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Jensen, Kim Nørgaard; Nielsen, Kjeld; Brunø, Thomas Ditlev; Larsen, Jesper Kranker

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Kim Noergaard Jensen, Department of Materials and Production, Aalborg University, Denmark
Kjeld Nielson, Department of Materials and Production, Aalborg University, Denmark
Thomas Ditley Brunoe, Department of Materials and Production, Aalborg University, Denmark
Jesper Kranker Larsen, Department of Materials and Production, Aalborg University, Denmark
knj@mp.aau.dk

ABSTRACT

Research demonstrate that productivity in the Danish building and construction industry has only doubled over the last fifty years, whereas the manufacturing industry has increased six times. Utilisation of mass customization as a strategy has achieved results in the manufacturing industry in terms of increasing productivity and competitiveness, so the strategy might have potentials in the building and construction industry as well. However, mass customization as a strategy for improving the productivity of the building and construction industry has not been explored as much as in the manufacturing industry. The purpose of this paper is to analyse the assumptions and possibilities for applying the principles of mass customisation related to establishing an adaptable integrated system of entities in the value chain of the building and construction industry. The outset of the paper is a literature review concerning the utilisation of mass customization as a strategy in terms of increasing productivity within the building and construction industry. An essential part of the paper is a case study of 11 building and construction companies and an analysis of the conditions for cooperation between the entities in the value chain of the building and construction industry. The paper induces to which extent it makes sense to talk about utilisation of mass customisation by applying the Industry Foundation Classes (IFC) and standardisation initiatives of the construction industry provided by buildingSMART, and at the same time harvesting the benefits of the mass customization.

KEYWORDS: buildingSMART. Construction industry, Industry Foundation Classes (IFC), Mass customisation, Productivity.

INTRODUCTION

Increasing opportunities and challenges, related to globalisation, affect companies concerning the manner they handle increasing competition and rapid changes in the inhomogeneous market-place (Salvador, Forza & Rungtusanatham, 2002). The customer demands a higher degree of customisation, and companies introducing new product faster than usual (Chryssochoidis & Wong, 2000). The varying product demand and increasing pressure for cost efficiency are conditions for manufacturing companies in order to stay competitive (Salvador *et al*., 2002).

Productivity Gap

The building and construction industry employ approx. 25% of the private workforce in Denmark (Boligministeriet & Force, 2000). The construction industry is currently facing a number of challenges including, a heavy burden on costs that makes companies continuously search for initiatives to reduce production costs to meet competition (Chryssochoidis & Wong, 2000; Piroozfar & Piller, 2013; Salvador *et al*., 2002). The focus is on lean and quality, digitization, Building Information Modelling (BIM), standardisation through Industry Foundation Classes (IFC) (Lisstrand & Lundin, 2017; Mia *et al.*, 2005). Increasing demand for customized products, reduction of energy consumption, and enhancing the cost efficiency, are all set of conflicting objectives impacting the performance of the building and construction industry (Piroozfar & Piller, 2013), thus the global crises drive the building and construction industry to seek new orientation and strategies (Piroozfar & Piller, 2013). The productivity in the Danish construction industry has only doubled since 1966, which, compared to other industry sectors in Denmark are significantly less (dst.dk, 2013) and the same trend for the last twenty years applies to the countries of Scandinavia and Europe (da Silveira *et al.*, 2018) (Figure 1). This will suggest that the productivity gap is industry specific.

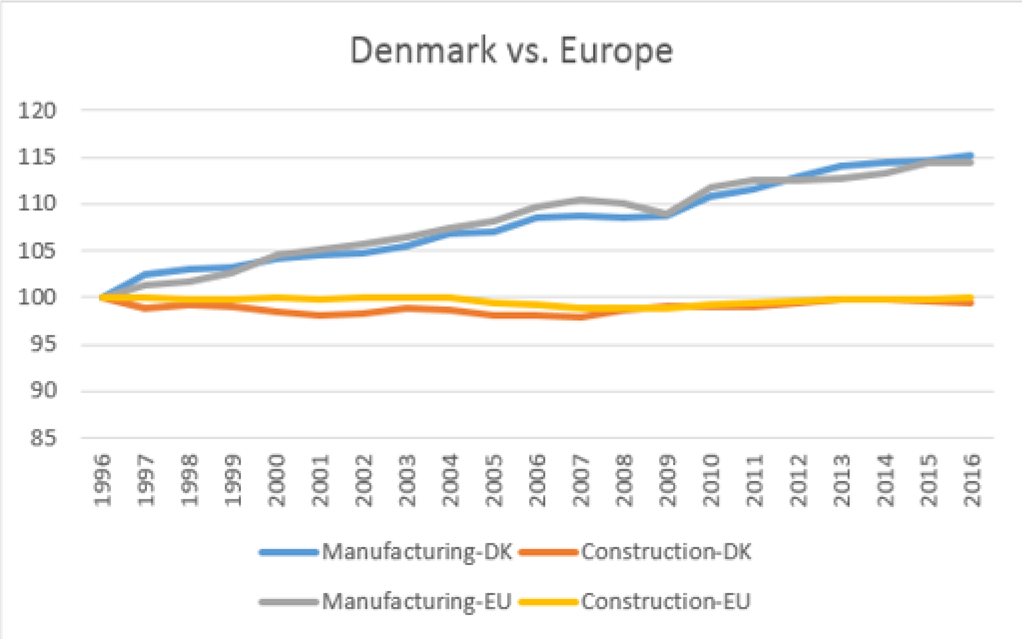

Figure 1. Productivity of Denmark vs. Europe (source: OECD Stat)

The manufacturing industry have to some extent adopted the mass customisation philosophy to meet the higher demand of product variety at a cost near mass production (Aigbedo, 2009; Edwards *et al*., 2009). Increasing industrialisation has achieved results in the manufacturing industry in terms of increasing productivity by utilising new technologies for production, streamlining and constant development of production processes and other correlated support processes (Fagerberg, 2000). Productivity is measured as output per working hour performed for the entire economy (dst.dk, 2013),

One of the reasons that the building and construction industry has less degree of industrialisation is that this industry, is very different as products and projects often are characterised as one-of-a-kind deliveries, and therefore it may seem difficult or challenging to streamline and optimize processes like ”assembly line production” (Bohnstedt, 2014). Nevertheless, it requires 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.

Over the past decades, industrial production has gone through a process in which more and more companies are offering customised products (Walcher & Piller, 2011) at a price near mass production (Batchelor, 1994) under the production strategy called mass customisation (Pine, 1993). Mass customisation is a strategy that focuses on offering customised products at low cost, and exploiting of principles like standardisation of modules (Salvador, De Holan, & Piller, 2009), configuration and changeable manufacturing (Brunoe, Bossen, & Nielsen, 2015; Andersen *et al.*, 2017; Wiendahl *et al*., 2007), and using a variety of tools to compose and produce customised products for commercialising at similar conditions as mass produced products (Koren, 2010a; Pine, 1999).

Therefore, the objective of this research lies in investigating the utilisation of mass customisation as a strategy in terms of increasing the productivity within the building and construction industry, and investing the conditions for cooperation between the entities in the building and construction industry value chain. The goal is to cast light on the relationship between mass customisation as a strategy and available standards and tools for cooperation in the building and construction industry aimed at improving the productivity.

The remaining part of the paper is organised as follows. Firstly, relevant literature is reviewed and the gaps in the literature are highlighted in order to refine some research questions. Thereafter an investigation of the 'tools and approaches' linked to the three capabilities of mass customisation, and finally a clarification of available standards supporting the cooperation between parties of the value chain is suggested.

LITERATURE REVIEW

Mass Customisation Capabilities

Recent research shows that companies that utilise mass customisation must have three fundamental capabilities (Salvador, De Holan, & Piller, 2009):

1. Solution Space Development - the ability to identify how customer requirements are different and to develop products that can effectively adapt to these individual requirements.
2. Choice Navigation - the ability to guide the customer to select or to configure the product that matches these requirements.
3. Robust Process Design - the ability to efficiently reuse and recombine existing organisational and value-chain resources to fulfill customer's needs.

According to (Salvador *et al.*, 2009) various 'tools and approaches' are available to help companies to develop the three fundamental capabilities of mass customisation.

Tools and approaches to develop Solution Space Development

- Innovation tool kits - Software enabling customers to translate preferences or unsatisfied needs into unique product/service variants or development ideas (concept lab).
- Virtual concept testing - Software for virtual testing of concepts, design ideas, product variants without making a prototype in a way so customers can evaluate/review them;
- Customer experience intelligence - Software for capturing 'designs proposals' of ordered and unordered products for analysis purposes as input for adjustment of future solution space.

Tools and approaches to develop Choice Navigation

- Assortment matching - SW building configurations based on 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 - SW to be used interactively for testing and experimenting of a model to see the match between available solutions with own requirements/needs.
- Embedded configuration - Reconfigurable products that "understand" how to adapt to the customer (reconfigurable solutions with extended utilisation and functionality)

Tools and approaches to develop Robust Process Design

- Flexible automation - Automation that can handle the customisation 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 - Segmenting existing organizational and value-chain resources into modules to be reused/recombined to fulfill differentiated customers' needs.
- Adaptive human capital - Developing managers and employees to deal with new and ambiguous tasks (that machines, ICT or AI are not yet capable of doing)

Enablers of Mass Customisation

Mass customisation enablers are the methodologies and the technologies that support the development of the following market-related factors and organisation-based factors, which have direct implication (Fogliatto, da Silveira, & Borenstein, 2012; B. J. Pine, 1999; Silveira, Borenstein, & Fogliatto, 2001):

- Customer demand for variety and customisation must exist. The increasing customer demand for innovative and customized products is fundamental and depending on the sacrifice that customers make for customized products and the company's ability to produce and deliver individualized products at an acceptable time and cost.
- Market conditions must be appropriate. A company's ability to transform the potential of mass customisation into actual competitive advantage depends on the timing to develop a mass customizing system, which can provide competitive advantages as the company may start being seen as innovative and customer-driven.
- The value chain must be ready, as mass customisation requires its supply chains entities (manufactures, suppliers, distributors, retailers) willingness and readiness to attend to the demands of products, materials, and components efficiently.
- The technology must be available. Mass customisation depends on the ability to integrate the information communication technology (ICT) across the value chain, and the process flexibility to be able to communicate and produce goods, at the cost and quality required.
- Products should be customisable, meaning it should be possible to assemble individual units into different products.
- 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.

Mass Customisation in the Construction Industry

The building and construction industry's traditional demand for customisation e.g. distinctive architecture, function, quality, timeframe, environment, seems difficult to reconcile with traditional standardisation, mass production, and modularisation etc. as products/projects often are one-of-a-kind (Dean, Tu, & Xue, 2009). Mass customisation focus on the customers requirement of products and services, and delivering affordable products and services with enough variety that ensures nearly everyone finds exactly what they want (Piroozfar & Piller, 2013). The core of mass customisation is flexibility and responsiveness, handling the challenges coming from the rapidly changing environment, people, processes, units and technology (I. Pine, Joseph, & Victor, 1993).

A literature search in the Web of Science (Thomson Reuters) revealed only 15 relevant papers addressing a combination of "Mass customisation" AND "building industr*" OR "construction industr*". By searching for mass customisation literature in the categories of architecture, civil engineering, and construction building industry approximately 25 relevant papers were found. Additional literature concerning modular building and pre-fabrication exists, which indeed are related to mass customisation, however not explicitly stating the concept in the articles (Lawson, Ogden, & Bergin, 2011; Otreba & Menzel, 2012). Mass customisation as a strategy of improving the productivity of the building and construction industry has not been widely explored in the research area, therefore, only limited theoretical background for the implementation is currently present.

Mass customisation is a competitive strategy focusing on providing individually designed products and services to customers through process flexibility and integration, and to optimize the unit cost/customer value ratio (Piroozfar & Piller, 2013) or producing goods and services to meet individual customers' needs with near mass production efficiency (Tseng & Jiao, 2001).

Customers do not want more choices, they want exactly what they want, when they want it, and where they want it (Gilmore & Pine, 2000; I. Pine et al., 1993). Technology makes it possible for companies to give the customers what they want, and application of IT tools allow a high degree of customisation where the end customer can choose from millions of product variants and chose the flavour that matches unique needs for a low price (cost minimisation) (Dean et al., 2009; Piroozfar & Piller, 2013). Automated business processes, product configurators, and product design are enablers of mass customisation and principles widely used with great success in e.g. automotive and computer industry (B. J. Pine, 1993; Salvador et al., 2009).

Making mass customisation work is a linkage system with four key attributes (I. Pine et al., 1993): instantaneous, costless, seamless, and frictionless. Instantaneous, link processes in collaboration with the customer trying to record customers desires and translating them into design specification for making and delivering the product or services. 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. Seamless, create dynamic organisational network dealing with customer interaction focusing on coordinating the creation of the customized product or service. Frictionless, create instant teams for the customer in the dynamic network operating frictionless where information and communications technologies are important to automate tasks, where it makes sense.

The applied principles behind mass customisation enables industrial production of customised products, and for the building and construction industry, a great potential may result in higher productivity in applying these principles, as they face the challenge of producing products with high variety and often one-of-a-kind production (Dean *et al.*, 2009). Some segments of the industry supplying the building and construction industry have already implemented parts of mass customisation e.g. manufacturers of windows, doors, kitchen, housing, and bath products offering customised products manufactured in a highly automated and flexible production (Benros & Duarte, 2009; Dean, Tu, & Xue, 2008). A research project (Jensen, Nielsen, & Brunoe, 2015) has as one of the objectives to increase knowledge and utilisation of mass customisation in the Danish building and construction industry to make companies capable of implementing the principles of mass customisation. This research project indicates a trend towards more customized products and that the participant companies all are planning to be more mass customisation oriented (volume, variants) (Jensen *et al.*, 2015).

Research Questions

The overall purpose of this paper is to analyse the assumptions and possibilities of applying the principles of mass customisation as a strategy for establishing an adaptable integrated system of members in the value chain of the building and construction industry in terms of increasing productivity. This paper also investigates how to utilise and benefit from implementing mass customisation as a strategy for entities individually and interconnected as cooperating entities in the value chain. Therefore, the main research questions of this paper are:

RQ1: How can mass customisation as a strategy for entities individually and interconnected within the value chain contribute to the building and construction industry in terms of increasing the productivity?

RQ2: Which standards are present for supporting the implementation of mass customisation as a strategy individually and integrated across the value chain of the building and construction industry?

RESEARCH METHODS

Research question 1 will be addressed by clarifying the entities of the value chain and by making a model of the value chain. Hereafter follows an investigating of the entities in the value chain individually and as interconnected working towards meeting the customer requirements, mostly to gain insight of the interconnectedness and importance of impacting the project performance, and thereby the productivity. The outset will be taken from the literature relative to the three capabilities of mass customisation; Solution Space Development, Choice Navigation, and Robust Process Design (Fogliatto *et al.*, 2012; Silveira , 2001) and the enablers of mass customisation such as 'tools and approaches' to be developed (Salvador *et al.*, 2009). A case study of 11 companies in the building and construction industry are included in order to analyse how they apply and plan to develop the 'tools and approaches' of the three capabilities of mass customisation.

Research question 2 is addressed by investigating available standards as foundation for cooperation efficiently between entities in the value chain by applying the Industry Foundation

Classes (IFC) as a standardisation initiative within the building and construction industry. Primary to understand the extent and quality hereof seeing in the light of utilising the ICT and digitalization advantages to cope with the challenges and delays factors that the building and construction industry is burdened with.

RESULTS

Mass Customisation as a Strategy for Increasing the Productivity

Entities involved in Architecture, Engineering and Construction (AEC) projects consist of architects, engineers, consultants and advisors; construction company and external parties working on site; suppliers of materials delivered to the site, tools and machinery applied on site; manufactures of prefabricated elements to be delivered on site; and the construction owner. A truly sustainable approach to any building and construction projects, can only be achieved where the views and needs of the target group(s) are recognized and incorporated in the de-sign process (Craig, Laing & Edge, 2000). In order to remain competitive, all manufacturing companies within the value chain of the building and construction industry (Figure 2) must respond to global challenges and efficiently offer a wide range of products that fits different customer needs and continuously includes new product technologies and product models (Hu *et al.*, 2011; Koren, 2010b).

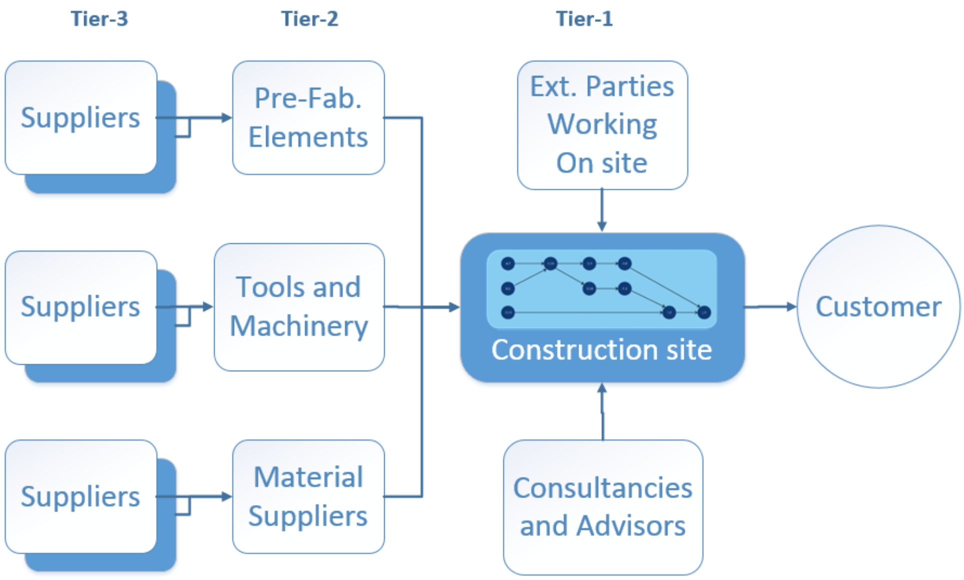

Figure 2. Parties of the Building and Construction Industry

Mass customisation is a widely adopted strategy for this, as it is a value-chain based concept (Silveira *et al.*, 2001), where individually configured products are delivered at a cost near mass production (Gilmore & Pine, 2000; Pine *et al.*, 1993; Salvador *et al.*, 2009). However, it does not make much sense to talk about mass production in relation to the building and construction industry as no buildings or constructions would as good as never be mass produced, even though there have been examples of standard house companies making and selling standard houses. Nevertheless, the principles behind mass customisation as a strategy might be applicable for companies within the building and construction industry, often referred to as engineer-to-order (ETO) companies, in a beneficial way harvesting some of the productivity advantages obtained by manufacturing companies.

One of the key enablers of mass customisation is modularity (Silveira et al., 2001; Tang, Qi, & Zhang, 2017), where end-variety achieves through configurations of standardized product modules. Introducing modular product mod-els is not enough for building and construction companies to gain competitive advantage, as the products needs to be produced and to be delivered to the market at the right time (Wolters, van Heck, & Vervest, 2002). A research project (Wolters et al., 2002) within the Dutch house building industry introduced beside product modularity two more dimensions to this: process modularity and supply chain modularity across the value chain (Figure 2). This implies that companies within the value chain (Figure 2) need to incorporate responsiveness to future challenges on various levels, and the three capabilities behind mass customisation should be applicable for companies individually and integrated across the value chain (Figure 2). On an operational level, the assembly systems, machines, tools must be able to switch quickly between the production of different products, and as well as the supply chain and the business processes must support the variety of products demand, quantities, and delivery demands (Silveira *et al.*, 2001; Wolters *et al.*, 2002).

The lifecycle of construction projects are often structured individually, however, a conformity about four overall project phases seems to exist; design [D], construction [C] and operations [O], and demolition [D]. These phases may be subdivided into sub-phases, activities, sub-activities and tasks, etc. involving management activities like planning, monitoring, leadership, handover, etc. There seems to be a productivity connection from each of the nine 'tools and approaches' of the three fundamental capabilities of mass customisation relative to the phases of a construction project (Jensen, Nielsen & Brunoe, 2018).

A resent research among 11 companies within the building and construction industry analysed the 'tools and approaches' of the three fundamental capabilities of mass customisation in or-der to clarify how the companies apply and plan to develop the 'tools and approaches' with the purpose of meeting the competition and improving the productivity. As seen in Table 1 this research measured how the companies apply and how they plan to develop the 'tools and approaches' of three fundamental capabilities supporting the implementation of mass customisation There is a diversity between the participating companies of how they apply the 'tools and approaches', but it is evident that all companies plan to develop the 'tools and approaches' and thereby develop the three fundamental capabilities of mass customisation. The transition for ETO companies moving towards mass customisation might be different according to mass production companies, and the same applies for the implementation ratio. There is no "perfect" state of mass customisation (Salvador *et al.,* 2009) meaning that the three capabilities are not meant as finite improvement destinations, but should be considered as guidance for a journey towards turning customer demands into profit drivers by designing a value chain that creates value from serving customers individually (Piroozfar & Piller, 2013). However, what is suitable for company X might not be suitable for company Y (Figure 3), and the development potential and the roadmap initiatives for company X might also be different according to company Y etc. However, some transition elements might be generic, which indeed require further research and case studies to determine.

Table 1. How 11 case companies apply and plan to develop the 'tools and approaches'

		CN		SSD		RPD		MC	
	Tier	Apply	Plan	Apply	Plan	Apply	Plan	Apply	Plan
CO1	1,2	3.33	4.00	4.00	4.00	3.20	4.00	3.51	4.00
CO2	1	3.33	4.00	3.00	3.67	2.40	3.00	2.91	3.56
CO3	1	1.67	2.80	1.80	2.00	3.20	3.75	2.22	2.85
CO4	1,2	1.83	3.20	2.40	3.67	3.40	3.75	2.54	3.54
CO5	2	2.33	3.60	3.00	3.67	2.40	3.75	2.58	3.51
CO6	2	2.50	3.60	2.40	3.00	2.40	3.25	2.43	3.20
CO7	2	2.67	3.60	3.00	3.67	3.40	3.00	3.02	3.76
CO8	2	1.67	2.20	1.60	2.33	1.80	3.25	1.69	2.59
CO9	1,2	2.17	3.60	3.00	3.67	3.40	4.00	2.86	3.76
C10	1,2	1.83	2.80	1.60	2.67	2.20	3.00	1.88	2.82
C11	2,3	2.67	4.00	3.40	4.00	2.40	3.50	2.82	3.83

As a part of the "Solution Space Development" a mass customizer must identify the needs of its customer, and define where the customers are different and where they care about the differences, leading to the solution space e.g. product attributers, to clarify what it will offer and what it will not. The foundation is a knowledgebase of preferences, needs, desires, satisfaction, motives of the potential customers and users of the products or services. However, this is a fundamental change for ETO companies as it limits the product variety offering to customers based on the solution space captured in the knowledgebase, which indeed are to be dynamic and adaptable for changes, so it always meets the needs of the customer to any solution to be delivered.

The "Choice Navigation" is about the mass customizer to support their customer in identifying their needs, specifying the wanted solution using a simple, effective and user-friendly product configuration system, also referred to as "co-design toolkits" (Franke & Piller, 2004). The "Choice Navigation" aims at finding the right level of choices as to many options can indeed reduce customer value instead of increasing it (Desmeules, 2002), which may lead to postponing their buying decision. The ever-increasing development of new efficient and user-friendly IT solutions supporting the users in their decision-making process will also optimize the ETO companies' opportunities of presenting their solution space, which is beneficial partly for the customers decision making process, and partly for the companies' transition process towards a higher ratio of the three mass customisation capabilities (Figure 3). Such tools are referred to as Virtual Design and Construction (VDC) and Virtual Reality (VR), which is valuable to both customers and business partners in the value chain, and it is a significantly improved basis for making important decisions about the design of the building. The basics in VDC is that all project participants have access to the right information at the right time, which means updated real-time information as a foundation for better understanding of customer needs and what it takes to realize their wishes. As a part of "Robust Process Design" is the firms' capability to reuse the existing organizational and value-chain resources to deliver customer solutions with high efficiency and reliability, so increased variability in customers' requirements will not significantly influence the operational efficiency (Pine *et al.*, 1993).

For ETO companies this include integration of business processes related to the engineering and the production value-chain involving internal and external entities of the value chain (Figure 2). As mass customisation is a value based concept, it is essential to integrate across the value chain to achieve full effect of mass customisation as a strategy (Fogliatto *et al.*, 2012; Silveira *et al.*, 2001). Thus, willingness and cooperation possibilities across the value chain is one of the success factors of application of mass customisation, therefore standards and tools applicable within the building and construction industry is of particular interest leading to the research question 2.

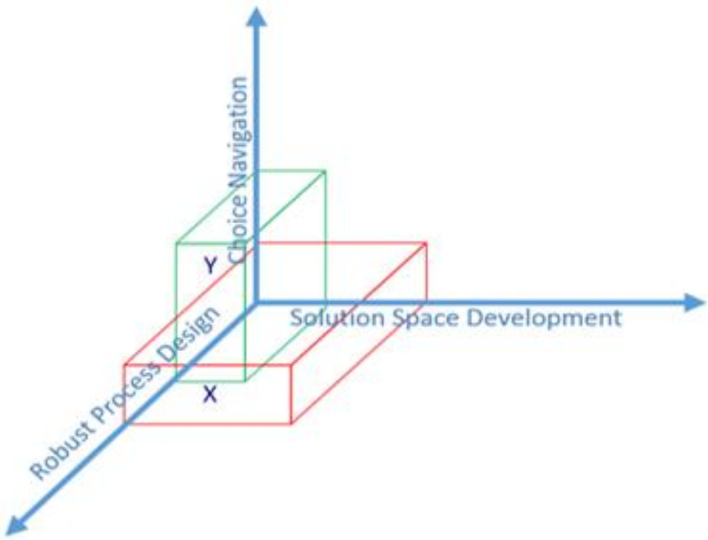

Figure 3. Ratio of the three capabilities of mass customisation for company X and Y

A higher level of customisation often increases complexity and uncertainty in business operations, and requires greater product variety, which often entails greater number of parts, pro-cesses, complex planning and production, more suppliers, retailers, and distributions channels, etc. The characteristics of a successful mass customisation system is stable, flexible, and responsive processes that provide a dynamic flow of products and services (Pine, 1995; Salvador, Rungtusanatham & Forza, 2004), and therefore, the objective is to optimize the additional cost deriving from flexibility requirements to serve customers individually and across the value chain. Hence, a number of methods can be applied to reduce these additional costs e.g. by delayed product differentiation (postponement), flexible atomization, product and process modularity, and utilisation of information and communications technology (ICT), where ICT focusses on unified communication and necessary enterprise software enabling users to access, store, transmit, manipulate, and share information between entities within the whole value chain. Therefore, it is interesting to study the research question 2 as it draws attention to the presence and application of standards and tools available in the building and construction industry for corporation purposes across the value chain.

Industry Standards Supporting Mass Customisation

The entities within the value chain of the building and construction industry, (Figure 2), must focus on improving the three capabilities of mass customisation to benefit of the strategy to meet the customers' needs of customizable products and services.

Therefore, the objectives are to develop these three capabilities for companies in order to utilising of mass customisation as a strategy, so companies will be able to realize a greater growth potential, as they will be able to meet the needs from their customers faster and at a lower cost (Jiao, Ma, & Tseng, 2003). This may also increase in the ratio of exports for those companies, because development of three fundamental capabilities focus on a greater share of the market (Jiao *et al.*, 2003). Furthermore, the objective is to identify the foundation required for companies within the value chain (Figure 2) to implementing mass customisation capabilities since these challenges expectedly differentiate from those met in the manufacturing industry. Finally, the objective is to adapt methods for enhancing the performance of the entities of the value chain by applying the mass customisation principles across entities, so they are applicable in the building and construction industry.

ICT is a crucial corporate asset helping firms attracting customers and expand market, so ICT is fundamental for establishing the cooperation practices between entities of the value chain; however, utilisation of ICT to assist customisation is well-documented (Piroozfar, 2013).For the building and construction industry the Industry Foundation Classes (IFC) is the foundation for cooperation between entities of the value chain, and IFC is also a standard required by public authority in more and more projects. Software support of early design decisions is possible and can be cost-effective with the use of existing, commercially available IFC-compatible software applications (Bazjanac & Crawley, 1999; Lee, Chin, & Kim, 2003; Lee, 2015). However, several Model View Definitions (MVD) defined for specifying data exchange requirements for diverse domains, BIM data exchanges using IFC-format still have numerous problems and challenges in syntax and semantics (Lee, 2015), which is likely to improve over time as it is a high priority area.

Building Information Modeling

Building Information Modeling (BIM) is a well-known concept widely discussed in the building and construction industry, and the purpose is to manage and improve the processes related to the building information in an integrated way before, during and after constructions pro-jects. Many researchers argue that having one single building information model would benefit construction projects in many ways. Having a single building information model integrating as much data as possible, has been the objective for academics, software developers, etc. for more than thirty years, and the time indeed seems promising for a greater use of BIM and the standards supporting the collaboration between entities within the value chain (Figure 2) of the building and construction industry (Howard & Bjork, 2007).

International Alliance Interoperability (IAI) has since 1994 worked with standardisation initiatives concerning interoperability (full information exchange) between the many software systems used between entities (Laakso & Kiviniemi, 2012). The name of the organization changed in 2008 to buildingSMART, but remained an open, neutral non-profit and international organization with the same main purpose of providing a set of standards for sharing and exchanging BIM data across different software solutions used by the entities of the value chain (Figure 2). The buildingSMART initiative enable a single method of how to manage product data information consistently in a digital workplace.

The standards of how to share data, what you are sharing, which data, when to share it, and why to share it consist of five types of open standard in the buildingSMART portfolio (Laakso & Kiviniemi, 2012; Liebich, 2013; van Berlo & Krijnen, 2014):

- Information delivery manuals
- International Framework Dictionaries
- Industry Foundation Classes
- Model View Definition
- BIM Collaboration Format

These standards will be further elucidated and followed by a description of how they work and interact with each other,

Information Delivery Manuals

Information delivery manuals (IDM) is generally a communication platform or an interaction framework to secure successful communication between entities in the building and construction industry (Figure 2) when working together on a specific project. The purpose of IDM is to capture processes and exchange requirements, and IDM is an accepted ISO standard (ISO 29481) used for documenting existing or new processes and describing relevant information between entities: Clients, Architects, Engineers, Companies, Contractors, Supplies, Operators, and Facility Managers (Figure 2). These entities are depending on relevant, reliable, complete, timely, understandable, verifiable, and accessible information between each other in order to ensure effectiveness and to work efficiently, so the background for IDM is to improve the information, communication, and process flow between entities. It is important to secure a uniform, transparent and traceable communication between all entities having a role in a specific project or during the lifecycle of a building. IDM defines an industry process that involves two types or more of software applications, and the information exchanged between those software applications. IDMs include four primary deliverables, using standard formats: 1/ Process Maps, which define the industry process 2/ Exchange Requirements, which define the information to exchange 3/ Exchange Requirements Models, which organize the information into Exchange Concepts linked to Concepts in the MVD and enable verification that all requirements have been satisfied 4/ Generic BIM Guide that documents what objects and data must be included in the BIM data exchange between entities

International Framework Dictionaries

International Framework Dictionaries (IFD) is the data dictionary, and it is one of the core components of the buildingSMART data dictionary (bSDD) as it is a reference library based on a standard, with the intention to support and improve interoperability in the building and construction industry. This standard defines the properties or attributers of what to be shared among entities in the building and construction industry. The bSDD is a library of objects and their corresponding attributes used to identify objects in the building and construction environment meaning their specific properties regardless of language, so a “door” means the same thing globally. Based on the standard definition the entities deliver the specific values as a founda-tion for the collaboration (Figure 3).

The bSDD is more than a set of definitions as the data dictionary maps relationships between objects and their corresponding properties, and it is a platform for sharing reusable object li-braries to reduce costs and improve quality. The objects and property definitions are available to collaboration software worldwide, which provide a mapping between different users and applications connecting objects to BIM-specific products, which creates data transparency by automatic rule checking preventing miscommunication and data duplication. Thus, the bSDD provides a database for building and construction information with terms and definitions in different languages.

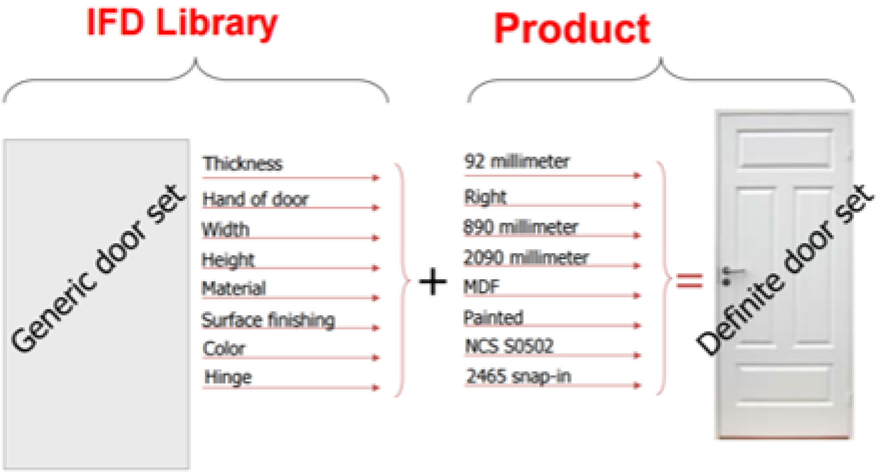

Figure 4. IFD illustration of principles. Source BuildingSMART.com

Industry Foundation Classes

Industry Foundation Classes (IFC), is a standard adopted as a central information repository in order to deliver the integrated building information throughout the entities within the sup-ply chain of the building and construction industry (Figure 2). IFC provide an environment of interoperability among IFC-compliant software applications in the architecture, engineering, construction, and facilities management (AEC/FM) industry. IFC represent an open specification for BIM data that is exchanged and shared among entities in a building construction and facility management project. This IFC standard is an international openBIM standard used in different software applications for projects collaboration, and IFC provide a specification of a data model that covers the domain of building information.

The IFC specification describe the data model in of terms, geometrics, concepts, quantity, actors, cost, material and data specification items that is used within collaboration issues related to the building construction and facility management industry. IFC consists of the data schema, represented as an IFC-EXPRESS schema specification, and reference data, represented as XML definitions of property and quantity definitions. The IFC specification differ between attributes and properties, whereas attributes attached to an object as an attribute of the entity. An object may have many attributes, but not all of them are necessary required to have a defined value. Properties are grouped as property sets and are assigned to an object by a relationship.

The actual version of IFC standard is IFC 2x3 (version 2, revision 3) launched in 2006, and currently a new updated version is under its way, IFC 4 addendum 1 (Liebich, 2013). The data schema architecture of IFC defines four conceptual layers, and each individual schema is assigned to exactly one conceptual layer. Resource layer is the lowest layer that includes all individual schemas containing resource definitions, which do not include a globally unique identifier and shall not be used independently of a definition declared at a higher layer. Core layer, is the layer that includes the kernel schema and the core extension schemas, containing the most general entity definitions, all entities defined at the core layer, or above carry a glob ally unique id and optionally owner and history information. Interoperability layer is the layer that includes schemas containing entity definitions that are specific to a general product, process or resource specialization used across several disciplines, those definitions are typically utilised for inter-domain exchange and sharing of construction information. Shared building elements like beam, door, roof, window or ramp are defined in this layer. Domain layer is the highest layer that includes schemas containing entity definitions that are specifications of products, processes or resources specific to a certain discipline, and those definitions are typically utilised for intra-domain exchange and sharing of information.

IFC data files are used to exchange between software applications and to be able to do so, the following three IFC data file formats are used: 1/ ifc: this data file format is using the STEP physical file structure according to ISO10303-21. These files are the default ifc exchange format that validates according to the IFC-EXPRESS specification. 2/ ifcXML: This data file format is using the well-known XML document structure. The sending software application generates the files directly using the conversion following ISO10303-28, and these files are normally larger than .ifc-files. 3/ ifcZIP: this data file format is a compressed file consisting of .ifc or .ifcXML files. For compressing files, a specific software program is used, e.g. PKzip 2.04g compression algorithm for making this file type, which is compatible with e.g. Windows compressed folders, winzip, zlib, info-zip, etc. The IFC standard itself does not provide an Application Programming Interface (API) to the data model, but APIs are designed to implement IFC in different software applications.

Model View Definition

Model View Definition (MVD), describes the contents of data to be exchanged in specific situations, aiming at mapping exchange requirements to a data schema, like the IFC, and potential constrains to the used data model. MVD is a subset of IFC, and it support recognized workflows in the construction and facility management industry, and each workflow identifies data exchange requirements for software applications.

Software applications need to identity the model view definition conforming to, which is useful when implementing IFC certified software, where one or more MVD's is implemented. The purpose of MVD is to support different workflows in the building construction and facility management industry aiming at being able to work efficiently and effectively in the supply chain (Figure 2) by identifying the data exchange requirements between different software applications.

However, a software application supporting IFC must therefore identify, which MVD it should use. mvdXML refers to a file format for representing MVD, and the mvdXML is a generic structure applying to any data schema used relative to the IFC data schema. The mvdXML format serves several purposes: 1/ to support automated validation of IFC data sets for quality assurance and certification 2/ to generate documentation for specific model views and the IFC specification itself 3/ to support software vendors providing filtering of IFC data based on model views 4/ to limit the scope of IFC to well-defined subsets applicable for particular applications.

BIM Collaboration Format

BIM Collaboration Format (BCF), is a format developed by several software vendors as a foundation for handling change management by tracking issues between entities. BCF is an open file format based on XML allowing addition of comments to an IFC model, and BCF is intended to streamline and simplify the collaboration challenges on a IFC model by allowing the entities within the supply chain (Figure 2) to raise issues, commentary, provide answers and make comments within an open file format that does not itself contain model elements. The BCF file holds the collaboration issues and a reference to the IFC model (IFC globally unique identifier) meaning that the communication tread is separated from the model itself.

Possibilities to enhance result-oriented business model

IFC is an open, formal, international, consortium standard currently involved in a hybrid standardisation process designed to enable indirect horizontal compatibility between AEC and FM software applications between the entities of the value chain (Figure 2) (Laakso & Kiviniemi, 2012) of the building and construction industry.

In a scenario an architect makes the high-level drawing material framing the building model of a specific project so the customer can see and relate to proposed building model, so the customer knows the framing of the design idea. The architect sends the IFC or MVD formatted information (.ifc, ifcXML, ifcZIP, mvdXAL) to the cooperating entities within the value chain (Figure 2), so they can continue their part of the work under the given frames on a more detailed level.

The IFC format contain in general all needed information from GIS data describing the location of the building to specific information about which walls and columns that are load bearing, function of the spaces in the building, etc. Each of the receiving company will typically run a test to verify that the IFC data file include all necessary information relative to IDM to get started. This raises the quality level and aims at clearing errors as early as possible. Hereafter, the IFC data are imported into own software application that might be unique for the specific company's role and purpose within the value chain (Figure 2). The IFD and bSDD has initially defined the attributers necessary to define doors, windows, insulation, walls, roof, heating system, foundation requirements, etc. meaning that all involved entities know about the boundaries and can communicate iteratively about the building requirements of parts, properties, units, and values. IFD also enables multiple ways of classifying and structuring information and set the names and definitions in different languages encouraging cooperation globally.

The engineers from the companies fulfill their part of the combined work e.g. calculating the dimensions of a load bearing structure, dimensioning of an air conditioning or heat supplying system, detailed drawings and calculation like roof, sewer and water installation, electric cables. The enriched data/information are exported and sent back to the architect that import into the BIM model for further cooperation purposes. During the collaboration process some issues may arise between entities, and these issues are documented and shared in the BCF file with a reference to the IFC model as a communication tread.

The IDM specifies the information to be exchanged in each exchange scenario identifying the series of processes undertaken during a construction project together with the information required in order for these processes to be carried out. IDM provides a methodology and format for describing coordination of acts between entities by mapping responsibilities and interactions that provide a process context for information flow, and a format for the interaction framework. The intention is to facilitate interoperability between software applications used by the entities during all stages in the sense of a digital collaboration platform as a basis for accurate and reliable information exchange providing transparency, reusing of data, reducing of errors, mistakes and misunderstandings which contribute to the productivity improvement.

DISCUSSION

Although BIM can provide benefits for the entities working in a long-term relationship, it seems that BIM and standards like IFC, IDM, IFD, and BCF can improve the possibilities of cooperation between entities across the value chain of a construction project obtained from cradle to grave of the building. In order to utilising BIM properly commitment between entities in the supply chain and requirements of data discipline, information management and coordinating of models throughout the entire project is widely important. Official agreements and requirements coming from public authority of using IFC format as a common communication format between entities within all the processes over the entire lifetime of the building is supporting the conditions and application of mass customisation within the building and construction industry as a development and manufacturing strategy improving the productivity.

Mass customisation as a strategy is applicable and widely used for each of the entities individually of the supply chain (Figure 2) in regards of improving productivity and thereby competitiveness and it is applicable to most businesses if it is appropriately understood and deployed. The objective is to consider it as a process for aligning an organization with its customers' needs, and it is about moving toward these goals by developing a set of organizational capabilities that will enrich an existing business (Salvador *et al*., 2009).

Mass customisation together with ICT and IFC standardisation initiatives as described in this article seems to indicate that it makes sense to talk about utilising of mass customisation as a strategy improving the productivity within the building and construction industry (Figure 2) as an integrated system across the value chain responding to the three capabilities of mass customisation (Salvador et al., 2009). Firstly, robust process design can be seeing in a broader perspective as integrated processes across the entities of the value chain (Figure 2) as the ability to reuse or recombine existing organizational and value-chain resources (Salvador *et al.*, 2009), which is provided and supported by the ICT, IFC and MVD standards as an integrated system (Laakso & Kiviniemi, 2012). Secondly, solution space development, which is the ability to identify and decide the product attributes along which customer needs (Salvador *et al*., 2009) provided and supported by ICT in general and the standardisation initiatives of buildingSMART, IFD and bSDD. Thirdly, choice navigation, which is the ability to help customers identifying or building the solution to their own needs (Salvador *et al*., 2009) provided by the integrated BIM process utilising ICT and standards across the entities of the value chain involved in a project or long term cooperation partnership.

The IFC initiative together with mass customisation strategy seems as means solving the inefficiencies of the whole building and construction industry. However, the success criteria is laying at the software developer in term of incorporation of the IFC standard effectively in efficiency and usable software supporting all the involved entities and their role in the value chain solving their individually tasks and contribution to the whole workflow related to a building and construction project.

CONCLUSION

This paper deduces that there is not much literature dealing with the utilisation of mass customisation as a strategy in terms of increasing the productivity of the building and construction industry nor in general in the building and construction industry.

This paper indicate some challenges related to establishing an adaptable integrated system between entities in the building and construction industry by applying the principles of mass customisation focusing on the three capabilities “choice navigation”, “robust process design” and “solution space development”, and the corresponding “tools and approaches” to be developed in order to increase the level of mass customisation. An essential part of the paper is the conditions for cooperation between the entities within the value chain of the building and construction industry (Figure 2) indicating that successful application of mass customisation as a strategy require the three capabilities for companies individually and as interconnected across the value chain. However, implementing the three capabilities is a gradually transition journey without any final optimal destination. IFC and IFD/bSDD is the backbone of the cooperation possibilities around a specific project between entities in the value chain of the building and construction industry.

IFC has the potential to transform the core fundamentals of building and construction processes, and the benefits and possibilities of having one global ontology seems to be many. Obviously, the information exchange between entities is possible in a standardized and global oriented way aiming at a total cost reduction of maintaining the database of material, products, and elements used between entities. Other benefits seem reachable like quality improvement in terms of exchanging knowledge between entities in order to ensure to comply with the basic requirements of involved entities and especially the customer and thereby reducing errors waste. Possibilities of logistic optimization in terms of delivering the right delivery at the right time seems possible in the construction process by utilising ICT and standardisation initiatives. However, the potential for productivity improvements is substantial through interoperability for BIM enabling seamless flow of design, cost, project, production and maintenance information, and thereby reducing redundancy and increasing efficiency throughout the supply chain and lifecycle of the building.

Looking at the building and construction industry applying ICT and IFC, MVD, IFD/bSDD as cooperation fundamentals for improving the industry it seems to correspond very well to mass customisation enablers and capabilities, thus it indicate that it is reasonable and possible to utilisation and harvesting the benefits of the three capabilities of mass customisation by applying the IFC and standardisation initiatives between entities of the building and construction industry.

Management must decide the approach to what make most sense for their businesses according to application of the three capabilities of mass customisation. As mentioned in the literature, the goal of mass customisation is to provide customers with what they want, when they want it at a low cost, and as there is no one best way to mass customize, the three capabilities (Figure 3) are meant as guidance for a journey towards moving customer demands into profit by creating a value chain that creates value serving customer individually.

In the long-term perspective, and with continuing software and standard development, it seems possible to apply and benefit of mass customisation and the corresponding 'tools and approaches' in the building and construction industry across the value chain. However, the use of any innovations initiatives like mass customization is depending on further research, transition guidance and pioneers achieving positive results.

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