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

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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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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].

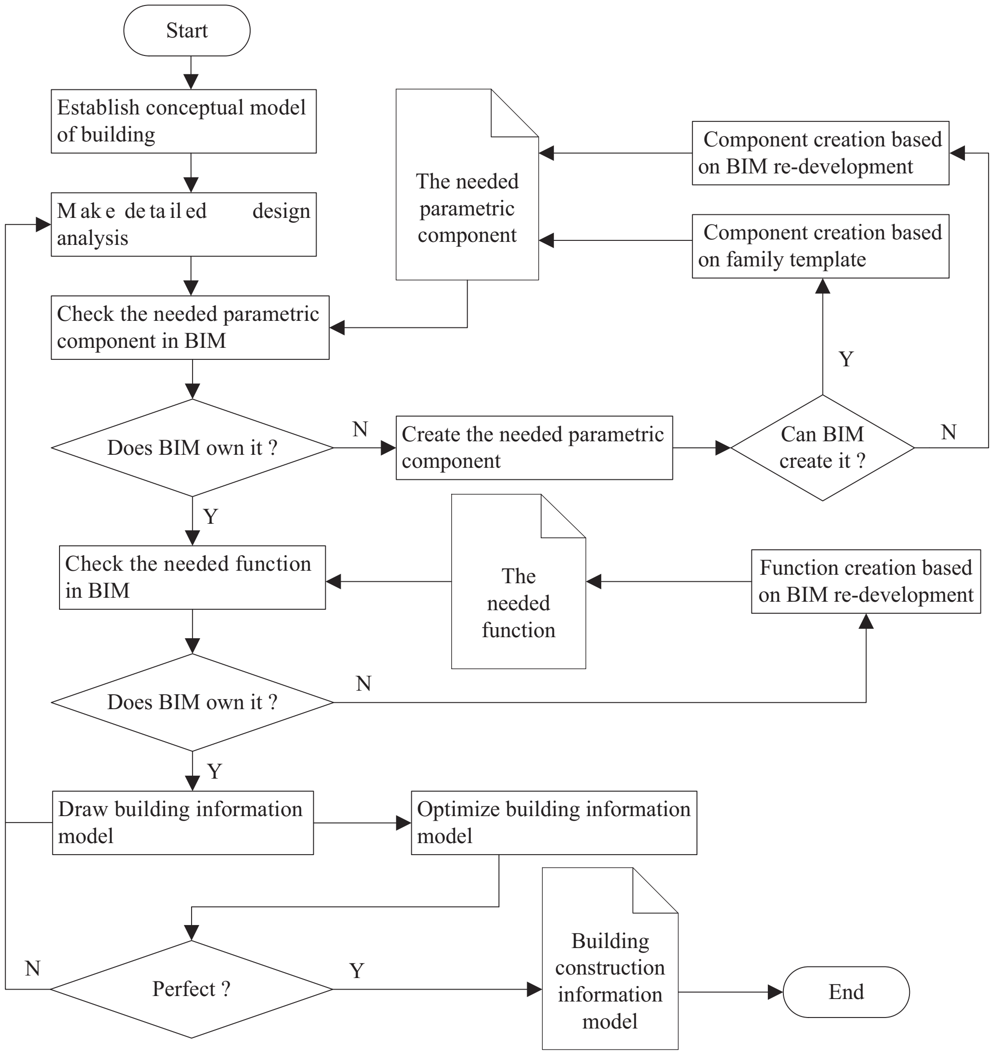


Fig. 1. Traditional parametric design process for non-prefabricated buildings.

3. Traditional parametric design system with BIM

3.1. Traditional parametric design process

Many existing BIM tools are developed in the background of traditional non-prefabricated buildings, such as cast-in-situ concrete structures and brick-concrete structures. The industry foundation classes (IFC) standard achieves the data interchange between these BIM tools [44]. Fig. 1 indicates the traditional parametric design process for non-prefabricated buildings. In Fig. 1, the first thing is to establish a conceptual model of non-prefabricated building on the basis of being familiar with design concept and intention. The concept model is a preliminary model created by architectural design team, which only has a rough building outline. The second thing is to make detailed design analysis on the basis of the conceptual model, and then check the needed parametric components and functions in BIM. If BIM does not own them, it needs to create them by means of BIM re-development or BIM family template. As the definition of family given by Autodesk, a world's largest three-dimensional design software company, family is a group of elements with a related graphical representation and a set of common properties. If BIM owns them, it needs to carry on the next step, namely drawing a building information model and optimizing it. Some feedback mechanisms are indispensable for continuous optimization of the building information model. The final result is to output a building construction information model instead of construction drawings to guide on-site construction. In Fig. 1, it should be noted that 'Y' means yes and 'N' means no.

3.2. Limitations of current prefabricated building design

Parametric design means that all entities in BIM are presented in the form of components. The feature of BIM happens to accord with prefabricated buildings made up of many precast components. Besides, it can be known that BIM has been equipped with a certain number of parametric precast component families and some functions for non-prefabricated buildings are also suitable for prefabricated buildings by studying some BIM products of AUTODEK over the years. According to the traditional parametric design process in Fig. 1, a simple prefabricated building information model is established, as shown in Fig. 2. Right side in Fig. 2 is some basic parametric precast components which constitute the prefabricated building information model, and BIM achieves automatic identification and connection between these parametric precast components during the modeling process. However, some problems are also found during the modeling process, and they are also common in some practical cases. Parametric precast component library in some BIM products does not have enough types of precast component families. Some assembly and connection functions between parametric precast components need to be improved. Besides, according to some relevant firms in Heilongjiang Province, it can be known that architectural design firms lack manufacture and assembly domain experts so that designers of architectural design firms can only draw construction drawings or models for non-prefabricated building

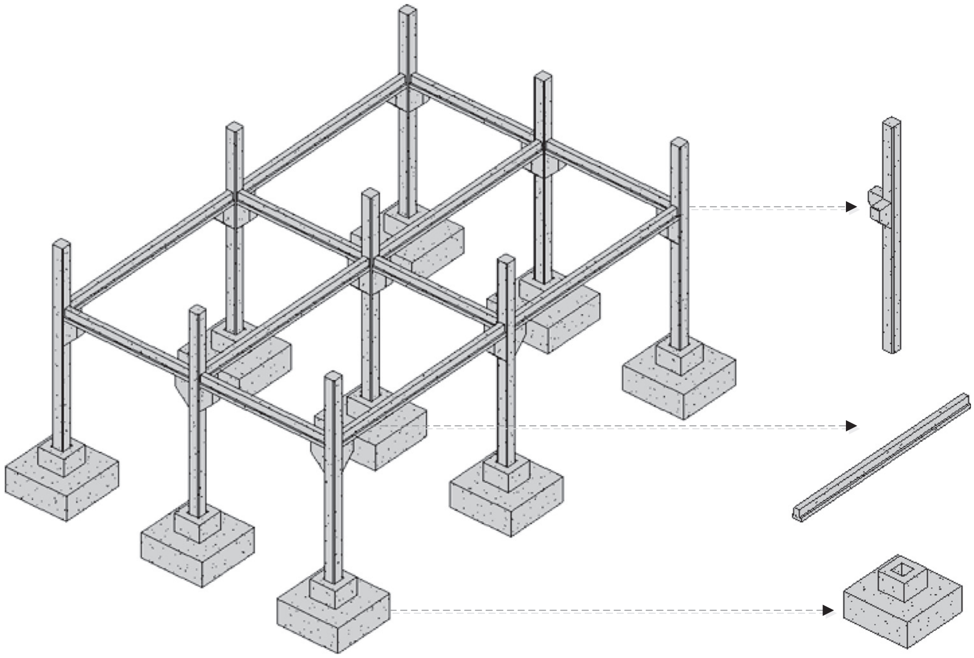


Fig. 2. A simple prefabricated building model.

and split design is handed over to designers of prefabricated-component factories. It reduces communication efficiency between different domain designers and cannot synchronously consider the requirements of manufacturing and assembly in prefabrication building design process. In turn, this will affect the design alteration times, cost and quality of a prefabricated building. Considering the above problems, it is necessary to develop a design system which is dedicated to prefabricated buildings.

4. Concept and process of DFMA-oriented parametric design

4.1. Concept of DFMA-oriented parametric design

Design for manufacture (DFM) means that the design of prefabricated building components should meet the requirements for manufacture in order to make them have good manufacturability [10,11,33,34]. Design for assembly (DFA) means that the design of prefabricated building components should fulfill the requirements for assembly so as to make them own good assemblability [10,11,33,34]. Design for Manufacture and Assembly (DFMA), the organic combination of DFM and DFA, means that designers fully consider the requirements from manufacture and assembly of prefabricated buildings at design stage so as to make the buildings have good manufacturability and assemblability [35,36,45]. It is a design-review method used during product development and improvement [36,51]. The organic combination of DFM and DFA means that DFM and DFA are interrelated and inseparable in DFMA. Good manufacturability and assemblability are embodied in the technological and economic feasibility of manufacture and assembly [35]. The core aim of DFMA is to help designers optimize prefabricated building design and improve its one-time success rate by means of integrating professional knowledge and information of other stages into design stage. So, DFMA principle should be applied at an early stage of prefabricated building design as much as possible.

4.2. Process of DFMA-oriented parametric design

BIM is a key technology capable of supporting DFMA, and DFMA makes BIM more suitable for prefabricated buildings. DFMA-oriented parametric design, a new design philosophy, is the organic combination of DFMA and BIM parametric design. It means that designers not only take into account the requirements of design stage but also consider the requirements of manufacture stage and assembly stage when they use BIM technology to design a prefabricated building. Except for architectural designers, there should be manufacture designers and assembly technicians to take part in design process so as to make the prefabricated building have good manufacturability and assemblability. Fig. 3 shows the process of DFMA-oriented parametric design. In Fig. 3, the first thing is to establish a construction information model similar to non-prefabricated building. The second thing is to make detailed design analysis, especially split design analysis and DFMA analysis, on the basis of the model. Split design analysis and DFMA analysis are used to determine which components of a building should be prefabricated considering the technological and economic feasibility of manufacture and assembly. The third thing is to check the needed parametric precast components and assembly functions in BIM. If BIM does not own the needed parametric precast components and assembly functions, they can be created by means of BIM re-development or BIM family template. Once the components and functions are created, it needs to recheck whether they meet the requirements of DFMA or DFA. Besides, the created precast components should also be saved to the standard parametric precast component library as this will simplify subsequent design works of prefabricated buildings [43,53]. If BIM owns the needed parametric precast components and assembly functions, it needs to carry on the next step, namely drawing and optimizing a prefabricated building information model. Some feedback mechanisms are indispensable for continuous optimization of the prefabricated building information model. The requirements of DFA are regarded as the judgment condition to output a prefabricated building construction information model. It also needs to make detailed design analysis for all parametric precast components on the basis of the prefabricated building construction information model. The requirements of DFM are regarded as the judgment condition to output precast component production information models. In Fig. 3, it should be noted that 'Y' means yes and 'N' means no.

The output results of DFMA-oriented parametric design process are some three-dimensional dynamic information models, namely precast component production information models and a prefabricated building construction information model. It is an important idea of DFMA-oriented parametric design to replace two-dimensional static drawings with three-dimensional dynamic information models created

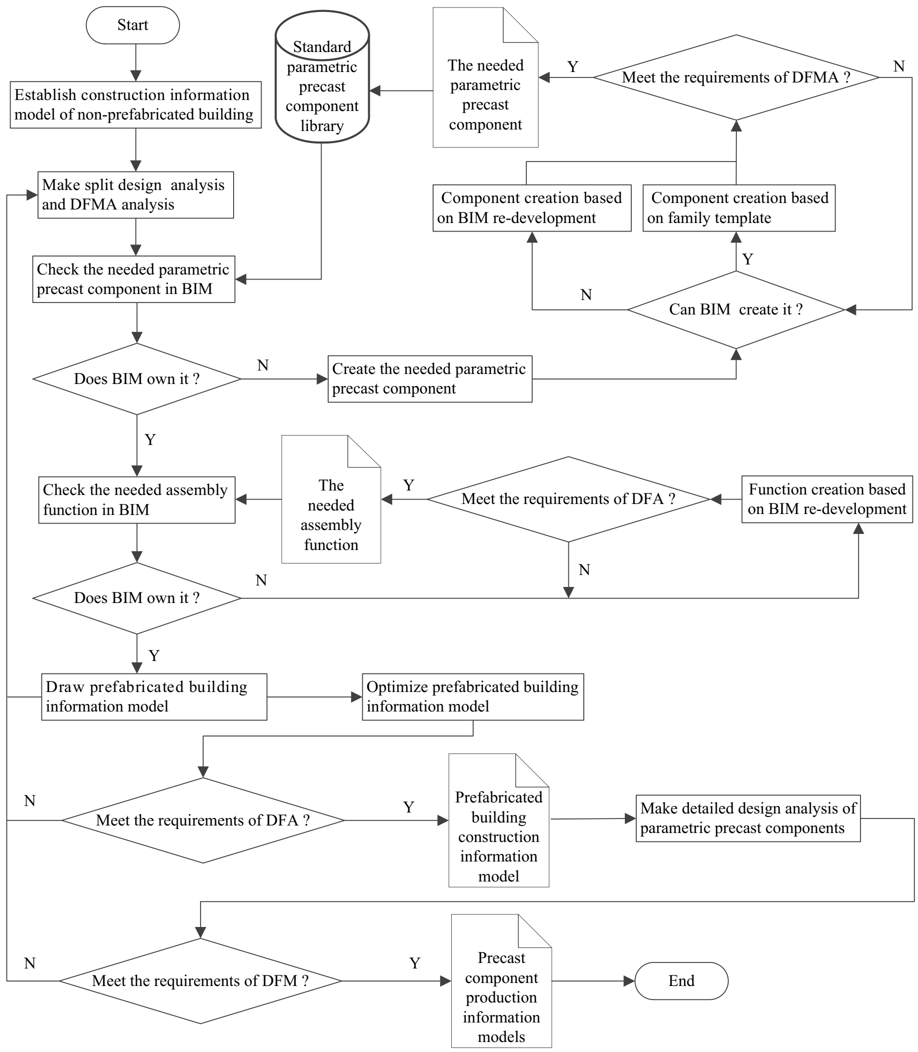


Fig. 3. DFMA-oriented parametric design process for prefabricated buildings.

by BIM technology. These three-dimensional dynamic information models can be displayed real-timely and multi-perspectively. Besides, they can also be used to carry out virtual production training and virtual construction training so as to improve work efficiency and quality of workers.

5. Methods for assisting DFMA-oriented parametric design process

5.1. DFMA-oriented architectural design team

Traditionally, split design of a prefabricated building is made by prefabricated-component factory after construction drawings are finished by architectural design firm [37]. Its limitation is easy to lead to design changes as different professionals cannot communicate with each other in advance. One of objectives of DFMA-oriented parametric design is to avoid the limitation, and it hopes that professional knowledge in manufacture and assembly fields can be used in or even before conceptual design stage of prefabricated buildings. In order to make DFMA-oriented parametric design implemented better, DFMA-oriented architectural design team is developed, as shown in Fig. 4. Compared with some traditional design teams, it also adds split designers and assembly technicians except for architectural designers and structural engineers. DFMA-oriented architectural design team takes BIM technology as design platform and pays more attention to the collaboration between different professions. Architectural design firm is dominant party in the design team, and the other two parties need to cooperate with the architectural design firm. Non-prefabricated building construction information model is mainly drawn by architectural designers and structural engineers, and split design of building is mainly done by split designers. Design communication between these persons is essential in the process. Assembly technicians provide some knowledge about on-site installation of precast components to other designers. In a word, all the information can get timely feedback in DFMA-oriented architectural design team.

5.2. Precast component creation based on family template and DFMA

With the increase of parametric precast component families and relevant assembly functions in BIM, BIM has achieved parametric design of prefabricated buildings to some degree. However, this cannot meet design requirements of all prefabricated buildings. As shown in the DFMA-oriented parametric design process, if BIM does not own the parametric precast components needed by a prefabricated building, they can only be created. There are two ways of creating them. One way is to create them by means of appropriate family templates in BIM. The other way is to create them through BIM re-development, and it needs to access BIM database through the application programming interface (API) of BIM [38,39]. Fig. 5 shows the parametric precast component creation process based on family template and DFMA. The process is running in Revit which is a typical BIM technology developed by Autodesk. The biggest advantage of Revit is parametric design, and it can generate the plan, elevation, profile, three-dimensional, and detailed

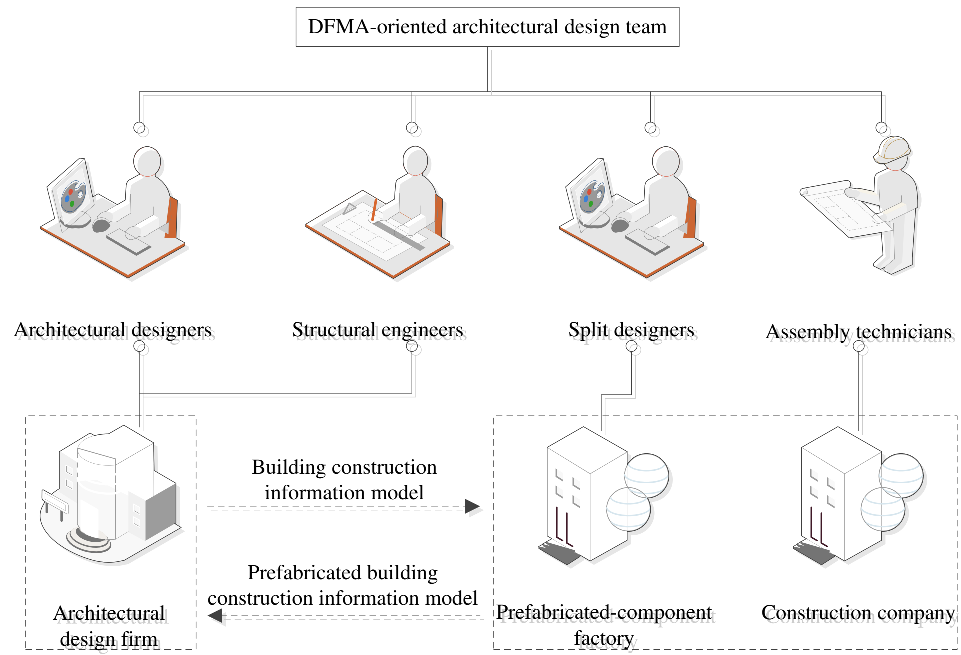


Fig. 4. DFMA-oriented architectural design team.

views at the same time in design process [40]. The advantage makes Revit very suitable for prefabricated building design. In Fig. 5, the first thing is to carry out DFMA analysis so as to timely integrate the detailed information required by manufacture and assembly stages of precast components into design stage, such as geometry, structure, connection, manufacture process, assembly process, mechanical equipment. The second thing is to plan and create a needed parametric precast component family. It is similar to the traditional workflow of creating a loadable family[41]. In the end, the requirements of DFMA should be considered once again to ensure the basic manufacturability and assemblability when DFMA-oriented architectural design team tests the family. In Fig. 5, it should be noted that 'Y' means yes, 'N' means no, and much basic content is from Autodesk and ChinaBIM.

The entire creation process of a new family is executed by using family editor in a predefined family template. Fig. 6 shows a parametric precast column family in Revit 2014, and the family is created through a column family template. Its specific creation process can be as follows. Firstly, DFMA-oriented architectural design team makes a detailed DFMA analysis of the needed precast column so as to identify the requirements of manufacture and assembly stages and select an appropriated column family template. Secondly, they draw the precast column family and set parameters according to the information gained from the DFMA analysis.

5.3. DFMA-oriented BIM re-development

In DFMA-oriented parametric design process, BIM re-development can create some functions needed by prefabricated building assembly so as to further exploit the potentialities of BIM. A software programmer can make use of a software development tool to do secondary development of BIM by calling BIM Application Programming Interface (API). Some special assembly functions can be created through BIM re-development. The Revit API, a kind of BIM API, allows a software programmer to write instructions for Revit [39]. Fig. 7 shows the process of DFMA-oriented Revit re-development. The essence of Revit re-development is to add a plug-in to Revit. In Fig. 7, the first thing is to conduct DFMA analysis so as to fully understand the intents and details of Revit re-development. The second thing is to plan and create a plug-in. A plug-in planning includes selecting a kind of suitable development software to do secondary development of BIM. According to Autodesk, C# programming language is more suitable for Revit re-development. Therefore, the process of creating a plug-in needs two tools: Visual C# Express and Revit. Visual C# Express can access Revit via Revit API. If Revit wants to use the plug-in, it is indispensable to write a plug-in manifest [38]. In the end, it needs to add the plug-in to Revit for test. Compared with traditional test of Revit re-development, the test in Fig. 7 adds the requirements of DFMA. In Fig. 7, it should be noted that

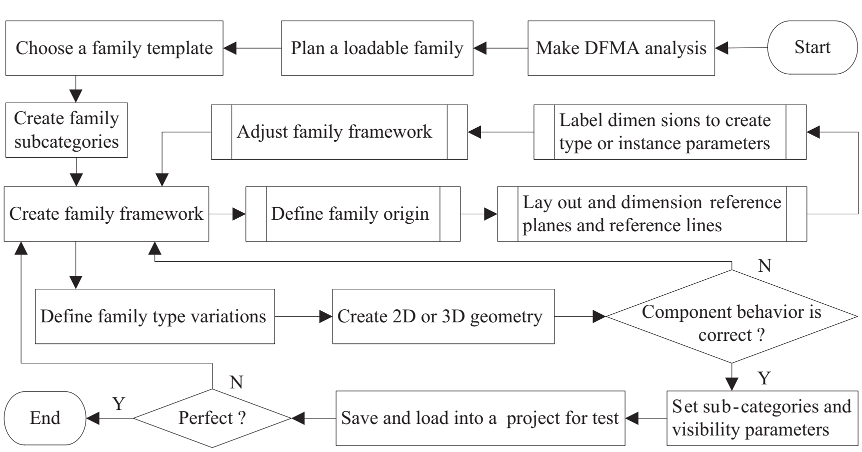


Fig. 5. Precast component creation process based on family template and DFMA [41,42,54].

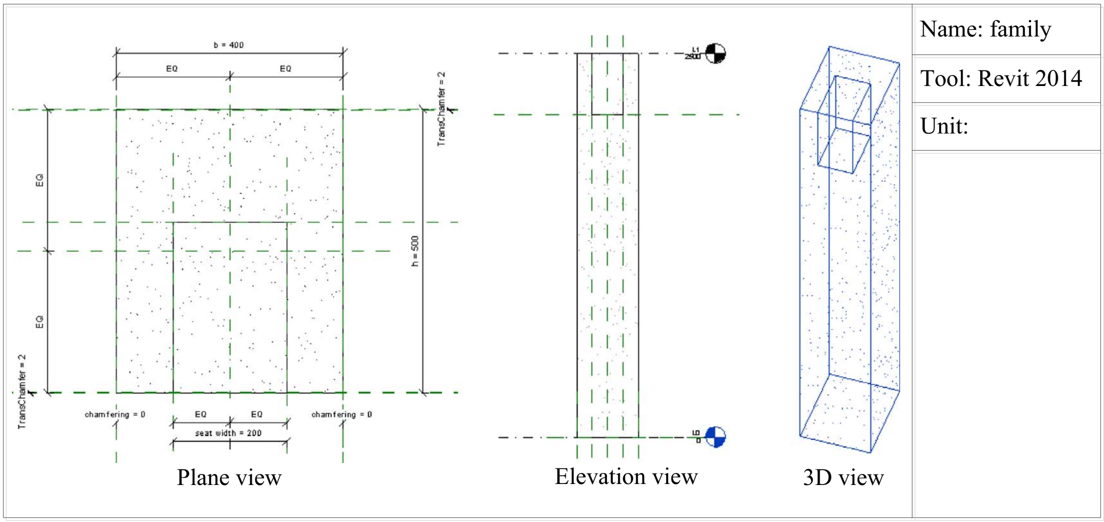


Fig. 6. Draw a precast column family through column family template.

'Y' means yes, 'N' means no, and much basic content is from Autodesk.

5.4. DFMA-oriented prefabricated building information model optimization

In DFMA-oriented parametric design process, the transition from non-prefabricated building construction information model to prefabricated building information model is a partial optimization process, but the transition from prefabricated building information model to prefabricated building construction information model and precast component production information models is a global optimization process. Fig. 8 shows the detailed global optimization process of DFMA-oriented prefabricated building information model. In Fig. 8, prefabricated building information model optimization mainly includes component optimization, joint design optimization, and clash detection and optimization. Besides, it also adds manufacturing simulation, transportation simulation, and assembly simulation. Component optimization is mainly used to reduce the types of precast components, and increase the versatility of precast components. Joint design optimization mainly considers seismic resistance. Clash detection and optimization is mainly to check and solve the conflict between precast components. Manufacturing, transportation and assembly simulation are mainly used to find some later problems caused by design. It is very important to veritably simulate the manufacture process of precast components as much as possible. A system integrating manufacture expert consultation function is indispensable for avoiding the knowledge gap between design and production [46]. DFMA-oriented architectural design team can use the system to carry on manufacture simulation of precast components. In manufacture simulation, the first thing is to determine the production process of a precast component.

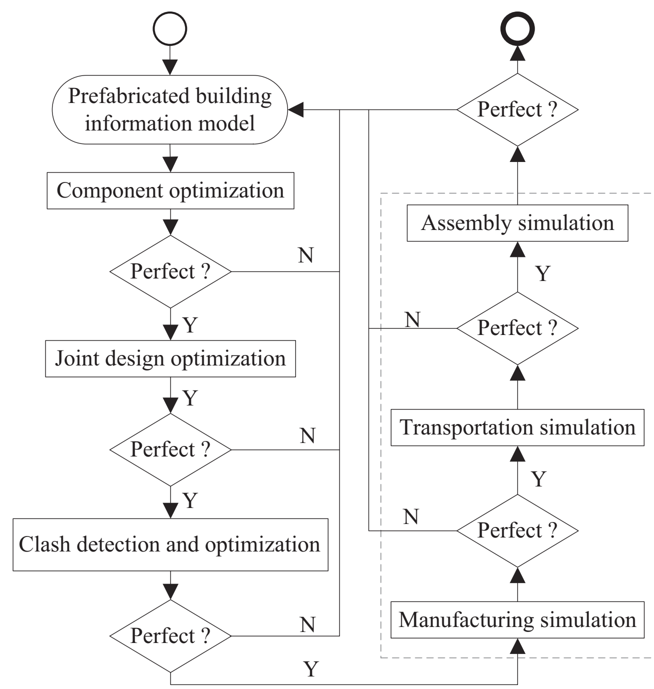


Fig. 8. Optimization process of DFMA-oriented prefabricated building information model.

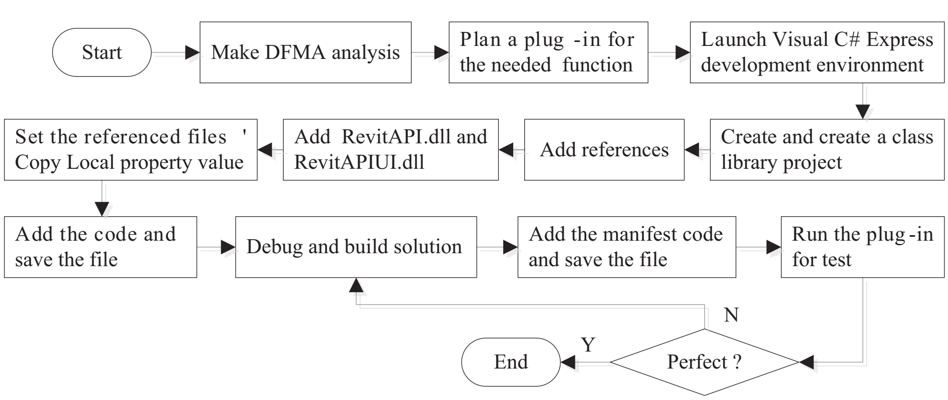


Fig. 7. DFMA-oriented BIM re-development process [38].

For example, the production of a precast concrete component needs to experience many steps, including: bind reinforcement cage, assemble mold, lay facing material, put steel into the mold, install embedded parts, cast concrete, etc [47,48]. If some questions are found in manufacture simulation, the information will be fed back to the prefabricated building information model so as to optimize it. If not, carrying on the next step. It is also very important to veritably simulate the assembly process of precast components as much as possible. The precast components which are within the working radius of cranes are lifted to an installation area by the cranes, and then are installed [50]. So, it needs to make a series of plans for assembly simulation, such as lifting sequence planning, lifting path planning, component's specific installation and connection [49]. If some questions are found in assembly simulation, the information will be fed back to the prefabricated building information model so as to optimize it. Otherwise, end the optimization process. In Fig. 8, it should be noted that 'Y' means yes and 'N' means no.

6. DFMA-oriented parametric design examples

DFMA-oriented parametric design encourages parametric design of BIM and takes into account the knowledge of manufacture and assembly stages in design stage. Some studies related to prefabricated buildings have mentioned parametric design, connection types and seismic behavior of precast components.

Ghang Lee, Rafael Sacks and Charles M. Eastman, three famous scholars, develop a parametric object design process [15]. When the three scholars study parametric building object behavior (BOB) notation, they consider connection between precast components. Fig. 9 shows various types of connections between parametric precast components. These parametric precast components and connectors are created by BIM technology. A prefabricated building construction information model shows not only all precast components but also all connections between them. Assembly behavior notation of parametric precast components is necessary for a prefabricated building construction information model. It is helpful to timely find out the problems related to the installation operation of precast components in design stage.

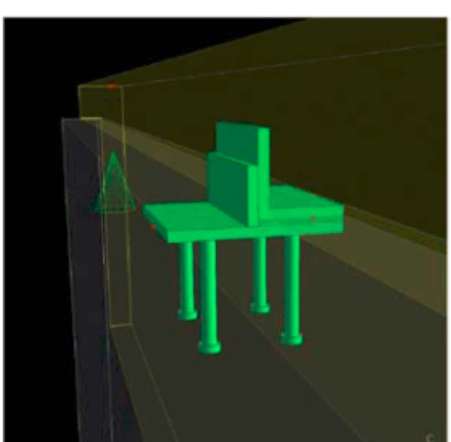
Ercan Yuksel, H. Faruk Karadogan, I. Engin Bal, Alper Ilki, Ahmet Bal and Pınar Inci, six famous scholars, study precast exterior beam-column connections, and compare industrial type connection with residential type connection in terms of seismic behavior [16]. Fig. 10 shows the precast exterior beam-column connections for an industrial building. In Fig. 10, the precast beam is connected with a skew bracket of cow-leg pillar by means of some connectors, and the virtual connection design in BIM meets some requirements of DFA. It is very important to consider joint's seismic behavior between precast components in design stage. This is good for modelers to timely adjust the original prefabricated building construction information model so as to avoid some potential security problems in the future.

Prefabricated building design is a systematic process. The requirements of design, manufacture and assembly stages are the indispensable elements of the system, and they are influenced and restricted between each other. Therefore, when a DFMA-oriented design team establishes a prefabricated building information model, they need to consider not only assembly but also manufacture. A DFM-oriented precast beam is designed with Revit by a temporary DFMA-oriented design team, as shown in Fig. 11. Some of its properties come from a prefabricated building project. Before creating the precast beam, the temporary DFMA-oriented design team consults some information related to precast component production. In the process of creating the precast beam, the temporary DFMA-oriented design team optimizes it for meeting the requirements of production better. After it is completed, the output is a three-dimensional (3D) information model called DFM-oriented precast beam. The DFM-oriented precast beam can be displayed from different perspectives, and its dimension can be labeled in real time. Therefore, the 3D information model can replace production drawings to better guide workers to machining a real precast beam. In Fig. 11, the selected bar appears transparent, and displays its related information in the properties column. These aspects are very helpful for precast component production.

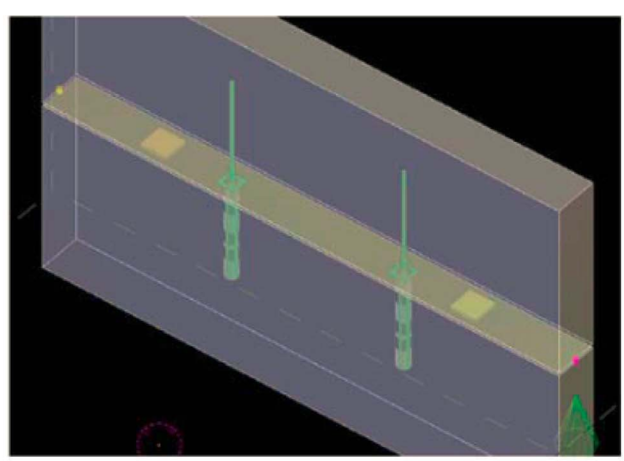
7. Results and discussion

Compared with the traditional parametric design process, the process of DFMA-oriented parametric design adds split design analysis and DFMA analysis, considers the requirements of manufacture and assembly stages, establishes a standard parametric precast component library via the re-development and family template of BIM, and expands BIM functions needed by precast component assembly by means of re-development technology. DFMA-oriented parametric design realizes the coordination of building domain designers, manufacturing domain designers and assembly domain technicians, and further taps the potential of BIM. The output results of DFMA-oriented parametric design are a prefabricated building construction information model and precast component production information models rather than lots of static two-dimensional drawings. All information required by the production and construction can be obtained from them.

In order to make DFMA-oriented parametric design better implemented, this paper further establishes some relevant auxiliary



(a) A slab-to-wall connection



(b) A wall-to-wall array connection

Fig. 9. Various types of connections between parametric precast components [15].

(a) An actual beam-to-column connection (b) A virtual beam-to-column connection

Fig. 10. Precast exterior beam-column connections for an industrial building [16].

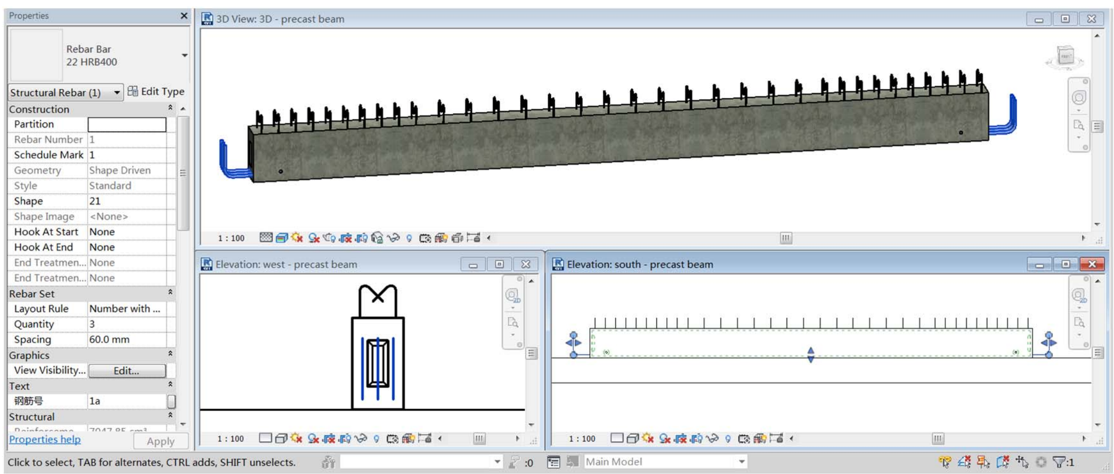


Fig. 11. A DFM-oriented precast beam.

methods, including DFMA-oriented architectural design team, precast component creation based on family template and DFMA, DFMA-oriented BIM re-development, and DFMA-oriented prefabricated building information model optimization. DFMA-oriented architectural design team adds split designers and assembly technicians on the basis of traditional design team, and is used to solve the communication problem between different domain designers in prefabricated building design process. Precast component creation based on family template and DFMA is used to solve the problem that some existing BIM products do not have enough types of precast component families. DFMA-oriented BIM re-development is used to solve the problem that some existing BIM products lack some assembly and connection functions needed by parametric precast components. The optimization process of DFMA-oriented prefabricated building information model is used to transform prefabricated building information model into prefabricated building construction information model and precast component production information models from a global optimization perspective.

The examples (proposed in Section 6) reflects some ideas of DFMA-oriented parametric design, such as connection between precast components, assembly behavior and seismic behavior of precast components, data-rich precast component production models. DFMA-oriented parametric design has a certain application value in the field of prefabricated buildings.

8. Conclusions

This research combines DFMA with BIM to develop the concept and process of DFMA-oriented parametric design. Compared with the traditional parametric design, DFMA-oriented parametric design is able to make designed prefabricated buildings own good manufacturability and assemblability. In order to further support and achieve DFMA-oriented parametric design, 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 developed successively. These four auxiliary methods can also be seen as the refinement of some content in DFMA-oriented parametric design, and show how to solve the manufacturability and assemblability problems of designed prefabricated buildings in detail.

As a new design philosophy specifically developed for prefabricated building, DFMA-oriented parametric design can integrate domain expertise of manufacture and assembly stages into design stage so as to increase the one-time success rate of design. However, for the complexity of prefabricated building design, DFMA-oriented parametric design needs to be continuously improved with the development of BIM technology and prefabricated buildings.

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