Automation in Construction 92 (2018) 270–285

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Parametric and Generative Design techniques in mass-production environments as effective enablers of Industry 4.0 approaches in the Building Industry

Gabriele Pasetti Monizza[a,b,*], Cristina Bendetti[b], Dominik T. Matt[a,b]

[a] Free University of Bozen-Bolzano, Italy
[b] Fraunhofer Italia Research s.c.a.r.l., Innovation Engineering Center (IEC), Italy

ARTICLE INFO

Keywords:
Product engineering
Glued-Laminated-Timber Engineering
Information technologies in design
Parametric Design
Generative Design
Information Technologies in manufacturing
Industry 4.0

ABSTRACT

While the manufacturing industry in Europe is looking at Industry 4.0 approaches and technologies to maintain the current competitive advantage, on the other hand, in the building industry (BI) they may push an improvement of the overall productivity also. This paper presents a research activity, which has aimed at investigating potentials and criticisms of Parametric and Generative Design techniques in mass-production environments of the BI though a pilot-case-study analysis in Glued-Laminated-Timber (GLT) industry. Starting from programming a parametric algorithm for GLT engineering, the research has measured manufacturing effectiveness and manufacturing efficiency through a Value-Stream Map of an ordinary supply-chain system of GLT. Considering all the limits of referring to a single case study, results highlight improvements both in manufacturing effectiveness and manufacturing efficiency; but limitations have to be considered as well, due to the complete absence of Industry 4.0 approaches and technologies in an ordinary supply-chain system of GLT.

1. Introduction

1.1. The lack of efficiency in the Building Industry

Nowadays, the manufacturing industry is introducing concepts and technologies based on the fourth industrial revolution (also known as Industry 4.0) [1] in order to maintain the current competitive advantage in long term [2]. To do so, according to Spath et al. the ability to respond to customer requirements quickly and flexible and to produce high version numbers at low batch sizes, must increase [3]. The characterization, description and definition of Industry 4.0 still varies greatly and a concrete, general accepted representation of Industry 4.0 does not exist at this time [4]. Focus of Industry 4.0 is to combine production, information technology and Internet. Thus, newest information and communication technologies are combined with classical industrial processes [5]. The fourth industrial revolution should extend more functionalities and customization options for the client and more flexibility, transparency and globalization for the supply-chain system [6]. In addition, the return to uniqueness should be achieved [7]. Industry 4.0 describes also a fundamental paradigm shift from a centralized to a decentralized control with the aim of a highly flexible production of customized products and services. More and more individualization and personalization of products leads to manufacturing concepts like X-to-order (Engineer-to-Order, Make-to-Order, Build-to-Order, Configure-to-Order and Engineer-to-Order [8]) and finally to mass-customization, which means the manufacturing of products customized according to customers' needs, at production costs similar to those of mass-produced products. Traditional structures are replaced by flexible reconfigurable manufacturing and logistics systems, offering interactive, collaborative decision-making mechanisms. There is an increasing network of industry, as well as a fusion of the IT environment with production and logistics [3]. Industry 4.0 leads this shift of structures through Cyber-Physical Systems (CPS) for self-organization and self-control. CPS are computers with networks of small sensors and actuators that are installed as embedded systems in materials, equipment and machine parts and connected via Internet [9–11]. Here physical and digital world are combined and are called Internet of Things [5]. Manufacturing data are provided in a completely new quality and with realtime information on manufacturing processes.

The building industry (BI) may be defined an Engineer-to-Order (EtO) industry, according to Wortmann classification [8]. This implies that every final product (building) is almost unique, a kind of prototype. Every new product has to be designed and engineered time by time, according to specific customers' needs. Thus, the BI pursues strong

* Corresponding author at: Faculty of Science and Technology, Free University of Bozen-Bolzano, Universitätsplatz 5 piazza Università 5, I-39100 Bozen-Bolzano, Italy.
E-mail address: gabriele.pasettimonizza@unibz.it (G. Pasetti Monizza).
URL: http://www.unibz.it/sciencetechnology (G. Pasetti Monizza).

https://doi.org/10.1016/j.autcon.2018.02.027
Received 22 June 2017; Received in revised form 28 November 2017; Accepted 9 February 2018

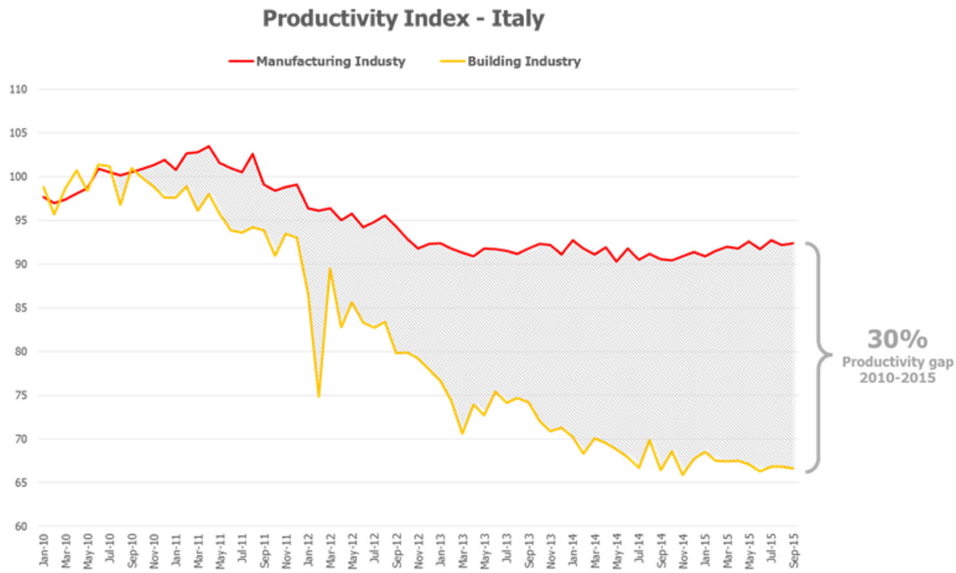

Fig. 1. Productivity index for Italian industry, data source: ISTAT.

customization of final products by definition. This strong customization is one of the main reasons for a lack in productivity of the BI. According to latest ISTAT's (Italian Institute of Statistics) surveys in 2015 [12], the BI is one of the less efficient industries in Italy and the productivity gap with other industries is growing faster (Fig. 1).

Although the supply-chain system is similar to other EtO industries, the BI identifies different task leaders for each process usually structured in a serial workflow. Serial workflow reduces the efficiency of information management by enhancing the propagation of errors (small details neglected at the beginning of the value-chain system could become a huge problem in latest processes, such as installation and maintenance) because of a fragmented information flow among the task leaders (Fig. 2) [13,14]. Strategies from other industries have been introduced so far in order to improve process efficiency in the BI. Since the 1940s [15], prefabrication and standardization (or modularization) of entire buildings or of complex components are effective strategies to push BI from an ETO industry towards an assembly-to-order industry (ATO) or towards a configure-to-order (CTO) industry. Although prefabrication and standardization strategies providing effective solutions to improve process efficiency, they are not widespread adopted, and they actually represent only a small percentage of the entire BI, approximately 8.5% for prefabricated timber buildings [16] in Italy. 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 [17,18].

Nowadays, the challenge for the BI is to reduce the productivity gap with other manufacturing industries by reducing wastes of resources and improving the overall efficiency of the supply-chain system [19,20]. Improving the overall efficiency in the BI may generate huge benefits: reduce social and economic costs, reduce the environmental footprint and enhance the quality of final products (buildings). Considering that strong customization is, by definition, a feature of the BI, Industry 4.0 approaches and technologies may improve the overall efficiency of the BI in order to introduce mass-customization capabilities effectively.

According to the Construction Industry Institute, Front End Planning and Alignment are effective strategies to improve process efficiency enhancing mass-customization capabilities in the BI. Front End Planning is defined as "the process of developing sufficient strategic information with which owners can address risk and make decisions to commit resources in order to maximize the potential for a successful project" [21]. Alignment is "the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives.

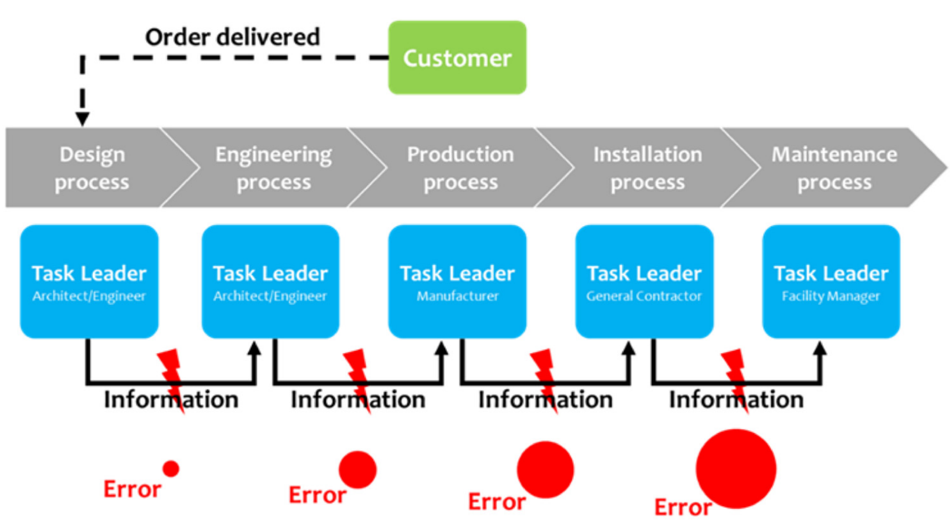

Fig. 2. Supply-chain system of EtO building industry.