View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by VBN

Aalborg Universitet

AALBORG UNIVERSITY
DENMARK

Mass Customization in Building & Construction

mass customization as a strategy improving the productivity within the building and construction industry

Jensen, Kim Nørgaard

Publication date:
2020

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Jensen, K. N. (2020). *Mass Customization in Building & Construction: mass customization as a strategy improving the productivity within the building and construction industry*. Aalborg Universitetsforlag. Ph.d.-serien for Det Ingeniør- og Naturvidenskabelige Fakultet, Aalborg Universitet

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

? Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
? You may not further distribute the material or use it for any profit-making activity or commercial gain
? You may freely distribute the URL identifying the publication in the public portal ?

Take down policy
If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from vbn.aau.dk on: December 26, 2020

MASS CUSTOMIZATION IN BUILDING & CONSTRUCTION

MASS CUSTOMIZATION AS A STRATEGY IMPROVING THE PRODUCTIVITY WITHIN THE BUILDING AND CONSTRUCTION INDUSTRY

BY
KIM NØRGAARD JENSEN

DISSERTATION SUBMITTED 2020

AALBORG UNIVERSITY
DENMARK

MASS CUSTOMIZATION IN BUILDING & CONSTRUCTION

MASS CUSTOMIZATION AS A STRATEGY IMPROVING THE PRODUCTIVITY WITHIN THE BUILDING AND CONSTRUCTION INDUSTRY

by

Kim Nørgaard Jensen

AALBORG UNIVERSITY
DENMARK

Dissertation submitted April 30, 2020

.

Dissertation submitted:	April 30, 2020
PhD supervisor:	Associate Professor Kjeld Nielsen Aalborg University, Denmark
Assistant PhD supervisor:	Associate Professor Thomas Ditlev Bruno Aalborg University, Denmark
PhD committee:	Kjeld Svidt, Associate Professor (chairman) Aalborg University
	Maria Kollberg Thomassen, Research Manager SINTEF Community
	Professor Frederik Elgh Jönköping University
PhD Series:	Faculty of Engineering and Science, Aalborg University
Department:	Department of Materials and Production

ISSN (online): 2446-1636
ISBN (online): 978-87-7210-507-9

Published by:
Aalborg University Press
Langagervej 2
DK – 9220 Aalborg Ø
Phone: +45 99407140
aauf@forlag.aau.dk
forlag.aau.dk

© Copyright: Kim Nørgaard Jensen

Printed in Denmark by Rosendahls, 2020

Thesis submitted: April 30, 2020

PhD supervisor: Associate Professor Kjeld Nielsen
Aalborg University, Denmark

Assistant PhD supervisor: Associate Professor Thomas Ditlev Bruno
Aalborg University, Denmark

PhD committee: Associate Professor Kjeld Svidt (chairman)
Aalborg University, Denmark

Professor Frederik Elgh
Jönköping University, Sweden

Research Manager, Maria Kollberg Thomassen
SINTEF Community, Norway

PhD Series: Faculty of Engineering and Science, Aalborg University

ISSN: xxxx- xxxx
ISBN: xxx-xx-xxxx-xxx-x

Published by:
Aalborg University Press
Skjernvej 4A, 2nd floor
DK – 9220 Aalborg Ø
Phone: +45 99407140
aauf@forlag.aau.dk
forlag.aau.dk

© Copyright by Kim Nørgaard Jensen

Printed in Denmark by Rosendahls, 2015

PREFACE

I was born in Aalborg, Denmark, which is also the place I live today with global memories and experiences. I graduated in 1987 as MSc. in Operations and Supply Chain Management, Aalborg University, and in 1987 as Bachelor of Commerce in Marketing, Aalborg Business School, and in 1990 as Bachelor of Commerce in Internal and External Accounting, Randers Business School. I have more than 25 years of international leadership experience, improving the performance of people and businesses in the manufacturing and construction industries. I am used to communicating with people from different cultures engaged in business functions at various organizational levels. From various industries and executed projects, I have gained in-depth business and technical understanding, knowing that successful deliverables are best realized via a strong project culture with close cooperation among between qualified teams and stakeholders.

I am driven by new knowledge and technology, as well as being able to share my knowledge and experience. So, since 2014, I returned to the Department of Materials and Production at Aalborg University as a full-time academic, lecturing and supervising within the field of Information Technology, Business Intelligence and Analytics, Operations and Supply Chain Management, Global Business Engineering, Export Technology in Global Systems, and Building Construction Management.

In 2015, the Department of Materials and Production at Aalborg University offered me four years to fulfill half time lecturing and supervising and half time as PhD fellow researching and documenting the research. I was associated with the Mass Customization research group, focusing on Building Construction Management. During 2018, I finalized an Excellence in Higher Education Teaching at Aalborg University with an English certification, CEFR C1.

In contrast, I spend much of my spare time renovating an old house from 1877 using traditional materials and techniques with the aim to preserve as much as possible of the original house. Unfortunately, this goal was not possible, so almost everything has been done, including demolition and reconstruction of interior walls, foundations, and floors. Water, sewer and electrical installation, windows, doors, ceiling, etc. are new. However, this project is a brand-new house in an old frame from 1877. If the walls could

gossip, they would probably tell many everyday stories from the time over the past 142 years. Besides that, my passion is being a recreation musician and songwriter, as well as doing activities like yoga, bicycling, running, badminton, reading to stimulate my health and mental energy.

This dissertation is the result of my PhD project conducted from August 2015 to April 2020. The project was generously financed by the Department of Materials and Production at Aalborg University for which I am very grateful.

Four years is a long time to stay focused on specific research objectives without knowing whether this research would contribute to improving the productivity of the building and construction industry. Reading, investigating, reflecting, and concluding is a time-consuming, repetitive act of never knowing when enough is enough. Surely, a delicate balance between insufficient or too much information, which indeed scratched a little at the edge of my comfort zone all the while my 25 years of professional career has been subject to fast decision-making providing result.

I have met many wonderful and inspiring people on my research-journey, who contributed and encouraged me in the completion of this dissertation. Firstly, I would like to express my gratitude to my supervisors Associate Professor Kjeld Nielsen and Associate Professor Thomas, Ditlev Brunø for their appreciated sustained support and their guidance, inspiring me throughout my research, which has benefited and encouraged my research activities significantly. Secondly, I am grateful of having inspiring colleagues at the Mass Customization research group at Aalborg University for making the last four years of hard work fun and enjoyable not only at the campus but also when traveling around the world. Thirdly, I would also like to thank Associate Professor Margherita Emma Paola Pero, Politecnico di Milano, Italy for the opportunity to take part in the research environment at Department of Management, Economics and Industrial Engineering. I am grateful for my three-month stay in Milan working together with dedicated people at Politecnico di Milano and helping two master students doing a thesis about the implementation of mass customization in the prefabrication construction industry. Fourthly, I would like to thank Jan Karlshøj Head of the section and Associate Professor, Department of Civil Engineering at Technical University of Denmark for his dedicated and detailed introduction to Building Information Modeling (BIM) in building design and planning, focusing on *buildingSMART* standards.

Finally, I would like to thank the people closest to me, especially to my lovely wife Ellen Marie for always being patient and supportive, and to my two adorable adult daughters Camilla and Annica for critical questioning, inspiring and supporting me, and not to forget, our little dog Coco, who was always happy and good at arranging walks and fresh air within my thinking breaks.

Aalborg, April 2020

Kim Nørgaard Jensen

ENGLISH SUMMARY

The powerful and disruptive forces. The global marketplace puts pressure on companies to stay competitive. Increasing opportunities, diversity, and challenges related to the globalization, affect companies concerning the manner they handle the increasing competition and the rapid changes in the inhomogeneous marketplace. This new business climate has driven the direction for diverse continuous improvement programs combined with complying customer requirements by offering more and more opportunities in the sense of customization, individualization, and personalization. The customer demands a higher degree of customization and companies introducing new products faster than usual, and the varying product demand and increasing pressure for cost efficiency are conditions for companies to stay competitive.

The productivity imperative. The building and construction industries in Denmark have suffered a lot compared to other industry sectors as the productivity development for the last five decades has only doubled, which is significantly less than the manufacturing industry that has increased six times. For the last twenty years, the same trend applies to the countries in Scandinavia and Europe, which leads to the fact that the productivity gap is industry specific.

The mass customization theory. The manufacturing industry has, to some extent, adopted the mass customization philosophy as a strategy to meet the higher demand of product variety at a cost near mass production, which has achieved results in the manufacturing industry in terms of increasing productivity by utilizing new technologies for production, streamlining and constant development of production processes and other correlated support processes.

The improvement paradigm. Companies search for improvement initiatives to increase their competition, and the building and construction industry focusing on, e.g., lean construction, Six Sigma, TQM, digitalization, BIM trying to reduce costs to increase productivity. The building and construction industry need to focus on new improvement strategies, which require a revolutionary open-minded innovation change, within an industry that to some extent seems conservative as many companies maintain traditions rather than looking at new possibilities by seeking inspiration from the manufacturing industry. For that reason, mass customization as a strategy might have potentials in the building and construction industry improving productivity.

Mass customization as a strategy within the building and construction industry. This thesis addresses the mass customization theory applied as a strategy within the building and construction industry to accommodate and deal with this productivity gap aiming at closing or minimizing this productivity gap. In the successful application of mass customization as a strategy, companies may master three fundamental capabilities: 1) Solution Space Development, the capability to identify customer requirements and to

develop products that meet these individual requirements; 2) Choice Navigation, the capability to guide the customer to choose the required product; 3) Robust Process Design, the capability to reuse existing organizational and value-chain resources to fulfill customer's needs.

Research contribution. This research contributes to new knowledge about utilizing the mass customization theory within the building and construction industry by developing the 'tools and approaches' relative to the three fundamental capabilities of mass customization. The availability of IT tools and standards used of companies and between companies across the value chain will not only accommodate the implementation of mass customization as a strategy but also be a necessity for the achievement of the benefits embedded in the 'mass customization' theory.

To endeavour to achieve an academic and industrial acceptance of the mass customization concept intending a better common understanding the creation of an extended definition of 'mass customization' appropriate and motivational for the building and construction industry has been carried out as: *Managing interlinked processes across entities of the value chain that are necessary for efficiently serving the customers uniquely by involving the customers in the processes needed for capturing their idiosyncratic needs and transforming them into system products or services in a cost-efficient way that will be adopted successfully by the customers.*

DANSK RESUME

De stærke og ustyrlige kræfter. Den globale markedsplads presser virksomhederne til at forblive konkurrencedygtige. Stigende muligheder, mangfoldighed og udfordringer relateret til globaliseringen påvirker virksomhedernes måde at håndtere den stigende konkurrence og de hastige forandringer på, som der hersker på den inhomogene markedsplads. Dette påvirker retningen af de forskellige forbedringstiltag kombineret med hele tiden at imødekomme kundens krav ved at kunne tilbyde flere og flere produkt- og service muligheder i form af kundetilpasning, individualisering og personalisering. Kunden kræver i større grad tilpassede produkter, som betyder at virksomheder må introducere nye produkter hurtigere end hidtil. Den varierende produktefterspørgsel og det øgede pres for omkostningseffektivitet er konkurrencemæssige vilkår.

Produktivitetskravet. Bygge- og anlægssektoren i Danmark har været meget under pres sammenlignet med andre industrisektorer i Danmark. Produktivitetsudviklingen for bygge- og anlægssektoren de sidste fem årtier er kun fordoblet, hvilket er væsentligt mindre end den seksdobling som fremstillingsindustrien har præsteret. De sidste tyve år har vist samme tendens for landene i Skandinavien og Europa, hvilket betyder at produktivitetsgabet er branchespecifikt.

Mass customization teorien (kundetilpassede produkter). Fremstillingsindustrien har til en vis grad adopteret 'mass customization' konceptet som en strategi for at imødekomme kravene om at kunne tilbyde et større produktsortiment til en pris i der minder om masseproducerede produkter. Koncept har opnået gode resultater i fremstillingsindustrien og fx øget produktivitet ved anvendelse af nye produktionsteknologier, optimering af produktions- og supportprocesser.

Forbedringsparadigmet. Virksomheder efterspørger forbedringsinitiativer for at øge konkurrenceevnen, og bygge- og anlægssektoren fokuserer på f.eks. 'lean construction', Six Sigma, TQM, digitalisering, BIM for at reducere omkostninger med henblik på at øge produktiviteten. Bygge- og anlægsbranchen er nødt til at fokusere på nye forbedringsstrategier, og det kræver en revolutionerende og innovativ tilgang i en konservativ og traditionsbunden branche ved at lade sig inspirere af nye muligheder fra fremstillingsindustrien. Derfor kan 'mass customization' have et strategisk potentiale i bygge- og anlægsindustrien med henblik på at forbedre produktiviteten.

Mass customization som en strategi indenfor bygge- og anlægsbranchen. Denne PhD afhandling behandler 'mass customization' teorien anvendt strategisk inden for bygge- og anlægssektoren for at imødekomme og håndtere produktivitetsgabet med det formål at lukke eller minimere det. En succesfuld anvendelse af 'mass customization' kræver at virksomheder mestrer tre grundlæggende kapabiliteter: 1) Solution Space Development (produktudvikling), som er evnen til at identificere kundens behov og at udvikle

produkter, der opfylder de individuelle krav; 2) Choice Navigation (ordre beslutningsprocessen), er evnen til at guide kunden til at vælge det rigtige produkt; 3) Robust Process Design (design af robuste processer), er evnen til at genbruge eksisterende organisatoriske ressourcer og logistik/SCM-processerne til håndtering af kundens behov.

Forskningsbidrag. Denne forskning bidrager med ny viden ved anvendelsen af ’mass customization’ teorien indenfor bygge- og anlægssektoren og derved udvikle 'værktøjer og tilgange' i forhold til de tre fundamentale kapabiliteter af ’mass customization’. De nødvendige it-værktøjer og standards er til stede for anvendelse i de enkelte virksomheder og imellem dem på tværs af værdikæden, hvilket ikke kun vil hjælpe med implementeringen af konceptet, men vil også være en nødvendighed for en succesfuld realisering af de indlejrede fordele i teorien.

For at opnå en akademisk og industriel interesse, motivation og bedre forståelse for anvendelsen af ’mass customization’ i bygge- og anlægssektoren er en udvidet definition af 'mass customization’ lavet som: *Styring af sammenkoblede processer på tværs af enheder i værdikæden, som er nødvendige for effektiv betjening af kunderne unikt ved at involvere dem i de processer, der er nødvendige for at opsamle deres idiosynkratiske behov og omdanne dem på en omkostningseffektiv måde til systemprodukter eller tjenester, der vil blive modtaget med succes af kunderne.*

.

TABLE OF CONTENTS

Chapter 1. Introduction 17

1.1. Motivation 17

1.1.1. Industrial Motivation 17

1.1.2. Scientific Motivation 19

1.2. Mass Customization 19

1.3. Building and Construction Industry 20

1.4. Summary 22

Chapter 2. State-of-the-Art 23

2.1. Mass customization 23

2.2. Critical Success Factors and Challenges of Mass Customization 26

2.2.1. Critical Success Factors of Mass Customization 26

2.2.2. Challenges of Mass Customization 28

2.3. Capabilities of Mass Customization 29

2.3.1. Tools and Approaches 30

2.4. Operations Management in Building and Construction Industry 34

2.4.1. Product Design and Development 36

2.4.2. customer order decoupling point 37

2.4.3. Industrialization of House Building 38

2.4.4. Prefabrication and Modularization 41

2.4.5. Supply Chain Collaboration 43

2.4.6. Marketing and Customer Involvement 46

2.5. Mass Customization and Productivity 46

2.6. Summary 48

Chapter 3. Research Objectives 50

3.1. Research Objectives 51

3.2. Research Questions 51

Chapter 4. Research Design 57

4.1. Scientific Paradigms 58

4.2. Methodological Approach 59

4.2.1. Literature review 61
4.2.2. Workshop approach 61
4.2.3. Trends analysis 61
4.2.4. Questionnaire (survey) 62
4.2.5. Case study (multi case studies) 62
4.3. Application of Methods *63*
4.4. Research Delimitations *65*
Chapter 5. Results and Contributions 66
5.1. Paper one *67*
5.2. Paper Two *68*
5.3. Paper Three *69*
5.4. Paper Four *72*
5.5. Paper Five *73*
5.6. Paper Six *75*
5.7. Summary *77*
Chapter 6. Discussion and Conclusion 84
6.1. Research Discussion *84*
6.2. Concluding Remarks *88*
6.3. Further Research *89*
References 90
Appended Papers 101

LIST OF PAPERS

Paper 1

Application of Mass Customization in the Construction Industry
Kim Noergaard Jensen, Kjeld Nielsen, Thomas Brunoe. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2015, Tokyo, Japan. pp.161-168, ff10.1007/978-3-319-22756-6_20ff. ffhal-01417455f

Paper 2

Mass Customization in the Building and Construction Industry
Jensen K.N., Nielsen K., Brunoe T.D., Lindhard S.M. (2017) In Bellemare J., Carrier S., Nielsen K., Piller F. (eds) Managing Complexity. Springer Proceedings in Business and Economics. Springer, Cham

Paper 3

Productivity, Challenges, and Applying Mass Customization in the Building and Construction Industry
Jensen, K. N., Nielsen, K., Brunoe, T. D., & Larsen, J. K. (2018). In Customization 4.0 (pp. 551-565). Springer, Cham.

Paper 4

Mass Customization as a Productivity Enabler in the Construction Industry
Jensen K.N., Nielsen K., Brunoe T.D. (2018) In Moon I., Lee G., Park J., Kiritsis D., von Cieminski G. (eds) Advances in Production Management Systems. Production Management for Data-Driven, Intelligent, Collaborative, and Sustainable Manufacturing. APMS 2018. IFIP Advances in Information and Communication Technology, vol 535. Springer, Cham

Paper 5

IT Tools and standards supporting Mass Customization in the Building Industry
Jensen, K.N, Nielsen, K. Brunoe, T.D., and Larsen, J.K. (2019). IT tools and standards supporting mass customisation in the building industry. International Journal of Construction Supply Chain Management Vol. 9, No. 1 (pp. 61-82). DOI: 10.14424/ijcscm901019-61-82

Paper 6

Applying and developing Mass Customization in Construction Industries
- A Multi case study
Kim Noergaard Jensen, Margherita Pero, Kjeld Nielsen, Thomas Ditlev Brunoe. In: International Journal of Construction Supply Chain Management Vol. x, No. x ().

TABLE OF FIGURES

Figure 1-1: Productivity development in Denmark: the manufacturing industry compared to the building and construction industry. 18
Figure 1-2: Parties of the Building and Construction Industry. 21
Figure 2-1: Framework of success factors adapted of (Broekhuizen & Alsem, 2002) 27
Figure 2-2: Ratio of capabilities of mass customization for company A and B..... 33
Figure 2-3: Approach to the CODP adapted of (Rudberg & Wikner, 2004) 37
Figure 2-4 Five supply chain models, adapted of (from (Barlow et al., 2003) 40
Figure 2-5 Supply Chain and Construction Site (Jensen et al., 2019) 44
Figure 2-6 Generic supply chain strategies applied to the housebuilding industry, adapted from (Barlow et al., 2003) 45
Figure 3-1: Research Framework 52
Figure 4-1: Methodical framework. (Arbnor & Bjerke, 2008) 58
Figure 5-1 Comparison between Danish and European productivity development 70
Figure 5-2: Manufacturing off-site and on-site 80
Figure 5-3: Companies positioning off-site and on-site 82

CHAPTER 1. INTRODUCTION

This chapter introduces the general context and the background for this dissertation. Firstly, a presentation of the overall motivation for the research both the scientific and the industrial motivation and secondly, a presentation of mass customization as a strategy successfully utilized in the manufacturing industry meeting customers' idiosyncratic needs in a cost-efficient way.

The paradigm of increasing opportunities and challenges related to the globalization, affect companies concerning handling the increasing competition and the rapid changes in the inhomogeneous marketplace. The customer demands a higher degree of customization, and companies introducing new product faster and faster. The varying product demand and increasing pressure for cost efficiency are conditions for manufacturing companies in order to stay competitive. However, responsiveness enables manufacturers to compete in the global marketplace (ElMaraghy, 2005; Koren, 2010).

Similarly, the building and construction industry is subject to several challenges and a lot of burden on costs, and the increased demand of customization related to products and services has impacted the performance of the building and construction industry, which makes companies continuously search for initiatives to decrease production costs to increase the competition. (Jensen, Nielsen, Brunoe, & Lindhard, 2017).

1.1. MOTIVATION

The point of departure for this research is the assumption of Danish companies within the building and construction industry can benefit from the advantages inherent in the application of mass customization as a strategy, and:

- the productivity gap between the manufacturing industry and the building and construction industry (Jensen, Nielsen, & Brunoe, 2015); and
- the limited research (knowledge and application) of mass customization as a strategy within the building and construction industry (Jensen et al., 2015; Nielsen, Brunoe, Jensen, & Andersen, 2017)

Therefore, the overall motivation for this research is anchored in the industrial and the scientific approach in terms of gaining and promoting research knowledge and investigating application possibilities of mass customization as a strategy increasing the productivity within the building and construction industry.

1.1.1. INDUSTRIAL MOTIVATION

The building and construction industry employ approx. 25% of the private workforce in Denmark (Boligministeriet & Force, 2000). The manufacturing industry in Denmark

has increased the productivity six times since 1966, whereas the productivity of the Danish building and construction industry has only doubled (dst.dk, 2013; Jensen et al., 2015). Figure 1-1 show the productivity development in Denmark for the last 22 years demonstrating a significant gap between the manufacturing industry and the building and construction industry.

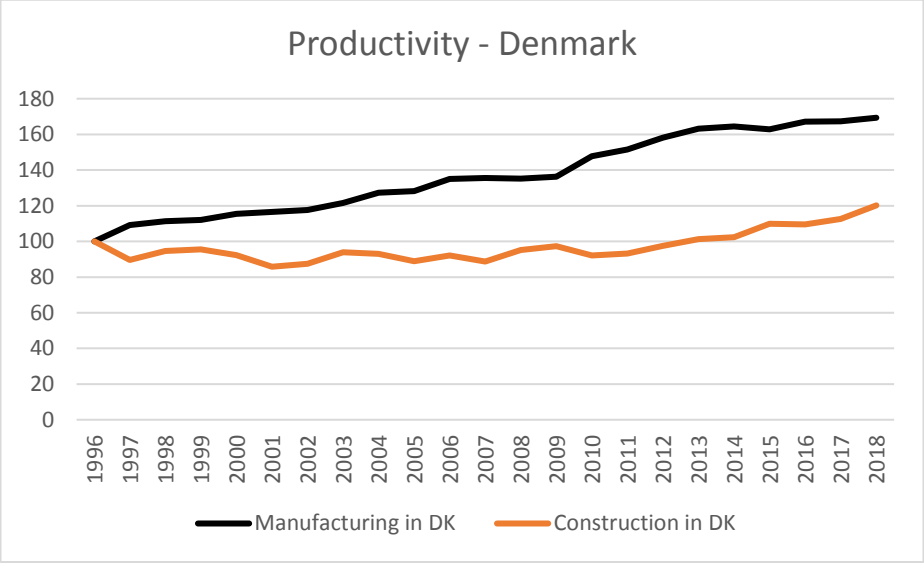

Figure 1-1: Productivity development in Denmark: the manufacturing industry compared to the building and construction industry.

Mass customization is a strategy that focuses on offering customized products at a cost near mass production and this strategy has achieved results in the manufacturing industry in terms of increasing productivity by utilization of new technologies for production, information communication technology (ICT), streamlining of production processes and correlated support processes (Fagerberg, 2000; Pollard, Chuo, & Lee, 2011). The manufacturing industry has adopted some of the principles behind mass customization aiming at meeting the increased demand of product variety by offering customized products at a low cost (Aigbedo, 2009) by utilizing enablers like product modularity, process modularity, supply chain modularity, standardization, postponement strategy (B. J. Pine, 1999; Walcher & Piller, 2012).

The principles behind mass customization enable the production of customized products (B. J. Pine, 1999), and applying these principles within the building and construction industry may have potentials as the interconnected value chain as a whole is challenged to produce and deliver high variance products (Dean, Tu, & Xue, 2009). Some segments of the building and construction industry have implemented principles of mass customization. Manufacturers of, e.g., windows, doors, kitchen, housing, and bath products offer customized products manufactured at low cost in automated and flexible

production facilities (Benros & Duarte, 2009). The diversity of the value chains with various constraints may prevent some companies from taking the needed steps towards mass customization. However, the possibilities for managing interlinked processes across the entities of the value chain is a necessity for efficiently serving customers uniquely, and, thereby, the fundamentals for improving the productivity (P. Piroozfar, 2013).

1.1.2. SCIENTIFIC MOTIVATION

This research deals specifically with the challenges related to establishing an adaptable integrated system between the members in the value chain of the building and construction industry in terms of applying the principles of mass customization as a strategy. The integrated system aims to be able to convert quickly to changing business conditions and exploiting the market opportunities within the integrated building and construction value chain.

Therefore, an essential part of the research is to investigate the traditions and challenges in the building and construction industry and the cooperation possibilities between the members in the value chain in terms of handling:

- new product introductions,
- product and project changes,
- creation of design and construction
- integrated planning and execution methods for manufacturing and assembling

in order to apply the principles of mass customization as a strategy:

- to reduce the project time,
- to minimize the resource utilization, and
- to ensure the quality of the project deliverables

and thereby to increase the productivity of the building and construction industry.

Mass customization as a strategy for improving the productivity within the building and construction industry has not been explored as much as in the manufacturing industry. Thus, further research is needed in order to understand the assumptions and requirements of the application of this strategy within the building and construction industry.

1.2. MASS CUSTOMIZATION

Mass customization is to accommodate the fact that all people are uniquely different, and therefore needs to be handled individually by setting up the right business processes and product architectures in order to serve customers' needs efficiently at prices near mass production (Tseng & Jiao, 2001).

The focus is on the customers problems and demand of products and services by offering exactly enough variety that nearly everyone needs (P. A. Piroozfar & Piller, 2013), and some of the cornerstones of mass customization is integration, flexibility, and responsiveness in handling the challenges coming from the rapidly changing environment, people, processes, units, and technology (B. J. Pine, 1999).

Mass customization is one possible strategy to take in to keep up with the competition in the marketplace. However, there is no best way that fits all people, serving customers uniquely, because customers, value chains, and products are different. Moving towards mass customization as a strategy seems appropriate for mass producers, but according to (Hvam, Mortensen, & Riis, 2008) it is also relevant for one-of-a-kind production, and research into 126 companies from different industries indicates that the origin of mass customization companies is mass production or one-of-a-kind manufacturing (Duray, 2002). Therefore, mass customization as a strategy could become one relevant strategy for the building and construction industry to consider in order to increase productivity.

1.3. BUILDING AND CONSTRUCTION INDUSTRY

The building and construction industry also referred to as architecture, engineering, construction, and facilities management (AEC/FM) is an inherently fragmented and multi-disciplinary industry with a wide range of complexity often characterized as one-of-a-kind projects. However, a clear definition of the building and construction industry seems complex as the value chain is combined of stages to feed into the end products or services, e.g.:

- single unit homes, cottages, apartments, townhouses
- sports facilities, shopping centers, hospitals, schools, universities, warehouses
- highways, roads, alleys, parking areas, bridges
- dams, sewage treatment plants, water treatment plants, sewer
- chemical processing plants, oil platform/refineries, nuclear power plants

The building and construction industry contain members like architects, engineers, consultants and advisors, construction company, external parties working on site, suppliers of materials to be delivered off-site or on-site, tools and machinery to be applied off-site or on-site, manufactures of prefabricated elements to be delivered on-site, construction owner to take care of operation and maintenance, etc. All members play an essential role, so they are supposed to work and interact against the same objectives within the value chain (see Figure 1-2). In order to be attractive and competitive, everyone must respond to global challenges and efficiently offer a wide range of products and services that fits different customer needs and continuously includes new product technologies and product models (Hu et al., 2011; Koren, 2010).

A sustainable approach to any building and construction projects can only be achieved where the needs of the target group are recognized and incorporated appropriately in

the design process (Craig, Laing, & Edge, 2000). Too often, activities are not completed on time, and problems, in most cases, end at the contractors, who executes the project plans. The causes can be divided into seven categories 1) *Design*, 2) *Workforce*, 3) *Connecting Works*, 4) *Materials*, 5) *External Conditions*, 6) *Space*, and 7) *Equipment*. (Lindhard, Jensen, & Larsen, 2017)

It seems challenging to optimize the processes within the building and construction industry as an 'assembly line production' (Batchelor, 1994; Bohnstedt, 2014) or a 'mass production' meeting high efficiency. However, some segments of the industry, e.g., manufacturers of doors, kitchens, windows, and bathrooms offer highly automated and flexible production (Benros & Duarte, 2009; Dean, Tu, & Xue, 2008). Essentially the building and construction industry is subject to improving a set of conflicting goals (P. A. Piroozfar & Piller, 2013):

- Improving cost efficiency (reducing project time, minimizing resource utilization, and ensuring the quality of the project deliverables
- Economic sustainability of the construction
- Reduction of energy consumption
- Increasing the functional performance of the construction
- Realizing of distinct aesthetic values in the design of the construction

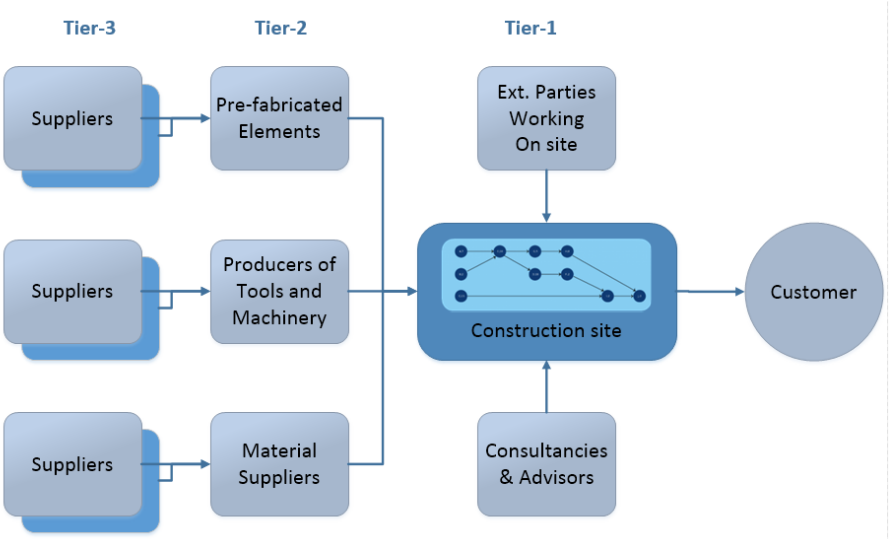

Figure 1-2: Parties of the Building and Construction Industry.

Nevertheless, it requires a revolutionary open-minded innovation change within an industry that to some extent seems conservative and less receptive to new ideas from other industries as many building and construction companies maintain traditions rather

than looking at new improvement initiatives and seeking inspiration from the manufacturing industry (P. Piroozfar, 2013). However, mass customization as a strategy is relevant for one-of-a-kind production to consider, and assumable to increase the productivity of the industry (Hvam et al., 2008).

1.4. SUMMARY

This chapter introduced the background for this dissertation, which is the realized productivity gap in Denmark between the manufacturing industry and the building and construction industry. The productivity gap may be industry specific or a Danish phenomenon, meaning that this research may be relevant in a wider industrial perspective. Mass customization as a strategy improving the productivity within this industry has not been explored as much as in the manufacturing industry, which motivates this research in the academic sense to achieve knowledge about the assumptions and requirements of successful application of this strategy within the building and construction industry. The building and construction industry are burdened with a set of conflicting goals and seem conservative and less receptive to new ideas from other industries. However, a shift to a strategy like mass customization is surely a significant innovation change, which requires a revolutionary open-minded approach, so moving towards mass customization as a strategy seems appropriate for the building and construction industry referred to as architecture, engineering, construction, and facilities management or one-of-a-kind production (Hvam et al., 2008).

CHAPTER 2. STATE-OF-THE-ART

This chapter presents the state-of-the-art of mass customization within the building and construction industry. The research is motivated by the utilization of mass customization as a strategy for improving the productivity. Therefore, this chapter is divided into five sections addressing the domains closely related to the study.

2.1. MASS CUSTOMIZATION

Companies make great effort to accommodate customers' demands and desires both on existing markets and on new markets that they try to penetrate (Salvador, Forza, & Rungtusanatham, 2002a), so introducing new products faster and faster is driving the manufacturing companies. However, this speed requires significant development investment and implementation cost leading to, e.g., decreased profitability, lengthen the product development and launching time, uncertain delivery times (Chryssochoidis & Wong, 2000). Nevertheless, the varying product demand for more choices of product features and design and increasing pressure for cost efficiency are conditions for manufacturing companies to stay competitive (Salvador et al., 2002a).

The definition of mass customization originates from the manufacturing industry and seems to be a combination of mass production and customization as paradoxical opposites of two production concepts. The mass customization concept was first defined as "*creating customized products with production cost similar to those of mass-produced products*" (Davis, 1989). Pine defined the concept as "*developing, producing, marketing and delivering affordable goods, and services with enough variety and customization that nearly everyone finds exactly what they want*" (B. J. Pine, 1999). Pine stated at MCPC in Aachen 2017, that "*mass customization is about efficiently serving customers uniquely*." Tseng and Jiao claim that "*mass customization aims at producing goods and services catering to individual customers' needs with near mass production efficiency*" (Tseng & Jiao, 2001). Ferguson et al. defines the concept as *"mass customization is a product development approach which allows for the creation of goods which minimize the tradeoff between the ideal product and the available product by fulfilling the needs and preferences of individuals functionally, emotionally and anthropologically"* (Ferguson, Olewnik, Malegaonkar, Cormier, & Kansara, 2010). It is argued that managing information is expected to be one of the most critical aspects of any successful mass customization approach together with the customer readiness and appropriate tools for guiding consumers in the ordering and customization process, and the engineering context relying on modular design and product platform architecture. Silveira et al. emphasized that the justification for developing of mass customization systems are conditions like a) the existence of new flexible manufacturing and information technologies, which enable production systems to deliver higher variety at lower cost; b) an increasing demand from the market for product variety and customization, and c) shortening of product life cycles and expanding industrial competition leading to changes of

many mass industries with increased the need for production strategies that focus on the individual customers (Silveira, Borenstein, & Fogliatto, 2001). Piller claim that the term is used for all kind of strategies related to high variety, personalization and flexible production, but not all flexible manufacturing strategies or customer-orientated product design or customer interaction methodologies can be termed as mass customization. Furthermore, it is argued that the lack of a suitable definition and a common understanding is one of the reasons preventing the implementation of mass customization, therefore the concept is clarified as: "*Customer co-design process of products and services, which meet the needs of each individual customer with regard to certain product features. All operations are performed within a fixed solution space, characterized by stable but still flexible and responsive processes. As a result, the costs associated with customization allow for a price level that does not imply a switch in an upper market segment"* (Piller, 2004). It is furthermore argued that *"mass customization is a vision to perform a company's processes in a truly customer-centric manner, resulting in products or services that are corresponding to the needs and desires of each individual customer, and doing this without the surpluses traditionally connected with customization"* (Piller, 2004). However, the mentioned definitions focus most on the word related to '*mass'* referring to high volume of products produced for a large market trying to satisfy specific needs of individual customers at production cost near mass-produced products. Therefore, the definitions appear to exclude companies producing low volumes products.

Dell computer manufacturing company is often cited as one of the best-in-class mass customizers due to its growth and success of making customizable computers on demand without having finished goods inventory before order intake and payment. The customer can use online toolkit for designing and configuring individual computers just like car manufacturing companies like BMW, VW, and Toyota are offering their customers for designing individual cars. Some segments of the building and construction industry making, e.g., kitchen, bathroom, façade elements have adopted elements of mass customization like a toolkit for designing. Toyota Homes is an example of a mass customization system integrating the design processes, production processes, and assembly processes of making residential buildings. The process is initiated by the customer who customizes what is needed based on defined features and options, where the order configuration is automatically released to the production system to produce components off-site to be assembled as prefabricated elements delivered to the construction site for final assembly of the product.

These companies have despite industry and product category turned their customers' diverse needs into opportunity creating value instead of being limited by 'one size fits all' preconditions known from the mass production industry (Batchelor, 1994; Salvador, De Holan, & Piller, 2009). Value creation through customization is the idea behind mass customization, just like the building and construction industry is aiming at meeting their customers' individual requirements via customization of, e.g., design and function.

Mass customization can be classified into soft customization and hard customization (Walcher & Piller, 2012). Soft customized products are mass-produced adaptable products with a built-in integrated customization option. Such products are customized or personalized after the production either by the retailer or by the customers themselves. Hard customized products are individually designed products requiring full clarification and specification before the production start, which impact the manufacturing and value chain processes. Hard customization is based on a product family, modular product architecture allowing many different combinations.

Four approaches to apply mass customization is identified as (Gilmore & Pine II, 1997):

- *Collaborative customizers*, who establish a dialogue to let the customers express their needs as the basis for developing customized products meeting these requirements. Companies use integrated, computer-aided toolkits collecting customer needs in terms of attributers, features and options to be released to the dedicated plant to produce this custom order, e.g., computer companies, car manufacturing companies or kitchen companies.
- *Adaptive customizers*: who make standard products that customers modify by themselves based on their needs and requirements, e.g., software companies or smartphone companies that offer built-in software packages designed to various purposes with possibilities of adding more functionalities if needed.
- *Cosmetic customizers* make standard products introduced differently to different customers, e.g., standard products packaged differently (private label) according to sales channels or customers.
- *Transparent customizers*, provide products to customers without their knowledge of that product has been customized, e.g. online software packaged (websites) like Amazon, Facebook that stores a small text-file (cookies) in the user's computer either temporarily or permanently to recognize you and keep track of your preferences and then suggest additional features or purchase proposals that customers may find useful.

Mass customization intends to deliver solutions (products and services) meeting individual customers' needs efficiently at a cost near mass production. It seems like a paradox, as it is crucial to provide individually designed solutions by considering every customer as an individual trying to understand the customers' subjective needs, which might be challenging and surely affects the entire set of downstream administrative, manufacturing and supply chain processes. Ensuring active customer involvement in an efficiency and effectiveness way is essential and requires, e.g., process agility, flexibility, integration, and collaboration throughout all steps of the product lifecycle (from the cradle to the grave). Therefore, focusing on technology availability and tools for user innovation, co-design, and user-friendly product configurators have become important.

Successfully achievement of mass customization companies must turn their processes into modules and create an architecture for linking them efficiently together in the best

combination or sequence that order handling of customized products or services require. To make mass customization work, four key attributes are mentioned: *instantaneous, costless, seamless,* and *frictionless* (I. Pine, Joseph, & Victor, 1993).

- *Instantaneous,* meaning that processes must be flexible and responsive to be linked together rapidly, and the product or service that the customer wants can be defined fast and ideally in collaboration with the customer. The ordering process is often supported by a product configurator or toolkit for co-creation for making the design specification for the needed product or components, and the chosen attributors will be translated into a set of processes to be performed.
- *Costless* implies the fact that the linkage system for making the products and services must add as little cost as possible, e.g. by establishing knowledge database for capturing important knowledge of the customer to be used smart within all the processes in a way, so everyone who gets in contact with a customer knows as much as possible.
- *Seamless* implies that all members of the dynamic organizational network dealing with customer interaction works seamlessly focusing on coordinating the creation of the customized product or service.
- *Frictionless* meaning that dedicated teams composed to a specific custom-order are intended to work frictionless in the dynamic network without having met before and without any extensive team building activities. Information and communication technology (ICT) is a necessity supporting the manual work processes in a uniform way or to automating tasks, where it makes sense as a mean supporting teams to work together immediately.

2.2. CRITICAL SUCCESS FACTORS AND CHALLENGES OF MASS CUSTOMIZATION

An international large scale research of 500 mass customization companies in the field of consumer goods located in 20 different countries with 43% in the USA and in 38% in Germany and only 1 company in Denmark indicates that 17 % of the companies fail to implement mass customization within the first year (Walcher & Piller, 2012). Even though this number consists of many start-ups and new businesses, also well-established companies are among these, which indicate uncertainty and a need for further research on success factors in the field of mass customization.

2.2.1. CRITICAL SUCCESS FACTORS OF MASS CUSTOMIZATION

The success of mass customization depends on how the customer perceives the value of buying mass-customized services or products, so before shifting to mass customization, it is crucial to examine some critical success factors. The mass customization literature seems to provide an inconsistent and incomprehensible framework for assessing the viability of a mass customization strategy, however a conceptual framework is created on the basis of classifying different success factors into external factors and internal factors as the basis for determining the success of mass customization (Broekhuizen

& Alsem, 2002) as illustrated in Figure 2-1. These external factors are categorized as opportunities related to 1) *the customer*, 2) *the product*, 3) *the market* and 4) *the industry*, which a company is supposed to exploit together with and depending on its internal capabilities to achieve mass customization strategy successfully.

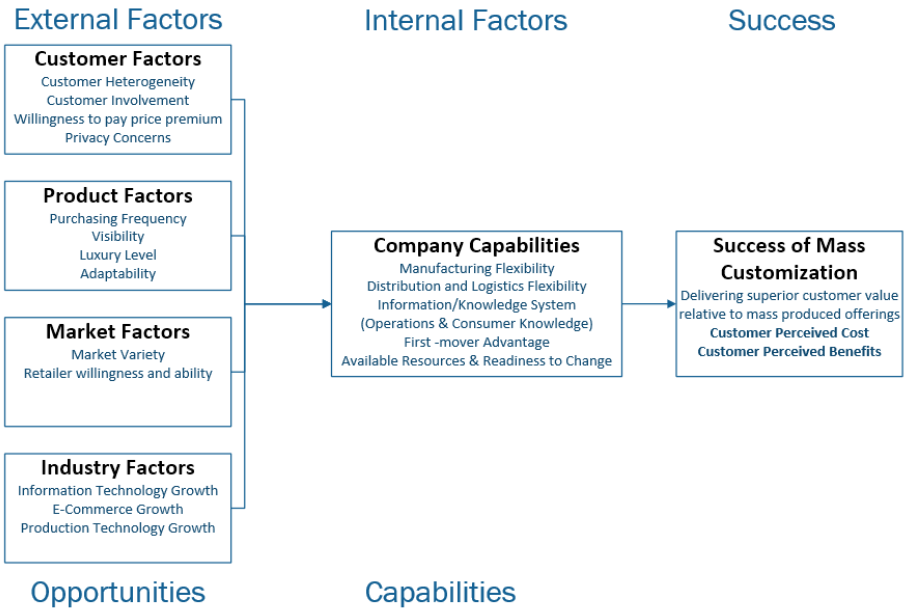

Figure 2-1: Framework of success factors adapted of (Broekhuizen & Alsem, 2002)

Approaches of critical success factors for implementing mass customization as a strategy is suggested as:

- *1) Customer demand for customized products must exist; 2) Market turbulence; 3) Supply chain readiness; and 4) Knowledge-driven organizations* (Blecker & Abdelkafi, 2006), or
- *1) Customer demand, 2) Markets, 3) Value chain, 4) Technology, 5) Customizable offer, and 6) Knowledge* (Fogliatto, da Silveira, & Borenstein, 2012).

There seems to be a definitive agreement about this conceptual framework and these two approaches of critical success factors for implementing mass customization as a strategy. Market conditions must be appropriate, so with high market turbulence, the company want to move towards mass customization being innovative and customer driven to stay competitive. Customer demand for variety and customization must exist. Thus, the increasing customer demand for innovative and customized products is fundamental; as well as the company's ability to produce and deliver the individual products and services at an acceptable time and cost. End-user products must be customizable, meaning it should be possible to assemble individual sub-products and components

into different finished products without extensive effort. The value chain must be ready, as mass customization requires its interconnected supply chains entities' (manufacturers, suppliers, distributors, retailers) readiness for efficiently attending the demand of products, materials, and components. Knowledge must be shared across the value chain, as the company should be able to "pick up" on new customer trends and demands and to be able to translate them into new products and services. The technology must be available because mass customization 1) depends on the ability to integrate the information communication technology (ICT) across the entities of the value chain, and 2) depends on the processes and equipment to be flexible and automated to communicating and producing goods, at the cost, time and quality required.

2.2.2. CHALLENGES OF MASS CUSTOMIZATION

External complexity and internal complexity are the main problems affecting the implementation of mass customization as a strategy (Blecker & Abdelkafi, 2006). External complexity is the uncertainty experienced by customers when customizing their products. Essentially, customers do not want endless choices; they only want the products or services that meet their needs, because too many choices or the lack of product knowledge turns the customers into frustrated and confused decision-makers. Internal complexity is experienced inside the company affecting the operations negatively as handling the variety requested by the customer may result in a certain loss of efficiency. That is due to the effort relative to the processes, tools, and equipment necessary to, e.g., order intake, purchasing, manufacturing, and internal logistic, distribution, and supply chain.

Successfully implementation of mass customization as a strategy requires understanding and integration of three major components*: "elicitation (a mechanism for interacting with the customer and obtaining specific information), process flexibility (production technology that fabricates the product according to the information, and logistics (subsequent processing stages and distribution that are able to maintain the identity of each item and to deliver the right one to the right customer* (Zipkin, 2001)*:*.

Interaction with the customers trying to understand and characterize customer needs is challenging (Wang & Tseng, 2011) as customer needs are subjective. Each individual customer's perceptions may differ from person to person due to solution preferences, decision-making criteria, and factors like mood, emotion, or impulsiveness. The mapping between the customer and the functional domain is about understanding individual customer's needs and using innovative tools for transforming them into functional and operative requirements in terms of information (understandable data put into context) like product properties and attributors. Such innovative tools and approaches for customization and personalization are fundamental prerequisites and capabilities, and therefore a necessity for meeting efficiency and effectiveness requirements in the collaboration process (Dean et al., 2009; B. J. Pine, 1999).

In order to take advantage of efficiency while serving the customers as individuals, product modularity, effective product family architecture have been considered as effective approaches to become a mass customizer (Craig et al., 2000; Feitzinger & Lee, 1997; Silveira et al., 2001; Tang, Qi, & Zhang, 2017). Product modularity is not enough. Companies must also focus on process modularity as possible approaches for meeting the challenges related to the rapidly changing technologies, product development, and customer demands. However, responsiveness enhances through manufacturing reconfigurability, the ability to efficiently adapt to, e.g., new functionality or changes in capacity setup in a profitable way, and through supply chain modularity across the value chain supporting e.g. variety of product demands, quantities and delivery demands (Andersen, Larsen, Brunoe, Nielsen, & Ketelsen, 2018; Silveira et al., 2001; Wolters, van Heck, & Vervest, 2002)

2.3. CAPABILITIES OF MASS CUSTOMIZATION

In "*Cracking the code of mass customization*" (Salvador et al., 2009), the three fundamental capabilities of mass customization were defined as cited here:

- Solution Space Development:
  "*The ability to identify the product attributes along which customer needs diverge*," (Salvador et al., 2009)
- Choice Navigation:
  "*The ability to support customers in identifying their own solutions while minimizing complexity and the burden of choice*," (Salvador et al., 2009) and
- Robust Process Design:
  "*The ability to reuse or recombine existing organizational and value-chain resources to fulfill a stream of differentiated customer's needs*." (Salvador et al., 2009)

Solution Space Development is for the company to understand its customers' idiosyncratic needs, and when these needs are understood, the company can design, make and deliver the products and services accurately to its customers. So, the objective is to understand how customer requirements are different by identifying valuable product attributes and properties as the foundation for the design and development of the products and services in a way that effectively meets these individual requirements through standardization, product platforms, modularization, etc. The solution space is a subset of the company's product strategy that clearly defines the boundary of what it is going to offer to the customers and what it will not offer. Defining the solution space include collecting knowledge from current and past customers, and even those who have not been customers, e.g., by collecting data of features and options that a potential customer evaluated but did not order. Such data from past interactions can be valuable input the future definition of the solution space.

Choice Navigation is for the company to guide their customers to efficiently identifying their own solution requirements by configuring the product or service that matches their

individual needs with a minimum of effort. The aim is to reduce complexity and increase user-friendliness in the configuration process to avoid the "paradox of choice" meaning that the customers are not exposed to too many choices leading to confusion and postponement of the decision. The ICT and technological availability in terms of user-friendly product configuration software, also referred to as co-design toolkits, can reduce the complexity of choice in the decision-making process. A positive perception of the co-design process has shown 50% additional willingness to pay for customized products. Likewise, the 'pride-of-authorship effect' adding value and pride due to the passion of co-creating the solution by themselves (Walcher & Piller, 2012).

Robust Process Design is for the company to have flexible and robust business processes and value chain resources to efficiently fulfill the increased variability in customers' requirements without extraordinary deterioration of the company's operations and value chain resources. The objective is to reuse, re-combine, or redesign existing organizational and value-chain resources to fulfill differentiated customers' needs. The utilization of (new) technology enablers plays a great role, e.g., flexible automation, process modularity, RMS (reconfigurable manufacturing systems), additive manufacturing technologies, digitalization, ICT (information communication technology), AI (artificial intelligence). Companies would still be depending on adaptive intellectual human capital to deal with new and ambiguous tasks in order to handle unpredictable increased variability in customers' requirements, which indeed require continuous training and education program upgrading competencies of employees. However, a critical success factor of implementing mass customization is balancing technology availability and the flexibility of human intellectual capital.

2.3.1. TOOLS AND APPROACHES

As described in chapter 2.2.1 six approaches of critical success factors are the cornerstones for implementing mass customization as a strategy: *1) Customer demand, 2) Markets, 3) Value chain, 4) Technology, 5) Customizable offer, and 6) Knowledge* (Fogliatto et al., 2012), which are to be considered relative according to the specific industry and company.

There are many tools and approaches in order to implement mass customization continuously, and the customer order entry point (postponement[1]) is a clear indicator for the degree of customization, e.g., customer integration and interaction, for which various *'tools and approaches'* are available to support companies developing the three fundamental capabilities of mass customization. (Salvador et al., 2009), which are:

[1] Postponement, meaning delaying the investment in a product or service until the last possible moment.

Tools and approaches to develop the *Solution Space Development* capability (Salvador et al., 2009):

- *'Innovation tool kits'*: software for customers in collecting and translating their preferences for a unique product or service variants or development ideas into understandable and structured information. Those variants or proposals for new product/service developments would be ideal for the company to decide whether to incorporate or discard to the solution space. Such software tools could be everything from well-known idea-bank (plans stored in a knowledge base) requiring a lot of effort to understand, interpreting and utilizing to more intelligent and integrated software tools allowing easy accessing and codifying so the company can bring product ideas into reality efficiently.
- *'Virtual concept testing'*: software for a sample of potential customers to evaluating and reviewing the products concepts, design ideas, product variants virtually without spending a lot of money and effort by making any physical prototypes. The testing of a new 'product concept' includes, e.g., testing its function, features, specifications, design and price range so the company can identify strengths or weaknesses and uncover reactions, attitudes, and purchasing willingness toward this specific 'product concept.
- *'Customer experience intelligence'*: software for capturing 'designs proposals' of ordered and unordered products for later analyzing purposes, which can serve as input for adjustment of the future solution space. Collecting data from the order intake process in terms of product configuration or virtual design variant, which would be beneficial for analyzing purposes even if the product was not ordered. Such important information would serve as background knowledge for better understanding the customer preferences, which may lead to refining the solution space for the benefit of other (existing or new) customers.

Tools and approaches to develop *Choice Navigation* capability (Salvador et al., 2009):

- *'Assortment matching'*: user-friendly software tools that intuitively and interactive support the customers in identifying their problems and solutions. The objective is to minimize complexity and avoid the 'paradox of choice' which can extend the decision-making process. The software tools take characteristics (attributes) from existing solution space from the outset in order to build configuration proposals matching customer's needs. Such software tools (product configurators) based on features and options with close integrations to the backend systems have been known for years. The evolution over time has changed these solutions into 3-dimensional interactive software tools with high visuality.
- *'Fast-cycle, trial-and-error learning'*: software tools used interactively for testing and experimenting of a model to verify the match between available solutions from the solution space with own requirements or needs. Such soft-

ware tools help customers learn about their own preferences like software solution for the design of kitchen or bathrooms in three dimensions with possibilities seeing the solution from different angles, zoom in and out on specific details.

- *'Embedded configuration'*; representing reconfigurable products with extended utilization and functionality that "understand" how to adapt to the customer's needs and requirements. Such solutions could be heating systems or lightning systems that turn on and off depending on the customers' preferences like where he is and what he does.

Tools and approaches to develop *Robust Process Design* capability (Salvador et al., 2009):

- *'Flexible automation'*: automation approaches for handling customization of tangible or intangible goods by utilizing and combining flexible and automated *processes* and *equipment*. The technology used for 'flexible automation' has evolved dramatically over the last two decades and will continue to do so in the future. This flexibility has resulted in the automation of many processes related to the project phases, e.g., design, specification, visualization, virtualization, design acceptance. Also, automatization of equipment for fulfilling manufacturing processes on-site or off-site.
- *'Process modularity'*: A company's resources or capabilities are divided into flexible modules to be put together in the right sequence to fulfill different customers' customized needs without unnecessary extra effort. The objective is to rethink and redesign the organizational resources and capabilities already existing in the company related to its operations and value chain into flexible segments of processes with high adaptability to be recombined easily into smooths and effective workflows to respond efficiently to specific needs of each customer of customizable products. Companies within the building and construction industry are to some extent familiar with this approach as they are project driven and used to dealing with ambiguous tasks, but despite this several challenges e.g. 'poor project performance', 'poor communication' and 'poor management' (Jensen, Nielsen, Brunoe, & Larsen, 2018) indicate room for improvements.
- *'Adaptive human capital'*: The capability of dealing with novel and ambiguous tasks to neutralize any potential rigidness embedded in organizational process structures and technologies. The objective is to develop managers and employees to cope with new, changing and unclear tasks that technology (machines, ICT or AI) cannot do yet in order to improve, e.g., their attitudes, their decision-making, their adaptive capabilities to support them in their tasks solving customers specific needs. Some employees within the building and construction industry are, to some extent, familiar with such an approach, but even the weakest link in the value chain can lead to everything from inconveniences to catastrophic economic consequences.

These nine tools and approaches constitute a framework for developing the three fundamental capabilities of mass customization (Salvador et al., 2009). From each of these nine tools and approaches there exist a potential productivity connection (Jensen, Nielsen, & Brunoe, 2018) to be explored further and adapted specifically for the building and construction industry, in particular, the specific company. However, these nine tools and approaches may not be considered as a complete and final list of initiatives to improve the productivity, but these are a reasonable starting point to be considered and developed in the transition of the building and construction industry towards mass customization.

There is no perfect state of mass customization (Salvador et al., 2009), so what works for one building and construction company may not necessarily work for another company, therefore the development initiatives and roadmap might be individually (Jensen et al., 2018) (see Figure 2-2), and depending of the maturity level of the company (Enkel, Bell, & Hogenkamp, 2011; Vaidyanathan & Howell, 2007).

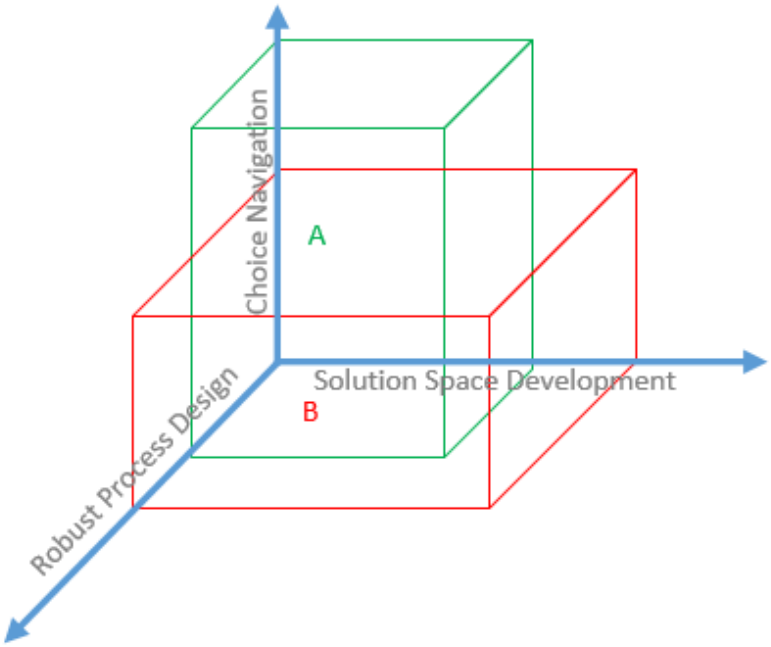

Figure 2-2: Ratio of capabilities of mass customization for company A and B

It is essential to realize that mass customization development and maturity should be realized in steps as the transition process to a greater or lesser extent impact the industry structure e.g. new technology, new tools, new processes, refined organizational roles,

internet of things, smart connected products, which require dedicated change management processes to archive successfully (Kotter & Cohen, 2012; Porter & Heppelmann, 2014).

In any industry, competition is driven by five competitive forces: 1) the bargaining power of buyers, 2) the nature and intensity of the rivalry among existing competitors, 3) the threat of new entrants, 4) the threat of substitute products or services, and 5) the bargaining power of suppliers (Porter & Heppelmann, 2014; Porter, 1985).

A maturity model describes how a company can move step-by-step from lowest level characterized as 'ad hoc' with unstructured, internal orientation and unpredictable performance to the highest level characterized as 'extended' with an effective external and trusted collaborative orientation involving the entire value chain. The five stages of maturity are: 1) Ad hoc, 2) Defined, 3) Linked, 4) Integrated, and 5) Extended, which indicate the progression toward an effective value chain and process maturity, and each level contains characteristics, e.g., predictability, capability, control, effectiveness and efficiency (Lockamy III & McCormack, 2004).

Higher levels of maturity in any business process result in 1) better control of results; 2) improved forecasting of goals, costs, and performance; 3) greater effectiveness in reaching defined goals; and improving managements' ability to propose new and higher targets for performance (McCormack, Bronzo Ladeira, & Paulo Valadares de Oliveira, Marcos, 2008). Companies reach greater levels of performance and a better work environment if they strategically focus on their business processes due to high levels of cooperation and less conflict (Lockamy III & McCormack, 2004). Therefore, the successful outcome of developing these nine tools and approaches goes together with the maturity of the company.

2.4. OPERATIONS MANAGEMENT IN BUILDING AND CONSTRUCTION INDUSTRY

Project management and operations management are fundamental disciplines within the building and construction industry to achieve long term business success and growth in a highly dynamic business environment. Operations consist of activities necessary to transform and deliver an organization's offering of products or services to its customers with the main objective to efficiently manage the available resources and activities to produce the products and services required. Moreover, *the operations management is the management of processes that transform inputs into products and services that add value for the customer with the goal to maximize efficiency while producing products and services that effectively fulfill customer needs* (Greasley, 2007).

Project management aims at effectively managing activities and resources in relation to a specific project or portfolio of projects to achieve business profits and growth. Moreover, *the project management is the science which applies skills, tools and techniques to fulfill project activities in a way that the expectations and requirements of*

stakeholders are fulfilled or exceeded (Ehsan, Mirza, Alam, & Ishaque, 2010). Business success is depending on how organizations perform their activities, and it is not possible for any organizations to achieve long term sustainable business success without proper measures to effectively manage the performance of their projects and operations. Significant improvements can be expected by implementing a structured performance measurement system through successfully tackling stakeholder requirements, focusing on critical improvement areas as well as focusing on cultural changes like proactive management and decision making (Nudurupati, Arshad, & Turner, 2007). New philosophies have arisen such as: concurrent engineering/construction, lean production/construction, just in time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM), Risk management to optimize an organization's performance internally and externally. Moreover, this has led to the rethinking of performance management systems through effective performance measurement. (Kagioglou, Cooper, & Aouad, 2001). *The construction industry still lacks a practical framework for performance measurement that takes into account both organization and project dimensions and utilizes in-built process-oriented indicators and data collection methods* (Pekuri, Haapasalo, & Herrala, 2011). Takim and Akintove propose a conceptual model for successful construction projects' performance, which include relevant performance indicators in relation to stakeholders' performances that could be measured based on the three phases of project life cycle: 1) *the procurement*, 2) *the process* and 3) *the phase out* (Takim & Akintoye, 2002).

The building and construction industry is characterized as engineer-to-order referring to a manufacturing strategy for highly customized products requiring design and engineering in detail based on the customer's order requirements and specifications. Extraordinarily customer requirements cause challenges in such systems, e.g. difficulties in the planning process by inaccurate estimation of lead time and delivery dates, late product/project changes, expensive reworks, poor product quality, and material waste.

Project performance is affected by the '*Lack of project coordination*' and '*lack of trust and shared objectives*.' It is understandable how complex corporation relationships affect the members within the value chain (see Figure 1-2) and how they behave in relation to one another. Therefore, proactive communication and interaction are unavoidable to consider (J. K. Larsen, Lindhard, & Jensen, 2017). A close relationship between the members of the value chain is motivating for the representatives to take ownership and an active role in the process. Therefore, enhanced collaboration supports the involved team to overcome project shortcomings and to secure a successful design and execution process (J. K. Larsen, Lindhard, Brunoe, & Jensen, 2018). Project problems in the execution stage relates to *'lack of project requirements and design'* and *'too optimistic project budget and deadlines'* originating from the initial stages, and the achievement of project success depends on the presence of experienced consultants through the project phases (J. K. Larsen, Brunoe, Lindhard, & Jensen, 2017).

2.4.1. PRODUCT DESIGN AND DEVELOPMENT

The capability of identifying customers' needs and turning them into valuable products is essential for economic success of most companies. The product development process help achieving these goals as an interdisciplinary activity requiring contributions from almost every function within a company, especially marketing, design and manufacturing. Product development can be defined as: *"the set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product"* (K. T. Ulrich & Steven, 2008).

In product development the customer requirements are translated into a 'design solution' specifying functional performance and customer value, whereas this 'design solution' is realized in production. Some of the significant differences between production of goods and product development are: 1) *more iteration in product development than in physical production*, 2) *more uncertainty in product development than in production*, 3) *product development is a non-repetitive activity in comparison to production*, and 4) *more customer relation and interaction in product development than in production* (Koskela, 2000). Thus, the value aspect in product development is more significant in comparison to production. The product development process in the manufacturing industry is generally used to produce a number of units of the same product; whereas the product development process in the construction industry aims (due to the specific characteristics of construction) at creating a unique product (often a single unit, one of a kind) e.g. a building, oil platform. Another difference relates to making prototypes, which are rarely in the construction industry due to the nature of the construction products (Tzortzopoulos, Betts, & Cooper, 2002).

The evolution within the building and construction industry has come a long way during the past two decades, because the industry continuously seeks tools and approaches that improve development process before the construction begins. Particularly significant is the evolution of the two-dimensional digital drawings into three (four) dimensional building information modeling (BIM) using object-oriented technology in a way that construction products can be assembled digitally and visualized in three-dimensional as virtual prototypes before it is built in reality (Jensen, Nielsen, Brunoe, & Larsen, 2019; Kiviniemi, Karlshøj, Tarandi, Bell, & Karud, 2008; Nawari, 2012).

The Architecture, Engineering and Construction (AEC) industry is embracing computer-based technologies for improvement in various processes of construction projects. Visualization is one of the main applications that helps project participants (stakeholders) to comprehend complex construction project more easily with a consistent shared understanding. Virtual Reality (VR) and Augmented Reality (AR) is some of the advanced computer technologies in the research stage that has potential to provide significant advantages (Dunston, 2008).

2.4.2. CUSTOMER ORDER DECOUPLING POINT

The customer order decoupling point (CODP) is a term of describing at which point the customer triggers the production activities, also referred to as a way of differentiating between four manufacturing approaches (see Figure 2-3); make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO), engineer-to-order (ETO) (Rudberg & Wikner, 2004).

Demand upstream activities (left to the CODP) is based on the forecast, whereas demand downstream activities (right to the CODP) is based on the customer order intake. Therefore, by placing the CODP further downstream in the value-adding material flow the higher productivity in operations, and by placing the CODP further upstream the higher degree of flexibility (Steiner, Piller, Zangitu, & Castellano, 2011). A mass customization system strives after an optimal balance between the productivity and flexibility by finding the best positioning of the CODP.

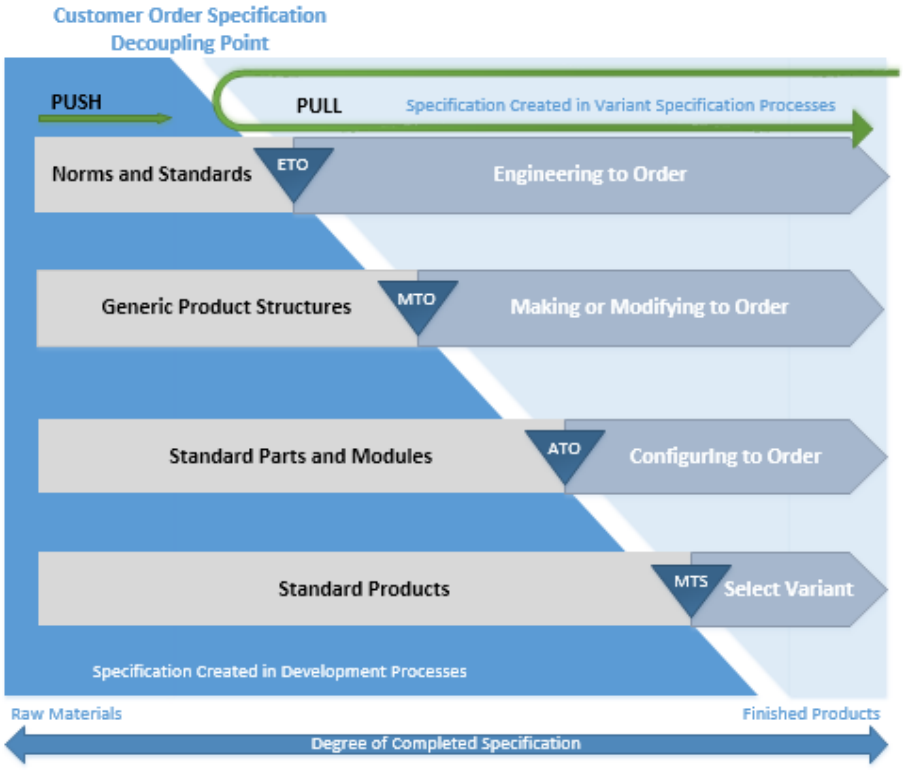

Figure 2-3: Approach to the CODP adapted of (Rudberg & Wikner, 2004)

As this sequential approach does not distinguish between production and engineering-related activities, the extended view of CODP is seen in an engineering dimension and a production dimension (Rudberg & Wikner, 2004). The production dimension (PD) covers the traditional view of MTO_{PD}, ATO_{PD} MTS_{PD}, whereas the engineering dimension (ED) referred to as ETO is divided into three: 1) engineer-to-order (ETO_{ED}), 2) adapt-to-order (ATO_{ED}) and 3) engineer-to-stock (ETS_{ED}). ETO_{ED} is initiated by an order containing engineering activities related to the development of a new product concept or project, and ETS_{ED} is engineering activities related to developing a new product without having an order. Therefore, the outcome is to be interpreted as putting the engineering activities on stock awaiting an actual order to be produced.

Considering production and engineering dimensional makes the CODP an appropriate tool for classifying ETO companies within the building and construction industry that strives to become a mass customizer (Rudberg & Wikner, 2004).

A typical mass customizer focusses on modularity, and ETO companies are project driven dealing with activities related to their deliverables of a product and services to be defined in a hierarchically work breakdown structure (WBS). Structuring end products can likewise be seen hierarchically as products, modules, components, where modules are defined as assemblies of components, and end products are composed of modules (Joergensen, 2008). Some modules are pure standard units produced to forecast, whereas some modules are customer specific depending on the engineering activities to be performed before the final product is assembled to order.

2.4.3. INDUSTRIALIZATION OF HOUSE BUILDING

Recent studies revealed that productivity improvements in the construction industry are significantly lower than improvements in other sectors (Jensen et al., 2018). Bashford, Walsh, and Sawhney (Bashford, Walsh, & Sawhney, 2005) argue the building and construction companies even now consider their projects as small individual construction projects despite the fact that many building projects possess characteristics that are similar to manufacturing processes and management principles that focusses on e.g. reducing delivery times and reducing work-in-progress. Furthermore, Nahmens and Bindroo (Nahmens & Bindroo, 2011) claimed based on a survey among U.S. homebuilders that operational performance become progressively worse with an increase in customization indicating that ideal mass customization still needs further research. It is argued that conventional on-site construction techniques have reached its limits, and consequently the future construction industry could utilize *automation techniques* that the manufacturing industry have successfully implemented. However, the construction automation techniques are still in an innovation phase, presumably leading to a change in the market competition and a technological disruption by applying the upcoming robotics, off-site construction and new strategies and technologies of construction automation (Bock, 2015). Consequently, the mass customization concept will in the future most likely take further market power due to the stagnation and technical limits of conventional construction. However, the mass customization concept is emerging in the building and

construction industry (Frutos & Borenstein, 2003; Frutos, Santos, & Borenstein, 2004). Firstly, as the industry is characterized by highly customized building projects represented by highly customizable products such as building residences, houses, and flats. Secondly, the successful customization is closely related to the level of satisfaction of the customer (Frutos & Borenstein, 2003).

Some ETO companies within the building and construction industry already construct their product of modules manufactured off-site, e.g., roof systems, prefabricated modular façade systems, kitchen elements, precast concrete elements, heating systems, timber house construction both consisting of standard and nonstandard modules to be delivered and installed on-site. This is achieved through a holistic approach towards industrialization using integrated BIM models optimizing supply chain of off-site production to be delivered on-time for assembly on-site. Modular prefabrication is optimized by adopting design for manufacture and assembly (DfMA) using parametric modelling software supporting interdisciplinary collaborations between teams of designers, engineers and manufacturing teams. (Arashpour, Miletic, Williams, & Fang, 2018; Correa, 2019; Santana-Sosa & Fadai, 2019).

Da Rocha et al. developed a method for improving the configuration process of customized house building to avoid customization problems based on late design changes and delays due to missing information (da Rocha & Formoso, 2013). Friedmann et al. and Duarte focus on design of configurations systems to support customization of buildings and housings (Duarte, 2005; Friedman, Sprecher, & Mohamed, 2013). Frutos and Borenstein developed an object-oriented model for an integrated process of exchanging information between the customer and the construction company, which enables the building of mass customized houses (Frutos & Borenstein, 2003). Benros and Duarte described an integrated system aimed at devising a framework for the mass customization of housing with the objective to lower the costs through large scale serial production while satisfying the unique customer requirement. The computer system contains of a design system (rules for composing design solutions) and a building system (specification of how to produce them), which jointly control and integrate the two systems using computer aided design and manufacturing (CAD/CAM) (Benros & Duarte, 2009).

Da Rocha and Kemmer propose a method for delaying product differentiation in the building of apartments, which includes defining the solution space (customizable attributes, options and features). Apartments are usually produced in a single batch meaning that no tasks can be performed before customization decisions are fully made, otherwise decisions delays directly result into delays in production. The proposed method recognizes the type of tasks (forecast and demand driven) that arise when customization is offered and organizes the production system to exploiting the benefits of each of them so the tasks influenced by the customization are identified and postponed as much as possible. (da Rocha & Kemmer, 2013).

Barlow et al. also considered the location of the customer order decoupling point in the Japanese housebuilding, which has adopted build-to-order techniques (standardization, prefabrication and appropriate supply-chain management) to deliver high levels of customization. Barlow et al. argues that mass customization could be supported by five supply chain models, which allows delivering houses with the appropriate degrees of customization targeted different market segments to be met more effectively without the costs associated with full customization (Barlow et al., 2003). The five models (see Figure 2-4) are, 1) the *pure standardization* (UK speculative), based on standard parts and components, so the houses are designed and built without any significant input from the customer; 2) the *segmented standardization* (Toyota Home) where customers selects from a range of pre-assembled modular units, which are configured and assembled to order in factories and distributed for on-site assembly; 3) the *customized standardization*, (Sekisui Heim), where customers specify a house configuration based on assembly of modular units made out of standard components and subassemblies; 4) the *tailored standardization* (Sekisui House), where customers selects from a wide range of components that are delivered to the building site for on-site configuration and assembly; and 5) the *pure customization* (pure self-build houses), where the customers affects all activities starting from the design. Housing unit production of these main players in 2009 was: Sekisui House (55.088), Sekisui Heim (14.550), and Toyota Home (4.302) (Linner & Bock, 2012).

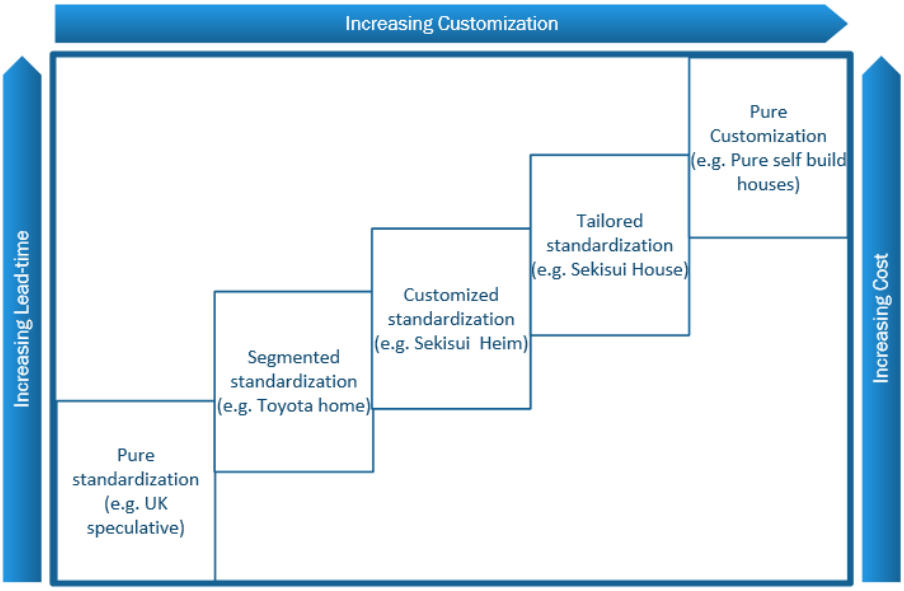

Figure 2-4 Five supply chain models, adapted of (from (Barlow et al., 2003)

The Figure 2-4 illustrate these five models position relative to the horizontal axis (the degree of customization required), and the vertical axes (the derived consequence relative to the lead time and the cost). Consequently, more customization leads to greater choices which leads to more costs and longer lead times. Obviously, there is a trade-off between levels of customization, lead time and cost, which is the approach closest to the classic notion of mass customization (Barlow et al., 2003). *Customized standardization* represents a compromise between the limited customization provided by *segmented standardization* and the extensive customer choice offered by *tailored standardization*. Research on mass customization as a business strategy within the house building industry is a highly unexplored research field, and the findings indicate a potential for exploiting mass customization in the house building industry aiming at to lower unit costs, increase quality, and shorten project duration (M. Larsen, Lindhard, Brunoe, Nielsen, & Larsen, 2019).

2.4.4. PREFABRICATION AND MODULARIZATION

Prefabrication is still considered as a relevant competitive strategy within the building and construction industry that transfer a part of the on-site work into components and modules to be manufactured on factories (off-site) and thereby generating a new decoupling point in the supply chain. The modular architecture of a product is divided into the *functional* and the *physical* parts, where the *functional* parts includes the individual operations and transformations that contribute to the entire module of a product, and the *physical* parts are the structure, components or subassemblies that implement the functional elements to the product (Miller & Elgard, 1998). Configurable products are divided into three modular concepts: 1) *slot modularity*, the interfaces between the components is of a different type from the others, so the various components in the product cannot be interchanged as they differ from each other, which prevents the interchangeability between the components; 2) *bus modularity*, the interfaces are identical and the different components are connected to an element (bus), which connect them; and 3) *sectional modularity*, the interfaces between the different components are identical allowing the connections between each other (support interchangeability) meaning, that there is no single element (bus) to which all the other components attach (K. Ulrich, 1995). The three concepts differ in the way the modules interact with each another, therefore, the use of modularity places high requirements for product adaptation and product variance with the architecture type used. The modular architecture allows to manage and develop complex products and systems efficiently, decomposing them into simple subsystems or modules, without altering the integrity of the system (Baldwin & Clark, 2003). Research in operations management put forward that companies can reduce the negative impact of product variety on operational performance by focus on modularity in the sense of design of product family architectures (Salvador, Forza, & Rungtusanatham, 2002b).

Terms used for pre-fabrication is off-site production, off-site fabrication, off-site manufacturing, off-site construction, and pre-assembly, and is defined as *"the manufacture and pre-assembly of components, elements or modules before installation into their*

final location" (Goodier & Gibb, 2007). Goodier and Gibb claimed that *"Shorter onsite construction time and increased quality were seen as the major advantages and the (real or perceived) additional cost of offsite was the main barrier to its use."* (Goodier & Gibb, 2007). Off-site construction can be classified by different types of off-site work 1) non-volumetric components, 2) volumetric components, and 3) modular building structures (Gibb, 1999) and by materials (e.g., timber, steel, concrete or hybrid).

Pre-fabrication or off-site production is a popular approach and increasingly applied technique, moving on-site operations to a more controlled, reliable and predictable factory environment without outside influences such as season and weather conditions. This strengthen and consolidating the design phase and the applied modules increase the predictability of cost and scheduling both during the manufacturing and assembly processes (Bekdik, Hall, & Aslesen, 2016). Compared to traditional on-site construction, off-site production offers advantages like e.g. reducing design defects and ensuring quality, swift delivery, improved health and safety, information technology, modern equipment, and innovative production layouts (Chen & Samarasinghe, 2020). However, there are production challenges impacting the performance, related to engineering faults and rework with process dependencies generating bottlenecks (Arashpour, Wakefield, Blismas, & Maqsood, 2015). Some of the benefits of off-site manufacturing of modular construction is 1) *construction time reduction,* 2) *quality control,* 3) *waste reduction,* 4) *safety improvement, and* 5) *hazard and injury mitigation* (Li, Al-Hussein, Lei, & Ajweh, 2013).

Linner and Bock, claimed that prefabrication in Europe is mainly a niche in the low-cost market not allowing product or service innovation, whereas the Japanese prefabrication industry acts more like a production industry than a construction industry focusing on the middle and high-end markets. This is explained by that European prefabrication is not industrialized as it has not yet reached the critical mass of annual production allowing investment in efficient processes and automation, whereas the prefabrication industry in Japan incorporates the latest product and process technologies. (Linner & Bock, 2012).

The construction industry needs to focus on concepts or strategies that allow a greater customer focus as the demand of individual customization is growing, and therefore, possible value creation is attempted achieved by utilization of mass customization to create industrialized buildings (Yashiro, 2014). However, there is no clear consensus on a proper definition of *industrialization in construction*, but a broad definition is suggested as: *'a rationalization of the work processes in the industry to reach cost efficiency, higher productivity and quality'* (Yashiro, 2014). The industrialization is described as: *"a structural means for eliminating, or at least sharply reducing, onsite activities in construction"*. (Koskela, 2003). It is furthermore argued that the problems of construction require new initiatives at the level of operations and to support the practical problems of construction, it is needed to develop the theoretical foundation of production in construction.

2.4.5. SUPPLY CHAIN COLLABORATION

The construction industry is a very competitive and complex industry with a high need of integration between many different disciplines (see Figure 2-1) and members (see Figure 1-2) of the value chain like internal and external suppliers, designers, vendors, contractors, subcontractors, and clients (Jensen et al., 2019). The objective of supply chain management is to manage their supply chains to achieve strategic advantages, and the construction management is unique due to its nature of sporadic, fragmentary, discontinuous flow of activities with a low level of repetition. The supply chain management in the manufacturing industry has been extensively explored, whereas the use of similar approach to the construction industry has shown that a major part of the problems arises at the interfaces between the disciplines of the complex nature of the construction environment (Papadopoulos, Zamer, Gayialis, & Tatsiopoulos, 2016).

Vrijhoef and Koskela claim three main conclusions: *Firstly, even in normal situations the construction supply chain has a large quantity of waste and problems, secondly, most of these are caused in another stage of the construction supply chain than when detected; and thirdly, waste and problems are largely caused by obsolete, myopic control of the construction supply chain* (Vrijhoef & Koskela, 2000).Therefore, to successfully accomplish the demands for the delivery of top-quality projects at very competitive prices, on agreed time meeting the right quality a significant need for an effective management of the construction supply chain has arose. Vrijhoef and Koskela argued that the construction supply chain is characterized by the following three elements:

- "*It is a converging supply chain directing all materials to the construction site where the object is assembled from incoming materials. The "construction factory" is set up around the single product, in contrast to manufacturing systems where multiple products pass through the factory and are distributed to many customers."* (Vrijhoef & Koskela, 2000)
- *"It is, apart from rare exceptions, a temporary supply chain producing one-off construction projects through repeated reconfiguration of project organizations. As a result, the construction supply chain is typified by instability, fragmentation, and especially by the separation between the design and the construction of the built object."* (Vrijhoef & Koskela, 2000)
- *"It is a typical make-to-order supply chain, with every project creating a new product or prototype. There is little repetition, again with minor exceptions. The process can be very similar, however, for projects of a particular kind"*. (Vrijhoef & Koskela, 2000)

Based on these characteristics, which have an impact on the management of supply chaims Vrijhoef and Koskela recognized four major roles of supply chain management in construction 1) *interface between the construction site and the supply chain* 2) *the supply chain* 3) *transferring activities from the construction site to the supply chain* 4) *integrated management of the construction site and the supply chain* (Papadopoulos et

al., 2016; Vrijhoef & Koskela, 2000) see Figure 2-5. Improvements initiatives must be found on:

1) The focus is on the interface between the construction site and the supply chain to reduce costs and duration of construction site activities to ensure that dependable material and labor flows to the construction site without disruption to the workflow.
2) The focus is to the supply chain itself aiming at reducing costs, related to logistics, transportation, lead-time and inventory.
3) The focus is transferring activities from the construction site to the earlier stages of the supply chain to achieve cohesiveness and concurrency between activities and technical dependencies aiming at reducing costs and duration.
4) The focus is on integrated management of the construction site and the supply chain to improve the common supply chain and all the production and assembly activities taking place on the construction site.

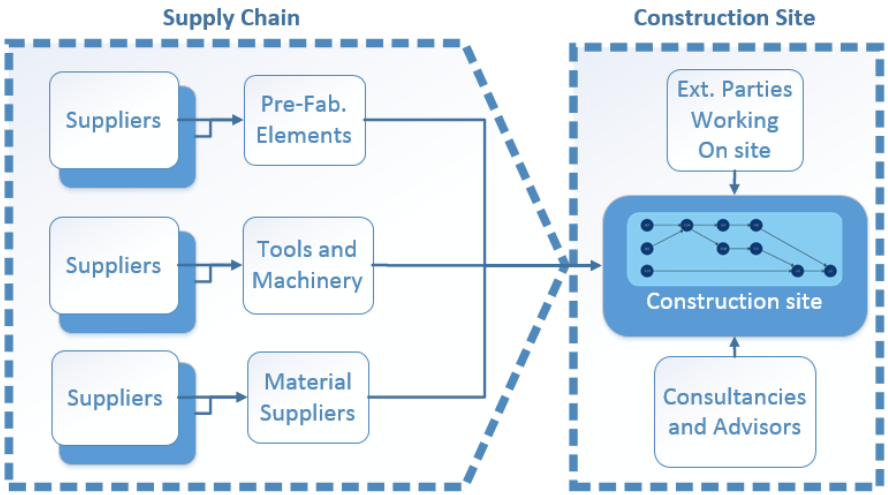

Figure 2-5 Supply Chain and Construction Site (Jensen et al., 2019)

The supply chain in construction is very fragmented, subject to unfavorable relationship, burdened by poor communication and lack of reliability. Therefore, strategic partnering seems as an effective way to deal with such problems, but nevertheless, the maturity of supplier management is low and despite of a close supplier relation contractors do not achieve inter-organizational integration between suppliers (K. Liu, Su, & Zhang, 2018).

Construction companies involving customers and planning to use customer choices to compete on the market need to reconsider the total process of the customer order decoupling point (CODP) (see Figure 2-3) and its effect on the supply chain. Companies

need to be explicit about the trade-off between the levels of customization, customer lead time and cost (Barlow et al., 2003). The Japan's factory-based housing industry, where companies supply customized homes preassembled from standardized components or modular systems, it is argued that mass customization can be supported by several generic supply-chain models (see Figure 2-6), which is a generic model applicable within a housebuilding context. The grey shading areas constitute the elements of the supply chain that are able to handle specific customer requirements, whereas areas without shading is elements of the supply chain where customers are unable to make choices (Barlow et al., 2003).

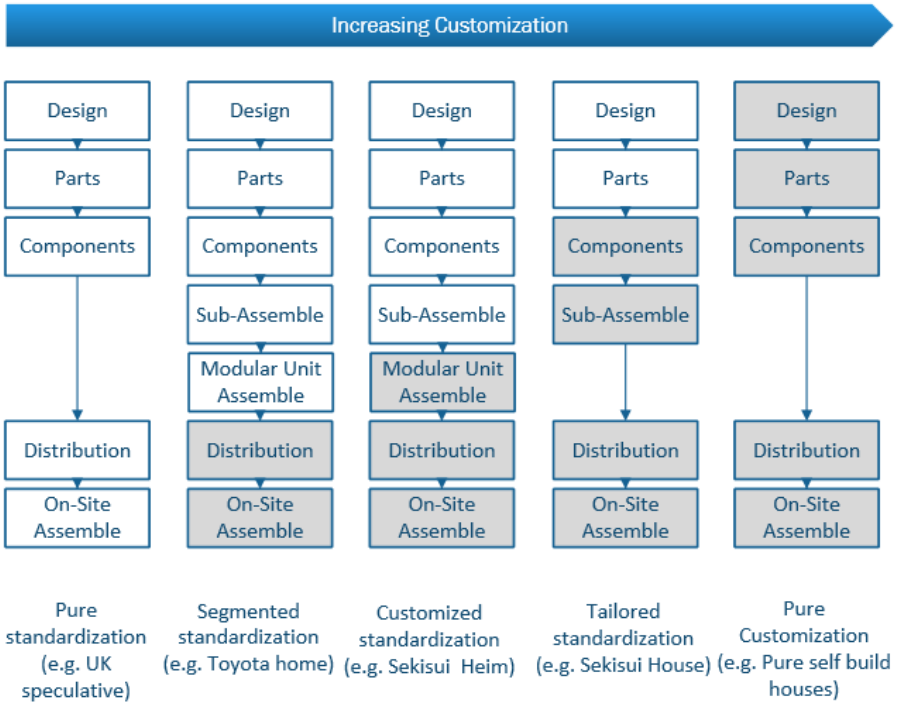

Figure 2-6 Generic supply chain strategies applied to the housebuilding industry, adapted from (Barlow et al., 2003)

Industrial construction contains high level of modularization and prefabricated components, which together with standardized supply-chain processes have been considered important. Based on modular construction, mass customization and industrial production of building modules it is likely that the standardized processes lead to less variances in performance and improved quality compared to the current practice of delivery (Kahkonen, Koskela, Leinonen, & Aromaa, 2003).

2.4.6. MARKETING AND CUSTOMER INVOLVEMENT

The Architecture, Engineering, and Construction (AEC) sector focus to create value and gain a sustained competitive advantage through various corporate strategies categorized into seven groups: 1) business strategy, 2) operational strategy, 3) information technology (IT) strategy, 4) marketing strategy, 5) technology strategy, 6) human resource strategy, and 7) financial strategy. Research has discovered that project managers often view certification of quality management systems as being valuable in terms of marketing, even though the existence of issues regarding implementation and the uncertainty of the short- and long-term value proposition to the operations, project and customers (Aburas & Lee, 2019). Customer satisfaction is usefully for evaluation of quality and assessment of the success of a company's improvement program, and measuring *customer satisfaction* has a number of benefits for the organizations: 1) *Improvement in communication between parties and enable mutual agreement*, 2) *Recognition of the demand of improvement in the process*, 3) *Better understanding of the problems*, 4) *Evaluation of progress towards the goal*, and 5) *Monitoring and reporting accomplished results and changes*. (Kärnä, Junnonen, & Kankainen, 2004). Co-creation has evolved and gained attention of academics and practitioners in the management literature, allowing collaboration between companies, customers and other stakeholders to create customer satisfaction and value through interaction. Research show the importance of co-creation as a paradigm in which theoretical statements has been developed and applied within different contexts and acknowledged in service and marketing as valuable for customers in the value creation process (Gummesson, Mele, Polese, Galvagno, & Dalli, 2014). In the client-contractor relationship co-creation create value by 1) early contractor involvement in the contribution of constructability expertise and 2) changing the client's attitudes to embrace value co-creation more than cost reduction. (Edvardsson, Tronvoll, & Gruber, 2011; A. Liu, Fellows, & Chan, 2014; Ranjan & Read, 2016).

2.5. MASS CUSTOMIZATION AND PRODUCTIVITY

Even though the existence of empirical evidence demonstrating that mass customization or modularity individually, jointly or sequentially increases the performance growth in terms of general productivity increase is limited. However, a typical mass customizer seeks for modularity in products, in processes and the entire supply chain mostly due to flexibility reasons preparing for accommodating for changes in the market.

There seems to exist broad agreement of several advantages to apply mass customization indicating a profit growth and productivity increase e.g. *maximizing market share, cut cost of inventory and material waste, increase cash flow, shorten time of responsiveness, ability to supply a full line of products or service with lower costs* (N. Liu, Chow, & Zhao, 2019; Pollard, Chuo, & Lee, 2016; Selladurai, 2004; Silveira et al., 2001; Wiengarten, Singh, Fynes, & Nazarpour, 2017).The principles behind mass customization as a strategy has achieved positive results in the manufacturing industry as

companies using mass customization has achieved benefits e.g. increased customer satisfaction, increased market share, increased customer knowledge, reduced order response time, reduced manufacturing cost, and increased profit leading to increasing productivity and competitiveness. (N. Liu et al., 2019; Selladurai, 2004; Silveira et al., 2001; Wiengarten et al., 2017). Research shows that product modularity directly and positively affects process modularity, manufacturing agility, and growth of company performance (Jacobs, Droge, Vickery, & Calantone, 2011). Recent research deduced a potential productivity connection between the nine tools and approaches of the three fundamental capabilities of mass customization and the six phases handling a building and construction project's lifecycle from the cradle to the grave (Jensen et al., 2018). The project phases are: 1) *plan* consisting of operations and management activities, planning and leadership relative to jobs carried out off-site and on-site, 2) *design*, containing development activities related to architecture and engineering, 3) *construct*, concerning manufacturing, assembly and montage activities off-site and on-site, 4) *hand-over*, including activities linked to reviewing and evaluating the project deliverables (quality, economic, time) and contract conditions; 5) *maintenance*, concerning activities related to the daily operations and maintenance of the product, and the final stage 6) *demolition*, comprising of activities related to destruction and reusing of materials, components used.

The CEO at one of the leading construction companies in Europe, claims in the context of implementing technological software tools like BIM and VDC (Building Information Modeling and Virtual Design and Construction) (Olsen, Khammar, Breiner, & Pape, 2016) that, e.g.:

- *Increasing productivity in the construction industry requires increased collaboration and better utilization of the technological tools*
- *The collaboration must begin at a very early stage in the process based on a virtual build-up of the project, linking to the project's schedule and finances for both the execution and operational phases*
- *Implementing the project virtually brings great and obvious benefits to both builders, suppliers, architects, advisers, and contractors*
- *A well-executed virtual model can already become visible in the idea phase choices for the builder, and this model can have a great impact on aesthetics, utilization options, flexibility, future energy consumption, and the total economy*
- *Linking planning and finances to the elaborate models ensure a streamlined construction process.*
- *We promise productivity in every part of the value chain - also for our builders, and the prerequisites for realizing this future are BIM and VDC*
- *We have put the technology into use, but we will achieve the full benefit when all the industry players work together*

2.6. SUMMARY

The aim of these five sections of 'State of the Art' was to explore existing research on application of mass customization in the building and construction industry including some relevant and related topics to identify gaps for determining the research directions. The explored research is widely based on case study research and the findings clearly indicate that there exists a potential for utilizing mass customization in the building and construction industry due to the nature of mass customization as a strategy with its ability to allowing customization, lower unit costs, increase quality, and shorten project duration as enablers of improving the productivity (N. Liu et al., 2019; Pollard et al., 2016; Selladurai, 2004; Silveira et al., 2001; Wiengarten et al., 2017). Consequently, the research on mass customization as a strategy applied within the building and construction industry aiming at improving the productivity is lacking and unexplored justifying this research, where the following findings motivate and are considered relevant for this research:

- Research on application of mass customization in manufacturing industry revealed significant benefits e.g. increased customer satisfaction, increased market share, increased customer knowledge, reduced order response time, reduced manufacturing cost, and increased profit, which are related to *'improved productivity'* (N. Liu et al., 2019; Pollard et al., 2016; Selladurai, 2004; Silveira et al., 2001; Wiengarten et al., 2017).
- Lack of research explaining the productivity gap between manufacturing industry and building and construction industry
- Limited research addressing application of mass customization within the building and construction industry in general and specific aiming at improving the productivity
- Limited research on tools and approaches applied in the building and construction industry for industrializing purposes relative to the manufacturing industry in terms of utilizing automation and digitalization in the industry despite the potential being high.

The literature indicates that focus in research so far has been on prefabrication and modularity as industrialization techniques applied in the building and construction industry, which indeed have improved quality and decreased construction time, waste, and costs. A research revealed that the construction sector should aiming to refine their practices to improve their business performance, and that the construction sector would likely benefit of utilizing practices from the manufacturing industry and the process oriented flow thinking (Pekuri et al., 2011). Since the literature dealing with mass customization relative to the building and construction industry is limited further research should be made in terms of realizing ideal mass customization in the building and construction industry aiming at improving the productivity. In this regard, all three capabilities '*choice navigation*', '*solution space development*' and '*robust process design*' are required and should be explored further for successful application of mass customization (Salvador et al., 2009).

CHAPTER 3. RESEARCH OBJECTIVES

This chapter presents the initial scientific objectives that have set the course and research direction for the project. The outset is a presentation of the assumptions and corresponding research as a foundation for this research to be verified throughout the thesis and presentation of the main research question that initiated this research.

The mass customization strategy has been known for three decades, and the manufacturing industry has to some extent adopted mass customization as a strategy or some elements of the concept for handling the increasing demand of product variety at a reasonable cost by utilization, e.g., new technologies to ensure increasing the performance. Increased demand of customized product, reduction of energy consumption, indoor climate requirements, enhancing the cost efficiency, skills shortages, and changing building regulation are among factors that have impacted the performance of the Danish building and construction industry compared to the manufacturing industry.

'*Mass customization as a strategy*' is meant as adopting mass customization on a strategic level as well as on tactical and operational level by dividing the strategic initiatives into specific action plans of implementing the mass customization tools and approaches. The '*performance'* is indeed a broad concept or an umbrella term covering many valid definitions, but the way it is meant here is operations management *'how successfully, or effective a company is at doing their core business activities or their primary value-adding activities compared to spent hours.'* Therefore, the initial scientific objective refers to productivity knowing that mass customization as a strategy offers further contribution than productivity improvement. Therefore, the *initial scientific objective* is to:

Contribute to the existing theory of mass customization targeting academia and practitioners in terms of determining how mass customization as a strategy can be extended to support the building and construction industry improving the productivity

---

The *contribution of this research* is to present a valuable addition to existing research in terms of a better understanding of the mass customization, adding new knowledge about the utilization of mass customization within the building and construction industry and bridging the gap between theoretical considerations and practical application and implementation of mass customization.

The principles of mass customization are widely used, and with great success in the manufacturing industry, therefore this research is based on the following assumptions as a guide for the research initiatives:

- *The utilization of mass customization as a strategy will increase the productivity within the building and construction industry*
- *The utilization of IT tools and standards supports the implementation of mass customization as a strategy in the building and construction industry*

3.1. RESEARCH OBJECTIVES

Because of the productivity gap between the manufacturing industry and the building and construction industry in Denmark, the main research objectives are formulated as:

***RO.1**: Determine how to improve the productivity of the building and construction industry*

***RO.2**: Clarify how can mass customization as a strategy support the building and construction industry towards improving the productivity*

***RO.3**: Identify tools and approaches from the mass customization domain to be applied within the building and construction industry improving the productivity*

The motivation of doing this research and establishing the above-mentioned objectives is threefold. *Firstly*, the realized productivity gap in Denmark between the manufacturing industry and the building and construction industry. *Secondly*, the findings from the literature review clearly indicate that there exists a potential for utilizing mass customization within the building and construction industry due to the fact that mass customization's ability is to lower unit costs, increase quality, shorten project duration, and at the same time acknowledge the need for customization and personalization, which are enablers of improving the productivity. *Thirdly*, the research of mass customization as a strategy applied within the building and construction industry is a sparse and unexplored research field, that strongly needs tools and approaches which help improving the productivity.

3.2. RESEARCH QUESTIONS

Based on the above-mentioned assumptions and the three research objectives, the following research framework (see Figure 3-1) is conducted illustrating the research opening, context and research questions (RQ.#) which drive the research:

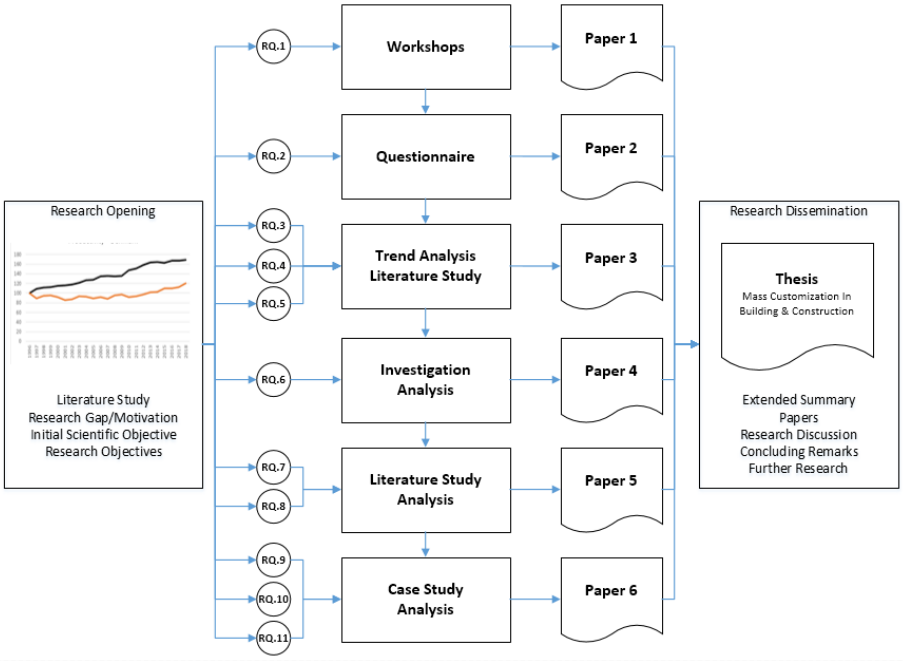

Figure 3-1: Research Framework

The starting point was an invitation to participate in a workshop associated with an innovation project, MCBYG that ran for 12 months. This workshop was a single part of the innovation project with the purpose to engage some companies within the building and construction industry aiming at dissemination of knowledge about the 'mass customization' concept. The purpose related to this research was to gather knowledge from the building and construction industry about to which extent they recognize and apply the concept and their viewpoints related to the concept by focusing on:

***RQ.1**: How does the building and construction industry assess "where are we today" and "where would we like to be" relative to mass customization?*

***RQ.2:** What are the building and construction industry's perception of themselves, the markets/customers, their competitors, and the technology available related to the application of mass customization?*

Research question 1 is reasoned in achieving knowledge from industry partners of their understanding of the mass customization concept relative to their own business and product offerings. This, in the sense of how they consider them-selves relative to their customers' expectations of product offerings and their competitors product offerings, and how they plan to develop their business in this respect and thereby in terms of trying to reach a higher degree of mass customizing by being able to offer their customers more variants at reasonable cost considerations than today. The knowledge of how the concept as an improvement strategy is received by the industry partners is considered important for the ongoing research.

Research question 2 is reasoned in achieving knowledge from industry partners 1) to determine the pre-requisites and viewpoint for utilizing the advantages inherent in the use of mass customization in terms of technology availability supporting the application of mass customization as a strategy, 2) to investigate the value proposition in the sense of, whether the industry partners' customers demand of customized products are justified in that customized products add value to their customers business, 3) to determine whether the industry partner consider the cost perspectives high in relation to making and delivering customized products to their customers, and 4) to determine how the industry partner rank themselves relative to their competitors.

Based on the Danish productivity gap between the manufacturing industry and the building and construction industry it was important to clarify whether this phenomenon is country or industry specific, as well as understanding the challenges that characterize the building and construction industry. Therefore, the following research questions:

***RQ.3**: How is the productivity development of Danish building and construction industry compared to other countries in Scandinavia and Europe?*

***RQ.4**: What are the challenges and the conditions that strain the building and construction industry in improving productivity?*

Research question 3 is reasoned in analyzing statistical productivity data from OECD stat (Organization for Economic Co-operation and Development) to achieve knowledge of the performance gap obtained between the manufacturing industry and the building and construction industry in Scandinavia and Europe. The reason is to clarify whether the gap is industry specific or country specific as it may affect the research approach.

Research question 4 is reasoned in studying the literature to explore the challenges that the building and construction industry is subject to. The reason is to determine whether

these challenges are significant different according to the manufacturing industry justifying or explaining the performance gap between the two industries, which as well will frame and influence the subsequently research.

To investigate the usefulness of the mass customization concept, it was interesting to study more closely the relationship between the capabilities of mass customization as a strategy and the building and construction industry, which resulted in the following research questions:

***RQ.5**: Which capabilities of mass customization can be applied to increase the productivity?*

***RQ.6**: What are the potential productivity effects of utilizing the fundamental capabilities of mass customization relative to the known phases of a typical building and construction project?*

Research question 5 is reasoned in studying the three fundamental capabilities of mass customization (Solution Space Development, Choice Navigation, and Robust Process Design) finding indicators, assumptions and requirement that justify mass customization as a strategy applicable within the building and construction industry. The reason is to gain knowledge of under which circumstances mass customization contribute to the building and construction industry.

Research question 6 is reasoned in achieving knowledge of to which extend the mass customization concept in terms of its tools and approaches relative to the three fundamental capabilities potentially contributes to increasing the productivity. The productivity contribution is divided into the well-known phases of a typical building and construction project to understand where to seek improvements initiatives increasing the productivity of the building and construction industry. This is done as project execution affect a significant part of the operations management of such companies.

Mass customization is a strategy depending on flexible and automated processes and equipment, and depending on the efficiency of the whole integrated value chain with the ability to share knowledge and information between the entities of the value chain in order to communicate and producing goods at the cost, time and quality required. Therefore, the following research questions are settled to investigate how the value chain collaboration can be improved in the context of applying mass customization and ICT resources:

***RQ.7**: What are the assumptions and possibilities for applying the principles of mass customization within the building and construction value chain?*

***RQ.8**: What are the conditions (standards and ICT tools) for co-operation between the entities in the building and construction value chain?*

Research question 7 is reasoned in studying the literature and the industry practices of establishing an adaptable integrated system of entities within the value chain of the building and construction industry. This is reasoned in achieving knowledge of how mass customization as a strategy for the entities individually and interconnected within the value chain can contribute to the building and construction industry in terms of increasing the productivity.

Research question 8 is reasoned in analyzing the industry practices to gain knowledge about which standards are present for supporting the implementation of mass customization as a strategy individually and integrated across the value chain of the building and construction industry?

The essence of mass customization is the customer-oriented approach of offering exactly enough variety in the product or service range that almost everyone finds what they want at affordable prices. To cope with this companies must master three fundamental capabilities 1) *Solution Space Developmen*t, 2) *Choice Navigation*, and 3) *Robust Process Design*, which can be achieved by developing the nine *Tools and approaches*. Therefore, the following research questions are settled:

***RQ.9**: How does the building and construction industry apply and plan to be develop the three fundamental capabilities of mass customization, and how has it affected the industry?*

***RQ.10** What are the characteristics of the above-mentioned building and construction industry and how does that correlate to the outcome from RQ9?*

Research question 9 is reasoned in understanding the industry practices of implementing the mass customization to see how it has affected the building and construction industry. Therefore, it is important to analyze the specific nine tools and approaches of mass customization to determine if there are any preferences that supports the industry

better than others aiming at explaining why it is so to. Furthermore, to understand which tools and approaches that are the most relevant for the industry supporting improvements of the productivity. This knowledge may be useful in relation to determine and prioritizing any roadmap of improvements initiatives targeted the building and construction industry generally or to any specific sectors of this industry.

Research question 10 is reasoned in determining any correlating between the findings from RQ.9 to the industry characteristics like the position in the value chain, industry level of automation, company level of maturity, strategy level of software/technology, company size. The purpose is to be better prepared when setting up a targeted development program that serve more specifically at specific sectors or companies of the industry.

Mass customization as a strategy improving the productivity of the building and construction industry has not been explored as much as in the manufacturing industry neither in relation to industry nor academia. Therefore, the following research question are formulated:

RQ.11 *To what extent are the existing definitions of mass customization appropriate and motivating for the building and construction industry?*

Research question 11 is reasoned in that the mass customization concept is not well-known and much used neither explored considerable in the building and construction industry. This might be due to many reasons, but also justified in the fact that the used definition of the concept is inappropriate or misleading in relation to be considered as a relevant improvement strategy applicable for the building and construction industry. Therefore, an adjustment of the definition may be convenient to popularize the concept to ensure an academic and industrial acceptance of the concept

These eleven research *questions* will shape the research project for the purpose of *developing tools and approaches enabling companies in the building and construction industry to adopt mass customization or some elements of the concept* to meet the customers demand for unique products cost-effectively and thereby improve the productivity.

CHAPTER 4. RESEARCH DESIGN

This chapter presents the applied scientific research design. The ultimate presumptions, the scientific paradigms, and the theory of science are the foundation for determining the methodological approach. The methodological approach leads to the research design containing related systematic procedures and research methods applied to the study area, positioning the research questions, and the contribution of the research. Finally, the delimitations and the structure of the dissertation are presented.

Every scientific research needs a research design to conduct research or guide the researcher through the research process for creating business knowledge. A research design framework involves the intersection of *Philosophical Worldviews*, *Selected Strategies of Inquiry*, and specific *Research Methods* (Creswell, 2013).

The creation of business knowledge refers to research activities as well as investigations and consulting (Arbnor & Bjerke, 2008). This topic, the creation of business knowledge has been extensively discussed, and it can be argued that it is not possible empirically and logically to determine one best research methodology and the idea of being able to determine a method exclusively from a certain problem is criticized (Arbnor & Bjerke, 2008). Therefore, it can only be carried out by considering the research to be done combined with researchers background and context as it affects how phenomena of the world are interpreted and understood by the researcher (Arbnor & Bjerke, 2008). It is important to be aware of that the presumptions of the researcher affect the observations, the collecting of data, and the way data is analyzed.

However, it is important to respond to the fundamental questions of what knowledge is, what conception of reality is, and what truths is, etc. An attempt to explain and understand this would require that the researcher provides a solid philosophical foundation of answering these five questions: 1) *What are the ultimate presumptions held by the creator of knowledge?* 2) *What kinds of questions are asked?* 3) *What kinds of concepts are used to formulate these questions?* 4) *What kinds of methods are used to explain and understand the world?* 5) *What kinds of answers or solutions are given to the questions?* (Arbnor & Bjerke, 2008).

The outset for this thesis is the methodology framework (Arbnor & Bjerke, 2008) illustrated in Figure 4-1, which contains two metatheories, *theory of science* and *methodology* characterizing the research process stating a connection between these two metatheories, scientific perspectives (ultimate presumptions), methodological approach and the study area.

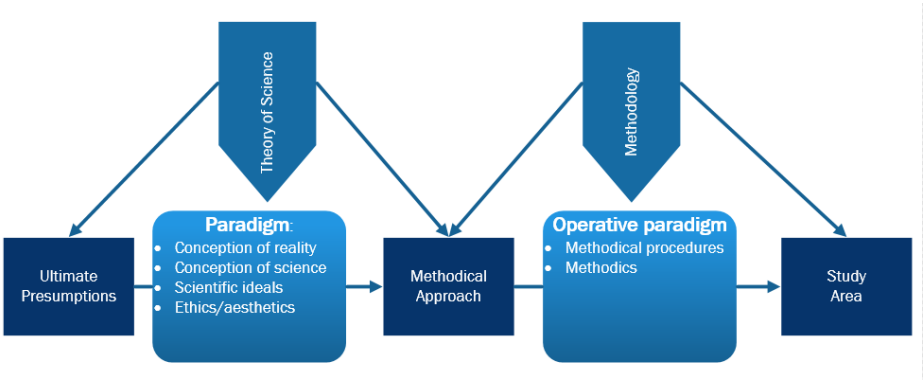

Figure 4-1: Methodical framework. (Arbnor & Bjerke, 2008)

The theory of science is the views on the reality, knowledge, and methods, whereas methodology is the set of techniques and principles used when studying an area of interest, e.g., experiments, case studies or surveys. The case study approach represents the majority of this research *'how to apply mass customization as a strategy within the building and construction industry, improving the productivity.'*

4.1. SCIENTIFIC PARADIGMS

Philosophical worldviews also referred to as paradigms, epistemologies[2] , and ontologies[3] (Creswell, 2013) is divided *into Postpositive* worldview, *Social Constructivist* worldview, *Advocacy and Participatory* worldview, and *Pragmatic* worldview (Creswell, 2013). Ultimate presumptions are characterized by a paradigm containing a specific perception of the world, which influences how researchers approach and interpret problems (Kuhn, 1962), and these ultimate presumptions rarely change or change gradually over time (Arbnor & Bjerke, 2008). New paradigms are replacing old paradigms. However, in the social sciences, old paradigms usually live alongside new ones (Arbnor & Bjerke, 2008).

Various classification of paradigms have been debated, and some authors promote two views, i.e. *Positivistic* (social science study is based on general natural scientific models) and *Hermeneutic* (everything needs to be interpreted in its context) (Coughlan & Coghlan, 2002; Gummesson, 2000), while others advocates for three views i.e. *Analytical* view, *Systems* view and *Actors* view (Arbnor & Bjerke, 2008). Some promote four views, i.e. *positivism*, *post-positivism*, *critical theory*, and *constructivism* (Guba, 1990).

[2] Epistemology is a study or a theory of the nature and grounds of knowledge especially with reference to its limits and validity (Merriam-Webster 2019)

[3] Ontologies means a theory about the nature of being or the kinds of things that have existence (Merriam-Webster 2019)

In *Methodology for creating business knowledge* (Arbnor & Bjerke, 2008), the authors cited (Törnebohm, 1974) for the four views (see Figure 4-1):

1) *The conception of reality*, which has to do with the researcher's philosophical ideas about how reality is constructed (view of the world);
2) *The conception of science*, which has to do with the researcher's knowledge gained through education (concepts and beliefs);
3) *The scientific ideal*, which is related to the researcher's desires of achievement from the research (persons desires and ambition); and
4) *The ethical/aesthetical* aspects, which has to do with the researcher's conception of morality (what is suitable/unsuitable to the researcher).

A scientific paradigm, *Critical rationalism* (Popper, 1959) defined as 'Theoretical progress is made by successive critique and revision of existing theories, which is governed by the idea of objective truth' (Schroeder-Heister, 2001), is considered fundamental and relevant for this research. One of the main principles of critical rationalism is the theory about falsification, saying that a generally acknowledged theory can be falsified by a single observation that proves the theory wrong. E.g., the observation of the black swan discovered in Australian falsified the theory of all swans being white as biologists initially acknowledged the theory that all swans are white since all observed swans in history have been white (Schroeder-Heister, 2001). Therefore, falsification (regardless of the number of observations) can be applied improving existing theories by revising the originally falsified instead of rejecting (Schroeder-Heister, 2001). The principles of critical rationalism theory should never be perceived as final, because the new knowledge or observations may lead to falsification reasoning that the new theory will be closer to the thrust (Schroeder-Heister, 2001). Critical rationalism tries to achieve objective truth but admit it may not be possible, so instead scientists perceive the existing theory as the closest possible to the fact if it has not yet been falsified. Business research has to a great extent acknowledged business propositions from other business areas as continuous improvement. Application of a theory to a new area is potentially a falsification of the current theory, but if the theory can be applied to the new business area, the theory is not falsified but expanded as new valuable business knowledge. If the theory is falsified, the existing theory can be revised or adapted and thus applicable in a broader perspective. Therefore, critical rationalism, both implicitly and explicitly is considered fundamental in this research by application of the theory *'mass customization'*, which originates from the *'manufacturing industry'*, where this theory is widely used (to mass producers to become mass customizers), to be applied or expanded to the new business area *'building and construction industry'* aiming at improving the productivity within this industry.

4.2. METHODOLOGICAL APPROACH

'The methodology is the understanding of how methods are constructed, that is, how an operative paradigm is developed' (Arbnor & Bjerke, 2008). A scientific effort should state its methods to ensure the validity of the research and its objectives as the

applied methods provide insight into the scientific research process for reproduction of the research to test the reliability of the obtained results.

The scientific paradigms and the ultimate presumptions as presented have a significant influence on the methodological approach applied. The following three main methodological approaches are suggested (Arbnor & Bjerke, 2008):

- *Analytical approach*: The analytical approach originates from classic analytical philosophy with its roots in western thinking. This approach assumes that the quality of the reality has a summative character, as described in the statement '*the whole is the sum of its parts*' (Arbnor & Bjerke, 2008). This fact implies that the analytical approach addresses research problems, in part, to develop a theory within a delimited area without emphasizing relations to other areas.
- *Systems approach*: The systems approach is addressed the synergy based on several problems by considering their relations and implications, as described in the statement *'the whole differs from the sum of its parts'* (Arbnor & Bjerke, 2008). Therefore, it is assumed that knowledge about a delimited area is highly dependent on the system of which the area is a part.
- *Actors approach*: The actor's approach is mainly relevant in relation to social research in the sense of understanding the social whole in terms of meaning structures, e.g., businesses and organizational structures as knowledge dependent on individual actors. (Arbnor & Bjerke, 2008).

In the *analytical approach*, the solutions are developed independently of the system that they are to be applied in, which means, e.g. that some elements of the 'mass customization' theory, developed using an analytic approach, adapted to fit one company might not necessarily be applicable for other companies.

The *systems approach* is a widely applied approach in business theory and practice because of its holistic orientation of problems. The solutions developed through the *systems approach* depends on the systems with attention to the interrelationships of the solutions and the system that they are to be applied in, which mean that there does not exist a single approach to application of the elements of the 'mass customization' theory as a productivity enabler that lead to optimal results for all companies. Therefore, the *systems* are considered the company and all the different sectors within the building and construction industry in which the developed *solutions* or the gained *knowledge* (adapted elements of the 'mass customization' theory) are supposed to be applied. Subsequently, the 'mass customization' theory is to be considered as one strategic improvement initiative out of a potential portfolio of other improvement initiatives planned or proposed within a company (*systems*).

The *actors' approach* is highly dependent on the involved actors and individuals' subjective meaning in the creation of solutions or knowledge. Therefore, relative to the

application of ‘mass customization’ theory within building and construction companies, it would be relevant to address organizational issues to adapting and implementing elements of ‘mass customization’ theory to be adopted successfully. Indeed, organizational issues are relevant. However, as described later, a delimitation has been made not to address organizational issues.

The focus in this research addresses the challenges related to establishing an adaptable integrated system applying the principles of ‘mass customization’ theory aiming at to be able to convert quickly to changing business conditions and exploiting the market opportunities within the integrated building and construction value chain. Therefore, the *analytical approach* and the *systems approach* have been applied. Since the research methods applied in this research includes ‘*case study research*’, interaction with actors in the involved organizations is a part of this research, which implies implicitly, that elements of the *actors approach* have been included, since different meanings and perceptions from actors needed to be interpreted to create knowledge about the systems.

4.2.1. LITERATURE REVIEW

The purpose of a *literature review* is to study and review existing literature about a chosen topic to gain insight to fully understand the research problem within the context of existing literature to determine whether the topic is worth studying (Creswell, 2013). A literature review is a qualitative study that relates the research to the ongoing dialogue in the literature, studying gaps that exist in the literature to be filled out with additional research in order to extend prior studies and existing knowledge, but also to avoid duplication of effort.

4.2.2. WORKSHOP APPROACH

A workshop is an event where a group of people are engaged to learn, acquire new knowledge, perform creative problem-solving, or innovate in relation to a domain-specific issue (Ørngreen & Levinsen, 2017). Workshops help researchers identifying and exploring relevant aspects of a given domain by bringing forth viewpoints, methods, and knowledge for better understanding the research problem in a context (Baran, Uygun, Altan, Bahcekapili, & Cilsalar, 2014; Ørngreen & Levinsen, 2017). Data generated in a workshop is different from data generated by, e.g., observations, questionnaire, interviews, and the documentation is typically via note-taking, recording (audio and video), and it is demanding and comprehensive both to document and to reuse the relevant outcome from a workshop in a uniform way.

4.2.3. TRENDS ANALYSIS

Trend analysis is a statistical method that tries to determine and predict future behaviors or movements of a specific factor based on the idea that what has happened in the past gives ideas of what will happen in the future. Another part is analyzing trend similarities

by using a dataset from different areas to verify correlations, e.g., similarities or dissimilarities between areas.

4.2.4. QUESTIONNAIRE (SURVEY)

A questionnaire is a research method that could be qualitative or quantitative. Questionnaires consist of a set of questions aiming at collecting information from the respondent. The questions are typically closed-ended questions, open-ended questions, or a mix hereof, where open questions offer the ability for the respondent to think and elaborate on their thoughts. Closed-ended questions answers in only one word or with a short, specific piece of information whereas open-ended questions require an answer with more depth and explanations, and open-ended questions help find out more details about a specific problem area.

4.2.5. CASE STUDY (MULTI CASE STUDIES)

Case study research is a scientific method of learning (exploration and understanding) about a complex instance through extensive interviews, description, and contextual analysis primarily used in sociology science. This method is recognized and appropriate for describing and analyzing phenomena in a single case and can be applied in many areas, e.g., studies of economics, business, psychology, and life sciences, and case studies are categorized as 1) *explanatory*, uses to answer a question in order to explain the phenomena, 2) *exploratory*, uses to explore phenomena in the data which are interesting to the researcher, or 3) *descriptive*, uses to describe the phenomena occurring within the data (Yin, 2003). Case study methods are frequently applied within operations management for the creation of knowledge and theories (Voss, Tsikriktsis, & Frohlich, 2002) and enable the researcher to go beyond the quantitative statistical numbers trying to understand the behavioral circumstances seeing from the actor's perspective. The researcher must avoid affecting the case due to the validity of the findings and conclusions. Therefore, the role of the researcher is to observe and subsequently to analyze the observations done to explain phenomena and their relationships as the foundation for creating new knowledge.

Three strength of using case studies (Meredith, 1998; Voss et al., 2002):

- *The phenomenon can be studied in its natural setting and meaningful, relevant theory generated from the understanding gained through observing the actual practice*
- *The case method allows the questions of why what and how to be answered with a relatively full understanding of the nature and complexity of the complete phenomenon*
- *The case method lends itself to early, exploratory investigations where the variables are still unknown and the phenomenon not at all understood*

Case study research is often criticized for its validity, whether the findings of a single case study can be generalized only based on a single specific case study (Flyvbjerg, 2006). It is argued that a case study to a large extent is relevant in the initial stages of research to make exploratory analysis, which should ideally be extended with a larger quantitative sample (Abercrombie, Hill, & Turner, 1984). Case studies are argued to be very useful for falsification of general theories if a single case does not fit a general theory (Flyvbjerg, 2006), and consequently, the outcome of case studies may be applicable for complementing existing theory.

Researchers must consider whether to conduct a *single case study* or a multiple case study. A *multiple case study* enables the researcher to study differences and similarities within a specific case and across the chosen cases for comparison. The knowledge creation from multi-case studies is considered robust and reliable, but it can also be time consuming and expensive to conduct.

4.3. APPLICATION OF METHODS

Research methodic applied in this research are:

- Literature review
- Workshop approach
- Trends analysis
- Questionnaire (survey)
- Case study (multi-case studies)

The initial research activities included *literature review*, which was successively expanded to establish the research purpose, and to gain insight and knowledge of the 'mass customization' theory generally and specifically relative to the building and construction industry, and other closely related areas. The initial literature search in Web of Science (Thomson Reuters) revealed only 15 relevant papers addressing a combination of "mass customization" AND "building industr*" OR "construction industr*". By searching for mass customization literature in the categories of architecture, civil engineering, and construction building industry approximately 25 relevant papers found. It should be noted that additional literature concerning modular building and pre-fabrication exists, which indeed is related to mass customization, however, not explicitly stating the concept in the papers, e.g. (Lawson, Ogden, & Bergin, 2011; Otreba & Menzel, 2012). Research and application of mass customization within the house building industry is considered highly unexplored (M. Larsen et al., 2019), and this despite of that the house building industry is looked at as industrialized, which indeed justifies further research of mass customization within the building and construction industry.

Workshop approach has been applied for the dissemination of knowledge about mass 'customization' theory to some companies as a preparation for their involvement delivering valuable knowledge involved in this research. The applied workshops focused on

the study of building and construction companies in relation to mass customization theory, which was authentic in the sense of it aims to fulfil participants' expectations to achieve objectives related to the interest of both partners. Workshops was beneficial in the initial phase as it holds a two-way communicative and collaborative approach, and they were specifically designed to fulfil the research purpose to produce reliable and valid data about the utilization of mass customization within the building and construction industry. The workshop approach was an authentic practice within the research area to 1) generate findings and guidelines on how to innovate the industry 2) dissemination of knowledge both ways, and 3) incorporating valuable knowledge to research going forward. Workshops were initially used to clarify the situation of "where we are today in relation to mass customization relative to the building and construction industry" and to determine the development potential for the involved companies.

Trend analysis was conducted to gain insight and understanding of statistical data about the productivity development of the manufacturing industry relative to the building and construction industry to determine whether the Danish productivity gap is a country-specific phenomenon or industry specific phenomenon. Productivity is considered as one of the best indicators of production efficiency meaning that high productivity usually corresponds to profitability excellence. Productivity is defined as the output per hour worked, and the calculation of productivity requires three variables: the industry's output, the industry's employment data, and the average number of hours worked. The trend analysis is first done in relation to countries in Scandinavian as these countries in many ways are comparable with Denmark due to e.g. common historical roots, cultural conditions, and common collaboration traditions. Secondly, the trend analysis is carried out for countries in Europe to justify, whether this productivity gap is country specific or industry specific.

The *questionnaire* was conducted to establish fundamental knowledge of some Danish companies within the building and construction industry to determine the pre-requisites and viewpoints for utilizing and harvesting the advantages inherent in the 'mass customization' theory. Questionnaire is a kind of survey research method, which can be conducted by structured interview and observation as a written interview, or they can be carried out face to face, by telephone, computer, etc. Such a research method was a relatively cheap, quick and efficient way of gathering of information from many participants based on a series of questions. The data was collected relatively quickly as the researcher did not need to be present when the questionnaire was completed. This research method was applied initially based on a questionnaire involving several Danish companies in the building and construction industry to determine the pre-requisites and viewpoint for utilizing the advantages inherent in the use of mass customization. The reasoning behind the choose of this method, was that if needed a questionnaire can be upscaled to a larger number of companies to increase the validity, and to get experiences in case this method could advantageously be used later.

For in-depth examination *case study* have been conducted as a significant part during this research involving multiple cases (companies) aiming at gaining new knowledge

of how to apply 'mass customization' theory within the building and construction industry improving the productivity. Although case study methods may seem as a controversial approach to data collection relative to quantitative data gathering as it lacks robustness as a research tool. Case study methods are used as in-depth knowledge and explanations are needed, and to go beyond quantitative statistical results and the limitations of quantitative methods. Therefore, understanding and providing holistic and in-depth explanations through the participants' perspective is considered important for this research as it holds a two-way communicative approach. The drawback of a single-case study is the inability to provide a generalizing conclusion. Therefore, a way of overcoming this is by triangulating the study with other methods or as done in this research utilizing multi case study as it increases the level of confidence in the robustness of the method to confirm the validity of the research.

4.4. RESEARCH DELIMITATIONS

In this research concerning the application of 'mass customization' theory within the building and construction industry, several delimitations have been made. The objectives have been to contribute to the science as well as to create applicable value and practical guidance for companies within the building and construction industry. The major delimitations are:

- *Organizational issues such as implementation and change management are not addressed, even though they are important success criteria.*
- *Quantitative cost-benefit analyses of the application of mass customization within any company are not performed.*
- *Building and construction industry is in this research considered broadly as a whole without targeting one specific sector within the industry, e.g., house-building, oil platform, bridges.*
- *Case studies are primarily anchored in Danish companies even though some of them operates in Scandinavian (a few in Europe and worldwide).*
- *This research does not provide a complete overview of all methods, tools, and approaches available for the transition towards mass customization*.

CHAPTER 5. RESULTS AND CONTRIBUTIONS

This chapter presents the result and contribution of the academic research concerning how mass customization as a strategy facilitates improving the productivity within the building and construction industry. This chapter accounts for the contribution derived from the conference papers and journal papers produced during this research project. This step is done according to the research approach for the purposes and results derived from each of the papers and the cumulative results to demonstrate the contribution of this research project.

The papers are organized in chronological order according to research framework (see Figure 3-1) and the corresponding research questions (RQ.#), which illustrates the general process applied in this research starting from the initiated investigation stating a significant Danish productivity gap between the manufacturing industry and the building and construction industry. The ambition is to understand and explain why it is so to elucidate the relevance of applying mass customization as a strategy within the building and construction industry aiming at providing guidance proposals of how to minimize this gap by improving the productivity of the Danish building and construction industry.

A summary of the following six papers will be presented:

- Paper 1: Application of Mass Customization in the Construction Industry
- Paper 2: Mass Customization in the Building and Construction Industry
- Paper 3: Productivity, Challenges, and Applying Mass Customization in the Building and Construction Industry
- Paper 4: Mass Customization as a Productivity Enabler in the Construction Industry
- Paper 5: IT Tools and standards supporting Mass Customization in the Building Indus-try
- Paper 6: Applying and developing Mass Customization in Construction Industries - A Multi case study

5.1. PAPER ONE

Title:

Application of Mass Customization in the Construction Industry

Purpose:

The purpose was to gain insight and collecting useful knowledge from companies within the building and construction industry about their understanding and approach to mass customization relative to their customers and competitors (Jensen et al., 2015).

Method:

Seven building and construction companies were engaged in some workshops aiming at dissemination of knowledge about mass customization as a preparation for their involvement delivering valuable knowledge of how they see themselves today and in the future, how they see the customers' expectations and how they see their competitors' position relative to mass customization (volume and variants). The workshops were carried out by discussion in groups and then mapping the results. Another aspect was to see the consensus and alignment between different personnel within the same company of how they see themselves today and in the future.

Result:

The workshop showed (RQ.1):

- Personnel within the same company have a different perception of how to indicate the current and future position relative to mass customization, but the majority seems to agree.
- The discrepancy between personnel in the same company can be explained by, e.g. individual skills, background and role in the company, their knowledge about products, customers, competitors and internal business strategy.
- All companies see themselves moving towards a higher degree of mass customizing by being able to offer more variants than today.
- Everyone considers themselves more mass customizer than their competitors
- Everyone has significant knowledge about their customers and what they want

It can be concluded that all the seven companies' foreknowledge about the mass customization concept was very limited, which demonstrates the importance of dissemination of knowledge about mass customization concept prior to the any workshop. Despite their foreknowledge, the workshops deduced that the companies see themselves moving towards a higher degree of mass customizing by being able to offer more variants than today, and by having a great knowledge about their competitors' capabilities and their customers' needs.

5.2. PAPER TWO

Title:

Mass Customization in the Building and Construction Industry

Purpose:

The purpose was to gain insight and expertise from some companies within the building and construction industry about their capabilities of providing customized products, examine the market/customers' demands and the value proposition of customized products, investigate the competitiveness of customized products within their markets, and finally scrutinize the availability of flexible manufacturing technologies supporting customized products. The aim was to determine the pre-requisites and viewpoint for utilizing the advantages inherent in the use of mass customization. (Jensen et al., 2017).

Method:

The knowledge gathering was carried out by making a small sample survey involving seven companies within the building and construction industry to answer a questionnaire based on nine questions to determine their perception of themselves, their customers (market), their competitors, and their technology suppliers related to the application of mass customization.

Result:

The survey showed (RQ.2):

- Companies' customers all want customized products
- Customized products add value to their customers
- Companies plan to introduce customized solutions
- Companies consider cost perspectives high related to customized products
- Companies consider that the industry offers flexible production technology
- Companies have efficient communications and relationships with their customers, and
- Some companies have relative strong change management capabilities

It can be concluded for all the seven companies that mass customization as a strategy has great potentials as there is a need for customizable products as it is value adding for the customers. Companies want to comply with the market demand, and the possibilities of doing so seems to be within easy reach as their technology suppliers support this change, which as well seems capable to implement as the companies have both a close relationship to their customers and strong change management capabilities.

5.3. PAPER THREE

Title:

Productivity, Challenges, and Applying Mass Customization in the Building and Construction Industry

Purpose:

The purpose was to gain insight and knowledge about the productivity development of the building and construction industry relative to the manufacturing industry to compare Danish trend similarities with Scandinavian and other European countries; and to determine whether the Danish productivity gap is country or industry specific as this knowledge might affect the upcoming research directions. Another aspect was to understand the challenges that strive the building and construction industry in improving the productivity, and the application of mass customization within the building and construction industry. (Jensen et al., 2018).

Method:

The outset was a trend analysis of statistical numbers of the productivity development of the building and construction industry relative to the manufacturing industry firstly based on countries in Scandinavian due to many similarities with Denmark, and secondly relative to other European countries. Hereafter a literature study was carried out focusing on firstly the challenges within the building and construction industry that strain the industry in improving the productivity, and secondly the application of mass customization within the building and construction industry.

Result:

The statistical analysis showed (RQ.3):

- Similarities between Danmark and all other countries in Scandinavian from 1994 to 2016 in terms of a significant productivity gap between the building and construction industry and manufacturing industry
- Similarities between Danmark and the average of all countries in Europe from 1996 to 2016 in terms of a significant productivity gap between the building and construction industry and manufacturing industry
- The Danish productivity gap between the building and construction industry and manufacturing industry is industry specific likewise other countries in Scandinavian and Europe, as well as the USA and Canada (see Figure 5-1 Comparison between Danish and European productivity development)

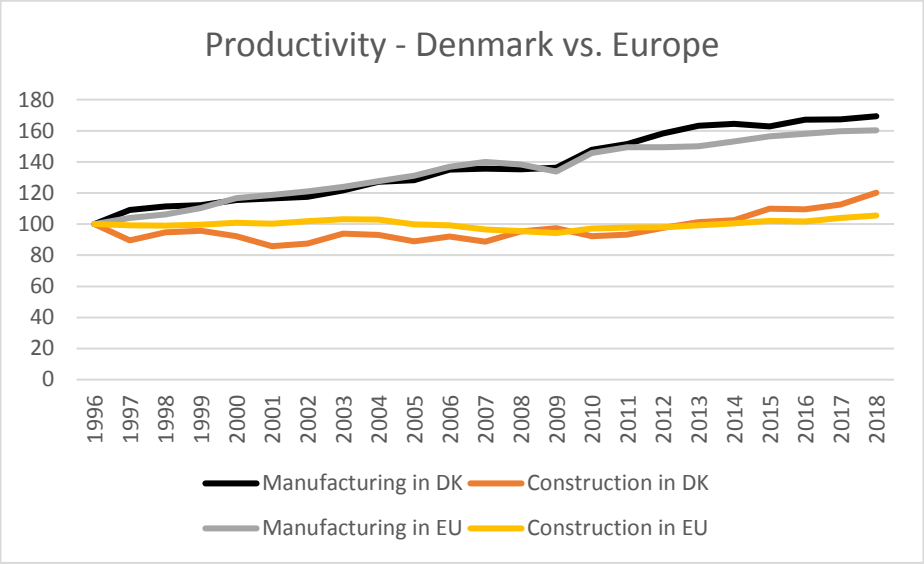

Figure 5-1 Comparison between Danish and European productivity development

Relative to the *challenges* in the building and construction industry the literature study substantiated (RQ.4):

- Practices to increase productivity are not necessarily similar in each country
- Productivity factors causing low productivity can be classified to the 1) *industry*, 2) *labors*, and 3) *management*:
    1. The singularity and complexity of construction projects built at varied locations, at adverse and unpredictable weather conditions and seasonality, traditions
    2. The union's influence, health and safety considerations and legal procedures, the learning potential, and lack of motivation, engagement, and wellbeing
    3. Insufficient leadership (poor communication and coordination, inadequate project supervision and management, shortages of skilled labor, sustainability concerns, late changes in plans), lack of material, equipment, tools, and technology. Lack of management tools (performance measures and management system)

Relative to the *application of mass customization*, the literature study indicated (RQ.5):

- It is sensible for the building and construction industry to apply the principles of mass customization for productivity improvements. *Firstly*, the building and construction industry design and deliver customized products. *Secondly*,

mass customization is a strategy aiming at efficiently handling of customizable products, and *thirdly*, mass customization has increased productivity in the manufacturing industry in Denmark

- Companies utilizing mass customization must master three fundamental capabilities 1) *Solution Space Development*, 2) *Choice Navigation*, and 3) Robust *Process Design* as direction for a 'journey' towards profitability serving customer demands by designing products, processes, and value chains in order to meet customer demands individually
- There is no "perfect end-state" of mass customization. Thus, the *development possibilities* and the *transition initiatives* are individually
- A higher degree of customization often leads to complexity and unpredictability in processes due to larger product variety, greater number of items, more processes, more suppliers, more retailers, more distributions channels, etc. resulting in higher resource consumption
- A well-functioning mass customization system provides stability, flexibility, and responsiveness in the business processes in order to handle the variance of products and services
- Appropriate techniques and approaches are 1) delaying product differentiation, 2) flexible automation technology, 3) modularity in products and processes and 4) information and communications technology (ICT) and industry foundation classes (IFC).
- Availability of technology, automated business processes, product configurators, product design tools support companies delivering customizable products
- Integrated communication between actors of the value chain is possible by using ICT and IFC, and building and construction projects can only be achieved by integrating customer needs across the design process

It can be concluded that the productivity gap between the manufacturing industry and the building and construction industry is *industry specific*, meaning that this research is of international relevance and application. The challenges and the conditions that strain the industry in improving productivity is found to be: First, the *industry:* traditions, varied built locations, unpredictable weather conditions, and seasonality. Second, the *labors:* unions influence, health and safety considerations, legal procedures, learnings and engagement problems. Third, the *management*: inefficiency operations anchored in insufficient leadership, poor communication, poor project performance, late changes in plans, lack of supplies (materials, equipment, tools), and lack of technology and management tools. It can be concluded that it is reasonable for the building and construction industry to apply the principles of mass customization as a strategy for productivity improvements, and companies must master three fundamental capabilities 1) *Solution Space Development*, 2) *Choice Navigation*, and 3) *Robust Process Design*. Furthermore, it is discovered that the development *possibilities* and the transition *initiatives* are individually according to each company and each sector within the building and construction industry. Additionally, appropriate *techniques* and *approaches* of a well-functioning mass customization system have been identified, which are supported by the availability of automation and communication technologies (ICT/IFC).

5.4. PAPER FOUR

Title:

Mass Customization as a Productivity Enabler in the Construction Industry

Purpose:

The purpose was to clarify the potential productivity effect of the three fundamental capabilities of mass customization relative to the phases of a typical building and construction project to points out where to seek improvements initiatives (Jensen et al., 2018).

Method:

The outset was an investigation of typical phases of building and construction projects to determine a common project structure. Hereafter, to analyze where the three fundamental capabilities of mass customization 1) *Solution Space Development*, 2) *Choice Navigation*, and 3) *Robust Process Design* contribute to the productivity. This is done by mapping the related *tools and approaches* (see chapter 2.3.1) to clarify their potential productivity effect on the phases of a typical building and construction project.

Result:

The investigation and analysis showed that (RQ.6):

- Construction projects are often structured individually even though there seems to be a certain conformity about four overall project lifecycle phases: *design*, *construction*, *operations*, and *demolition*,
- The productivity analysis deduces a potential productivity connection from all the nine tools and approaches to one or more of the following six 'phases':
    1. *Plan*: management, planning, monitoring, leadership, start to end
    2. *Design*: product development, architecture, and engineering
    3. *Construct*: off-site and on-site manufacturing, assembly and montage
    4. *Hand-over*: reviewing project deliverables according to contract.
    5. *Maintenance*: daily operations/maintenance of the product
    6. *Demolition*: destruction and reusing of a product
- This paper does not clarify *how to* harvest the productivity gains besides indicating that mass customization as a strategy is applicable in the building and construction industry in terms of developing the nine tools and approaches

It can be concluded that the three fundamental capabilities of mass customization influence the productivity of the building and construction industry by applying and developing the nine tools and approaches used in one or more of the six typical project phases.

5.5. PAPER FIVE

Title:

IT Tools and standards supporting Mass Customization in the Building Industry

Purpose:

The purpose was to gain insight and knowledge of the presumptions and possibilities for applying the principles of mass customization to establishing an adaptable integrated system of entities in the value chain of the building and construction industry. Moreover, the objective is to gain specific insight and knowledge of available standards and tools for cooperation across the value chain within the building and construction industry. (Jensen et al., 2019)

Method:

First, a literature review was conducted concerning the utilization of mass customization as a strategy in terms of increasing productivity within the building and construction industry. Second, a desktop analysis of the relationship between mass customization and available standards and tools for cooperation across the value chain within the building and construction industry aiming at improving the productivity.

Result:

The literature review showed that (RQ.7):

- There is not much literature about utilization of mass customization as a strategy to improve the productivity of the building and construction industry
- It makes sense to take in mass customization as a strategy to be applied of the entities in the value-chain of the building and construction industry both *individually* and *interconnected*.
- Mass customization is a value-chain based concept, and successful application of mass customization requires three fundamental capabilities 1) *Solution Space Development*, 2) *Choice Navigation*, and 3) Robust *Process Design* for companies to master individually and interconnected across the value chain
- Implementing the three fundamental capabilities is a gradual act of developing the *nine tools and approaches* and there is no optimal 'end-destination'

The analysis of available standards demonstrated that (RQ.8):

- *Industry Foundation Classes* (IFC) and other standardization initiatives provided by *buildingSMART* is a solid backbone for a digital cooperation between entities within the value chain of the building and construction industry

- *Information exchange* between entities is possible in a standardized and global oriented to achieve the following benefits:
    1. a *total cost reduction* by maintaining a common database with specifications of e.g. materials, products elements, dimensions, properties and requirements to be used between entities,
    2. *quality improvement* and reducing errors and through exchanging and sharing knowledge between entities to comply with the requirements, changes about products, processes, and supply chain entities and especially the customer and thereby
    3. *logistic optimization* in terms of delivering the right deliverables at the right time
    4. *seamless flow of activities* relative to design, cost, project, production and maintenance information, and thereby reducing redundancy and increasing efficiency throughout the supply chain and lifecycle of the building.

It can be concluded that mass customization is a value-chain based concept appliable in the building and construction industry, and the implementation of the concept should be carried out by applying and developing the *nine tools and approaches* relative to the three capabilities of mass customization. The availability of software tools and standards (ICT/IFC) support the implementation of the concept and yields its advantages across the value chain. The potential for productivity improvements seems obtainable through interoperability using ICT/IFC as enablers for establishing an efficient and digital information flow encouraging collaboration across the value chain to reduce cost and redundancy and increase efficiency and effectiveness throughout the entire product and project lifecycle.

5.6. PAPER SIX

Title:

Applying and developing Mass Customization in Construction Industries - a Multi case study.

Purpose:

The purpose was to gain quantitative insight and knowledge of how companies apply the three fundamental capabilities of mass customization, and how companies' initiatives affect the performance, and how companies plan to develop the three capabilities of mass customization.

Another aspect was to understand some characteristics of the companies to determine eventual correlations to the above-mentioned bullets points; the characteristics are:

- *project phases* in order to understand how they handle project deliverables to clarify similarities,
- *critical success factors* to gain an understanding of their operation priorities,
- *position in the value chain* to investigate its influence,
- *industry level of automation* to investigate its influence,
- *company level of maturity* to investigate its influence,
- *strategy level of technology application* to investigate its influence, and
- *company size* to investigate its influence.

The definition of mass customization concept originates from the manufacturing industry aiming at a transition from mass-produced products to customized products. As the definition has evolved, it is fundamental to determine whether the definitions are appropriate and motivating for the building and construction industry or it might be ready for an adjustment to popularize the concept to ensure an academic and industrial acceptance of the concept (Jensen, Pero, Nielsen, & Brunoe, 2020).

Method:

A case study with 11 companies in the building and construction industry was carried out to analyze *how they apply the three fundamental capabilities* of mass customization, *and how their initiatives affect the performance*, and *how they plan to develop the three capabilities* of mass customization, which were done accordingly by analyzing the *tools and approaches* related to the three fundamental capabilities of mass customization.

All 11 companies deal with projects, so the outset is an analysis of their project phases to determine similarities, and of their critical success factors to assess their operational

priorities. For determining eventual correlations, the following characteristics are collected: 1) their position in the value chain, 2) industry level of automation, 3) company level of maturity, 6) strategy level of technology application, and 7) company size.

A study of the most known definitions of mass customization concept is carried out in order to determine whether these definitions are convenient and motivating for the academia and the building and construction industry.

Result:

The multi-case study demonstrated (RQ.9, RQ.10):

- All 11 companies operate according to the 6 phases 1) plan, 2) design, 3) construct, 4) hand-over, 5) maintenance and 6) demolition, even though they name them differently.
- The common critical success factors address primarily the collaboration between entities of the value chain focusing on:
    - *good and effective communication between parties,*
    - *good collaboration tools and techniques,*
    - *the clear understanding of agreements,*
    - *respect to planning and arrangements,*
    - *organizing, planning, managing projects, and*
    - *handling changes in client demands*

  which stresses the attention on developing the tools and approaches of mass customization to become a "*better*" mass customizer.
- The reason for applying the tools and approaches of mass customization, and how it affects the performance can be summarized as followed:
    - *Using digitization and software tools provides insight about the construction as the basis for decision-making and cooperation between entities of the value chain*
    - *Improving processes aiming at improving the quality, customer experience and performance*
    - *Using flexible manufacturing equipment, prefabricated elements, and module-based construction increases the competitive position*
- All 11 companies aim at increasing all parameters of the tools and approaches, which indeed strengthen the three fundamental capabilities of mass customization, and thereby the utilization of mass customization.
- The significant span of how companies plan to invest in the 9 tools and approaches of mass customization seems not to be due to the position in the value chain, but probably related to characteristics of the companies like the type of job carried out, size of the company, level of automation, maturity of the company, and chosen strategy.

The analysis of the current definition of mass customization revealed (RQ.11):

- A new definition of mass customization as a strategy for the building and construction industry has been created as it seems necessary to ensure an academic and industrial acceptance of the concept aiming at a better common understanding

It can be concluded that all companies apply the same project phases when execution projects even though they name them differently, and all companies share the same perception that critical success factors, which primarily concern the collaboration between entities of the value chain. Furthermore, it can be concluded that the application of the tools and approaches of mass customization in terms of utilizing digitization and software tools is motivated by the affect it has on their capabilities on decision-making and cooperation between entities of the value chain. It provides insight, improves the collaboration within the design and construction process, and raises the quality, customer satisfaction and the performance. The companies plan to develop the tools and approaches of mass customization as they are convinced it increases the competitive position, and therefore the awareness is also on using flexible manufacturing equipment, prefabricated elements, and module-based construction. The results indicate a correlation between applying the tools and approaches of mass customization and the characteristics, as all the top five companies also scores highest on the characteristics (size, level of automation, maturity, strategy). However, mass customization concept seems applicable within the building and construction industry, but since the concept is not well-known and explored in the building and construction industry it might be due to an unsuitable definition of the concept. Therefore, a new definition of the mass customization concept targeted the building and construction industry is suggested.

5.7. SUMMARY

This research consisting of six papers has concluded that it is reasonable for the building and construction industry to apply the principles of 'mass customization' theory for productivity improvements. The outset for this research was the Danish productivity gap between the building and construction industry and the manufacturing industry, and the fact that the:

- building and construction industry *design* and *deliver* customized products,
- mass customization is a strategy efficiently used for handling customizable products, and
- mass customization as a strategy has increased productivity in the manufacturing industry.

A well-functioning mass customization system provides stability, flexibility, and responsiveness in the business processes in order to handle the variance of products and services, and therefore it is obvious that 'mass customization' companies must master three fundamental capabilities (Salvador et al., 2009): 1) *Solution Space Development*, 2) *Choice Navigation*, and 3) *Robust Process Design*.

,

It turned out that the Danish productivity gap is not a Danish phenomenon, but an industry specific challenge as other countries in Scandinavian and Europe, and as well as the USA and Canada experience the same. However, it does not mean that the practices to increase the productivity necessarily are the same for each country.

Productivity factors causing low productivity can be classified into (Jensen et al., 2018):

- *Industry*: The singularity and complexity of building and construction projects as they are built at varied locations, at adverse and unpredictable weather conditions and seasonality, traditions.
- *Labor*: The union's influence, health, and safety considerations and legal procedures, the learning potential, and lack of motivation, engagement, and wellbeing.
- *Management*: Insufficient leadership, poor communication, and coordination, inadequate project supervision, and management, shortages of skilled labor, sustainability concerns, late changes in plans, lack of material, equipment, tools, and technology.

The productivity analysis deduces a potential productivity connection from all the nine *'tools and approaches'* of 'mass customization' to one or more of the six project phases: 1) *Plan*, 2) *Design*, 3) *Construct*, 4) *Hand-over*, 5) *Maintenance*, and 6) *Demolition.*

The research finds that:

- 'available technology,' 'automated business processes,' 'product configurators,' and 'product design tools' *support* companies in delivering customizable products,
- Integrated communication between actors of the value chain is possible by using available current standards and ICT, and
- The building and construction projects can only be executed successfully by integrating customer needs across the design process within the value chain

Every company involved in this research:

- see themselves moving towards a higher degree of mass customizing by offering more variants than today,
- revealed that their customers want customized products since customizable products add value to their customers.
- consider that the industry offers flexible production technology supporting the implementation of 'mass customization.'

The common critical success factors pointed out by the involved companies is primarily the collaboration between entities of the value chain by focusing on:

- good and effective communication between parties
- good collaboration tools and techniques
- the clear understanding of agreements
- respect to planning and agreements
- organizing, planning, managing projects
- handling changes in client demands

One of the important factors addressing the critical successes to take in mass customization is the availability of standards and ICT. Applying the *Industry Foundation Classes (IFC)* and standardization initiatives, provided by *buildingSMART*, is the backbone for digital cooperation of a specific project between entities within the value chain. This enables information exchange between entities in a standardized and globalized way. Therefore, the potential for productivity improvements seems obtainable through interoperability using ICT and BIM standards, as an enabler for efficient information flow related to collaboration about e.g. *project design*, *specifications*, *cost*, *materials*, *production*, *supply chain*, *handling of changes* and *maintenance*, which will reduce redundancy and increase efficiency throughout the entire product lifecycle.

The development possibilities and the transition initiatives to become a mass customizer are individually according to the specific sector and company. Thus, there is no perfect 'end-state' of 'mass customization,' but rather to be considered as an ongoing development process.

The reason for applying the 'tools and approaches' of 'mass customization,' and how it affects the performance can be summarized as followed:

- Using digitalization and software tools provides insight about the construction as the basis for decision-making and cooperation between entities of the value chain,
- Improving processes aiming at improving the quality and performance
- Using flexible manufacturing equipment, prefabricated elements, and module-based construction increases the competitive position

This research contribution, especially paper 6, indicates that adoption of prefabrication has potentials in the building and construction industry as there is correlation between 'degree of cost reduction' and 'degree of prefabrication', meaning that usage of standardization, prefabricated elements, and module-based construction approaches leads to 1) cost reduction, 2) shorten construction time, 3) waste minimization and 4) quality improvement, and 5) integrity on the building design and construction, which as well is substantiated from the literature (Chen & Samarasinghe, 2020; Hvam, Mortensen, Thuesen, & Haug, 2013; Linner & Bock, 2012; Noguchi, 2013; Paoletti, 2013; Tam, Fung, Sing, & Ogunlana, 2015).

As part of the overall knowledge found in this research, a model is created (see Figure 5-2) showing that a building and construction project to a greater or lesser extent consists of work done in a factory (off-site), work done at the construction site (on-site) and assembly work of prefabricated elements (Jensen et al., 2020). The model should be understood that the sum of the work is depending on the degree of the prefabrication since it is presumably smaller and faster by the higher degree of prefabrication. This is reasoned by the fact that the manufacturing process accomplished on the factory, where the quality can be easier controlled, improve the quality and the assembly predictability on-site. Prefabrication has less on-site processing of materials, which reduces environmental pollution and resource consumption, and the construction site can be better managed as the number of materials and equipment can be reduced while there is no on-site manufacturing process (Chen & Samarasinghe, 2020). Thus, the building and construction efficiency, quality and safety guarantees have been effectively improved, resulting in lower construction costs indicating an increase of the productivity.

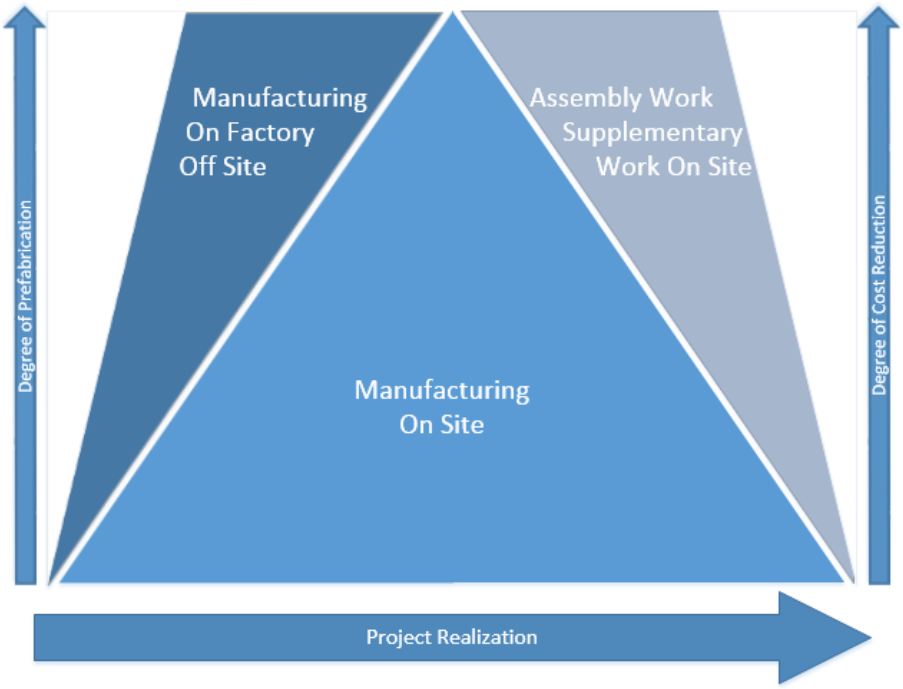

Figure 5-2: Manufacturing off-site and on-site

Therefore, it must seem attractive to seek a greater degree of prefabrication, and indeed, that is also what has happened during the last two decades at least for some companies. A transition towards more prefabrication seems more achievable for some sectors of the building and construction industry than others. Nevertheless, some factors need to be considered in order to be successful, e.g. 1) traditions and culture in the society, 2) transparent customer integration in the value chain on choice navigation, 3) impact of

modularity, 4) production technology, supply chain resources, and service requirements, 5) digital involvement of every partner and in every project phases (Jensen et al., 2020).

Furthermore, some barriers and challenges are to be considered e.g.: 1) to make all components fit together (individually and interconnected), as modules and components require accurate sizes and interfaces (industry standards) to be defined in advance; 2) to include initial cost for development (design and engineering work required upfront) before the modules and components are ready to be released to the production ; 3) there is a certain dependency on suppliers offering customized modules and components that may become difficult to substitute if needed; 4) the acceptance of the modules and components may sometimes be difficult, since customers often tend to prefer traditional solutions or on-site constructions; 5) the supplier dominance, as suppliers of construction materials are generally a few large players that provide standard modules and components, which may be reluctant to customize; 6) the inability for the customer to make changes during the construction process; 7) module size and weight may influence the design and engineering due to the shipment challengers and transportation laws; 8) the responsibilities of involved parties must be clearly defined when combining modules from more suppliers; 9) architects are not familiar with modular construction and prefabrication practices; which may affect or lengthened the design and engineering process (Bildsten, 2011; Schoenborn, 2012).

Besides showing the 'degree of cost reduction' and 'degree of prefabrication' relative to the 'project realization' the model is useable to illustrate different sectors of the building and construction industry or to illustrate different tasks of a building and construction project (see Figure 5-3), like:

- production of windows or doors done off-site on factories with subsequent assembly work done on-site (*Company E* and *Company F)*,
- clearing the building site, demolition of existing building, excavating as preparation for the foundation, install plumbing, which is manufacturing work necessary to be done on-site (*Company G*, *Company H* and *Company I*)
- making balconies off-site on a factory (*Company A)*, which are to be installed on-site by the same company (*Company A*)
- making industrial houses out of prefabricated elements done off-site (Company C), then excavating as preparation for the foundation (Company D), and after that the concrete elements and other prefabricated elements are assembled (Company D)

In case companies strategically expand or change their business by doing more prefabrication in the factory, this approach will lead to less manufacturing work to be done on-site. Thus, the work done off-site on factory has potentials to be more efficient without dependency of the weather conditions, which as mentioned above brings several benefits related to, e.g. cost, quality, waste, construction time, which will increase the productivity.

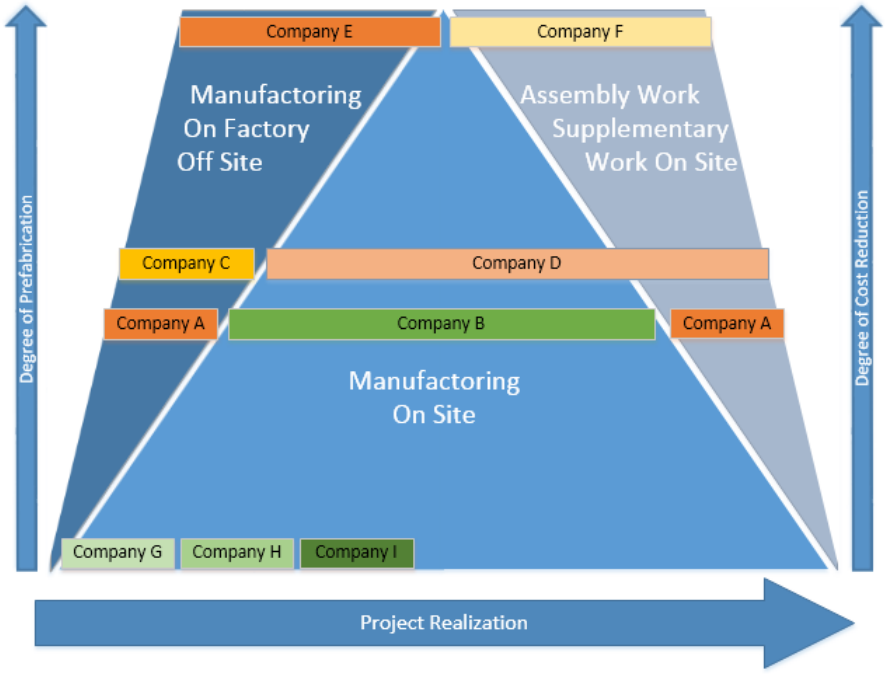

Figure 5-3: Companies positioning off-site and on-site

Due to the applicability of mass customization concept within the building and construction industry, this thesis has contributed with an extended definition of 'mass customization' appropriate and motivational for the building and construction industry:

- **Definition**: *Managing interlinked processes across entities of the value chain that are necessary for efficiently serving the customers uniquely by involving the customers in the processes needed for capturing their idiosyncratic needs and transforming them into system products or services in a cost-efficient way that will be adopted successfully by the customers.*

The relevance of this new definition of mass customization concept targeted the building and construction industry is justified as the concept is not well-known and explored in the building and construction industry, especially no aiming at improving the productivity. This may indicate that existing definitions of the concept might be unsuitable. Therefore, the adaption is made to ensure an academic and industrial acceptance of the concept aiming at a better common understanding. The outset of this new definition is investigating of existing definitions of the concept combined with findings made from this research. The definitions are elaborated in chapter *2. State of the Art* and apparently no applicable definitions of the concept seem to be present for the building and construction industry. Most definitions focus on the word 'mass' referring to high volume

of products that are produced for a large market striving at satisfying specific needs of individual customers at production cost almost like mass-produced products.

However, the most used definitions seem to exclude those companies that produce low volumes products. The building and construction industry consist of companies that focus on customization (more than 'mass') and thus producing low volumes products and sometimes only one unique customized piece. Such products are often referred to as one-of-a-kind projects where architects design a unique solution with specific requirements to be built for a client at a specific site.

This research has concluded that *managing interlinked processes across entities of the value chain* is critical for the efficiency of the project realization, and thereby the foundation for increasing the productivity of the industry. Efficiently utilizing new technology in terms of software and flexible manufacturing equipment aiming at *serving customers uniquely* is essential, together with *involving customers* (responsibility) *in the processes needed* for decision-making providing insight about the construction and reconciliation of requirements in order *to capturing individual requirements*, and *transforming them into system products or services that are successfully adopted by the customers*. Therefore, these statements are combined and formulated into the new definition applicable for the building and construction industry.

CHAPTER 6. DISCUSSION AND CONCLUSION

This chapter is divided into three sections. Firstly, a discussion of the research objectives pursued in this research project and a validation of the assumed hypotheses stated initially. Secondly, a brief overall conclusion of the completed research, and finally a presentation of the further research that is proposed to be carried out from here.

6.1. RESEARCH DISCUSSION

The initial scientific objective was to:

Contribute to the existing theory of mass customization targeting academia and practitioners in terms of determining how mass customization as a strategy can be extended to support the building and construction industry improving the productivity

---

The outset for this research was the following assumptions:

- *The utilization of mass customization as a strategy will increase the productivity within the building and construction industry*
- *The utilization of IT tools and standards supports the implementation of mass customization as a strategy in the building and construction industry*

The direction for the research was three research objectives and 11 research questions (see chapter 3), which are addressed in the enclosed six papers in which further details and conclusions are available. However, the following is a comprehensive overview of the findings from the papers relative to the 11 research questions:

A workshop involving seven companies addressing the research question *RQ.1: How does the building and construction industry assess "where are we today" and "where would we like to be" relative to mass customization* finds that the involved companies' knowledge about the mass customization concept was limited, which indicate the importance of dissemination of knowledge about the concept. However, the workshops concluded that the companies are moving towards a higher degree of mass customizing by offering more variants than today and by having extensive knowledge about their competitors' capabilities and their customers' needs.

A survey addressing the research question *RQ.2: What is the building and construction industry' perception of themselves, the markets/customers, their competitors, and the technology available related to the application of mass customization* concludes that mass customization concept is relevant due to the need for customizable products as it is value adding for the customers. Furthermore, companies want to comply with the market demand, which seems possible as their technology suppliers support this change, and moreover, it seems achievable as the companies have a close relationship to their customers and strong change management capabilities.

A trend analysis addressing *RQ.3: How is the productivity development of Danish building and construction industry compared to other countries in Scandinavia and Europe* concludes that the productivity gap between the manufacturing industry and the building and construction industry is not a Danish phenomenon but *industry specific*, which makes this research of international relevance and application.

A literature study addressing the research question *RQ.4: What are the challenges and the conditions that strain the building and construction industry in improving productivity* finds that the challenges and the conditions that makes it difficult for the industry to improve the productivity is three-fold: 1) the *industry* is subject to traditions, varied built locations, adverse and unpredictable weather conditions and seasonality; 2) the *labors* affected by the unions influence, health and safety considerations, legal procedures, learning and engagement problems; and 3) the *management* characterized by inefficiency operations due to insufficient leadership, poor communication, poor project performance, late changes in plans, lack of supplies (materials, equipment, tools), and lack of technology and management tools.

A literature study addressing the research question *RQ.5: Which capabilities of mass customization can be applied to increase the productivity* concludes that it is reasonable for the building and construction industry to apply the principles of mass customization concept for productivity improvements in terms of mastering the three fundamental capabilities 1) *Solution Space Development*, 2) *Choice Navigation*, and 3) *Robust Process Design*. The development *possibilities* and the transition *initiatives* are individually relative to each company and each sector of the industry. Appropriate *techniques* and *approaches* of a mass customization system have been identified e.g. 1) *delaying product differentiation*, 2) *flexible automation technology*, 3) *modularity in products and processes* and 4) *information and communications technology* (ICT) and *industry foundation classes* (IFC), which are supported by the availability of automation and communication technologies (ICT/IFC).

An investigation and analysis addressing the research question *RQ.6: What are the potential productivity effects of utilization the fundamental capabilities of mass customization relative to the known phases of a typical building and construction project* concludes that the three fundamental capabilities of mass customization in terms of the nine tools and approaches affect the productivity of one or more of the six typical project phases.

A literature study addressing the research question *RQ.7: What are the assumptions and possibilities for applying the principles of mass customization within the building and construction value chain* concludes that mass customization is a value-chain based concept applicable for the industry, and the implementation of the concept should be carried out by applying and developing the *nine tools and approaches* of the three capabilities of mass customization.

An analysis addressing the research question *RQ.8: What are the conditions (standards and ICT tools) for cooperation between the entities in the building and construction value chain* concludes that the availability of software tools and standards (ICT/IFC) support the implementation of the mass customization concept leading to advantages across the value chain. Moreover, productivity improvements seem obtainable using ICT/IFC for establishing an efficient and digital information flow encouraging collaboration across the value chain to reduce cost, improve quality, and reduce time, and thereby increase efficiency and effectiveness throughout the entire product and project lifecycle.

A multi case study addressing the research question *RQ.9: How does the building and construction industry apply and plan to be develop the three fundamental capabilities of mass customization, and how has it affected the industry* concludes that the involved companies apply common project phases when execution projects and have the same perception of the critical success factors primarily concerned about the collaboration between entities of the value chain. The application of the nine *tools* and *approaches* of mass customization are motivated by e.g. improved decision-making, improved cooperation between entities of the value chain according to the design, construction and building process, and improved quality, improved customer satisfaction and improved performance. Furthermore, the companies plan to develop the nine *tools and approaches* of mass customization as they are convinced it increases their competitive position together with the awareness on using flexible manufacturing equipment, prefabricated elements, and module-based construction.

The same multi case study addressing the research question R*Q.10 What are the characteristics of the above-mentioned building and construction industry and how does that correlate to the outcome from RQ9* indicate a correlation between the characteristics and applying the tools and approaches as the top five companies also scores highest on the characteristics (size, level of automation, maturity, strategy).

An analysis addressing the research question *RQ.11 To what extent are the existing definitions of mass customization appropriate and motivating for the building and construction industry* revealed that the mass customization concept is not well-known and explored in the industry presumable due to an unsuitable definition of the concept. Therefore, a new definition of the concept targeted the industry is suggested to ensure an academic and industrial acceptance of the concept.

The empirical work done in this research is based on more than twenty companies from same and different sectors of the building and construction industry, so, therefore, the results are not representative for all sectors and the whole industry, which indeed could question the applicability of the results. However, the impression is that other companies, and for that matter entire sectors are facing similar challenges and can benefit from the results obtained in this research. It is acknowledged that different companies and sectors have different challenges and are at different maturity levels so the application of the improvements initiatives would be different and of course adapted individually.

It is assumed that 'mass customization' theory especially the 'tools and approaches' to be developed to a greater extent for the building and construction companies would increase the productivity within the companies and thus increase the productivity for all sectors and the whole industry by 1) cost reduction, 2) shorten construction time, 3) waste minimization and 4) quality improvement, and 5) integrity on the building design and construction, which are even more important in today's business environment with high labor costs competing in an ever-changing global market.

Therefore, applying new and more cost-effective business and production processes are vital for the industry in order to customize products more efficiently than traditional building and construction products. Initially, it is important to understand how companies in the Danish building and construction industry can benefit from utilizing mass customization principles, by identifying which specific challenges these companies face when implementing 'mass customization' theory, since the challenges may be different from those met in the general manufacturing industry. This approach requires companies to be aware of how to adapt the methods for enhancing the performance, so the methods become applicable for the individual companies within building and construction industry.

The availability of IT tools and standards within the building and construction industry in terms of good collaboration tools and techniques enables excellent and effective communication between parties, which is a necessity for organizing, planning, managing projects and handling changes in client demands uniformly and efficiently. Application of such collaboration tools require clear understanding of agreements and provides transparency across the value chain encouraging to mutual understanding and respect to planning and agreements.

It is acknowledged that implementing decisions, actions and new strategy requires clarity on what needs to change and how it becomes anchored in a sustainable way in the company's organization and culture, where the objective is to motivate behavioral change and support the learning process as an ongoing process.

6.2. CONCLUDING REMARKS

This research has contributed to the application of 'mass customization' theory within the building and construction industry. Each of the six papers enclosed in this dissertation represents an individual perspective and contribution to a specific scientific research objective. Thus, each paper can be read separately, and the findings can be used independently or in connection to the other papers. Every published conference paper or journal paper have gone through a peer-reviewed before conference proceedings or journal publication.

The research of mass customization as a strategy applied within the building and construction industry is limited and unexplored, which obviously needs tools and approaches to help improving the productivity. This research has identified nine tools and approaches capable of improving the productivity, and thereby achieved the research objective *RO.3: Identify tools and approaches from the mass customization domain to be applied within the building and construction industry improving the productivity*. The literature acknowledges the need for customization and personalization and clearly indicates the potential for application of mass customization concept within the building and construction industry. This research has clarified mass customization's ability to lower unit costs, increase quality, and shorten project duration, which are enablers of improving the productivity, and thereby achieved the research objective *RO.2: Clarify how can mass customization as a strategy supports the building and construction industry towards improving the productivity*. The realized productivity gap in Denmark between the manufacturing industry and the building and construction industry surely burden the industry. This research has investigated the application of mass customization concept and found tools and approaches to be developed in order to improve the productivity of the building and construction industry, and thereby achieved the research objective *RO.1: Determine how to improve the productivity of the building and construction industry*.

The key findings from the six papers are described in chapter 5 and summarized in chapter 6.1. The contribution of this thesis is three-fold:

1. Mass customization as a strategy has potential in the building and construction industry to *increase the productivity* in terms of developing the 'tools and approaches' relative to the three fundamental capabilities of mass customization.
2. The availability of *IT tools* and *standards* to be used within a company and between companies across the value chain will not only support the implementation of mass customization as a strategy but also be a prerequisite for the achievement of all the benefits related to 'mass customization' theory.
3. An extended definition of 'mass customization' appropriate and motivational for the building and construction industry to ensure an academic and industrial acceptance of the concept aiming at a better common understanding.

The initial scientific objective *Contribute to the existing theory of mass customization targeting academia and practitioners in terms of determining how mass customization as a strategy can be extended to support the building and construction industry improving the productivity* has been fulfilled with this dissertation supported by the three research objectives and 11 research questions published in six papers. These 11 research questions revealed *that utilization of 'mass customization' theory within the building and construction industry have potentials to increase the productivity of the industry and that IT tools and standards are available and must be considered as prerequisites for a successful implementation of the theor*y.

To popularize the mass customization concept within the building and construction industry an extended definition has been created to ensure an academic and industrial acceptance of the concept, which is:

Definition: *Managing interlinked processes across entities of the value chain that are necessary for efficiently serving the customers uniquely by involving the customers in the processes needed for capturing their idiosyncratic needs and transforming them into system products or services in a cost-efficient way that will be adopted successfully by the customers.*

However, it is acknowledged that further research in this area is required before establishing a framework or roadmap to be used in a specific sector of the industry.

6.3. FURTHER RESEARCH

Future research related to application of mass customization as a strategy for improving the productivity of the building and construction industry could cover several subjects because this research topic is relatively unexplored. However, the topic of improving the productivity within the building industry has been the main theme for the last decades utilizing other theories and focus areas than mass customization. Therefore, some of the most interesting and relevant issues are:

- Establishing comparable *metrics* to be used to verify and measure the productivity of the effect of the initiatives (tools and approaches) relative to the three fundamental capabilities of mass customization
- Making a roadmap targeted and dedicated for one *specific sector* within the building and construction industry addressing specifically which and how 'tools and approaches' of mass customization can be applied
- Choosing several companies within the specific sector to be subject to a case study with an outset in the established metrics for measuring as-is, and hereafter implement the suggested initiatives to-be from the roadmap and measure the effect of the implemented initiatives.

REFERENCES

Abercrombie, N., Hill, S., & Turner, B. S. (1984). *Dictionary of sociology* Penguin Books.

Aburas, M., & Lee, A. (2019). A LITERATURE REVIEW EXPLORING THE CRITICAL SUCCESS FACTORS FOR THE EFFECTIVE IMPLEMENTATION OF THE ISO 9001 QUALITY MANAGEMENT SYSTEM IN CONSTRUCTION PROJECTS. Paper presented at the *14th INTERNATIONAL POSTGRADUATE RESEARCH CONFERENCE 2019: Contemporary and Future Directions in the Built Environment*, 61.

Aigbedo, H. (2009). A note on parts inventory and mass customization for a two-stage JIT supply chain with zero-one type of bills of materials. *Journal of the Operational Research Society, 60*(9), 1286-1291.

Andersen, A., Larsen, J. K., Brunoe, T. D., Nielsen, K., & Ketelsen, C. (2018). Critical enablers of changeable and reconfigurable manufacturing and their industrial implementation. *Journal of Manufacturing Technology Management, 29*(6), 983-1002.

Arashpour, M., Miletic, M., Williams, N., & Fang, Y. (2018). Design for manufacture and assembly in off-site construction: Advanced production of modular façade systems. Paper presented at the *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction, , 35* 1-6.

Arashpour, M., Wakefield, R., Blismas, N., & Maqsood, T. (2015). Autonomous production tracking for augmenting output in off-site construction. *Automation in Construction, 53*, 13-21.

Arbnor, I., & Bjerke, B. (2008). *Methodology for creating business knowledge* Sage.

Baldwin, C. Y., & Clark, K. B. (2003). Managing in an age of modularity. *Managing in the Modular Age: Architectures, Networks, and Organizations, 149*, 84-93.

Baran, E., Uygun, E., Altan, T., Bahcekapili, T., & Cilsalar, H. (2014). Investigating technological pedagogical content knowledge (TPACK) in action: Workshop design cases. Paper presented at the *EdMedia Innovate Learning*, 1536-1541.

Barlow, J., Childerhouse, P., Gann, D., Hong-Minh, S., Naim, M., & Ozaki, R. (2003). Choice and delivery in housebuilding: Lessons from japan for UK housebuilders. *Building Research and Information, 31*(2), 134-145. doi:10.1080/0961321031000083931

Bashford, H., Walsh, K., & Sawhney, A. (2005). Production system loading-cycle time relationship in residential construction. *Journal of Construction Engineering and Management-Asce, 131*(1), 15-22. doi:10.1061/(ASCE)0733-9364(2005)131:1(15)

Batchelor, R. (1994). *Henry ford, mass production, modernism, and design* Manchester University Press.

Bekdik, B., Hall, D., & Aslesen, S. (2016). Off-site prefabrication: What does it require from the trade contractor? Paper presented at the *Proc. 24th Ann. Conf. of the Intâ€™l. Group for Lean Construction, Boston, MA, USA, Sect,* 43-52.

Benros, D., & Duarte, J. (2009). An integrated system for providing mass customized housing. *Automation in Construction, 18*(3), 310-320.

Bildsten, L. (2011). Exploring the opportunities and barriers of using prefabricated house components. Paper presented at the *19th Conference of the International Group of Lean Construction (IGLC), July 13-15, Lima, Peru,*

Blecker, T., & Abdelkafi, N. (2006). Mass customization: State-of-the-art and challenges. *Mass customization: Challenges and solutions* (pp. 1-25) Springer.

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. *Automation in Construction, 59*, 113-121.

Bohnstedt, K. D. (2014). Enabling facilitation of mass customization via partnering in the construction industry. Paper presented at the *Proceedings of the 7th World Conference on Mass Customization, Personalization, and Co-Creation (MCPC 2014), Aalborg, Denmark, February 4th-7th, 2014*, 179-188.

Boligministeriet, B., & Force, B. T. (2000). *Byggeriets fremtid: Fra tradition til innovation*

Broekhuizen, T. L. J., & Alsem, K. J. (2002). Success factors for mass customization: A conceptual model. *Journal of Market-Focused Management, 5*(4), 309-330.

Chen, H., & Samarasinghe, D. A. S. (2020). The factors constraining the adoption of prefabrication in the new zealand residential construction sector: Contractorsâ€™ perspective.

Chryssochoidis, G. M., & Wong, V. (2000). Customization of product technology and international new product success: Mediating effects of new product development and rollout timeliness. *Journal of Product Innovation Management, 17*(4), 268-285.

Correa, F. (2019). Simulating wood-framing wall panel's production with timed coloured petri nets. Paper presented at the *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction, , 36* 1026-1033.

Coughlan, P., & Coghlan, D. (2002). Action research for operations management. *International Journal of Operations & Production Management, 22*(2), 220-240.

Craig, A., Laing, R., & Edge, M. (2000). The social acceptability of prefabrication and standardisation in relation to new housing. Paper presented at the *16th IAPS Conference: 21st Century: Cities, Social Life and Sustainable Development, Paris,* 4-7.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches* Sage publications.

da Rocha, C. G., & Formoso, C. T. (2013). Configuring product variants in customisation strategies for house-building. *Open House International, 38*(3), 48-56.

da Rocha, C. G., & Kemmer, S. L. (2013). Method to implement delayed product differentiation in construction of high-rise apartment building projects. *Journal of Construction Engineering and Management, 139*(10), UNSP 05013001. doi:10.1061/(ASCE)CO.1943-7862.0000758

Davis, S. M. (1989). From "future perfect": Mass customizing. *Strategy & Leadership, 17*, 16-21.

Dean, P., Tu, Y., & Xue, D. (2008). A framework for generating product production information for mass customization. *The International Journal of Advanced Manufacturing Technology, 38*(11-12), 1244-1259.

Dean, P., Tu, Y., & Xue, D. (2009). An information system for one-of-a-kind production. *International Journal of Production Research, 47*(4), 1071-1087.

dst.dk. (2013). Dansk statistik - www.dst.dk.

Duarte, J. (2005). A discursive grammar for customizing mass housing: The case of siza's houses at malagueira. *Automation in Construction, 14*(2), 265-275. doi:10.1016/j.autcon.2004.07.013

Dunston, P. S. (2008). Identification of application areas for augmented reality in industrial construction based on technology suitability. *Automation in Construction, 17*(7), 882-894.

Duray, R. (2002). Mass customization origins: Mass or custom manufacturing? *International Journal of Operations & Production Management, 22*(3), 314-328.

Edvardsson, B., Tronvoll, B., & Gruber, T. (2011). Expanding understanding of service exchange and value co-creation: A social construction approach. *Journal of the Academy of Marketing Science, 39*(2), 327-339.

Ehsan, N., Mirza, E., Alam, M., & Ishaque, A. (2010). Risk management in construction industry. Paper presented at the *Computer Science and Information Technology (ICCSIT), 2010 3rd IEEE International Conference, , 9* 16-21.

ElMaraghy, H. A. (2005). Flexible and reconfigurable manufacturing systems paradigms. *International Journal of Flexible Manufacturing Systems, 17*(4), 261-276.

Enkel, E., Bell, J., & Hogenkamp, H. (2011). Open innovation maturity framework. *International Journal of Innovation Management, 15*(06), 1161-1189.

Fagerberg, J. (2000). Technological progress, structural change and productivity growth: A comparative study. *Structural Change and Economic Dynamics, 11*(4), 393-411.

Feitzinger, E., & Lee, H. L. (1997). Mass customization at hewlett-packard: The power of postponement. *Harvard Business Review, 75*, 116-123.

Ferguson, S., Olewnik, A., Malegaonkar, P., Cormier, P., & Kansara, S. (2010). Mass customization: A review of the paradigm across marketing, engineering and distribution domains. Paper presented at the *ASME Design Engineering Technical Conferences, Montreal, Quebec, Canada, August*, 15-18.

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry, 12*(2), 219-245.

Fogliatto, F. S., da Silveira, G. J. C., & Borenstein, D. (2012). The mass customization decade: An updated review of the literature. *International Journal of Production Economics,*

Friedman, A., Sprecher, A., & Mohamed, B. E. (2013). A computer-based system for mass customization of prefabricated housing. *Open House International, 38*(1), 20-30.

Frutos, J. D., & Borenstein, D. (2003). Object-oriented model for customer-building company interaction in mass customization environment. *Journal of Construction Engineering and Management, 129*(3), 302-313.

Frutos, J. D., Santos, E. R., & Borenstein, D. (2004). Decision support system for product configuration in mass customization environments. *Concurrent Engineering, 12*(2), 131-144.

Gibb, A. G. (1999). *Off-site fabrication: Prefabrication, pre-assembly and modularisation* John Wiley & Sons.

Gilmore, J. H., & Pine II, B. J. (1997). The four faces of mass customization. *Harvard Business Review, 75*(1), 91-101.

Goodier, C., & Gibb, A. (2007). Future opportunities for offsite in the UK. *Construction Management and Economics, 25*(6), 585-595.

Greasley, A. (2007). *Operations management* Sage.

Guba, E. G. (1990). *The paradigm dialog* Sage.

Gummesson, E. (2000). *Qualitative methods in management research* Sage.

Gummesson, E., Mele, C., Polese, F., Galvagno, M., & Dalli, D. (2014). Theory of value co-creation: A systematic literature review. *Managing Service Quality,*

Hu, S. J., Ko, J., Weyand, L., ElMaraghy, H., Lien, T., Koren, Y., . . . Shpitalni, M. (2011). Assembly system design and operations for product variety. *CIRP Annals-Manufacturing Technology, 60*(2), 715-733.

Hvam, L., Mortensen, N. H., Thuesen, C., & Haug, A. (2013). Conceptualising the use of system products and system deliveries in the building industry. *Mass customisation and personalisation in architecture and construction* (pp. 91-101) Routledge.

Hvam, L., Mortensen, N. H., & Riis, J. (2008). *Product customization* Springer Science & Business Media.

Jacobs, M., Droge, C., Vickery, S. K., & Calantone, R. (2011). Product and process modularity's effects on manufacturing agility and firm growth performance. *Journal of Product Innovation Management, 28*(1), 123-137.

Jensen, K. N., Pero, M., Nielsen, K., & Brunoe, T. D. (2020). Applying and developing mass customization in construction industries - a multi case study. *Journal of Management in Engineering (Pending), (forth coming)*

Jensen, K. N., Nielsen, K., Brunoe, T. D., & Larsen, J. K. (2019). IT tools and standards supporting mass customization in the building industry.*International Journal of Construction Supply Chain Management Vol. 9, No. 1*, 61-82. doi:10.14424/ijcscm901019-61-82

Jensen, K. N., Nielsen, K., & Brunoe, T. D. (2015). Application of mass customization in the construction industry. Paper presented at the *IFIP International Conference on Advances in Production Management Systems*, 161-168.

Jensen, K. N., Nielsen, K., & Brunoe, T. D. (2018). Mass customization as a productivity enabler in the construction industry. Paper presented at the *IFIP International Conference on Advances in Production Management Systems*, 159-166.

Jensen, K. N., Nielsen, K., Brunoe, T. D., & Larsen, J. K. (2018). Productivity, challenges, and applying mass customization in the building and construction industry. *Customization 4.0* (pp. 551-565) Springer.

Jensen, K. N., Nielsen, K., Brunoe, T. D., & Lindhard, S. M. (2017). Mass customization in the building and construction industry. *Managing complexity* (pp. 1-12) Springer.

Joergensen, K. A. (2008). Development of product configurators. Paper presented at the *Presented at: IMCM&PETO2008 Conference, , 19* 20.

Kagioglou, M., Cooper, R., & Aouad, G. (2001). Performance management in construction: A conceptual framework. *Construction Management and Economics, 19*(1), 85-95.

Kahkonen, K., Koskela, L., Leinonen, J., & Aromaa, P. (2003). In Uwakweh B. M.,IA (Ed.), *Supply chain management aspects for top quality industrial construction*

Kärnä, S., Junnonen, J., & Kankainen, J. (2004). Customer satisfaction in construction. Paper presented at the *Proceedings of the 12th Annual Conference on Lean Construction*, 476-488.

Kiviniemi, A., Karlshøj, J., Tarandi, V., Bell, H., & Karud, O. J. (2008). Review of the development and implementation of IFC compatible BIM.

Koren, Y. (2010). *The global manufacturing revolution: Product-process-business integration and reconfigurable systems* John Wiley & Sons.

Koskela, L. (2000). *An exploration towards a production theory and its application to construction* VTT Technical Research Centre of Finland.

Koskela, L. (2003). Is structural change the primary solution to the problems of construction? *Building Research & Information, 31*(2), 85-96.

Kotter, J. P., & Cohen, D. S. (2012). *The heart of change: Real-life stories of how people change their organizations* Harvard Business Press.

Kuhn, T. S. (1962). The structure of scientific revolutions.

Larsen, J. K., Brunoe, T. D., Lindhard, S. M., & Jensen, K. N. (2017). Project management and scheduling through national project management phases in government construction agencies. *International Journal of Information Technology Project Management (IJITPM), 8*(1), 1-16.

Larsen, J. K., Lindhard, S. M., Brunoe, T. D., & Jensen, K. N. (2018). The relation between pre-planning, commissioning and enhanced project performance. *Construction Economics and Building, 18*(2), 1-14.

Larsen, J. K., Lindhard, S. M., & Jensen, K. N. (2017). Analyzing the key process factors effect on project performance. Paper presented at the *The 2016 International Conference on Construction and Real Estate Management*,

Larsen, M., Lindhard, S., Brunoe, T., Nielsen, K., & Larsen, J. (2019). Mass customization in the house building industry: Literature review and research directions. front. *Built Environ*, *5*, 115.

Lawson, R. M., Ogden, R. G., & Bergin, R. (2011). Application of modular construction in high-rise buildings. *Journal of Architectural Engineering*,

Li, H. X., Al-Hussein, M., Lei, Z., & Ajweh, Z. (2013). Risk identification and assessment of modular construction utilizing fuzzy analytic hierarchy process (AHP) and simulation. *Canadian Journal of Civil Engineering*, *40*(12), 1184-1195.

Lindhard, S. M., Jensen, K. N., & Larsen, J. K. (2017). Looking into not-completed activities by applying the 5 WHYs method. Paper presented at the *The 2016 International Conference on Construction and Real Estate Management*,

Linner, T., & Bock, T. (2012). Evolution of large-scale industrialisation and service innovation in japanese prefabrication industry. *Construction Innovation*, *12*(2), 156-178.

Liu, A., Fellows, R., & Chan, I. (2014). Fostering value co-creation in construction: A case study of an airport project in india. *International Journal of Architecture, Engineering and Construction*, *3*(2), 120-130.

Liu, K., Su, Y., & Zhang, S. (2018). Evaluating supplier management maturity in prefabricated construction project-survey analysis in china. *Sustainability*, *10*(9), 3046.

Liu, N., Chow, P., & Zhao, H. (2019). Challenges and critical successful factors for apparel mass customization operations: Recent development and case study. *Annals of Operations Research*, , 1-33.

Lockamy III, A., & McCormack, K. (2004). The development of a supply chain management process maturity model using the concepts of business process orientation. *Supply Chain Management: An International Journal*, *9*(4), 272-278.

McCormack, K., Bronzo Ladeira, M., & Paulo Valadares de Oliveira, Marcos. (2008). Supply chain maturity and performance in brazil. *Supply Chain Management: An International Journal*, *13*(4), 272-282.

Meredith, J. (1998). Building operations management theory through case and field research. *Journal of Operations Management*, *16*(4), 441-454.

Miller, T. D., & Elgard, P. (1998). Defining modules, modularity and modularization. Paper presented at the *Proceedings of the 13th IPS Research Seminar, Fuglsoe,*

Nahmens, I., & Bindroo, V. (2011). Is customization fruitful in industrialized home-building industry? *Journal of Construction Engineering and Management-Asce, 137*(12), 1027-1035. doi:10.1061/(ASCE)CO.1943-7862.0000396

Nawari, N. O. (2012). BIM standard in off-site construction. *Journal of Architectural Engineering, 18*(2), 107-113.

Nielsen, K., Brunoe, T. D., Jensen, K. N., & Andersen, A. (2017). Utilization of mass customization in construction and building industry. *Managing complexity* (pp. 115-125) Springer.

Noguchi, M. (2013). Commercialization principles for the low-carbon mass customized housing delivery in japan.

Nudurupati, S., Arshad, T., & Turner, T. (2007). Performance measurement in the construction industry: An action case investigating manufacturing methodologies. *Computers in Industry, 58*(7), 667-676.

Olsen, P. B., Khammar, L. K., Breiner, O. M., & Pape, D. W. (2016). *En praktisk guide til BIM i bygge- og anlægsprojekter
(A practical guide to BIM in construction projects)*. ISBN: 978-87-990534-7-6 (paper), ISBN: 978-87-990534-8-3 (electronical): MT Højgaard, Knud Højgaards Vej 7, 2860 Søborg.

Ørngreen, R., & Levinsen, K. (2017). Workshops as a research methodology. *Electronic Journal of E-Learning, 15*(1), 70-81.

Otreba, M., & Menzel, K. (2012). A modular facade design approach in buildings renovations. *Ework and Ebusiness in Architecture, Engineering and Construction,* , 609-616.

Paoletti, I. (2013). Two case studies of mass customisation and digital fabrication in building industry.

Papadopoulos, G. A., Zamer, N., Gayialis, S. P., & Tatsiopoulos, I. P. (2016). Supply chain improvement in construction industry. *Universal Journal of Management, 4*(10), 528-534.

Pekuri, A., Haapasalo, H., & Herrala, M. (2011). Productivity and performance management–managerial practices in the construction industry. *International Journal of Performance Measurement, 1*(1), 39-58.

Piller, F. T. (2004). Mass customization: Reflections on the state of the concept. *The International Journal of Flexible Manufacturing Systems, 16*, 313-334.

Pine, B. J. (1999). *Mass customization: The new frontier in business competition*. Boston, Mass.: Harvard Business School Press.

Pine, I., Joseph, B., & Victor, B. (1993). Making mass customization work. *Harvard Business Review, 71*(5), 108-117.

Piroozfar, P. (2013). Advancements of mass customisation in service and manufacturing industries: Lessons for the built environment. *Mass customisation and personalisation in architecture and construction* (pp. 55-65) Routledge.

Piroozfar, P. A., & Piller, F. T. (2013). *Mass customisation and personalisation in architecture and construction* Routledge.

Pollard, D., Chuo, S., & Lee, B. (2016). Strategies for mass customization. *Journal of Business & Economics Research (JBER), 14*(3), 101-110.

Pollard, D., Chuo, S., & Lee, B. (2011). Strategies for mass customization. *Journal of Business & Economics Research (JBER), 6*(7)

Popper, K. R. (1959). The logic of scientific discovery. *London: Hutchinson, 1*

Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard Business Review, 92*(11), 64-88.

Porter, M. E. (1985). *Competitive advantage: Creating and sustaining superior performance* New York: Free Press.

Ranjan, K. R., & Read, S. (2016). Value co-creation: Concept and measurement. *Journal of the Academy of Marketing Science, 44*(3), 290-315.

Rudberg, M., & Wikner, J. (2004). Mass customization in terms of the customer order decoupling point. *Production Planning & Control, 15*(4), 445-458.

Salvador, F., Forza, C., & Rungtusanatham, M. (2002a). How to mass customize: Product architectures, sourcing configurations. *Business Horizons, 45*(4), 61-69.

Salvador, F., Forza, C., & Rungtusanatham, M. (2002b). Modularity, product variety, production volume, and component sourcing: Theorizing beyond generic prescriptions. *Journal of Operations Management, 20*(5), 549-575.

Salvador, F., De Holan, P. M., & Piller, F. (2009). Cracking the code of mass customization. *MIT Sloan Management Review, 50*(3), 71-78.

Santana-Sosa, A., & Fadai, A. (2019). A holistic approach for industrializing timber construction. Paper presented at the *IOP Conference Series: Earth and Environmental Science, , 323*(1) 012015.

Schoenborn, J. (2012). *A Case Study Approach to Identifying the Constraints and Barriers to Design Innovation for Modular Construction,*

Schroeder-Heister, P. (2001). Popper, karl raimund. *International Encyclopedia of the Social and Behavioral Sciences,*

Selladurai, R. S. (2004). Mass customization in operations management: Oxymoron or reality? *Omega, 32*(4), 295-300.

Silveira, G. D., Borenstein, D., & Fogliatto, F. S. (2001). Mass customization: Literature review and research directions. *Int.Journal of Production Economics, 72*, 1-13.

Steiner, F., Piller, F., Zangitu, M., & Castellano, E. (2011). Mass customization strategies. *Retrieved On, 20*(01), 2018.

Takim, R., & Akintoye, A. (2002). Performance indicators for successful construction project performance. Paper presented at the *18th Annual ARCOM Conference, , 2* 545-555.

Tam, V. W., Fung, I. W., Sing, M. C., & Ogunlana, S. O. (2015). Best practice of prefabrication implementation in the hong kong public and private sectors. *Journal of Cleaner Production, 109*, 216-231.

Tang, M., Qi, Y., & Zhang, M. (2017). Impact of product modularity on mass customization capability: An exploratory study of contextual factors. *International Journal of Information Technology & Decision Making, 16*(04), 939-959.

Törnebohm, H. (1974). *Paradigm i vetenskapernas värld och i vetenskapsteorin*

Tseng, M. M., & Jiao, J. (2001). Mass customization, . In Gaviel Salvendy (Ed.), *Handbook of industrial engineering* (). New York: Wiley.

Tzortzopoulos, P., Betts, M., & Cooper, R. (2002). Product development process implementation–Exploratory case studies in construction and manufacturing. Paper presented at the *CONFERENCE ON INTERNATIONAL GROUP FOR LEAN CONSTRUCTION, , 10*

Ulrich, K. (1995). The role of product architecture in the manufacturing firm. *Research Policy, 24*(3), 419-440.

Ulrich, K. T., & Steven, D. (2008). Eppinger, product design and development.

Vaidyanathan, K., & Howell, G. (2007). Construction supply chain maturity model–conceptual framework. Paper presented at the *Proceedings IGLC, , 15* 170-180.

Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations & Production Management, 22*(2), 195-219.

Vrijhoef, R., & Koskela, L. (2000). The four roles of supply chain management in construction. *European Journal of Purchasing & Supply Management, 6*(3-4), 169-178.

Walcher, D., & Piller, F. (2012). *The customization 500: A global benchmark study of online BtoC mass customization* (1st ed.) www.mc-500.com.

Wang, Y., & Tseng, M. M. (2011). Adaptive attribute selection for configurator design via shapley value. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 25*(02), 185-195.

Wiengarten, F., Singh, P. J., Fynes, B., & Nazarpour, A. (2017). Impact of mass customization on cost and flexiblity performances: The role of social capital. *Operations Management Research, 10*(3-4), 137-147.

Wolters, M., van Heck, E., & Vervest, P. (2002). Modularity in three dimensions: A study of mass customization in the dutch house building industry. *Moving into mass customization* (pp. 215-230) Springer.

Yashiro, T. (2014). Conceptual framework of the evolution and transformation of the idea of the industrialization of building in japan. *Construction Management and Economics, 32*(1-2), 16-39.

Yin, R. K. (2003). *Case study research: Design and methods* sage.

Zipkin, P. H. (2001). The limits of mass customization. *MIT Sloan Management Review, 42*(3), 81-87.

APPENDED PAPERS

Paper 1: Application of Mass Customization in the Construction Industry
Kim Noergaard Jensen, Kjeld Nielsen, Thomas Brunoe. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2015, Tokyo, Japan. pp.161-168, ff10.1007/978-3-319-22756-6_20ff. ffhal-01417455f

Paper 2: Mass Customization in the Building and Construction Industry
Jensen K.N., Nielsen K., Brunoe T.D., Lindhard S.M. (2017) In Bellemare J., Carrier S., Nielsen K., Piller F. (eds) Managing Complexity. Springer Proceedings in Business and Economics. Springer, Cham

Paper 3: Productivity, Challenges, and Applying Mass Customization in the Building and Construction Industry
Jensen, K. N., Nielsen, K., Brunoe, T. D., & Larsen, J. K. (2018). In Customization 4.0 (pp. 551-565). Springer, Cham.

Paper 4: Mass Customization as a Productivity Enabler in the Construction Industry
Jensen K.N., Nielsen K., Brunoe T.D. (2018) In Moon I., Lee G., Park J., Kiritsis D., von Cieminski G. (eds) Advances in Production Management Systems. Production Management for Data-Driven, Intelligent, Collaborative, and Sustainable Manufacturing. APMS 2018. IFIP Advances in Information and Communication Technology, vol 535. Springer, Cham

Paper 5: IT Tools and standards supporting Mass Customization in the Building Industry
Jensen, K.N, Nielsen, K. Brunoe, T.D., and Larsen, J.K. (2019). IT tools and standards supporting mass customisation in the building industry. International Journal of Construction Supply Chain Management Vol. 9, No. 1 (pp. 61-82). DOI: 10.14424/ijcscm901019-61-82

Paper 6: Applying and developing Mass Customization in Construction Industries
- A Multi case study
Kim Noergaard Jensen, Margherita Pero, Kjeld Nielsen, Thomas Ditlev Brunoe. In: International Journal of Construction Supply Chain Management Vol. x, No. x ().

ISSN (online): 2446-1636
ISBN (online): 978-87-7210-507-9

AALBORG UNIVERSITY PRESS