sustainability

Article

Innovative Rammed Earth Construction Approach to Sustainable Rural Development in Southwest China

Li Wan [1,*], Edward Ng [1], Xiaoxue Liu [2], Lai Zhou [2,3], Fang Tian [1,3] and Xinan Chi [1]

1 School of Architecture, The Chinese University of Hong Kong, Hong Kong 999077, China
2 TOTAL Atelier, Hong Kong 999077, China
3 Faculty of Architecture and City Planning, Kunming University of Science and Technology, Kunming 650032, China
* Correspondence: wanli@cuhk.edu.hk

Abstract: Raw earth is the main material used in traditional architecture in Southwest rural China because it is inexpensive, accessible and exhibits remarkable thermal performance. However, local residents stopped implementing traditional rammed earth building technology because of several limitations. An innovative rammed earth construction approach suitable for Southwest rural China has been developed by One University One Village (1U1V) Team. The "local material, local technology, local labour" principle and the "high-science-low-technology" strategy has been used to improve the safety, quality and dignity of the living environment without adding substantial environmental load (negative aspects of environmental impact). The Terra Centre has been built in Kunming as the working base to research, promote, train and knowledge transfer. This holistic strategy creatively mended the long-term environmental, economic, and social sustainable development of poor rural areas and contributed to the local endogenous development significantly. It also responds to multiple targets of the 17 Sustainable Development Goals (SDGs).

Keywords: sustainable architecture; endogenous development; Sustainable Development Goals

check for updates

Citation: Wan, L.; Ng, E.; Liu, X.; Zhou, L.; Tian, F.; Chi, X. Innovative Rammed Earth Construction Approach to Sustainable Rural Development in Southwest China. *Sustainability* **2022**, *14*, 16461. https://doi.org/10.3390/su142416461

Academic Editors: Antonio Serrano-Jiménez, Carmen Díaz-López and Konstantin Verichev

Received: 1 November 2022
Accepted: 6 December 2022
Published: 8 December 2022

1. Introduction

1.1. Background

China features a vast territory and a large population of 1.41 billion. Until 2020, 36.11% of the population in China lived in rural areas [1]. During the rapid development and urbanization of China, a widening gap between urban and rural areas has appeared. The Chinese government launched several rural development policies such as The Construction of New Socialist Countryside since 2006 [2] to address this issue. Under these policies, the government increased funding for rural infrastructure. In some rural areas that have relatively convenient transportation, this modernization development model significantly improved rural life and urban-rural integration [3]. However, the said model is not comprehensive and sustainable for most of the poor rural areas of China, which exhibit the following characteristics:

- located in mountainous areas with poor traffic and dispersed population
- located in ecological fragile regions, which feature harsh natural conditions, frequent natural disasters, and relatively low agricultural productivity [4]
- lack of infrastructure development [5]
- mainly occupied by minority groups, with a relatively low educational level [6]
- primarily resided by the elderly and children due to migration of the majority to urban areas to find work [7]

Considering these limitations in poor rural areas, the following problems emerged during the implementation of rural construction:

- the conventional new buildings that use industrial materials are unaffordable to poor rural residents;
- despite the use of industrial materials to rebuild rural houses, building quality and performance is not guaranteed because rural self-built houses often do not comply with building codes for economic and practical reasons;
- a large amount of rural construction with industrial materials leads to a sharp increase in building energy consumption and environmental load (negative aspects of environmental impact) [8];
- top-down planning and construction work, which often lacks public engagement and cannot meet the actual needs of villagers, have led to a lack of cultural identity and sense of belonging [9].

Currently, sustainable rural construction and development is a significant issue in China. "Advancing Rural Revitalization" and "Promoting Harmony between Humanity and Nature" were emphasized in the Report to the 20th National Congress of the Communist Party of China [10]. However, the improvement of poor rural areas that are usually located in mountainous regions has been relatively slow and unsustainable. It is necessary for these areas to create their own development model instead of following urban/modernization models. Meanwhile, the government also encourages such autonomous, diverse, endogenous, and sustainable rural development. The crucial support that the poor rural areas of China require is not only funding but also innovative ideas and systematic strategies.

Southwest rural China is one of the main areas to implement China's rural development and construction. This region is mountainous and underdeveloped. One of the main traditional buildings in this area is earth building, which has long history and low environmental loading (Figure 1). Soil is the main material used in traditional architecture because it is inexpensive, accessible and exhibits remarkable thermal inertia. However, according to the authors' experience and observation of more than ten years of rural work in Southwest China, local residents stopped implementing traditional rammed earth building technology because of several reasons.

Figure 1. Traditional earth houses in rural areas of Southwest China.

On one hand, people's requirements for the living environment quality have increased. Their imagination of a good living environment has changed as well. Under the impact of urbanization, rural residents tend to think that earthen buildings are associated to poverty and backwardness. Moreover, improving the seismic performance of earth buildings is a big challenge since many of them are located in earthquake-prone areas (Figure 2).

Figure 2. An old rammed earth house in Southwest China damaged after an earthquake.

On the other hand, in rural areas where outside support is easier to obtain, high-speed, top–down construction and transformation funded by external capital limited the time and space for innovation and expansion of local traditional technology. Actually, a remarkable number of rural earthen architecture are classified as dangerous buildings that need rebuilding. The vast amount of villages in Southwest China are facing the choice of maintaining the traditional architecture or applying industrial building materials. The local government is still looking for a good solution that is low-cost and can improve the safety and comfort of the vernacular architecture without destroying the historical and cultural values of some certified villages.

This study provides a new construction solution that integrates the "high-science-low-technology" strategies with 'local labour, local materials, and local technology' principle 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.

1.2. Research Review

The current research on the sustainability of earth buildings mainly focuses on low energy consumption and stable indoor temperature [11,12]. Besides, studies on earth building construction technology are mainly focused on improving the mechanical properties and construction quality of earth buildings so that they can meet the living needs of contemporary people [13,14]. Clearly, earthen architecture has great potential to improve environmental sustainability. With the in-depth study of materials and the innovations of construction tools, the limitations of traditional earth building construction techniques are being lifted. Modern earthen architecture could be used and promoted as a more sustainable solution in suitable rural areas.

In terms of economic and social sustainability, earth building construction system also have the potential to make an important contribution to the development of poor rural areas. In Europe and other developed regions, a critique of rural modernization that focuses on the problems of over-production, environmental degradation, and spatial inequality was developed as early as the 1970s. This action has led to the conceptualization of a new rural development paradigm that is more sustainable than the rural modernization paradigm [15].

Unlike the rural modernization paradigm, the rural sustainable development paradigm compensates for inconvenient transportation and insufficient financial capital, utilizes local resources, limits environmental impact, respects local culture, and benefits human development. This paradigm respects the unique features, resources, and limitations of poor rural areas and aims to solve the problem through local actions rather than copying the rural industrialization model. Practice has proven that this endogenous development-based new paradigm benefits rural development in mountainous areas of different countries [16].

Prof. Xuefeng He, who studied rural policy and management of China argued that large-scale and mechanized cultivation is unsuitable for poor rural areas that have small pieces of lands located in mountainous areas. For a long period in the future, most rural residents who work in urban areas will come back to rural areas when they become aged because urban areas cannot provide decent life for them based on the current level of urban development. Therefore, adequate economic and social support should be provided to small-scale peasant economy and aged farmers rather than introducing large agriculture business entities from urban areas [17].

The above studies imply that, the rural sustainable development paradigm could be a suitable solution for areas with inconvenient transportation and rich regional culture, such as the rural areas in Southwest China. The local traditional earth architecture has more advantages and sustainability under this development paradigm. Different from the industrialized construction system, earth building construction system is a labor-intensive construction system that utilizes local resources, responds to the local climate, and carries local wisdom. It can reunite rural residents, and more importantly, rebuild the spiritual tie of rural residents. Therefore, the traditional earth buildings in the Southwest rural areas have great social value and development potential.

1.3. Research Gap

Despite much effort to research and enhance design of earth building construction in rural areas, it seems there are still aspects not yet addressed in a systematic and comprehensive manner. The environmental sustainability of earth buildings has been mentioned repeatedly, but its social and economic sustainability in rural areas has not received enough attention. In addition to material research, structural and architectural design, the social and economic sustainability of rammed earth buildings is also closely related to the local climate, geographical conditions, the organization of artisans, and the mode of economy. Not only earth building construction technology, but also technological innovation, the training and organization of craftsmen, understanding and inheritance of local wisdom, together constitute a construction system suitable for the mountainous rural areas such as Southwest China.

The scope of this study is in villages of Southwest China that traditionally use rammed earth construction techniques. The hypothesis of this research is that it is possible to promote the environmental, social, and economic sustainability of villages of Southwest China through the innovation of traditional rammed earth construction technology, combined with the training of villagers' craftsmen and the organization of villagers' construction teams.

2. Case Study

2.1. Project Intruduction

The One University One Village (1U1V) Initiative was launched at The Chinese University of Hong Kong (CUHK) in 2014. It aspires to bring together the expertise, knowledge and human resources of "a university" to improve the livelihood of "a village" and its needy villagers in a strategic, systematic and sustainable manner. In 2015, the 1U1V team conducted a post-earthquake reconstruction project in Guangming Village, Yunnan Province, China to demonstrate the use of the "high-science-low-technology" strategy with the "local materials, local labour, and local technology" principle of rural construction, and to encourage endogenous development in rural China. The project and the holistic strategy behind it creatively mended the environmental, economic, and social sustainable development of poor rural areas. Experts from Kunming University of Science and Technology (KUST) and University of Cambridge also contributed to this project in terms of structural design and seismic performance improvement [18].

Through the cooperation with the School of Architecture and Urban Planning, KUST, 1U1V have improved the construction technology and seismic performance of the earth buildings in Southwest rural China. In order to carry out more earth house projects in Yunnan region in the future, the team built the Terra Centre in KUST campus, with funding support from the Chan Cheung Mun Chung Charitable Fund. The center is mainly carried out the following functions:

- to carry out long-term artisans training, to teach the local villagers the new seismic earth construction technology, to form long-term stable construction teams, and to increase the villagers' self-reliant abilities to improve rural endogenous development.
- to provide space for conducting experiments, research and practical study, but also for the team to provide office and accommodation for the full-time staff, and storage of construction tools and project materials.
- to showcase the technologies and achievements of new seismic earth construction, to carry out domestic and foreign exchange learning activities for all levels of government, domestic and foreign professionals and students.

With the support of the Terra Center, the 1U1V team continued to carry out a series of rural construction projects in the surrounding areas (Yunnan and Sichuan Province). This study will analyze how this "high-science-low-technology" strategy with the "local materials, local labour, and local technology" principle contributes to the sustainable development of local rural areas from three aspects: environment, society and economy.

2.2. *Environmental Sustainability*

The aim of improving environmental sustainability is to reduce the environmental load throughout the life cycle of buildings, including the resources consumption, energy consumption, water consumption, carbon emissions and pollution, thereby maintaining the size, vitality and diversity of habitats [19].

2.2.1. Passive Design

In order to reduce the environmental load of the building and reflect the regional characteristics, the project design is highly based on local climate condition of Kunming. Kunming has a humid subtropical climate that is mild with dry winters, mild rainy summers and moderate seasonality. There is sufficient sunshine and significant temperature difference between day and night (Figure 3).

According to the climate condition of Kunming, the project team designed a semi-outdoor space with top lighting in the middle to create passive solar heating in winter, shading and natural ventilation in summer, for a comfortable multifunctional space for different training and academic activities. Small functional spaces such as laboratories, exhibition rooms and studios are located on both sides of the building (Figures 4–6). The main rooms of the building face southwest with floor-to-ceiling windows. Indirect daylight is set on the top of the first-floor rooms to provide soft natural lighting, so the use of artificial lighting is reduced (Figure 7).

Concrete columns and ring beams are enclosed inside the rammed earth walls to get a complete facade and avoid cold bridges. Double-glazing bridge-cut-off aluminum alloy windows were used to improve the thermal performance of the building. Besides, the project adopts a low maintenance landscape design. The front yard is paved with gravel and stone, considering the needs of walking, viewing and drainage (Figure 8).

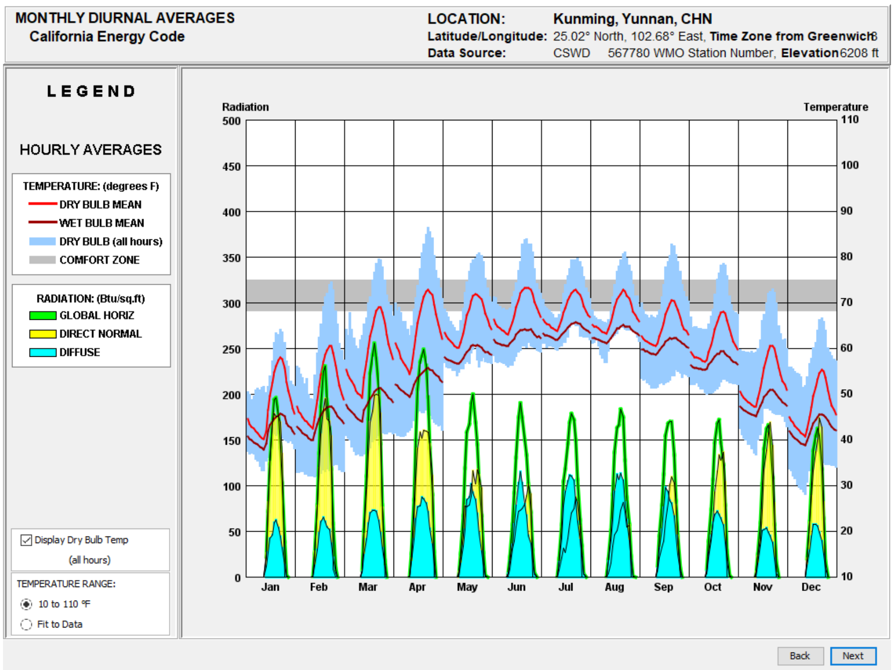

Figure 3. Climate data of Kunming (data source: EnergyPlus).

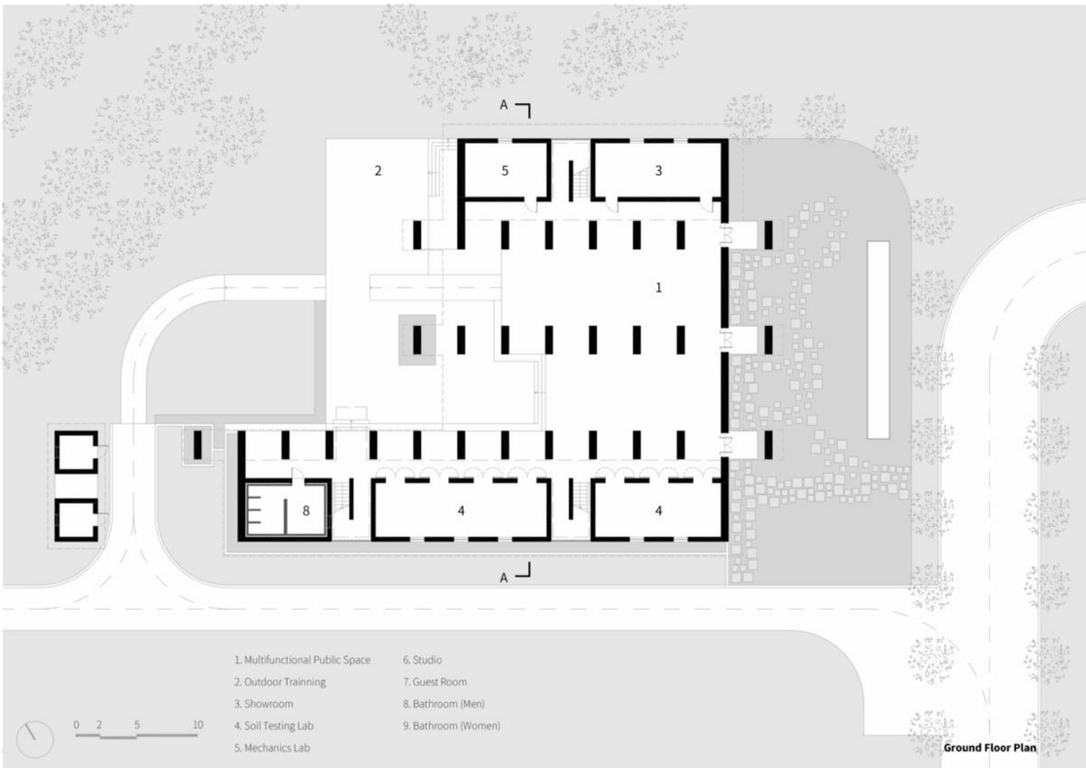

Figure 4. Ground floor plan of Terra Centre.

Since the project team planned to hire villagers to carry out the construction of the project in order to train the villagers as craftsmen, they tried to keep the building shape and joints simple to ensure that the difficulty of construction does not exceed the ability of the villagers.

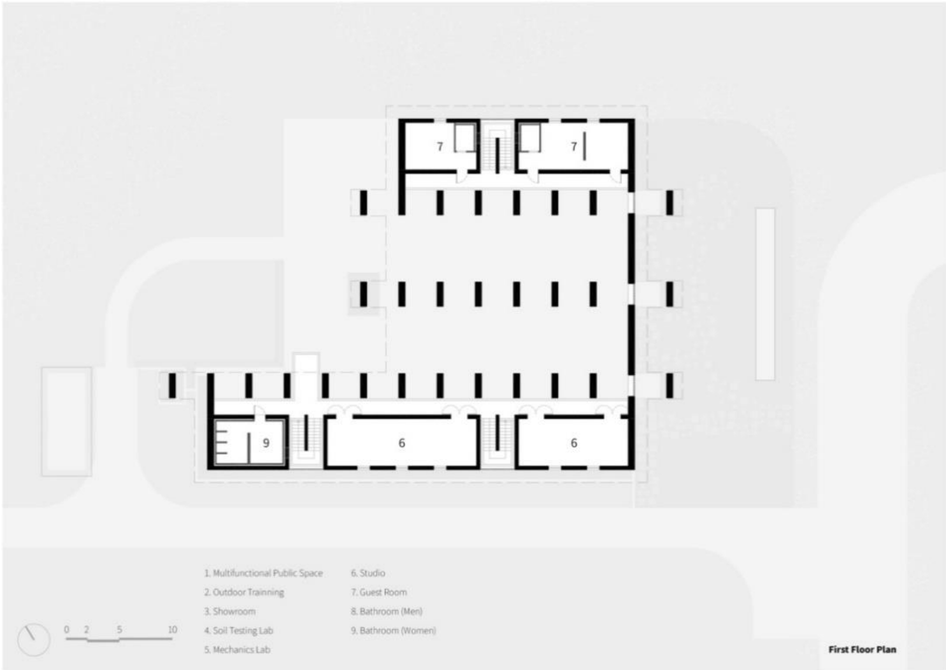

Figure 5. First floor plan of the Terra Centre.

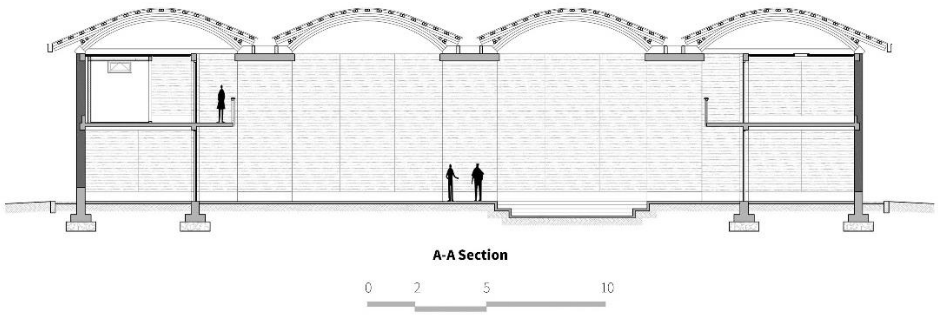

Figure 6. A-A section of the Terra Centre.

Figure 7. Indoor indirect sunlight of the Terra Centre.

Figure 8. Entrance and front yard of the Terra Centre.

2.2.2. Local Buikding Materials

Preferential use of local and natural materials minimized the embodied energy and respond to the target 12.2 (Achieve the sustainable management and efficient use of natural resources) of SDGs [20]. The Laterite Plateau in Southwest China, where Kunming is located, is rich in iron and aluminum and has less organic matter. The laterite there is heavy and clayey. Usually, in those areas with a large number of traditional rammed earth buildings, there is also an abundance of soil suitable for rammed earth buildings.

The soil used in this project is the abandoned soil from the excavation of a high-rise building foundation 6 km away from the project site. About 89% of the building materials (by weight) are local natural materials, including local raw earth, gravel, and sand (Figure 9). No industrial stabilizer such as cement was added in the wall, i.e., the wall of this building is 100% recyclable and pollution-free. The roof structure is made of bamboo that is a fast-growing material with low embodied energy. The use of industrial materials, such as cements and steels, is limited and efficiently used in key structural parts to ensure building safety and building environmental quality.

This measure greatly also reduces the construction waste caused by building construction, responding to the Target 12.5 (Substantially reduce waste generation through prevention, reduction, recycling and reuse) of SDGs [20].

Furthermore, the carbon emission in the whole life cycle of this project is minimized. According to the literature, the average annual carbon emission of the whole life cycle of a rammed earth house in Zhejiang, China is 17.37 kg/m^2, which is only 25–38% of conventional reinforced concrete frame residential buildings in the same area [21,22]. It can be inferred that Terra Centre also has great potential in reducing carbon emissions.

2.3. Social Sustainability

The social dimension of sustainability deals with issues of the improvement of human development and human rights. The idea of 'human needs' was highlighted in the influential definition of sustainable development given by Brundtland Report and can be classified according to Maslow's five level hierarchy (see Table 1) [23,24]. The idea of social sustainability was developed to consider and support these different levels of human needs.

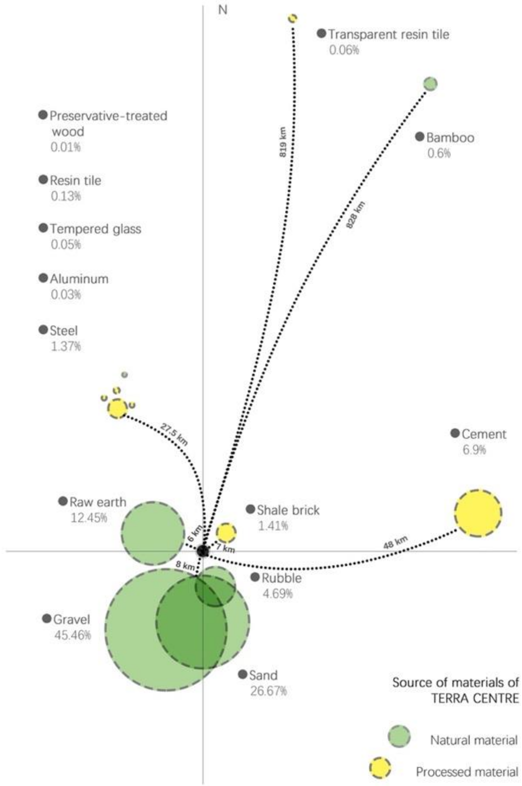

Figure 9. Source of materials (by weight) of the Terra Centre.

Table 1. Key issues of social dimensional built environmental sustainability [25].

Human Needs	**Social Dimensional Sustainability Issues of Built Environment**
Level 1. Physiological needs	1. Health and comfort: Ensures that built environment can meet the basic physiological needs of occupants and be good for occupants' health.
Level 2. Safety needs	2. Safety and security: Ensures that the built environment supports safety of occupants.
Level 3. Love and belonging needs	3. Culture and heritage: Ensures that the heritage value of existing cultural relics and intangible cultural heritage is maintained. 4. Accessibility: Provides increased access to social capital, such as information, technology, and communications.
Level 4. Esteem needs	5. Inclusiveness: Ensures that the process and outcome of the built environment consider the benefits of different groups of people.
Level 5. Self-actualization needs	6. Participation: Ensures that the process and outcome of the built environment support partnerships, social interaction, and involvement, and are influenced by the people it affects. 7. Education: Ensures that the process and outcome of the built environment improve the levels of education and awareness.

2.3.1. Building Safety and Quality

The project meets the safety needs of people by improving the building seismic performance, and meets the physiological needs of people by improving the building quality and performance.

Earth building has a very long history in China. Approximately 60 million people in China live in earth buildings now. These earth houses distributed throughout the country are an important part of China's variety of regional culture. On the other hand, Southwest China is an area with frequent earthquake disasters. Previous earthquake damages show that traditional rammed earth houses are often seriously damaged by earthquakes. Therefore, people lost their confidence in the reliability of the traditional earthen buildings. Little attention is paid to the innovation of traditional building materials, which has gradually led to the disappearance of traditional building techniques in China. How to pass on the local traditional rammed earth construction skills and meet the needs of modern lifestyle in rural areas is a significant issue. The challenges of this project are also common to other areas with high seismic intensity in China and all around the world. In this context, the 1U1V team came up with the idea of the "high-science-low-technology" by practicing in the villages.

The seismic fortification intensity of Kunming is 8 degrees in China's building code. This is a high seismic intensity area which has a design value of the basic seismic acceleration of 0.2 g [26]. The requirements for the structural system, foundation, and floor slab of an earth building in the high seismic intensity areas are strict.

The typical traditional rammed earth house in Southwest China is a bearing wall structure with timber floor and timber roof. Some houses use wood columns inside for greater interior space. Villagers use local raw earth directly to build the wall. Some old craftsmen will add gravel to the earth to increase the strength of the wall according to their experience. After a survey and study of the local traditional rammed earth building after the earthquake in 2014, several weak points have been identified as below [27]:

- nonrigid foundation made of stone and mud;
- irregularly shaped and asymmetric structural system;
- limited compressive strength and shear strength of walls rammed by manpower and wooden tools;
- weak connection between the longitudinal and lateral walls;
- weak connection between the wooden beams and rammed earth wall;
- lack of constraints at the top of the wall.

Innovations were made to improve the seismic performance based on the diagnosis above.

The shape of the building is designed to be as regular and balanced as possible to improve the seismic performance of the building.

To improve wall strength and reduce cracks, the project team analyzed the basic properties of the soil, such as particle integration curve, liquid limit, plastic limit, etc., from which they optimized the proportion of the soil by adding natural aggregates such as gravel and sand (Figure 10).

The compressive strength of the material directly affects the bearing capacity of the wall. Meanwhile, improving the compressive strength of the material can effectively enhance the overall performance of the wall, which will exert positive effects on seismic performance. Therefore, the air compressed rammers and the aluminum alloy formwork are applied in this project instead of traditional wooden tools and manpower ramming. Air compressed rammers and aluminum formwork are lighter than electric rammers and steel formwork, and the size of individual formwork is controlled to further reduce weight (Figure 11). The result of cylinder (H = 30 cm, D = 15 cm) compression test showed that the above improvement measures have increased the compressive strength of the rammed earth wall to more than 2.2 MPa.

In terms of structural design, Terra Center adopts bearing wall system. Reinforced concrete tie columns are set in the rammed earth walls to improve the anti-shearing performance, and to facilitate the installation of doors and Windows. Reinforced concrete ring beams are set at the bottom and top of the tamed earth wall, together with reinforced concrete foundation and floor slabs, to enhance the structural integrity, so as to resist seismic forces (Figure 12). Reinforced concrete are selected instead of steel or other measures, mainly because: 1. The villager craftsmen are more familiar with the construction techniques of reinforced concrete, which has relatively low precision requirements. 2. Cement, sand and gravel are easy to purchase and transport. 3. Concrete has a long service life and does not require maintenance. Moreover, prestressed steel bars were added to the short rammed earth wall of the atrium to resist overturning.

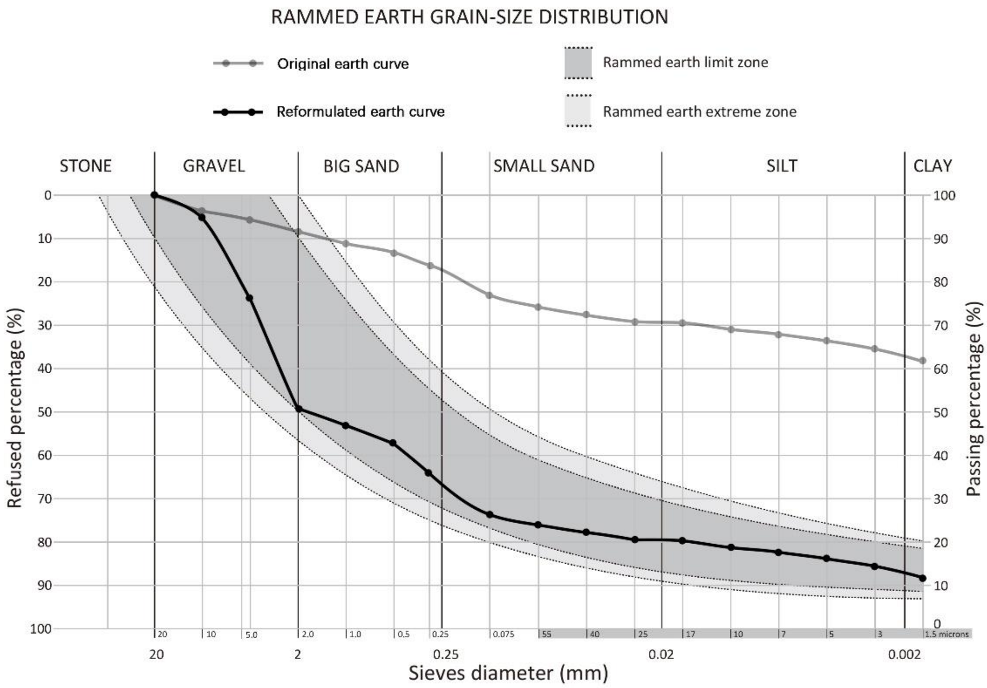

Figure 10. Soil sample analysis and optimization chart of the Terra Centre.

Figure 11. Rammed earth wall construction of the Terra Centre.

In order to verify the reliability of the above technical innovations, a full-size rammed earth house model was constructed and tested with a seismic simulation shaking table test. The result showed that under the action of a 7 and 8 degrees seismic intensity, the earthen house remained intact and the stiffness was basically unchanged. This seismic performance is significantly higher than China's building code requirement, which means the building safety is guaranteed in the earthquake-prone zones.

Figure 12. Concrete tie columns and ring beams of the Terra Centre.

Bamboo is a vernacular building material in China. But it has poor durability and difficult to be standardized. Furthermore, the traditional construction technology cannot meet the needs of large public building spaces.

In this project, the durability of raw bamboo was improved through a high pressure immersion process. For achieving the standardization of the structure component of the long span, each bamboo rod was designed and prefabricated into a standardized arch structure in the factory. It highly improved the reliability and convenience of the joint construction (Figure 13).

Figure 13. Construction of bamboo roof structure of the Terra Centre.

This project provided a comfortable and artistic building environment for the users including teachers, students, scholars, and villagers. It created high architectural quality and aesthetics although it was built by village craftsmen rather than a professional construction team. The whole space presents a quiet and meaningful aesthetic feeling, as the sun shines on the rammed earth colonnade in the atrium. It brings a special atmosphere to teaching, communication, and activities (Figures 14–16). Double-glazed windows and insulated roofs of the rooms improved the thermal performance of the building.

Figure 14. Aerial view of the Terra Centre.

Figure 15. Multifunctional public space of the Terra Centre.

Figure 16. Soil testing lab of the Terra Centre.

In summer, the roofed semi-outdoor space blocks Kunming's strong sunlight and ultraviolet rays. In winter, rammed earth wall with outstanding thermal performance provide stable and comfortable indoor temperature in most of the working days. Figure 17 shows that the indoor temperature is about 5–10 °C higher than the outdoor temperature. With Anthropogenic heat, the indoor temperature is acceptable before winter holiday (Mid-January to February). Due to the short number of extremely cold and extremely hot days in Kunming, and a flexible timetable of use, no active cooling and heating system has been applied in this project.

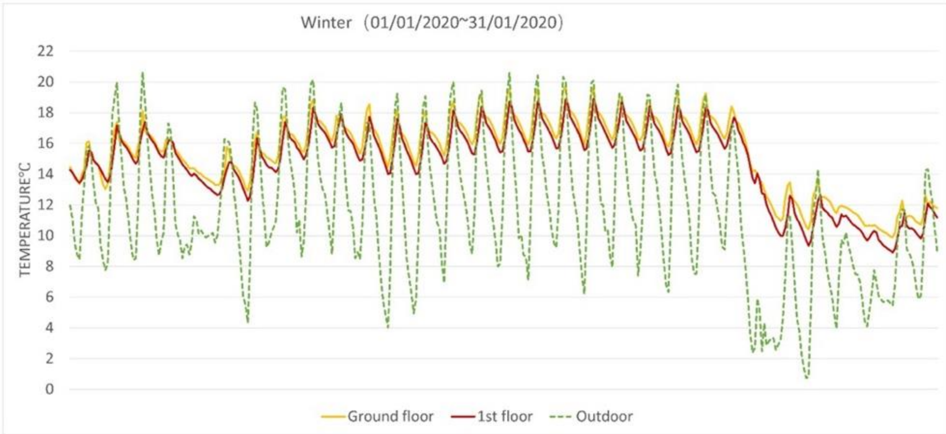

Figure 17. Temperature measurement data (unoccupied) of the Terra Centre.

2.3.2. Training and Education

The project team's craftsman training plan and construction organization have a comprehensive and positive impact on the psychological needs of villagers at all levels. It also respond Target 4.4 (substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship) of SDGs [28].

For love and belonging needs, the response to the specific historical context of Southwest China has not been to imitate the form of the local traditional buildings but to regenerate local culture by following the principle of "local materials, local labour and local technology". The Terra Centre is not only a building but a research and education tool. The project team trained and employed villagers to build the Terra Centre. 33 villagers joined this project and passed the craftsmen training. They are all from the villages with high seismic intensity, and most of them have lived in the traditional earthen buildings.

Besides, the team implemented several rammed house construction projects in villages nearby Kunming during the construction period of the Terra Centre. The team also created a series of design prototypes for villagers based on the local climate, lifestyle, and skill (Figure 18). These designs simplified the building form and reduced requirements for construction precision to ensure that the village craftsmen can implement it. The villager craftsmen were empowered through the learning-by-doing process. Villagers are respected and fully engaged in the whole reconstruction process, apart from construction works, they also involved in designing their new home. The esteem needs and self-actualization needs of villagers are also considered and valued in this process. These projects changed the attitude of the villagers towards rammed earth buildings. They became interested in switching back from their brick-concrete houses because the project protected their local traditional construction method and lifestyle. Such a shift is consistent with the Target 12.8 (ensure that people have the relevant information and awareness for sustainable development and lifestyles in harmony with nature) of SDGs [20].

Figure 18. New rammed earth houses in Sichuan and Yunnan built by the villagers' construction team, with the support of the Terra Centre.

Furthermore, a women construction team with a female leader and half of women workers has been established. Men and women get equal pay for equal work. Accordingly, the equipment has been improved to make them more convenient to control for women. In many of poor rural areas in China, only women, children and the elderly stay in the village. The 1U1V project engaged women into construction to promote gender equality, which is also emphasized in SDG 5 [29]. Participation of women not only helped solve the problem of labour shortage, but also provide rural women with job opportunities and skills and enhanced their self-confidence. The women construction team have since been working on other rural reconstruction projects. They demonstrated high construction efficiency and excellent construction quality. It proves that these women team members were well adapted to the work.

2.4. Economic Sustainability

The aim of economic sustainability is to Decouple the relationship between environmental degradation and economic growth. It is important to move towards a system of economics that improves resource efficiency and values the environment and people. An economic approach that emphasizes equality, promotes local economy, protects complexity and diversity, and values the environment and people needs to be established [19].

2.4.1. Local Economy

This project integrated the local people with the larger context of rural China by providing an endogenous and sustainable solutions. At least 5 village construction teams were established after completion of the Terra Centre. They can use their knowledge of such new construction technology and framework as their livelihood. With the formwork and rammer donated from the team, villagers can own this technology and pass it on. Supporting productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro- and small-sized enterprises is also emphasized in Target 8.3 of SDGs [30].

More importantly, the lower construction cost, compared with "modern" concrete/brick buildings, allows villagers to live debt-free, and the low operation cost (due to the good thermal performance of earth materials and passive design) can even help them save money for other necessities to improve their living conditions. With the support of the Terra Center, the 1U1V team and the village construction teams has completed the reconstruction of more than 60 rural houses, and more than 70 houses are under construction.

Furthermore, the 1U1V rural projects are based on voluntary participation. The team will start by building a demonstration project in one area. Villagers could join or opt out according to their view of the demonstration and the resources they could obtain. The diversity and complexity of a region are respected and protected.

2.4.2. Partnership and Education

The project team not only provide design as architects but also worked with the villagers throughout the process as partners. The team contributes professional knowledge and advanced technology while local residents provide local knowledge and manpower. The project wouldn't be success if effort from either side is missing. Through this long-term cooperation and learning-by-doing process, the project team established mutual trust and long-term connection with the villagers and convinced them that innovative rammed earth building was a good solution.

Besides, this solution has been generated by multidisciplinary partnerships and networking platforms. The team established effective network of academics, professionals, students and volunteers who share the same aspiration to generate academic and societal impact by intervening practical projects, to build a knowledge community. Local government is also involved to coordinate and explore this new sustainable way of rural reconstruction. The 1U1V team members has been invited to prepare the national earth building code and local earth building construction guidelines for Sichuan and Yunnan provinces.

As a research center, Terra Center carried out a variety of research, experiments, academic workshops and seminars relevant to earthen architecture and rural sustainable development. Both undergraduate and graduate teaching, as well as various activities, are often held in the Terra Centre. Visitors can touch the walls and see every detail of the building directly. It makes the Terra Centre itself a living teaching tool.

The project and the philosophy behind it were recognized with the following awards:

- HKIA Annual Awards 2021—HKIA Merit Award outside Hong Kong—Institutional Building & Special Architectural Award—Humanity & Social Inclusion
- Green Building Awards 2021—Special Citation on UN Sustainable Development Goals
- TERRAFIBRA Award 2021—Winner in the "Public Cultural Equipment" category
- 2021 International Green Gown Award—Winner in the benefitting society category

The impact of the project proves that, this model not only benefits the villagers, but also has a positive impact on other participants and contributes to improving the policy. It responds the Target 17.16 (Enhance the Global Partnership for Sustainable Development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources, to support the achievement of the Sustainable Development Goals in all countries) and Target 17.17 (Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships) of SDGs [31].

2.5. Discussion

Research shows that socioeconomic value is crucial in sustainable rural construction and development [32,33]. In the poorest rural areas with inconvenient transportation, the environmental load of vernacular houses is low already. The key issue is how to improve the safety, quality and dignity of the living environment without adding substantial environmental load. Relying on external funds, non-local industrial materials and high technologies can bring huge environmental load to mountainous rural areas in China. It is unrealistic for rural residents to stay in their village and contribute to the local development if they have no confidence in their local resources, lifestyles and abilities. Even if a new farmhouse can be built with external funds and support, villagers will still try to get rid of everything 'local', which in their mind represents poverty. Only by endogenous development which values local resources, local technologies, and local culture, villagers can see a bright future for their homes.

Therefore, choosing appropriate building materials, building technologies and construction workers is crucial and tricky in mountainous poor rural areas. The architect must consider local climate, construction costs, the source of materials and workers, and the operability of building technology carefully.

More importantly, architects need to redefine their role in rural construction. In the practice of the 1U1V team, architects are more like scaffolding for villagers, paying attention to the local context and looking for the nearest development area of the villagers with the language close to the villagers.

In the process of more than 10 years of rural work, the 1U1V team found that most of the existing building environmental assessment methods were established for urban areas and are based on the development model of modernization—that is, they are aimed at transforming markets, and criteria are based on quantifiable and comparable technical measures with a linear approach toward conserving resources. Some mountainous rural areas, such as those in southwest China, are undergoing major construction and development without adherence to appropriate guidelines and assessment methods. The project result provides references for national rural construction policies and local earth building seismic guidelines and standards.

3. Conclusions

The Terra Centre and following rural rammed earth house projects built not only the infrastructure, but also villager's psychosocial wellbeing, core value and sense of belongings by changing villagers' attitude toward rammed earth building. They demonstrated an approach to rural construction that integrates environmental, social and economic sustainability. The implementation and promotion of this innovative rammed earth construction technology in rural areas of Southwest China have significant value of rural revitalization and sustainability. Moreover, the innovative rammed earth building technology can be replicated for the improvement of poor rural areas where there are similar natural and social conditions to those in the poor rural areas of Southwest China, for example, in the rural regions of Nepal and India.

Author Contributions: Conceptualization, L.W. and E.N.; Methodology, L.W.; Investigation, X.L., L.Z. and F.T.; Data curation, X.L., L.Z., F.T. and X.C.; Writing—original draft, L.W.; Visualization, X.L.; Supervision, E.N.; Project administration, F.T. and X.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Chan Cheung Mun Chung Charitable Fund Ltd. Grant number IR91/9906.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The climate data of Kunming is generated by a software called Climate Consultant 6.0 And here is the data used: https://energyplus.net/weather-location/asia_wmo_region_2/CHN/CHN_Yunnan.Kunming.567780_CSWD.

Acknowledgments: The authors wish to thank Lucia Cheung, Wenfeng Bai, Marc Auzet, Juliette Goudy, Shan Dai, and Changzhuan Shao, for their valuable technical support on this project. We would also like to extend my thanks to Chan Cheung Mun Chung Charitable Fund Ltd. for offering us the funding of the program. Special thanks should be given to Changfu Yang, Qingguang Yang, and the village artisans they led for their dedication in the project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. National Bureau of Statistics of China. *China Statistical Yearbook 2021*; China Statistics Press: Beijing, China, 2021. Available online: http://www.stats.gov.cn/tjsj/ndsj/2021/indexeh.htm (accessed on 21 September 2022).
2. Looney, K.E. China's campaign to build a new socialist countryside: Village modernization, peasant councils, and the Ganzhou model of rural development. *China Q.* **2015**, *224*, 909–932. [CrossRef]
3. Zhang, Q.; Chang, Z. *A Comparative Study of New Rural Construction in Different Regions of China*; Social Sciences Academic Press: Beijing, China, 2010; pp. 11–13.

4. Li, X.; Zhuo, T.; Ye, J. (Eds.) *Status of Rural China*; Social Science Academic Press: Beijing, China, 2008; pp. 310–311.
5. Jia, R.; Hou, X. New pattern of distribution in major poverty-stricken areas in China and new ideas for poverty alleviation and development. *China Develop. Obs.* **2011**, *7*, 27–30.
6. Liu, Y.; Zhou, Y.; Liu, J. Regional differentiation characteristics of rural poverty and targeted poverty alleviation strategy in China. *Bull. Chin. Acad. Sci.* **2016**, *3*, 269–278.
7. Liu, Y.; Liu, Y.; Zhai, R. Geographical research and optimizing practice of rural hollowing in China. *Acta Geogr. Sin.* **2009**, *64*, 1193–1202.
8. Zhang, C.; Suo, C.; Solvang, W.D. *Efficiency and Effectiveness of Energy-efficient Building Technology in Chinese Rural Area*; Economic Science Press: Beijing, China, 2010; pp. 36–39.
9. Qiu, B. Planning and construction of villages and towns in the age of ecological civilization. *China Anc. City* **2010**, *6*, 4–11.
10. Full Text of the Report to the 20th National Congress of the Communist Party of China. Available online: http://english.www.gov.cn/news/topnews/202210/25/content_WS6357df20c6d0a757729e1bfc.html (accessed on 15 November 2022).
11. Sameh, S.H. Promoting earth architecture as a sustainable construction technique in Egypt. *J. Clean. Prod.* **2014**, *65*, 362–373. [CrossRef]
12. Li, Q.; You, R.; Chen, C.; Yang, X. A field investigation and comparative study of indoor environmental quality in heritage Chinese rural buildings with thick rammed earth wall. *Energy Build.* **2013**, *62*, 286–293. [CrossRef]
13. Maher, J.; Madrigal, J. Earth Architecture in Rural Egypt: Challenges of the context and the material. *A+ Arch. Des. Int. J. Archit. Des.* **2021**, *7*, 99–112.
14. Maniatidis, V.; Walker, P. *A Review of Rammed Earth Construction. Innovation Project "Developing Rammed Earth for UK Housing"*; Natural Building Technology Group, Department of Architecture & Civil Engineering, University of Bath: Bath, UK, 2003.
15. Woods, M. *Rural*; Routledge: New York, NY, USA, 2011; pp. 132–161.
16. Caraveli, H. Endogenous rural development prospects in mountainous areas-the case of mount Parnonas in Greece'. *Rural Areas Develop.* **2006**, *4*, 143–163.
17. He, X. Agricultural Modernization for Whom? *Open Times* **2015**, *5*, 36–48.
18. Wan, L.; Ng, E. High science and low technology for sustainable rural development. *Archit. Des. Spec. Issue Soc. Value Archit.* **2020**, *9*, 74–81. [CrossRef]
19. Gibberd, J.T. Integrating Sustainable Development into Briefing and Design Processes of Buildings in Developing Countries: An Assessment Tool. PhD Thesis, University of Pretoria, Pretoria, South Africa, 2003.
20. Goal 12. Ensure Sustainable Consumption and Production Patterns. Available online: https://sdgs.un.org/goals/goal12 (accessed on 25 November 2022).
21. Du, S.; Ma, J. Analysis on low-carbon technology and CO_2 emission of rammed earth building: The case of eco-house in Anji. *Ecol. Econ.* **2012**, *250*, 143–146.
22. Zhou, X. Research of CO_2 Emission of Urban Residential Buildings in Zhejiang Province Based on Life Cycle Assessment. Master's Thesis, Zejiang University, Hangzhou, China, 2012.
23. World Commission on Environment and Development. *Our Common Future*; Oxford University Press: Oxford, UK, 1987.
24. Maslow, A. A Theory of Human Motivation. *Psychol. Rev.* **1943**, *50*, 370–396. [CrossRef]
25. Wan, L.; Ng, E. Evaluation of the social dimension of sustainability in the built environment in poor rural areas of China. *Archit. Sci. Rev.* **2018**, *61.5*, 319–326. [CrossRef]
26. Housing and Urban-Rural Development of the People's Republic of China. *Code for Seismic Design of Buildings GB 50011—2010*; China Architecture & Building Press: Beijing, China, 2016; p. 206.
27. A Brief Introduction of Anti-Seismic Earthen Building Technology and Demonstration Project for Post-Earthquake Reconstruction in Ludian, China. Available online: http://web5.arch.cuhk.edu.hk/server1/staff1/edward/www/1u1v/files/CUHK/Ludian/Manual.pdf (accessed on 12 October 2022).
28. Goal 4. Ensure Inclusive and Equitable Quality Education and Promote Lifelong Learning Opportunities for All. Available online: https://sdgs.un.org/goals/goal4 (accessed on 25 November 2022).
29. Goal 5. Achieve Gender Equality and Empower All Women and Girls. Available online: https://sdgs.un.org/goals/goal5 (accessed on 25 November 2022).
30. Goal 8. Promote Sustained, Inclusive and Sustainable Economic Growth, Full and Productive Employment and Decent Work for All. Available online: https://sdgs.un.org/goals/goal8 (accessed on 25 November 2022).
31. Goal 17. Strengthen the Mans of Implementation and Revitalize the Global Partnership for Sustainable Development. Available online: https://sdgs.un.org/goals/goal17 (accessed on 25 November 2022).
32. Hussain, S.; Maqbool, R.; Hussain, A.; Ashfaq, S. Assessing the socio-economic impacts of rural infrastructure projects on community development. *Buildings* **2022**, *12*, 947. [CrossRef]
33. Wan, L.; Ng, E. Assessing the Sustainability of the Built Environment in Mountainous Rural Villages in Southwest China. *Mt. Res. Dev.* **2016**, *36*, 4–14. [CrossRef]