Applying and developing mass customization in construction industries – A multi case study

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ABSTRACT

Mass customization as a strategy has been utilised successfully in the manufacturing industry meeting customers' idiosyncratic needs in a cost-efficient way. The productivity of the Danish manufacturing industry has increased six times over the last 50 years, whereas the Danish construction industry has only doubled. Mass customization has not been extensively explored in the construction industry; therefore, the theoretical background is currently limited. Nevertheless, utilization of mass customization as a strategy might have potentials in the construction industry. This research is a multi-case study of 11 companies in the construction industry focusing on how the cases apply the three fundamental capabilities of mass customization 1) solution space development, 2) choice navigation and 3) robust process design, and how their improvement initiatives effect performance, and how the cases plan to develop the three fundamental capabilities of mass customization. The outset is an analysis of project phases and critical success factors characterizing the cases followed by an analysis of how the cases apply and plan to develop the nine tools and approaches supporting the development of the three fundamental capabilities of mass customization. The data are collected through interview as a two-way communicative approach providing holistic and in-depth explanations of the 18 variables of the analysis. The results are that all 11 cases aim at increasing all nine tools and approaches, which strengthen the utilization of the three fundamental capabilities of mass customization in the sense of improving the productivity. This research put forward a definition of mass customization intending to make the concept more visible and accessible for the construction industry.

KEYWORDS： Choice navigation, Construction industry, Mass customization, Productivity, Solution space development, Robust process design.

INTRODUCTION

Productivity in the Danish construction industry has doubled over the last 50 years, whereas the productivity in the manufacturing industry has increased six times (dst.dk, 2013). The same characteristic applies to the countries of Scandinavia and Europe for the last twenty years (Jensen, Nielsen, Brunoe & Larsen, 2018), which indicate that the productivity gap is industry specific (Figure 1). Productivity is measured as output per performed working hour for the entire economy (dst.dk, 2013).

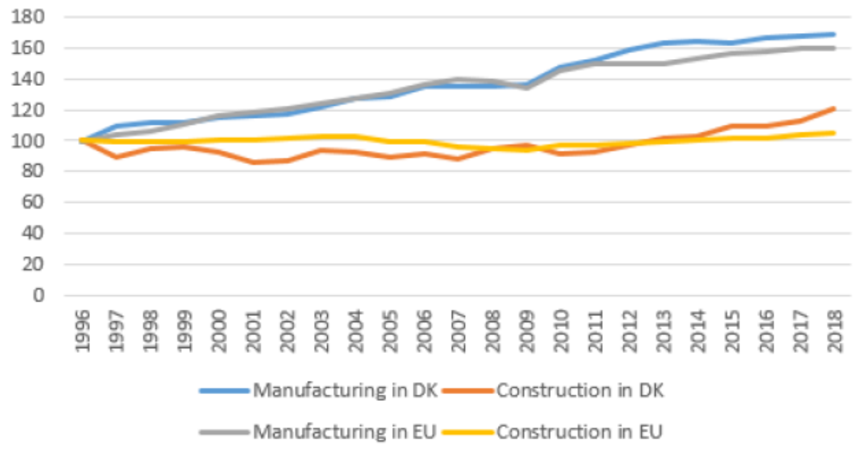

Figure 1: Productivity development (Jensen *et al.*, 2018)

The productivity of the construction industry has been the top priority for many decades knowing that project success depends of cost, time and quality as the three most important performance indicators used for measuring project success (Lazarević & Prlinčević, 2014). These three performance indicators are closely related, thus a change in one affects the others, so finishing off the project at an agreed deadline and at calculated budget is simply not sufficient, since the project must be delivered at an acceptable and agreed quality (Morris & Sember, 2008). It is argued that project quality leads to increased customer satisfaction, cost reduction, productivity increasing, and better competitiveness and that 'top quality' require higher costs and time (Lazarević & Prlinčević, 2014). Many construction projects experience an unsuccessful project process and outcome, and looking into the cost overrun of construction projects, studies have documented a significant waste of project resources (Flyvbjerg, Skamris Holm, & Buhl, 2003; Love, Tse, & Edwards, 2005; Nicholas & Steyn, 2017). A research demonstrates that 'lack of project coordination' and 'lack of trust and shared objectives' explained 75.4% of process factors affecting project performance (Larsen, Lindhard, & Jensen, 2017) and project problems in the execution phase due to 'lack of project requirements and design specifications combined with too optimistic project deadlines and budget frame' (Larsen, Brunoe, Lindhard, & Jensen, 2017).

Most industries are dynamic in nature due to the increasing pressure coming from uncertainties of environmental factors like globalization, market conditions, and new technology development (Sharda, Delen, Turban, Aronson, & Liang, 2014). The conditions for both the manufacturing industry and the construction industry are characterized by these external factors and their customers' demands of more choices of product features. Therefore, companies make great effort to meet customer demands and new market requirements on the market they try to penetrate (Salvador, Forza, & Rungtusanatham, 2002). Introducing new products faster and faster have become the daily competition conditions, and the extensive product customization may require considerable development investments and rollout costs leading to decreasing profitability, lengthen the development and rollout times, and increasing the likelihood of delays (Chryssochoidis & Wong, 2000).

Companies search for initiatives to increase their competition, and the construction industry focus on lean construction, six sigma, TQM, digitalization, BIM, standardization, and modularization trying to reduce project and production costs to increase productivity (Chryssochoidis & Wong, 2000; Lisstrand & Sikell Lundin, 2017; Pero, Stößlein, & Cigolini, 2015; Piroozfar & Piller, 2013; Salvador *et al.*, 2002; Schevers & Drogemuller, 2005). The performance of the construction industry is subject to conflicting objectives affecting the productivity. First, the 'market and regulation' demand functional performance of a building like indoor quality, insulation values, comfort levels and social sustainability. Second, the construction companies strive to reduce energy consumption, enhance cost efficiency, and meet environmental sustainability. Third, the architects have different aesthetic values and design ambitions that they strive for to realize in the building design (Piroozfar & Piller, 2013).

Mass customization was first coined by Davis in 1987 as *"creating customized products with production cost similar to those of mass-produced products"* (Davis, 1987). Salvador *et al* (2002) identified the following three fundamental capabilities that determine the ability of a company to mass customize: 1) solution space development, 2) robust process design, and 3) choice navigation (Salvador, De Holan, & Piller, 2009).

The construction industry needs to focus on new improvement strategies (Pekuri, Haapasalo, & Herrala, 2011), and the principles behind mass customization has achieved results in the manufacturing industry in terms of increasing productivity and competitiveness (Liu, Chow, & Zhao, 2019; Pollard, Chuo, & Lee, 2016; Selladurai, 2004; Silveira, Borenstein, & Fogliatto, 2001; Wiengarten, Singh, Fynes, & Nazarpour, 2017). A broad agreement from the literature points at several advantages to apply mass customization e.g. indicating a profit growth, productivity increase, maximizing market share, cut cost of inventory, reduce material waste, increase cash flow, shorten time of responsiveness, and the ability to supply a full line of products or service with lower costs. For that reason, mass customization as a strategy may have potentials in the construction industry improving the productivity. Therefore, the objective for this research is to analyze the utilization of mass customization as a strategy aiming at increasing the productivity within the construction industry. The research is carried out in a multi case study of 11 companies in terms of how they apply and plan to develop the three fundamental capabilities of mass customization: *Choice Navigation*, *Solution Space Development*, and *Robust Process Design*, aiming at finding enablers and awareness relative to application of mass customization as a strategy improving the productivity within the construction industry.

STATE OF THE ART

New manufacturing philosophies, business processes reengineering, ICT optimization, and development of production processes and correlated support processes are initiatives improving the productivity of the manufacturing industry (Fagerberg, 2000; Pollard *et al.*, 2016). Some companies of the manufacturing industry has undergone a transition process of offering customized products (Walcher & Piller, 2011) at prices near mass production (Batchelor, 1994; Bohnstedt, 2014) under the strategy called mass customization (Pine, 1999; Piroozfar & Piller, 2013) to meet the higher demand of product variety (Aigbedo, 2009; da Silveira, Fogliatto, & Fendyur, 2012; Haug, Ladeby, & Edwards, 2009).

The definition of mass customization has evolved over time but originates from the manufacturing industry moving from mass production towards creating customized products at production cost similar to mass-produced products. Davis in 'Future perfect' (Davis, 1987) proposed mass customization to be defined as: *"the same large number of customers can be reached as in mass markets of the industrial economy, and simultaneously treated individually as in the customized markets of pre-industrial economies"* (Davis, 1987). Pine (1999) in 'Mass customization: the new frontier' 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"* (Pine, 1999). Pine emphasized *"variety and customization through flexibility and quick responsiveness"* or *"efficiently serving customers uniquely"* as stated at MCPC in Aachen 2017. Tseng and Jiao claims that, *"mass customization aims at producing goods and services catering to individual customers' needs with near mass production efficiency"* or *"the technologies and systems to deliver goods and services that meet individual customers' needs with near mass production efficiency"* (Tseng & Jiao, 2001). Kaplan and Haenlein (2006) did a research based on three research questions striving at defining mass customization as: *"a strategy that creates value by some form of company-customer interaction at the fabrication/assembly stage of the operations level to create customized products with production cost and monetary price similar to those of mass-produced products"* (Kaplan & Haenlein, 2006). Blecker and Abdelkafi (2006) define 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"*.

Manufacturing companies are focusing on standardization of modules, prefabrication (Salvador *et al.*, 2009), configuration and changeable manufacturing (Andersen, Brunoe, Nielsen, & Rösiö, 2017; Brunoe, Bossen, & Nielsen, 2015; Wiendahl *et al*., 2007) to meet similar conditions as mass produced standard products (Koren, 2010; Pine, 1999), and therefore aiming at exploiting the three fundamental capabilities of mass customization (Salvador *et al*., 2009):

1. Solution Space; *"Development identify the product attributes along which customer needs diverge"*.
2. Choice Navigation; *"Support customers in identifying their own solutions while minimizing complexity and the burden of choice"*.
3. Robust Process Design; *"Reuse or recombine existing organizational and value-chain resources to fulfill a stream of differentiated customers' needs"*.

Solution Space Development; is about understanding the customers' needs of products and services, and the objective is to understand how customer requirements are different by identifying valuable product attributers. Hereafter, to develop products and services that effectively can adapt to these individual requirements through standardization, product platforms, modularization, etc. *Choice Navigation*; is about guiding the customers to identify requirements and to configure the product or service matching these requirements. *Robust Process Design*: is about having flexible and robust business processes and value chain resources to efficiently fulfill the customers' requirements.

The essence of mass customization as a strategy is the focus on the customers problems, and the demand of products and services by offering exactly enough variety so nearly everyone finds what they want (Piroozfar & Piller, 2013). The core of mass customization is integration, flexibility and responsiveness in handling the challenges coming from the rapidly changing environment, people, processes, units, and technology (Pine, 1999).

The construction industry is characterised as handling complex projects often one-of-a-kind that are built at varied locations and exposed to adverse and unpredictable weather conditions and seasonality, which indeed is different compared to the manufacturing industry and therefore may seem challenging to optimize (Batchelor, 1994; Bohnstedt, 2014). The construction industry's demand for customization in terms of individual architecture, function, quality, timeframe, environment, may seem challenging to handle with standardization, mass production, and modularization etc. because of the uniqueness of the products and projects (Dean, Tu, & Xue, 2009). Prefabrication has been known since the 1970s, and technologies have been continuously developed and improved, and although it requires significant coordination and standardization in the designs some successfully applications of prefabricated elements exist (Hvam, Mortensen, Thuesen, & Haug, 2013; Linner & Bock, 2012; Paoletti, 2013; Tam, Fung, Sing, & Ogunlana, 2015).

Mass customization has not been widely explored in the research area of the construction industry in comparison to the manufacturing industry, therefore, only limited theoretical background is currently present and apparently no applicable definitions of the concept targeted the construction industry.

Table 1 Tools and approaches to be developed, adapted from (Salvador et al., 2009).

Capability	Tools and approaches	Characteristics
Solution Space Development SSD	Innovation tool kits ITK	Software helping customers transforming preferences and unsatisfied needs into unique product/service variants or ideas (concept lab).
	Virtual concept testing VCT	Software for virtual testing of concepts, design ideas, product variants without making a prototype so customers can evaluate and review them;
	Customer experience intelligence CEI	Software for capturing 'designs proposals' of ordered and unordered products for analyzing purposes as input for adjustment of future solution space
Choice Navigation CN	Assortment matching AM	Software building configurations based on attributers or characteristics from existing solution space matching requirements of customer's needs. Intuitively, interactive and user-friendly product configuration tools
	Fast-cycle, trial-and-error learning FC/TEL	Software or models to be used interactively for testing and experimenting to see the match between available models of solutions and own requirements/needs.
	Embedded configuration EC	Reconfigurable products that "understand" how to adapt to the customer. Reconfigurable solutions with extended utilization and functionality.
Robust Process Design RPD	Flexible automation FA	Automation that can handle the customization of tangible or intangible goods. Flexible and automated processes for making design and specifications, or flexible automated equipment for fulfilling manufacturing processes on-site or off-site.
	Process modularity PM	Divide existing organizational power, business processes and value-chain resources into modules to be reused or recombined to meet differentiated customers' needs.
	Adaptive human capital AHC	Organizational developing and training of managers and employees to handle new and ambiguous tasks that machines, ICT or AI are not yet capable of doing

"*Customers do not want more choices; they want exactly what they want, when they want it, and where they want it*" (Pine, 1999). If customers are exposed to too many choices, the cognitive cost of evaluation can outweigh the value of having many choices (Piroozfar & Piller, 2013), therefore the choice navigation is one of the three important capabilities of mass customization. Automatic manufacturing equipment, automation of production processes and intuitive product configurators are some enablers of mass customization widely used in the manufacturing industry (Pine, 1999; Salvador *et al.*, 2009) allowing companies to provide the customers with a high degree of customization in a way that customers can choose from a wide range of product variants matching unique needs for a low price (cost minimization) *(*Dean *et al.*, 2009; Piroozfar & Piller, 2013).

The construction industry designs and produces products with high variety, which are one of the objectives of mass customization (Silveira *et al.*, 2001). A recent research revealed a potentially productivity connection from each of the three fundamental capabilities of mass customization into the phases of a construction project (Jensen, Nielsen, & Brunoe, 2018). Therefore, applying the principles behind mass customization may result in higher productivity like in industrial production of customized products (Selladurai, 2004; Silveira *et al.*, 2001). According to Salvador, 'Cracking the code of mass customization' (Salvador *et al.*, 2009) various 'tools and approaches' are available to assist companies to develop the three fundamental capabilities of mass customization (see Table 1).

RESEARCH

An initial review of mass customization in the construction industry revealed limited literature with focus on mass customization as a mean for increasing productivity in construction industry, which indicate that further research is needed to understand clearly, how mass customization as a strategy can facilitate improving the productivity of the construction industry. However, all the three capabilities of mass customization: *1) solution space development; 2) choice navigation; and 3) robust process design*; needs to be explored further for successful application of mass customization. Entities in the value chain both individually and interconnected are of particular interest in utilizing the three capabilities of mass customization. Availability of standards and tools are prerequisites for a successful cooperation between entities in the value chain and therefore the foundation for the application of mass customization improving productivity in the construction industry. Consequently, this multi case study analyzes how 11 companies have applied and how they plan to develop the three fundamental capabilities of mass customization. The case study research was selected and conducted in line with the explorative nature of the research questions with the intention of developing new insights and theory of application of mass customization within the construction industry. Therefore, case studies are considered suitable for addressing research questions that requires a comprehensive and full understanding of the relations to its context (Yin, 2014). Multi case study help to increase the confidence in the findings and support their external validity (Miles & Huberman, 1994).

Research Questions:

The objective of this research is to analyze the suitability of the three fundamental capabilities of mass customization: 1) Choice Navigation, 2) Solution Space Development, and 3) Robust Process Design to be applied within the construction industry to improve the productivity. This is done specifically by assessing the applicability of the tools and approaches associated with the three fundamental capabilities of mass customization to be applied successfully within construction industry.

The research is conducted as a multi case study analyzing 11 companies. The point of departure is a clarification of 1) the project phases used by the companies, 2) the related critical success factors for effective project execution, and 3) five characteristics of the companies. The cases are analyzed in terms of how they currently apply and plan to develop mass customization. Therefore, the research questions are:

- RQ1: How do the companies currently apply the 'tools and approaches'
- RQ2: How does the application of the 'tools and approaches' affect the performance
- RQ3: How do the companies plan to develop the 'tools and approaches'

METHODS

The research questions are addressed in a multi case study interviewing and analyzing 11 Danish construction companies that have different position and role in the value chain. This descriptive, explanatory and exploratory method (Voss, Tsikriktsis, & Frohlich, 2002; Yin, 2003) aim to gain useful data of the three fundamental capabilities of mass customization to get insight. The data gathering is divided in three parts 1) *Background information* (project phases, critical success factors, five characteristics), see definition in section of *Characteristics of the companies*, 2) *Three open-ended questions* and 3) *Questionnaire 28 questions*. See Methodical Framework, see Figure 2 developed for this research.

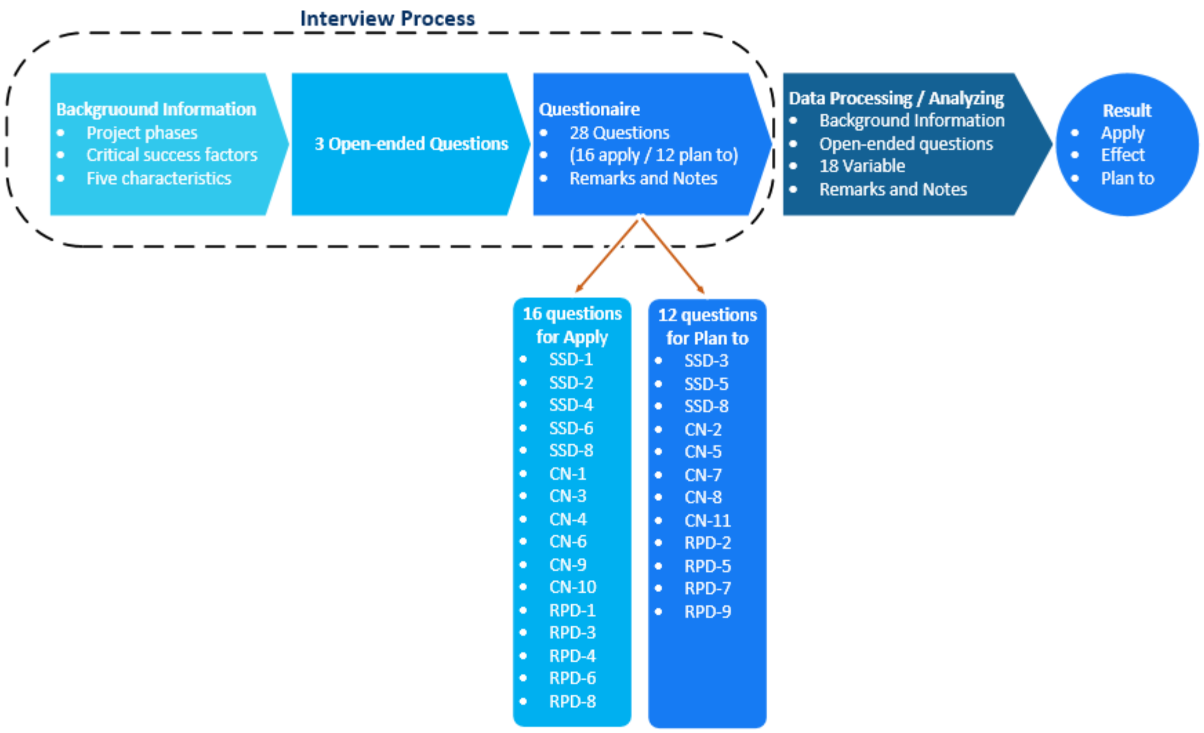

Figure 2 Methodical Framework

The gathering of *Background information* is a clarification of a) how the cases are structuring their projects (applied phases) to gain knowledge about their structural approach of construction projects to determine similarities or dissimilarities of project execution, b) which critical success factors do they consider important as prerequisites for successful project execution aiming at understanding their challenges and priorities, and c) clarifying five characteristics: 1) where in the value chain (tier) does the case operate, 2) what is the size of the case according to European Commission definition, 3) what is the level of automation of case, 4) what is the maturity level of the case and 5) what is the strategy level of the case (see definition in section *Characteristics of the cases*). The purpose is to investigate how the five characteristics correlate to the result of the questionnaire.

The background information is collected by interviewing and analyzing the 11 cases. Research question RQ1 is addressed by interviewing and analyzing the cases in relation to how they handle 1) the configuration process, 2) the product development process, and 3) the process of reusing existing resources to handle ambiguous task. The research question RQ1 takes its outset in three open-ended questions related to the three fundamental capabilities of mass customization followed by a questionnaire covering research question RQ1 and RQ3 in detail. The close-ended questionnaire consists of 28 specific questions aiming at measuring the 18 variables that identifies 1) how the cases apply the tools and approaches and 2) how the cases plan to develop the tools and approaches aiming at increasing the level of the utilization of the three fundamental capabilities of mass customization. The answers of the 28 close-ended questions (see questions in appendix A) are given a value (4: High, 3: Moderate, 2: Low, 1: None). Application of other types of Likert scales (3, 5 or 7 points) to measuring the result have been considered without obvious needs. Research question RQ2 is addressed by investigating and analyzing the feedback of the questionnaire done by the respondents to understand their reasoning and motivation of doing as they do to determine the effect of their initiatives on the performance. Research question RQ3 is addressed by the combined questionnaire with 28 specific questions aiming at measuring how they plan to develop the nine tools and approaches to increase the future utilization of the three fundamental capabilities of mass customization. Finally, the corresponding feedback achieved through the questionnaire in terms of remarks are analyzed to find commonalities in statements supporting the mass customization principles.

Variables to Measure

The variables to measure are based on the nine tools and approaches, see Table 1, (Salvador *et al.*, 2009), which are considered as guidance direction and not necessary a limitation to the work related to developing the three capabilities of mass customization. These nine tools and approaches to be analyzed bases on current state and future state, which turns into 18 variables supported by 28 questions, see appendix A.

Questions to be Asked

The open questions are the basis for the interviews carried out together with the 11 cases to gain overall insight supporting the answers to the three research questions [1 to 3]:

1. What are the phases (stage gate model) that your company are using during a typical construction projects, and to which extent is it carried out (mandatory to follow, flexible/adaptable, reasons of using it)?
2. What are the critical success factors in your company concerning completion of a typical construction projects?
3. How do your company support customers in identifying their own problems and solutions while minimizing complexity and the burden of choice (CN)?
4. How do your company understand and identify your customer's 1) needs of products or services, 2) requirements of valuable attributers, and 3) developing of products/services that effectively can adapt to individual requirements (SSD)?
5. How do your company reuse or recombine existing organizational and value-chain resources (processes) efficient and effectively to fulfill a stream of differentiated customer's needs (RPD)?

The 28 questions used for the interviews are described in appendix A and illustrated in the Methodic Framework (Figure 2), which are the basis for the analysis carried out with the 11 cases to gain measurable insight to answering the three research questions.

CASE FINDINGS

Description of Case Studies

The following cases [C01-C11] are subject for the case study:

Case 1. Is a large company working in the field of construction and property development. Is one of Northern Europe's largest companies and operates in 5 countries. Revenue ~ 40 billion DKR, employees ~16.000. Dealing with the entire value chain: development and construction of residential and commercial properties, industrial plants and public buildings, roads, bridges and other forms of infrastructure.

Case 2. Is a large company working in the field of design and advisory. Is one of the largest companies in Northern Europe and operates in 35 countries worldwide. Revenue ~ 14 billion DKR, employees ~16.500. Dealing with the entire value chain: development and construction of residential and commercial properties, industrial plants and public buildings, roads, bridges, infrastructure like transport, urban development, water, environment and health, energy, oil & gas and management consulting.

Case 3. Is a large company working in the field of contractors, developers and property investors. Is one of the largest companies in a region of Denmark. Revenue ~ 3 billion DKR, employees ~ 500. Dealing with the entire value chain: involving entities along with the development and construction of residential and commercial properties, industrial plants and public buildings

Case 4. Is a medium company working in the field of construction and development. Is performing construction tasks and operates in Denmark. Revenue < 1 billion DKR, employees ~ 200. Dealing with the value chain: development and construction of business and institution buildings, residential and residential buildings and single-family homes.

Case 5. Is a medium company working in the field of roof and façade constructions taking part of design, production and mounting of roof, wall and façade construction. Operates in primarily Denmark. Revenue < 0,5 billion DKR, employees < 100. Dealing with a part of the entire value chain in terms of supplying its products to the building site.

Case 6. Is a small company working in the field of delivering small and large advanced steel constructions of balconies, stairs, railings, façade claddings. Operates in primarily Denmark. Revenue < 0,5 billion DKR, employees < 100. Dealing with a part of the entire value chain in terms of supplying its products to the building site.

Case 7. Is a medium company, one of the leading manufactures in Denmark working in the field of prefabricated concrete elements and façade panels. Operates in primarily Denmark. Revenue < 0,5 billion DKR, employees ~ 200. Dealing with a part of the entire value chain in terms of supplying its products to the building site.

Case 8. Is a medium construction company working in the field of sewerage, power lines, road construction, and concrete work. Operates in primarily Denmark. Revenue < 0,5 billion DKR, employees ~ 150. Dealing with a part of the entire value chain in terms of onsite task using own machinery facilities.

Case 9. Is a large Danish construction company working in the field of concrete and steel constructions, surface treatment in buildings, industries and offshore constructions, focusing on warehouses and production buildings. Operates in primarily Denmark. Revenue ~ 2 billion DKR, employees ~ 500. Dealing with the entire value chain in terms.

Case 10. is a medium company performing construction tasks in the northern part of Denmark. Operates in Denmark. Revenue ~ 0,5 billion DKR, employees ~ 100. Dealing with part of the value chain and rarely with the whole value chain concerning construction of business and institution buildings, and residential buildings and single-family homes.

Case 11. Is a large company, one of the leading manufactures in world working in the field of manufacturing of products, like windows, doors, staircases. Operates worldwide. Revenue ~ 35 billion DKR, employees ~ 22.000. Dealing with a part of the value chain in terms of supplying some of its products to the building site.

Project Phases

The analysis of how the cases structure their project phases to handle their typical construction projects is seen in Table 2. Only one case has included the demolition phase in their model, which not necessary mean that this phase is not carried out by the other cases, but rather handled as a separate project. Even though, the cases are naming the phases differently and doing different jobs, the applied phases are to be considered the same as a typical construction project (Jensen *et al*., 2018).

Characteristics of the Cases:

The 11 cases hold different positions in the value chain meaning that they have different roles and type of jobs to carry out and thereby also different involvement in a project, e.g. making products off-site to be delivered and assembled on-site, making products on-site, preparation and supporting work on site using machines for preparing the ground, installing pipeline, piling, digging in the ground, using cranes lifting materials, components, etc.

The five characteristics to be investigated for correlations are defined as followed:

1. The position in the value chain [1, 2, 3] tier 1 operates on-site, tier 2 supplies materials on-site, and tier 3 supplies companies at tier 2
2. Case size [small, medium, large] or [3, 2, 1] (Small < 50 employees, Medium 50-249 employees, Large > 250 employees)
3. Case level of automation [low, middle, high] or [3, 2, 1] in terms of accessibility and practices used in the industry of applying new technology for automation of processes and/or equipment related to the job taking place ‘on site’ or ‘off site’
4. Case level of maturity [low, middle, high] or [3, 2, 1] in terms of how the company standardized and controlled processes for managing the interdisciplinary effort necessary for transforming the customer needs and expectations into a product deliveries [low: unpredictable processes, poorly controlled, middle: processes well understood and controlled, and high: predictable processes, excellent controlled].
5. Strategy level of software/technology [low, middle, high] or [3, 2, 1] in terms of to which extent software/technology have been proactive putting on the agenda as important enablers for improving the performance.

The cases are given a value as seen in Table 3 to clarify any correlation between these characteristics and the result of the case study.

Table 2: Comparing the project structure

Case	Phases	Plan	Design	Construct	Hand-over	Maintenance	Demolition
C01	1. Project development	X					
	2. Offer Preparation	X	X				
	3. Draw out contracts and main agreement		X				
	4. Complete Order Designing		X				
	5. Plan production	X		X			
	6. Complete production				X		
	7. Submission (hand over the delivery)	X				X	
	8. After delivery (after hand over)						
C02	1. Capture (Discover, Quality)	X	X				
	2. Tender (Develop, Negotiate)	X					
	3. Planning (Project Execution Plan)	X					
	4. Execution (Phase 1, 2, 3, 4)		X	X			
	5. Closing (Project closure requirement)	X			X	X	
C03	No formalized stage gate plan, project managers make their own best practices						
C04	1. Tendering	X					
	2. Ordering (Calculation, Drawings, Planning)	X	X				
	3. Execution			X			
	4. Delivering			X	X		
C05	1. Tender procedure (BID, time, quality)	X					
	2. Design (Detailed drawings, time, quality)		X	X			
	3. Manufacturing (Planning, packing)			X			
	4. Delivering to construction	X			X		
C06	1. Tender procedure (price, time, quality)	X					
	2. Design (drawings, planning, calculations)		X				
	3. Manufacturing (plan, pack, deliver)			X	X		
C07	1. Tendering	X					
	2. Scrutinizing (drawings, order project)	X	X				
	3. Implementation						
	4. Planning		X	X			
	5. Execution			X			
	6. Delivering			X	X		
	7. Guaranty					X	
C08	No stage gate plan						
C09	1. Programming (Clarification requirements,)	X					
	2. Design (construction, documentation)		X				
	3. Execution (Pilling, assembly, installation)			X			
	4. Commissioning (hand over, defect liability)			X	X	X	
C10	1. Program (overall project framing)	X					
	2. Design (tender stage,		X				
	3. Proposal phase (design, main design)	X	X				
	4. Execution (plan, coordination, monitoring)			X	X	X	
	5. Demolition						X
C11	1. Tendering (pre-calculation)	X	X				
	2. Ordering (Calculation, Drawings, Planning)	X					
	3. Production			X			
	4. Delivering on-site			X	X	X	

Table 3: Characteristics of the 11 cases

Case	Tier	Size	Automation	Maturity	Strategy
C01	1,2	Large	High	High	High
C02	1	Large	High	High	High
C03	1	Large	Middle	Low	Low
C04	1,2	Medium	Middle	Middle	Middle
C05	2	Medium	Middle	Middle	Middle
C06	2	Small	Low	Middle	Middle
C07	2	Medium	Middle	High	High
C08	2	Medium	Low	Middle	Middle
C09	1,2	Large	High	High	High
C10	1,2	Medium	Middle	Middle	Middle
C11	2,3	Large	High	High	High

Project Critical Success Factors

Construction projects are completed as a result of planned and unplanned interactions and communication between members within the value chain. Changing participants and processes; improper collaboration tools, and other conditions are common during projects in a constantly changing environment, which are subjects for a successful completion of any project. These conditions and factors are referred to as critical success factors.

Based on interviews and analysis the critical success factors are presented by the 11 cases, see Table 4. They are sorted by frequency of which critical success factors the cases consider important in relation to their construction projects. As seen from the top seven of the critical success factors, they address different issues related to the collaboration between entities of the value chain, and there is a common agreement of that "Good and effective communication between parties" is the most important factor to address. "Good collaboration tools and techniques" is the second most important factor to address, which points at the tools and approaches disseminated in this research as a part of becoming a "better" mass customizer.

RESULTS

The results of the case studies are divided in three sections addressing the three research questions. The results are based on how the 11 cases have scored on the individual 28 questions represented with nine variables describing 'current state of mass customization' respectively 'future state of mass customization'. The developed tables and figures include aggregated numbers representing a) the nine 'tools and approaches', b) the three fundamental capabilities and c) the mass customization concept.

The Current State of Mass Customization

Table 5 is a heat diagram showing to which extent the 11 cases currently apply the nine 'tools and approaches' of mass customization (see appendix B). The higher the value is (the greener), the higher is the utilization of the specific 'tools and approaches'. Some cases are scoring high in several of variables meaning that they have invested money in these areas as they believe the investment will pay off.

Table 4: Critical Success Factors sorted by frequency

	Critical Success Factors	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	Sum
1	Good and effective communication between parties	1	1	1	1	1	1	1	1	1	1	1	11
2	Good collaboration tools and techniques	1	1		1	1		1		1	1	1	8
3	Clear understanding of agreements	1					1		1	1	1	1	6
4	Respect to planning and agreements	1							1	1	1	1	5
5	Organizing, planning, managing projects		1	1		1	1		1				5
6	Handling changes in client demands	1			1	1						1	4
7	Identify risk and opportunities within the project.		1					1		1			3
8	Experienced and flexible workforce	1		1	1								3
9	External factors e.g. weather conditions troubling the execution process	1											1
10	Identifying and understanding stakeholders' expectations and influence		1										1
11	Health/safety perspectives			1									1
12	Own production			1									1
13	Strong Management			1									1
14	Inventory handling					1							1

Table 5: Heat diagram of how cases apply the 'tools and approaches' of mass customization

Capability	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	Total
CN	**10**	**10**	**4**	**5**	**7**	**7**	**8**	**4**	**6**	**5**	**8**	**74**
AM	4	3	2	3	3	3	3	2	3	2	3	**32**
EC	2	3	1	1	2	2	2	1	2	1	2	**18**
FT, TEL	4	4	1	1	2	2	3	1	2	2	3	**25**
RPD	**10**	**9**	**10**	**10**	**7**	**7**	**10**	**5**	**11**	**7**	**7**	**94**
AHC	4	4	4	4	3	3	4	2	4	4	3	**39**
FA	3	2	3	3	2	2	3	2	3	2	2	**28**
PM	3	3	3	3	2	2	3	1	4	1	2	**27**
SSD	**12**	**9**	**5**	**7**	**9**	**7**	**9**	**5**	**9**	**5**	**11**	**87**
CEI	4	4	3	3	4	3	4	3	4	2	4	**38**
ITK	4	2	1	2	2	2	2	1	2	1	3	**22**
VCT	4	3	1	2	3	2	3	1	3	2	4	**28**
Total	**32**	**28**	**19**	**22**	**23**	**21**	**27**	**14**	**26**	**17**	**26**	**256**

Table 6 show the characteristics relative to how the cases apply mass customization, and the top five cases are also scoring highest on the characteristics indicating a correlation between the degree of mass customization and the characteristics (size, automation, maturity, strategy) of the cases.

Table 6: The cases sorted by how they currently apply to mass customization (MC)

Company	Tier	Size	Automation	Maturity	Strategy	MC
C01	1,20	3	3	3	3	32
C02	1,00	3	3	3	3	28
C07	2,00	2	2	3	3	27
C09	1,20	3	3	3	3	26
C11	2,30	3	3	3	3	26
C05	2,00	2	2	2	2	23
C04	1,20	2	2	2	2	22
C06	2,00	1	1	2	2	21
C03	1,00	3	2	1	1	19
C10	1,20	2	2	2	2	17
C08	2,00	2	1	2	2	14
Total	**17,10**	**26**	**24**	**26**	**26**	**256**

Figure 3 show the distribution of how the 'tools and approaches' are applied by the 11 cases, where the 'adaptive human capital' and 'customer experience intelligence' scores highest.

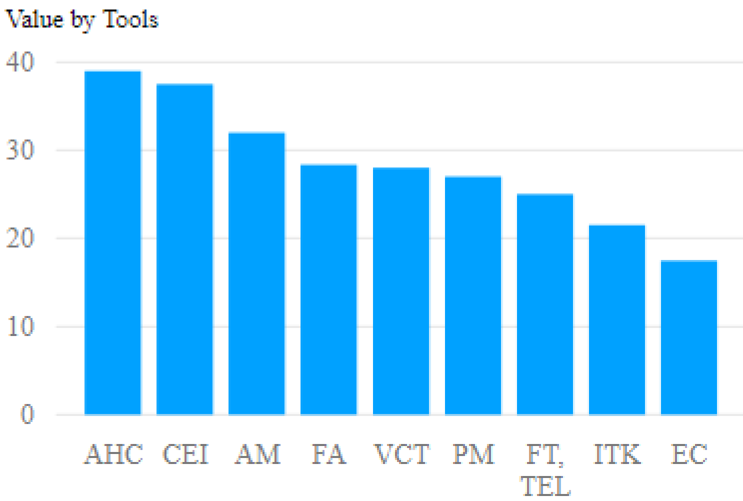

Figure 3: The sorted application of the 9 'Tools and approaches' of mass customization

Figure 4 and 5 show for each of the four characteristics (see Table 3) the value divided in the three fundamental capabilities of mass customization. Figure 4 (left) show that the largest case also scores highest on all three capabilities, and this tendency is the same for the 'level of automation' as illustrated in Figure 5 (left). For the 'solution space development' and 'choice navigation' the four figures (Figure 4 and 5) show a correlation to the highest value of all the four characteristics.

Based on the tables and figures the following can be deduced to clarify how the cases apply the 'tools and approaches' of mass customization:

- Adaptive human capital is the highest rated of the tools and approaches primary because of the ability to reuse existing organizational resources in terms of the necessity of having people able to deal with ambiguous task.

- Customer experience intelligence is the second highest rated of the tools and approaches in terms of using engineering software for the storing and analysis purposes as basis for decision making relative to the solution space
- Assortment matching is the third highest rated of the tools and approaches mostly due to the usage of engineering software like computer aided design (CAD), 3-dimension modelling, standards, and using building information modelling (BIM) elements for capturing the customer needs.
- There is a significant span of how the cases apply the nine tools and approaches, and thereby how they apply the three fundamental capabilities of mass customization
- The span seems not to be due to the position in the value chain, but more related to the type of job carried out, size of the case, level of automation accessibility, the maturity of the case, the chosen strategy, and applicability where it makes sense (efficiency, productivity)
- There is a correlation between the case size and how the cases apply the three capabilities, and this tendency is the same for the 'level of automation' as illustrate in Figure 5 (left).
- For 'solution space development' and 'choice navigation' a correlation exits to the highest value of the characteristics.

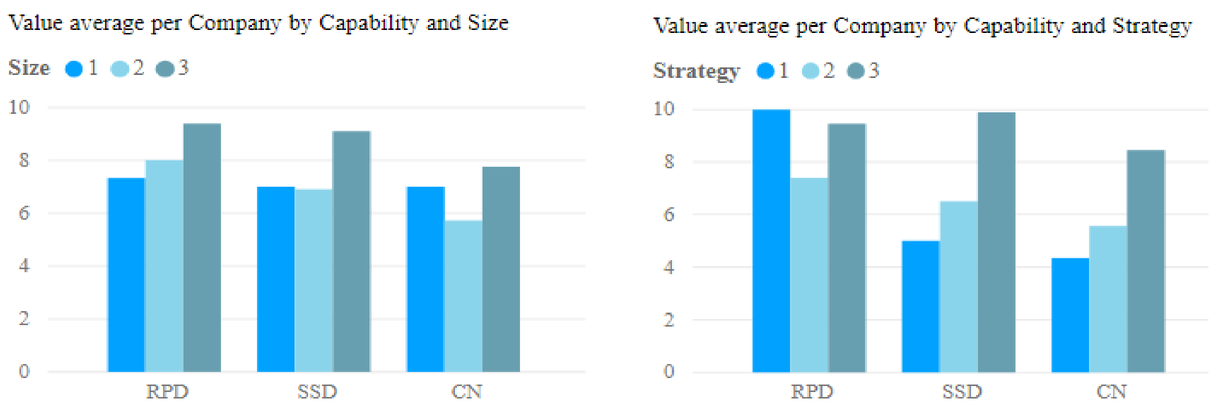

Figure 4 Value per Size (left) and Strategy (right)

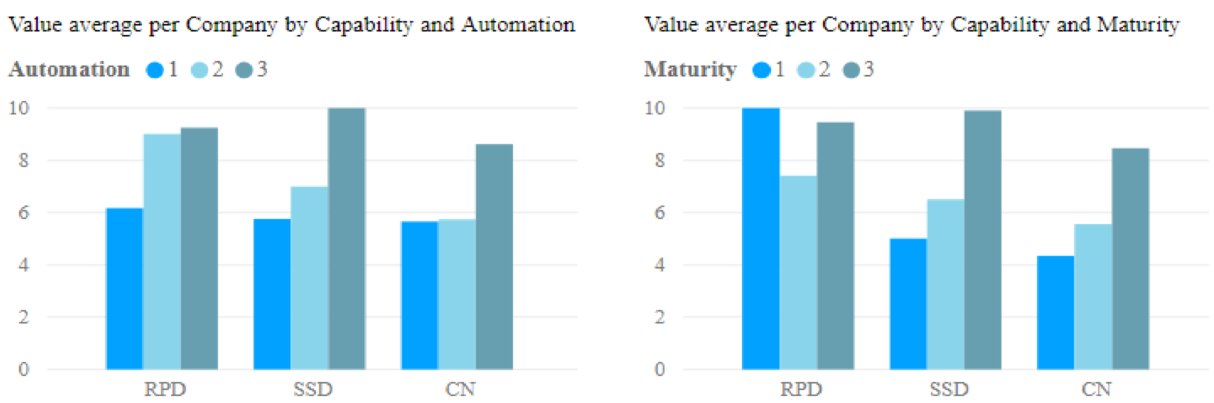

Figure 5 Value per Automation (left) and b) Maturity (right)

Table 7 Why the cases apply 'tools and approaches' of mass customization

Case	Effect of doing what they do

1	Use new software (SW) as it gives all parties knowledge for decision-making. Good cooperation and strong processes are critical for our project efficiency. SW are the basis for planning and execution of the projects. Prioritize digitalization for efficiency reasons. Improve through process optimization to be more effective. It is a necessity having people being able to deal with ambiguous task. Involvement of customers in the processes, virtual design construction, VDC gives opportunities not seen before.
2	Use computer aided design (CAD) to validate 3-dim models and improving collaboration. Use std. items, prefabricated element to increase efficiency and productivity. Focus on digitalization for efficiency reasons. Use virtual glasses allowing customers to validate the concept, which increase efficiency. SW for testing is important, customers see opportunities. Have employees with ambiguous skills, spends time on training
3	Communication between parties is crucial, SW and digitalization is used for efficiency reasons. Look for SW possibilities, to increase efficiency. Projects vary (new building elements/design changes), which requires flexible employees.
4	Uses CAD for engineering, and product configurator to be efficient. Dialogue with customers and parties is important. Our processes support collaboration, based on trust and many years of experience, focus on improving processes. Use digital catalogs, so customers understand our competences. Use std. items from factory or buying. It makes sense to invest in SW for presenting solution to improve the dialogue.
5	Use SW for working with the customers and the contractors. Use 3-dim, it is valuable for customer's visual experience. Use Internet as product/projects catalog of std. goods as it is important for our customers. Important to use SW to improve quality and save time. Large part of projects is std. items to be assembled, adapted to the specific design, which improves the efficiency. It is important having responsible, highly motivated and well-qualified employees, we train people being flexible to handle sophisticated tasks.
6	Uses Winbeam, Inventor, building and information modelling (BIM) as it improves the cooperation and efficiency. We work close together with our customers and contractors. See opportunities by investing in new technology and SW.
7	Use module-based construction adapted to customer needs. Use CAD, BIM for efficiency reasons. Project is done in collaboration with architect, who determine design. Use digitalization to present products. New SW/technology is important for future competitiveness as it can speed up the process and reduce misunderstandings. Search for SW for optimizing workflow, reducing project duration and improving collaboration. Need flexible employees to handle ambiguous tasks.
8	Need SW to support our processes, we cooperate with customers. Use simple SW, but want to implement SW with project/activities, and resource management, staffing, etc. for efficiency reasons. SW help reusing experience from old projects. This industry is manually, search for new technologies, robotic. Want to be a fast second mover.
9	Focus on processes to improve collaboration ensuring delivery. Our projects are standard elements to be recombined. Uses 3-dim CAD. Focus on utilizing SW where it is beneficial. Virtual SW might be useable for the customers. All tasks are staffed optimally to solve the customer needs, we are flexible when changes occur. SW and atomization improve efficiency and quality. Want to adapt our employees to new requirements.
10	Use CAD for larger projects, it improves the collaboration and efficiency. See opportunities of SW for collaboration and customer service. People are used to work with ambiguous tasks task, which is important to strengthen.
11	Product configurator handles most orders, only a few needs ETO. Improve the order intake process using SW. Customers want to see products in landscape of use before buying. Invest in SW and ways to improve the collaboration to become more productive. Invest in SW to speed up the order intake process. Have flexible manufacturing equipment and invest in such to improve/keep prices down and to stay competitive.

Effect of Applying the Three Capabilities of MC

Comments registered relative to the questionnaire in terms of reasoning and motivating of why they do as they do have been analyzed, and the result is summarized in Table 7.

Based on Table 7, the following can be deduced of why the cases apply the tools and approaches of mass customization and how it affects the performance:

- Uses digitalization and virtual software tools as it provides insight about the construction as basis for decision-making and cooperation between entities of the value chain for efficiency and productivity reasons
- Process optimization by improving processes to increase the quality and performance, and thereby to increase the productivity
- Usage of flexible manufacturing equipment to stay competitive and efficient, and thereby to increase the productivity
- Uses prefabricated elements and module-based construction due to efficiency and quality reasons, which affect the productivity

Consequently, the prefabrication has potentials in the construction industry due to efficiency reasons, demonstrating a 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 (Hvam *et al.*, 2013; Linner & Bock, 2012; Noguchi, 2013; Paoletti, 2013; Tam *et al.*, 2015).

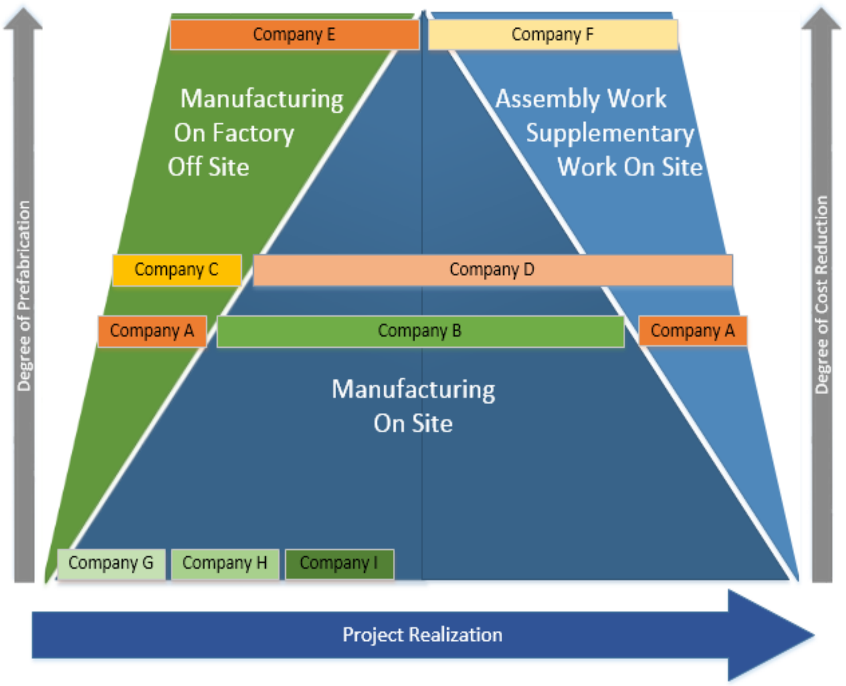

Figure 6: Degree of prefabrication

Figure 6 show that a construction project consists of work done at the factory, work done at the construction site and assembly work of prefabricated elements carried out on-site. The total work is depending of the degree of the prefabrication since the manufacturing work done off-site and the assembly work done on-site it is smaller and faster, which is substantiated from the literature (Chen & Samarasinghe, 2020). A greater degree of prefabrication seems attractive and took place for some companies during the last decades, which seems more achievable for some sectors of the construction industry than others. However, some factors to consider to be successful might be 1) traditions in the society, 2) transparent customer integration, 3) impact of modularity, 4) production technology, 5) supply chain resources, and 6) digital involvement in project phases.

Planning to Develop the Three Capabilities of MC

Table 8 shows the result of the multi case study (see appendix B) divided into the nine variables describing to which extent the 11 cases currently plan to develop the nine tools and approaches of mass customization. The higher the value is (the greener) the more utilization of the tools and approaches of mass customization. According to Table 5 the Table 8 has generally changed to higher values (become greener), meaning that all the cases plan to develop the nine tools and approaches of mass customization.

Table 8: Heat diagram of how the cases plan to develop the 'tools and approaches'

Capability	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	Total
CN	**12**	**12**	**8**	**9**	**11**	**11**	**11**	**6**	**11**	**8**	**12**	**109**
AM	4	4	4	4	4	4	4	3	4	3	4	**41**
EC	4	4	2	2	3	3	3	1	3	2	4	**31**
FT, TEL	4	4	3	3	4	4	4	2	4	4	4	**37**
RPD	**12**	**10**	**11**	**11**	**10**	**9**	**12**	**10**	**12**	**9**	**10**	**114**
AHC	4	4	4	4	4	4	4	3	4	4	4	**43**
FA	4	3	4	4	4	3	4	4	4	4	4	**40**
PM	4	3	3	3	2	2	4	3	4	1	2	**31**
SSD	**12**	**11**	**6**	**11**	**11**	**9**	**11**	**7**	**11**	**8**	**12**	**109**
CEI	4	4	4	4	4	3	4	3	4	3	4	**41**
ITK	4	3	1	3	3	3	3	2	3	2	4	**31**
VCT	4	4	1	4	4	3	4	2	4	3	4	**37**
Total	**36**	**33**	**25**	**31**	**31**	**29**	**34**	**23**	**34**	**25**	**34**	**332**

Table 9 (left) illustrate the gap between how the cases apply and plan to develop the three fundamental capabilities of mass customization. In reality it demonstrates their intended investment initiatives, and the higher the number is, the more initiatives they plan to do. Table 9 (right) show the characteristic relative to how the cases plan to develop mass customization combined with the gap to how they apply mass customization. The top five cases are the same as shown in Table 6, but the order has slightly changed compared to Table 6. However, the top five cases are scoring highest on the characteristics (size, automation, maturity, strategy).

Figure 7 shows the distribution of how the tools and approaches are planned to be developed, where 'adaptive human capital' is the highest rated just as it is currently applied, see Figure 3.

Figure 8 show the cases are ranked according to how the cases apply mass customization and illustrate their planned initiatives (MC-gap), so the higher the gap is, the more improvement initiatives, they plan to put on the agenda.

Table 9: Cases ranked by gap between apply and plan to develop mass customization (left) and cases ranked by how they plan to develop mass customization (right)

Company	CN	RPD	SSD	Total
C04	4	1	4	**9**
C08	2	4	3	**9**
C11	4	3	2	**8**
C05	4	2	2	**8**
C09	4	1	2	**7**
C10	3	1	3	**7**
C06	4	2	2	**7**
C07	3	2	2	**6**
C03	4	1	1	**6**
C02	2	1	2	**5**
C01	2	2	0	**4**
Total	**35**	**20**	**22**	**76**

Company	Tier	Size	Automation	Maturity	Strategy	MC-plan	MC-gap
C01	1,20	3	3	3	3	36	4
C11	2,30	3	3	3	3	34	8
C07	2,00	2	2	3	3	34	6
C09	1,20	3	3	3	3	34	7
C02	1,00	3	3	3	3	33	5
C04	1,20	2	2	2	2	31	9
C05	2,00	2	2	2	2	31	8
C06	2,00	1	1	2	2	29	7
C03	1,00	3	2	1	1	25	6
C10	1,20	2	2	2	2	25	7
C08	2,00	2	1	2	2	23	9
Total	**17,10**	**26**	**24**	**26**	**26**	**332**	**76**

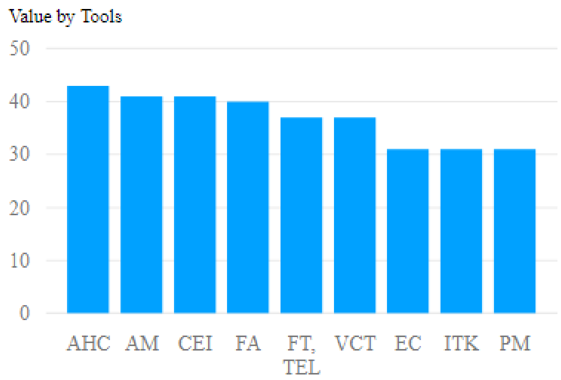

Figure 7: The ranked application of the Nine 'Tools and approaches' of mass customization

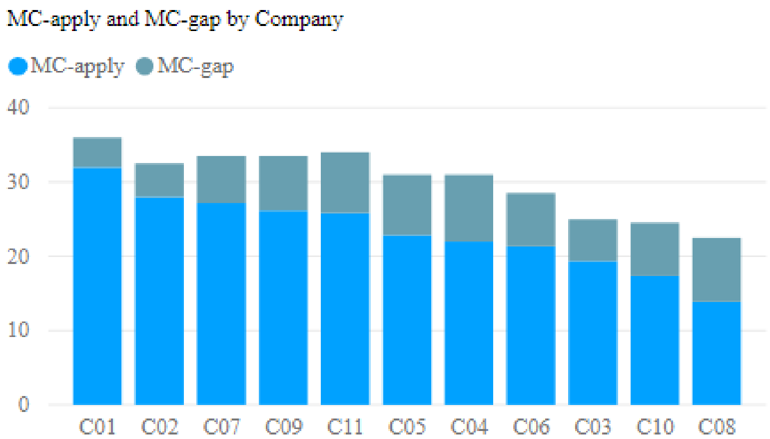

Figure 8: How companies apply and plan to develop MC

Based on the Tables and Figures the following can be deduced to clarify how the cases plan to develop the tools and approaches of mass customization:

- Adaptive human capital is the highest rated of the tools and approaches. The reason is the ability to deal with ambiguous task as expected to increase in the future, and the use of new technology relative to automation (processes/equipment) to strengthen the competitiveness.
- Assortment matching is the second highest rated of the tools and approaches. The focus is on increasing the usage of engineering software e.g. 3-dimension modelling, digitalization, Virtual Design and Construction and Virtual Reality for capturing and visualizing customer needs as enablers for collaboration, communication, and managing interlinked processes across entities of the value chain in a more efficient way. Assortment matching increases the possibilities of involving customers in the decision-making process providing insight about the construction and reconciliation of requirements for customers to take more responsibility.
- Customer experience intelligence is the third highest rated of the tools and approaches, and the reason is the increasing use of engineering software and digitalization possibilities for storing and analyzing purposes as enablers for decision making relative to the solution space development. The aim is to efficiently utilize new technology and software aiming at serving customers uniquely
- All cases without exceptions aims at increasing all tools and approaches, which strengthen the three fundamental capabilities and thereby the usage of mass customization. The focus is on capturing individual requirements and transforming them into system products or services that are successfully adopted by the customers.
- There is a significant span of how the cases plan to develop the 9 tools and approaches, and thereby the three fundamental capabilities of mass customization. The span seems not to be due to the position in the value chain, but related to the type of job carried out, the size of the case, the level of automation accessibility, the maturity of the case, the chosen strategy, and the applicability where it makes sense (efficiency, productivity).
- There is a gap between how the cases apply and plan to develop the tools and approaches, and the gap states that the cases have realized the necessity of improving the tools and approaches in terms of investments and change management initiatives.
- The top five cases are the same as shown in Table 6, but the order has slightly changed. All of the top five cases are as well scoring highest on the characteristics (size, level of automation, maturity, strategy).

Definition of Mass Customization in Construction Industry

Based on this research it can be argued that mass customization as a strategy is perceived useful even without knowing it. The tools and approaches to be developed to increase the level of mass customization have for the 11 cases shown a significant gap of how the cases apply them and how they plan to develop them, which indicate a certain awareness of the tools and approaches. However, the mass customization concept is not specific on the agenda for the 11 cases with the tittle ‘mass customization’ even though this research has shown that the concept is feasible. The definition or a common understanding of the concept relative to the construction industry is lacking, therefore a new definition of the concept may be appropriate for an academic and industrial acceptance.

As argued in section *State of the Art* a proper definition of mass customization suitable for the construction industry seems not yet to be present. 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, and the construction industry consists 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. Therefore, the following key findings from this research would be useful for redefining or refining the concept relative to the construction industry:

- The focus on 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
- The focus on efficiently utilizing new technology in terms of software and flexible manufacturing equipment aiming at serving customers uniquely
- The focus on involving customers in the processes needed for decision-making providing insight about the construction and reconciliation of requirements
- The focus on capturing individual requirements, and transforming them into system products or services that are successfully adopted by the customers

Based on these statements deduced from this research the following definition of mass customization aims at providing high customization at low cost for the construction industry:

Managing interlinked processes across entities of the value chain that are necessary for efficiently serving the customers uniquely, and 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 successfully will be adopted by the customers.

CONCLUSION

This research concluded that there is not much literature dealing with the utilization of mass customization as a strategy in terms of increasing productivity of the construction industry.

As most literature concerning mass customization in the construction industry deals with a single case study, this research is based on 11 cases to gain more quantitative data of the utilization of the three capabilities of mass customization to gain more insight. This research investigated the application of mass customization as a strategy in the construction industry by observing and analyzing 11 Danish construction cases positioned at different tier in the value chain.

This research answers three research questions: 1) *How do the companies currently apply the 'tools and approaches'?* 2) *How does the application of the 'tools and approaches' affect the performance?* and 3) *How do the companies plan to develop the 'tools and approaches'?*

The outset was a clarification of the applied project phases and critical success factors to gain background information about the 11 cases. Obviously, the cases define their phases differently, but they plan with the same phases and the same main operation activities as part of a typical construction project, meaning that they can fit into e.g. 1) plan, 2) design, 3) construct, 4) handover, 5) maintenance, and 6) demolition (Jensen *et al*., 2018). The common critical success factors address primarily the collaboration between entities of the value chain focusing on "Good and effective communication between parties" and "Good collaboration tools and techniques", which stresses the awareness of developing the tools and approaches of mass customization as disseminated in this research to become a "better" mass customizer.

Hereafter followed a definition of relevant characteristics to identify possible correlations to the result of the multi-case study. The characteristics are 1) the position in the value chain, 2) company size, 3) the industry level of automation, 4) the level of maturity in terms of standardized and controlled business processes 5) the strategy level of software/technology in terms of how software/technology have been put on the agenda as improvement initiatives.

The interview of the 11 cases consist of three open questions related to the three fundamental capabilities of mass customization and 28 specific questions related to the Nine tools and approaches of mass customization. These 28 specific questions turned into 18 variables, whereas Nine covers how the cases *apply* the tools and approaches and Nine covers how the cases *plan to* develop the tools and approaches.

The effect of applying the tools and approaches is derived from the corresponding text from the three open questions and the notes to the 28 specific questions, which is summarized as:

- Digitalization and software tools provide insight and knowledge about the specific construction as basis for decision-making and cooperation between entities in the value chain
- Optimizing processes aiming at improving the quality and performance
- Using flexible manufacturing equipment, prefabricated elements, and module-based construction approach increases the competitiveness

Digitalization and software tools contribute to transparency across the value chain and is considered important as prerequisites for efficient collaboration between the entities. Optimizing processes and utilizing prefabricated 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 also is substantiated by the literature (Hvam *et al*., 2013; Linner & Bock, 2012; Noguchi, 2013; Paoletti, 2013; Tam *et al*., 2015).

The result of the case study:

- 'Assortment matching' is in the top-3 of the tools and approaches due to the collaboration, communication benefits of using engineering software like 3D modelling, digitalization, VDC, and VR for capturing and visualizing customer needs.
- 'Customer experience intelligence' is in the top-3 of the three tools and approaches, which increase the use of engineering software and digitalization possibilities for storing, analyzing and decision making.
- 'Adaptive human capital' is in the top-3 of the three tools and approaches to have people capable of dealing with ambiguous tasks, and using new technology for automation of processes and equipment to strengthen the competitiveness

All 11 cases aim at increasing all the 'tools and approaches', which strengthen the three fundamental capabilities and the utilization of mass customization within the construction industry. The correlation indicates that the higher score on the characteristics, the higher score in *applying* and *planning to* develop the mass customization.

The gap between current state and future state illustrate the ambition of the cases in terms of investments and change management initiatives. The significant span of how cases plan to invest in the Nine tools and approaches seems not to be due to the position in the value chain, but related to the characteristics of the cases 1) the size of the case, 2) the level of automation, 3) the maturity of the case, and 4) the chosen strategy.

Even though this multi case study is limited to 11 cases it can be scaled up by using more cases from other sectors and other countries to increase the validity. However, this research indicates that the mass customization concept is applicable within the construction industry, even though the title 'mass customization' is not directly on the agenda. However, a definition and common understanding of the concept relative to the construction industry is lacking, therefore a new definition of the concept is argued and suggested in this research, which seem appropriate for an academic and industrial acceptance of the concept to be applied of the construction industry: *Managing interlinked processes across entities of the value chain that are necessary for efficiently serving the customers uniquely, and 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 successfully will be adopted by the customers.*

This definition is intended to make mass customization more visible and accessible as a coveted strategy useful for improvement of the construction industry and to ensure an academic and industrial acceptance of the concept. However, the definition is fully in line and supported by the three fundamental capabilities of mass customization

Mass customization as a strategy have great possibilities to improve the collaboration between the entities of the value chain and to raise productivity by evolving the various 'tools and approaches' associated to the three fundamental capabilities of mass customization. Software tools, standards, and technology at hand to be used by and between the entities across the value chain will encourage a successful implementation of mass customization as a strategy to harvesting the benefits related to the 'mass customization' theory.

This paper is based on 11 cases from same and different sectors of the construction industry, therefore, the findings may not necessary be representative for all companies and sectors within construction industry. The diversity is acknowledged, meaning that companies and sectors are at different maturity level and are impacted by different challenges, which means that the improvements initiatives must be adapted individually.

However, further research is required before making a dedicated framework or roadmap to be used in a specific sector of the construction industry. E.g. a) 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; b) choosing several companies within a specific sector to be subject to a case study with an outset in the established metrics for measuring as-is, and here-after implement the suggested to-be initiatives and measure the effect of the implemented initiatives.

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APPENDIX A

This Appendix contains the questions created for measuring the 'tools and approaches' related to the three fundamental capabilities of mass customization: Choice Navigation, Robust Process Design, and Solution Space Design.

Choice Navigation (CN)

1) Assortment Matching (AM):

CN-1: To which extent does your company use software tools describing your solution space (4: High, 3: Moderate, 2: Low, 1: None)

CN-2: To which extent (seeing from a customer perspective) does it make sense to use software tools describing your solution space (4: High, 3: Moderate, 2: Low, 1: None)

CN-3: To which extent does your company use configuration software tools in the 'order intake process' that is based on characteristics from existing solution space? (4: High, 3: Moderate, 2: Low, 1: None)

CN-4: To which extent is the 'order intake process' characterized as being ETO without consideration to 'existing solution space' or previous projects? (4: High, 3: Moderate, 2: Low, 1: None)

CN-5: To which extent does your company consider investing in software tools for the 'order intake process that uses characteristics from existing solution space? (4: High, 3: Moderate, 2: Low, 1: None)

2) Fast-cycle, trial-and-error learning (TEL):

CN-6: To which extent does your company use software tools for customers to interactively test and experimenting of a model to match between available solutions with own requirements/needs? (4: High, 3: Moderate, 2: Low, 1: None)

CN-7: To which extent would such software tools be beneficial for customers to interactively testing and experimenting with a model to match between available solutions with own requirements/needs? (4: High, 3: Moderate, 2: Low, 1: None)

CN-8: To which extent does it make sense for your company to invest in such software tools for customers to interactively testing and experimenting with a model to match between available solutions with own requirements/needs? (4: High, 3: Moderate, 2: Low, 1: None)

3) Embedded Configuration (EC):

CN-9: To which extent does your company offer reconfigurable products that "understand" how to adapt to the customer by re-configuring themselves (4: High, 3: Moderate, 2: Low, 1: None)

CN-10: To which extent does your company offer reconfigurable products that can adapt to the customers' requirements by re-configuring (4: High, 3: Moderate, 2: Low, 1: None)

CN-11: To which extent does it make sense for your company to consider developing such reconfigurable products that can adapt to the customer by re-configuring manually or automatically (4: High, 3: Moderate, 2: Low, 1: None)

Solution Space Development (SSD)

4) Innovation Tool Kits (ITK):

SSD-1: To which extent does your company provide your customers (existing or potential) with software tools to translate their preferences or unsatisfied needs into unique product/service variants or proposals for development ideas (4: High, 3: Moderate, 2: Low, 1: None)

SSD-2: To which extent does your company provide your customers (existing or potential) with the possibility (in a manual but systematic way e.g. in a concept lab) to translate their preferences or unsatisfied needs into unique product/service variants or proposals for development ideas (4: High, 3: Moderate, 2: Low, 1: None)

SSD-3: To which extent does it make sense for your company to invest in tools (manually, software, or concept labs) for collecting your customers (existing or potential) preferences or unsatisfied needs of unique product/service variants or proposals for development ideas (4: High, 3: Moderate, 2: Low, 1: None)

5) Virtual Concept Testing (VCT):

SSD-4: To which extent does your company use software tools for virtual testing of concepts, design ideas, product variants without making prototypes in a way so customers can evaluate/review them (4: High, 3: Moderate, 2: Low, 1: None)

SSD-5: To which extent does it make sense for your company to invest in software tools for virtual testing of concepts, design ideas, product variants without making prototypes in a way so customers can evaluate/review them (4: High, 3: Moderate, 2: Low, 1: None)

6) Customer Experience Intelligence (CEI):

SSD-6: To which extent does your company have software solutions for capturing 'designs proposals' of ordered products for analyze purposes as input for adjustment of future solution space (4: High, 3: Moderate, 2: Low, 1: None)

SSD-7: To which extent does your company have software solutions for capturing 'designs proposals' of unordered products for analyze purposes as input for adjustment of future solution space (4: High, 3: Moderate, 2: Low, 1: None)

SSD-8: To which extent does it make sense (competitiveness) for your company to invest (or expand) in such software solutions for capturing 'designs proposals' of ordered and unordered products for analyze purposes as input for adjustment of future solution space (4: High, 3: Moderate, 2: Low, 1: None)

Robust Process Design (RPD):

7) Flexible Automation (FA):

RPD-1: To which extent does your company have flexible and automated processes necessary for making design or requirement specifications, or for ensuring mutual clearance of interests (4: High, 3: Moderate, 2: Low, 1: None)

RPD-2: To which extent does it make sense for your company to invest in flexible and automated software tools supporting processes necessary for making design or requirement specifications, or for ensuring mutual clearance of interests (4: High, 3: Moderate, 2: Low, 1: None)

RPD-3: To which extent does your company have flexible automated equipment for fulfilling manufacturing processes taking place on-site (4: High, 3: Moderate, 2: Low, 1: None)

RPD-4: To which extent does your company have flexible automated equipment for fulfilling manufacturing processes taking place off-site (4: High, 3: Moderate, 2: Low, 1: None)

RPD-5: To which extent does it make sense for your company to invest in flexible automated equipment for fulfilling manufacturing processes taking place on-site or off-site (4: High, 3: Moderate, 2: Low, 1: None)

8) Process Modularity (PM):

RPD-6: To which extent does your company have segmenting existing organizational and value-chain resources into modules, which can be reused or recombined to fulfill differentiated customers' needs (4: High, 3: Moderate, 2: Low, 1: None)

RPD-7: To which extent does it make sense to use (or improving) segmenting existing organizational and value-chain resources into modules, which can be reused or recombined to fulfill differentiated customers' needs (4: High, 3: Moderate, 2: Low, 1: None)

9) Adaptive Human Capital (AHC):

RPD-8: To which extent does your company have managers and employees to deal with new and ambiguous tasks (as the machines, ICT (AI) are not **yet** capable of doing) (4: High, 3: Moderate, 2: Low, 1: None)

RPD-9: To which extent does your company want to invest in developing managers and employees to deal with new and ambiguous tasks (as the machines, ICT (AI) are not **yet** capable of doing) (4: High, 3: Moderate, 2: Low, 1: None)

APPENDIX B

This appendix consists of three tables representing the result from the 11 cases. Table 10 contains data from the eleven questions (detailed described appendix A) created relative to investigate the 'tools and approaches' of 'choice navigation' capability (CN).

Table 10: How 11 cases apply and plan to develop CN

			Assortment matching				Fast-cycle, trial-and-error learning			Embedded configuration		
Case	**Tier**	**CN 1**	**CN 2**	**CN 3**	**CN 4**	**CN 5**	**CN 6**	**CN 7**	**CN 8**	**CN 9**	**CN 10**	**CN 11**
1	1,2	4	4	4	4	4	4	4	4	2	2	4
2	1	3	4	3	4	4	4	4	4	3	3	4
3	1	3	3	2	2	4	1	2	3	1	1	2
4	1,2	2	4	2	4	4	1	2	4	1	1	2
5	2	3	4	3	3	4	2	3	4	1	2	3
6	2	4	4	2	3	4	2	3	4	1	3	3
7	2	4	4	3	3	4	3	3	4	1	2	3
8	2	1	2	2	4	4	1	2	2	1	1	1
9	1,2	3	4	3	2	4	2	3	4	1	2	3
10	1,2	2	2	1	4	3	2	3	4	1	1	2
11	2,3	3	4	4	2	4	3	4	4	2	2	4

Table 11 contains data from the eight questions (detailed described appendix A) created relative to investigate the 'tools and approaches' of 'solution space development' capability (SSD).

Table 11: How 11 cases apply and plan to develop SSD

			Innovation tool kits		Virtual concept testing	Customer experience intelligence		
Case	**Tier**	**SSD 1**	**SSD 2**	**SSD 3**	**SSD 4**	**SSD 5**	**SSD 6**	**SSD 7**	**SSD 8**
1	1,2	4	4	4	4	4	4	4	4
2	1	2	2	3	3	4	4	4	4
3	1	1	1	1	1	1	3	3	4
4	1,2	2	2	3	2	4	3	3	4
5	2	2	2	3	3	4	4	4	4
6	2	2	2	3	2	3	3	3	3
7	2	2	2	3	3	4	4	4	4
8	2	1	1	2	1	2	2	3	3
9	1,2	2	2	3	3	4	4	4	4
10	1,2	1	1	2	2	3	2	2	3
11	2,3	2	3	4	4	4	4	4	4

Table 12 contains data from the nine questions (detailed described appendix A) created relative to investigate the 'tools and approaches' of 'robust process design' capability (RPD).

Table 12: How 11 cases apply and plan to develop RPD

		Flexible automation					Process modularity		Adaptive human capital	
Case	**Tier**	**RPD 1**	**RPD 2**	**RPD 3**	**RPD 4**	**RPD 5**	**RPD 6**	**RPD 7**	**RPD 8**	**RPD 9**
1	1,2	3	4	3	3	4	3	4	4	4
2	1	3	4	1	1	1	3	3	4	4
3	1	2	4	3	4	4	3	3	4	4
4	1,2	3	4	3	4	4	3	3	4	4
5	2	3	4	2	2	3	2	2	3	4
6	2	3	3	2	2	3	2	2	3	4
7	2	4	4	3	3	4	3	4	4	4
8	2	2	4	2	2	3	1	3	2	3
9	1,2	3	4	3	3	4	4	4	4	4
10	1,2	2	4	2	2	3	1	1	4	4
11	2,3	3	4	1	3	4	2	2	3	4