

DESIGN RESEARCH ESSAY

Deciding on Bamboo or Steel as a Building Material in Rural China: The Area X Project

Daniel Stamatis and Tan Gangyi
Huazhong University of Science and Technology, CN
Corresponding author: Daniel Stamatis (chus90@aliyun.com)

The rapid process of quasi-urbanisation in rural China is promoting Western styles of architecture along with imported materials, making rural tourism less appealing. Despite the abundance of highly renewable bamboo, rural dwellers tend to overlook it for construction purposes. This essay therefore discusses the potential of bamboo architecture to help the regeneration of traditional Chinese villages. A participatory action approach was used to design and construct a touristic building called Area X in Zhengjia Shan village, Hubei province, completed in 2017. Initially we as the architects had wanted to use a bamboo structure for Area X but instead the villagers chose steel scaffolding. After explaining how the decision was made in favour of steel, the essay examines bamboo and steel in terms of their comparative environmental impacts: it shows that the steel scaffolding has a very negative impact in emitting 6,410.25 kg of CO$_2$, regardless of its rapid assembly and reusability, whereas the bamboo version would have made a very positive impact by storing 14,384.13 kg of CO$_2$ over the building’s lifetime. These findings suggest that the aspiration for modernity by the villagers in Zhengjia Shan took priority over environmental awareness. Hence the essay concludes by arguing that bamboo architecture should not be taken lightly, and indeed can be seen as essential given humankind’s need to adapt to climate change by only designing carbon-positive buildings from now on.

Keywords: Moso bamboo; Metallic scaffolding; Rural Tourism; Architectural Regionalism; Participatory design; China

Background

After the 1948 Communist Revolution in China, the term ‘city’ became synonymous with the concept of modernity. ‘Rural enclaves’, on the other hand, remained associated with older Chinese traditions. Furthermore, the modernisation process initiated under Chairman Mao Zedong also sought to redefine rural regions in two ways: firstly, by offering a romanticised vision of natural scenery as an idyllic part of a ‘greener’ lifestyle; and secondly by portraying them also as areas with high levels of poverty, poor education standards, lack of sanitation, and general cultural barbarism [1]. China possesses the largest agrarian population in the world, and so the socio-economic development of its rural regions has always been one of the major priorities for its Communist leaders – mainly addressed by encouraging internal rural tourism as the means through which to diversify an overreliance on agricultural income. Paradoxically, however, the widespread use of imported Western materials and ‘European’ building styles as a result of the rapid urbanisation that took place following Deng Xiaoping’s ‘Open Door’ policy in the 1980s, which in effect created the state-controlled capitalist model that exists today, have made the recent examples of Chinese rural architecture far less appealing in the eyes of tourists.

As one obvious example of this dilemma, although renewable bamboo is abundant across China, contemporary architecture in rural areas generally overlooks it entirely as a construction material [2]. This introductory section will therefore trace the interaction between three crucial topics – rural tourism, Critical Regionalism, and bamboo – as the background for how one might start to imagine new possibilities for Chinese rural architecture as part of the current revitalisation plans in many traditional villages.
Taking the first of these issues, that of rural tourism in China, it is clear that increasing income within its countryside areas is also leading to a reduction in the latter’s architectural appeal. Globally, we can find many similar efforts of agricultural regions to promote rural tourism to improve local people’s livelihoods. Indeed, it was nineteenth-century European nations – experiencing industrialisation and the mass movement of populations to cities – that initiated this approach, meaning that today, in countries such as France, Austria and Britain, rural tourism constitutes a significant economic strand that shows remarkable growth in terms of demand [3]. In China, this tendency only really began in the late-1980s in wake of the ‘Open Door’ transformations. Given the increasing disparity of socio-economic conditions between urban and rural life, Deng Xiaoping’s government promoted rural tourism in an attempt to eradicate countryside poverty, increase the quality of life for village inhabitants, and to reduce the rural-to-urban migration flow. Rural tourism has as a consequence increased the earning capacity of villagers, promoted wider ecological awareness, and encouraged the consumption of organic products among city-dwellers [4].

Nowadays, due to the quasi-urbanisation of settlements throughout rural China, non-renewable building materials such as concrete, steel and aluminium have become the predominant architectural materials. This is because Western-style designs and non-renewable materials represent a more modern, urban style that is increasingly fashionable among rural populations. Due to this preference, new buildings in villages now often resemble city architecture, thereby making rural tourism less appealing to urban Chinese or international visitors who are seeking the traditional, or ‘real’, China (Figure 1). The aspirations of rural villagers for images of modernity are likewise echoed in the lack of interest in historical forms and local resources [5].

Turning now to the possibility of Critical Regionalist architecture offering an alternative approach to Chinese rural construction, Hadas Shadar points out that the essence of Critical Regionalism – as formulated first in the late-1980s by Alexander Tzonis and Liane Lefaivre – is in its integration of global architectural aesthetics and modern technology with local characteristics, even if there is often regrettable little social or theoretical questioning of such concepts [5]. Moreover, Thorsten Botz-Bornstein highlights the importance of Critical Regionalism in considering contextual elements such as local scenery, historical forms and daylight conditions, but without descending into the imitation of tradition [6]. Any authentic example of Critical Regionalist architecture should this be regionally different and be able to change over time to continue to provide a relevant ‘support system’ for the building.

Due to the sheer variety of conditions across the world, Critical Regionalism has branched out into different sub-styles, often carried out by solo architects or smaller practices. In Australia, for example, Glenn Murcutt focuses his attention upon environmental aspects such as wind direction, water circulation, temperature and daylight patterns, prior to designing relatively economical and multi-functional projects (Figure 2a). Peter Zumthor enhances the symbolism of his structures by relating them directly to their natural context through the use of local materials, as in the Steilneset Memorial in Vardø, Norway (Figure 2b). Botz-Bornstein has mentioned the possibility of finding similar approaches from Chinese rural traditions, while also noting that the main obstacle for Critical Regionalist architecture in China is what he sees as the absence of a self-critical ‘Enlightenment’ tradition. Peter Eisenman likewise describes Asian architecture as conservative because there is no tradition of resistance and opposition. Indeed until the impact of nineteenth-century colonialism there was no clear theoretical foundation for architecture in China as builders were merely local
artisans. Nevertheless, in the past few decades, Chinese architects who practice a kind of Critical Regionalism have emerged, including Yung Ho Chang, Ma Qingyun, Liu Jiakun, and most famously of all, Wang Shu and Lu Wenyu of Amateur Architecture Studio [5, 6].

According to Wang Shu, in order to practice Critical Regionalism, one must first of all be a researcher and scholar, secondly a craftsperson, and only thirdly a builder. Moreover, he argues that if architecture hopes to work hand-in-hand with time, this generally means using cheap replaceable materials as the best option to allow for damage and repair. For instance, the large roof structure over the guesthouse that Amateur Architecture Studio designed for the China Academy of Art campus in Hangzhou is in fact constructed from multiple small pieces of cheap timber that are easy and quick to replace (Figure 2c) [7].

In this sense, too, bamboo can be seen as a possible bridge between rural tourism and Critical Regionalist architecture. As a sustainable and ancient symbol in Asian societies like China, the constructional use of bamboo however still lags far behind its potential. Yet at least half of the concentrated clusters of rural settlements are to be found within the natural bamboo forests of southern China (Figure 3). The provinces with the highest density of rural settlements and also the largest presence of bamboo in China are Hunan, Hubei, Jiangxi, Zhejiang and Anhui [8, 9] – with the border between Hunan and Hubei being the location for the case-study project to be discussed later in this essay.

After all, it is nature that ‘engineers’ bamboo. It does not need to be manufactured; instead its growth consumes minimum energy while also readily absorbing carbon dioxide. Farmers can harvest mature bamboo poles after 3–5 years of growth, meaning that millions of rural Chinese residents now gain sustainable income from these tropical forests [10]. Among more than 1600 variant species worldwide, it is Moso bamboo (Phyllostachys edulis) that is the basis for the US$ 30 billion per annum bamboo industry in China. Its many applications could include architectural construction because of its sufficient diameter

![Figure 2: a) Australia (Glenn Murcutt, 1984); b) Norway (Peter Zumthor, 2011); c) China (Wang Shu and Lu Wenyu, 2012). [Photographs: Riley Sherman, Louise Bourgeois and Edward Denison, respectively].](image)

![Figure 3: The highest densities of village distribution in China generally match with the areas of Moso bamboo forests. [Image: Daniel Stamatis].](image)
and renowned structural properties. Along with a particular South American species (*Guadua Angustifolia*), Moso bamboo is the one that has been most researched into as a building material. Chinese state officials and businessmen at all levels are now recognising that the bamboo industry could be expanded even further if only it were more commonly used in architecture [11]. Before looking at why this is not happening, it is useful first to look at the architectural potentials of bamboo construction.

**Bamboo-driven architectural design**

There is no bamboo that is quite like another; instead, it adapts to differing natural environments and so varies in diameter, length and colour, depending on the local climate (*Figure 4*). The key unifying physical characteristics of bamboo can be summarised as follows:

- Bamboo has a round profile.
- Bamboo fibres grow in a longitudinal direction.
- Bamboo is hollow, with its nodes optimising tensile and compressive strength.
- Bamboo has no cross-fibres, which allows loads only in a parallel direction.

One of the more controversial aspects of bamboo cultivation is the harvesting method. Rural dwellers across Asia and South America follow the lunar cycle to identify when is the best moment to do so: generally it is recommended to harvest bamboo immediately after the rainy or snowy season ends, and between the 6th and 8th day after a full moon, between 4 pm and 6 am. Although these recommendations are sometimes dismissed as ‘superstitions’, they in fact relate directly to the levels of humidity found within bamboo, which otherwise increases its weight considerably and thereby affects transportation logistics and the suitability of the material for construction. Importantly, each bamboo culm shares exactly the same root system underground as the entire rest of the bamboo forest, meaning that the harvesting cut needs to be made as close as possible to the first or second node on a bamboo pole so as to protect the shared root from rotting.

Although bamboo architecture has existed in China for thousands of years, there are not many surviving examples of these buildings because bamboo biodegrades so quickly. In other words, all bamboo architecture is eventually going to disappear. However, there are now certain techniques that are able to increase significantly the lifespan of bamboo construction [2, 8, 10]. This section therefore discusses three primary considerations in manipulating the durability of structural bamboo: protection by design, preservation treatment, and suitable joinery systems.

To enable bamboo structures to last for a century or more, one needs to protect it through architectural design [12]. For this are two simple rules: do not let the bamboo touch the ground, and make sure that it avoids direct sunlight. One of the pioneers of this concept, the Colombian architect Simon Velez, explains this approach as ‘good shoes, good hat’. He recommends that bamboo columns need to stop 200 mm above the ground, or in the case of bridge supports, at least 400 mm above. During the 1970s, Velez

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*Figure 4*: Characteristics of the bamboo culm of the monopodial kind. [Image: Daniel Stamatis].
also pioneered the process of injecting concrete into the joints of bamboo structures to increase their mechanical performance notably. The protection by design approach to bamboo architecture is currently used more in countries such as Colombia and Indonesia, but almost never in China. This lack of awareness of the ‘good shoes, good hat’ approach is hence negatively affecting the attitude of Chinese rural dwellers towards bamboo architecture.

When it comes to preservation treatment, all bamboo is susceptible to insect infection, fungal growth, and splitting. Without proper treatment, its average natural lifetime is less than two years. If stored under cover, untreated bamboo can last 4–7 years. Yet for the optimal adoption of bamboo within architecture, it is essential to increase its durability up to 50 years or more. Preservation treatment for bamboo will increase the initial costs but will also reduce the overall lifetime cost of a building, so is worth doing on that basis. Yet another problem is that all bamboo preservatives are toxic to some degree, with the least toxic being boron, which is also a relatively low-cost option [13]. Borate solution can be reused multiple times, but not indefinitely; instead the residual solution can be applied as a plant fertiliser [14].

In regard to joinery, it is well known that bamboo’s outstanding structural strength counts for nothing if there is not a strong union between the poles. Bamboo joinery can be classified roughly into vernacular joinery (90% bamboo, 10% another material, usually organic), affordable joinery (80% bamboo, 20% steel/mortar), or modern joinery (65% bamboo, 35% steel/mortar) (Figure 5).

In rural China, the typical fabrication of animal shelters and farm tools depends on vernacular joinery techniques, yet for this essay our proposition is that affordable joinery offers the most reasonable choice for new bamboo construction. For affordable joinery, site workers are required to drill a hole into the key connection joints between the bamboo poles, with mortar then being injected into it: doing this increases the compression strength from 300 kilogrammes per metre up to 3 tons per metre [10, 13] (Figure 6).

|                      | Vernacular | Affordable | Modern |
|----------------------|------------|------------|--------|
| Cost access          | ✔          | ✔          |        |
| CO₂ balance          | ✔          | ✔          |        |
| Structural strength   | ❌          | ✔          | ✔      |
| Durability            | ❌          | ✔          | ✔      |
| Aesthetic value      | ✔          | ✔          | ✔      |

Figure 5: Joinery systems for bamboo structures, with the choice of technique depending on the socio-economic position of the project in question. [Image: Daniel Stamatis].

Figure 6: Basic understanding of bamboo pole connections. [Image: Daniel Stamatis].
If the use of local resources is what characterises Critical Regionalist architecture, then bamboo is the most obviously abundant and renewable resource in China to provide the ‘regional’ element. But this is not happening at the moment, as shown clearly by the example of Anji County near to the prefecture-level city of Huzhou in northwest Zhejiang province. Anji County had a population of 461,800 in late-2013, and remains much the same today. It is particularly known for its bamboo, containing as it does 60,000 hectares of bamboo groves, with over 40 different species of bamboo of which the most common is Moso bamboo. Anji is indeed considered to be China’s ‘bamboo town’ – winning multiple awards including the China National Habitat Environment Award, UN-Habitat Scroll of Honour, and National Ecological County Award, due to its leading position in the bamboo industry. Despite these accolades, there is still no link between bamboo architecture and rural tourism in the area. Statistics reveal that everywhere else in China faces a similar situation [11]. Hence we will now describe a case-study project we were involved in designing that is instructive in identifying those factors that persuade local villagers to select a non-renewable material like steel over sustainable bamboo – in this case for a brand new building titled Area X, which also helps us in assessing the relative environmental impact of both materials.

Case Study: The Area X project

Area X is a 272 m² indoor-outdoor, low-cost facility that hosts entertainment activities for predominantly urban Chinese tourists. It was completed in May 2017 at the Qianyi Farm Hotel in Zhengjia Shan village, Hubei province. In fact it constitutes the second phase of this farm hotel, the first phase having initially been set up in an abandoned school that was transformed into a hotel in 2014 to promote organic food as a healthy lifestyle option. For the second phase, the design process for Area X involved a continuous open dialogue between the villagers and our architectural team, and which was predicated on a combination of handcrafts and digital tools. Our initial proposal was for a structure created primarily of bamboo, but after we showed this to the villagers they asked us to reconsider the choice of building material to find a faster assembly technique. Area X was hence ultimately built with a steel scaffolding frame instead of bamboo (Figure 7), and the remainder of this essay will analyse the motivations, factors, and consequences of this decision.

As mentioned, a participatory action research-based methodology was adopted for the design and construction of Area X. Our initial assumption was that bamboo would be able to meet all of the necessary standards for a building material that could help to regenerate traditional Chinese villages. During the design stage, we held three key meetings with the villagers: the first about the project’s requirements, the
second to present our bamboo proposal; and the third to discuss the steel scaffolding proposal. During the first meeting, the majority of villagers had stated a desire to continue to use bamboo, as in the first phase of the Qianyi Farm Hotel. Yet when we presented our bamboo scheme at the second meeting, they asked us to explore instead a steel scaffolding system, an option that they then approved at the third meeting (Figure 8). It was at this point that the villagers, in collaboration with two of our Masters students, carried out the actual construction work. But before looking at the comparison between the bamboo and steel proposals, it is worth first mentioning more about the context and design process for Area X.

Zhengjia Shan is a typical traditional village located in the Qichun Mountains, which abut Hunan and Hubei provinces, and as such a continuous forest of bamboo and deciduous trees, along with multiple water-springs, surround the village. Most of its houses are empty, abandoned during the rural-to-urban migration phenomena that as noted started in the 1980s (Figure 9). Zhengjia Shan is thus a typical example of a rural Chinese village below the poverty line, one where people’s traditions and skills are at risk.

In the first phase of Qianyi Farm Hotel (Figure 10), which consisted of a refurbishment scheme by other architects, bamboo was used but for 80% as an ornamental material and only 20% as a structural material. Because the bamboo design for this initial phase lacked protection by design, it was exposed to rain or sun for a long time and so the bamboo began to weaken and break up after just 2–3 years. For the second phase, our aim was to develop some land to the rear of the existing building into a space for entertainment and leisure activities. It was the local villagers that called this site ‘Area X’; s measurements are 9 metres × 33 metres, and it had previously been used as a sweet potato garden (Figure 11). This piece of land had also further back in time been excavated to construct a primary school, and so the joint decision between the villagers and us as architects was that this was the optimal site to develop.

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**Figure 8:** Project sequence for Area X. [Image: Daniel Stamatis].

**Figure 9:** Typical house in Zhengjia Shan. [Photograph: Daniel Stamatis].
Working with the villagers, we realised that the project needed to consider water management, daylight, airflow and humidity. During our initial scoping and configuration process (Figure 12), the initial intention was to connect Area X to the existing first-phase building using three entrances. We then worked out that by rotating the grid by 45 degrees, pedestrian movement and airflow would improve (Figure 12.2). Additionally, by using this diagonal grid, an additional 4 metres in building depth could also be gained. Columns were placed evenly at 3.8-metre intervals (Figure 12.3). The walls angled at 45 degrees made hollow to maintain ventilation flows and views, while solid walls were placed parallel to the existing building (Figure 12.6). The roof system was designed to be half-transparent and half-solid. Area X was to be organised around three units: a bar and music corner; a reading room and manual workshop; and a meeting room (Figure 12.7). In compliance with the villagers’ original view about the structural material, the columns were intended to be bamboo, the walls of hollow concrete blockwork, and the roof of polycarbonate and plywood sheets. Above all, a low-cost form of construction was the agreed priority.

Our initial principle for Area X’s structure arose from fieldwork in Colombia in 2011, whereby Jorg Stamm, a German bamboo expert, had determined that the strength of a column was 16 times stronger if four bamboo poles were joined together and then linked by intersecting horizontal elements. We duly sketched out some hand drawings prior to constructing scaled models to test out the configuration and position of each bamboo composite column and beam, with each piece fitting like in a Lego assembly (Figures 13 and 14). Computerised design was thus consciously delayed until we had produced these early hand drawings and scale models.
Figure 12: Architectural layout configuration for Area X. [Image: Daniel Stamatis].

Figure 13: Hand-drawn structural design translated into a scale model. [Image: Daniel Stamatis].
Next, an overall model was made to give a bird’s-eye view of Area X, showing especially the open spaces between each of the three main units (Figure 15). These public spaces between the units were designed to have small pools that received spring water from the nearby mountain, prior to diverting it onto the rice terraces located downhill from the project.

The joinery system for the bamboo version of Area X was based upon the wide knowledge built up in Colombia, Germany and Indonesia, along Velez’s protection by design concept. In utilising the bamboo structure to its optimal mechanical capacity, it would have been the first such building to do so in this Chinese region (Figure 16). But when we came to present our scale models and basic CAD drawings to the villagers, while they were enthusiastic about the spatial configuration of the scheme, they also began to recall their previous bad experiences with bamboo in the first phase of the Qianyi Farm Hotel. This made them fearful about the risk of rapid material degradation, which they felt would ultimately make the bamboo costlier to maintain over the building’s lifespan. Even though we explained the concepts of protection by design and

![Figure 14: Generation of 3-dimensional space using the protection by design concept. [Image: Daniel Stamatis.]](image1)

![Figure 15: Overall scale model of the bamboo design for Area X combined with Adobe Photoshop effects. [Image: Daniel Stamatis.]](image2)

![Figure 16: Examples of joinery systems to be used in the bamboo design for Area X. [Image: Daniel Stamatis.]](image3)
of preservation treatment, the villagers opted for an imported modern material – steel – rather than making use of the plentiful local bamboo.

Moreover, villagers asked us to find ways of designing a demountable portable structure just in case they decided to reuse the site for other purposes. As a compromise midpoint between non-renewability and total sustainability, a steel scaffolding system was chosen for its overt re-usability, standardisation, image of lightweight modernity, plus the fact that it would be fast and easy to assemble and disassemble. Our counter-arguments were that, in the long run, steel would have a much higher carbon footprint than bamboo and it would contribute nothing to the local economy. Yet we had to agree with the villagers that a scaffolding structure required less technical skill to erect than bamboo joinery, and would be lower maintenance, which led to the overall decision to use a steel structure for Area X.

With this rethink in mind, we proceeded to make a 1:1 test model of a steel scaffold joint so as to assess whether or not the revised design would require a significant change to the overall architectural configuration. Thankfully we found that it could be kept, albeit now requiring four more columns to be added to each module to provide the necessary support and stability, as the raking elements simply could not work as effectively as in the bamboo design. Now the foundations consisted only of galvanised steel based that gently held the hollow steel scaffolding poles, stabilising the latter only via the force of gravity (Figure 17).

Based on the findings of our 1:1 steel joint test, a further scale model was crafted to refine the structural method, resulting in a slimmer structure with a more modern appearance (Figure 18). As bamboo and steel have different mechanical behaviours, some of the steel scaffolding joints needed to be designed using Sketch-Up software prior to construction, while many others had to be improvised on site (Figure 19).

Figure 17: A 1:1 test for the scaffolding structure to translate the bamboo design into the steel version. [Photographs: Daniel Stamatis].

Figure 18: Design evolution through scale models for one unit of the steel scaffolding version of Area X. [Images: Daniel Stamatis].

Figure 19: Studies of joints in the steel scaffolding structure using Sketch-Up software. [Image: Xie Long].
In our view, bamboo would have been the optimal design choice, yet for the villagers the advantages of the steel scaffolding system—in being extremely user-friendly and requiring lower levels of skill—were paramount. The revised design was drawn up digitally and granted final approval by the villagers (Figures 20 and 21). Our concern was that although the steel scaffolding version offered a degree of sustainability due to its portability, its carbon footprint would be inevitably far higher than with bamboo; furthermore, it seemed to rule out the possibility of proposing alternatives to Western industrialised materials in rural China, hampering the wider process of research into bamboo as a viable constructional solution.

These regrets aside, and working with the villagers, we managed to build Area X in an overall seamless construction period of just 65 days between February 2017 and April 2017. The budget for the construction had been 100,000 RMB, although this crept up slightly to a final cost of 110,000 RMB, equivalent to around US$ 16,000. The construction process used the same methods as for the scale models and joint tests, and
thus did not present any substantial problems (Figure 22). All of the components for Area X project were portable, from its foundations through to the hollow blockwork walls. The whole building can be easily dismantled, with its parts stored or reassembled at another location, such that the Area X site could once again become a sweet potato garden or be used for another purpose. Several adjustments were however made during construction. The original 4-metre grid layout was reduced slightly to 3.88 metres along each side of each square. Some reinforcing elements were added to increase the stability of the overall structure, albeit on the identical foundation system to the bamboo version. In other words, the scheme could easily be rebuilt in bamboo in future using the same pile foundations.

We found that our digital model was provided sufficient information to begin construction, and by working alongside the villagers, it meant that vernacular techniques and architectural knowledge were fused into a comprehensive participatory process. Men and women participated equally, continuing a long tradition of collective labour in Chinese villages. The construction documentation was clear enough to direct these

Figure 22: Construction process of the steel design for Area X. [Image: Daniel Stamatis & Xie Long].
workers through a clear set of instructions and orders for assembly. The finished product satisfied the expectations of the villagers, with the multiple angles within Area X dramatically enhancing the views that visitors can have of its various spaces simultaneously (Figure 23).

Once Area X had been completed, the local villagers and visiting tourists discovered that they could use its different spaces for a greater variety of activities than initially conceived. Where originally an area had been designed as a wine bar, it became instead an outdoor piano corner. During the autumn of 2017, some visitors even used Area X as a shelter for camping. This diversity of social usages for Area X was far beyond our expectations, meaning that our role shifted from that of design and construction experts to that of semi-invisible collaborators and facilitators of ideas (Figure 24). The adaptations that took place resulted in a building that meshes vernacular elements with a thoroughly modern touch.

Comparative study between bamboo and steel construction
According to state-of-the-art research by the likes of Simon Velez or Jorg Stamm, bamboo ought to be playing a crucial role in bridging the gap between rural tourism and Critical Regionalist architecture in areas such as Zhengjia Shan village. However, as noted, there the villagers ultimately chose steel over bamboo for Area X. This section of the essay will thus reflect upon this dilemma by using a non-exhaustive yet comparative study to clarify the impacts that both materials have on global climate change. For this purpose, the project’s other materials (black brick floors, hollow blockwork walls, plywood roofs) will not be considered. Instead our goal is to offer an understanding of the comparative environmental impacts of bamboo versus steel in future designs. Here it is also important to mention that our comparative study does not define the functional units in the

Figure 23: View of Area X after its construction. [Photograph: Tan Gangyi].

Figure 24: Logic of design: from scale model to digital model to the construction of the west façade. [Images: Daniel Stamatis, Xie Long & Tan Gangyi].
way that a Life Cycle Assessment (LCA) might do, given that that LCA is expensive and requires great experience and exhaustive detail, yet is still subject to great uncertainty [16]. Our comparison will rather present a reliable insight into the environmental impacts of bamboo versus steel, as based on a range of inventories:

- Transportation distances: these were calculated as being from the production locations for the bamboo and steel to the Area X site, as identified and geo-referenced using Google Maps (however the collection of a fuller data-set for diesel-fuelled fleet travel was beyond the scope of our study).
- Maneuverability: this was compared in terms of the number of days required to assemble, disassemble, and reassemble each material, thereby providing an understanding of the difficulty levels involving in creating the structures.
- \( \text{CO}_2 \) balance: this is based on the calculation of the cost and storage of \( \text{CO}_2 \) in relation to the total mass of each material (1,925 kg of bamboo; 1,487.5 kg of steel), and in which a positive \( \text{CO}_2 \) balance means that more \( \text{CO}_2 \) is being emitted, while a negative \( \text{CO}_2 \) balance represents a reduction over the duration of the building’s life.

However, there is as yet no scientific consensus about the most appropriate method for making an environmental impact comparison of \( \text{CO}_2 \) levels [14]. To overcome this challenge, the equivalents for the \( \text{CO}_2 \) balance of each version were calculated in kilogrammes, as based on the works of Trujillo and Malkowska [10] and Escamilla et al. [16]. For the transportation distance, the equivalent figures were compared in terms of kilometres; for maneuverability, it was the equivalents in days. Distance thus corresponds to higher \( \text{CO}_2 \) emissions from transportation vehicles, and more manufacturing days also equate to higher \( \text{CO}_2 \) emissions.

The length of bamboo poles that would have been required for Area X was 1,750 meters; meanwhile, the length of steel scaffolding that was actually used in the building is 875 meters. Even though the bamboo design methods were translated directly into steel scaffolding, the former system would have required four bamboo poles per column whereas the latter needed only two tubes. Bamboo also required extra reinforcement elements during the construction process. To construct Area X using steel (1.7 kg/lm), the material was imported from the nearest urban settlement, which was Huangmei County, some 60 kilometres away. To construct Area X using bamboo (1.1 kg/lm), however, the transportation distance would have been less than 2 kilometres. Overall, therefore, the shipping of 1,487.5 kg of steel over a distance of 60 kilometres represents a far higher environmental impact than transporting 1,925 kg of bamboo for just 2 kilometres.

The construction of Area X using steel took only six days; bamboo would have taken approximately 30 days. Although both materials can be disassembled relatively quickly, the bamboo construction would still take 5 times longer than the steel scaffolding. In the case of re-assembly, bamboo construction would also require the substitution of at least 25% of the poles and 50% of the steel joints each time. Using steel components, no components would need replacement. Hence in terms of construction time and level of construction difficulty, the steel scaffolding system presents considerable advantages over bamboo. In our assessment of maneuverability (Figure 25), therefore, steel offers a significant advantage over bamboo due to its easy-assembly system and low-skill requirement.

According to the work of Trujillo, a one-metre run of steel tube contributes 3.33 kg of \( \text{CO}_2 \) to the environment, while for bamboo it is only 0.33 kg of \( \text{CO}_2 \) [10]. Furthermore, steel cannot store \( \text{CO}_2 \), whereas

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**Figure 25:** The maneuverability assessment for both bamboo and steel. [Image: Daniel Stamatis].
bamboo stores 10 kg of CO\textsubscript{2} per kilogram of mass \cite{8}. Bamboo is hence dramatically superior to steel if one is comparing the total CO\textsubscript{2} balance of both materials. The bamboo version of Area X would hence have stored 14,857 kg of CO\textsubscript{2} during its lifetime. However, the steel version cannot store any CO\textsubscript{2} at all – and moreover, it emits 6,410.25 kg of CO\textsubscript{2} into the environment (Figure 26). And even though the steel construction is more reusable, it is very unlikely that the structure will ever need to be relocated.

Hence, all in all, bamboo is far superior in terms of its environmental impact (extraction and transport), yet steel is faster and easier to assemble. The final decision was hence finely balanced, and so the villager’s eventual choice of steel scaffolding was based more upon the cultural need to have an emblematically ‘modern’ solution. Our participatory design process thus failed in our aim of using bamboo construction for Area X in Zhengjia Shan, even if it did succeed in bringing a unique design to a village that relates to local conditions without imitating tradition. Several architectural features used in Area X were indeed taken from observation of the village’s existing buildings and elements: stone paths, natural daylight via roofs, and the continuity between enclosed-open spaces. Given that the villagers participated actively in the design and decision-making at each stage, it does seem that these artistic traditions are an internalised part of the villagers’ personal psychology, meaning that Area X possesses abstracted elements that resemble those from its cultural background (Figure 27).

Given the complexity in choosing the main structural building materials for Area X, its short construction period, and the temporary nature of the project, the results of the project can be seen as relatively successful. But on a wider level, because the construction industry is such a significant contributor to climate change, any choice of fossil-fuel materials like steel may not be the wiser choice over the longer term. In this sense, the use of sustainable materials as bamboo becomes the priority, even if the case of

**Figure 26:** Cost and storage of CO\textsubscript{2} in relation to the mass of bamboo and steel. [Image: Daniel Stamatis].

**Figure 27:** Some aspects of Area X compared to those that are found in the village. [Photographs: Daniel Stamatis & Tan Gangyi].
Area X shows that the quasi-urbanisation process occurring in rural China often overwhelms these environmental considerations.

Laleicke et al. confirm that steel is one of the main contributors to the planet’s environmental degradation [15]. Steel scaffolding did offer a degree of sustainability due to its reusability and easy assembly, plus it provided an image of modernity, but its carbon footprint was far higher than the bamboo version. As a single project, the utilisation of steel for Area X might appear insignificant. Yet based on our analysis of its CO₂ emissions, if we collectively continue to construct with materials like steel that require huge amounts of fossil fuels to produce them, in preference to biological materials like bamboo, then human-created climate change will only escalate. Considering that bamboo construction offers a negative CO₂ balance (and hence a positive environmental impact), the urgent issue becomes that of encouraging social acceptance in rural China of local building resources. In general, of course, the social factors involved in the selection of materials are highly complex subjects that need to be analysed across several disciplines. In certain countries, notably Colombia and Indonesia, research suggests that bamboo construction is less accepted among the lower-income classes and yet more appreciated by those with middle and higher incomes.

Much of the refusal of villagers to use bamboo for Area X could be blamed on the failure of the first phase of the Qianyi Farm Hotel to use protection by design. Its bamboo was directly exposed to both sunlight and rain – i.e. it lacked ‘good shoes, good hat’ – and thus degraded rapidly. Although we had discussed this design concept with the villagers, time pressures and budget restrictions resulted in the overly fast decision to use steel scaffolding. This situation within Chinese rural society could well be reversed through comprehensive training programmes, as the International Network for Bamboo and Rattan (INBAR) has suggested. Although villagers found more value in the speed and portability of the steel structure, they simply did not grasp the longer-term economic and ecological benefits of bamboo. Nonetheless, the Area X project is still young, and so perhaps more time is needed to refine such decisions in future. Given that bamboo as a potential material for Critical Regionalist architecture in China is still in its investigatory stage, a necessary first step would be through the construction of exemplar buildings using bamboo, thus showing also how this might help also the rural bamboo industry generally.

But there is also other necessary research to undertake, which can be grouped into three main issues. Firstly, how can we employ bamboo in such a way that its unique structural qualities simply cannot be replaced by another building material such as steel? Designers need to test its properties to take full advantage of facts like bamboo’s tensile strength being three times greater than its compressive strength. Secondly, could bamboo and steel scaffolding be combined to get the best of both materials? Steel scaffolding is versatile and reusable but has a high environmental cost; bamboo is environmentally positive, but cannot be easily standardised. One possible research topic would be to investigate whether setting out a steel scaffolding grid on the ground could then provide accurate CAD details to create a specific bamboo structure, perhaps using arches and so on, which could be prefabricated in a factory and transported site. And thirdly, might the use of a full Life Cycle Assessment (LCA) help to persuade villagers in future to choose bamboo, as opposed to looking only at initial costs. Further research is needed into how to conduct a LCA for bamboo, although this essay provides a starting point for understanding its beneficial environmental impact. As Escamilla et al. have observed generally: ‘A full LCA should be conducted at the early building-design stage when it is still possible to make substantial changes to the design. However, this is the period when the last amount of information is available and comes at the cost of higher uncertainties regarding the construction materials to be used’ [16]. With this in mind, the lessons learned from the Area X project may serve as a useful case study for future projects (Figure 28).

![Figure 28: Steel and bamboo: made for each other? [Image: Daniel Stamatis]](image)
Conclusion

This essay began by recounting our experience with the participatory design process for Area X and ended with a comparison of the environmental impacts of bamboo (positive) and steel (negative). The choice to use a steel scaffolding structure for Area X using steel was based on it being a reversible form of construction that could be dismantled and relocated if desired – but although the project is still relatively young, it seems unlikely will be moved elsewhere in the foreseeable future. Thus the crucial factors that influenced the selection of a human-made material (steel) over a locally abundant and renewable material (bamboo) were primarily social. Among Chinese rural dwellers there is a sense of urgency for modernity alongside a lack of interest in being informed about the protection by design method for bamboo construction. In the end, some echoes of Critical Regionalist architecture were reflected in the design if Area X and was well accepted by the villages and visiting tourists: however the project missed out on the opportunity to make a positive environmental contribution by building with bamboo.

The modernisation of China’s agricultural depends on the ability to merge complementary knowledge: modern and vernacular; Eastern Western; symbolic essence and pragmatic function. In the longer term, bamboo construction can contribute to the successful adaptation of humankind in the face of dramatic climate change. Steel by contrast can only add to global warming. Future projects should focus more on applying a full Life Cycle Assessment to show the importance of sustainable, non-renewable materials. Our overarching conclusion is that building with bamboo in rural China should not be taken lightly, but further in-depth research is needed. Many questions remain. How can we encourage rural communities to embrace bamboo as their primary construction material? How can we educate villagers to understand and appreciate the importance of sustainable construction in terms of climate change? How can we collaborate with villagers in a manner that also empowers community decision-making generally?

Bamboo is not only a local and abundant resource in China, but its adaptability to human needs has few peers in the plant kingdom. Building with bamboo opens a huge area of opportunity to create new kinds of rural wealth, benefitting the bamboo industry as a whole. To stimulate this change, it will be necessary to create excellent designs for bamboo architecture. And because building construction is one of the major contributors to global warming, it means that China possesses the potential to become a leader in sustainable development. Buildings with low or neutral carbon footprints are no longer enough: architecture that has a positive decarbonising environmental impact is now essential.

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Competing Interests

The authors have no competing interests to declare.

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