RICE RESIDUE POTENTIAL IN RURAL ZHEJIANG

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ABSTRACT

The paper tested the possibility of using rice straw as self-built residential buildings material in Zhejiang province. Three construction methods (rice straw bale, light straw clay, rice straw thatching) are identified through studying related literature and realized projects around the world and evaluated using local restricted criteria including construction ease, maintenance ease, affordability, thermal insulation performance, and aesthetic acceptance through interviews with local contractors and residents. The evaluation of the first four metrics confirms the hypothesis of the author that the rice straw is a building material with great potential in low-rise self-built houses. The evaluation towards the last metric aesthetic indicates the power of design and the necessity of intervention of new techniques and methods.

KEYWORDS: *Agricultural Residue, Construction Methods, Vernacular Architecture*

I. INTRODUCTION

1.1. Rice Industry

Rice is an important staple food in China, providing 30.4% of dietary energy and 19.5% of protein per capita (Kennedy et al., 2002). China has the highest rice output in the world and has around 33.01 million hectares of rice area spread across 33 provinces. As a populous country, demand for rice is still increasing. As a result, the waste output of the rice industry is very high. Among the by-products of the rice industry, only rice straw is generated in the harvest process by rice farmers, and the other by-products are generated in the factory, which brings obstacles to the centralized use of the straw. Straw burning is banned in China as it is a pollutant action. However, the quick disposal of residues is the key to providing available land for the next agricultural production after harvesting. This has led many rice farmers to ignore the ban.

Like many other areas, rural areas in Zhejiang are showing bipolar development. Demand for housing is increasing in smaller towns going through urbanization and attracting migrants. A single choice of materials for self-built homes tends to homogenize the villages. The skew in labor and material costs has resulted in many low-quality homes being built, unable to face local climate challenges nor to provide a comfortable living environment. As for some backward and remote villages, people are eager to develop tourism to increase their income, and the new hotels or guesthouses are taken as the starting point. Demand for new housing in these areas is high, and at the same time, the average life span of residential buildings is less than 30 years, which leads to high waste and pollution (Zhou et al., 2012). That is why bio-based materials are attracting more attention in the professional sector.

As a kind of bio-based material, rice straw has great performance in sustainability. The material can be buried in situ without additional contamination at the end of its service life. Therefore, this paper intends to test whether rice straw can be used in self-built residential construction in

Zhejiang province in southeast China, thereby consuming rice industry waste and contributing to the sustainability of buildings and optimizing the rice industry.

1.2. Thesis statement

This paper will focus on the possible application of rice straws in the field of residential architecture. It will evaluate the three rice straw related building methods to provide a basic understanding of the advantages and disadvantages of the methods when applied in Zhejiang province according to five criteria: construction ease, maintenance ease, affordability, thermal insulation performance, and aesthetic acceptance.

II. RESEARCH METHOD

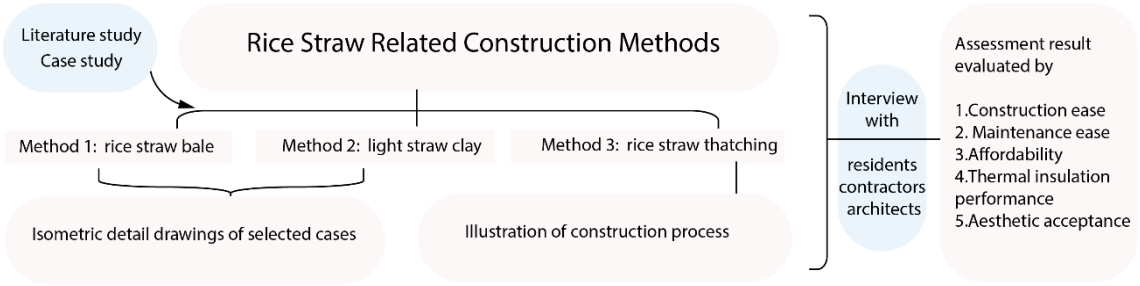

Figure 1. Method diagram drawn by author

Among the five selected standards, evaluation towards construction ease considers the complexity of the construction process and whether there are requirements for the technical level of workers. Except for the complexity and worker requirement, the evaluation of maintenance ease also takes the use period into consideration. Affordability measures the total cost, including material price, transportation, and labor cost. Thermal insulation performance is related to indoor comfort, while aesthetic acceptance measures the three construction methods according to the aesthetic preference of local people.

The first three standards (construction ease, maintenance ease, and affordability) will directly affect the willingness of residents to use this construction method. Zhejiang is located in a climate zone with cold winters and hot summers, so there is a demand for refrigeration in summer and heating in winter. Therefore, the fourth standard is thermal insulation performance because the improvement of thermal insulation performance can increase indoor comfort and reduce energy consumption during cooling or heating. As a subjective measure of aesthetic acceptance, understanding how local people view the possible aesthetic effects of these three architectural methods will guide future design.

2.1. Case study selection criteria

The research object of this article is rice straw. Therefore, rice straw should be adopted in all the studied projects. However, most of the cases of using straws do not specifically indicate which straws are used, as the basic logic is to obtain local materials. For example, wheat straw is the most popular material in the European context. After studying the specific literature, I learned that for rice straw bale and light straw clay, rice straw can theoretically replace any other fiber and has better performance in some aspects. Therefore, the criteria for choosing a case are the amount of information. I did not deliberately avoid the projects using straw other than rice straws but chose relatively informative cases to grasp the specific construction steps better.

For rice straw thatching, rice straw cannot replace the more rigid and longer fiber such as reed straw. Therefore, I only choose the projects that use rice straws. The specific difference between rice straw and some other straws in the architectural application will be discussed in the following two chapters.

2.2. Interviewees

I chose two groups of interviewees, three to five in each group. The first group is local contractors, and the second group is residents, that is, the target group. In the field of self-built rural houses, contractors usually have multiple identities. They sell building materials and sometimes give suggestions and guidance on designing self-built houses.

III. RESULTS

The section summarized and illustrated all the information assembled through literature study, case study, and interview. After showing the essential information (see Table1 below; Table 3 in the appendix), a detailed Table 2 of the evaluation towards the application of three construction methods in Zhejiang is provided. From the perspective of construction ease, maintenance ease, affordability, thermal insulation performance, and aesthetic acceptance, the possibility of adopting rice straws in residential architecture in rural Zhejiang is illustrated.

Table 1. The amount of rice straw used for different construction methods

Construction methods	**Amount of rice straw needed per square meter/per cubic meter**
Rice straw bale	non-load bearing wall: 70-110 kg/m³ load-bearing wall: >130 kg/m³
Light clay	from 1 kg/m³ to 50 kg/m³ (depend on the clay content)
Rice straw thatching	from 1.5 kg/m² to 3 kg/m²

Table 2. Performance of the three construction methods

Method	**construction ease**	**maintenance ease**	**Affordability**	**Thermal performance**	**Aesthetic acceptance**
Rice straw bale	Easy when rice straw are baled before, unskilled worker can finish. Difficult when the baling process should be done by workers.	easy when extra protection added (rain screen/coating layer)	Affordable as local rice straw is cheap (20 euros for 500 kg rice straw) 1 m³ wall cost 22.4 ¥ to 41.6 ¥ (2.8 € to 5.2 €)	u-value between 0.1 to 0.2 U = 0.167 [W/m^{2}K] (external clay plaster 0.07 m, straw bale 0.45 m, internal clay plaster 0.04 m)	Acceptable (As the straw bale must need coverage such as rain screen or plastering therefore it is not exposed)
Light clay	Between easy and difficult. Ordinary construction workers can complete.	Feasible when skilled workers are hired.	Ditto. Besides, mud/clay is also a residue (from basement digging) 1 m³ wall cost 0.32 ¥ to 16 ¥ (0.04 € to 2 €)	u-value = 0.19 [W/m2K] (exterior clay plaster 0.03 m, light clay 0.5 m, interior clay plaster 0.03 m) thermal conductivity 0.067 W/mK	Acceptable (As the light clay wall need coverage therefore it is not exposed)

That chin g	Quite difficult as there is a prone of leakage when the construction is not carefully done. Skilled workers needed.	Feasible when replacem ent is applied (every 1-3 years dependin g on the quality)	Ditto. 1 m² roof cost 0.48 ¥ to 0.96 ¥ (0.06 € to 0.12 €) Affordable but skill requirement is higher and the wage of skilled worker would be therefore higher	thermal conductivity 0.07 and a resistivity of 14.3 u-value = 0.2 [W/m2K] (0.35m of straw)	For most residents not acceptable as the rice straws are exposed. For some it can be a point to attract tourists.

IV. DISCUSSION

The results chapter showed that all three construction methods are theoretically feasible in the rural areas of Zhejiang, as long as some specific premises are met.

4.1. Rice straw bales

4.1.1. typical construction requirements and property

Though the straw bales commonly refer to wheat straw bale, especially in the European context, the definition of straw includes leftover remnants from all grain products like wheat, rice, and barley. Straw bales are commonly used on walls, including interior walls, exterior walls, and insulation. The technique of baling will not change regarding the type of straw. Therefore, some selected cases do not indicate adopting rice straws for the straw bale. However, the property of the straw bales does vary from different straw types.

According to King (2006), rice straw bales have better rigidity and durability performance than wheat straw bales when acting as baling material. As mentioned before, rice straw as a bio-based material cannot face wet weather conditions. Extra protection methods should be considered. There are several different methods of protection. The first one should be rain-screen which is the method taken in the project of Stock Orchard Street (see Figure 2 in the appendix). The building is now 28 years, and the straws are still performing exceptionally well. An experiment conducted in Chiba Prefecture, which has hot and humid summers, also demonstrated that the passively ventilated rain-screen positively affects the weather resistance ability of the straw bale wall (Holzhueter & Itonaga, 2014). Besides, render is also a possible solution to protect the straw bales, especially high permeable render materials (Yin et al., 2018).

4.1.2. Construction ease

Learning from the case study, the intervention of large-scale equipment can make the baling process easier but need extra investment. The actual construction process is easy, possible to be done by unskilled workers. It also has a short construction period as the standard size of straw bale would be large (1 m*0.5 m*0.4m). Therefore, it will not take long to build a wall.

4.1.3. Maintenance ease

During the service life of straw bale walls, they are subjected to different environmental conditions, with constant wetting and drying process. The ability to quickly complete the drying cycle contributes to the durability of straws. Compared to wheat straws and oat straws, rice straw shows similar adsorption performance. However, rice straw shows a less hysteresis effect, which means a quicker desorption phase (Marques et al., 2020). No need to change if the straw bale is protected well. It can last longer than 30 years.

4.1.4. Affordability

In rural regions, the price of raw materials is almost zero compared with standard building materials, and the installation period will be shorter than ordinary construction. Therefore, the total cost will drop significantly.

4.1.5. Thermal insulation performance

According to the research outcome of Marques et al. (2020), the thermal conductivity of rice straw bale did not improve when the density of the bale increased. The insulation performance of straw bales is excellent, especially compared to the popular self-built house materials in rural areas of Zhejiang. People do not add additional thermal insulation materials and directly paste ceramic tiles into the surface (external side of brick walls and concrete pillars) as decoration.

4.1.6. Aesthetic acceptance

All interviewees indicated that they could accept the straw bale technology. In the case of Stock Orchard Street, architects deliberately use a transparent rain screen to make the straw bale visible. However, it is not acceptable among most interviewees that are above 55 years old. The guessing of the reason is as follows. A few decades ago, rice straw was still used as a building material in villages. It was usually the choice of the poorest people for temporary housing. The associations caused by such exposed straws are unpleasant and remind them of the most difficult periods of their lives. Therefore, the aesthetic acceptability of bare straw is lower among older people.

4.2 Light straw clay

4.2.1. typical construction components

The technique has a long history. A light straw clay wall should exceed 600mm when acting as a load-bearing wall. The wall can be thinner when it has a skeleton (normally timber poles), and the light straw clay can be used on the floor and roof as well (Drozd et al., 2019).

4.2.2. Construction ease

The construction difficulty of this technique depends on the specific construction process and construction quality. There are both simple and challenging examples in the selected case. A higher mud content was adopted in the project Wadi Abu Hindi primary school (see Figure 3 in the appendix). The mixture was poured directly between the two walls. In the case of Japan, a higher straw content was adopted, which requires mixing the soil and making light straw clay blocks beforehand. It also requires the careful installation to protect the light clay.

4.2.3. Maintenance ease

According to Baker-Laporte and Laporte (2015), light straw clay has proven durable and rot-resistant when constructed correctly. The standard of correct construction is mainly related to the careful design of moisture protection.

Through interviews, I found that the dwellings in the Zhejiang mountainous area have also used a similar construction technique (see Figure 5 in the appendix). The walls use weaving bamboo strips as an attachment of the light clay and can last for a few decades.

4.2.4. Affordability

This construction method will lead to an increase in the construction period and wages. However, considering the average wage of construction workers in Zhejiang, this method is still affordable. The contractor revealed that they are not happy to recommend this type of construction method, which is labor-intensive while the material cost is low. Most contractors in Zhejiang province also sell building materials. Customers are less sensitive to the use amount and price of common building materials (cement, reinforced bars, concrete, and bricks), so they have the opportunity to make a profit from the difference. Whereas for straw, which costs almost nothing, most of the

income will pay workers' salaries. Drozd (2016) also mentioned the phenomenon in his paper. Large construction companies that dominate the market will not promote the development of such unprofitable solutions.

4.2.5. Thermal insulation performance

Holzhueter and Itonaga (2017) demonstrated the detailed building process of a residential building adopting light straw clay for its wall, roof, and floor in Japan. To decrease the thermal conductivity of light straw clay walls, increasing the width and decreasing the density can be two possible methods. The clay content proportion in the soil determines the amount of soil needed. The higher the clay content, the lower the soil needed, so that the wall can provide greater thermal resistance due to a lower density (Holzhueter & Itonaga, 2017). Purer clay should be chosen to decrease density and achieve similar thermal insulation performance in practical application. Some traditional houses in rural Zhejiang use this technique for the infill wall. Interviewees who have lived in these buildings describe them as "cooler in the summers and warmer in the winters".

4.2.6. Aesthetic acceptance

All interviewees indicated that they could accept the light straw clay technology. The use of light straw clay will not influence the appearance of the buildings. Cases shown to the interviewees look like ordinary residential buildings, and it is possible to use any decoration they prefer.

4.3 Rice straw thatching

4.3.1. Typical materials for thatched roof

The recommended fibers for the thatched roof are water reed, wheat reed or devon reed, long straw, heather or turf, and rye straw. Thatched roofs examples adopting rice straws can be found in Asia, with a different appearance and life span.

4.3.2. Construction ease

There are already local machines for making straw ropes, so it will be simpler than when all the work should be handmade. The skill is mastered by Zhejiang farmers (above 65 years old), and it is not difficult to learn. The key to construction is to avoid rainy days. Therefore, the braided rice straw is set in the line beforehand. Then it is possible for the farmers to complete the roof in one day by simply laying out the bundle on the roof.

4.3.3. Maintenance ease

Though the replacement process is easy, the replacement period of the rice straw thatched roof is short. Through interviews and literature studies, rice straw roofs are quite different from other common fiber roofs. The aquatic reed roof looks smooth and can last for twenty-five years. However, thatched roofs with rice straws usually require replacement every one to three years. Locals said in interviews that such frequent replacements are too troublesome.

4.3.4. Affordability

Due to the short construction period and little workforce required, the construction and materials themselves are very low-cost. Even considering that it needs to be replaced every year, the cost of thirty years will not be too much.

4.3.5. Thermal insulation performance

There is little detailed data for the thermal performance of rice straw-thatched roofs. The standard thickness of the rice straw thatched roof is 45mm. According to Miyako (2017), the 45mm thickness roof helps keep the interior temperature above 10 degrees Celsius in the winter of Japan.

4.3.6. Aesthetic acceptance

As mentioned above, the elderly interviewees could not accept bare rice straw. The interviewees praised some neatly thatched roofs as "they do not look like straw roofs". However, the characteristics of rice straws determine that the thatched roof made of it cannot be as smooth as other examples.

V. CONCLUSION

5.1. Discussion of the method and further research

Reusing agricultural residue is a widely considered subject. The research paper also provides an architectural view and chooses to intervene in a specific context in Zhejiang province, southeast China, which set the material in a new climate environment. The combined research methods contribute to the multiply factors-affected result. Considering opinions from both inside and outside of the professional world is essential, therefore I interviewed local contractors and residents. However, the method does have some limits. Due to the time limit, the sample size was insufficient. Secondly, for some subjective questions, villagers' attitudes will change with the guidance of the interviewers during the interview.

However, the inadequacy and fallibility of subjective question answers indicate the direction of follow-up research. It may be more reasonable to observe villagers' habits or needs directly than to get their attitudes and considerations directly through interviews. Therefore, ethnography research and vernacular architectural research are worthy of consideration in the follow-up research.

5.2. Potential contribution

According to the research result, rice straw is a material that has great potential in Zhejiang, China. The prevailing material in Zhejiang province for self-built houses is reinforced concrete structure with brick infill. Based on the interview with local contractors, the price of these materials is rising a lot this year due to high demand and government control.

For researchers interested in applying rice straws in the architectural field, the paper can be used as it named the building techniques adopting rice straws and chose several innovative cases to study in detail. For practical experimental tests of the rice straw application in Zhejiang province, the evaluation of the three different building techniques can be a reference.

Due to the limitation of time and length, a practical experiment of construction and monitoring the buildings adopting rice straw in Zhejiang is not done. It will be nice to compare the three construction methods with the new techniques and monitor the performance of the buildings in Zhejiang province. Then the two metrics, affordability and thermal insulation performance can be evaluated by calculating of cost for each construction process and the u-value of the building components.

Rice is the staple food for Zhejiang and a staple food that feeds more than half of the world’s population. It is a most important food crop, especially in developing countries of Africa and Asia (Seck et al., 2012). Therefore, the methods discussed in the paper can be used as a reference for a wider world.

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APPENDIX

1. By-products of rice industry

In some areas, there are one to three rounds of rice cultivation. In Zhejiang Province, it is generally two rounds of rice cultivation a year. It is worth noting that the price of rice is low to ensure the food security, and the government needs to provide subsidies to farmers to ensure that they continue to grow rice instead of choosing other crops with higher profits. If the utilization value of rice industrial wastes has been fully explored, the add value of the rice industry can make up the low value of rice itself and increase the income of the rice farmers. The possible uses are listed in the table below.

Table 3. Type, origin and possible use of rice industry by-products

Type of by-products	**Origin of by-products**	**Possible usage**
Straw	Harvesting	fuel, chemicals, paper industry, food industries, animal feed, building industry (particle boards, fiber, cement bonded boards, cob, soil ash bricks, pressed panels), nutrients for soil, substrate for mushrooms, erosion control application
Husk	Shelling	Biomass fuel, adsorbent for the removal of heavy metals, silica production, bioenergy
Bran	Milling	Edible oil production, animal feed, medical application
Germ	Milling	Germ oil, flours, concentrates, dietary fiber
Brewer	Milling	Animal feed, winemaking, food industry/ (Similar nutrients as in bran but content much lower)

Except for the other fibers that are widely considered as a possible building material such as reed or wheat straws, the performance of rice straw as building material doesn't have so much written information. As mentioned above, among the by-products of the rice industry, straw came from the first step of harvesting which is more closely related to farmers while the later steps are mostly done in the factory. It increased the difficulty of centralized disposal of the rice straws and therefore can easily become waste.

Because the rice straw is biodegradable in its nature, the long-term storage of large quantities of rice straw requires a dry environment and should protect from moisture, which is difficult for marginal farmers. Many farmers choose to burn rice straws in open farmland, which will lead to the emission of hydrocarbons, suspended particulate matter, and greenhouse gasses to the environment (Abril, Navarro & Abril, 2009). In addition, straw burning can lead to loss of soil nutrients, contamination, and eventual soil degradation. This creates a vicious cycle in agricultural production, in which soil degradation negatively affects yields, leading farmers to use more fertilizers, and together with straw burning further affects the soil.

Compared to normal straw types such as wheat or barley, it takes much longer to damage the rice straw due to its high silica content (Khir& Pan, 2019). The yield of rice straw relates closely to the variety of rice, the cutting height, and the moisture content during harvesting, therefore there are differences in rice straw production in different fields. According to the International Rice Research Institute (2015), the rice straw produced may range roughly from 0.7 to 1.4 kilograms per kilogram of milled rice. Another statistic shows that each kilogram of paddy produced in fields results in 0.41 to 3.96 kilograms of rice straw (Koopmans & Koppejan, 1997).

Table 4. Use of local rice straw

Type of use	**Once used**	**Still in use**
Direct use	Biofuel for cooking, Forage, Under-course of pigpen	Insulation material for newly cultivated crop
Indirect use	Straw boots material, Straw mat material, Straw raincoat material, Roof material, Wall material	Material for straw rope

2. Construction methods related drawings

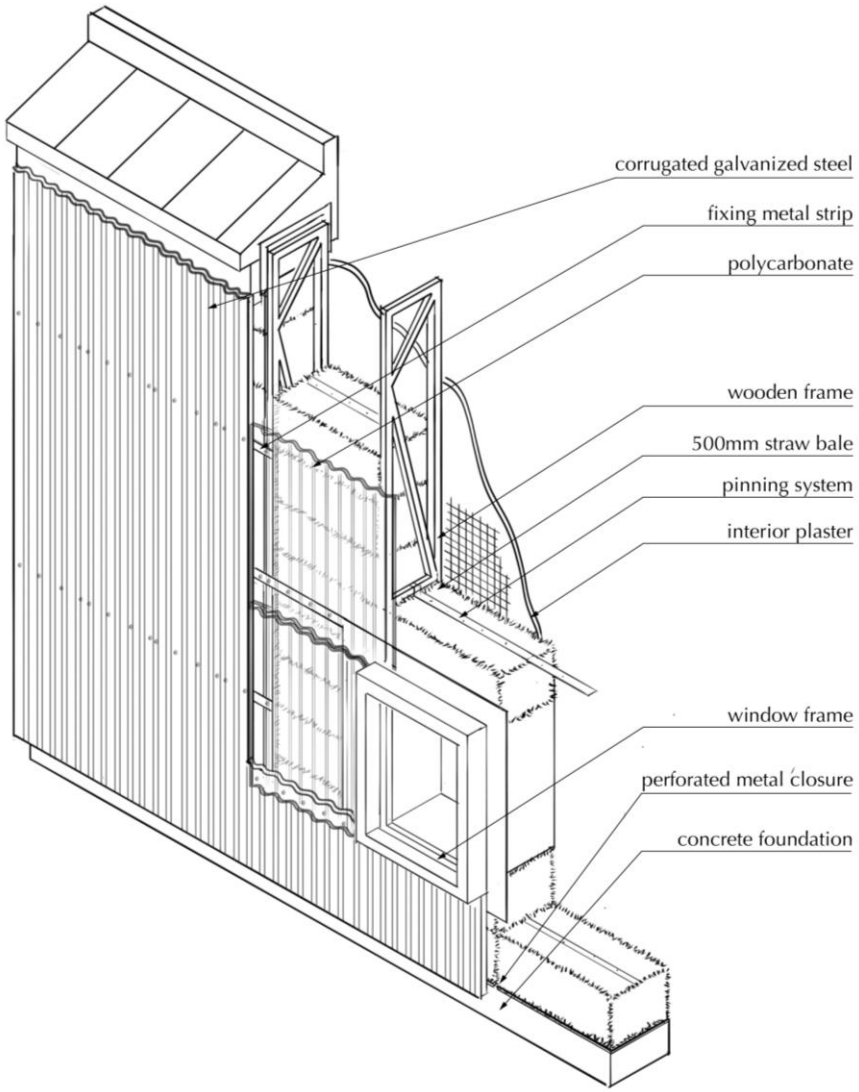

Figure 2. Isometric drawing of the wall (Stock Orchard Street) drawn by author

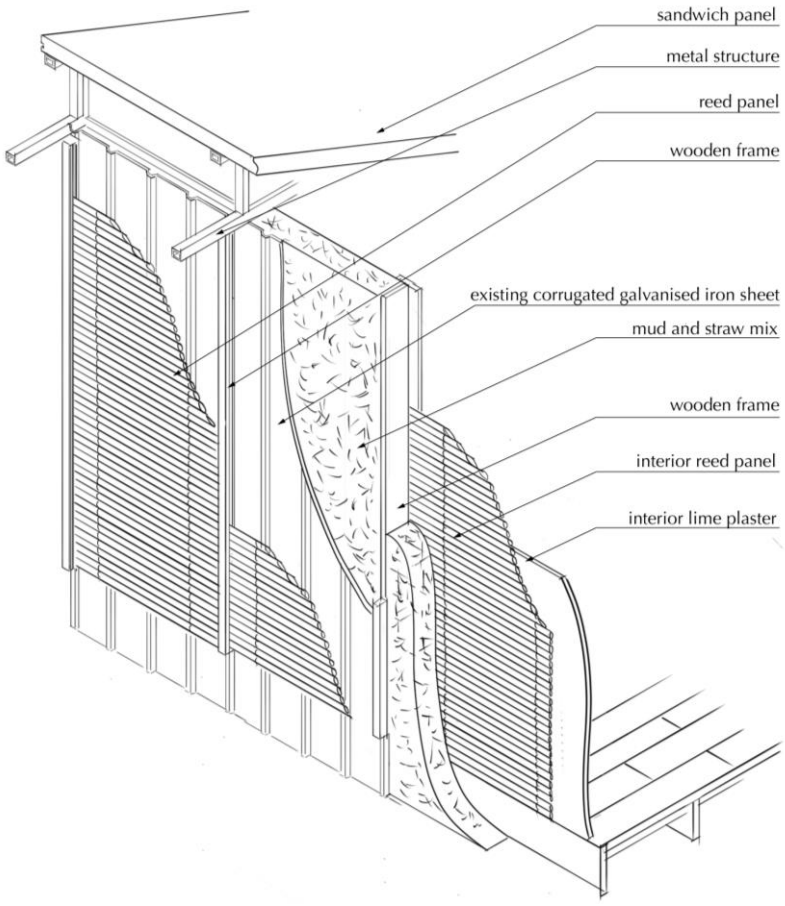

Figure 3. Isometric drawing of the wall (Wadi Abu Hindi primary school) drawn by author

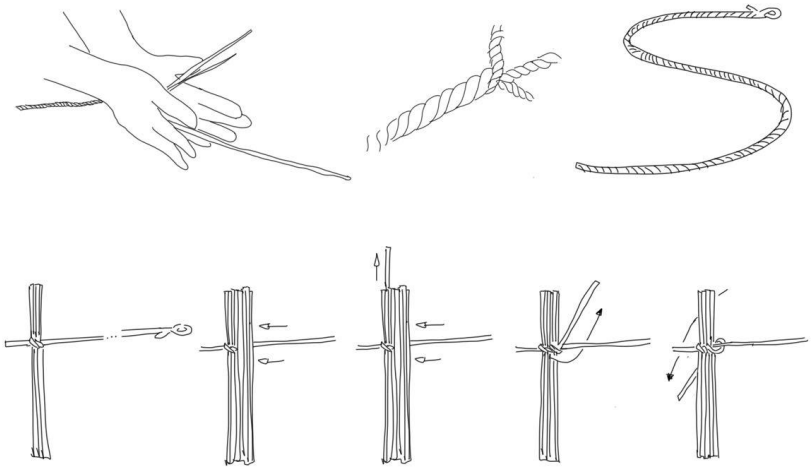

Figure 4. Detailed construction process of method 3 drawn by author

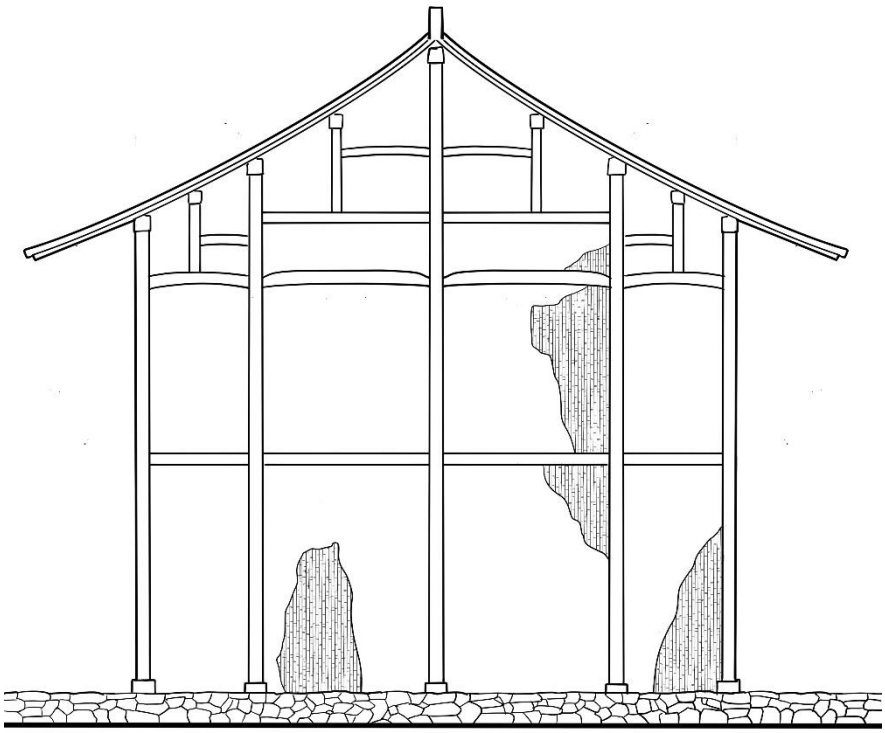

Figure 5. Diagram of Zhejiang vernacular houses using light straw clay for infill wall drawn by author

3. Interview questions

For local residents:

1. What do you do to make a living?

2. How did local residents use rice straw before?

3. Could you please introduce the harvesting process in your field?

4. How much straw is created in your field every year?

5. How to deal with the straw in your village now?

6. Apart from agriculture, do you wish to develop tourism? What is the biggest bottleneck?

Show the cases using straw as a building material to the interviewees.

7. Do you think these cases are aesthetically acceptable? Please rank the projects I show you from 1 to 5 (5 is the favorite and 1 is the least favorite). Please give the reasons.

8. If you have the opportunity to build a new house, what is your budget?

9. After showing the case, would you consider using the material and construction methods I introduced?

10. Do you think it's practical to use this method in terms of heating/changing the roof every 2 years/……

For building contractor/ local craftsman:

1. How many years have you been in this industry? Please introduce your customer base. What is the general cost of building a house for a family?

2. Have you formed your own construction team? Are the personnel of the construction team fixed or mobile? Please introduce the average skill level of the local workers/ When you hire someone, what kind of construction methods skill do you expect?

Show project pictures to interviewees.

3. Please state the cases you think are not feasible locally and give the reasons. Or, for the cases, can you think of alternative construction ways to make it possible for the cases?

4. Among the feasible cases, if a similar quality should be achieved locally, is the labor input the same as the original case? What are the expected costs and construction period?

If the raw construction material is straw, can it be equivalent to zero raw material cost?

5. Would you consider recommending these feasible construction methods to customers? Why? (Is it profitable for you?)

6. Choose one case and improve the affordability, time input, labor input, or customer preference by possible solutions.