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Petteri Annunen

INDUSTRIALIZATION IN CONSTRUCTION – A PROCESS MODEL FOR CAPABILITY CREATION

UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
FACULTY OF TECHNOLOGY

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Abstract

Productivity improvement in the construction industry has been modest for decades. Problems with the schedules and costs of construction projects are well documented, as are the quality problems affecting buildings. There are several reasons behind this situation, but one of the main challenges has its roots in the fragmentation of the industry, which causes several problems between different construction stakeholders—but especially between different construction projects and project phases. Furthermore, the absence of product-based thinking and process management practices causes challenges in continuous improvement between projects.

The objective of this dissertation is to boost productivity improvement by proposing an industrial operation model (IOM) for the construction industry. This dissertation presents capability creation practices—which have not been studied previously in the context of the construction industry—as a component of the IOM. This research uses qualitative interviews to study elements of the proposed IOM and capability creation practices for sales, production, and maintenance processes to create a basis for capability creation in these three operative business processes.

The results of this dissertation include preconditions and steps for construction companies to implement the IOM. As part of the IOM, the capability creation processes, roles, and practices are described for sales, production, and maintenance. Capability creation practices take the requirements of the later phases of construction projects into account during the early design phase while simultaneously improving the design itself, enhancing the preplanning of sales, production, and maintenance, and preventing many known problems across the building lifecycle. In addition, capability creation practices enable the creation of more innovative solutions for the end customer.

Keywords: capability creation, continuous improvement, early involvement, industrial operation model, operative business processes

Annunen, Petteri, Teollinen rakentaminen – Prosessimalli kyvykkyyksien luomiselle.
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Tiivistelmä

Rakennusteollisuuden tuottavuuskehitys on ollut vaatimatonta jo 1970-luvulta lähtien. Ongelmat rakennushankkeiden aikatauluissa ja kustannuksissa ovat varsin tuttuja, heikentäen samalla myös asiakkaalle myytävien tuotteiden eli rakennusten laatua. Syitä ongelmiin on monia, mutta yksi keskeisimmistä on alan pirstaloituminen, mikä aiheuttaa ongelmia sekä alan eri toimijoiden, että etenkin rakennushankkeen eri vaiheiden välillä. Samoin teollisen tuote- ja prosessiajattelun puuttuessa jatkuva parantaminen ja toiminnan tehostaminen eri projektien välillä jää vaillinaiseksi.

Tämän väitöstutkimuksen tarkoitus on edistää rakennusalan tuottavuuskehitystä kuvaamalla teollinen toimintamalli alan yritysten toiminnan tehostamiseksi. Väitöstutkimuksessa esitellään eri liiketoimintaprosessien kyvykkyyksien luomisen menetelmät, joita ei ole aiemmin tutkittu rakennusteollisuudessa. Tutkimuksessa on käytetty laadullisia haastatteluja, joilla on tutkittu teollisen toimintamallin osatekijöitä sekä kyvykkyyksien luomisen mallia myynnin, rakentamisen ja ylläpidon liiketoimintaprosessien näkökulmista, kehittäen samalla tutkittavien yritysten avulla kyvykkyyksien luomisen perusteet kaikille kolmelle liiketoimintaprosessille.

Väitöstutkimuksen tuloksena esitetään esivaatimukset ja menetelmät teollisen toimintamallin käyttöönotolle. Lisäksi kuvataan prosessit, roolit ja toimintatavat, joilla rakennusteollisuus voi huomioida myynnin, rakentamisen ja ylläpitovaiheen vaatimukset jo suunnitteluvaiheessa. Samalla suunnittelusta tulee tehokkaampaa, parannetaan myynnin, rakentamisen ja ylläpidon tehokkuutta sekä luodaan myös innovatiivisempia ratkaisuja asiakkaalle. Ja mikä tärkeintä, vältetään lukuisia ongelmia koko rakennushankkeen ja rakennuksen elinkaaren ajan.

Asiasanat: aikainen osallistaminen, jatkuva parantaminen, kyvykkyyksien luominen, teollinen toimintamalli, toiminnalliset liiketoimintaprosessit

Acknowledgments

After a 20-year career at Nokia, I needed a change. I had already been thinking about doctoral studies years prior but never started on the path until now. When Professor Harri Haapasalo presented the construction industry as one of several options for my dissertation, I made my decision quickly. My father had a lengthy career in the construction industry from the 1950s to the 1990s.

I have always liked project work and gathering empirical material, but the writing was not easy in the beginning. In addition to normal problems of the doctoral student, the world faced COVID-19 when I was just beginning to proceed with the text. Writing scientific texts without a proper work environment and with the entire family at home did not succeed at all. Nothing really progressed, and I was heavily stressed. I read the book *Writing Your Dissertation in 15 Minutes a Day* for professional tips to advance with my work. The advice it supplied included: do not undertake renovation, do not take a pet, better not to have small children, do not have too many hobbies, and also work in the evenings. Ultimately, I think I made all the "mistakes" the book listed. Nonetheless, life is full of choices, and for me, it is usually full of action.

My deepest thanks go to Professor Harri Haapasalo for providing me with the opportunity to return to my school of the 90s: Industrial Engineering and Management (IEM), University of Oulu. Thank you for guiding me throughout these three and a half years and for being an active coauthor of our articles, which are the foundation of this dissertation. Furthermore, thank you, especially for pushing me tremendously through last year. Harri knows the science world, the construction business, and which strings to pull and when. Thus, things have always progressed as needed.

I am also grateful to my colleagues at the IEM unit. University Lecturer Osmo Kauppila has given me the most guidance on just about everything. Associate Professor Jukka Majava, Senior Research Fellow Janne Härkönen, and others have supported me on all kinds of questions related to this dissertation and the world of science in general. Dr. Erno Mustonen, M.Sc. Juho Tella and M.Sc. Sini Pekki have given valuable support as coauthors of our articles, Erno also as my first mentor in writing. We have had great discussions about work and this dissertation with my colleagues Joni Koskinen, Solmaz Mansoori, Juha-Antti Rankinen, Elina Jääskä, Laura Saukko and Suvi Leinonen—to name a few. Over the last one and a half years, our biweekly Friday morning coffee sessions with Kari-Pekka Tampio and

Farooq Ali have propelled me quite remarkably. Kari-Pekka is defending his dissertation 13 days before me, and Farooq will surely follow us soon.

I want to thank the preexaminers, Professor Jussi Heikkilä and CEO Juho-Kusti Kajander, for their valuable work reviewing my dissertation. Thanks also to my follow-up group, Research Manager Pekka Tervonen and Senior Research Fellow Arto Reiman, for their competent and efficient support during my journey. I have received additional funding to support my work from several foundations. For this, my sincere thanks go to the Tauno Tönning Foundation, the Riitta and Jorma J. Takanen Foundation, the Confederation of Finnish Construction Industries RT (Rakennusteollisuus RT), the real estate industry educator, Kiinko, and the Kerttu Saalasti Foundation.

I am not sure if there is even a need to thank my parents, Maila and Pentti, regarding this dissertation because there are so many much bigger things to thank them for. They have raised me and given me the foundation for my life. It is easy to build when the base is strong. My family is the most important thing in my life. I thank each of you because you are who you are. My four girls, Iina, Kerttu, Mila, and Roosa, all with different personalities, fill my days with action and my heart with pride. My loving wife Tiia is my number one supporter in the most stressful moments—always reminding me of what is important in life.

During this doctoral journey, I learned better self-management, how to get difficult things done, and how to (try to) control stress. Concurrently, I also learned about the construction business and how to give my input to the scientific world. Overall, this journey has been a wonderful learning experience.

20th October 2022 Petteri Annunen

Abbreviations and definitions

BIM	Building Information Modeling
BM	Business Model
CC	Capability Creation
CI	Continuous Improvement
DfX	Design for eXcellence
EI	Early Involvement
IOM	Industrial Operation Model
KPI	Key Performance Indicator
MCC	Maintenance Capability Creation
MCM	Maintenance Capability Manager
OBP	Operative Business Processes
PCC	Production Capability Creation
PCM	Production Capability Manager
PDM	Product Data Management
PLM	Product Lifecycle Management
SaCC	Sales Capability Creation
SaCM	Sales Capability Manager
Business Model	A business model describes how an organization creates, delivers, and captures value.
Capability	Capabilities refer to an organization's preparedness to manage and execute its key operative business processes across its entire lifecycle.
Capability Creation	Systematically building capabilities for later project phases concurrently with earlier project phases. For example, capability creation integrates the receiving business processes, such as sales, production, and maintenance processes, into the design process.
Collaborative Projects	Projects allow groups of people to work together toward joint targets with minimal constraints and can be used to work toward complex and diverse targets.
Early Involvement	Method in which stakeholders in the later project phases are engaged in the project at an early stage to offer input to the design phase.

Industrialization	Transforming the industry or a company to use repetitive products, systematic processes, and continuous improvements to increase productivity.
Industrial Operation Model	Representation of how an organization delivers value to its customers and how the organization actually runs itself; how an organization operationalizes its BM at a more detailed level.
Key Performance Indicator	Type of performance measurement. KPIs evaluate the success of an organization or a specific process, product, or activity in which the organization engages.
Lean	Management philosophy aiming to reduce waste and improve processes. Customer value and employee satisfaction take center stage in lean thinking.
Lean construction	Implementing lean in the construction industry by adopting general lean practices, especially in the design and construction phases of construction projects.
Lifecycle project	Project type used in Finnish construction business. In lifecycle project the customer and contractor make a longitudinal agreement on the design, construction and maintenance of a building.
Stakeholder	Person or organization with interest in a company or project who can affect or be affected by the project.

List of original publications

This dissertation is based on the following publications, which are referenced throughout the text using designated Roman numerals:

I Annunen, P., & Haapasalo, H. (2022). Industrial operation model for the construction industry. *International Journal of Construction Management*. https://doi.org/10.1080/15623599.2022.2092810

II Annunen, P., Mustonen, E., Härkönen, J., & Haapasalo, H. (2021). Sales capability creation during new product development – early involvement of sales. *Journal of Business & Industrial Marketing, 36*(13), 263–273. https://doi.org/10.1108/JBIM-06-2020-0274

III Annunen, P., & Haapasalo, H. (2022). Production Capability Creation (PCC) for Collaborative Construction Projects – A Qualitative Study from Finland. *Construction Economics and Building*, *22*(3), 1–20. https://doi.org/10.5130/AJCEB.v22i3.8146

IV Annunen, P., Tella, J., Pekki, S., & Haapasalo, H. (2022). Maintenance capability creation for buildings – Concurrent process with design and construction. *Journal of Facilities Management.* Advance online publication. https://doi.org/10.1108/JFM-05-2022-0052

All four original studies have been published in scientific journals and have undergone a double-blind review process. The author of this dissertation is the primary author of all four original publications. The author was responsible for formulating the research problems, collecting the relevant literature, formulating the research questions, coordinating the collection of empirical material, analyzing the material, drawing conclusions, and undertaking the role of primary author in all four publications. Exceptions are as follows: E. Mustonen coordinated the collection of empirical material in Publication II, and J. Tella and S. Pekki coordinated the collection of empirical material in Publication IV for companies A and B, respectively. In all four studies, H. Haapasalo supported in the research design and empirical source selection. All coauthors reviewed and commented on the manuscripts.

Contents

1 Introduction

1.1 Background and research environment

The construction industry has experienced only modest productivity development during recent decades (Dave, 2017; Dixit et al., 2019; Halttula et al., 2017; Jarkas et al., 2012; Pekuri et al., 2011; Teräväinen & Junnonen, 2019). One of the key root causes has been the fragmentation of construction projects, i.e., poor collaboration between constantly changing project stakeholders and poor synergy between the various project lifecycle phases and between different projects (Aapaoja et al., 2013; Alashwai & Fong, 2015; Grenzfurtner & Gronalt, 2021; Halttula et al., 2020; Härkönen et al., 2019; Khoshgoftar et al., 2010; Larsen et al., 2018).

The construction industry traditionally uses design–bid–build contract models for projects (Walker, 2018). In the design–bid–build project model, the main designer is chosen by the client. During the design phase, the customer organizes a competitive tendering process through which a contractor is selected to manage the construction phase. The lowest-cost bid usually wins, typically leading to problems later, especially with complex or extensive projects involving copious design work. Additions and changes during the construction phase mean that the main contractor and the subcontractors can then charge the customer for the extra work (Halttula et al., 2015). Consequently, project costs and schedules are usually affected (Yeganeh et al., 2019).

Using traditional project models with a *project-based* mindset has also caused several problems with key processes and information sharing (Halttula et al., 2015; Johnsson, 2013; Sarhan et al., 2018). Steep division into design, construction, and maintenance phases, and poor synergy between these phases hinders projects from succeeding and causes several problems that impact quality, schedule, and costs (AlMunifi & Almutairi, 2021; Ebekozien, 2021; Ebekozien et al., 2022; Hassanain et al., 2019; Hauashdh et al., 2022; Love et al., 2004; Ulrich & Eppinger, 2008; Waziri, 2016). The project-based mindset and its attendant problems that plague the transition between project phases impede the progress of process development, often causing the projects to begin from scratch without the possibility of improving through repetitiveness (Halttula et al., 2020; Lessing, 2015).

Recently, the construction industry has begun introducing the utilization of lean principles in a bid for improved productivity (Mesa et al., 2019). Lean is a philosophy aimed at designing and managing processes to minimize waste and maximize value for the customer (Ohno, 1998; Womack & Jones, 2003). The key principles of lean construction are customer focus, culture and people, waste elimination, and continuous improvement (CI). Lean is an integral component of the development of the construction industry, analogous to other industries (Young et al., 2016). The construction industry is adopting new lean-related operational methods and practices from other industries, including process management principles, product-related inventions such as modularization, and new data management practices (Alaloul et al., 2020).

One of the fundaments in lean involves decreasing variation and achieving efficient reiteration through a scale of benefits (Liker & Morgan, 2006). A *product-led* strategy, beginning with systematic product development and leading to product platforms and repetitive modular products, systematizes product offerings and ultimately facilitates the standardization of these processes (Jansson et al., 2014; Jensen, 2014; Lessing, 2015; Liker & Morgan, 2006). A new type of product-led management, with standardized and repetitive processes, is integral to reducing errors, providing consistent service, and mastering performance (Liker, 2004). Standardized and repetitive processes increase efficiency, allow a step-by-step introduction of automation, and ultimately, enable benefiting from economies of scale in the construction industry (Andersson & Lessing, 2020; Höök, 2008; Stehn et al., 2021).

The two key dimensions in lean for efficient processes are a continuous flow in the sequence of activities within a project and the process of repetitiveness between projects (cf. Ohno, 1998), which are at the core of development in many other industries (Womack & Jones, 2003). These two dimensions of fragmentation in the construction industry are illustrated in Figure 1. Fragmentation between the project phases means that due to missing processes and practices, there is no flow of information and knowledge between the project phase, e.g., between the design phase and the construction phase. Fragmentation across the project is caused by missing products and processes, causing new projects to begin development practically from scratch every time.

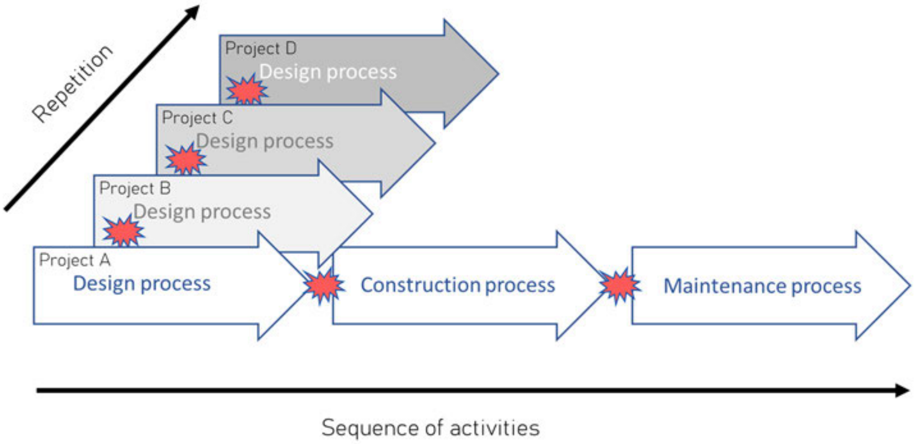

Fig. 1. Fragmentation in the construction industry. Key problem areas lie between the project phases and between projects.

The foundation of any company must be its strategy and its business model (BM) (Johnson et al., 2008). In industrial companies, repetitive products, systematized processes, and continuous improvement are part of an industrial operation model (IOM) through which the BM is operationalized at a finely detailed level (Brege et al., 2014; Osterwalder, 2004; Pekuri et al., 2015). With an IOM, a company can illustrate how it delivers value to its customers and how it can be intentionally managed through predefined processes (Pekuri et al., 2015). To industrialize the construction industry, there is an evident need for an IOM and its implementation to enable product-led development, standardized and repetitive processes, and continuous improvement.

Capability creation processes are an aspect of systematically managed industrial companies (Isoherranen & Majava, 2018; Verrollot et al., 2017). In the capability creation (CC) concept, the planning and creation of all the key capabilities for the core processes are initiated early on during the design phase to ensure efficient project implementation and successful sales, production, and maintenance phases right from the beginning (Tolonen et al., 2017). CC processes can be considered instrumental to reducing fragmentation, especially between the different project phases, as well as between different projects (Figure 1). CC processes provide a systematic and pre-agreed way of working across the entire product lifecycle, enabling collaboration through each project phase and systematic repetition in subsequent projects.

1.2 Objectives and scope

In IOM, companies no longer design their products or services from scratch according to customer needs, whereas they can offer specialized products that enable efficient processes and improve the synchronization of the processes. As a result of IOM, construction companies can standardize their operations, supporting the reduction of variation in products and processes, and finally, improving efficiency and resulting in productivity improvement in the whole industry. To industrialize construction, the IOM is required to present how construction delivers value to customers and how the construction industry actually runs itself.

Earlier research emphasizes the importance of involving construction stakeholders during the design process but does not provide efficient solutions regarding how readiness for sales, production (construction), and maintenance can be created concurrently with the design process (Tolonen et al., 2017; Verrollot et al., 2017). Systematic processes are also missing from preplanning. Based on this assessment, the overarching research problem in this study is as follows:

> *The poor productivity development in the construction industry is caused by fragmentation and the absence of an industrial operation model. These deficiencies prevent preplanning and standardization of the processes and disallow benefiting from economies of scale.*

This dissertation aims to clarify the content and need for an IOM in the construction industry and presents the preconditions for an IOM on the path to industrialization. Based on the key elements of an IOM, this dissertation presents essential CC processes for the construction industry, aimed at efficiently synchronizing the operative business processes through early involvement and systematic preplanning. This dissertation describes how to create the capabilities for sales, production, and maintenance already in the design phase of the construction project. In this study, CC processes are positioned as an integral part of the proposed IOM.

To achieve the objective, the research topic has been divided into four publications, which have been explored with dedicated research questions (RQs), with the first, RQ1, concentrating on the IOM in the construction industry, and the analogous RQ2, RQ3, and RQ4, focusing on studying the CC principle step by step, introducing the concept within the scope of each operative business process (OBP). Therefore, the primary objective has been divided into the following detailed RQs:

RQ1: What are the elements of an IOM in the construction industry?

RQ2: How to establish a sales capability creation (SaCC) process?

RQ3: How to establish a production capability creation (PCC) process?

RQ4: How to establish a maintenance capability creation (MCC) process?

This dissertation comprises four publications constituting the entire content of the study. Basic information on the publications is presented in Table 2.

Table 2. Publications and research questions.

Publication	RQ#	Publication title	Publication forum
I	RQ1	Industrial operation model for the construction industry	International Journal of Construction Management
II	RQ2	Sales capability creation during new product development – Early involvement of sales	Journal of Business and Industrial Marketing
III	RQ3	Production capability creation for collaborative construction projects	Construction Economics and Building
IV	RQ4	Maintenance capability creation for buildings – Concurrent process with design and construction	Journal of Facilities Management

The logic of the publications is presented in Figure 2. Publication I defines the main elements of an IOM as a critical basis for effective OBPs in the construction industry. Publications II, III, and IV define how three OBPs—the sales process, production process, and maintenance process—are preplanned and synchronized in every project concurrently with the design phase, using different setups to demonstrate the functionality of the processes.

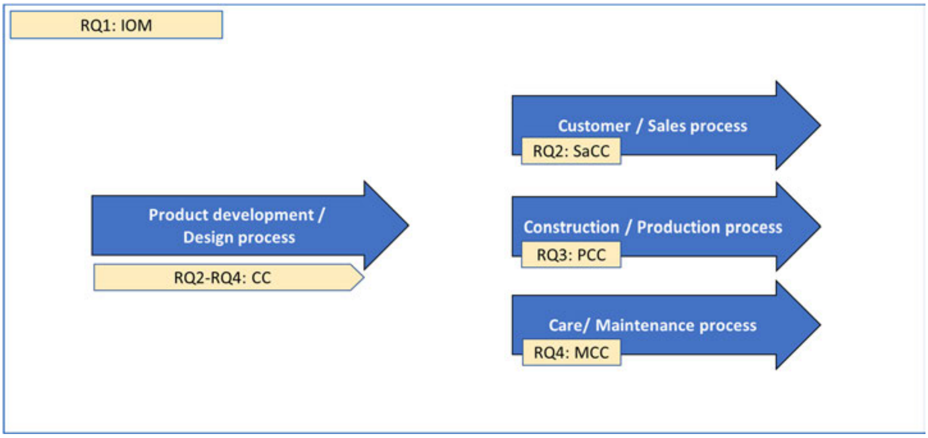

Fig. 2. Logic of the publications.

These four publications are integrated with the dedicated RQs, contributing to the primary objective. The first study answers RQ1 by defining the theoretical foundation for an industrial operation model, investigating the current state of IOM elements in real construction companies, and defining the preconditions for implementing an IOM in the construction industry. The second publication answers RQ2 via its exploration of the cornerstones supporting sales capability creation, the status of the SaCC in real companies, and the question of how systematic SaCC should be described as a process. The second publication builds up basic knowledge and possibilities of CC processes in an environment with established and effective processes within an advanced industry.

Publication III answers RQ3 via its study of the CC methodology in the construction environment, especially in a collaborative project environment, with tight synergy between the design and production phases as a fundamental setup. This study examines the critical issues during the production (construction) phase and how those should preemptively be addressed early on during the design phase of the project. Furthermore, this publication describes the main PCC areas and activities for the construction industry. In the fourth publication of this dissertation, RQ4 is answered by defining the key elements involved in creating the capabilities for the maintenance of lifecycle projects in construction, then studying the key challenges in the area, and presenting a detailed setup for the MCC process. Lifecycle projects are analyzed as an empirical context due to the existing synergy between the design, construction, and maintenance phases.

In summary, the dissertation addresses the main research problem through four RQs. Each publication contributes to the research problem from its own viewpoint but in an interconnected manner. The first publication defines the basis for the more detailed studies in Publications II–IV, which present the key principles of the CC methodology for use in the construction industry.

1.3 Research process

In science philosophy, scientific research includes fundamental philosophical assumptions related to ontology, epistemology, and axiology (Bryman & Bell, 2011; Saunders et al., 2016).

Ontology describes reality and how the studied phenomena are related to reality. Ontological assumptions affect the research setup and how the research is conducted (Guba & Lincoln, 1994). Ontology can be divided into subjectivism and objectivism, where objectivism assumes that research is based on facts that are the same for everyone, and reality exists without social actors. Subjectivism assumes that studied phenomena are created by people affecting the environment and that reality is created by social actors. In pragmatism, both objectivism and subjectivism are viable. In pragmatism, reality exists when social actors utilize information and theories (Bryman & Bell, 2011). The setup of this research has aspects of both objectivism and subjectivism; however, the setup leans most closely toward pragmatism.

Epistemology is an area of science philosophy that involves the study of what is considered appropriate knowledge in a field of study. The crucial point is whether the social world can be studied using the same methods applied in the natural sciences. The opposing aspects of epistemology are positivism and interpretivism. Positivism assumes that principles from the natural sciences can be used when studying social reality. In strict positivism, only observed and measured information is credible. Interpretivism assumes that social actions cannot be measured using the methods employed in the natural sciences alone, and that study results always require some interpretation and cannot be generalized as strict laws (Saunders et al., 2016). This study can be considered as primarily interpretative because the topics studied cannot be measured through causal regularities as in natural sciences, as social actors impact the outcomes. In this study, it has been important to build the research setup carefully, based on approved theories—a stable research setup surveying experienced interviewees to achieve results and implications that are as credible as possible.

Axiology is related to how the researchers' individual goals and values affect the research (Easton, 1995). If the data is independent of the researcher, and the researcher maintains an objective stance, then the research can be said to be value-free. If the researcher is biased toward interviewees and his/her own cultural experiences, the research is value-bound. In the midpoint of these axiological aspects, there is value-driven research, in which the researcher's doubts and beliefs initiate and sustain the research (Saunders et al., 2016). This study can be considered value-driven research because the researchers have (and had) a desire to solve specific problems in the construction industry, which has driven the study. The researcher's background has inadvertently affected the research setting, even if the aim has been to have a research setting that is as value free as possible.

The research methods used in this dissertation are qualitative in nature. Qualitative research attempts to gain a deep understanding of the people and phenomena studied, including the cultural and societal contexts (Myers, 2019). Typically viewed as the opposite of qualitative research, quantitative research uses statistical analysis and, for example, broader queries with numerical questions for larger numbers of respondents. Qualitative research is often conducted using unstructured or semi-structured interviews to allow respondents to present their views on the research topic without any constraints. The downside to qualitative studies is that it is usually difficult for other researchers to replicate that exact study, and there can only be a weak generalization of the results (Saunders et al., 2016). The novelty and complexity of this study have been the reasoning behind the choice to use qualitative research methods to understand the chosen subject area in depth within a specific context.

The research setup can be approached from a deductive or inductive perspective. In the deductive approach, research progresses from general ideas to specific conclusions, while in the inductive approach, specific observations form general conclusions. In other words, in the inductive approach, data collection and analysis are used to develop a theory. Typically, the inductive approach is associated with interpretivism, focusing on collecting qualitative data and trying to understand the studied phenomena (Bryman & Bell, 2011). This study uses an inductive approach to gather qualitative data via semi-structured interviews and presents generalizable conclusions. The philosophical positioning of this dissertation is presented in Figure 3.

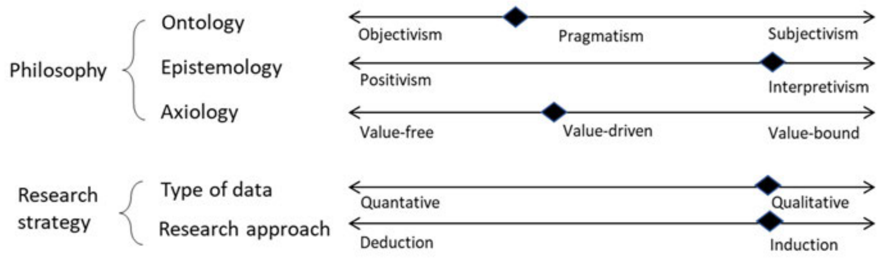

Fig. 3. Philosophical positioning of this dissertation.

The research process is presented in Figure 4. Each publication commenced with the creation of its theoretical foundation. The review focuses on the main topic of each research question in this dissertation. Relevant literature was reviewed, with web search engines (e.g., Google Scholar and Scopus) used to find all the necessary information for the theoretical foundation. The literature reviewed comprises mainly original studies published in research journals and several books. The interview questions for semi-structured qualitative interviews (Bryman & Bell, 2011; Clifford et al., 2016) were created based on the literature review.

Each publication had a different scope, serving the entity described and determining the choice of the interviewee companies. In Publication I, a broad selection of different kinds of construction companies was chosen for the formulation of an IOM. In Publications II, III, and IV, the interviewee companies were selected to support the research topic and to achieve results that were as refined as possible. The companies are listed in Table 3 (51 interviewees across 23 construction companies A–W) and Table 4 (18 interviewees across seven high-tech companies A–G). An analysis of the empirical findings was performed in Publications I, II, and III, along with content analysis (Duriau et al., 2007), and thematical analysis (Braun & Clarke, 2006) in Publication IV.

In Publications II, III, and IV, validation was conducted to confirm and potentially finetune the findings from the analysis. In Publication II, the proposed SaCC process was presented to interviewees to receive their opinions and proposed updates and to have the process scrutinized against real-life use. In Publication III, three experts (who did not participate in the first set of interviews) were invited to validate the study findings and support formulating the PCC process areas and activities. In Publication IV, the full MCC process, with detailed activities, was validated via a company adopting the process and putting it to use.

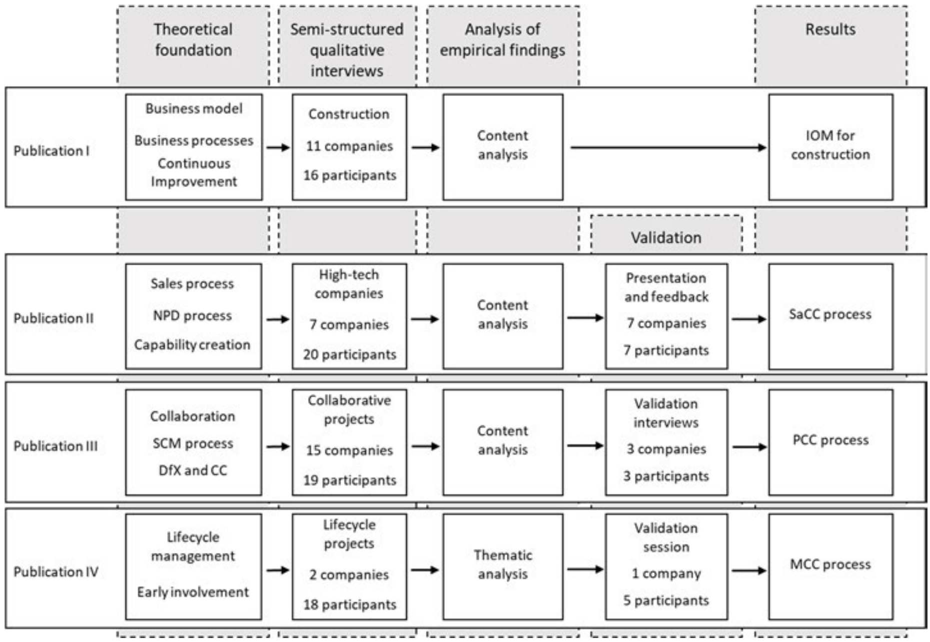

Fig. 4. Synchronized overarching research processes in the publications.

Table 3. Participating construction companies and their characteristics: Publications I, III, and IV.

Company	Publication(s)	Size	Type of the company	The role of each informant in interviews
A	I	large	building services	area director
	III			design director
	III			builder consultant
B	I, III	large	main contractor	chief development officer
C	I	medium	main contractor	chief executive officer
	I			business manager
D	I	small	consultant	chief executive officer
E	I, III	large	main contractor	chief executive officer
	I			project manager
F	I	medium	building technology	head of R&D
	I		provider	vice president
G	I	small	architect	shareholder
H	I	micro	architect	chief executive officer
I	I	small	building services	director of development
J	I	large	building services	director of design
K	I	medium	building services	head of business area
	I			project director
	I			commercial director
L	III	small	building authority	director
M	III	small	main designer	team manager
	III			architect
N	III	large	subdesigner	executive vice-president
O	III	medium	main contractor	area director
	III			project development manager
P	III	large	main contractor	area director
Q	III	large	main contractor	head of department,
	III			production manager
R	III	large	design, maintenance	project director
	IV		and industrial	design automation designer
	IV		services	design project development manager
	IV			facility maintenance mngmt service manager
	IV			remote management specialist
	IV			2 estate management technical managers
	IV			3 facility maintenance service technicians
	IV			head of sales
	IV			development manager
	IV			innovations and dev. department manager

Company	Publication(s)	Size	Type of the company	The role of each informant in interviews
S	III	large	client/user	program director
T	III	medium	client/owner	project manager
U	III	small	consultant	managing partner
	III			partner
V	III	small	consultant	chief operating officer
W	IV	large	architecture, engineering and construction	area director
	IV			real estate area manager
	IV			design director of the lifecycle projects
	IV			property manager of the maintenance phase
	IV			manager of virtual design coordination
	IV			BIM coordinator
	IV			director of lifecycle projects
	IV			vice president of strategy and development
	IV			director of property and facilities management

Table 4. Participating high-tech companies and their characteristics (Publication II).

Company	Publication	Size	Type of the company	The role of each informant in interviews
A	II	small	designing and manufacturing of electronic components	sales manager head of product creation field application engineer
B	II	medium	designing and manufacturing of customised electronic products	senior application specialist
C	II	large	designing and manufacturing of mechanical power transmission equipment	vice president of R&D key account manager head of product lifecycle management
D	II	small	designing and manufacturing of electrical devices and solutions for medical operators	sales and marketing manager R&D director
E	II	large	manufacturing of high-end medical equipment	product manager area export manager after sales director program manager
F	II	large	leading provider of heavy equipment in its industry	director, business processes and IT sales support and process manager vice president, technology manager of engineering
G	II	large	component manufacturer of electromagnetic products	product manager production manager

The typical interview in this study involved 2–4 interviewers and 1–3 interviewees, and lasted 1–2 hours. Usually, one interviewer asked the predefined interview questions, while others took notes, with all the interviewers asking additional questions based on the answers and overall discussion. All interview sessions were recorded for detailed analysis.

2 Theoretical foundation

2.1 Theoretical framework

The theoretical framework of this dissertation is presented in Figure 5. It is essential to understand how the different discussions relate to the key items in this dissertation. In the invisible background, the scope includes the strategy of the company and the BM based on that strategy (cf. Johnson et al., 2008; Osterwalder, 2004). An IOM is needed to operationalize the BM (cf. Pekuri et al., 2015). IOM must be built on the most fundamental elements, covering OBPs, product and data, and continuous improvement (cf. Andersson & Lessing, 2020; Li et al., 2018; Liker, 2014).

The IOM and its elements are presented in Chapter 2.2, with a special focus on OBPs (i.e., design, sales, production, and maintenance) as the essential background of this dissertation. The capabilities discussed in this dissertation are to be created during the design phase for other OBPs. Early involvement is explained in Chapter 2.3, adding another important dimension to this dissertation by justifying the importance of having involvement of the later project phase early on at the front end of the project (cf. Aapaoja & Haapasalo, 2014). Early involvement is critical to understanding the nature of CC processes as a synergistic link between the project phases. In Chapter 2.4, earlier research on the capability creation process is explained in detail, exploring the key theoretical elements of CC and how it should be utilized to enhance the success of the companies (Tolonen et al., 2017). CC processes are critical to understanding how these processes improve performance in other industries and to identifying the cornerstones for building these processes in the construction industry.

The primary theoretical elements described are critical for understanding the background of this dissertation and the empirical research performed in Publications I–IV. An IOM involves setting up an operational environment for the construction industry, and CC processes and practices are established as an integral part of the IOM. To describe the link between the IOM and the CC processes, OBPs and early involvement are required, and the efficient implementation of both is achieved with the CC processes (Tolonen et al., 2017).

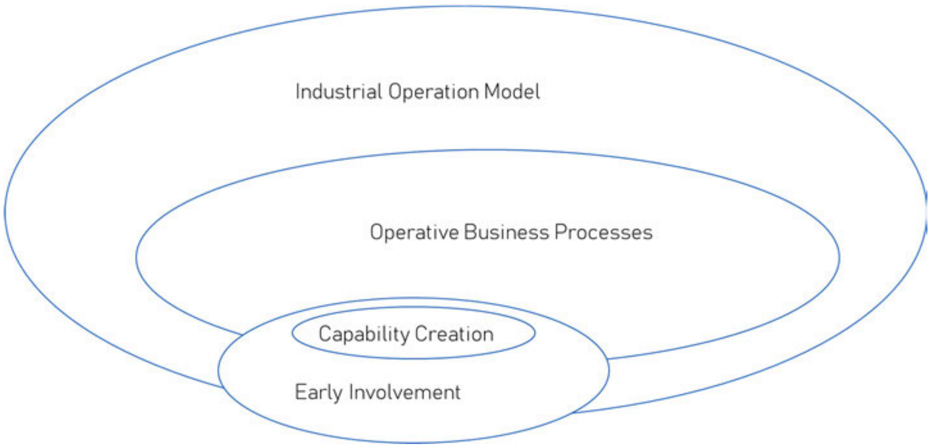

Fig. 5. Theoretical scope of this dissertation.

To concentrate on the discussions most relevant to this thesis, some related discussions in the literature have been mentioned or presented only at the general level in the literature review in this dissertation.

One of the out-scoped but related topics is the detailed design process in different engineering disciplines. Pikas et al. (2015) presents the overall construction design process in two stages: schematic design and preliminary design, which are divided into 24 design tasks owned by the architect, structural designer, and building services engineer. Important aspects in the construction design are the modularization and open building concepts, which are integral to future design methods aimed at industrialization (Cuperus & Napolitano, 2005; Zhang et al., 2016). Furthermore, these modularization and open building concepts can be considered to have similarities with the lean construction principles of batch sizes and flow (Cuperus & Napolitano, 2005). Nonetheless, this research does not aim to improve the design method itself but to increase the synergy between the design phase and later phases of a construction project.

Another related area is the different types of construction project models. Traditional project models such as design–bid–build and design–build have significant differences from collaborative project models, such as project partnering (Borve et al., 2017), project alliances (Ross, 2003), and integrated project deliveries (Walker, 2018). In addition, there are several other project types, such as lifecycle projects in Finland (Kerosuo et al., 2012). All these project types trigger specific special issues with IOM and CC implementation; hence, the relevant project models have been chosen as part of this research based on suitability. Nonetheless, this research has been performed with an eye on the other project models, such that the results can be utilized across the construction industry.

Lean has been an integral part of the construction industry's recent evolution (Martinez et al., 2019), and the industry has begun applying several lean tools and methods to improve productivity in construction, such as the lean project delivery system (LPDS) described by Ballard and Howell (2003), which is widely regarded as a key method (Mesa et al., 2019). Furthermore, big room, last planner, takt time, value stream mapping, visualization, and other lean tools have played an increasingly important role in construction industry projects (Hietajärvi et al., 2017b; Tampio & Haapasalo, 2022). The basic philosophy of lean is essential to this dissertation, but detailed tools and methods are not presented, as they are not at the core of this research.

2.2 Industrial operation model

To build the industrial operation model, the foundation shall be firm. Osterwalder (2004) presented a widely used definition of a successful and systematic business with three layers of business sustainability (Figure 6). In the top of the model there is the strategy layer (planning) leading vision, goals, and objectives of the company. In the middle layer the business model (architecture) describes the money earning logic. The final layer is processes, guiding the implementation of the strategy and business model and including the organization and actual workflow. The industrialization of the construction business cannot be built with fundamentally different kind of setup (Brege et al., 2014; Pekuri et al., 2014).

Fig. 6. Layers for successful business (Modified from Osterwalder, 2004).

The purpose of a business model is to present the revenue logic of the company, but it also supports as the concrete management method in describing and communicating the logic of a company (Johnson et al., 2008; Osterwalder, 2004).

The BM in construction industry should include three main elements (Brege et al., 2014; Pekuri et al., 2013; Suikki et al., 2006):

- the offering, defining products and services, which create value for the customers. Efficient research and development processes may be key in creating the offering
- the value creation system, including all processes and resources required for project execution, from customer order to actual delivery of the product or service and
- the revenue model, describing how the company attain value from the projects and how it creates money

However, construction companies have had difficulties in defining their BM logic (Abeynayake et al., 2021). Products are usually not defined, and the product selection is not systematic. Typically, construction companies apply cost-based pricing for a wide variety of project types. They do not choose the projects fitting their BM, which would support achieving the benefits of scale (Pekuri et al., 2015). Unawareness of the intent of the actions lead to the unintended use of processes and resources, affecting the performance of the construction companies negatively (Höök et al., 2015).

Already Porter (1987) noted that companies can succeed if they have the competitive advantage through their BM. Benefits of the scale can be built based on systematic and repetitive processes, with products fitting to BM (Chandler, 1993; Liker, 2014; Lillrank, 2002), while modular and repeatable product architecture supports industrialization (Lessing, 2015). The product portfolio of the company needs to be built on strengths and competencies of the company (Tolonen et al., 2015a). Additionally, BM is a key requirement for the data management, especially Industry 4.0 bringing in the new requirements for the construction industry (Das et al., 2021).

To summarize, efficient implementation of the BM enables the starting point for the IOM, which is operationalizing BM. Industrialization is built on product platforms benefiting from modularization and standardized processes (Andersson & Lessing 2020; Höök, 2008; Jansson et al., 2014; Jensen, 2014; Stehn et al., 2021). Cooperating operational processes (e.g., product process, customer process, supply chain process and maintenance process) are essential when building the efficiency (Goulding et al., 2015; Tolonen, Härkönen, et al., 2015). At the same time, product and process data needs to be managed systematically (Li et al., 2018; Tolonen, Shahmarichatghieh et al., 2015). Continuous Improvement fulfills the IOM with supportive culture, an improvement process, actual shop floor management system and with the performance management system including targets and key performance indicators (KPIs) (Liker, 2014).

The literature review from 55 original studies published during 1993–2019 supports these views, including product and process management and efficient CI practices as part of critical success factors in the construction industry (Wuni & Shen, 2020). Figure 7 presents the basic elements of the IOM for the construction industry, Chapters 2.2.1–2.2.3 sharing insights to the included main elements.

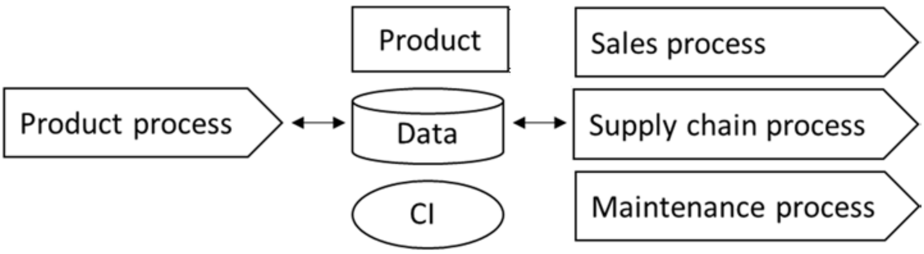

Fig. 7. Basic elements for industrial operation model (Modified from Silvola, 2018).

2.2.1 Product and data

A product is the item offered for sale. A product can be a service or a physical product. Stark (2015) describes product lifecycle management (PLM) as an area of business management, where products of the company are managed efficiently during their whole lifecycle. Product lifecycle includes all process phases from initial business idea up to the product removal. All the process phases should have requirements to produce, utilize and maintain data (Crnkovic et al., 2003; Stark, 2015). This applies also to construction, where product lifecycle typically includes four phases, depending on the project model used: preplanning, design, construction and maintenance (Halttula et al., 2020). Target of the PLM is to coordinate the product, product related data and the processes of the company according to strategy and the business model of the company (Saaksvuori & Immonen, 2008).

The product is managed through its lifecycle with PLM systems, supporting especially in process management and information management. PLM systems can be centralized data systems, which can be utilized by all the operational business processes of the company (Tolonen, Shahmarichatghieh et al., 2015). In construction, BIM is aimed for the purpose, although it is not yet fulfilling requirements of the efficient PLM tool (Jupp, 2013, Mansoori et al., 2022). PLM requires product data management (PDM) to manage the products through the whole product lifecycle and to manage the operative business processes (OBPs) (Gimenez et al., 2008).

One of the most important areas of product data management is data governance. According Halttula et al. (2020) it includes data quality, consistency, security, usability, and availability. Data owner is an especially important role for the data management and maintenance, leading the development and acting as a key contact related to data (Silvola et al., 2019).

Today, digitalization is enhancing the construction industry making the data usage and process management more efficient. At the moment building information modeling (BIM) is seen as an answer to digitalisation in construction, supporting the productivity development. Halttula et al. (2020) argues, that BIM today is answering to the challenge mainly in the planning level, but not yet in the practical implementation. Known problems in the industry are software problems, missing data and mismatch of the different data systems (Gao & Pishdad-Bozorgi, 2019; Mansoori et al., 2022). Focus on BIM development should be in the processes from the design phase up to the maintenance phase. BIM deployment would have better foundation for success, if solving the problems in the operative business processes would be the first priority (Eastman et al., 2008; Halttula et al., 2020).

Process management is also heavily linked to PDM, because all process data needs to be easily accessible to needed stakeholders (Li et al., 2018). On the other hand, PDM tools and concepts support successful operational business process management (Silvola et al., 2011).

2.2.2 Operative business processes

Operative business processes are in key position when operationalizing the BM (Becker et al., 2003; Osterwalder, 2004). The logical division based on the BM is product development process and order-delivery process (Pekuri et al., 2014), where product process (design process) is creating an offering and order-delivery process is delivering value to customers. The order-delivery process can be divided into OBPs, depending on the industry and nature of the business. One commonly used division for the operative business processes is (Tolonen, Härkönen et al., 2015):

- design/ product development process
- customer/sales process
- supply chain/ production process
- maintenance/care process

A problem in the construction industry has been that processes have not been stabilizing due to project-based setup, meaning that the forming of new processes has been needed for each project (Pekuri et al., 2015). Due to this reason, it is difficult to standardize and measure and systematically manage the processes. Economies of scale are difficult to achieve, if processes change depending on the variating projects having variating demands (Lessing, 2015).

The interaction between design and other OBPs is essential (Goulding et al., 2015). Processes need to have nominated owners, explicit development responsibilities and processes must be measured against the defined goals, at the same time to measure the performance of the whole company (Tolonen, Shahmarichatghieh et al., 2015).

Design process

Product development or design process has a key role in the product lifecycle. All the decisions made in design phase affect the costs and the quality of the product and the following processes (Ulrich & Eppinger, 2008). Key processes of the company need to be aligned with the product during the design phase (Filippini et al., 2004). Design phase needs to contemplate information flows to both directions, from later process phases to the front-end and from design phase to later process phases (Lehto et al., 2011; Tolonen et al., 2017). Capabilities built parallel to design work also create market success (Tatikonda & Montoya-Weiss, 2001), design process itself supporting the efficient and systematic design work (Harmancioglu et al., 2007).

Design phase in construction industry includes several areas, which are usually the following four phases included in the Finnish national Building Information File (Rakennustieto, 2020): project planning, sketch design, general design and implementation design, all which including several sub-phases. In a systematic design process, there must cooperation with sales, supply chain and maintenance (Tolonen et al., 2017).

Sales process

Sales process is usually defined in 5–8 phases of selling, including prospecting, pre-approach, approach, presentation, overcoming objections, closing and follow-up (Moncrief & Marshall, 2005). Sales includes complex processes principles and tasks to increase margins and to create more sales (Jobber & Lancaster, 2009). Sales capability is critical to be created parallel to product development to enable efficient sales (Jobber & Lancaster, 2009).

Sales is an important part of the company, not only in selling the products of the company but also in providing the information from the customers to the design process (Morgan et al., 2019; Sundquist & Melander, 2021). Sales supports the design organization to connect with the customers and presents the new products to the customer (Malshe & Biemans, 2014). It is not a surprise that cooperation between sales and design organizations have a positive effect on the project performance and success (Gordon et al., 1997; Kang et al., 2021). It has been also studied that sales and design cooperation especially in the earliest phases of the product development is critical for the product success (Ernst et al., 2010).

Sales force resourcing to design projects correlates strongly total product development performance (Cooper et al., 2004a) and well-executed sales-related tasks during the design phase has a connection with the success of the whole company (Cooper et al., 2004b). Anyhow, sales participation in design phase has not been studied extensively enough (La Rocca et al., 2016; Malshe & Biemans, 2014). Sales capabilities and other related planning should be part of design phase, considering the requirements of both design and sales processes benefits (Barczak & Kahn, 2012). In construction, key sales principles and practices are generally similar than in other industries, although the area has been scarcely studied (Storbacka et al., 2009). In construction industry sales related processes and development are more incoherent and less studied than in many other industries because several different project types utilize different type of selling practices (Pekkanen, 2005).

Supply chain management process

Supply chain management (SCM) includes the design, planning, execution, control, and monitoring of activities in the supply chain. It focuses on optimizing and enhancing the flow and value creation in the supply chain. (Fawcett & Magnan, 2002). Christopher (2011, p. 13) defines SCM as “network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer".

For the construction business, SCM includes multiple subcontractors and businesses providing needed materials and services for the projects (McDermotti & Khalfan, 2012; Meng, 2013). Supplier relationships in the construction supply chain are usually short-term and often include conflicts (Bresnen & Marshall, 2000; Fulford & Standing, 2014; Meng, 2013; Saad et al., 2002). Supplier cooperation is also suffering from lack of collaboration, making information exchange difficult (Papadonikolaki et al., 2016; Succar, 2009). Today, a more collaborative project model presented by Dyer et al. (1998) encourage better information sharing and coordination of the tasks, improving overall performance, with better quality and lower costs. In the literature it is evident, that tighter stakeholder relationships and transparent processes are required for improving supply chain process performance in construction industry.

Supply chain (including production) is linked closely with value stream management and lean implementation (Womack & Jones, 2003). Waste reduction has been seen as one of the most important targets in the supply chain, focusing in solving the problems already in the planning phase to eliminate waste in the actual supply chain (Ohno, 1998). Ohno's seven types of waste have been studied extensively and tailored for the construction industry by Koskela (2004). Halttula et al. (2017) conducted an analysis of the wastes in construction business and listing the key ones in priority order, starting with the most important waste:

- communication and documentation
- people's unused potential
- defects
- making wrong products or services
- unnecessary movements
- inadequate processing
- making do
- overloading
- poor constructability
- overproduction
- waiting
- unnecessary transportation

All these 12 wastes in construction are directly or indirectly linked with inaccurate or incorrect planning of the supply chain in construction. Supply chain integration to design process support in improving supply chain performance and reducing the waste (Caniato & Größler, 2015).

Maintenance process

The maintenance process usually covers the longest phase in the lifecycle of the product (Cooper, 2011), and it causes a major part of the total lifetime costs of the building (Heaton et al., 2019). Facility maintenance includes in construction industry the real estate maintenance, energy management services, and facility and user services (Rakennustieto, 2013, 2020). Building management plan and maintenance manual are also essential parts of the facility maintenance (Rakennustieto, 2008, 2020). Real estate maintenance include technical services, maintenance operations, cleaning services and maintenance of outdoor areas, and facility and user services include office, lobby, canteen, security, IT, user and employee services (Rakennustieto, 2013, 2020).

Maintenance phase is often not planned well in construction (Halttula et al., 2020), especially information transfer between the phases having severe problems (Gao & Pishdad-Bozorgi, 2019). Lean methods such as last planner and big room usage are widening the focus from design and construction phases to whole lifecycle (De Silva et al., 2012), but involving the maintenance phase stakeholders to earlier project phases is missing especially in construction business (Ganisen et al., 2015). Contract models in the construction industry are one reason for this; in traditional contract models maintenance phase is usually managed with different stakeholders. In Finland, lifecycle contracts are better in paying attention to maintenance capabilities from the beginning of the project, because maintenance phase is managed and the cost covered with the same company than design and construction (Kerosuo et al., 2012).

2.2.3 Continuous improvement

Lean thinking aims for perfection, and perfection can be achieved with CI. Lean thinking considers CI and people as the most important elements of a company (Liker, 2014). PPT model proposed by Liker and Morgan (2006) includes the following elements for organising operations in an organization:

- Process
- People, including employees, teams, leaders. The suppliers and partners of the company
- Tools & technologies, which are used to support people to follow a process.

In CI, the process ownership, training of the process users and owners is essential, while developing people with systematic development plans is similarly important. Systematic leadership and management lead the CI work. (Ohno, 1998)

Successful CI includes the following key elements: a performance management system including well-managed KPIs, a shop floor management system, an improvement process (e.g. plan-do-check-act or PDCA), and culture promoting the learning from failures (Liker, 2014). Some companies have built CI organization to support the improvement, and have own organizations for advanced methods, such as Lean Six Sigma.

Continuous improvement and processes have a big role in lean thinking: the right process will produce the right results (Ohno, 1998). Systematic management and development of the processes is essential. For construction, it is important to concentrate on process development leading to industrialisation (Uusitalo & Lavikka, 2020). Project orientation, short-term agreements, and fragmented processes cause problems in the CI work in construction industry (Grenzfurtner & Gronalt, 2021). Systematic processes and systematic CI would support in these problems (Dave, 2017). While construction instruction is aiming towards lean operations with improving usage of the lean tools, the CI culture with systematic CI and competence development should be improved (Goulding et al., 2015; Mansour et al., 2021). As a summary, CI is an essential part of IOM.

2.3 Early involvement and integration

Early involvement means systematic approach, which has been taken to identify, analyze, and classify main stakeholders and to involve them in the beginning of a project, enabling stakeholders to contribute to value creation (Aapaoja & Haapasalo, 2014; Halttula et al., 2017). Early involvement enables better planning and preparation for later project phases, improving the information flow and cooperation with the stakeholders of the later project phases, both internal and external (Aapaoja & Haapasalo, 2014). Integration refers to collaborative methods and cooperative behaviour to enhance an environment where information is exchanged transparently among stakeholders, ensuring the best possible decisions in the early phases of the project (Baiden et al., 2006).

In construction industry, most projects are complex, involving many stakeholders from different levels of the project organization. This complexity affects easily the many known problems in information sharing, trust and processes (Aapaoja & Haapasalo, 2014). One of the recognized root causes for these problems is lack of collaboration between different construction project phases, e.g. between design and construction (Love et al., 2004). Early involvement of the construction and maintenance phase stakeholders would help with the problems.

One of the key methods to support early involvement in the construction industry is design for excellence (DfX). DfX is a method, which takes the requirements from the later phases of the project systematically into account already in the design phase of the project (Lehto et al., 2011). DfX covers DfA (assembly), DfT (testing), DfL (logistics). In construction, the most familiar DfX concepts are DfM (manufacturing), DfA (assembly) and DfMA (manufacturing and assembly) (Gerth et al., 2013; Lu et al., 2020).

The growing use of collaborative project models is leading to better stakeholder involvement already in the front-end of the project, when construction phase has been part of the organization from the beginning of the project (Tampio & Haapasalo, 2022). Current practices with the adopted lean tools are good starting point for future development (Halttula et al., 2020; Hietajärvi & Aaltonen, 2018). In collaborative projects, main contractors and suppliers are selected and permitted to collaborate in very early phases of the project, supporting more efficient design work (Aapaoja & Haapasalo, 2014, Hietajärvi et al., 2017a). Contractors and suppliers can collaborate in creating the most efficient delivery plan and even providing the most innovative solutions for the customer (Hietajärvi et al., 2017b). With collaborative projects and early involvement of the stakeholders, projects avoid several problems between the design and construction phases (De Blois et al., 2016).

2.4 Capability creation

Another possibility for systematic early involvement would be capability creation process. Capabilities refer to organization readiness to manage and act according to its key operative business processes over its entire lifecycle. CC processes aim to systematically build these capabilities from the beginning of the new product development (Verrollot et al., 2017). Tolonen et al. (2017) defined capability creation principles with supply chain capability creation (SCCC) based on the findings from the electronics industry. Building on that, Verrollot et al. (2017) further defined supply capability creation (SCC) process and detailed activities based on six different companies from several industries. Previous studies have also shown, that creating capabilities for care are integral for the success of the maintenance phase (Isoherranen & Majava, 2018).

Aligning the later phases of the project should start as early as possible (Van Hoek & Chapman, 2007). Customer (internal or external) inputs are vital in the design phase and should be part of the design phase (Cooper, 2019; Tih et al., 2016) Built capabilities have a positive effect on the overall performance of the company and the market success (Brahmane, 2014; Guenzi et al., 2016). Based on the analysis, the following gap is recognized in the literature:

> *Previous studies recognise the benefits building the capabilities already during design phase, but it does not explain how to systematically build the readiness and capabilities for later project phases parallel to earlier process phases.*

The main goals of the systematic CC are to improve the product design with the valuable information from later project phases and to facilitate effective management of the later project phases (Tolonen et al., 2017). As an example, the material, assembly, supplier and maintenance provider related information are available and well-utilized in design phase of the construction to create capabilities for later phases, for example by building and preparing the supply network and the supplier to fit the supply chain of the company and the project. When the construction project proceeds, the construction phase should be mainly implementing the tasks agreed, with the capabilities already agreed.

Dedicated CC manager should lead the work, for example maintenance capability manager (MCM) for the maintenance and production capability manager (PCM) for the production (construction phase). They should be persons competent in the area, e.g. PCM as competent in the production. To be able to present the requirements, constraints, and best practices for the design phase to direct the design people to work according to the best of the project (Tolonen et al., 2017)

One of the most important pre-requisites for successful capability creation are mature operative business processes (design, sales, production and maintenance). These processes must be described and managed in a proper manner, CC processes parallel to the especially with design process, but also with other OBPs. Process governance model must exist and process owners are required for both the OBPs and CCs leading the development of the processes. Efficient milestone process and related criteria are important, led by main KPIs targeting to the quality of the product itself and the quality of the related processes, subsequently leading to better time and cost management (Tolonen et al., 2017; Verrollot et al., 2017)

The key elements of the successful CC process are described in the Figure 8. The CC process is led by CC manager, who might have sub-area managers supporting the work in their sub-CC-streams. All the actions to create capabilities are defined for each stage 0–5 and the results of the stages are reviewed in gates G0–G5. Main work to create the capabilities is done in early stages, but some tasks are completed in the last stages of the process.

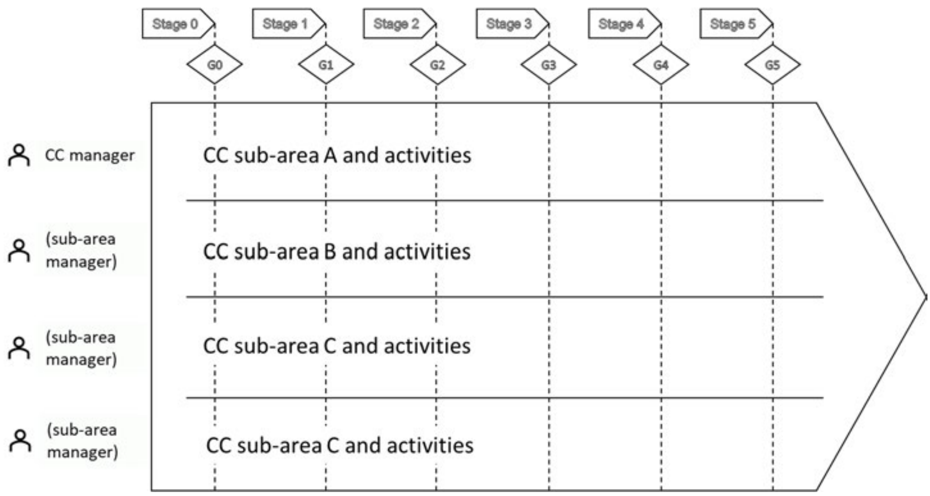

Fig. 8. Capability creation process with possible process sub-areas (Modified from Tolonen et al., 2017).

To summarize, key preconditions for successful CC process implementation are (Isoherranen & Majava, 2018; Tolonen et al., 2017; Verrollot et al., 2017)

- Operational business processes must be in place (design, sales, production and maintenance processes).
- Support processes must be in place (e.g. quality management, product management and data management processes).
- Capability creation processes must be synchronized with operative business processes. In all the process phases, all the gate reviews and with all the key KPIs.

- The requirements of later project phases need to be involved with earlier project phases, for example with DfX practices.
- Governance and roles must be in place, including global owner for the CC methodology and CC processes.

2.5 Synthesis of the literature review

Efficient implementation of a BM requires an IOM as the framework for offering a value creation system and revenue logic. It is a representation of how an organization delivers value to its customers as a component of the entire value chain and how an organization runs itself (i.e., how an organization operationalizes its BM at a finely detailed level). An IOM is built on product platforms, modularization, systematic management of product and process data, synergizing operational business processes, and CI (including the CI culture and the performance management system).

Systematic processes have not stabilized in the project-based construction industry; consequently, new versions of the processes are formed for each construction project (Pekuri et al., 2015). Therefore, standardization, measuring, and systematic management of processes have been difficult, and economies of scale have been difficult to achieve (Lessing, 2015). Industrialization with a product-based strategy can lead to improvements in systematic and repetitive OBPs (Andersson & Lessing 2020; Stehn et al., 2021).

Integration of the design process and other OBPs is essential (Goulding et al., 2015). One of the problems in the construction business has been poor information and knowledge sharing between different project phases, such as the design and production phases (Love et al., 2004). Early involvement can support the creation of the required cooperation between stakeholders in the different project phases (Halttula et al., 2017; Tampio & Haapasalo, 2022).

CC processes have been considered a link that creates flow for products in other industries and can be viewed as a missing link between the construction project phases for systematically involving stakeholders of the later project phases early on during the design phase. Operational business processes (the design process, sales process, production process, and maintenance process) must be in place for successful CC process implementation. Similarly, support processes such as product management, data management, and quality management processes are needed in the background. OBPs and CC processes need to be synchronized with the governance model, KPIs, and review practices, as in the stage-gate model (Kess & Haapasalo, 2002). A synthesis of the literature review is summarized in Table 5.

Table 5. Synthesis of the main propositions relevant to this dissertation.

Topic	Description	Proposition
Industrial operation model	Implementing an IOM is essential to successful industrialization	An IOM should be implemented in the construction industry, beginning with the sub-elements
Operative business processes	Effective OBPs are needed to implement the strategy and the BM	OBPs with governance, project-based milestones, and KPIs are integral to an IOM and required for CC processes
Early Involvement	Stakeholders are integrated and synergy between the project phases is enhanced through EI	Collaboration between construction industry stakeholders through different project phases is crucial
Capability creation	Capability creation is a method whereby later phases of the project are addressed early on	CC practices can improve the productivity and efficiency of advanced construction companies utilizing an IOM

3 Research contribution

3.1 Industrial operation model in construction industry

Publication I address RQ1 on the status of the IOM elements in construction industry, presenting the preconditions for IOM implementation. The structure of the IOM (Figure 9) is similar than in other industries, including three main elements:

- product and data
- operational business processes
- continuous improvement

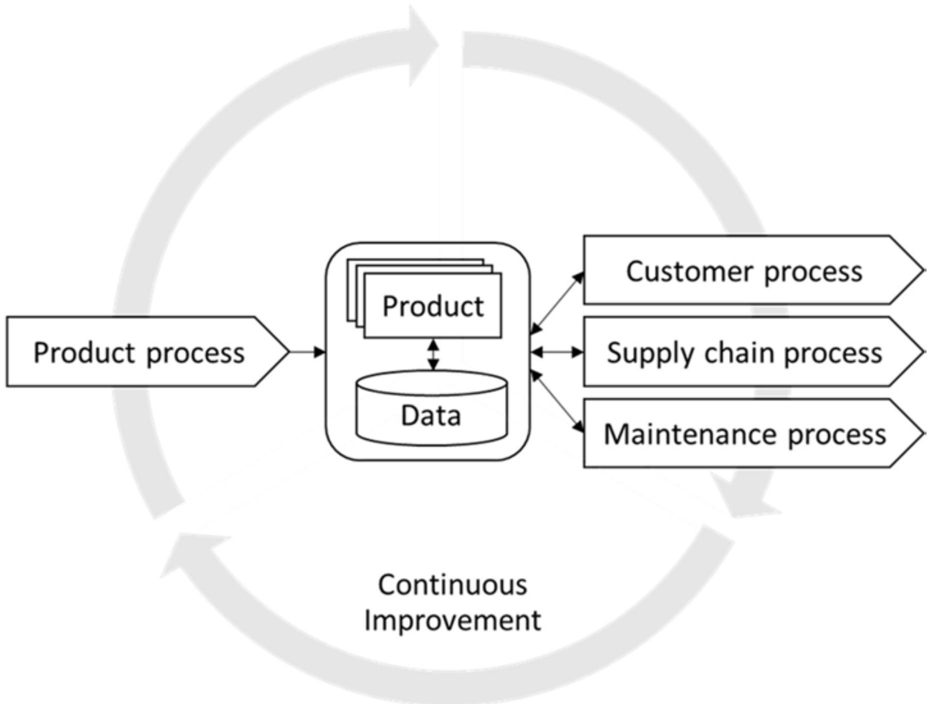

Fig. 9. Industrial operation model (Reprinted under CC BY-NC-ND 4.0 license from Publication I © 2022 Authors).

Publication I studied IOM elements in the various levels of construction industry. The findings reveal that the management of product and data related topics varied a lot in the studied companies. Construction companies had target customers and related products defined better than in engineering and service companies. Product and data related topics are in overall managed the better the larger company is, anyhow also the bigger companies have severe weaknesses in this area.

Study revealed that construction companies measure and lead projects rather than processes. Factory manufacturing processes are becoming more common with the main contractors. Anyhow, product development process is not defined in any of the studied companies. The key reason is that companies are not offering their own products but are rather working to satisfy customer needs in variating type of development projects. Similarly, most of the companies were lacking systematic CI practices, anyhow recognizing the importance of the systematic development.

The study identified a total of 21 challenges in at least one, but usually in several of the studied companies. These challenges are presented by categories in Table 6.

Table 6. IOM related key challenges in construction industry (Reprinted under CC BY-NC-ND 4.0 license from Publication I © 2022 Authors).

Main IOM elements	Key challenge	Details of the challenge
Product and data	Product definitions	A company's own products and services not always defined
	Product portfolio management	No systematic management of product portfolio; no reproducible products and services; no clear development targets
	Product architecture	Product architecture does not support modular product development for instance
	Target markets	Products do not have clearly defined customer segments
	PDM principles	PDM principles not defined; data are found in different systems; data not readily available
	Role of NPD	NPD not a key part of the company; it plays a minor role
Operative business processes	Defined key processes	Product, customer, supply chain and maintenance processes are not always defined
	Process ownership	No unambiguous ownerships and development responsibility; sometimes the ownership belongs to the management, which has no time to develop processes
	Governance and structure	Process governance within the management and between organizations is not defined
	Process development	No explicitly measurable processes; no KPIs or development targets; process development not systematic
	Process integration	Process integration to other processes and information flow between these processes usually not defined
	Standardisation	Processes not standardised, rendering the process development difficult
	Process management	Milestones or stage-gate model that support process-based management is not in use
	Focus on processes	Companies focus mainly on projects
Continuous improvement	Organization and responsibilities	Organization chart indicating one's responsibilities not always available
	Job descriptions	Job descriptions not always available
	Systematic competence development	Competence development usually exists and supports company targets but not done systematically; competence mapping not usually done
	Employee involvement	Employees not usually involved in development
	Defined development targets	Development plans partly done; KPIs and targets for CI are lacking in many companies
	Development tools and methods (e.g. Lean)	Tools and methods either lacking or not systematically used
	CI ownership	Responsibilities related to CI not always agreed upon

The construction industry is improving the operational business processes aiming for industrialisation. Due to fragmentation between the processes and projects it is difficult to develop the industry systematically.

Construction projects are often compared to prototype production, with missing or inefficient operative business processes. It is impossible to develop efficiency and difficult to utilize learned lessons if the next project is again a prototype project without an industrialized way of working. Construction companies do not have own products, making it difficult to improve productivity. With own products created by own research and development, it is possible to define product and data management principles, systematic CI and efficient OBPs and gain productivity growth with IOM-based business development.

With the challenges listed in Table 6, improving the status can start with fulfilling the basic preconditions. Business model is the foundation for IOM and all the fundamental elements of the IOM can be described with following details:

1. *Target markets and products*. Business model of the company requires specific offering and a revenue model to build the value creation system (order-delivery process).
2. *Product portfolio.* Product management and optimisation is needed to define owned/sourced products and modular/reproducible products to support IOM and to achieve the development targets for the products.
3. *Product data and process data.* Data governance and data management are important backbone for the company. Data must be maintained in one system and must be visible and available for needed stakeholders based on their roles. Processes and process data must be integrated to allow systematic management and development of the processes.
4. *Operative business processes.* Defined and standardised product process, customer process, supply chain process and maintenance process form the basis for the IOM. The customer process relates to the customer base, the supply chain process controls the inbound, in-house and outbound value chain of the company and the maintenance process includes the service, maintenance and care of existing deliveries. Measuring processes with milestones and systematic development of the processes are the key requirements for IOM.
5. *Continuous improvement.* Company culture is built on measurable CI used to develop standardised processes and to maintain product data and portfolio. Personnel involvement and systematic competence development form key part of this precondition.

6. *Governance and owners.* Efficient control and development of the main IOM elements is difficult without agreed governance model and owners for product and data, operational business processes and CI.

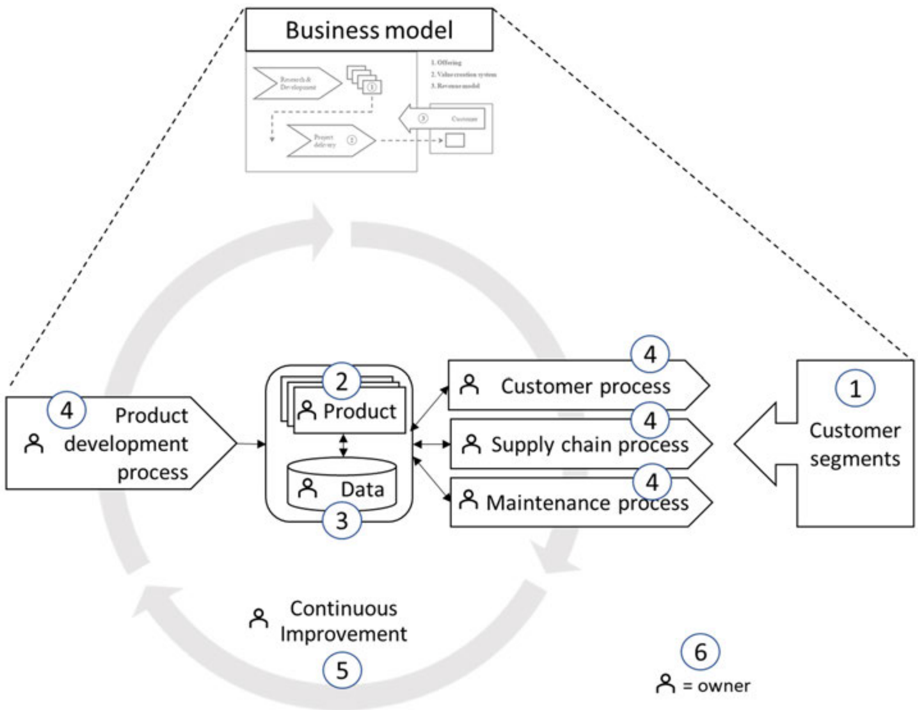

Fig. 10. Preconditions for IOM in construction (Reprinted under CC BY-NC-ND 4.0 license from Publication I © 2022 Authors).

Figure 10 describes the connections between preconditions of the IOM. Importance of the preconditions may vary, but the preconditions start from the customer segments ordering the product. Product and data form the core of the preconditions supporting the money-making machine—the operational business processes. Continuous improvement is ensuring to stay in the competition, governance and roles supporting the model.

3.2 Sales capability creation during product development

Publication II address RQ2 on the sales capability creation process as integral part of effective operative business processes. Publication II focuses on what the needed basis for creating the SaCC process are, and how the process should be built to support efficient product development process and sales process. Study was done in high-tech industry to build an understanding on how the CC process development should be done in demanding environment having key processes in place. Compared to construction companies, linking the customer processes and product development process has urgent need in high-tech companies, at the same time providing a good benchmark for the initial work in construction industry.

NPD process and sales process are the backbones of all the analysed companies. Companies have process descriptions in place, each process phase including key tasks with responsibilities and those are seen as essential. Both processes have good communication between the process phases, working documentation practices and KPIs as a basis for efficient work. Companies also had some form of a stage-gate model in use as part of their product development processes. Companies have some variation in the structure of the NPD project management team. Most of the companies have wide participation of all key organizations in NPD projects, usually sales representatives included.

Studied high-tech companies have some good practices in place for systematic SaCC, including feedback channels between NPD and sales. Several practices exist, but the implementation method is variating. Sales capability creation is currently carried out in the studied companies as part of NPD process, sales process or some other process, but in some companies, it is not done at all. Missing key elements are mainly process relationships, with some parts of the processes missing. The actual definition of the SaCC process is missing in almost all the analysed companies, and systematic management of creating sales capability is weak. Companies recognized the need for a systematic process.

Publication II proposes SaCC process based on the literature and empirical analysis. Process is built on the assumption that a company has relevant pre-requisites implemented, including NPD process, sales process, organized NPD project management team and stage-gate model in use in NPD, to ensure the needed reviews. Figure 11 presents the process landscape and the interaction of the processes. Sales capabilities are started to build in the beginning of the NPD process (and each NPD project) and the capabilities are being built throughout the project up to the launch and sales plan finalization. Sales capabilities are established before the actual sales starts.

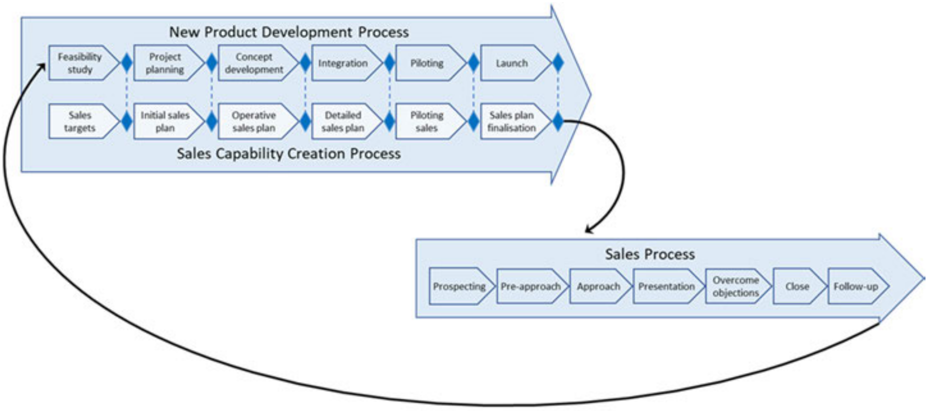

Fig. 11. The SaCC process parallel to the NPD process. The SaCC process building the capabilities for the sales process and the sales process giving inputs to the whole NPD process (Reprinted under CC BY 4.0 license from Publication II © 2021 Authors).

Detailed stages, gates and activities in each stage of the SaCC process are presented in the Figure 12. SaCC process is managed by sales organization (namely SaCC manager role) as part of NPD project management team.

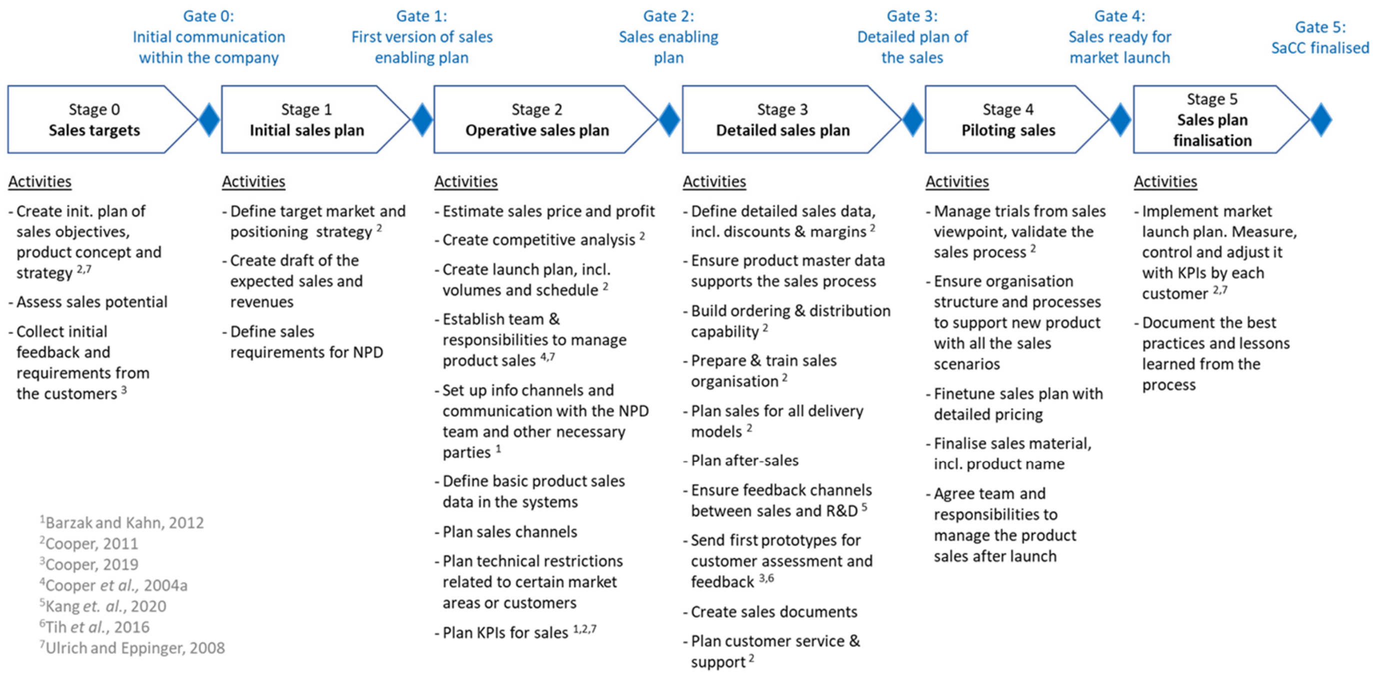

Fig. 12. Key activities in each stage of the SaCC process (Reprinted under CC BY 4.0 license from Publication II © 2021 Authors).

3.3 Production capability creation in collaborative projects

Publication III address RQ3 on production capability creation as part of effective operative business processes. Publication III focuses on the problematic areas of Finnish collaborative project production (construction) phase and proposes the PCC process structure and areas for collaborative project use. Collaborative projects form a good basis for CC processes, due to already established links between the project phases, especially between the design and production phase.

The study revealed that biggest problems in the production phase are from analysis point of view basically the same as the key issues requiring preplanning in design phase (Table 7). The typology of the key issues requiring preplanning were quite consistent throughout all the interviewed stakeholders, whether they were main contractors, subcontractors, designers, owner or a client. Some issues were related to collaborative project arrangement (e.g., big room working efficiency), but some of the issues do relate to all construction project types.

Table 7. Key issues requiring preplanning in the design phase to ensure an efficient production phase (Reprinted under CC BY 4.0 license from Publication III © 2022 Authors).

Key issue requiring preplanning	More detailed description of the issue causing challenges in the production phase
1. Change management in the production phase	The change management process is not defined well enough. There are too many changes in production phase, and these are not managed in a proper way.
2. Big room	Working efficiency in big room is low. The right people are not in the right place at the right time. Facilitators are missing.
3. Decision management	Decisions are delayed and are not properly communicated. Forming of the decision board is a problem.
4. How a collaborative organization is formed roles and responsibilities	The user and especially the customer have too small role in the management group; they are not properly allocated to the project. Construction companies are not sufficiently involved in the design phase.
5. Subcontracting	Subcontracting decisions should be made earlier to involve the subcontractors. Subcontractors should be reliable with high-quality supply chains.
6. KPIs and target setting	Target setting should be visible. KPIs should guide the work in the right direction and should as far as possible be in real-time.

Key issue requiring preplanning	More detailed description of the issue causing challenges in the production phase
7. Training, teaching, lessons to learn	Training and lessons to learn are not utilized as they should be; people are not participating in training.
8. Clear and exact project requirements	The customer does not make sufficient effort, especially at the beginning of the project. The project owner must set more precise starting points.
9. Lack of communication, shared expertise	Designers do not sufficiently participate in common project work, and construction companies do not participate enough in the design phase. Best practices should be shared.
10. Transparency/cooperation	People are too used to working with traditional design–bid–build projects, making it more difficult to begin working together for the common good, and company boundaries remain in place.
11. Design phase readiness	Development work ends too early because of time pressure. Construction companies should be involved earlier and be trained in a timely fashion to be ready for the production phase.
12. Quality and innovation management	Quality management is of importance throughout the project; innovation workshops should be organized to boost collaboration and development.

These 12 key issues were then used in CC process concept and combined after analysis into the PCC areas. Areas were created based on the literature and validation interviews with three experienced construction industry representatives (Table 8).

Table 8. Main areas of production capability creation in collaborative projects (Reprinted under CC BY 4.0 license from Publication III © 2022 Authors).

Area of production capability creation	Activities included in the area (numerals refer to key issue requiring preplanning number in Table 7)
Collaboration capability creation	Forming and maintaining organization setup [4, 8] Defined roles and responsibilities for activities Efficient and transparent decision management [3] Change management process and practices [1] Communication methods [9, 10] Defined follow-up training [7]
Production process capability creation	Production and material management (both onsite and prefabrication) Time management (scheduling and follow-up) Risk management [12] Cost management (TVD, close follow-up of KPIs) [6] Quality management (including big room and innovation practices) [2,12] Safety and environmental management

Area of production capability creation	Activities included in the area (numerals refer to key issue requiring preplanning number in Table 7)
Sourcing capability creation	Supplier selection process [5] Affective supplier management [5] Subcontracting [5] Purchasing [5] Logistics and site logistics–related methods

First area of PCC is collaboration capability creation, including many of the key challenges found in first interviews, namely related to organizational setup, decision management, change management, communication methods and trainings. Area includes all the project setup related general capabilities.

Production process capability creation includes construction related, more technical activities. From the first round of interviews cost management, quality management and risk management related topics, but also important construction related areas such as production and material management (both onsite and prefabrication). Time management with for example takt time planning is included and growing area of safety and environmental management concludes the area.

Sourcing capability creation includes all activities related to suppliers and subcontractors, from supplier selection to effective management of supplier relationships. Logistics and site logistics belonging to this area.

PCC process with general setup is presented in the Figure 13, with three main areas of the process as part of a collaborative construction project. Project phases 1–6 and milestones 1–6 are described according to current Finnish construction project phases used in collaborative projects.

Phases and milestones can be modified based on the phases used in the local process. The model includes production capability manager (PCM) leading capability creation work already during the design phase. PCM needs to be part of the respective management team leading the design phase. In larger projects, there might be needed production process capability creation manager or sourcing capability creation manager, but in smaller projects PCM can manage all these three main areas.

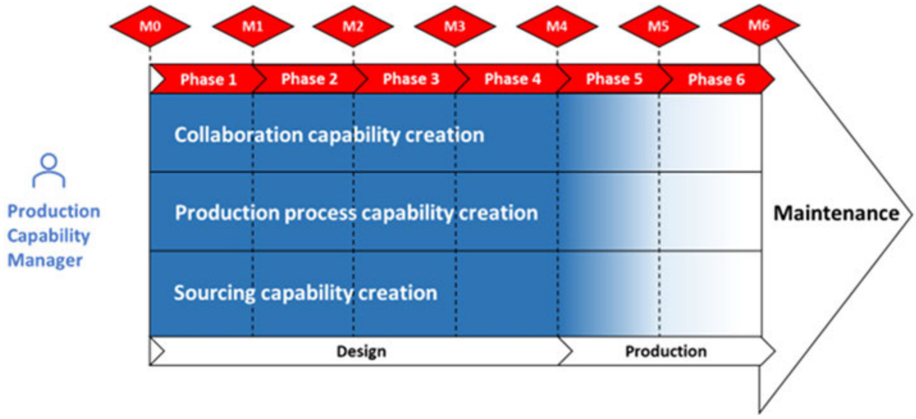

Fig. 13. PCC process structure with collaborative construction project (Reprinted under CC BY 4.0 license from Publication III © 2022 Authors).

It is critical to agree activities and tasks for each project phase to managed by responsible persons. And to be followed up in each milestone review by the milestone review team during collaborative projects.

3.4 Maintenance capability creation in lifecycle projects

Publication IV address RQ4 on the maintenance capability creation as part of effective operative business processes. Publication IV focuses on the maintenance of Finnish construction lifecycle projects and proposes the MCC process structure and areas with detailed elements and activities. Lifecycle projects form a good basis for MCC processes, because all construction project key phases are managed by the same company, easing the building of the new way of work, involving stakeholders from the maintenance already in design and construction phase.

Study started with finding the challenges in the maintenance phase of the construction projects in two large construction companies acting in maintenance phase. As Figure 14 presents, most of the depicted challenges are associated with data. Challenges were combined into five categories, where first relates to poor cooperation between project phases, three following categories relate to data and final category relate to people.

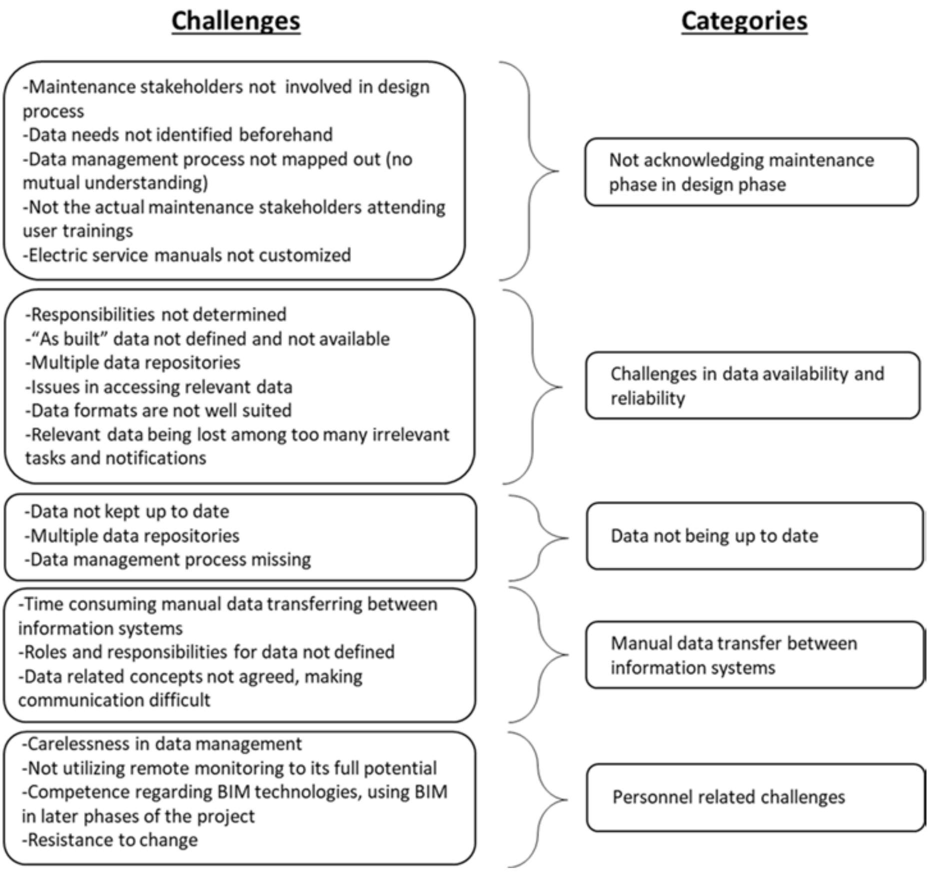

Fig. 14. Depicted challenges in the analysis of maintenance activities in the case companies (Reprinted under CC BY 4.0 license from Publication IV © 2022 Authors).

To describe the MCC process for the use of one of the two studied companies, we organized a second round of interviews concentrating specifically on the items found from the literature and findings from the first interviews. The results of this analysis are shown in Table 9, presenting 4 MCC areas and 12 MCC elements with key requirements and activities.

Table 9. 4 MCC areas and 12 MCC elements, with associated key requirements and activities (Adapted under CC BY 4.0 license from Publication IV © 2022 Authors).

MCC area	MCC element	Key requirements and activities in the design and construction phases
I. Service and maintenance	Real estate maintenance	Choose and involve service partners. Create the needed practices and foundation for successful technical services, real estate maintenance, cleaning services and maintenance of outdoor areas. Select necessary tools, building elements and materials from a maintenance point of view. Take care of device and system requirements of the maintenance phase.
	Energy management services	Choose and involve energy management service partner. Ensure proper energy usage and energy-efficient target setting, simulations and tests during the design phase and achievement of the targets for the maintenance phase. Notice and create energy consumption, follow-up and savings-related capabilities.
	Facility and user services	Plan and ensure maintenance phase readiness according to requirements for the office, lobby, canteen, security, IT, user and other employee services. Choose and involve required service partners.
	Building management plan and maintenance manual	Start the creation of a building management plan and the electrical service book at the beginning of the project. Choose and involve the BM service partner. Define the correct contents of the BMP and maintenance manual during the design and construction phases. Ensure the correct IT systems and necessary instructions to use and maintain BMP and the maintenance manual during the maintenance phase.
	Sourcing and logistics	Note sourcing and logistics requirements and ensure seamless functioning of these in the maintenance phase. Ensure that the required equipment (e.g. spare parts) is available in the correct place on the required schedule. Agree on suppliers, required materials and define the logistics process for main supplies in the maintenance phase. Ensure the availability of the most critical materials for the whole maintenance phase. Prepare and agree on contracts with the key suppliers and service providers.
II. Quality	Quality management	Define and implement quality requirements for service partners and stakeholders with agreed responsibilities (operative management, cleaning services, outdoor area maintenance). Define quality follow-up and testing practices and schedule for the maintenance phase. Implement customer satisfaction measurements and auditing practices.
	Reporting and coordination	Ensure the capability to follow-up on maintenance phase service and quality for both personnel and data systems. Build reporting and control systems for maintenance.

MCC area	MCC element	Key requirements and activities in the design and construction phases
III. Data and product	Data management	Create instructions, practices and governance to ensure good data management capabilities during the design, construction and maintenance phases. Create capabilities to utilise, create, store, update and archive the data efficiently with the data management systems. Define communication channels and the data transfer policy. Implement a centralised PDM system, including responsibilities. Harmonise data updates and software interfaces with as much automation as possible.
	Product management	Specify instructions to create a product structure to ensure maintenance requirements for the building. Define product data and data for maintenance phase business process. Address product data requirements for earlier phases and data creators in the design process. Define and ensure the instructions, practices and governance of the product data for the maintenance phase, including change management and updates.
IV. Project management	Training	Ensure maintenance personnel and user trainings and introductions before the maintenance phase. Prepare the necessary documentation, training materials and practices. Ensure resources (with work amount estimates) and their competencies to perform the required maintenance tasks.
	Collaboration	Involve users and maintenance personnel in the design phase. Ensure requirement integration with stakeholders in the design process, including required practices and methods, such as big room and last planner. Plan and create the capabilities for collaboration in the maintenance phase, including contact lists.
	MCC project management	Lead the MCC project based on a detailed stage-specific project plan and report the status in each gate in the project design and construction phases. This area includes required general project management activities, such as cost, document and requirement management. This part also includes other tasks, such as insurance for service providers.

The defined MCC process covers four MCC areas: service and maintenance, quality, data and product, and project management. The service and maintenance main area includes five different elements, targeting to build the capabilities for the most technical areas of maintenance. Quality main area includes creating the systematic quality control practices for the maintenance service quality, including auditing process and systematic improvement of customer satisfaction.

Data and product main area is targeting to ensure, that all the data of the building is supporting efficient maintenance practices. Standardized product data structure and BIM design are essential, and all the data has to be in usable mode for all the needed stakeholders. The target of the project management main area is to involve all the necessary stakeholders to ensure competencies and resources for the maintenance phase. All the trainings and the actual MCC project management belong to this area, including e.g. the cost management activities.

Figure 15 presents the whole setup in one picture. All the MCC areas and elements are built parallel to construction project, defined activities of each element divided into construction project phases. In the actual study, all the activities were divided also in the phases, but the key thing is to do this definition work project by project depending on the project specific needs. The role of the MCC manager cannot be underestimated, when leading the MCC work during design and construction phases with the mandate of the maintenance phase and participating to management team of the earlier phases. MCC manager might have other dedicated roles reporting to him/her, for example taking care of the first main MCC area in bigger construction projects. It is also important to understand, that these are not new additional resource, but current resources doing the work systematically with the defined process. For example, in the company participating this MCC definition work, maintenance manager or real estate manager will take the MCC manager role depending on the project.

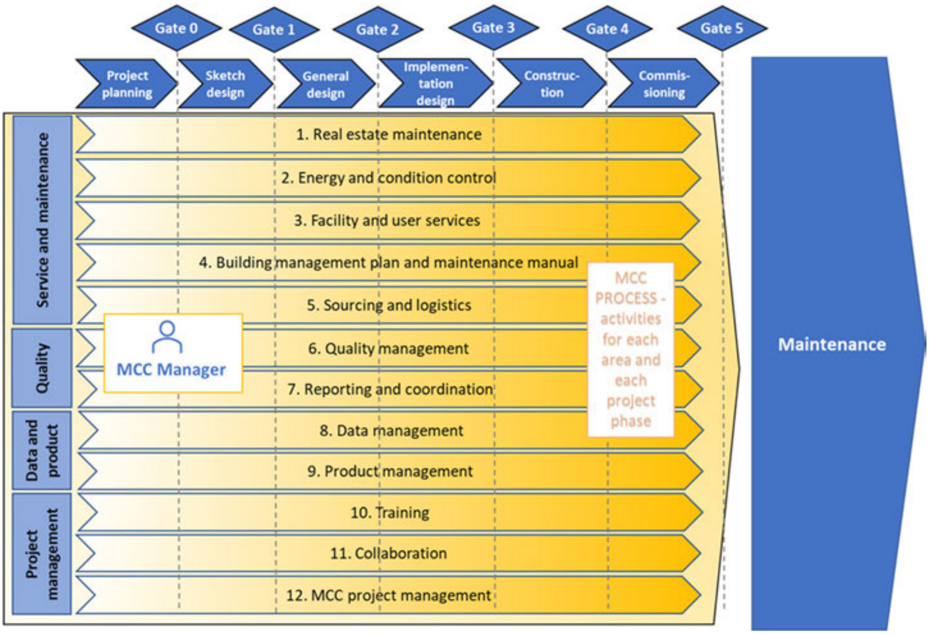

Fig. 15. MCC process phases and structure increase the level of detail in maintenance plans and capabilities throughout the evolution of the design and construction process (Reprinted under CC BY 4.0 license from Publication IV © 2022 Authors).

The pre-requisites of the systematic and workable MCC process are the definitions of the design, construction and maintenance processes, including process owners. Governance needs to be in place for each construction project, with the review process including all the project phases and review gates. Global MCC process owner is required to support in the implementation of the process in actual projects and to improve the process based on gathered feedback, at least after each project.

3.5 Results synthesis

This doctoral dissertation contributes to the research knowledge on industrialization in the construction industry. Efficiency improvement resulting in productivity development requires a BM analysis in the background. This study proposes a more detailed industrial operation model (IOM) with its primary elements as follows:

- product and data
- operative business processes

– continuous improvement (CI).

The IOM for the construction industry has the same primary elements as those in other industries, which makes IOM implementation possible and eventually inevitable in construction. This dissertation presents the preconditions for IOM implementation in the construction industry. Furthermore, this dissertation presents CC processes and their benefits for the construction industry.

With the implementation of the IOM elements and CC practices, companies support the preplanning and standardization of these processes, and in the bigger picture, benefit from economies of scale. Implementation of the IOM and CC practices reduces fragmentation and improves the productivity of the construction industry. Based on the findings of the publications, the construction industry has preconditions for IOM implementation and a basic setup available for CC process utilization. As proven, both the IOM and CC processes will provide major benefits to the industry.

This study presents CC practices for the construction industry, which impact all OBPs with early involvement principles. Companies need an IOM in the background for efficient implementation of systematic CC processes. Figure 16 presents a key synthesis of the Publications I–IV in a single picture that captures the following points:

- sales, production, and maintenance processes determining the requirements for the design process through the CC process
- CC processes providing input to the sales, production, and maintenance processes early on and concurrently with the design phase.
- SaCM, PCM, and MCM leading the CC effort during the design phase.
- IOM implementation providing the elements in the background makes the setup possible, with fully implemented OBPs, support processes, review practices, KPIs, a requirement management process (such as DfX), governance, and the roles of the processes, including global CC process owners.

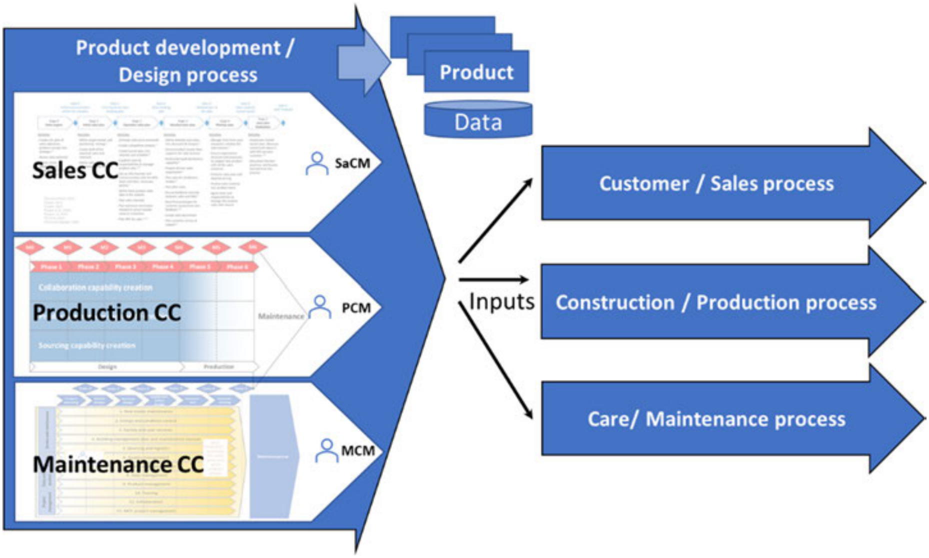

Fig. 16. Capabilities for three operative business processes created concurrently during the design process (Adapted under CC BY 4.0 license from Publications II, III and IV © 2021, 2022 Authors).

During the CC process, CC managers (SaCM, PCM, and MCM) lead the CC effort as part of the management team of the design phase, overseeing the defined activities for each design phase and ensuring that actions are completed by the respective gate review/milestone. From a resourcing perspective, these roles do not require additional hiring but efficient organizing of the work effort: doing the right things earlier and building the needed capabilities on time. The current workforce can be reorganized, and the effort exerted during the design phase will translate to a reduction of the challenges and required resources for later phases of the project. In the average project, for example, creating sales capability requires much less effort than creating production capability. It could be that an allocation of 0.2 persons as project resource can fulfill the needed sales activities, and it might require two full-time resources to fulfill the needs for production in the design phase.

With systematic CC processes sales, production, and maintenance capabilities are ready to be implemented in time, with no gaps in information sharing, responsibilities, and processes. This will then support raising the productivity of the construction industry by keeping costs at an agreed-upon level, keeping projects on schedule, and ensuring the planned quality level of the work. The main research contributions of this dissertation are listed in Table 10, which presents the main results for each research question.

Table 10. Summary of the research contribution (Publications I–IV).

RQ#	Main results
1. What are the elements of the IOM in the construction industry?	Key elements of the IOM. IOM-related challenges in the construction industry. Preconditions for IOM in the construction industry.
2. How to establish a sales capability creation (SaCC) process?	Cornerstones supporting the creation of sales-related capabilities. Current state of creating sales-related capabilities in the high-tech industry. SaCC process with activities for each project stage.
3. How to establish a production capability creation (PCC) process?	Key issues with requiring preplanning in the design phase of a collaborative project. PCC main areas, with activities for collaborative projects.
4. How to establish a maintenance capability creation (MCC) process?	Primary challenges in the maintenance phase of construction projects. MCC main areas and key elements, with activities for construction lifecycle project.
Overall contribution	Cornerstones for implementation of CC processes. General setup for CC implementation in the construction industry.

4 Discussion

4.1 Theoretical implications

This research has scientific contributions with each publication, as well as overall contributions. In the first study presenting the IOM for the construction industry, the contributions are somewhat different from those in the three other publications. Publication I presents the IOM elements as a foundation for industrialization, sharing similar discussions on BM in the literature (Brege et al., 2014; Das et al., 2021; Johnson et al., 2008; Osterwalder, 2004; Pekuri et al., 2013; Suikki et al., 2006). Publication I complements OBP-related research findings (Becker et al., 2003; Dave, 2017; Tolonen, Shahmarichatghieh et al., 2015) and product data-related (Silvola et al., 2011; Li et al., 2018) findings as building blocks of the IOM. The research is also globally in line with studies on CI across other industries (Liker, 2014; Liker & Morgan, 2006; Ohno, 1998) and in the construction industry (Grenzfurtner & Gronalt, 2021).

The findings of Publication I also support the need for process standardization and repetitive processes (Chandler, 1993; Liker, 2014), leading to the industrialization of construction (Andersson & Lessing, 2020; Höök, 2008; Stehn et al., 2021; Uusitalo & Lavikka, 2020). One of the most significant scientific implications is the discussion of the six preconditions for IOM, especially in the context of the construction industry. Industrialization has been widely studied, but scarcely at the level in Publication I of this dissertation. Finally, linking systematic BMs to IOM elements can be seen as a significant contribution.

Publications II–IV of this dissertation dive deeper into OBPs and how capabilities for these processes are built during the earlier phases of the project. The novel contribution of Publication II includes presenting the potential SaCC process for the science, including a detailed proposal of the stages, gates, and activities for creating the capabilities. Concurrently, the publication describes the current status of SaCC in real high-tech companies. The study provides detailed information on these activities, filling the gaps in previous studies (Cooper, 2019; La Rocca et al., 2016; Lehto et al., 2011; Malshe & Biemans, 2014). This study offers a solution to internal sales activities that support a customer-centric perspective in product market launch (Kuester et al., 2012) and marketing in general (Tynan & McKechnie, 2010).

Publication III discusses the importance of creating capabilities needed for production capability during the earlier phases of the project. The findings confirm the importance of collaboration between all stakeholders (Kang et al., 2021) and highlight the need for their early involvement in the construction project (Aapaoja & Haapasalo, 2014; AlMunifi & Almutairi, 2021). The study complements earlier research on methods for involving stakeholders during the design phase, i.e., the design for excellence principles proposed for construction (Gerth et al., 2013, Halttula et al., 2017; Lehto et al., 2011; Lu et al., 2020). This study proposes CC as a practice for achieving the setup established by these principles.

In Publication IV, the key theoretical contribution of the study is related to the MCC process, with detailed areas and elements, presenting the status of MCC-related work in real companies. The study supports the current view on the maintenance phase in construction (Halttula et al., 2020; Härkönen et al., 2019; Heaton et al., 2019) and the current problems in the industry (Gao & Pishdad-Bozorgi, 2019; Hassanain et al., 2019; Hauashdh et al., 2022; Wasiri, 2016). The results of the study offer a concrete method for creating maintenance-phase capabilities in a construction project (Ganisen et al., 2105).

The overall theoretical contributions include the importance of concentrating on the processes (Dave, 2017; Eastman et al., 2008; Halttula et al., 2020) and the governance of the processes (Silvola et al., 2019) in the construction industry. The proposed processes in Publications II, III, and IV provide an analogous continuum to earlier CC processes presented in the literature: the supply chain capability creation (SCCC) process (Tolonen et al., 2017) and the supply capability creation (SCC) process (Verrollot et al., 2017). The study findings are also fully in line with other related research (Barczak & Kahn, 2012; Isoherranen & Majava, 2018), highlighting the importance of creating later phase capabilities early on during earlier phases of the project (Aapaoja & Haapasalo, 2014; Love et al., 2004). The study findings support Kess and Haapasalo (2002), Ulrich and Eppinger (2008), and Cooper, (2011), promoting systematic stage-gate logic in processes. Concurrently, this dissertation brings new elements and perspectives to the use of stage-gate models when building capabilities during the design phase, as well as its utilization in the construction industry. Theoretical implications of the dissertation are summarized in Table 11.

Table 11. Theoretical implications.

RQ#	Theoretical implication
1. What are the elements of the IOM in the construction industry?	Supports process standardization and repetitive processes for industrialization. BM is linked to IOM elements. Supplements OBP, product and data, and earlier CI-related findings. Confirms and discusses preconditions for IOM elements in construction.
2. How to establish a sales capability creation (SaCC) process?	Provides potential SaCC process for creating capabilities during design phase. Describes the current status of sales-related planning in real companies. Supplies missing information on detailed activities during sales-related planning.
3. How to establish a production capability creation (PCC) process?	Confirms the importance of cooperation among the various project participants and collaboration with the customer. Recognizes the need for early involvement in construction.
4. How to establish a maintenance capability creation (MCC) process?	Describes the current status of maintenance work in real construction companies. Proposes a concrete method for addressing maintenance during earlier phases of the project.
Overall contribution	Highlights the importance of concentrating on processes and governance of these processes. Emphasizes the importance of creating relevant capabilities during the earlier phases of the project. Encourages utilization of systematic methods such as the stage-gate model when building capabilities in early project phases.

4.2 Practical implications

The practical implications of this study can be extended to more general implications related to industrialization in Publication I and to more detailed implications related to processes—especially CC practices in Publications II, III, and IV. The managerial implications of Publication I begin with the requirements for an industrial work mode for the construction industry. The listed challenges and six preconditions for the IOM can be used by companies when implementing an

IOM as part of BM deployment. The listed challenges and preconditions can be used as a starting point when defining action plans on the path to industrialization and a systematic workflow.

The practical implications of Publication II include detailed instructions on how companies can utilize SaCC processes during the design phase while concurrently improving the efficiency of the product development. Publication III presents the framework for PCC for the construction industry, including what needs to be done and how. The importance of early involvement, especially for construction-phase companies, is emphasized because it is the basis for establishing dedicated roles for efficient production CC. Various ways to decrease waste and improve cost efficiency are also listed. Publication IV contributes to proposing a detailed MCC process to support companies when creating their maintenance-related capabilities. Prerequisites and detailed steps are provided for building these capabilities during the design and construction phases.

As an overall practical implication, this dissertation shows how CC processes should be managed concurrently with business processes and how a systematic stage-gate model supports the targets of systematic processes when aiming for productivity with industrialization. The CC model includes guidance to begin CC implementation and tailoring based on the project size and type. The basics for an IOM need to be in place, with the management commitment providing the needed governance and tools for CC implementation through the company. Practical implications of the dissertation are summarized in Table 12.

Table 12. Practical implications

RQ#	Practical implication
1. What are the elements of the IOM in the construction industry?	Determines the requirements for an industrial work mode in the construction industry. Presents preconditions that can be used as a starting point for defining company-level action plans.
2. How to establish a sales capability creation (SaCC) process?	Provides an understanding of how practitioners can utilize the proposed SaCC process in creating their sales-related capabilities early on during the design phase, including tailoring of the process. Suggests how product design can be made more efficient.

RQ#	Practical implication
3. How to establish a production capability creation (PCC) process?	Provides a framework for PCC in the construction industry, clarifying what needs to be done in practice. Offers potential rapid benefits from agreeing to requisite roles and actively managing essential activities by relevant milestones.
4. How to establish a maintenance capability creation (MCC) process?	Presents a detailed MCC process that supports companies in creating their maintenance-related capabilities. Clarifies prerequisites and offers detailed steps for creating MCC capabilities during the early project phases.
Overall contribution	Outlines how a systematic stage-gate model supports the targets of efficient projects and recommends the tailoring of guidance based on project type and size. Proposes the CC model as a solution to managing construction projects efficiently.

4.3 Reliability and validity

Assessing the reliability and validity of research methods and results is crucial to ensuring the quality of scientific research. Research results can be considered reliable if the same results can be subsequently achieved with a similar research setup. Research validity refers to how well the research results correspond to real characteristics in the physical or social world. In other words, a reliable and valid research produces valid results in a reliable way.

These characteristics of a study have been traditionally associated with quantitative research but are now increasingly used in qualitative research. Reliability and validity can be assessed in qualitative research using the following criteria (Lincoln & Guba, 1985):

- Credibility: How well the results interpreted by the researchers match the real world.
- Transferability: How well the results hold in other contexts or times.
- Dependability: How well the research can be replicated.
- Confirmability: How objective the results are in relation to the researchers' personal values and theoretical conjectures.

Credibility: Earlier studies in the literature supply a solid backbone for the research items, and the research findings are in agreement with previous findings. All the publications in this research were conducted with several companies to reflect the status of the studied items in the real world. Semi-structured interviews allowed the respondents to explain their insights, and the researchers could ask additional questions that complemented the predefined questionnaires. Interviewees were selected from different roles and from different types of companies to support various views. Furthermore, their relevance and knowledge of the topics were considered separately for interviews and validations while primarily sampling people with extensive experience and broad insight due to their role at the company. Additionally, interviewees were typically matched with 2–4 interviewers, with one asking the questions and the other taking notes—along with recordings of the session. An analysis was also performed collectively by the research group to ensure the correct interpretation of the interviewees' responses. Validations were used to confirm findings from three different publications and to give the company representatives an opportunity to review the results of the researchers' analysis to confirm the match—or mismatch—with the real world.

Transferability: In the industrialization studies, several types of construction companies with different sizes and different types of products were chosen. These companies were using all project types and had been in the construction business for a long time. Global transferability can be considered limited, even if some of the companies have a global presence. The subject matter has been timely for years, with the construction business aiming for industrialization, and the results can be expected to hold over time. With Publications II–IV concentrating on capability creation, we again chose several types of companies of different sizes. The same was done with Publication II, but companies from other industries were included. Interviewee companies were from different phases of the construction project and had the most stakeholders possible, adding to the transferability of the results. Cooperative project models and lifecycle projects were studied, which makes transferability slightly limited. However, this was chosen to initiate the development of novel research in scoped environments, meaning more studies are needed to ensure the findings apply in other contexts. Nonetheless, the start has been promising.

Dependability. The research process and method documentation are critical for replicating the research. This study has been performed to the best of our ability, and all the available details are provided. The expertise of the researchers and interviewees impacts dependability, especially with semi-structured interviews, as individual expertise affects understanding at all levels for both the questions and answers, with this impact potentially also extending to the additional questions and discussions during the interview. There are recordings, data summaries, and analysis-related information on this research, but the general setup of the semi-structured interviews and the competencies of the interviewees make repeatability difficult.

Confirmability: The areas of interest, experience, and competence of the researchers affect the findings of a qualitative study (Bryman & Bell, 2011). In this study, the lead researcher has background in the industry and 20 years of experience, which has naturally influenced the study findings. Other researchers in the publications have varying lengths of scientific backgrounds. Interviewees were presented with summaries of the interviews, and they were part of the validation, counterbalancing the researchers' opinions and ensuring the confirmability of the results. Nonetheless, the researchers have not made any commitments or ties with the interviewee companies, as the objectivity of the research has been one of the main targets of the study.

There are limitations related to the findings of this dissertation. A small number of the studied companies must be understood when generalizing the study results. There were 69 interviewees from a total of 30 different companies, with 51 of these interviewees and 23 of the companies being from the construction industry. The interviewees were experienced with the topics researched in all the studies, making the results particularly reliable. The total number of interviewees and companies can be considered sufficiently large, but there was a smaller number of interviewees per study. Furthermore, most of the findings pertain to Finland-based companies, which makes the findings and results a bit regional, even if the key trends and causalities in the construction industry are significantly global. Furthermore, in Publication III, most of the companies were participating in the same large projects, which negatively impacts the generalization of the findings.

In addition, even if the CC processes and their applicability were validated together with the companies in Publications II, III, and IV, one limitation remains: the findings of these studies have not yet been applied to their full extent; therefore, the feedback from real-world use remains limited and further validation is required to strengthen the findings. Furthermore, the application of the findings in Publication II that are related to the SaCC process have not yet been tested in the construction industry. However, the main results of the study can be considered relevant also for the other industries.

4.4 Recommendations for further research

Recommendations for future studies include a detailed analysis of each of the main elements of the IOM model proposed for the construction industry. CI-related practices (lean construction) and data management (e.g., BIM) have already been studied extensively in the construction industry. However, more emphasis should be placed on product-led strategy, product-led mindset, and OBPs. Each OBP-related deficiency should be studied extensively to build a basis for CC process implementation.

CC practices should be studied with a larger number of companies than in this study, and with more interviewees from all industries. Regarding the construction industry, regional markets other than Finland should be studied. The CC processes should also be studied extensively in different setups and different types of contract models and projects, especially in larger companies, which seem to have a suitable current status for IOM implementation.

With detailed processes, broader views can be adopted. Along these lines, the marketing aspects of SaCC and the care and service aspects of MCC should be studied. All the CC concepts (SaCC, PCC, and MCC) should also be studied more extensively and in greater detail, especially the broad scope of PCC, in which each subarea needs to have detailed subprocess definitions for activities at each stage and gate. The better the processes are defined, the easier the tailoring for daily use.

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