Strategies for Implementation of Integrated Prefabrication Technology in Small Scale Isolated Buildings

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Abstract
As a developed technology, prefabrication is widely used in the field of industry for its organized and efficient work process. Yet up to now the progress in the architectural field in China is limited. With the increasing labor costs, architecture will have to get rid of the dependency of large human sources, which makes prefabrication one of the most practical solutions. Given these situations, this article discusses specific technologies of prefabrication in buildings. The article includes following respects.

First, Integrated prefabrication in designing----learning from industrial productions. Taking several industrial productions as reference, analyze what benefit can be gained through the separation of manufacture and combination, and list the conclusions respectively in architecture. Second, Integrated prefabrication technologies in architecture and structure system. Based on the analysis of proposals of SD competitions, specific changes from current work process are depicted, and relative profits in resources, costs and efficiency are discussed. Third, Equipment system integration and full life cycle operation. The article summarizes equipment necessary for a sustainable prefabricated building, including solar photovoltaic system, reclaimed water system and ventilation system, followed by the methods of integration and their feasibilities.

Keywords: Prefabrication; integration; sustainability;

1. Background

As the rapid development in science and technology and the rocketing pacing of life, traditional constructing technologies are showing their deficiency when faced with high-efficient, high-quality and low-impact construction needs. Traditional structural technologies prefer separate component as the basic unit during constructing, followed with on-site process of assembling the components which favored by most with the intrinsic ubiquity as one of the major advantage. Nevertheless, the traditional constructing patterns

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are no longer suitable towards current situation, bringing about negative effects in scheduling, quality or surrounding environment during the construction. Different from the common constructing approaches, the integrated building systems, synthesizing a variety of technologies, can efficiently make up the major disadvantages of the previous approaches and facilitate the development of industrious construction via prefabrication.

In China, the prefabricated approaches appeared in the 1970s for the first time referring to the process of prefabricating and assembling some component before the on-site construction. Over the latest decades, Chinese government has been encouraging through media in order to promote the development of prefabricated building. According to the 2012 official report, the government is looking forward that in coming ten years the prefabricated buildings can occupy 30% of future constructions. The message illustrates social attention nowadays about the utility of the prefabricated technology.

However the current reality is not showing the rosy anticipations. The prefabrication meets several obstacles: First, the cost rises as the rate of prefabrication increases. When the rate of prefabrication is 20% to 30%, the construction cost is 300-500 RMB per square meter more than buildings without prefabrication. Second, the management of the field of prefabrication is yet imperfect. Besides, the industry chain in China is still developing and is far from well-established. Based on this situation, we hope to be able to implement the technical reform of the industry to all stages of the full-cycle construction process, and to facilitate the pace assembly-based technology integration by identifying the tasks and key points of each stage.

2. Methods

The article takes small-scale isolated building as an example to propose the concept of small-scale isolated building in building system, and explains the requirements in energy saving problems based on the discussions on its characteristics. This special type of building is a carrier of study on technology integration and has template meanings as well as universal effects. In the article, analysis about its life cycle is shown to explain the key points during all the architectural periods in order to make the target clear.

Small-scale isolated building is an ideal model which leads to the building or building group that is self-sufficient and able to have operations over totally no-infrastructure conditions. This model has mainly two important meanings in theory discussion and system construction: Firstly, it has universal potential. In real situations, researches on a building is influenced by environmental facts, while an ideal model can simplify the discussion; secondly, this model requires the sustainable capability at the same time. In this condition we focus more on the energy problem which contains a great deal of technology branches.

The article takes the perspective of life cycle as the basic framework and small-scale isolated building as its carrier, and discusses the working style and according technology advantages of integrated prefabrication buildings in order of design, structure, equipment and operations.

3. Technologies in the full-cycle of small-scale prefabricated building

3.1 Integrated prefabrication in designing----learning from industrial productions

Today, building prefabrication is put into practice worldwide. Nevertheless, compared to the popularity of other fields of industrial manufacturing, that of the assembly in the field of building remain insufficient. A building can be considered to be a product, but it relies on a certain site and circumstances, which is closely related to the whole process from the initial design to the final construction. Compared to the highly assembly design of industries such as the automobile manufacturing, the obvious difference is the depth of design. A complete automotive product must be assembled from thousands of parts, demanding a high-level of
accuracy. It focuses on the composition of the products while the building industry emphasizes the assembly of different products, although the complexity of the building industry is not lower than that of the automobile industry considering the detailed difficulties in the constructing process. Firstly, the accuracy controlling is relatively rough within building industry. That is, the requirement for individual phase are not high enough to emphasize the degree of assembly. Secondly, from the design to the construction phases, excessive barriers prevent the designers from reaching the building industry. The implementation of the assembly technology is expected to transcend the barriers.

One solution is to adopt the “bottom-up” design approach. In the automobile industry, for example, although the major design method is carried out in accordance with “top-down” approach, that is, from concept to details; in practice, however, the adopted software involves the powerful part of the physical modelling function which involves the “bottom-up” methods based on the component unit to finish further design. As for the building industry, designers should bring the assembly concerns into the initial design process which in general create an integrated, coherent and systematic design method. Take a small-scale isolated building as an instance, the demands of assembly integrated design can be summarized as the following:

a. At the beginning of the design, it is necessary to consider the assembly of the program in general.

b. The design process should respond in time to the assembly needs, update the module system refactoring and make replacement to components.

c. The depth of future design model should be enhanced and be more comprehensive, through technology including BIM.

d. The designers should recognize the scope of their responsibilities. The conceptual design of a certain building cannot be divorced from the practical feasibility, and the designer needs to take the meticulous issues into account including assembly, transferability and prefabrication.

Correspondingly, the new design pattern can bring following advantages:

a. Efficiency. The impact of assembly is crucial to the construction stage for it can tightly control the procedure and the schedule, avoiding the unnecessary temporary consumption of the scene. Moreover, the design that adopted assembly strategies is beneficial to the on-site construction due to the highly-accurate and united working process is finished before the on-site construction, leaving the clear task to the on-site workers.

b. Cost. Admittedly, to build a generally recognized new technology system, the initial cost is relatively high. Yet once the assembly pattern is completed, there will be a large amount of pooled resources accumulated during the application phase, resulting in a significant reduction in the cost of duplication.

c. Commonality. When the whole industry adopts a unified design method, the transformation of design results will be more systematical and universal than the current system. The design method provides a more consistent template between designers and builders and between each designers, so as to enhance the exchanging of information.

3.2 Integrated building prefabrication technologies in SD competitions

To analyze the technologies related to small-scale isolated houses, the article takes the Solar Decathlon (SD) competition for an example. The Solar Decathlon Competition is a representative international student building competition toward small-scale isolated house to design, build and operate a fully functional, comfortable, sustainable solar home. The SD competition encourages college students to combine solar technology, energy saving strategies and architectural design in general. During the competition, energy for operating the solar house is entirely supplied by solar energy equipment. The SD competition has ten
individual contests: architectural design, engineering, market appealing, communication, innovation, comfort zone, applications, family life, electric vehicles and energy balance. The ten individual contests evaluate the building comprehensively and make it possible to indicate the general performance of the small-scale isolated buildings and their adopted assembly technology.

**Structure**

Every work in the competition series are supposed to meet the basic needs of a small residential house, that is, living demands, water supplying, electricity system and control system. Because of the short on-site competing period (15 days, including construction and equipment debugging), each team starts their initial design considering the integrated prefabrication, and then, under the premise of meeting the basic space functions, tries to achieve optimal solutions among the structure, transportation, assembly technology. Therefore, the design strategy of each project in SD competition illustrates the correlation between spatial organization and the chosen construction system. The 22 programs from SDC 2013, for example, can be divided into four types.

a. Wall assembly. The enclosure of the house is divided into wall units, followed by relatively simple prefabrication process yet convenient transportation. The drawbacks are the complexity of on-site construction resulted from the circuit lines cannot be entirely prefabricated but assembled on-site.

b. Box assembly. The method refers to the process of directly placing the highly completed box on the site, then merely carrying out the assembly of equipment and finishing. The equipment system has been installed in the box unit during the reassembly process, thus the construction speed is faster. The disadvantage is its strict requirement of precision, and minor adjustment can be made during the construction. Therefore the designer are required to make construction process simulation and planning while the design stage.

c. Component assembly. There is not completed unit during the prefabrication process, the construction work is mainly concentrated on site instead. Therefore, the obvious drawback is that the construction schedule is relatively longer. Yet because of the use of individual components as the basic units, larger adjustment can be endured on site and thus this demonstrates flexibility in error control.

d. Mixed assembly. The method combines two or more building units. The building is divided into appropriate units during the design stage, such as box or component, and reflects mixed characteristics.

The decisions among construction system of SD teams illustrate that the choice comes from a comprehension of various demands of design. In general, the demands are as follows: spatial layout, reasonable structure, functional needs, passive strategies, and transportation from factories to the site.

**Design Stage**

In addition to the basic functional requirements from the SDC Competition rules, each team has put forward a certain target group for their house according to the pre-survey relating to market appealing, which leads the individual needs of the building, such as elderly residential design or children activities, etc. Unlike the idea of “proposal - functions - layout” in a traditional architectural design process, the designer of a prefabricated building is limited by the suppliers and is forced to select the type of assembly system at the initial part of the design stage, after which they are able to determine what is considered the pre-set of a traditional design, such as layout, spatial form, etc. The selection of assembly systems is followed by the selection of general design strategy, during which the factors like comfort zone or the specific functions are also taken into accounts. Afterwards there will not be big differences between the practice of assembly design and that of the traditional design. Yet there are still many detailed issues to be concerned, such as material selection, modulus development, etc.
Furthermore, in order to overcome some of the limitations of small assembly buildings, such as precision controlling and transportation restrictions, as well as the strict requirement from the competition, such as the extremely short on-site schedules and the strict construction regulations, BIM software is involved in the further stage of design as a necessity to verify the feasibility of the project. In the detailed design process, the crucial part for the designer is to concern about the construction procedure, for example, the electrical installation of prefabricated buildings.

BIM Application

The construction sequence of the assembled integrated building is divided into prefabrication and on-site construction. For the SD competition, the assembly quality and the speed of on-site construction are largely influencing the general performance of the whole building in both subjective individual competitions and objective ones. Because of the dichotomous stages of the assembly technology, the architects are enabled to control the construction quality to a greater extent through greater adjustment during pre-construction process. The application of BIM technology also ensures a more complete information retention and interaction, to attain a better participation of the designer through the whole life cycle.

Because of the great differences in technique, structural construction and interior decoration are often two separated steps when adopting traditional construction methods. After the completion of the basic structure, usually reinforced concrete, the interior designer needs to re-measure the site to determine the actual structural finishing due to the error between the original model and the actual construction to feedback and to modify the initial interior design. On the contrary, the component of small scale houses are more industrial which preserves the possibility that to add image recognition point on the products. During the construction, three dimensional scanning can be adopted in monitoring of construction errors, then re-entered into the BIM software, for each step of the next step to provide guidance and correction. Meanwhile, the manager can utilize WSN so as to provide clear information and communicate the information to each on-site worker and manager and thus resources are saved.

3.3 Equipment system integration and full life cycle operation

Despite of limited area, small-scale assembly building is fully functioning, so there is also need for adequate intelligent control system. The intelligent control system should fulfill a variety of integration, including functional integration, technology integration, and information integration. Functional integration, stands for the integration of functions that are traditionally separated in a building, and in the integrated system, the control can be easily achieved with the user interface, one-key operation, for example. Technology integration, stands for the integration of information from different disciplines, which has impact on the building through information exchange, processing, and coordination. Information integration means, through information collection, processing and feedback, to integrate and evaluate data from individual equipment systems, and to optimize energy and resource allocation while taking into account the immediate needs of users, so as to efficiently meet the need of running a building.

Control system

According to the rules of the competition, when the house is completed, three individual contests including energy balance, comfort zone and appliances, will be measured with the data of housing performance. To evaluate the energy balance of the building, the overall use of power generation and power consumption will be assessed. Each team is equipped with two-way electrical meter, if the electricity generation is greater than the electricity consumption, the house is considered zero energy consumption, and if the difference is below zero, the points linearly decreases (-50 Kwh corresponds to 100 points of deduction). Comfort zone contest
is divided into two parts, the temperature and humidity, and full points can only be achieved with the indoor temperature between 23-25 degrees and the humidity between 40%-55%. It is worth mentioning that in the competition of 2017, the assessments of indoor CO2 concentration and PM2.5 concentration are add as test items, and indoor air quality is assessed from a more comprehensive perspective. Appliances are to examine the work capacity of washing machine, dryer, dishwasher and refrigerator, and also a daily measurement of solar water heaters, to test whether the building has the capacity to meet the need of daily life.

In fact, besides the appliances and equipment required by the rules of the competition, the selection of eco-strategies, either passive or active, will lead to some additional reconfigurable figures, such as electric shade. Moreover, necessary water circulation system, lighting equipment, and home entertainment equipment are also essential elements of building use. Therefore, a sound and stable control system is cardinal in the background to support the operation of the building, while meeting the needs of everyday life. Intelligent control system makes the various parts of the building coordinate with each other, and manages the building from four respects: lighting, air conditioning, building components and household appliances.

4. Conclusion

Prefabrication is a new method of construction, whose benefit include safety, endurance, convenience in construction and sustainability. However, the deficiencies include high cost, immature management and industry chain. Small scale isolated architecture can be a versatile experiment platform for the promotion of building prefabrication in China. It can test: first, multiple structural system and means of assembly; second, the full cycle management from manufacture to maintenance; third, the application of sustainable technologies, for example, intelligent control or passive design.

Currently the criteria of the design, construction and maintenance of integrated prefabrication buildings in China is immature, much of which is still at the researching stage. In the future, there should be a more systematic assessment standard, in order to assess various technologies and provide reference for the further marketing of integrated prefabrication technology.

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