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Parametric and Generative Design Techniques for Mass-Customization in Building Industry: a Case Study for Glued-Laminated Timber

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Abstract

According to Wortmann classification, the Building Industry (BI) can be defined as engineer-to-order (ETO) industry: the engineering-process starts only when an order is acquired. This definition implies that every final product (building) is almost unique, and processes cannot be easily standardized or automated. For this reason, the Building Industry is one of the less efficient industries today, and the productivity gap with other industries is growing faster. Since the 1940s, prefabrication and standardization of entire buildings or of complex components are effective strategies to push BI from an ETO industry towards an assembly-to-order industry (ATO). Although, prefabrication and standardization strategies provide effective solutions to improve process efficiency, they are not widespread adopted. The reason for this poor success can be identified in limits of customization that afflicts prefabricated and standardized products, which do not satisfy completely the needs usually delivered by customers. This paper presents a research activity aiming at enhancing Mass-Customization capabilities in the BI through Parametric and Generative design techniques in frontend activities of the value-chain system. Referring to a case study for Glued-Laminated Timber (GLT) products, a parametric algorithm has been programmed in order to satisfy two specific design intents: reducing the usage of unneeded high-quality raw material in final products and facilitating the manufacturing process of complex products, such as doubled-curved ones. Crossing capabilities of the parametric algorithm in Digital Fabrication strategies and capabilities of a standard production system of GLT, authors discuss whether Parametric and Generative Design techniques may enhance Mass-Customization capabilities in the BI, pushing the whole production system towards more efficient processes.

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1. Introduction

According to Italian Institute of Statistics (ISTAT), the Building Industry (BI) is characterized as one of the less efficient industries on the market and the productivity gap with other industries have been growing up [1] in the last decade. This lack of efficiency in BI is mainly due for the following reasons:

- The BI is a highly customized Engineer-to-Order (ETO) industry. This means that every product has to be engineered as soon as an order from a customer is delivered.
- The supply chain system is structured according to a rigid serial workflow that does not always allow to prevent errors among the supply chain itself.
- A front-end strategy supported by a digital information management is missing and errors have to be solved time by time.

One main reason for low-efficient processes in the BI is the high amount of customized work content. Traditionally, projects in the BI are characterized by highly customized products and components. In the case of timber building industries, companies have to realize customized timber houses in shortest time, with lowest costs as possible and with a high

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attention to the individual needs and requirements of the single customer. To improve efficiency of such customized building projects this work shows an approach using Parametric and Generative design techniques. Through the application of the proposed approach and algorithm building companies in the timber sector, should be able to increase industrialization in a typically handcraft sector maintaining and maximizing the grade of customization needed in this special environment.

Mass-Customization as a combination of highly industrialized mass production and customized craft production is the response from the manufacturing industry to the requirements of an increasingly modern and dynamic world. The increasing desire for individuality of people promotes the trend towards Mass-Customization. The producer, which is able to produce a product to low prices and with customer specific characteristics as quickly as possible, has the highest competitive advantage on the market. Simultaneously, new technologies such as advanced web technology, digitalization or additive manufacturing technologies have opened new possibilities for capturing customer requirements and for producing customer-specific products. Mass-Customization is combining the highly controversial objectives of individualization and cost-efficient production and allows maximum flexibility producing products with a reasonable cost structure [2].

2. Theoretical background – state of the art

There are already many studies on Mass-Customization in the literature. In this paragraph authors will first discuss the basic theory of Mass-Customization based on a brief literature review. In the next section the current state of Mass-Customization in traditional manufacturing processes and subsequently in the BI is explained.

2.1. The concept of Mass-Customization

It has been shown by empirical and simulation studies [3, 4] that increased product variety has a significant negative impact on the performance of manufacturing processes. The higher the number of product variants, configurations or overall variety, the more complex difficulties in the production design and operational management of production systems or supply chains are [5]. Mass-Customization has been identified as a competitive advantage strategy by an increasing number of companies [6] to overcome these difficulties. The concept of Mass-Customization was first expounded formally in the book "Future Perfect" by Stanley M. Davis in 1989 [7]. Mass-Customization means manufacturing products, which have been customized for the customer, at production costs similar to those of mass-produced products [8]. Mass-Customization allows customers to select attributes from a set of pre-defined features in order to design their individualized product, by which they can fulfill their specific needs and take pride in having created a unique result [9, 10, 11] Thus, customization integrates customers within the design process [12]. The primary focus of the product designer should be on providing value to the end user. To achieve personalization increasing the value for the end user, different authors suggest a user-centered design approach. [13].

2.2. Mass-Customization Manufacturing

Numerous authors have published articles about Mass-Customization; many of them discussed Mass-Customization from a strategic and economic point of view. Only few works investigate technical aspects of manufacturing and manufacturing systems design of mass customized products [14, 15, 16 and 17]. Mass-Customization Manufacturing (MCM) has been gaining recognition as an industrial revolution in the 21st century. Customers usually can select options from a predetermined list and request them to be assembled [12]. While the manufacturing industry in the past distributed globally standardized products to keep the production cost and complexity low, nowadays a customization of products based on customer specific needs is becoming more and more important [17].

Manufacturing systems in a Mass-Customization environment should be able to produce small quantities in a highly flexible way and to be rapidly reconfigurable [12, 19]. Such a manufacturing system fits the needed requirements for Mass-Customization manufacturing better than a traditional one. The latest trend in Mass-Customization is digitalization in manufacturing, also known under the term "Industry 4.0" or "Cyber-Physical-Systems" (CPS). The large potential of Industry 4.0 will be a key enabler for further developments in Mass-Customization manufacturing [19]. To reach such a next level of changeability it is necessary to equip manufacturing systems with cognitive capabilities in order to take autonomous decisions in even more complex production processes with a high product variety [20].

2.3. Mass-Customization in the Building Industry

Mass-Customization has been used inadvertently in the BI since a long time. But only very little and scattered systematic attempts have been made to apply it within the field [21].

Also in the BI there could be recognized a growing trend in customization and thus in mass customized products or objects. Frutos and Borenstein [22] developed in 2004 a prototype implementation of a web based information system framework for agile interactions between building companies and customers for flat customization for a Brazilian building company.

In the Korean housing market the level of customization for houses has been restricted by economics of scale in the construction processes. Shin et al. [23] described in 2008 their Finishing Information System (FIS) approach based on a case study in a real apartment complex project. FIS is a web-based interactive design program to configure and visualize customized housing solutions and extra options.

According to Bock and Linner [24] customizations' heart in the BI is information and communication technology used for forming continuous IT structures on which those information flows are then created. Customization is deeply based on the evolution and interconnection of all computer based technologies.