LOCAL GRAND PRIZE AWARD

Use of Innovative Rammed Earth Construction Technology in Rural Areas of Southwest China – with Post-earthquake Reconstruction Project in Guangming Village as a Demonstration

Li WAN[1], Xinan CHI[1], Edward NG[1], Wenfeng BAI[2]

[1] School of Architecture, The Chinese University of Hong Kong

[2] Faculty of Architecture and City Planning, Kunming University of Science and Technology

ABSTRACT

Rural construction and development are significant issues in China, which has more than 40% of its population living in rural areas. The improvement of poor rural areas in mountainous regions has been relatively slow and unsustainable. Most rural areas should create their own development model instead of following urban/modernization models. Meanwhile, the government also encourages autonomous, diverse, endogenous, and sustainable rural development. The crucial support that poor rural areas of China require is not only funding but also innovative ideas and systematic strategies. This study explores the research and implementation of a post-earthquake reconstruction project in Yunnan, China to demonstrate the use of "high-science and low-technology" strategies with the "local materials, local labor, and local technology" principle of rural construction, and to encourage sustainable and endogenous development in the poor rural areas of southwest China.

Keywords: high-science and low-technology, local materials, local labor, local technology, rural endogenous development

1. INTRODUCTION

Rammed earth construction has a long history in China, particularly in rural Yunnan. Mud is the main material used in traditional architecture because it is inexpensive, accessible and exhibits remarkable thermal performance. However, local residents stopped implementing traditional rammed earth building technology because of several reasons. On the one hand, traditional rammed earth buildings have several limitations, such as poor seismic performance, limited daylighting and insufficient ventilation. Moreover, most rural residents viewed earthen buildings as symbols of poverty and backwardness. On the other hand, high-speed, top-down rural construction and transformation funded by external capital limited the time and space for innovation and expansion of local traditional technology. This study provides a new construction solution that integrates 'local labour, local materials, and local technology' (3L) through an innovative development of local traditional rammed earth construction. A demonstration project was implemented to persuade stakeholders of its viability and to promote the new construction solution in southwest China.

2. CHALLENGES OF POST-EARTHQUAKE RECONSTRUCTION IN GUANGMING VILLAGE

Guangming Village is in Ludian County, Yunnan Province, China. A total of 90% of the local houses in this village are rammed earth structures. Guangming Village was hit by a shallow earthquake with a magnitude of 6.1 on 3 August 2014. After the earthquake, villagers lost their confidence in the local traditional rammed earth buildings, 90% of which were damaged during the earthquake (**Figure 1**). Therefore, most villagers preferred to build brick–concrete houses during the reconstruction period. However, the prices of building materials rapidly increased and became unaffordable for most of the local villagers because of the increase in reconstruction needs and poor traffic conditions after the earthquake. Consequently, most of the local conventionally reconstructed buildings were built without any passive design, insulation and decoration.

The quality of these buildings and their indoor environments was poor (**Figure 2**). Furthermore, the villagers had to seek financial assistance to complete the reconstruction. The debt incurred after the disaster was an economic and psychological burden to the villagers. A considerable number of the residents attempted to find jobs in urban areas for increased income. Consequently, the elderly and children were left behind in the village.

In Ludian County, most of the traditional rammed earth residences in rural areas are considered a testament to poverty rather than historical heritage. Many rural earthen buildings were built by manual labour at least 50 years ago. These structures are dangerous because of their poor construction quality and disrepair. For villages that can obtain external capital for tourism development, the rural landscape is commonly disconnected from local materials, technology and labour. Therefore, rural residents and the local government are still looking for a good low-cost solution that can improve the safety and comfort of the vernacular architecture without destroying its historical and cultural values.

To provide a suitable and sustainable solution for local reconstruction, we innovated the local house-building technology using local materials and labour. However, several challenges remained regarding the local traditional rammed earth buildings:

- Anti-seismic performance of traditional rammed earth buildings built by wood rammers and manual labour was poor and urgently needed to be improved.
- Most villagers considered traditional earthen buildings as a symbol of poverty and backwardness.
- Local traditional artisans and crafts were gone. New knowledge and technology needed to be studied to innovate the rammed earth buildings.

Figure 1: Local traditional rammed earth building destroyed by earthquake

The re-empowerment of the local residents needed a long-term relationship and mutual trust to be established with the research team.

3. INNOVATIVE RECONSTRUCTION STRATEGIES IN GUANGMING VILLAGE

3.1 "High-science and low technology" strategy of reconstruction

To ensure systematic and sustainable rural reconstruction work with innovative ideas, scientific research is essential to understand the context, identify the problem, and find a proper solution.

A prototype house was built to demonstrate a comprehensive and systematic construction system and the resulting substantially high building quality. This house was built for an aged couple who lived in a tent after the earthquake. A passive design with recycled local materials gathered from the ruins ensured a comfortable indoor environment and low energy consumption. The design was integrated with semi-outdoor spaces to provide a comfortable and artistic living environment for the couple (**Figure 3**). The semi-outdoor atrium with a skylight and cross ventilation was bright and had natural ventilation. Double-glazed windows and insulated roofs were used to improve the thermal performance of the building. A steel roof structure and aluminium alloy windows were used to increase building quality and airtightness.

After a survey and study of the weak points of the local traditional rammed earth buildings, several innovations were made to improve the seismic performance. Appropriately-sized concrete foundations formed with a correct cement mortar was selected to enhance the integrity of the foundation of the house. The soil at the site was

Figure 2: Local conventional reconstruction

examined in the laboratory of the Kunming University of Science and Technology (KMUST) and mixed with sand, straw, and a small amount of cement (<3%) to prevent cracking and to make the walls solid. Concrete ring beams were added to the walls to improve structural integrity and to prevent vertical cracking. Aluminum alloy formwork and an electric rammer was used to make the walls substantially compact and smooth. A shaking table test on a single-layered rammed earth house pilot project was conducted at KMUST to verify the improved technology we used in the reconstruction project.

To empower the local residents and encourage endogenous development, the proposed innovative technology should be simple and easily disseminated within the community. The use of outside materials and labour should be limited to reduce construction cost and improve the local market. Therefore, the 3L principle was considered suitable for the conditions of the poor rural areas in southwest China. Instead of promoting the benefits of imported brick and concrete, we determined whether the shortfalls of traditional rammed earth technology and the fragility of village life could be addressed in situ. The implementation of this strategy was a simple step in rebuilding the lives of the people. With this simple strategy and empowerment of the local residents, the performance of the rammed earth buildings was improved, thereby protecting the lifestyle of the village.

3.2. Implementation of demonstration project in Guangming village

Facing the aforementioned challenges of reconstruction, external financial capital could not improve local development efficiently and sustainably, because the potential to improve the self-organising ability of the local residents was limited. Studies have shown that besides financial capital support, the empowerment of local residents and promotion of local endogenous development are other significant strategies for the development of poor rural areas (Wan & Ng 2016). A systematic and strategic bottom-up implementation method needed to be developed in these regions.

This bottom-up implementation meant applying the 3L principle. The residents were empowered through the demonstration project with craftsman training and co-construction. Furthermore, the project was based on the principle of volunteerism. Villagers could join or opt out according to their view of the demonstration and the resources they could obtain. They were not required to join. We not only created the design as architects but also worked with the villagers throughout the process as partners. Through this long-term cooperation and learning-by-doing process, we established mutual trust with the villagers and convinced them that our innovative, anti-seismic rammed earth building was a good solution.

This project was organised by the One University One Village (1U1V) rural programme of The Chinese University of Hong Kong (CUHK), which was donated by the Chan Cheung Mun Chung Charitable Fund. The 1U1V team

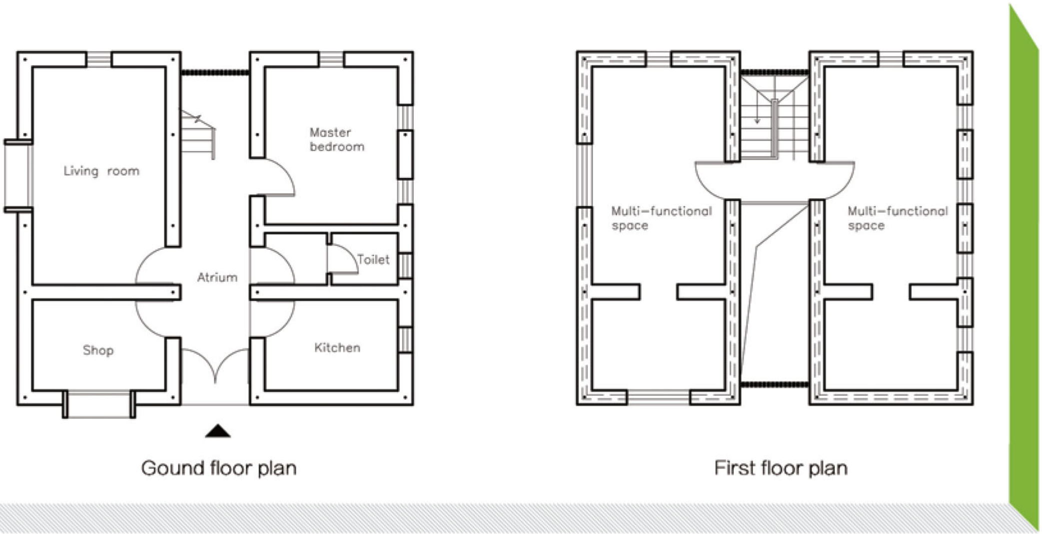

Figure 3: Floor plans of prototype house

Figure 4: Entrance and courtyard of prototype house

conducted investigation, research, building design, on-site construction supervision, and coordination. The programme provided construction materials and tools to the villagers. Furthermore, the project was supported by KMUST and the University of Cambridge in terms of building structure, seismic performance improvement, and testing. The Construction Bureau of Zhaotong City supported the project through local coordination, and the local residents handled the construction with guidance from the 1U1V team.

4. PROJECT OUTCOME

A contemporary design was used to address the physical and social needs of the villagers. The building shape and facade were simple and tidy (**Figure 4**). The indoor environment was spacious, bright, clean and well ventilated (**Figures 5 & 6**). Accordingly, the villagers could not connect this modern living environment to backwardness anymore and were willing to participate in the testing and training. The residents easily felt and understood the benefits of the innovative system after completion of the demonstration project.

4.1. Environmental friendliness

Natural resources and recycled materials from seismically-ruined buildings were the major construction materials used in the project. This choice reduced the environmental impact and solved the disposal problem of the seismic ruins. The use of industrial materials was carefully controlled so as to minimise the embodied energy of the prototype house. Proper passive design guaranteed low operating energy consumption.

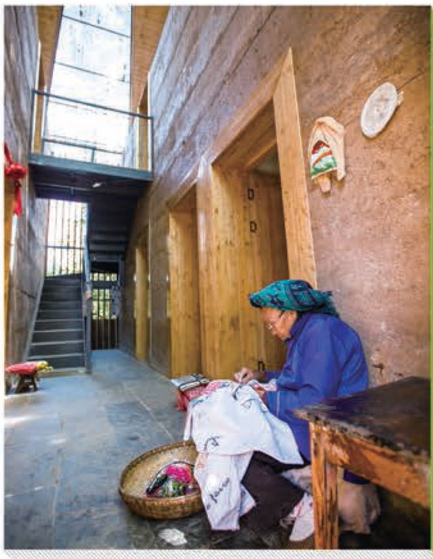

Figure 5: Atrium of prototype house

4.2. Cost efficiency

Use of naturally-resourced and recycled materials from seismic ruinshelped to minimize construction costs. The cost of the prototype house is only 60%-70% of that of a local conventional brick-concrete building in the same region. The operation cost of the project was also small because of proper passive design. With the affordable reconstruction system and well-trained villagers who were equipped with knowledge of this new technology and framework, such houses can be easily improved and maintained in the future. The residents can also utilise this technology as their livelihood.

4.3. Seismic performance improvement

The shaking table test results showed that the seismic performance of the innovative rammed earth building significantly improved and could meet fortification intensity 8 of the national seismic code, which is higher than the local requirement (Engineering seismic institute in Yunnan Province 2015).

4.4. Thermal performance improvement

In comparison with local building materials for conventional reconstruction, earth materials have outstanding thermal performance that provides a cooling effect to houses in summer and warmth in winter. Double-glazed windows and insulated roofs were used to further improve the thermal performance of the prototype building. **Figures 7 & 8** illustrate the enhanced thermal performance of the prototype house.

4.5. Protection of local traditional construction method and lifestyle

The project changed the attitude of the villagers towards rammed earth buildings. Our innovative technologies ensured the safety of new rammed earth houses by improving and enhancing the traditional technology with simple materials and tools. Villagers became interested in switching back from their brick-concrete houses because the project protected their local traditional construction method and lifestyle. The success of this project showed the villagers that the newly-energised local construction industry could not only provide potential employment opportunities but also allow the ?architecturally-influenced design of these buildings to include social spaces, passive ventilation, private gardens and an aesthetically pleasing finish.

4.6. Awards and media coverage

This project has been widely reported by media from Hong Kong and Mainland China, thereby attracting considerable

Figure 6: Multi functional space of prototype house

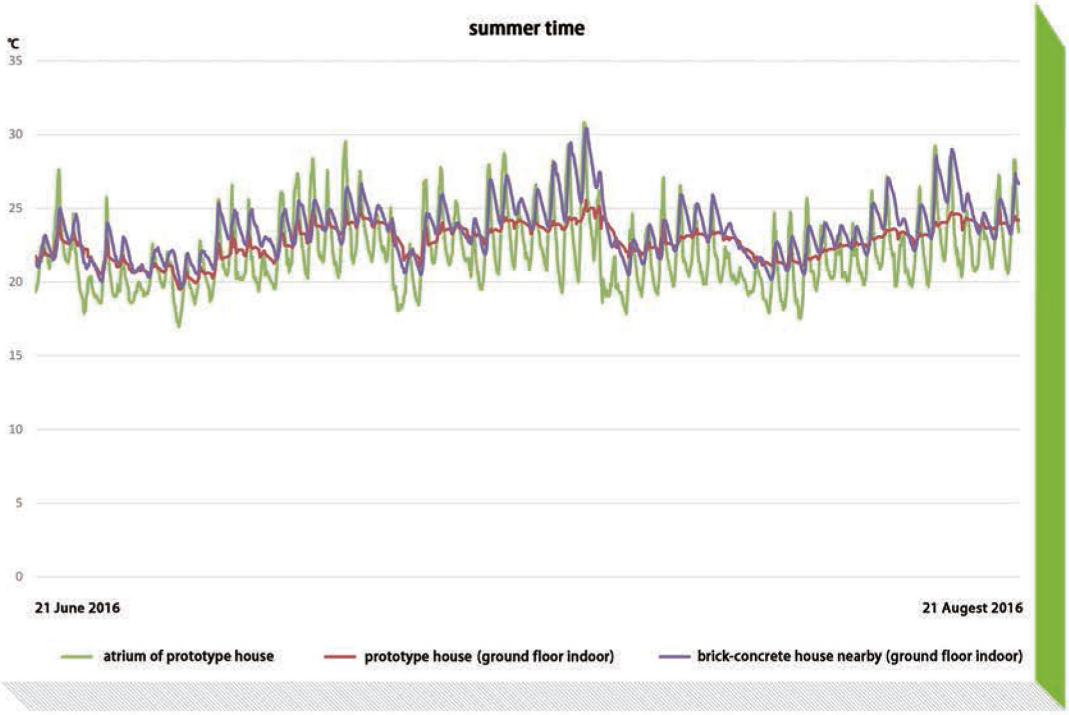

Figure 7: Thermal performance in the Summer time

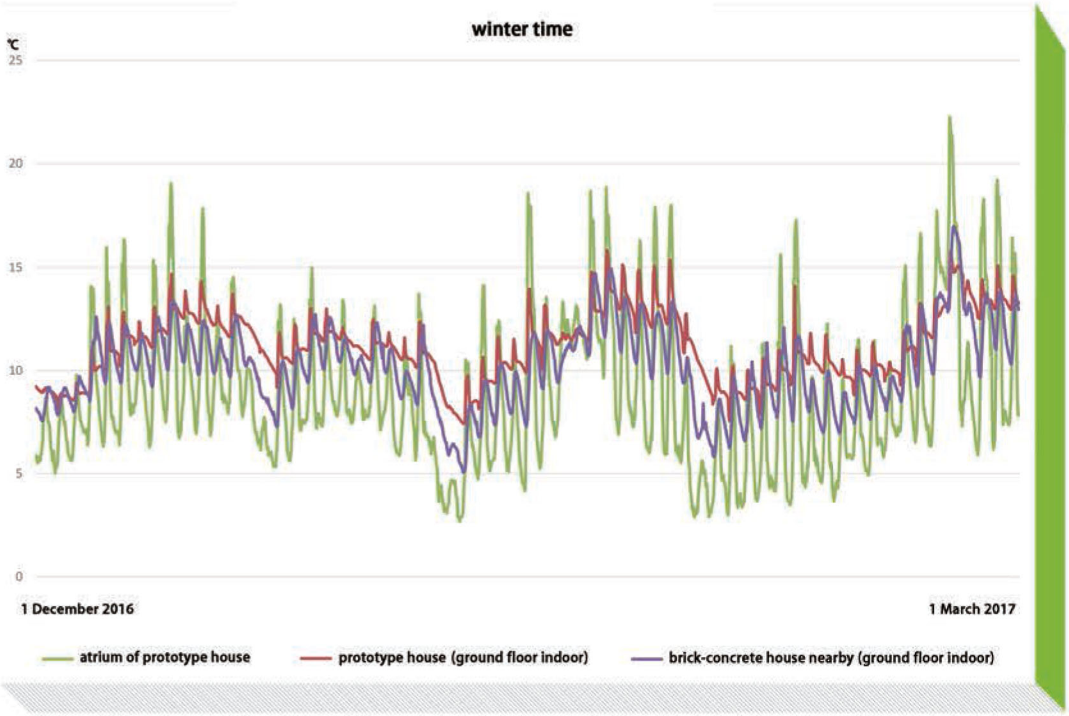

Figure 8: Thermal performance in the Winter time

attention. The project also won several local and international awards in 2017, such as the Architectural Review House Award, World Architecture Festival Building of the Year, Silver Award of the Design for Asia, and the Local Grand Prize of the CIC Construction Innovation Award.

5. CONCLUSIONS

This project innovated traditional rammed earth building technology and provided a safe, economical, simple and sustainable reconstruction strategy that the villagers could afford, own and disseminate. The design of the project attempted to integrate with the large context of the rural areas in southwest China by providing an endogenous and sustainable solution. We believe that fixed long-term support can help in the substantial understanding of the situation and needs of a village, thereby allowing a strong relationship to be established with local residents and systematic and efficient long-term support to be provided.

Several similar new rural construction projects have been launched in the provinces of Yunnan and Sichuan. Books and guidelines will be published to systematically document the innovative rammed earth method and provide references for national reconstruction policies and seismic standards for buildings made of earth materials in the future. The team has also been invited to formulate the seismic standards for local earth buildings in Yunnan Province. Moreover, a terra centre is under construction at KMUST to support the research and testing of earth architecture in southwest China. In this centre, considerable craftsman training, research and international academic exchange will be conducted.

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BIOGRAPHY

Li WAN

Dr Li WAN is a postdoctoral fellow in the School of Architecture of The Chinese University of Hong Kong. She specializes in sustainable building design and assessment system in poor rural areas of China. She is also the co-founder and project convener of "One University One Village" initiative. Their rural projects have been honored by numerous international awards such as the UNESCO Asia Pacific Awards for Cultural Heritage Conservation, the Terra Award, the AR House Award, and World Architecture Festival Building of the Year Award.

Xinan CHI

Mr. Xinan CHI is a PhD student in the School of Architecture of The Chinese University of Hong Kong. His study is mainly focusing on anti-seismic rammed earth building technology and rural sustainable development in China. He is also the Project Coordinator of "One University One Village" initiative who work closely with rural residents and local craftsmen in rural China.

Edward NG

Prof. Edward NG is an architect and Yao Ling Sun Professor of Architecture in the School of Architecture of The Chinese University of Hong Kong. He specializes in Green Building, Environmental and Sustainable Design, and Urban Climatology for City Planning. In early 2014, noting the cultural and socio-economical needs of remote villagers in Southwest China, Professor NG established the "One University One Village" initiative to continue his humanitarian work with his students. He believes that knowledge creates the future, and it is the responsibility of academia to chart this future.

Wenfeng BAI

Prof. Wenfeng BAI is a professor of the Faculty of Architecture and City Planning, Kunming University of Science and Technology. He specializes in green building and structure design. He is the director of Institute of Green Vernacular in Kunming and engineer partner of "One University One Village" initiative.