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Z-Panel System - Lightweight Prefabrication

Z-PANEL - PREFABRICATED LIGHTWEIGHT ARCHITECTURAL SYSTEM IN PLATEAUS

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Extreme climatic conditions of thin mountain air, long freezing winter and rapid temperature changes in summer in plateaus require buildings of special concern to the surrounding environment. In 2015, the Architecture Integrity and Innovation Association (AIIA) of the Chinese University of Hong Kong developed Z-Panel system, a prefabricated lightweight architectural system for plateau area, and applied to a new school in Lawuga Village, Yushu, Qinghai. By introducing the system and the built project, this paper illustrates a sustainable building possibility, which is not only applicable to plateaus but all alternatives.

Keywords: lightweight, prefabrication, plateau, yushu.

1. INTRODUCTION

In 2013, Architecture Integrity and Innovation Association (AIIA), a research team from the School of Architecture, The Chinese University of Hong Kong was committed for a charity school project in Yushu Autonomous Prefecture, Qinghai Province, which experienced a 7.1MS earthquake in 2010.

The site is located at an altitude of 3900 meters above sea level. It has a typical plateau climate with prolonged freezing winter and rapid temperature changes in summer. Construction of buildings on the unveiling plateau is required to take into account its relationship with the special environment. Besides, considerable structural demand needs to be met in terms of snow, wind and earthquake. The construction process should consider the plateau environment of fragile ecology system, thin mountain air, and limited construction period (construction works is forbad from October to April because of inclement weather). A comprehensive architectural proposal is required with considerations of sustainability, users' comfort and construction methods.

Figure 1 Lawuga School and Village

Site visit was carried out before the detail design process. Locating in the plateau area, Yushu does not have advanced manufacturing technology. However, the highway network connecting to surrounding cities is well developed. The school site is adjacent to the No. 214 state road. Large-scale construction machines such as crane are available in the city, which might be used for the rescue and reconstruction activities in previous years. All these criteria provide excellent conditions for adopting prefabrication in Yushu.

Founded and led by Prof. ZHU Jingxiang since 2008, AIIA has focused on investigation and design works on prefabricated lightweight architectural system, attempting to provide prototypes by integrating the manufacture strengths and latest technology of the production chain. From 2009 to 2015, three rural primary schools in the Mainland China, four eco stations for natural reserves, and a primary school in Mathare, Kenya were completed.

After conducting corresponding researches and studies, the AIIA research team found the answer - Z-shaped panel. It is a simple but effective response to all-round considerations. More importantly, it leaves enough flexibility for development of different architecture with varied scale and programme. The fundamental element of Z-Panel System is large panels with a sectional Z-shape.

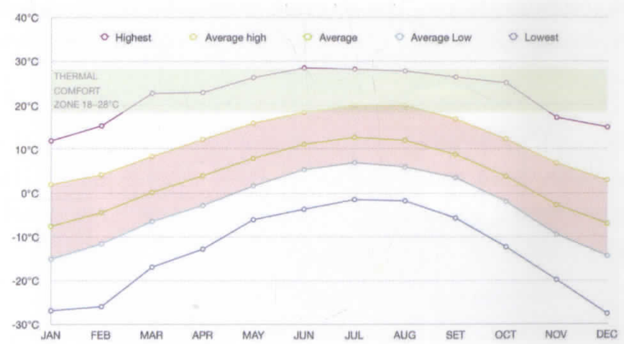

Figure 2 Yushu Temperature (1971-2000)

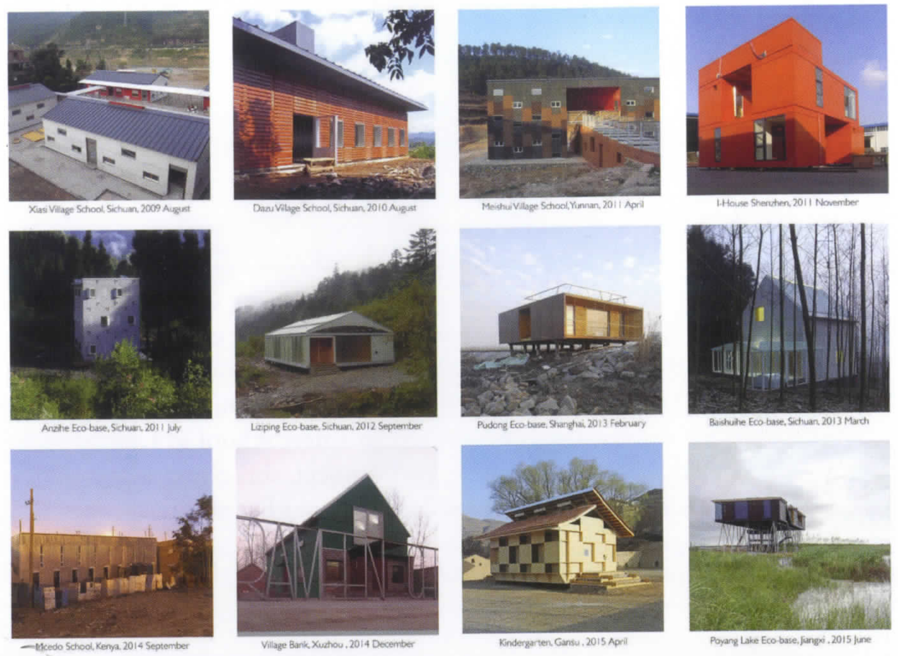

Figure 3 AIIA Projects (2009-2015)

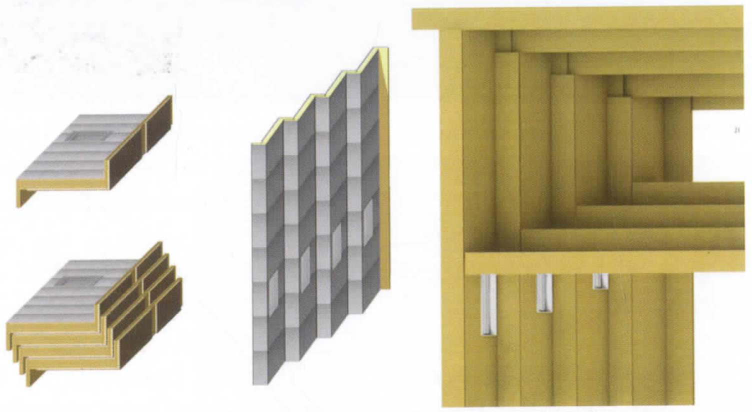

Figure 4 Z-Panel System : Element, Stack, Wall, Floor, Roof, Building

2. Z-PANEL SYSTEM

Large effort was spent on investigating the breaking point of the existing practice of lightweight prefabrication. Based on the previous experience, the research team attempted at a new system which can further enlarge the advantages of lightweight prefabrication: rapid assembling period, high quality control of building, etc., and at the same time reduce the potential weaknesses including labour intensive construction methods, high transportation cost of components, etc. The research team believed it is worth exploring a lightweight prefabricated product for the New Lawuga School project in Yushu.

Through in-depth investigation and researches, the AIIA research team found the answer - Z-shaped panel. The fundamental element of Z-Panel System is large panels with a sectional Z-shape.

2.1 Design Concept

The two "wings" at the long edges entrust the spatial defining panels with the structural possibilities. In the transportation and construction process, the wings help prevent the flat panel from transformation. In the building system, if the panel is placed horizontally as floor or ceiling slabs, the wings become beams overcoming the span; if it is placed vertically as a wall panel the wings would help resist the lateral force.

Besides, Z-shaped panel has a high spatial efficiency in stacking for storage. This is important especially in the case of prefabrication when the logistic takes up a large portion of the budget. The Z-panel can stand by itself, greatly reducing the temporary structures required during construction. When two Z-shaped panels are connected, overlapping the "wings" is an easy connection which gives strong structural performance, and provides excellent air-tightness.

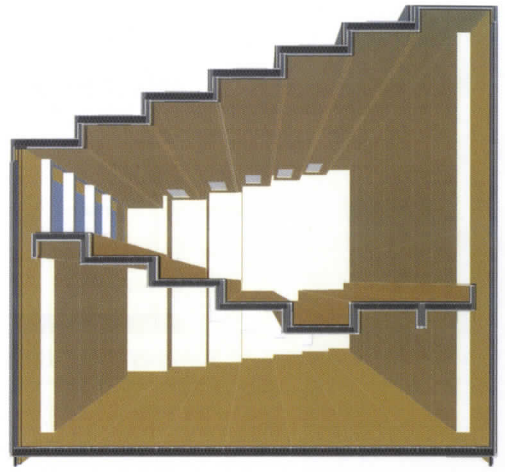

Figure 5 Sectional Perspective

In the later stage, panels with C-shaped and L-shaped sections are also developed.

2.2 Composition

The composition of the Z-shaped panel is based on Structural Insulated Panel (SIP), which is a sandwich composite with foam core (e.g., expanded polystyrene (EPS) or extruded polystyrene (XPS)) in between the sheeting material (plywood, oriented strand board, steel or fibre-cement). SIP has an outstanding performance in both thermal insulation and structural stability. In the New Lawuga School, XPS with plywood on two sides make up the central core of the panels. Other layers of gypsum board, waterproofing membrane, finishing materials such as acoustic panels and metal claddings are incorporated to fulfill the requirement of water/fire-proofing and protection, according to the role of the panel in the building.

2.3 Panel Dimension

The thickness, width and length of each panel is an integrated result responding to multiple disciplines of manufacturing, transportation, construction, structural requirement, thermal performance, and the spatial requirement. For example, the periphery wall panel (Thickness = 150mm) is thicker than the suspended floor panel (90mm) to withstand the exterior environment; the width of the panels is defined by that of the raw plywood panel (1220mm); the length of all panels are limited by 9m for lorry transportation.

3. NEW LAWUGA SCHOOL

A successful application in the harsh natural environment will be a powerful convincing showcase of promoting the system. Using the innovative Z-Panel System, the New Lawuga School was completed in August 2015, and was soon put into operation. Originated from Z-Panel system, the building also incorporates architect's design philosophy and becomes an outstanding architecture in the village.

3.1 Spatial Quality

The New Lawuga School was a two-storey building providing 200 sqm of usable floor area. The simple "Z-Panel" idea allowed complex spaces to be formed within the small tidy building. The stepped peripheries of the walls and roof were the direct visual interpretation of the Z-shaped panels. The school consisted of a central double-height stairway connecting to four classrooms, with an independent storage underneath. Each space was different from each other. This differentiation originated from the space's scale, spatial geometry and orientation. The G/F classrooms had a stepped ceiling getting higher at the East. The 1/F rooms were stepped classrooms, with a dramatic ceiling height at the West. The differentiation was further enhanced by window design, which controlled the view and light condition. Each space had an individual spatial geometry, yet all different spaces were dependent closely with each other. Loop circulation was formed providing a rich and endless spatial experience to the users.

3.2 Openings

The unique spatial identity of each room was enhanced by the opening designs. Large sky windows in the central stairway flooded the space with natural light, creating a reverential atmosphere. There was a series of side windows looking towards the school campus in the G/F classrooms, while in the 1/F classrooms, the side windows faced inwards to the bright central stairway. Besides, small sky windows and large translucent panels at the East could capture the extraordinary landscape outside the classrooms.

3.3 Internal Finishes

Contrasting to the complicated spatial geometry, only two materials were used for the interior finishing: acoustic panel and wood floor plank, both with the warm wood colour. All the doors, window frames, and built-in furniture shared the similar warm and golden tone. The plasticity of the surfaces created a cosy atmosphere for teaching and studying. The pattern of the acoustic panel used in the walls and the ceilings diminished the gaps due to construction. The intervals between the acoustic panels allowed certain degree of bending during installation.

Figure 6 1/F Classroom

3.4 Exterior Finishes

The facades at the South and North, and the roof of buildings were coated with a thin layer of metal cladding. The metal claddings offered robust and lasting protection against water, wind and weather. To explore the materiality, two types of metal were applied: galvanised steel was used in the South elevation and the roof, while stainless steel was used at the North Elevation. The claddings were arranged from the top. As the roof was stepping, alternative pattern was created. The windows were covered with the claddings. The East and West elevation were large pieces of polycarbonate sheet, with dark wooden channels at the back. Thus, a monolithic object shimmering with a vast range of colours and reflections was erected on the plateau.

Figure 7 South-west view of New Lawuga School

3.5 Building Physics

Construction of buildings on this unyielding plateau areas needed to pay special attention to the relationship with the environment. The New Lawuga School was lifted up from the ground to prevent undesirable emission of heat to the subsoil. The massing reduced heat loss from the building shell by having a lower surface to volume ratio. All the periphery panels, floor, wall and roof panels, had a thick insulation layer of 150mm, ensuring low thermal transfer values. All the fenestrations were double-glazed to improve thermal isolation. At the East and West elevations, trombe walls which were made up of wooden L-shaped framework and polycarbonate sheets were installed. Simple operation could allow the trombe walls, which could obtain large quantities of passive-solar energy and create air barrier, to prevent energy exchange, with the external environment. The external polycarbonate sheets, depending on the light situation, could appear anything from deep black, like an abstract black hole, to dazzlingly bright, reflecting the mountains and sky.

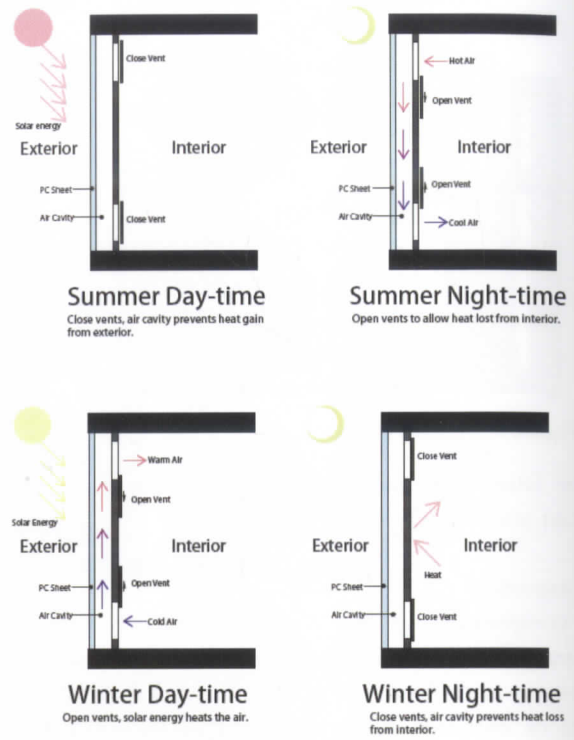

Figure 8 Trombe Wall Concept

3.6 Foundation

The New Lawuga School was only half weight of the same size concrete building. Because of its light weight, ground screw system was introduced for the foundation construction. Comparing to the traditional foundation method such as raft or piles, ground screw system considered both the structural aspect and the construction process, providing a rapid and environmental friendly option. Galvanised steel ground screw, with a diameter of 110mm and length of 2.8m, were pierced into the soil by the powerful driver. The screw pile penetrated through the 1m-thick permafrost layer. The installation of the ground screw was a reversible process, preventing permanent damage to the subsoil.

Figure 9 Installation of Ground Screw

Figure 10 Manufacturing Factory in Chengdu

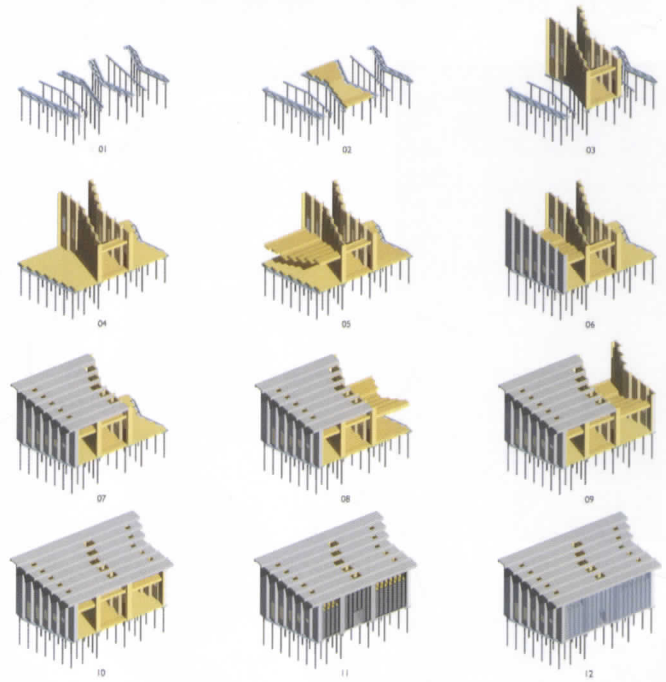

Figure 11 Construction Sequence

4. REALISATION

Solidifying an innovative idea to an authentic building is always an arduous challenge. But founded on the valuable experience of previous practices, and with great effort from different local parties, the New Lawuga School has been operated since 1 September 2015. Erected on the plateau grasslands, it provides a safe and warm learning environment for the remote students, and presents a promising future of the new building prototype.

4.1 Manufacturing

There were two rounds of mock up testing respectively in 2014 June and 2015 January before the formal manufacturing process, to ensure the performance of the Z-shaped Panels. The large-scale manufacturing took place in Chengdu. Manufacturing of all components were carried in three different factories, two wood factories (one responsible for the main panels production, and the other responsible for all other wooden components) and a metal processing factory. The architect had coordinated with different factories for effective manufacturing process.

4.2 Construction

The construction period of New Lawuga School lasted for 2.5 months in Yushu. This was the first time for the design team to work on a project in the province. The 2.5-month period included all preparation works such as searching for co-operating builder and suppliers.

The assembling of all the 80 pieces of panels only took up eight days. The high efficiency was achieved by a simple installation process where the panel is either erected or placed. The efficiency still has room for improvement as this was the first time for the local builder to construct the prefabricated system.

The construction of the building started from the erection of the central core, so that a stable structure could be erected independently. The tolerance due to the construction was shifted to the exterior sides. Following was the installation of the suspended or panels at the South. Temporary steel members were used to support the panels.

Among the assembling process, as the Z-panels were independent objects with strong structural strength, only small amount of temporary support was needed. About 1,500 number of steel members of different length (1.5 m, 3 m, 6 m) were used. Three workers were responsible for the installation of the panels, and other three workers for the temporary supports, hence achieving maximum efficiency of the installation. After all the panels were installed, the trombe wall units and the polycarbonate sheets were furnished.

Figure 12 Construction Process

The erection of the school is a valuable experience to review the design and construction process. The concept of the Z-shaped panel is proven to be effective in shortening the construction period and reducing workers' workload on site, yet some detailed designs could be improved to finalise the application of the system, such as the tolerance control of the panels. The research team has started the reviewing process while the Z-shaped panel is already applied in other project's feasibility stage.

4.3 BIM Application

There were in total 80 pieces of panels to be produced for the project. Although all panels share the same strategy, each panel is unique in terms of size, geometry, opening, finishes, depending on the exact role of the panel in the building system.

The usage of Building Information Modelling (BIM) software (ArchiCAD) increased working efficiency of the architect's team throughout the whole project stage. Fabrication and assembly drawings were directly exported from the 3D model. This allowed realisation of geometrical complicated design by producing precise representation drawings with limited human resources and within short time. Schedules of ordering parts were generated. Cost, weight, and quantity data was monitored throughout the design process. In the following fabrication stage, factories could prepare the raw materials according to the schedules, and manufacture with the detailed drawings. 3D model and the supplementary drawings promoted effective communication between different parties.

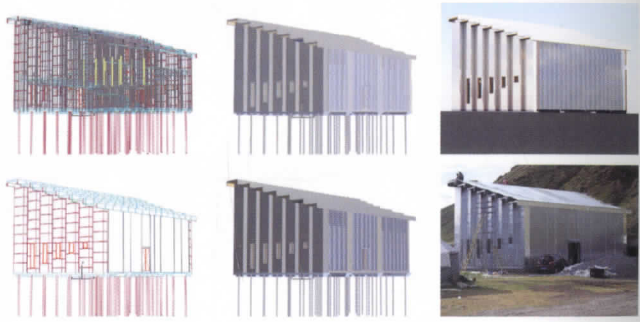

Figure 13 BIM Application

5. EPILOGUE

Prefabrication technology has been the development direction of the building industry for decades. It greatly increases construction efficiency by ensuring building components quality, shortening assembling period required on site, and improving working environment for the workers. Yet the potential of prefabrication should be far more than these.

"Z-Panel System" is the fruitful brainchild through series of research and study. It is an architectural synthesis solution that would be feasible in terms of production, logistic, insulation and assembly, and capable of adopting the special plateau climate. It is simple but effective, and leaves enough flexibility for developing architecture with different scale and programme. The investigation of the innovative technology required the design team to have complete knowledge from manufacturing to assembling, and to work closely with material suppliers and the factories to produce all-round design proposal. The potential and benefits of the system are shown by the New Lawuga School, which are not only applicable to the remote plateau area, but also in other environment including high-density city.

Figure 14 Children having lesson in New Lawuga School

Comprehensive construction investigation should include not only high-rise buildings, but also small buildings and lightweight structure. A rich ecosystem contains tree, shrubs and herbs. Scientists study stem cells as it could be easily converted to other organs and tissues. The "stem cells" in building industry means system. Among systems, geometric system would particularly influence performance of the material, structure and construction. The pioneers of both architectural, engineering and invention capability include Richard Buckminster Fuller from USA and Frei Otto from Germany. Following the great pioneers, AIIA explored along the direction, and achieved three levels of milestone in New Lawuga School: (i) completion of an exemplary school in Tibetan plateau of 3,900 a.s.l. ; (ii) application of BIM technology as the key design tool; and (iii) invention of the Z-Panel prefabrication system.

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BIOGRAPHY

LAU Hing Ching received his Master of Architecture at The Chinese University of Hong Kong in 2011. After graduation, he was selected for The Architectural Design Internship provided by the Wharf ArchDesign Resource Trust to work in Christian Kerez's Office in Switzerland for 1 year. He acquired his professional qualification of Hong Kong Registered Architect in 2015.

ZHU Jingxiang, associate professor in School of Architecture, The Chinese University of Hong Kong (CUHK), received his education in Southeast University and Swiss Federal Institute of Technology Zurich. Before joining CUHK in 2004, he taught in Southeast University and Nanjing University for 10 years. His specialty is in the area of new articulation of structures and space, light-weight building system, cost-effective architecture and vernacular construction.