Overview of Modular Design Strategy of the Shipping Container Architecture in Cold Regions

Zexin Sun, Hongyuan Mei and Ruixian Ni

School of Architecture, Harbin Institute of Technology, Room 325, No.66 Xidazhi St, Harbin, Heilongjiang, China

736087330@qq.com

Abstract. In recent years, the shipping container architecture, as an emerging green building mode, has grown in popularity. In this article, we analyse the advantages of applying shipping container architecture in cold regions, such as shortening the construction cycle, saving construction materials, reducing energy consumption and adapting to diverse sites. Then we analyze the modular design strategy and the modular design strategy in architecture. In the end we introduce the modular design strategy of shipping container architecture in cold regions with the technology roadmap, classification and combination.

1. Introduction
In recent years, the shipping container architecture has grown in popularity. The shipping container architecture refers to a type of architecture transformed from the steel intermodal containers (Figure1). With the crises of resources and environment, sustainable and green are becoming the consensus of architecture gradually. As an emerging type of green building, the shipping container architecture has shown great potential in construction efficiency, economy, mobility and sustainability [1]. As a transportation product, shipping containers have standard sizes and high structural strength so they are very suitable for standardized construction. Besides, the shipping containers is an eco-friendly building material which can be easily recycled and reused and also the shipping containers are with a relatively low expense and have a wide range of sources, there are more than 1 million TEU (Twenty-Feet Equivalent Units) of shipping container selimized every year, provides sufficient materials for the construction[2]. Architecture in cold regions have the problems of short construction cycle, high building energy consumption and high construction material consumption, the introduction of the shipping container architecture provides a new opportunity to solve these problems and develops a new territory of architecture in cold regions.

2. The advantages of shipping container architecture in cold regions
The cold regions are at high latitudes and have relatively longer winter (Figure2). Due to the limitation of region and environment, architecture in cold regions faces a great shackle on greenization [3]. Under such circumstances, there are many advantages of applying shipping container architecture in cold regions as follows.

2.1. Prefabrication, shorten the construction duration
In cold regions, it is very difficult to carry out construction in the long cold winter, which leads to a poor economic performance due to the short construction cycle and long-duration of the project. However, the shipping container architecture is more adapted to the industrialization since it is easier to be prefabricated in the factory with a more stable construction process and a higher degree of standardization. The construction duration will be shortened by using standardized prefabricated modules and the construction efficiency will be improved greatly as well. Compare to the traditional reinforced concrete structure buildings, the construction duration will be shortened to 1/3, and the useful life will be increased by 40% [4].

![Figure 1. Stacked shipping containers form temporary pavilion in Shanxi, China, by People's Architecture Office](image1)

![Figure 2. Cold regions in China (the blue part) according to the “Thermal Design Code for Civil Buildings”](image2)

2.2. Recycling, save the building material
The building envelope is thick and heavy in cold regions due to the requirement of insulation performance, and the components of therein forced concrete structure buildings are in large size, both of them lead to a low effective area coefficient of the buildings. Besides, the traditional buildings cannot ensure the maximum performances of the materials and also the construction materials are difficult to recycle and reuse, it will produce a lot of construction waste during the construction process, leading to a huge waste. Shipping container architecture applies the standard container, which is an ideal building material with good structural strength and long durability as the basic module, lead to a relatively high effective area coefficient of the building. At the same time, shipping container is easily to recycle. The introduction of shipping container architecture in cold regions will bring more than90% of reducing, reusing, and recycling the building materials.

2.3. Standardization, reduce building energy consumption
The climate of cold regions can be characterized by low temperature, little sunshine and long winter, therefore, buildings should take full account of the demand of adaptive with the cold climate. As an industrial product, the shipping container is easier to standardized prefabricated in factory. The performance of the building will be improved through a systematic design and construction process from the inside to outside, through using the integrated heat preservation and heat storage technology as well as the BIM (Building information modeling) platform; it will effectively improve the thermal performance and reduce the energy consumption of the building. Compare to the traditional construction methods, the shipping container architecture can achieve 40% of water saving, 90% of energy saving, 20% oflandsavingand80%of construction waste reducing [5].

2.4. Removable, adapt to diverse sites
Cold regions are with varied landscapes, such as snow, ice, lakes, forests, grasslands, wetlands, farmlands and so on; the diverse sites have more requirements for the buildings. Besides, the buildings
are significant seasonal, the frequent demolition and construction of seasonal service buildings will cause a huge waste of resources. While the shipping container architecture has the characteristic of moveable and convenient to assemble or disassemble, it cannot only be used to build mobile homes for various sites, but also can be applied in the seasonal service facilities and shelters, so that it will greatly expand the scope of buildings in cold regions.

3. Analysis of the modular design

In the perspectives of globalization and industrialization, the concept of modular design was formed based on the idea of standardization. The modular design aims at improving the degree of versatility, reducing the variety and numbers of components in order to use less cost to get more series of productions. The concept of modularity was applied to manufacturing industry first, and then it was widely applied in architecture gradually.

3.1. Modular design

The modularity is based on the idea of standardization with an advanced form. The so-called standardization is to develop common and repeated service regulations for specific or potential problems in order to get best orders. The essence of standardization is achieving unity through customizing, distributing and implementing the standards. And the modularity is aimed at simplifying the design process in order to use the manpower and resources effectively, shorten the construction cycle and improve the quality of products, so that it will reduce the cost and maximize economic benefits in the end.

Modular design doesn’t have a unified and precise definition (Table1), it usually refers to break up a large system into several subsystems within a series of relations, and each subsystem can be replaced or combined with each other. Masahiko Aoki indicated that each module is a half self-discipline subsystem, the modules are connecting with each other in certain rules in order to interrelate and constitute a more complex system, the modularity contains the two behaviors of division and concentration of the modules[6].

| Table 1. Narrow sense and broad sense of modular design |
|--------------------------------------------------------|
| **Connotation**                                      | **Denotation**                        |
| Narrow sense                                         |                                     |
| 1. The system has a clear multistage modular hierarchies | Modular production composed by different modules. |
| 2. Modules have compatibility on function and size   |                                     |
| Broad Sense                                          |                                     |
| 1. Project is with a clear hierarchy                 | Everything composed by typical generic units |
| 2. Modules are with generality and representativeness |                                     |

The modular design strategy is of great significance for contemporary manufacturing. The practice of modular design started long before, in 1964, IBM designers creatively developed the IBM360 system through using modular design strategies, achieved the important landmark in the history of computer innovation. Then, the modular design strategy was widely applied in the industry of automotive, furniture, integrated circuits, manufacturing and so on. In recent years, the modular design strategy has been adapted to the new industrial revolution with the emerging computer technology, become the important force to promote the development of manufacturing industry, which is on a transition from the standardized production to mass customization. Professor Baldwin and Clark from the Harvard Business School indicated that the contemporary is the modular time, pointed out that the modularity has significant impacts on the upgrade of the industrial structure and the manufacturing industry has entered a time of modularization design, modularization production and modularization consumption[7]. Masahiko Aoki even believed the essence of the new industrial is modularity.
The service object of the modular design is system, the unit is the module. Modular design is based on the system and it realizes combination and utilization of the different modules with the greatest extent. Modular design strategy is not only a kind of design and technical method, but also a complicated system engineering and a systematic process.

3.2. Modular design in architecture
The purpose of applying the modular design strategy in architecture is to improve the efficiency of construction. In the development of architecture, the modular design concept was always implied in the architectural design process. As early as back to the days of the Song Dynasty in China (960–1279), the book “Yingzao Fashi” (Treatise on Architectural Methods or State Building Standards) recorded the utilization of the modular strategy in the traditional Chinese architecture. The modular system was adopted to construct different components such as Dougong, which is a unique structural element of interlocking wooden brackets. This system stipulated different modules such as “cai”, “fen” and “qi”. The height of “cai” is 15 “fen” and the thickness of “cai” is 10 “fen”, the distance between the layers of “Dougong” is 6 “fen”, which is the “qi”. Almost all of the wood components used “cai”, “fen” and “qi” to determine the size, making a unified standard between the components [8] (Figure 3).

![Figure 3. “Yingzao Fashi” by Li Jie indicated the modular wood components of dougong.](image)

After the Renaissance, the architectural design and construction were gradually separated, the design process is operating in the architectural work space based on the orthogonal projection system and applies the architectural drawings to represent. The concept of modularity is throughout the process of design, such as using the modulus and axis, dividing the building into components and so on. In modern architecture, the modularity idea was widely applied by the pioneer modernism architects, for example Le Corbusier adopted the standardized and modular strategy not only as his starting point of architectural aesthetics, but also an important designing tool in his projects. His design process was based on division and combination of the building components such as foundations, walls, columns, floors, stairs, roofs and so on, reached a high degree of unity of the logic and aesthetics[9].

In the 1960s, the concept of modular design gradually raised with the high-tech architecture movement and utopian ideas. In the 1967 International and Universal Exposition, Safdie Moshe finished his first project Habitat 67 with the idea of providing affordable residences for the low-income groups, 158 houses were constructed from 354 modular units. Each box type residential unit was prefabricated and then scattered piled up together (Figure 4). At the same time in 1960s, Japanese architects brought the Metabolism which also applied the modular design strategy; the difference from Safdie is that the modules were plugged into the structural and service core. One of the most famous Metabolism projects is the Nakagin Capsule Tower by Kurokawa, he set up are cycling strategy that the modules could be easily extracted and updated if needed (Figure 5).
In recent years, the contemporary architects combine the modular design strategy with the green and ecological concept, create the “modular homes” which are sectional prefabricated buildings. The module sections are prefabricated at an offsite facility and then delivered to the site for construction. The “modular homes” realize more variability of configurations and styles in the building lay out through the systematic combination of the function modules and building envelop modules [10]. Now, the concept of modular design grows more and more popular with the rise of mass customization and the rapid development of computer technology [11].

4. Modular design strategy of shipping container architecture in cold regions

In the design and construction process of the shipping container architecture in cold regions, the modular design strategy refers to using the shipping container as a standard unit to carry out the process, the shipping container is not only the unit module of construction and the basis of the design operation, but also the structural components due to its high structural strength and durability. The design work is not limited on paper but rather applying the BIM technology and operating the design in three dimensional, the modular design strategy of shipping container architecture in cold regions has significance as follows:

1. The mechanism of modular design simplifies the design process; architects are able to solve specific problems with modular logic by applying the serialized modules.
2. The modularity is an advanced form of standardization with higher performance; the shipping container architecture in cold regions will be more integrated and diversified by applying multi-functional composite modules.
3. The application of modular design strategy in shipping container architecture is not only during the design process, but also throughout the whole process of construction and operation, such as modular management and modular construction, and thus it will significantly improve the construction efficient in cold regions.

4.1. Classification of the modular design strategy

The utilization of the modular design strategy is the key to promote the development of architecture industrialization that can be characterized as standard design, industrialized production, prefabrication and informatization management, and thus will have revolutionary impacts on architecture in cold regions. The modular design strategy of shipping container architecture in cold regions is based on the existing adaptive design techniques and different demands of cold regions aimed at energy saving, sustainable and movable. And the modular design strategy is an integrated system of operation method and technology strategy with the subsystems of building envelope modules, equipment modules, transportation and construction modules. In this system, the subsystem of building envelope modules include the roofs, panels, windows, floors and so on; focus on adaptive design, insulation technology, air tightness of the joints and so on. The equipment modules include solar dynamic power system, thermal storage battery system, water treatment system, auto leveling system and so on. The
transportation and construction modules include the prefabrication and transportation system, construction management system and so on; form the self-sufficient passive high-performance shipping container architecture design and construction strategy as well as the municipal pipe network interface modules of the shipping container architecture. The system is targeting at greenization and based on the strategy of serialization, recycle and integration. All in all the modular design strategy is not only a design method of the shipping container architecture in cold regions, but also the technology road map that indicates the implementation of the operations (Figure 6).

![Diagram](image_url)

Figure 6. The modular design system technology road-map of shipping container architecture in cold regions.

4.2. Combinations of the modular design strategy

The combinations of the modular design strategy of the shipping container architecture in cold regions can be characterized with the equation as:

- Project = Universal Modules + Special Modules + Functional Modules

In this equation, the universal modules refer to the invariant parts which are the structural components and the standard shipping container units; the special modules refer to the variable parts which are the building envelope modules and equipment modules mentioned before; the functional modules are the adaptive parts which are the construction and transportation modules. The
combinations of the modular design strategy are not only the different combination of modules, but also the adaptive operation methods. On the other hand, the combinations are also indicating the form design strategy of the shipping container architecture; usually refer to the combinations of the shipping container units. The shipping container unit is a box-type element with characters of simple and high strength performance, it is easier for the architects to carry out the adaptive design with simple logos through different combinations of the units, such as side-by-side style, converging style, unit style, stacked style, mixed style and so on.

As mentioned before, the modularity is a systemic operation method of the shipping container architecture in cold regions. The modularity put forward an application strategy of standardized construction which is adapted to the mass customization of the contemporary architecture industrialization, so that it will achieve intelligent construction and lean production of the shipping container architecture. By applying different combinations of the modules and shipping container units according to the functions and sites, so that it will realize the variability of configurations and styles of the buildings.

5. Conclusion
As an emerging green building mode, the shipping container architecture will provide an effective way of construction in cold regions. The application of the modular design strategy of the shipping container architecture is not only the way to optimize the design process, but also an implementation strategy of the whole industry. Develop the modular design system with the subsystems of building envelope modules, equipment modules, transportation and construction modules based on the strategy of serialization, recycle and integration, thus establishing an innovative operation method of the shipping container architecture in cold regions.

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