

Applications of Mobile Aluminum Light Structure Housing System in Sustainable Building Process

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Abstract—Problems exist in the present construction industry in China. Conflicts hinder the development of the whole society, such as contradictions between resource reservation and a huge population, living space needs and low building production efficiency, as well as environment protection and high pollution production pattern. In order to solve the problems and find a solution, research is needed to explore a building system. By investigating the whole architectural process and contrasting analysis of light structures and heavy structures, the paper raised the concepts to cope with the existing challenges, such as design conception based on product and real construction processes, design methods focusing on components, and maximum utilization of the temporary building by optimizing the construction speed and building performance. The project was not only designed in virtual reality, but was also physically constructed in the real world. A series of aluminum light structure housing systems were dictated at last, with the characteristics of high performance, extremely rapid construction speed and also flexible function. It can be used in lots of aspects ranging from a single building in a remote area to a large residential community.

Keywords—Aluminum house, light structure, rapid assembly, repeat construction.

I. INTRODUCTION

BUILDING is one of the most important things related to daily life. Especially in developing countries like China, rapid urbanization needs more and more buildings constructed for the growing population in cities. Compared to other fields, the building industry occupies an enormous amount of resources and brings a lot of pollution. In current situations, many existing methods such as positive and passive energy-saving technologies reduce energy consumption in the maintenance stage of buildings. However, the construction and demolition phases still need effective approaches to improve their sustainability, since these phases produce a lot of waste sand which occupies a much bigger percentage of energy consumption in the entire life-cycle of the building. In order to address this issue, in this research the author proposed to use a light-weight and mobile housing system to improve the sustainability in the building industry. This project was developed by the Architecture School of Southeast University. It was headed by the Architecture Technology Department, and has been supported by R&D teams from the Civil Engineering School and Energy and Environment School since the

beginning of development. During the developing process, many companies have participated and an industry alliance was founded to cover the building lifecycle. This housing system used modularized envelope and standardized connections, which were pre-fabricated and assembled in factories and transported as containers. Aluminum was used as the structural material in this system, and inorganic thermal insulation material was used in the envelope, which secured a level A fireproof rating in China.

II. SUSTAINABLE OBSTACLE IN CHINA

A. Labor Factor

In China, reinforced concrete is used as the structural material in most projects, which requires many manual processes on the site and is very labor-intensive. In an earlier age, there were sufficient resources of human labor, resulting in this material being widely used ever since. However, single child policy resulted in an aging population and hence a decrease in labor resources. Most young workers prefer working inside rather than out, because of tougher working environment outside and lower income level. Therefore, nowadays most construction sites have issues of labor shortage. According to statistics, currently the average age of constructors in Nanjing is 43, while this number was 27 one decade ago. Therefore, the traditional construction pattern is not sustainable, and the construction industry would probably collapse if the situation were not to change.

B. Building Life Cycle

1. Design Stage

In the design stage, most projects pay limited attention to the following phases. For the construction stage, they only ensure the projects do not violate mandatory requirements in national standards and pass evaluation by the government. For the facility management, most designs are not concerned with the maintenance of buildings, especially for external thermal insulation materials and HVAC systems e.g. central air conditioning units. Furthermore, the demolition of buildings is not a consideration at all [1].

2. Construction Stage

During the construction process especially while structuring buildings, many operations such as staging, formwork and reinforcement assembly are finished manually without taking advantage of construction machines. Moreover, most concrete formwork uses wooden slabs, which are disposable and hence waste many materials. The used wooden slabs can only be discarded because of the leftover concrete, which means they

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cannot be recycled in to a material that can be used to produce paper or even combusted as a fuel.

3. Operation Stage

Problems will occur during the life of any building, so fixing on these issues on time is very important for the long-term sustainability of the building [2]. That said, the life span of some building parts such as pipes and water proof material cannot share the same value as the main structure. So many problems emerge from buildings that were constructed during the 1980s. In order to fix the drainage problem, some external or even structural parts should be taken off due to the lack of consideration for repairs. For another aspect, the installation of large HVAC equipment was only planned as a once-off, so it would be impossible to change the equipment entirely without demolishing the floor.

4. Demolition Stage

The problems will be more evident for the heavy reinforced concrete at the demolition stage. Although some environmental protection technology may be applied in some aspects such as recycled concrete, it is not easy for the concrete parts to be transferred into the next material circulation, as the pressure resistance level is so low that it cannot be used in high-rise buildings. Although the steel parts can be recycled and melted, the close bonding between concrete and steel is so hard to break apart that the stripping process needs certain labor and energy. So the current situation is that the recycle ratio of construction waste in China is so low that most materials are sent to landfills far from the city.

C. Planning Aspect

The development of a city is so fast in China. The average age of a building is only 30 years which is far from the 50-100 years that was set at the design stage. Considering this, one aspect is that the building itself is lacking in performance and durability. On the other hand, the urban planning scheme is modified frequently for irrational reasons, such as for the hierarchy and the administrator's interests. Because of the frequent changes of function between different zones, it will be difficult for the building to switch the function itself. As such, the only solution would be to focus on demolition which will always leave waste behind [3].

D. Living Capacity

The expansion of a city in China is so fast that it could stimulate the acceleration of development in public transportation facilities, allowing some remote area to become accessible. In the meantime, it's impossible to provide enough residences in a short time because heavy structure (which is permanent) needs a lot of time in planning approval, preparation, the construction phase and the acceptance check. For all kinds of facilities and buildings to be completed, you would need to allow another 5 years. That is a severe waste of land resources in an urban area. If idle land can be fully utilized in this window period to solve people's residential issues, the housing pressure in downtown can be reduced [4].

III. METHODOLOGY

This research is based on a mobile light structure system, trying to cope with the sustainability problems in present China by a systematic study. This system cannot replace the permanent heavy structure completely, so the goal was the improvement of the whole building system by additional utilization of light structure. This methodology emerged as the last four parts.

A. Investigation

There were two aspects regarding investigation. Firstly, finding out questions through the investigation of the sustainable development of ordinary permanent heavy structures in China. Secondly, investigating the current light housing structure comprehensively and gathering basic information that can be useful.

B. Contrastive Analysis

Systemic analysis of the results at the investigation phase. First of all, identifying the benefit and shortage of current permanent heavy structures, figuring out the blanks that can be filled which is also the advantage of the mobile light structure. Rationally determine the design target and the realization of the concrete function.

C. Design Based on Component with BIM

The design method based on components used modular assembly as the installment in the construction site. Classification hierarchy with tree structure made every component that was designed was catalogued into one precise branch. The information of the components such as manufacturing, physical identity, and installment procedure were integrated with digital physics models by BIM technique. Also the manufacturing and construction process was virtually tested though construction simulation software.

D. Experiment before Real Construction

By Confirming the achievements that the system should be guaranteed while on the manufacturing stage in the factory and eliminating all puzzlements for further phases, and problems which may occur on following stages such as construction and demolition phases that could be prevented. The experiments included structural strength, durability of the components, installment procedures and connecting construction.

IV. CONCEPTION

From previous investigation research and contrastive analysis, the conception emerged as the last six aspects.

A. Design Conception Based on Product

The system was based on a product development model which was different in comparing with the traditional engineering design pattern. In that pattern, designers only need to consider the design issue itself, and could effectively ignore the following problems such as manufacturing, transportation, hoisting and installment at the site [5]. In considering the building system as procedure, the request is not only the architecture design service, but also the architectural products.

B. Design Method Focus on Construction

Design focusing on construction should fully consider the difficulties of site construction. It should set the targets of mechanized operation and modular assembly. Efforts should be made to reduce labor intensity, the ratio of handy operations and the construction period. As the specific target decision optimization has been changed in the design process, it took construction as the most important standard to evaluate, while space form was the most important in traditional design process.

C. New Manufactory and Construction Pattern

The relationship between manufacturing and construction of the system was progressive hierarchy [6]. They existed as First Industrial, Second Industrial, Third Industrial and Site Assembly Stage. The results of First Industrial were samples, and Second Industrial were parts, which means the parts were large modules that must satisfy the size request of highway transportation. The results of Third industrial were hoisting components which were consisted of Second Industrial's results to be assembled on the site. Then, at the last stage, hoisting components should be put in position by crane, then the modules were to be connected as a whole by reserved interface.

D. Purpose on Multi Disassembly

The designated disassembly time was 50 years, so all the aspects of component intensity and connecting construction must be focused on multiple repeat construction. That required the consideration of convince of reassembly, joint duration, and reserved interface operation in the design stage [7].



Fig. 1 Temporary residential zone near metro

E. Mobile Temporary Equals Permanent

Temporary and permanent are opposite, but for the object of building, the meaning of two words can be altered when used in conjunction with one another. A designated permanent building which was demolished after less than ten years of utilization should be defined as temporary. Take for example another temporary building which existed in a different site for a long time. Although the time in each site was short, the whole service time of the mobile building itself was long enough that it can be defined as permanent. So in that case, long time mobile temporary equaled permanent (Fig. 1).

F. Rich Modular Combination

Consider a building as a product, so the series of the building systems should cover all usage aspects. For the price aspect, it spanned from basic/cheap to high performance/expensive level [8]. For the utilization function, the system contained a main part module, cycling module, roof module, solar module and an equipment module. The combination of these modules can create many kinds of variations which would fulfill the needs of buildings.

V. RESULTS AND DISCUSSION

A. Fast Construction Speed

Due to its high degree of prefabrication, i.e. as high as 93% of industrialization, the in-situ workload of this system was low. In addition, the in-situ equipment procedure was simple and convenient, such as fastening the bolt, since the modular assembly idea was applied in this system. The most complicated part of the products was sealed within modules, thus, the in-situ work only required minimum engineering instruments and equipment. According to data collected from the experimental building NO. 2 of this system, it only took 6 hours for most of the assembly work of 12 modules before the interior assembly began, and consumed less than 3 days for all assembly construction to be completed.

B. Rapid Cycling and Reuse

Except for rapid construction, this system also had the advantage of being reused. During its early phase of design, the system bore the characteristics of modular assembly and transportation, as well as the well-developed container transport system. The biggest advantage of aluminum construction was its light-weight but also its high-strength. These features made the reuse of the system possible. Additionally, in this system, each module was designed with full consideration of transportation and various stress conditions during the hoisting and transportation processes in mind. As a result, the system was guaranteed a stable structure and a full-feature even after multiple reuses. The rapid construction speed also made reusing possible.

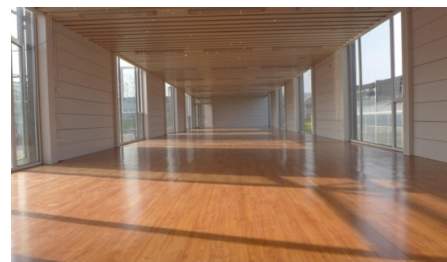


Fig. 2 Open space created by 12 models

C. Suitable for Multi-Function

For the modular design conception adopted in this system, the strategy of modular customization can be used to satisfy completely different needs. A large open space can be formed to different volumes with the help of the special structural treatment measures, for which a patent has already been applied

for (Fig. 2). The separation between space utilization and functional assistant model created independence of each other which could assist future maintenance and repair. The interface made further function module expansion possible.

D.Space Variable and Function Expansion

There were unique design concepts in space distribution and interior function layout. People's need for space is always variable, which means in order to cope with the problem different spaces should exist in different times. Static design meant the wastage of space by preparing all the space at one time. For the sustainable reason, dynamic concept can be used to solve the contradiction by changing all the furniture. For example, by allowing all the furniture to be folded inside the wall, different functions can be converted within a few seconds. It could provide accommodation for 6 people at night or allow 20 people to have a party (Fig. 3).



Fig. 3 Function change of the interior space

E. Self-Guarantee

By adopting integrated solar photovoltaic and decentralized domestic biological sewage treatment systems the use of electricity and water can be significantly reduced, lowering the dependence on the municipality.

The solar photovoltaic system integrates electricity and heating, providing both energy and hot water while improving the utilization of solar resources. This reduces fossil fuel consumption, cost and associated logistical burdens.

The distributed wastewater biological treatment system was based on a small scale operation. In this treatment method, organic matter is removed biochemically. Also, in the biological treatment unit, nutrients such as nitrogen and phosphate can be reutilized by medium and by plant roots via infiltration, absorption and assimilation.

F. Strong Environmental Adaptability

The structural component used high intensity aluminum alloy as its material, while the exterior envelop adopted aluminum alloy composite inorganic thermal insulation. For the erosion resistance of aluminum and fire resistance of inorganic thermal insulation, the system integration and function could be guaranteed in high salt, high humidity, low temperature, and other harsh environments. Because the unit is mobile, the more remote zones of a city can be utilized. This is

invaluable as it allows a well-performing residential zone to be established.

VI. CONCLUSION AND FURTHER WORK

In conclusion, the mobile aluminum light structure housing system can satisfy the need for sustainability throughout the whole life cycle of the building. It could maximize the land usage capacity by fully exploiting the area where normal permanent architecture is unable to do so. Not only does the building system itself save energy - especially the thermally isolated materials used and the active solar photovoltaic system employed - but also the way the product is developed is sustainable in itself. All the advanced technology integrated in to the housing system can guarantee operation with high-efficiency, health and stability.

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