Automation in Construction 88 (2018) 13–22

Contents lists available at ScienceDirect

Automation in Construction

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

Design for Manufacture and Assembly-oriented parametric design of prefabricated buildings

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ARTICLE INFO

Keywords:
Prefabricated buildings
DFMA
BIM
DFMA-oriented parametric design

ABSTRACT

Many design systems are developed in the context of non-prefabricated buildings, and cannot be well suitable for prefabricated buildings which are being popular at present. In order to solve the problem, this paper introduces Design for Manufacture and Assembly (DFMA) into prefabricated building design, and combines it with parametric design of Building Information Modeling (BIM) to develop the concept and process of DFMA-oriented parametric design. For making DFMA-oriented parametric design implemented better, DFMA-oriented architectural design team, precast component creation process based on family template and DFMA, DFMA-oriented BIM re-development process, and optimization process of DFMA-oriented prefabricated building information model are also explored and developed. In the end, some principles of DFMA-oriented parametric design are partially reflected by several examples, and DFMA-oriented parametric design needs to be constantly improved according to its subsequent actual use.

1. Introduction

Prefabricated buildings that are made of precast components at construction site are a recent trend in China. Although prefabricated buildings have been extensively studied and widely used in some developed countries, prefabricated buildings in China still have a certain research value and significance due to the particularity of each country. Compared with other kinds of prefabricated buildings, prefabricated concrete structure has developed rapidly in China. Prefabricated buildings studied in this paper mainly refer to prefabricated concrete structure. In comparison with traditional cast-in-situ concrete buildings, prefabricated buildings own lots of advantages, such as reducing environmental burdens, saving on-site construction labors, increasing on-site construction quality and efficiency [1,2,3]. Developers and owners can also gain a rapid return of investment due to the improvements of construction quality and efficiency [4]. Therefore, prefabricated buildings have a very good development prospect.

Ulrich Bogenstätter points out that design stage determines up to 80% of building operational costs [5,6]. Therefore, a good design system (or process) is vital to prefabricated buildings. However, the current design of prefabricated buildings is largely based on the original design system of traditional non-prefabricated buildings, and lacks a suitable method or principle considering the requirements of manufacturing stage and construction stage in prefabricated buildings. In 1992, Lauri Koskela, a Finnish scholar, proposed that some mature principles of the manufacture industry should be applied to the construction industry, and then put forward the concept of lean construction according to lean production [7]. Design for Manufacture and Assembly (DFMA) is one of mature principles in the manufacture industry. Table 1 shows general DFMA guidelines and their benefits. According to Table 1, DFMA is good to simplify design, manufacture and assembly, save time and costs, improve quality and environment [8,9]. According to the research theory of Lauri Koskela, DFMA can also be introduced into the construction industry to improve the current design system (or process) of prefabricated buildings.

If DFMA can be achieved well in the construction industry, a supporting technology related to building design is indispensable. In comparison with traditional Computer-Aided Design (CAD), BIM is more suitable for modern building design, and reduces design coordination errors and later construction costs [52]. The most striking feature of BIM is parametric design, which all entities in BIM are presented in the form of components [12,13]. Any modifications in building design will be automatically reflected in other related parts [12]. The feature greatly lightens the work of building designers so as to

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https://doi.org/10.1016/j.autcon.2017.12.021
Received 10 April 2016; Received in revised form 8 December 2017; Accepted 10 December 2017
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Table 1
General DFMA guidelines and their benefits [10,11].

Guidelines	Benefits
Minimize precast component types	Simplify design, manufacture and assembly so as to reduce time and costs.
Use standard and off-the-shelf components	Lower purchasing lead time, and reduce costs.
Minimize connector types and quantity	Simplify design, manufacture, assembly, repair and maintenance so as to reduce time and costs.
Use as similar materials as possible	Need fewer manufacture processes and simplify jointing so as to reduce time.
Use as environmental friendly materials as possible	Reduce the harm to environment and residents.
Consider modular designs	Reduce time and costs due to simplified design and assembly.
Aim for mistake-proof designs	Avoid unnecessary re-work so as to improve quality and save time and costs.
Consider design for mechanized or automated assembly	Improve assembly efficiency, quality and security.

Table 2
Researches on the BIM application in prefabricated building design.

Authors	Years	Relevant research
Ghang Lee, et al. [15]	2006	Study building object behavior (BOB) notation and create a BIM-based parametric object design process.
Ercan Yuksel, et al. [16]	2015	Analyze two exterior beam-column connections including industrial type connection and residential type connection.
Tushar Nath, et al. [14]	2015	Map and re-engineer the current practices for shop drawings generation and propose a BIM-based technologically-enhanced workflow.
Nawari O. Nawari [17]	2012	Study how to establish and implement BIM standard in off-site construction domain.
Jeonghyun Kim, et al. [18]	2012	Design an integrated parametric modeling methodology for Han-ok which is the timber frame structure.
Jungdae Park [12].	2011	Propose a BIM-based parametric design methodology and a new design process for Han-ok.
G. Costa, et al. [19]	2015	Use Semantic Web technologies to connect building component catalogues with BIM models for providing links to product components.
Rafael Sacks, et al. [20]	2010	Utilize the Rosewood experiment to examine BIM and product data exchange in the design and fabrication of architectural precast facades.
Alireza Khalili, et al. [21]	2013	Develop an IFC-based system to configure groupings of precast elements for a prefabricated building to minimize the total number of components.
Dehai Zhang, et al. [22]	2014	Describe the application of BIM-based modular design method in prefabricated buildings.

improve design efficiency [14]. Although BIM has made great contributions to the construction industry so far, most of existing BIM tools are developed in the context of traditional non-prefabricated buildings and do not well take into account the new process that building components are produced in factory and moved to construction site for assembly [19]. Some functions related to prefabricated building design are not complete in some existing BIM products. Therefore, it is very urgent to make improvements to current BIM technology to meet the requirements of prefabricated building design. There have been some researches on BIM applications and improvements in prefabricated building design so far. Table 2 indicates some researches on BIM applications in prefabricated building design. According to the research results shown in Table 2, some scholars have realized that design, manufacture and assembly of prefabricated buildings are not isolated and should be integrated together when they utilized BIM to solve the problems encountered in design stage. However, they have not carried out a systematic and detailed study to improve the design of prefabricated buildings.

This paper aims to study how to establish a prefabricated building information model for construction and its precast component information models for manufacturing, which have good manufacturability and assemblability so as to avoid the manufacture and assembly problems in later stage and improve the one-time success rate of design. To achieve the purpose, this paper first analyzes the characteristics of prefabricated buildings which are different from traditional cast-in-situ concrete buildings, and then try to apply BIM technology to prefabricated building design. However, some limitations are found in BIM application process. Therefore, DFMA is introduced to propose the concept of DFMA-oriented parametric design and develop the process of DFMA-oriented parametric design. Then, in order to make the DFMA-oriented parametric design implemented smoothly, some relevant auxiliary methods are also developed, namely DFMA-oriented architectural design team, precast component creation process based on family template and DFMA, DFMA-oriented BIM re-development process, and optimization process of DFMA-oriented prefabricated building information model. These auxiliary methods can also be seen as the refinement of some content in DFMA-oriented parametric design. In the end, some principles of DFMA-oriented parametric design are partially reflected through several examples.

2. Characteristics of prefabricated buildings

A prefabricated building is made up of many precast components, and these components are typically produced in a factory and transported to construction site for assembly [23,24,25]. Prefabricated buildings can date back to 1940 when their applications could be found in various countries, and quickly spread around the world [26]. With the development of prefabricated buildings, their characteristics gradually become clear. The basic characteristics which differ from non-prefabricated buildings are as follows:

(1) Design standardization. Design standardization means that prefabricated buildings with different functions and shapes are designed according to a uniform architectural design criterion. The contents of design standardization include precast component standardization and building design process standardization [3]. Standardization is conducive to the accumulation of design knowledge, saves design time and cost, and improves design quality.
(2) Industrial production. Industrial production means that most of building components are produced as per flow-line production mode in factory rather than be cast at construction site. Lean production or construction provides important savings opportunities for enterprises [28,30]. Due to advanced manufacture process, industrial production is helpful to realize the lean production of precast components and also lays the foundation for achieving lean construction [27,29].
(3) Assembly construction. Assembly construction is also known as modular construction. It means that precast components produced in factory are transported to construction site to be assembled according to construction drawings or construction information model [31]. The process is conducive to promote the standardization, mechanization and informatization of construction and improve the environment of construction [32].

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