliminate on-site activities (Warszaswki, 1990).
Role 4: Integrate on-site activities within the supply chain and deliver a higher degree of standardized products.

Regarding industrialization in construction industry, the third role is the most applicable and results to a change in the structure and behavior of the total process, especially as the amount of required design increases substantially. Industrialized efforts involving supply chain management in construction have often fallen short due to lack of a basic SCM. In order to reap the benefits of transferring activities from on-site, controlled design, fabrication and site processes involving non-value adding activities have to be carefully managed (Vrijhoef & Koskela, 2000).

3.2.2 Attributes of industrialization

Industrialization in construction industry has been revolving around the concepts of standardization and pre-assembly (S&P), in pursuit to improve the value of production activities and therefore increase efficiency in the industry. The approach has been based on a presumption, that by applying rigorous standardization and pre-assembly practices, the deficits of construction industry can be resolved by S&P-principles alone. (Gibb, 2001) These principles however are not often understood properly, and industrialization in the industry requires a solid understanding of S&P incorporated with other attributes of industrialization to establish a complete industrialized concept (Lessing, 2006).

Standardization and pre-assembly

The focus of standardization is the extensive use of components, methods and processes in areas where regularity, repetition and experience of previously successful procedures are proven. Standardization focuses not only on the components themselves, but rather on the interfaces between the components in order to ensure fit of interchangeability. (Gibb, 2001) Standardization in construction industry should be approached from the standpoint of continuous improvement as in any other industrial sectors. Standardization is closely connected to the concept of pre-assembly. Pre-assembly is related to the off-site production of parts which enable modularization at the construction site (Lessing, 2006).

On-Site and Off-Site Production

Construction revolves around the manual on-site work. On-site production is defined as the period from the start of the site phase to the completion of the build phase. On-site phase includes principles such as pre-construction activities, monitoring and management reporting and construction activities (Pan et al., 2012). Industrialization often refers in on-site and off-site production to the use of computer-controlled equipment and automation. Off-site production and pre-fabrication have automated product plants, but on-site construction is still mostly dominated by manual work with non-automated mechanized equipment. (Girmscheid, 2005)

Industrialization of production for on-site and off-site can be achieved by optimization of mechanical and automated machinery in the use of production. The challenge for on-site development and automation of activities is not as much the technological capability of automating on-site production, but rather the lack in industry processes and working environments which are not traditionally supportive of automated practices. Developments in automation are proven in multiple other industries such as in space and underwater technology. (Girmscheid, 2005)

Off-site production is the manufacturing and preassembly of building components, elements or modules in a specialized factory prior to the installation in the destination (Goodier & Gibb, 2007). Off-site production's main enabler has been standardization and the industry's requirement to develop standardized systematic building practices to meet the demand for new buildings (Groák, 1992). Benefits of increasing off-site production are numerous, as off-site prefabricated elements and modules would ideally only have to be assembled on the construction site with minimal workforce effort (Gibb, 2001). Some of the main benefits of off-site production are reductions in project time, defects, health and safety risks, environmental impact, and whole-life cost. Off-site production can ultimately lead to increases in production predictability, productivity, whole-life performance and profitability of the organization. (Pan et al., 2012)
Increasing pre-assembly and off-site production and manufacturing units before they are required on-site, also increases the confidence that the project would meet the predicted price and schedule (Construction Industry Research & Information Association, 2000)

Reducing non value-adding activities

It is estimated that approximately 33% of the workforce's time in traditional construction site is used for non value-adding activities such as searching and rearranging materials (Boemert & Bloemeke, 2003). According Girmscheid (2005), the efficiency of construction can be classified in seven different categories;

1) Increase of the efficiency of the production processes and methods
2) Reduction of working hours lost due to inclement weather
3) Reduction of weather-related fluctuations in performance
4) Increase of efficiency by clear work flow processes

5) Reduction of the time searching for material
6) Reduction of rearranging material
7) Reduction of loss of material

By applying these principles the non-value adding working time, or non-productive time, for workforce can be greatly reduced.

Information Flow

Project delivery in construction requires a coordinated, reliable and ongoing flow of information. Coordination involves multiple parties in the project with different information systems. Information flow is used to maintain control and to link all the planning and construction departments together (Girmscheid, 2005). Information and communication technology (ICT) provides support for multiple areas for the organization in the construction industry, including supply of products and services, managing demands and solutions and sharing knowledge and experiences in the building process (Lessing, 2006).

Improvements in collaborative communication and information exchange throughout all phases of construction projects are one of the main enablers for industrialization of construction industry. On-demand access, mobility of information and communication tools can together provide more efficient ways to perform collaborative work in the industry. (Wikforss & Lofgrenn, 2007) In pipe repair projects, information flow on-site often requires communication between subcontractors. Traditionally, information flow has been performed via phone, email and even fax. Modern information management methods are required, to distribute information regarding acquisition management, workforce hourly bookkeeping, additional work bookkeeping, weekly planning and shared documentation to subcontractors.

ICT practices in construction industry also often refer for example to the use of computer aided design (CAD) by architects, or the use of estimating software by engineers (Peansupap & Walker, 2006). According to Lessing (2006), industrialized house-building has opportunities to benefit from the use of ICT tools such as Product Data Model and Enterprise Resource Planning systems. Product Data Model systems are beneficial for example to exchange and use information such as 3D models, calculations and CAD drawings. 3D-based CAD systems require data supply to the system and creation of standard information flow to exchange information. Ultimately CAD enables improved production of integrated elements / modules and assembly on-site. ICT applications also enable integration of all parties involved in the project into the same Electronic Data Management (EDM) solution. EDM enables simulation of the construction processes and prior information on efficiency, conflicts in the sequence of work, timeframes and costs. (Girmscheid, 2005)

Management and Performance Measurement

In construction industry management has evolved to take into consideration effective performance measurement. Bititci et al. (1997) state that management is essentially a closed loop control system, which deploys policies and obtains feedback to manage the performance of the system. The effectiveness of performance management system depends on the chosen performance metrics, which define the performance of the organization. Traditionally performance measurement in construction industry has been simplistic and has taken into consideration two factors; relation to the product as a facility and relation to the creation of the product. (Wikforss & Lofgrenn, 2007)

UK's best practice programme CBPP (1999) proposes a more comprehensive set of performance management metrics including the following key performance indicators;

1. Client satisfaction – product
2. Client satisfaction – service
3. Defects
4. Predictability – cost
5. Predictability – time
6. Profitability
7. Productivity
8. Safety
9. Construction cost
10. Construction time

Management relates around management of productivity, profitability, subcontractors, logistics and material supply, briefing of safety practices, information flow on-site with workforce, reduction of waste and defects, reaction swiftness to variability and management of customer communications (Wikforss & Lofgrenn, 2007). Material supply management is essential to ensure that workforce on-site receives the required supply of materials in the correct capacity and at the correct time. Information flow to workforce ensures that workforce performs efficiently when possible changes occur on-site. Workforce also has to be briefed of potential safety hazards and in general about safety practices. Finally, management needs to emphasize customer communication and customer awareness of the progress (Sivonen, 2011).

3.3 Digital industrialization

The presence of the internet, computing and digitalization has presented a new paradigm called 'digital personalization' in addition to the traditional industrial paradigms. The main difference of digital personalization to traditional paradigms, is the involvement of consumers to enable a co-design process. (Hu, 2013) In order for manufacturing companies to increase customer value and optimize resource utilization, offerings have to transition from products to functions and services (Isaksson et al., 2009). The differences are illustrated in Table 2.

Table 2: Differences of the personalized production to traditional industrial paradigms (Hu, 2013)

	Mass Production	**Mass Customization**	**Personalized Production**
Production Goal	**Scale**	Scale **Scope**	Scale Scope **Value**
Desired Product Characteristics	Quality **Cost**	Quality Cost **Variety**	Quality Cost Variety **Efficacy**
Customer Role	Buy	**Choose** Buy	**Design** Choose Buy
Production System	Dedicated Mfg Systems (DMS)	Reconfigurable Mfg Systems (RMS)	On-Demand Mfg Systems (OMS)

According to Hu (2013), digital personalization and co-design process is enabled by applying four principles to meet consumer needs and preferences;

1) Open Architecture Products

Products are personalized by allowing three different types of modules to be used; common modules which are shared across the product platform, customized modules which allow customers to choose, mix and match and personalized modules which are solely created by customers.

2) Personalization Design

Consumers are aided by designer mentors and visualization tools to create design choices without having to experience physical prototypes. A design environment which supports both novice and experienced designers to design under open architecture product platform is desirable.

3) On-demand Manufacturing Systems

To meet the personalized customer demands rapidly, fabrication of personalized product features and modules and assembly need to be configured in a cost-effective manner.

4) Cyber-Physical Systems

Personalization design and on-demand manufacturing require interface methods and tools which support collaborative user experiences in a scalable manner. Personalization refers also to the emergence of communities of like-minded designers, which allows manufacturers to gather a database to aid in identifying trends and product potentials.

Isaksson et al. (2009) present a distinction between product and service as following;

"A service is viewed as a part of the wider concept product. A product can be a commodity, a service, computer software or – more common – a combination of these. A product is the result of a production process."

When offerings are function-based, integration of services, hardware and software is essential. This approach is often referred as 'functional sales' or 'product-service systems' (PSS). The basic premise of PSS is that customers have specific needs for functionality, which are provided as a PSS solution by applying function-based integrations. Ikea has been a great example of a company which has embraced PSS-approach by delivering e.g. "create a home" –service instead of only focusing on selling furniture products. (Isaksson et al., 2009)

Mont (2002) further defines Product-Service System (PSS) as following;

"A product service system (PSS) is a system of products, services, supporting networks and infrastructures that are designed to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models"

The main benefits of a PSS-approach are higher quality offerings that are more customized to customers, higher retention and customer loyalty, longer customer life-cycle and a stable cash flow management (Gaiardelli et al., 2014; Isaksson et al., 2009). In a manufacturing industry, such as construction, PSS allows companies to provide services during the complete life cycle of the physical products and therefore increase the return of the installed base (Oliva & Kallenberg, 2003).

In order to apply PSS successfully in a manufacturing industry, new aspects of functionality have to be considered in the early phases of the development process as the physical elements have to be reconfigured to support the implementation of PSS. Implication of PSS is that a product is only a part of the complete solution. Development of the physical artefact, or product, is therefore a part of the process, not the final solution. (Isaksson et al., 2009) Functional product development process essentially aims to translate all the possible market opportunities gathered from customer interactions to the physical artefact throughout the customer lifecycle (Krisnan & Ulrich, 2001; Grönroos, 2000). In functional product development, customer plays an integral role in the development, and designers are required to be extremely customer-oriented (Baxter, 1995).

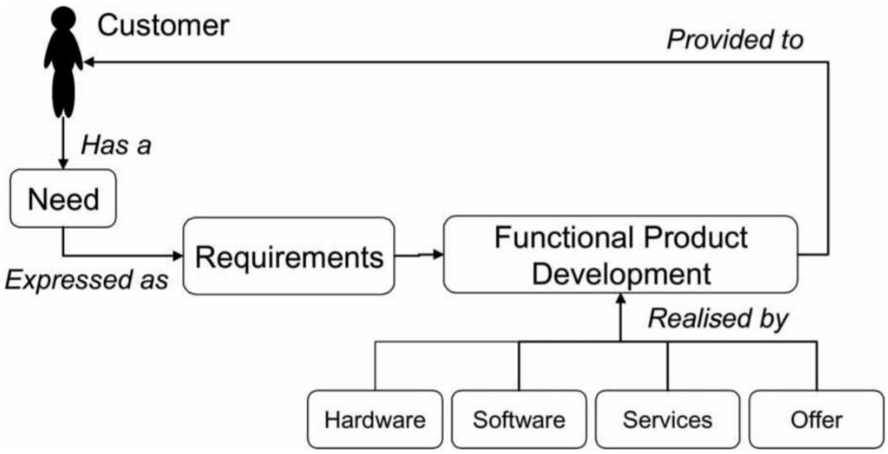

Figure 3: Functional Product Development-process in Product-Service-System (Isaksson et al., 2009)

4 Maturity concept

This chapter presents the concept for the maturity model to measure industrialization in pipe repair industry. The first section synthesizes the theory gathered in the literature review. In the second section, theory for a maturity model is presented and a maturity concept is structured based on the literature review.

4.1 Synthesis of the theory

The construction industry and pipe repair sector is different from other manufacturing industries due to the requirement to produce physical artefacts, which involves a high number of on-site labor and ad-hoc execution. Projects are often temporary, the usage of suppliers and subcontractors are high and workforce varies a lot depending on the project. Continuity regarding the workforce, project management and execution are therefore low, and changes occur repeatedly as projects change. These cultural obstacles in the industry have presented a bottleneck for industrialized, standardized and reproducible behavior to occur. (Section 3.2.1)

In order for an organization in the industry to experience true industrialization and reap the benefits, behavior change in multiple areas is essential. The cultural change towards industrialization has to start from the top as current practices have to evolve on multiple areas. The most important transformations have to occur in management practices, on-site production practices regarding minimizing non-value adding activities, establishing information flow, embracing modularity, preassembly and pre-designing and therefore increasing the relocation of activities from on-site. (Section 3.2.1, 3.2.2)

Industrialization is closely linked to digitalization, as reducing non-value adding activities occurring in on-site practices is not a one-way street. Relocation of activities from on-site to off-site production is a given, but organizations should also embrace the possibilities digitalization provides. Relocating activities via digitalized practices to remote design locations is essential to increase efficiency regarding planning and design, which improves the whole production process by optimizing resource utilization more efficiently and streamlining the work on on-site. (Section 3.3)

Figure 4: Transfer activities from on-site to off-site and design

Lean, Agile and SCM paradigms all have three main principles which are beneficial for construction industry. Organizations should focus on the customer needs and delivery of value for the customer in the most efficient way, minimize waste in all phases of production and strive for continuous improvement of the current processes (Section 3.2.1).

In pipe repair industry, customers have been used to lengthy project durations and invasive procedures, which enables a great potential for an organization embracing the industrialized and digitalized practices to offer a much more swift, painless and more personalized pipe repair process for customers (Section 3.2) In the spirit of the industrial paradigms, the next step for organizations in the industry is to involve customers even more in the production and personalization of pipe renovations by offering access to design practices via digitalized methods. Organizations in the industry should learn from other manufacturing industries and companies, such as Ikea, which has shifted from product-offering to service-offering. By enabling customer involvement via digitalized practices, customers can design and have an impact on the end-product. (Section 3.3)

Pipe repair sector has a great potential for such a paradigm shift, as installation of physical artefacts, enables organizations to offer home-owners additional services and offerings. Compounding the renovations on other areas of their homes such as kitchens and additional re-establishment of bathrooms enables additional revenue streams. Therefore customer involvement should be high on the priority while pursuing to transition from ad-hoc and project-based thinking to product and ultimately to product-service offering. (Section 3.4)

4.2 Maturity concept for pipe repair sector

4.2.1 Maturity model theory

Maturity models are used to assist organizations to gain and retain competitive advantage by improving current organizational practices. Maturity models aid to identify opportunities for cost-efficiency, improve quality of products and customer satisfaction and reduce time to markets. Maturity models assess maturity of a selected domain based on a set of criteria. (Bruin et al., 2005) The purpose of maturity models is to showcase and identify the gaps between the actual and intended organizational design. After succeeding in the suggested activities demonstrated by a maturity model, organization can reach the intended design and elevate the maturity of its processes. (Mettler & Rohner, 2009)

According to Lahrmann. et al. (2011), ‘maturity’ is defined as “the state of being complete, perfect or ready.” Mettler and Rohner (2009) presented, that as formality in maturity measurement is incorporated into the organizational development activities, decision makers are enabled with a pragmatic instrument to determine whether potential benefits have been realized. Comprehension of the current state enables organizations to continue improving and set higher goals.

Maturity models traditionally have five specified maturity stages, such as in Capability Measurement Model (CMM), with the fifth stage representing the highest maturity and first stage the initial and the lowest maturity. In top-down approach, a fixed number of maturity stages is specified first and further established with characteristics which support the initial assumptions. With bottom-down approach, the characteristics or assessment items are determined first and then included into suitable maturity stages. (Mettler & Rohner, 2009)

Key process areas, KPAs, are clusters of related activities which need to be performed to establish process capability at certain maturity stage. KPAs are categorized into broader categories, or processes, which are the main domains under maturity inspection. Each KPA is even further described in short descriptions named Key Practices, which state the fundamental policies, procedures and activities for each Key Process Area to succeed. (Paulk et al., 1993) The categorization of KPAs to Process Categories at different maturity levels is illustrated in Table 3.

Table 3: Key Process Areas (KPAs) and representation of characteristics in maturity model (Paulk et al., 1993)

Processes Categories / Levels	**Management** *Software project planning, management, etc.*	**Organizational** *Senior management review, etc.*	**Engineering** *Requirements analysis, design, code, test, etc.*
5 Optimizing		Technology Change Management Process Change Management	Defect Prevention
4 Managed	Quantitative Process Management		Software Quality Management
3 Defined	Integrated Software Management Intergroup Coordination	Organization Process Focus Organization Process Definition Training Program	Software Product Engineering Peer Reviews
2 Repeatable	Requirements Management Software Project Planning Software Project Tracking & Oversight Software Subcontract Management Software Quality Assurance Software Configuration Management		
1 Initial	Ad Hoc Processes		

In order to design a maturity model, a comprehensive design process is required. Lahrmann et al. (2011) propose a five-step design process for maturity model development.

1) Identify Need or New Opportunity

In order to develop a maturity model, a new opportunity or an innovation in the industry has to be as a focal point for the organization. Literature review is often a profound design method to identify an opportunity.

2) Define Scope

The domain for the scope of the maturity model should be defined properly. At this step, the decision is made which characteristics and assumptions are included in the model.

3) Design Model

The artifact, or a maturity model, is designed in the third step. Top-down approach is often suggested to first define relevant domain dimensions, the big picture, and afterwards fill the chosen dimensions with suitable characteristics using e.g. literature review as the basis.

4) Evaluate Design

Maturity models are evaluated by the utility of the model. Evaluation by performing e.g. surveys, interviews and structural testing is essential to validate the model.

5) Reflect Evolution

Assumptions on the different levels of maturity are affirmed and it is important to handle alterations and model deployment. Maturity models should therefore be further developed after the initial establishment of the model by performing e.g. field studies.

4.2.2 Maturity stages

In this research, the top-down approach for designing maturity model is applied. Maturity model includes maturity stages, which assess the levels of implementation regarding industrialization practices. Maturity stages are the backbone of any maturity model, and showcase each process categories' maturity in relation to key process areas and key process features. (Section 4.2.1) For this research, it is beneficial to approach maturity stages from a more concrete point-of-view in designing the terminology for each stage.
Moving up on each maturity stage, essentially requires higher level of digitalization to stage to enable further industrialization.

Ad-hoc

Initial level is the first maturity stage, which showcases the pipe repair's current state in the industry. In construction industry and pipe repair sector, ad-hoc is the initial stage for most of the work. According to the Cambridge Dictionary, ad-hoc is defined as following;

"Ad-hoc is made or happening only for a particular purpose or need, not planned before it happens and problems are dealt as they happen."

In pipe repair and construction industry, ad-hoc is related to the simplistic task-oriented approach work is performed in, especially on-site, and can be perceived generally as the current climate in many of the production practices. Ad-hoc also requires a workforce which is capable of producing outputs by improvising with limited guiding or management. Digitalized practices are minimal, and production is mostly performed in a traditional and non-digitalized manner. (Section 3.2.1, 3.2.2) Industrialization is highly related to the standardization of processes and production practices, which creates a juxtaposition regarding ad-hoc work. (Section 3.2)

Process-oriented

Second stage in assessing industrialization in pipe repair industry, is a stage in which processes are somewhat managed, and reproducibility is attainable in some cases. In pipe repair sector, projects have elements of manageable processes in addition to ad-hoc practices. Project, as a term, is presented by Cleland and Kerzner (1985) as following;

"A combination of human and non-human resources pulled together into a temporary organization to achieve a specified purpose."

Project is therefore a state, in which the main goal is to produce the outputs with temporary practices. Practices are adjusted regarding a specific isolated purpose with the end-result in mind. Project-thinking therefore has a lot of ad-hoc -driven practices, and the two approaches have a lot of similarities. In order to differentiate the second maturity stage in comparison to ad-hoc, a process-orientated approach is a more fitting definition. The definition for process in literature is scattered and consensus for the definition of the term is hard to find. According to Jacobson (1995), definition for process is presented as following;

"Process is the set of internal activities performed to serve a customer."

In a more comprehensive manner, Eriksson and Penker (2000) define process as following;

"Process emphasizes how work is performed rather than describing products or services that are a result of process"

Process-approach has a strong emphasis on work-related practices, but does not emphasize the product or service management regarding end-products. Process-orientated approach has some elements of digitalization by digitalizing the processes at hand.

Product-oriented

Third stage in maturity assessment includes many industrialized principles, emphasizing standardization of end-products. As seen for example in automobile industry, which applies industrial paradigms in a successful manner, work and production management leads to reproducible, standardized and cost-efficient production. (Section 3.2.1) The main aspects in product-orientation are the elimination of wasted resources and materials, and the reduction of any sort of internal variance and deviation in production.

The main distinction to process-approach, is the almost rigorous approach to continually improve the current production practices. In addition, the pursue to minimize all sorts of variability in production, results to manufacturing reproducible and near-perfect quality products. (Section 3.2.1)

Product Service

The fourth, and final, maturity stage is named product-service. In addition to standardized procedures in product-offering, product service-stage includes comprehensive digitalized methods to advance product-centered approach to a function-based offering. The main distinction between product-service stage and product-stage, is related to the customer involvement. Even though product-stage has many industrialized processes already intact, the customer involvement, design practices, customer loyalty and customer retention can be developed further to create longer and stronger customer relationships. Essentially product-services aim to digitalize the customer involvement. (Section 3.3)

In traditional pipe repairs, constructed physical elements are often seen as the be-all-end-all in customer collaborations. However, when practices are product-service - oriented, all possible market opportunities are included in the pipe repair offering after the initial installation as seen in multiple subscription-based services in other industries. Ultimately, product-services prolong customer lifecycle and increase possibilities for additional sales. (Section 3.2, 3.3)

4.2.3 Process categories

Process categories are the relevant domains and areas in the maturity model. Process categories are the most interesting subjects for maturity measuring regarding industrialization in pipe repair. In this thesis, six process categories are chosen, which can be developed and implemented to different levels in the company. Each of the process categories are viewed separately, and maturity should be developed by focusing on each category individually. Some categories are however closely related, which means that development in one category can also affect the implementation and development in another closely related category.

The chosen process categories describe the most significant areas of industrialization in pipe repair industry. The six process categories are listed and described below.

1. Site design
2. Work instructions
3. Resource allocation
4. Management
5. Material supply
6. Documentation

Site design

Transitioning activities from construction site is possible only if planning and designing are increased. In order to increase site design, digitalized procedures are required to create reusable and standardized site designs for pipe repairs. (Section 3.2.2) Site design refers to the amount of pre-planning a specific site includes prior to actual installments on-site. Industrialization by increasing site design is obtainable by having site designs, which are reusable for multiple pipe repair sites. Buildings which follow the same scheme should not therefore be to designed multiple times, but rather site designs which have properly performed in the first place, are obtainable for similar pipe renovations.

Information flow is an important factor in site design, as information flow between multiple parties allows transparent and controlled planning procedures. ICT applications can benefit site design practices, as the use of systems, such as Electronic Management Data, can offer prior information on sites. (Section 3.2.2) Site design is an enabler for applying the main industrial attributes such as preassembly and standardization. Especially agile project management practices are essential in increasing pre-design and design phases. (Section 3.2.1)

Site design also decreases the variability and ad-hoc practices in the production and especially on-site, as comprehensive information is obtainable prior to the actual installment in pipe repairs. This approach enables pipe repairs to move towards more industrial procedures seen also for example in automotive industry (Section 3.1, 3.2.2) Ultimately site design should also lead to a higher customer involvement and more agile procedures, as product-offerings transition towards service-offerings also in the pipe repair industry. Customers can export site designs via digitalized practices, which increase the customization and personalization in the renovation projects and therefore increases customers loyalty towards the service provider. (Section 3.3)

Work instructions

As mentioned, reducing non-value adding activities is an essential part of an industrialized process. By enabling workforce with a transparent and easy-to-follow work instructions, ad-hoc work can be decreased on-site. Work instructions relate especially to streamlining the work on-site. Digitalized efforts are necessary as working instructions should be transparent, up-to-date, real-time and easy to follow. Digitalization and information flow are necessary to enable workers with sufficient information.

Ultimately work instructions should be obtainable for even customers to perform their own pipe renovations especially afterwards the initial installment if a customer so chooses to. Personalization of the pipe renovation is enabled, by allowing customers a DIY-process (do-it-yourself) as seen in IKEA's "create a home" –service.

Resource allocation

Resource allocation is one of the main aspects in construction industry to create unnecessary waste. In an industrialized production practice, resources are allocated at the correct time, in correct place, in correct capacity. (Section 3.2.1) Waste of time on hand causes a lot of inefficiencies in the construction industry and pipe repair sector. Resources should therefore have a transparent knowledge prior to any on-site practices regarding the time and place of the execution.

Synchronizing activities through shared information is the key for allocating resources in a correct manner. Digitalized efforts in enabling workers with an information flow, which is easy-to-follow and allows workers to have confidence in knowing where to be at which time is essential when approaching industrialized production practices. Ultimately, resource allocation leads to minimization of on-site activities and therefore resources should be allocated to tasks which support the product-service offering. Workforce should experience a culture change, resulting to the transition of workforce to design and customer relationship management practices to support customer involvement in designing and producing pipe renovations.

Management

Higher level of industrialization includes management of products and the management of customer involvement and customer lifecycle. Management is a complex issue which has to take into consideration a multitude of factors in construction industry and pipe repair sector. Managing profitability, supply, workforce and customers are the most important domains organizational management should consider in industrialized construction. Industrialized management is also closely related to determining the most beneficial key performance indicators and measuring and improving them rigorously. (Section 3.2.2)

Managing ad-hoc work on-site and project-specific processes are the traditional characteristics of construction industry management. As organizations move towards industrialization, management also considers communication methods and information flow between all the parties involved in production. (Section 3.2.2) When industrialized practices are intact, management of continuous improvement and product development becomes extremely important, as the reduction of non-value adding activities is in the focus. (Section 3.2.2).

In addition to applying a more industrial philosophy to management such as lean production, a statistical and analytic-based management method e.g. Six-Sigma is beneficial in order to measure manufacturing quality and customer satisfaction. By managing and improving processes, products and services in a more analytical manner, defects can be greatly reduced and organizations can reach higher maturity in management. (Section 3.2.1) When production establishes a product-service stage, management of customer lifecycle is at utmost importance, as customers are nurtured, maintained and provided a service for longer periods of time rather than in one-and-done project-approach. (Section 3.3)

Material supply

Material flow and material supply refers to the transportation of materials, prefabrication, pre-assembly, standardization and supply chain management. The integration of suppliers and subcontractors in supply chain is vital for an effective material supply to take place. (Section 3.2.1, 3.2.2) The goal is to reduce non-value adding activities and in-bound lead times, increase simplicity in production and performance management to reduce costs and utilization of materials and workforce efficiently. (Section 3.2.2) Supply chain management consists of managing relationships, information and material flows across enterprise borders to deliver enhanced customer service.

In ad-hoc centric production, material supply focuses on meeting the requirements of activities in order to have materials to perform individual tasks on-site. As mentioned, it is estimated that 33% of workforce time in traditional construction sites is used for non-value adding activities due to lack of supply chain management, which results to increased time in searching and rearranging materials (Section 3.2.2) In order to reduce non-value adding activities, supply chain management considers the integrated behavior of having mutual customer-oriented goal and sharing of information between suppliers and subcontractors. By increasing prefabrication, activities are transitioned from on-site which reduces on-site non-value adding activities (Section 3.2.2)

In customer-centric supply chain, which is applicable to product-services, applying agility in the supply chain management is required. Digitalized measures and information flow are necessary to capture data on-demand from the point-of-sale or point-of-use. Agile supply chain answers rapidly to customer requirements through virtual supply chain which is based on information rather than inventory. Agile supply chain requires a close network and high connectivity between all parties in the supply chain to have on-demand responsiveness for the customer needs. Web-based technologies enable different parties in a network to share real-time information on demand, inventory and capacity. (Section 3.2.1, 3.3)

Documentation

Documentation revolves around the premise of continuously improving current practices and establishing information to predict future changes. By continuously improving current production procedures, defects in construction industry can be minimized and thus providing customers higher quality products and services. Improvement is not a one-and-done procedure, but rather a continuous process of focusing on smaller details in repetitive procedures to have more knowledge for future practices. (Section 3.2.2)

Documentation enables to more knowledge after each repetition and performance similar tasks more efficiently which reduces all sorts of waste and increases the value of each action. (Section 3.2.2)

By applying industrial paradigms' core principles to continuously improve the current procedures, non-value adding activities can be reduced or diminished and the value of each action can be increased. Ultimately technology is a key component in allowing pipe repairs to reach higher levels of industrial maturity by measuring the state of the site. By producing real-time information of the current state in pipe repairs, technology also enables proactive involvement in customer relationships. (Section 3.3)

5 Case study of industrialized pipe repair

This chapter describes case study for the research project. Finally, the designed maturity model is evaluated regarding by conducting interviews with experts in the case company.

5.1 The case company

Case study for the case company was executed in order to apply the maturity model presented in this thesis. The focus of the case study is in construction industry and specifically in pipe repair sector. The case study had two main factors; the overview of the company's way of working in pipe repair sector and the related process of the company. Information for the case study was gathered primarily via interviews and discussions with persons working in the case company. Additional information was gathered via public domains to present a comprehensive overview of the case company's practices.

The case company consists of three independent business units: The case company, Digital Business Unit and the case company subdivision. The largest and oldest unit is focuses on developing and building construction projects. The case company was founded in 2002, which focused solely on concrete construction until 2009. Since then the case company has transitioned towards other construction sectors such as pipe repairs, house-building and building construction establishing a more comprehensive organization. The case company has grown rapidly in 2010s. In 2009 the case company's revenue was €15M. Seven years later in 2016 the case company had established revenue of €139M in 2016 and it employed over 200 personnel.

Digital Business unit is a new sector in the case company which focuses on digital transformation and pursues digital initiatives to establish new technologies and services concepts to humanize and disrupt the traditional construction sector. The goal of Digital Business unit is to create more service concepts, which are scalable for international markets and customer-oriented. The customer-orientated business approach of Digital Business unit supports the industrialized product-service offering, which involves customers and end-users more than ever before in traditionally inhumane construction sector. In addition Digital Business unit looks to implement digitalized methods which enhance the performance of on-site construction in building and pipe repair projects. One of the main examples of such tools, is a workforce management tool named SiteDrive, which the case company has implemented for work management.

In addition to the previously named business unit and Digital Business unit, a subdivision of the case company, was established in 2010. The subdivision generated €29M revenue in 2016 in addition to the case company's revenue. The subdivision was chosen as the business unit for the case study due to it's innovative pipe repair business concept. The business concept is a concept of the subdivision, operating in property pipe repairs and pipe renovations. The business concept is an interesting case study subject since the methods of working in the business concept have aspects of industrialized production practices.

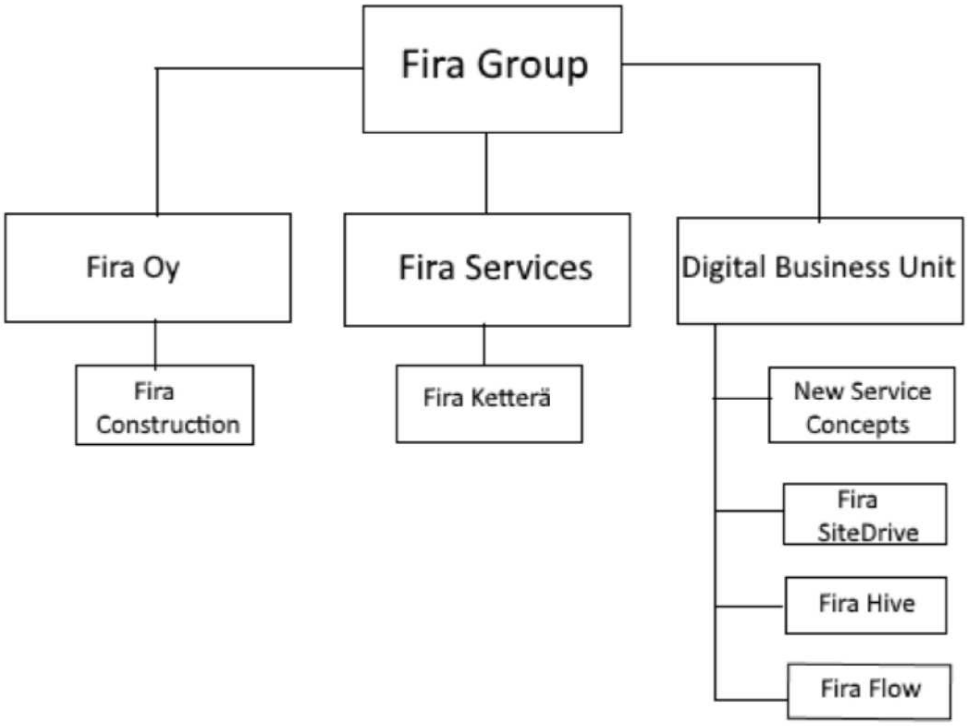

Figure 5: The case company organizational structure

The business concept stands out in contrast to traditional pipe repair projects. The main features in the business concept are less invasive on-site operations due to higher levels of pre-planning and much shorter evacuee time for property residents during the pipe renovation. In traditional pipe renovations the evacuee time is estimated to be approximately 12 weeks and in some cases even 6 months. With the business concept the evacuee time has been decreased to as low as 2 weeks. The first business concept 2-week pipe renovation was successfully performed in November 2017.

Due to the business concept's groundbreaking approach to offer customers much less invasive pipe renovation projects, it is an interesting research topic regarding possibilities industrialization and digitalization can offer. Construction and pipe renovation industry has not evolved in the same pace as other manufacturing industries, which enables the business concept to be a forerunner in offering swift and less invasive pipe renovations by applying industrial principles in it's production practices.

5.2 The business concept process

In the business concept, pipe repair has higher emphasis on pre-planning, design and customer involvement in comparison to traditional pipe repairs. The business concept philosophy is structured towards co-design with customers, accurate and transparent predictions on cost structure and commitment on common goals between all parties in the project including housing cooperative, contractor, designers and workforce. Common goal is incentivized by distributing value fairly between all parties if predicted project costs and timetable are exceeded.

The business concept process is categorized into six different modules, which consist of Verstas, Design, Tracking, Production Planning and Supervision, Acquisitions and Material Supply and Customer Communication. Each of these modules are linked to each other to produce higher quality outputs for customers and enable higher customer involvement. The business concept process is illustrated in the Figure 6.

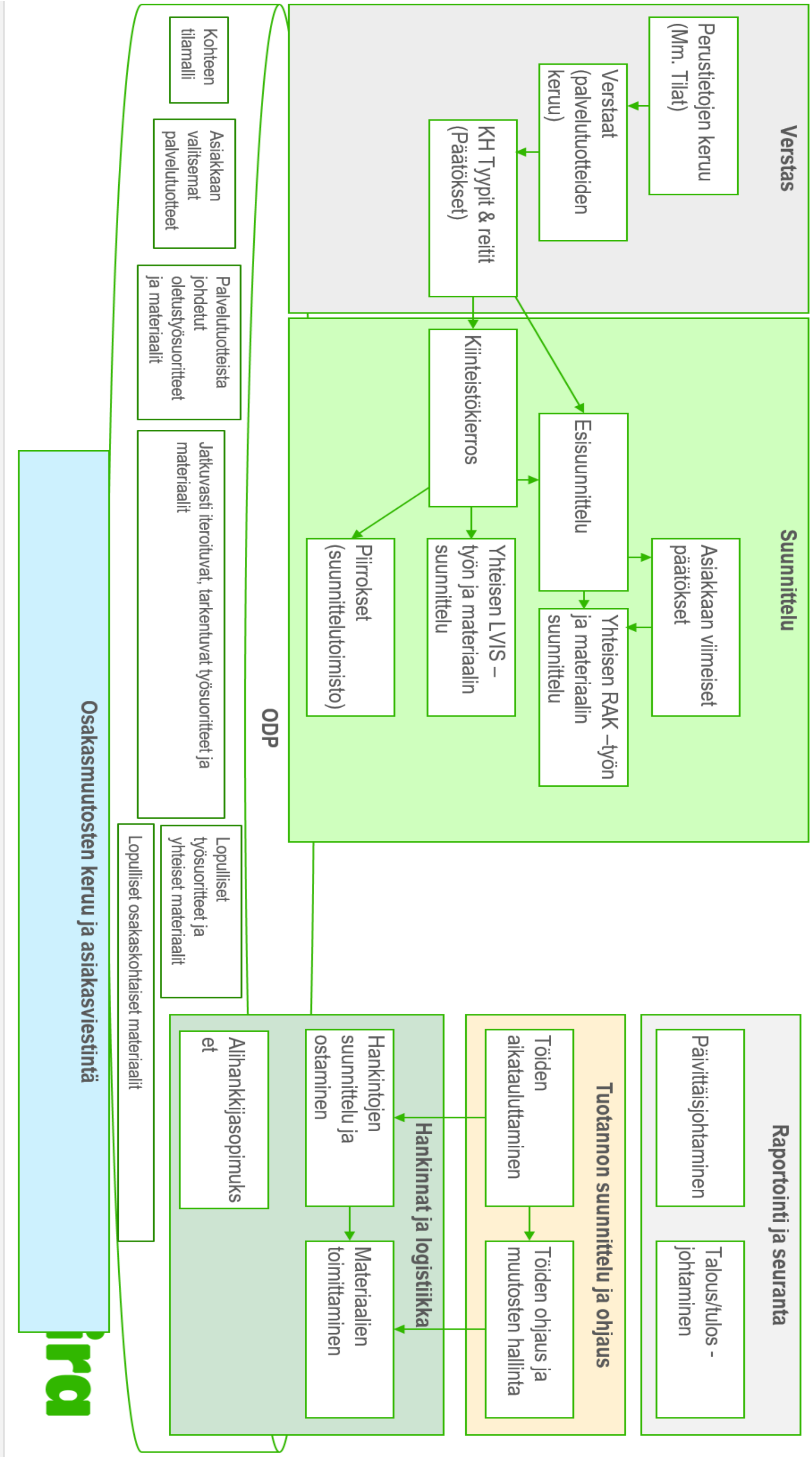

Figure 6: The progress in the business concept process

Verstas is an inclusive collaborative method to gather information from the residents regarding the pipe repair project. During Verstas, residents can exchange opinions regarding the project and hear other's viewpoints how to proceed with the project. During Verstas, the case company gains insight of the cost structure for the project and customizes the offering. Depending on the resident's views, the case company presents the projected timeline for the pipe repair project.

The Design phase of the business concept process introduces pre-planning for the project. During pre-planning, the business concept specialists gather information regarding the site, to ensure that as much information is accessible prior to on-site execution. The business concept's higher level of pre-planning ensures lower risk of errors and invariabilities during on-site execution. Different phases of the work are planned and visualizations of the site are produced by the design office and design architects. Customers have traditionally expected all pipe repairs to take at least 12 weeks and in some cases even as long as 6 months. Due to higher level of planning and design practices, on-site execution times for pipe renovations have been decreased greatly, in some cases to as low as two weeks.

The Tracking phase includes the day-to-day management of the project's execution including the cost and goal management. The costs are tracked with the use of Insite-tool, which provides an overview of the project's costs. Residents of the building also gain transparent access to overview the costs based even on a single invoice level.

Production Planning and Supervision introduces the use of SiteDrive during on-site execution. SiteDrive enables a task-based management method to categorize and schedule work in a transparent manner for the workforce. SiteDrive also gives access for managers to supervise the executions and to stay on top of the site's progress. In SiteDrive, each task's time, result and reporting of possible changes and modifications which occurred during the work are reported.

Acquisitions and Material Supply phase consists of planning and purchasing required acquisitions and the contractual agreements between the case company and it's subcontractors for the project. Material Supply gains insight from the production and reacts to the site's requirements to supply the required materials. The case company has started a collaboration with Assembly & Logistics Unit (ALU) in 2017 to enhance the material supply. ALU tracks the material flow and plans the required supply units based on the insights from the site. ALU also tracks the success of the deliveries and ensures constant material sufficiency.

Customers are in the core of the business concept's process. As the project advances customers have transparent access to project's progress and cost structure. In the business concept's final phase, Customer Communication, customers are informed of the project's status and the premise's shareholders are delivered materials regarding the project.

5.3 Case study – the maturity concept verification

Experts in the field of industrialized pipe repair in the case company were interviewed in order to get feedback on the definition of industrialization in the pipe repair sector and to verify the concept of maturity model for measuring the maturity of industrialization in pipe repair. The interviewees actively work in product development, design management, technical design, site logistics and site supervision in the case company. Hence the interviewees have well-established views of the areas regarding industrialization and development in pipe repair industry.

Perception of industrialized pipe repair

The interviews started with a discussion on what industrialization regarding pipe repair means to the interviewee and what are the most crucial parts in industrializing the sector. All of the respondents concluded that it means decreasing the variability in production practices. The target should be to minimize the variance in construction by increasing the amount of data gathered on sites and putting more effort into pre-planning of production. One interviewee also stated that even though the nature of the industry is complex as each site always differs from others in some aspects and variability between sites can never be completely eliminated, standardized procedures for production should be able to minimize variability greatly and increase efficiency for the production. Each site should therefore not have completely different procedures and schemes, but rather each site should follow a similar approach in planning of the production which would create a coherent and well-established routine all of the personnel are familiar with.

Two of the respondents also stated that in addition to increasing standardized pre-planning, on-site production suffers from continuous variation of subcontractors. The use of subcontractors is mandatory, but subcontractor relations should be more stable and with less variation. Each project introduces new habits with each new subcontractor and on-site teams vary greatly from site to site. By having a stable network of well-established subcontractors, site teams can build rapport from site to site and minimize the hassle of creating habits from the scratch on each pipe repair site with a set of new subcontractors.

The interviewees made clear, that construction industry is an area, which is undergoing extensive development from which the pipe repair industry would benefit. One of the respondents was very enthusiastic about the possibility to use digitalized methods to industrialize the industry.

"The concept is very relevant as these topics have been discussed extensively as of late. The framework enables excellent possibilities for our future development. By having a comprehensive knowledge of the concept, we can develop innovative digital solutions to disrupt the market place."

The concept's sufficiency

In the interviews the content of the concept for industrialized pipe repair with it's four maturity stages and six process categories was discussed, in order to assess its completeness and comprehensiveness. All of the respondents believed that the process categories covered the most important areas of industrialized pipe repair. It was also pointed out that many of the process categories understandably overlap each other, as the decisions made in a specific category would have some affect at least in one or two related categories. One of the respondents stated the following:

"It is difficult to dissociate the categories completely from each other as for example Site Design has a strong association to Resource Allocation and Management. However

I do believe you have succeeded in assorting the categories in most likely the best possible manner."

One of the respondents pointed out, that even though it is necessary for the maturity concept to have the fourth product-service maturity stage, it is a very difficult stage to reach as the nature of the pipe repairs does not currently support this approach. In order for a product-service or a subscription-based service to succeed, repairs should be able to be performed gradually when a specific component is starting to decrease in quality. However currently this is nearly impossible, as the whole technical architecture is repaired in the building at the same time instead of fine tuning one or two issues.

Most of the respondents also pointed out that digitalization enables the growth in maturity and production. Digital methods should however be viewed as enablers for industrialization and not as solutions. In addition, in the discussions the concept was concluded as a useful tool especially when used in an iterative manner for further development. One of the respondents concluded the concept's usefulness as following:

"This maturity framework for industrialization is a useful method to understand if some category is lacking in maturity compared to others. If we identify such a category, we have the comprehension to emphasize the development of that specific category."

6 Case study analysis

This chapter includes an analysis of the case company's industrial maturity where levels of implementation are measured based on interviews and discussions in the case company.

6.1 Levels of implementation

The concept of industrialized pipe repair is described as consisting of six process categories that together constitute the whole maturity model. The six categories can be developed and implemented to different maturities in the case company depending on the company's organizational choices, vision and emphasis. Some categories may have higher level of maturity, while other categories are lacking in maturity and therefore require more development in the future. The categories for the industrial maturity measurement in the maturity model are constructed as independent categories. However, some categories are closely related to each other, which means that development in one category may have affect also on other categories' maturity.

In the analysis of the case company's industrial maturity, a model with exemplifications or indicators was required in order to perform a comprehensive assessment of the maturity. The different process categories, or domains, are presented with exemplifications for each maturity stage. Each stage introduces more complexity and industrial implementation as maturity rises. The exemplifications regarding each process category and maturity stage are illustrated in Table 4.

Table 4: Maturity model with exemplifications of stage achievements

Process Categories (Activities)	Stage 1 Ad-Hoc task-oriented	Stage 2 Process-oriented	Stage 3 Product-oriented	Stage 4 Product Service customer-oriented
1. Site Design ***pre-planning, digital standardized design, customer personalization***	Site designs are rough sketches and approximations Site designs have no reusability in similar sites Site designs introduce surprises on on-site	Site designs are well planned for a spesific site Introduce less surprises due to higher-level of site-spesific planning Site designs have no reusability in similar sites	Site designs are standardized for all similar sites Site designs are continuously improved based on previous knowledge Site designs have high reusability via digitalized tools such as Electronic Data Management (EDM)	Site designs are standardized and transparent for customers to export for all similar sites Customers can personalize site renovations via digitalized tools
2. Work Instructions ***on-site work, digital and transparent instructions, DIY***	Work instructions are minimal, even non-existent Knowledge of good practices is required from workforce to produce desired outputs	Work instructions are comprehensive, but require management to define them for site-spesific purposes Instructions are not easy to obtain and in-efficiently distributed for the workforce	Work instructions are comprehensive, transparent and standardized Instructions are easily obtainable for the workforce via digitalized tools and sufficient information flow	Work instructions are easy-to-follow, digitalized and exportable for customers Instructions enable customers to perform DIY renovations
3. Resource Allocation ***on-site resource allocation off-site and design activities, customer relationships***	Resources are allocated based on managers' hunch Requires a lot of management due to incomplete knowledge of resources' whereabouts	Resources are allocated based on comprehensive schedule, location and expertise management via digitalized tools However due to missed deadlines short-term resources are used and good starts in projects transition to ad-hoc practices	Construction sector experiences cultural change by diminishing resource allocation to on-site Resources are allocated to other stages of production with an emphasis on pre-design and design phases	Resources are allocated to further develop current practices and to proactively monitor customer lifecycle Resources are allocated with an emphasis on customer involvement in product-service offering

Process Categories (Activities)	Stage 1 Ad-Hoc task-oriented	Stage 2 Process-oriented	Stage 3 Product-oriented	Stage 4 Product Service customer-oriented
4. Management ***digital management methods, product development, customer management***	Managing practices on-site and individual tasks Management lacks in comprehensive information flow and digital management methods	Managing processes on the terms of a specific project Management uses some digital methods especially regarding communication Management lacks in information flow with subcontractors	Managing product development and continuous improvement Reducing non-value adding activities by applying digital methods and analytical performance management tools (e.g. Six-sigma)	Managing customer lifecycle Increasing customer retention and loyalty with an emphasis on customer relationships past the initial installment of base
5. Material Supply ***supply chain management, prefabrication, material flow management***	Material supply reacts to ad-hoc practices and individual tasks Low emphasis on pre-fabrication and separate parts are produced to on-site High waste of materials SCM is non-existent or lacking in partner integration	Material supply reacts to project requirements Increased pre-fabrication and material kits are produced to on-site Lacking list of bill of materials SCM is constructed and focus is on inventory	Material supply proactively optimized to production requirements Standardization in product families SCM is based on web-based technologies to control material flow	Material supply includes on-demand practices to answer to customer requirements rapidly SCM is agile, real-time and virtual supply chain is established SCM is focused on point-of-sale or point-of-use rather than on inventory
6. Documentation ***continuous improvement, reactive and proactive customer involvement***	On-site documentation is non-existent or very limited and not recorded and distributed in organizational databases Zero emphasis on continuous improvement	Documentation of current practices is detailed and recorded via digitalized tools Estimations for future practices is limited, varies greatly and is subjective Low emphasis on continuous improvement	Documentation is reusable for other use cases if beneficial Documentation enables reactive involvement on customers' needs High emphasis on continuous improvement	Documentation via technological tools (e.g. sensors) Documentation enables proactive involvement on customers' needs Customers are provided real-time information and predictions on future and additional repairs

6.2 Assessment of the business concept's industrialization

In the case study an assessment of stages of achievement was measured in order to test the maturity model and illustrate the current level of industrial maturity in the areas of industrialized pipe repair. The assessment is based on the description of each process category and exemplifications above. The assessment of the levels is shown in Table 6.2

Site design

The construction industry sets up a problematic context for site designing, as each site differs at least in some manner from the others. Due to this industry constraint, it is extremely difficult to have completely standardized site designs for all sites. However, in The business concept sites have been documented more carefully and with more emphasis on pre-planning.

"Site designs have reusability in many sites as good design work is already done in the business concept. However pipe routings do differ from site to site and structural differences in the buildings often need to be designed in a site-specific manner as more information is gathered from the site."

Site designs are quite well planned with certain details already implemented in the beginning of each project. Site designs are often well suitable if the projects do not experience any changes in the production phase. Problems do arise when production phase experiences surprises, as site designs are not continuously improved based on the newly gained information in the production. Due to scheduling pressures, site designs are therefore lacking in real-time information and may become outdated as the project advances and ad-hoc practices are required.

Work instructions

As products and requirements evolve all the time, work instructions also have to evolve and be updated continuously. If industrialized production and higher maturity stages are to be reached, work instructions not only need to be easily accessible for the workforce but also information has to be up-to-date. Another cultural constraint becomes obvious regarding industrialization of work instructions. Workers in the construction industry, especially the more experienced, have established habits in how the work is performed. The difficulties therefore arise in implementing standardized work procedures for all personnel as good practices are still part of the whole construction industry.

In the business concept work instructions are not standardized and may not even be easily accessible for the workforce. Currently work instructions are in most sites verbally expressed by project managers for the workforce, and high levels of good practices is required from the workforce to be able to produce quality outputs. Even if in some cases work instructions would be properly documented and accessible, the workforce is not following them unless problems in the production arise on site.

"This is an area where we are lacking, as not only are the work instructions underdeveloped, but the habits of experienced workforce are difficult to change and it would require a lot of work from us to have everyone approbative of standardized working methods."

Resource allocation

The business concept has established digitalized tools to have a better understanding how to allocate resources. SiteDrive enables allocation of resources with schedule, location and expertise management features. SiteDrive however is not currently applied in the most profound manner. Problems in resource allocation arise if any surprises or changes occur as the projects advance. The challenge in the case company is that when these changes occur, digital tools such as SiteDrive are currently too complex to keep up-to-date as emphasis on-site is on solving surprises instead keeping the information flow up-to-date.

SiteDrive may not, atleast for now, be the perfect tool for resource allocation and would require further development to have a more comprehensive and easily accessible mechanisms to track all the changes occurring on site. Digital tools are currently useful for having an overview and a setup of specific sites, but lack in implementation when any sort of variability occurs during the production.

Management

Management in an industrialized manner requires a well-established information flow, standardized procedures and digitalized methods for project managers to update changes in a transparent way which enables information to be easily accessible for all the personnel. In the business concept management still relies too much on individual expertise, and projects tend to personify on managers. The success of production is therefore too dependent on the managers' competence and ad-hoc decision making.

In order for an industrialized management style to be established, all the managers should apply similar standardized methods in managing each project. Currently in the business concept information flow is well established inside the organization and enables a standardized procedure with suitable digitalized tools. However digital tools have not been implemented fully and integration of standardized tools in a management process is currently lacking.

"Information flow regarding site specifications is available, but it has not yet been applied to achieve a standardized industrial management process."

Material supply

Industry constraints are also apparent regarding material supply. First of all, prefabrication can currently only be performed at a certain level due to differences in pipe repair sites. Sites differ too much in building and apartment structures to have a higher level of prefabrication implemented. Secondly, the construction industry as a whole is outdated and partners are lacking in modern technologies to distribute information in a transparent manner on web-based technologies.

The business concept has put a lot of emphasis in creating an efficient material supply process. Material supply is well-established in collaboration with Assembly & Logistics Unit (ALU). ALU enables a higher level of prefabrication and production of material kits to on-site. SiteDrive has proven to be a useful digital tool in material supply, as information regarding sites is well distributed for ALU to produce correct supply of materials based on the site requirements. The business concept has also hand-picked modern supply partners in it's supply chain which support the case company's approach.

Documentation

Industrialized approach to documentation requires two main aspects; documentation is gathered in measurement points and during on-site and documentation is applied to further develop current production practices. The business concept has established digital methods to gather documentation of any deviations in quality occurring during production. Lacking in documentation may arise, as understandably documentation for development may be ignored if it is not properly incentivized for the workforce and if events, which would have been useful to document on-site, have to be dealt with in a timely manner.

The business concept's culture is however all-around supportive for establishing a comprehensive documentation. Information is gathered fairly well on-site for example with a construction quality and safety management tool Congrid, but analyzing of the gathered data and incentivizing workforce for even more detailed documentation has to have more emphasis in order to reach higher maturity stages and ultimately industrial level of continuous improvement.

"Digitalized tools are used for documentation, data is fairly well analyzed afterwards and a lot of information is gathered on any deviations in quality."

Table 5: Assessment of the levels of industrialization in the business concept

Process Category	Fira Ketterä
1 Site Design	2
2 Work Instructions	1
3 Resource Allocation	2
4 Management	1
5 Material Supply	3
6 Documentation	2

6.3 The business concept's industrial maturity

In Table 5 and in the radar chart presented in Figure 7, the overall view of the business concept's level of industrialization is shown. The levels are generally low, with some exceptions showing the company's strengths. The process category of Material Supply can be viewed as the core of the company, which is supported by digitalized tools and collaboration with Assembly & Logistics Unit. Material Supply as a category is the company's highlight, and can reach even higher maturity and ultimately customer-orientation by further developing the well-established logistics network.

Even though most of the other levels are fairly low, the business concept has an excellent basis to further develop industrialization in pipe repair sector. The company is already striving to improve their production practices by applying digitalized tools which would create a more transparent information flow and tracking of resources, sites and useful documentation as seen in categories Resource Allocation, Site Design and Documentation. These three areas are related and have the same basis for industrialization: sufficient and up-to-date information flow. Company has already established multiple digitalized tools, which however have not yet been used to their full potential. The emphasis has to be put on distributing real-time information regarding resources and design which is easily accessible and transparent.

The biggest shortcomings currently in industrializing the business concept's practices, are in Work Instructions and Management. These two areas are closely related and require further development, especially regarding personification of managers. By introducing standardized processes, which managers can apply, projects become less dependent on the managerial competence. Sites can perform on well-established processes which all the personnel are aware of and follow on- and off-site.

It is also important to point out, that while assessing the current maturity of the case company, very few divergences were pointed out between the responders. This indicates a high level of coherence in the case company culture which should be viewed as an advantage for further development. The lack of divergence also speaks to the favor of the constructed framework as a sufficient tool for measuring the level of industrialization.

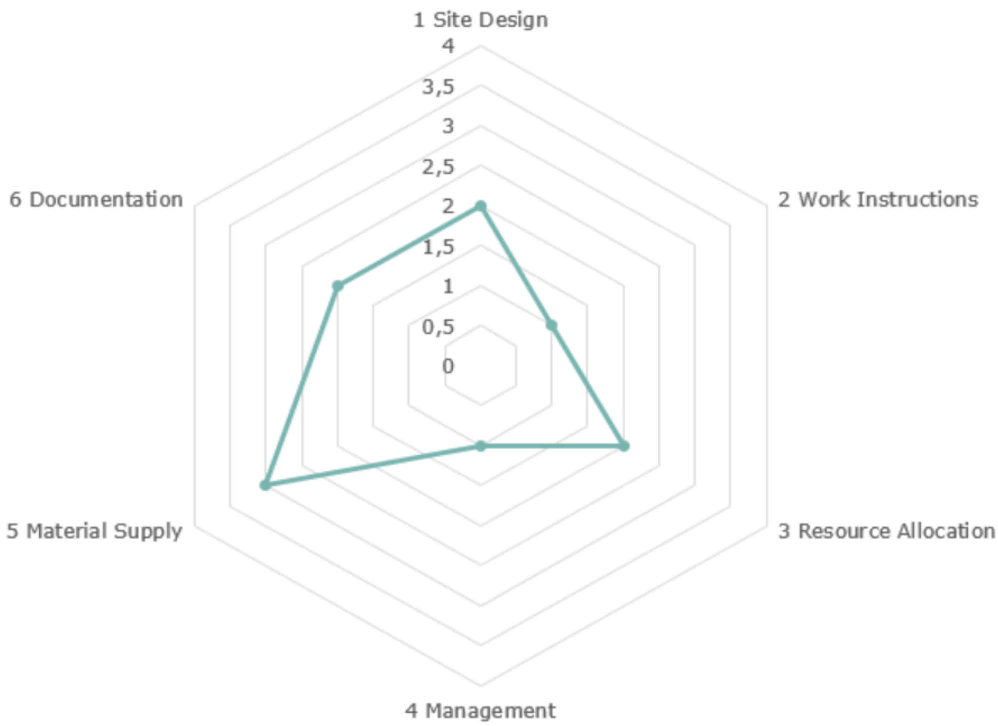

Figure 7: Illustration of the business concept's level of industrialization

7 Conclusions and discussion

This chapter presents the conclusions and discussions of the research project in the field of industrialized pipe repair. Avenues for future research are proposed and discussed.

7.1 The concept of industrialization

Construction industry has been justly stigmatized for a long period of time as an industry which relies on traditional value creation and traditional industrial paradigms. Digitalization enables the industry to transform the whole ecosystem and forces companies to adopt paradigms and production practices which have already been established in other more developed manufacturing industries. As companies in the construction sector accept digitalization as an enabler for higher industrial maturity, resources can be capitalized in a much more efficient manner.

In this thesis, the research was constructed on three research questions. In order to understand the possibilities of industrialization, the concept of industrialization in general and in construction industry was defined in the first research question:

Q1: What is industrialization and what are the characteristics and consequences of industrialized construction and pipe repair?

The first research question was answered by composing a comprehensive review on current literature in the area of industrialization. Industrialization has evolved from craft production, to mass production and ultimately to other industrial paradigms. Modern industrialization relies on main features which consist of standardization, interchangeability, repetition, modularization and minimizing variabilities in the production.

Industrial paradigms such as lean and agile production strive to reduce any sort of waste by standardizing production practices. In lean production, waste elimination is the ultimate target with continuous fine tuning of standardized production in a fixed product family. Agile production has many similarities to lean production, but with higher emphasis for customization and flexibility to meet differing customer requirements. Often organizations should combine both paradigms depending on the customer requirements and required customization in their offering. To support lean or agile production, supply chain and supply chain management are essential concepts to produce sufficient material supply and to establish an efficient production system.

Industrialization in construction industry and pipe repair sector strives to make production effective by repeating work processes in factories, design offices and at building sites by the coordination of different activities. Industrialization was defined as "structural means for eliminating, or at least drastically reducing, on-site activities in construction.". In the core of industrialization in construction industry is the emphasis of relocating activities from on-site to specialized off-site factories (pre-assembly) and to remote digital units (designing). This approach supports the lean and agile paradigms in minimizing the waste by eliminating non-value adding activities and standardizing all areas in production to minimize variabilities.

In lean construction paradigm, the approach is to categorize activities in a manner that non-value adding activities can be reduced or diminished and efficiency of production is increased by increasing the amount of value adding activities through continuous improvement and new technology. In construction industry both lean and agile paradigms approach the concept of construction by categorizing design processes and production (execution) processes. This approach enables companies in construction industry and pipe repair sector to transition from the ad-hoc -and project-based approach to a product-approach, in which pre-planning and designing create more effective production mechanisms for on-site work.

In addition to developing production systems which efficiently produce standardized products and product families, digitalization has transformed the way customers collaborate with companies. The unquestionable presence of Internet has introduced a new paradigm called digital personalization, and has brought customers closer to service providers. Digitalization has enabled more transparent collaborations in which co-design processes and personalization are demanded from customers also in construction industry, as customers have been used to such an approach already in other industries. Digital personalization has introduced a new business concept, product-service system.

Product service systems consists of infrastructure which is designed to satisfy the customers and integrate customers as a part of the decision-making. This phenomenon is apparent in different kinds of subscription-based services.

Q2: What are the most important aspects in pipe repair in order to measure the industrial maturity of the current practices?

The second research question considered the most important aspects in industrialization, to create a sufficient framework for industrial maturity measurement for companies operating in construction industry and pipe repair sector. In this thesis the focus was specifically in creating a maturity model which would serve the case company's business concept's maturity measurement regarding it's production practices in pipe repairs. In order to construct a sufficient maturity model, the most important areas, process categories, had to be defined to measure the levels of maturity in a comprehensive manner. The six most relevant areas in pipe repairs were chosen as the process categories based on the literature review and discussions in the case company. The following six process categories defined the core of the constructed maturity model.

1. Site design
2. Work instructions
3. Resource allocation
4. Management
5. Material supply
6. Documentation

The industrial maturity model for pipe repair emphasizes that in order to create a strong industrialized process in production, all these areas must be developed. Each of the six process categories can be implemented to different levels in a company, or collaborating group of companies, on a scale of 1 to 4. The scale includes maturity stages ranging from ad-hoc, process-oriented, product and product-service. The scale is a useful method to assess the level of each process category's implementation in a company. The assessment gives an overview of the present situation and showcases shortcomings and strong points in the case company regarding industrialization.

Q3: What is the current industrial maturity of pipe repair in the case company?

The third research question assessed the business concept's industrial maturity. The assessment was performed by conducting interviews in the case company and the results are illustrated by using the maturity model constructed in this thesis. The business concept's assessment of industrialization scored generally low levels with the overall score of maturity at 1.83 on a scale of 1 to 4.

Material Supply was identified as the strongest process category in the company, with the highest maturity assessment at stage 3. Material Supply has most of the industrialized aspects intact, with optimized material supply to production requirements, well-established SCM with well-chosen partners and standardization in product families in collaboration with Assembly & Logistics Unit (ALU). The possibilities for material supply as a process category are high, and ultimately maturity stage 4, product-service, is achievable. In the future, logistics as a service is a business concept, which would allow building sites a "turn-key" service by supplying materials to on site based on a comprehensive information flow gathered via digitalized tools from on-site. Material supply would therefore have a strong customer-orientation by having SCM focusing on point-of-use rather than on inventory.

The process category for Site Design, was assessed at stage 2, based on the fairly high level of site design work already performed in the case company. The most notable deficiency in the site design category is the lack of improvement of designs and continuous improvement as more information is gathered on site. Thus an emphasis should be put on continuously updating the site designs as projects advance, which would enable further standardization in the site designs for similar sites in other projects. Site design requires a sufficient information flow and digitalized methods to enable designers access to real-time information gathered from on-site.

The business concept has many aspects in it's practices already input, which enable development for higher industrial maturity. The focus should now be put on developing standardized digital solutions to a level which are applicable for the whole organization, rather than on few specific sites. SiteDrive has a lot of promise, but still needs more development to answer the variabilities occurring on-site. Resource Allocation was assessed at stage 2, but by having a transparent and real-time information on all the variance occurring in projects, a higher maturity stage in Resource Allocation can be achieved.

Documentation is already well gathered in the business concept, but even more emphasis has to be put on analyzing, and ultimately implementing, the gathered data into practice. It was apparent in the case context, that possibilities for documentation on-site are higher. A lot of “silent information” is transferred on all sites, but this information is currently documented in a very limited manner, or not at all. By incentivizing workforce to perform more comprehensive documentation on-site, a lot of additional information can be gathered which would serve the case company well to establish even stronger culture of continuous development and would allow the company to reach overall higher industrial maturity also in other process categories.

The most notable shortcomings in the business concept’s industrialization are in Work Instructions and Management. Both of the process categories were assessed at only stage 1, due to the very primitive approach to perform work. In order to industrialize work instructions and to reach a higher maturity, the case company has to apply sufficient and easy-to-use digitalized methods for workforce, in order to create coherent and standardized working methods on-site. Management was assessed at such a low level, due to a high level of personal expertise required from managers in order to produce quality projects. Management currently relies too heavily on individuals. In order to shift the focus from ad-hoc –management to process management and ultimately to product development management and customer management, standardized management processes have to be developed and applied for managers throughout the company.

The biggest constraints in industrializing pipe repair sector, and the business concept, are however not only related to the case company but rather on the construction industry itself. These cultural constraints are, unsurprisingly, most apparent in the lowest scoring process categories Work Instructions and Management. The problem therefore is not only in the case company’s implementation, but also in the whole construction ecosystem. Construction sector in it's nature is still highly dependent on workers' individual competence and experience. This approach permits ill-advised and ad-hoc driven decision-making by the workforce and management, as the current ecosystem does not support industrialization. In order for the business concept to truly experience industrialization, workforce and management has to accept a standardized way to perform work and embrace a more efficient, selfless approach which is better suited for the philosophy of industrialization. As a starting point for industrialization, management should first accept a more standardized, less personified, industrial management approach. After management has engaged to a new process, the new approach would sprinkle down and change the culture for the case company's workforce and ultimately even the whole ecosystem of construction industry.

7.2 Managerial implications

This thesis offers several implications for managers in construction industry, and specifically in pipe repair sector, to pursue further industrialization by transitioning towards modern industrial paradigms and by applying the potential of digitalization. The thesis provides not only a framework of industrial maturity model to keep score of development, but also an assessment of the case company's business concept's current status. The framework and the assessment are a comprehensive set of managerial tools, which enable development towards industrialization in a systematic and categorized manner on each main area related to production.

In order to experience higher stages of industrialization, development and implementation of a comprehensive strategy based on the assessment performed with the constructed framework is required. To achieve a comprehensive strategy for industrializing production, companies first of all have to gather the knowledge of industrialization as a concept. The literature shows that modern industrial paradigms such as 'leagility' and 'agile supply chain management' are concepts which are suitable for construction industry and have proven to be efficient in other manufacturing industries, and should therefore be viewed as useful methods for the construction industry as well.

If the managers accept the deficiencies of the current climate in the industry, and accept the inevitable disruption in their current practices as a consequence in striving towards industrialization, comprehension of the current status is required for implementation. By assessing the current level of industrial maturity in a company with the framework constructed in this thesis, objective dissection can be performed to understand the status of company's industrialization.

The most important managerial implication presented in this thesis is not only the proposition that industrialization can be quantified by having a comprehensive framework, but also the presentation of the current metrics by applying such a framework. The empirical analysis performed in this thesis with the constructed framework, enables the case company to pinpoint the weakest and strongest areas in their current practices and enables development of a strategy which pursues higher level of overall industrial maturity in the company. By applying the constructed framework, companies can therefore develop strategies which strive first and foremost to enhance the weakest areas. By having the knowledge to address these shortcomings, companies can prevent such areas from functioning as bottlenecks for further development of overall industrialization.

As presented in the empirical analysis, industrialization in the construction industry is however not only dependent on the implementation, but also on the ecosystem of the whole industry. Hence managers have to pursue the best possible outcomes until the confines of the industry are apparent. In the case company context, the boundaries of the industry are already evident in some categories even at relatively low stages of industrialization. Site design is a problematic area to develop to highest maturity stages due to the variability of the sites. It is extremely difficult to eliminate differentiation of the sites completely, as the sites are in their nature different from others. Work instructions and Management are also difficult areas to increase to the highest maturity stages due to the outdated ecosystem of the whole industry.

Case company should however strive to push these weakest areas further as there is still room for improvement until the ecosystem truly hinders the development. Product-service category, and subscription-service approach is a complex concept in the construction industry due to the current nature of the industry which approaches pipe repair as complete rectification of the site as a whole rather than as fixing elements in a just-in-time manner. If the approach can be transformed to implement fine-tuning and focus can be put more on single elements, product-service could be achievable and would allow higher customer involvement.

Industrialization of the current practices in the construction industry, with digitalization as an enabler, should be taken into consideration for the future development in the case company. As seen in the empirical analysis, digitalization and digitalized tools should not be viewed by the case company as the be-all and end-all solution, but rather as an enabler for implementing a comprehensive strategy, which focuses on industrializing the current ecosystem of construction industry. Even though the industry is complex and reluctant to evolve, there are a lot of uncovered possibilities, which allow the case company to improve in multiple areas. The potential for increasing efficiency in the case company related to production are apparent and this potential should be harnessed by implementing a strategy which increases the case company's industrialization and therefore overall competence.

7.3 Research limitations

The core limitations of this thesis concerns the chosen research method. A qualitative single-case study is a favorable method when exploring a new approach and the possibilities it introduces. The chosen method has a specific context, in which to understand the topic in an agile manner. Single-case study method however does have two major limitations. The results gathered in this thesis are limited and the reliability of the results is debatable. Also due to the nature of the research method the generalizability of the results is limited due to the case-specific approach.

The data collection for the thesis was performed by conducting a limited number of face-to-face interviews, where the interviewer steered the conversation in a favorable direction from the interviewer's perspective. Even though the interviewer allowed the conversation during the interviews to flow as naturally as possible, to allow an iterative process to take place regarding the construction of the framework, the setup of the interviews is biased for the interviewer's favor when assessing the results gathered for the assessment of the case company's maturity. The interviewer has a planned routine to conduct the interviews and is looking for specific answers which support the research.

The setup in which the interviews were conducted, emphasizes the interviewer's role and own agenda to conduct the interview in a manner which is most favorable for the interviewer and for the research. In addition to the reliability of the results regarding the conducted data collection method, the interpretation of the gathered data is possibly also skewed due to interviewer's own objectives and knowledge. An individual researcher can have biases which determine the interpretation of the gathered data.

Another limitation in this research is the generalizability of the achieved results. The research on industrialization and digitalization in construction industry focuses mainly on the case company, and specifically on the business concept in pipe repair sector. The gathered results are therefore representing the case-specific context and thus the results may not be applicable to the whole construction industry, not to mention to other industries. However, the case company can be described as an innovative company in the construction industry and the gathered knowledge regarding the case company could offer relevant insights for other companies in the industry as well. This thesis offers a framework specifically for the business concept's pipe repair purposes, but the framework could be a useful starting point for other industries as well in industrializing and digitalizing production practices.

Even though these limitations are apparent in the chosen research method, it can be argued that a qualitative single-case study's objective isn't even in the first place to generate objective and undeniable facts as conclusions. In order to research a new opportunity, interpretation of the gained insights should be allowed to be performed by the individual researcher. Hence, it should be noted that this thesis does not promote it's insights as the absolute truth, but rather aims to discover a new phenomenon in a traditional industry, explore the opportunities and inspire further discussion and development.

7.4 Avenues for future research

The area of industrialized pipe repair requires further research since the sector and digitalization is developing rapidly. As mentioned in this research, and in the constructed framework, the sub-areas regarding the production practices in the pipe repair sector affect each other. Further research, beneath the scope of this research, should be conducted on each of the sub-areas to further iterate the constructed framework.

The final step of maturity framework development is reflecting evolution of the initially designed framework. Further research and development of the designed framework model should be carried on after the establishment of the initial framework to iterate the model for the purposes of the organization. (Lahrmann et al., 2011) The framework constructed in this thesis, and the assessment of industrial maturity conducted with the framework, should therefore be viewed as the initial framework for further development. Case company should aim to develop an even more comprehensive framework for the organization's purposes to assess the organization's industrial maturity. Alterations and model deployment to the initial establishment of this thesis' framework can be conducted by performing e.g. field studies and interviews with a larger sample size in the organization.

The aim of this research was to explore opportunities industrialization and digitalization enable in a traditional and outdated construction industry. The constructed framework for measuring organization's industrial maturity assists organizations to clarify the potential for further development. The attempt of this research was not to produce a strategy to implement the gathered knowledge. In addition, this thesis does not reflect in-depth on the impact that implementation of such a strategy would have in the organization. Further research should therefore be conducted on producing a comprehensive strategy for industrializing an organization, which also takes into account the impact of implementing the strategy. By having the knowledge of all the opportunities industrialization can offer for organizations, establishing a strategy based on the knowledge and implementation of such a strategy are next steps to reap the benefits in reality.

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