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## **FLOOD-RESILIENT EARTHEN CONSTRUCTION TECHNOLOGY: WHEN EARTH MEETS FABRIC**

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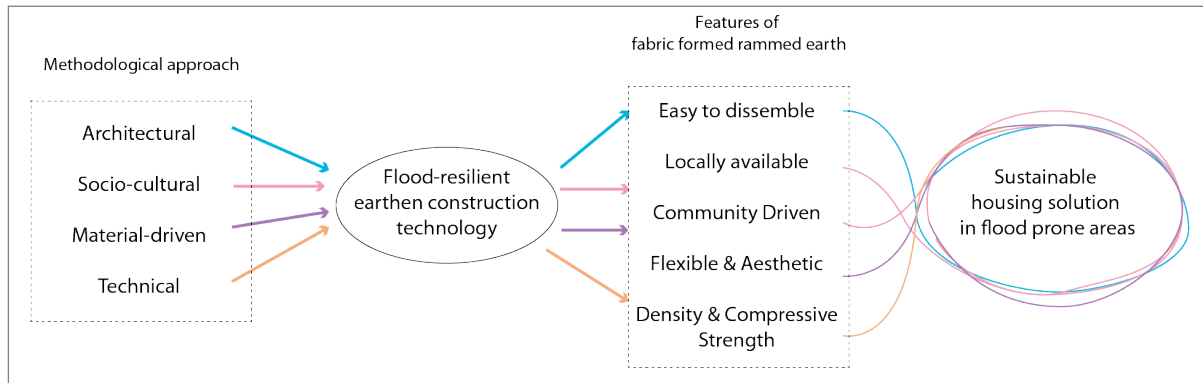
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### **Why is flood-resilient earthen construction technology needed?**

Human-induced climate change is causing extreme weather patterns, increasing the power and frequency of flooding that does not have the same impact on everyone across the globe. According to the Global Climate Risk Index (2021), developing countries have been the most severely affected by flooding for the last two decades. For example, floods in Mozambique and Pakistan are becoming stronger, denser and more widespread year by year. Most of the low-income people in these countries live in earthen houses. In Mozambique, most houses are made from wattle and daub and, in Pakistan, cob or adobe, and all of these houses are susceptible to flooding, having been built with low-compaction. While humanitarian agencies and respective governments have aided these flood-affected people, their help has been limited and caused problems. In flood affected areas, most international agencies have built houses with concrete blocks (IOM and Arup, 2017), which is an expensive building material that most local people have never used before. Because of a limited budget, only a very small number of people are privileged to have a concrete block house, and the vast majority end up living in temporary tents and makeshift houses. The short-sighted approach of humanitarian agencies has caused more environmental and social problems. Because they focused on dealing with the most pressing issues, they failed to provide a sustainable and flood-resilient housing solution and lacked foresight of the negative impact of their responses. In view of these limitations of humanitarian agencies and the context of flood-prone areas, where resources are scarce (for instance, timber for formwork) and construction budgets are very low, the author of this paper has conceived of flood-resilient earthen construction technology that can be built with locally-available and low-cost resources: soil and fabric. Based on the prototype developments and tests, fabric formed rammed earth technology is found to have the following four crucial aspects:

- Formwork that is easy to disassemble
- Materials that are locally-available and community-driven
- Forms that are flexible and aesthetically appealing
- Density and compressive strength

These features are also closely aligned with the author's PhD research, which is based on finding



**Figure 1.** Approach of flood-resilient earthen construction technology.

a sustainable housing solution by interweaving an architectural, material-driven, socio-cultural, and technical approach (see Figure 1).

In the following sections, the fabric formed rammed earth's features will be introduced in detail questioning its potential as flood-resilient earthen construction technology.

### Formwork that is easy to disassemble

The advantages of fabric formwork were discovered by building conventional timber-formed rammed earth (TR) and fabric-formed rammed earth (FR) walls<sup>1</sup> for a comparative test. Fabric formwork is much easier to remove than timber formwork.<sup>2</sup> Since the fabric does not attach to the rammed earth, it does not require any additives to be applied to it, such as the oil which is traditionally applied to rigid formwork and is essential for its easy removal. For timber formwork, although oil had been applied evenly throughout the timber panel, a large amount of soil was still attached to the timber formwork when it was dismantled a week after the ramming; when the weight of soil attached to the fabric formwork and timber formwork was compared, it was found that the quantity of soil attached to the fabric was less than 1/3 of the soil on the timber (fabric: 170g, timber: 690g).

The easy removal of fabric formwork is highly advantageous for the outcome of rammed earth and fast construction. It is also expected and could be argued that the easy removal of fabric formwork accelerates the construction process, thereby reducing the time needed to dry rammed earth compared to that built with rigid formwork. This feature would be particularly useful for building houses in an emergency: accelerating the construction process with a shorter drying period and producing densely compacted rammed earth with fabric formworks that are more lightweight and portable than those traditionally used.

The tests also showed that excessive moisture and air were extracted through the permeable fabric during the ramming course of fabric formwork (see Figure 2). This played a crucial role in creating a

<sup>1</sup> Each built model was 1000mm high, 250mm wide, and 600mm long, and each pair was built with same earthen mixture and by a same person (the author) simultaneously for an exact comparison.

<sup>2</sup> For this test, woven geotextile was used for fabric formwork.



**Figure 2.** Moisture and air are extracted through the fabric during the ramming course of fabric formwork.



**Figure 3.** Both the FR and TR walls were produced with the same unstabilised earthen mixture. The FR wall had a smooth, fine surface (left), but the TR wall had a patchy surface (right).



**Figure 4.** Both the FR and TR walls were built layer by layer with an unstabilised earthen mixture and a lime-stabilised earthen mixture. The patchy surface of the TR wall is clearly shown at the unstabilised earthen layer.

smooth, fine surface of the fabric-formed rammed earth and enabled it to dry quickly, unlike the rigid-formed rammed earth, which had a patchy surface (see Figure 3). This was more severe for the unstabilised earthen layer than the lime-stabilised layer (see Figure 4). These results show that moisture and air trapped in the impermeable rigid formwork affect the surface of an unstabilised rammed earth wall. Importantly, it is estimated that the patchy surface of the TR walls will be more eroded by rainfall because it is not densely compacted and smoothed. The low compaction is possibly due to the friction between the rigid formwork and the rammer (Bui et al., 2009). The change in the performance and surface of both the FR and TR test walls will be carefully observed and recorded to detect any erosion in the forthcoming years.

### Materials that are locally-available and community-driven

Since fabric-formed rammed earth is low-technology,<sup>3</sup> it can be made and maintained by local people using locally-available materials. Soil and fabric are available anywhere in the world. The use of these local resources will potentially have a positive impact on a community by building a sense of belonging, involving local skills, and enhancing a sustainable local economy in the long run. This

<sup>3</sup> According to the OECD (2003), technology is classified based on the expenditure invested in it. Basically, low-technology is low-cost as it uses locally-sourced materials and local labor. The use of local resources also has a low impact on the environment. On the other hand, high technology is associated with industrial materials, machine or highly skilled-driven production, energy-intensive manufacturing process, which are more expensive.





**Figure 5.** The proposal of Weave (Senegal Elementary School project) suggests fabric-formed rammed earth technology to empower a local community by involving them in the construction process, to build a water-resistant earthen structure, and to demonstrate the aesthetic feature of low technology.

will reduce dependency on imported expertise, resources, and labour, but increase opportunities for local people to use their skills, knowledge and power. Empowerment is an important element in the creation of sustainable and climate-resilient dwellings, but it is what most humanitarian shelter programmes lack.

The limitations of humanitarian agencies' response to an emergency are their focus on building temporary shelters, and a top-down approach that restricts disaster-affected people from taking the initiative in the construction process. For instance, very few concrete block houses were built in response to the floods in Pakistan in 2010-2012 (IOM and Arup, 2017) and they were built for, not by the people. Also, after cyclone Elosie hit Mozambique, only a few beneficiaries were chosen to have concrete block houses and the majority of people lived in temporary tents in resettlements areas (Wadekar, 2021), which were at high risk of upcoming cyclones and flooding. Even the small number of beneficiaries had to wait at least several years for their concrete houses to be built by skilled workers because local people had not used this material before. The living condition of concrete block houses is also not good because it is unbearably hot to live in them in a humid tropical climate (IOM and Arup, 2017).

On the other hand, with fabric-formed rammed earth technology, local people can take the initiative to build their buildings with local resources, whether in an emergency or not. Different from cement,



**Figure 6.** The fabric lends its quality and texture to the rammed earth, transforming the monolithic structure into a fabric-like texture and contour.

brickwork and carpentry that require highly skilled workers, fabric-formed rammed earth can be built by unskilled laborers and one skilled one.

The Weave Senegal elementary school is designed to show how fabric-formed rammed earth technology can empower local communities and strengthen their cultural identity based on the use of local materials, such as fabric and soil (see Figure 5). Not only is fabric a strong local economic resource in Senegal, but it also represents different ethnic identities with distinctive patterns. As a locally-available material, soil has also been used as a vernacular building material in Senegal. As these two materials are closely linked with the local culture, fabric-formed rammed earth technology was proposed to reinvigorate the local community by involving them in the construction process and to create a sustainable school with the enhanced water-resistant performance of an earthen structure. The undulating appearance of the fabric-formed rammed earth can also be an appealing aesthetic feature of this low technology.

### **Forms that are flexible and aesthetically appealing**

Fabric-formed rammed earth is material-driven technology. The innate quality of materials is honestly expressed during the production process and the outcome, acting as a design generator. This is in contrast to rigid formwork, which has a fixed shape that limits the movement of the material. Since the uniformed shape of rigid formwork is pre-designed by a designer, there is much less scope for the performance of the materials. On the other hand, fabric formwork is led by the materials' performance, which plays a leading role in shaping the form. The fabric looks flaccid before the ramming starts, but it bulges during the ramming course, lending the texture and morphological change of the fabric to the monolithic structure (see Figure 6). The extent of the fabric's bulging is controlled by shuttering; therefore, the position and amount of shuttering also play an active role in creating the pattern of rammed earth walls (see Figure 7). The compaction given by the builder also affects the extent of the fabric's bulging. Therefore, the fabric and the builder's performance are closely linked in the fabrication process, broadening the spectrum of the role of materials and builders and involving them as generators of the design.

Furthermore, the flexible quality of fabric is advantageous to create any rammed earth forms with low-cost and simple fabrication. Flood-resilient forms such as rounded corners or shapes can be easily



**Figure 7.** The arrangement of shuttering affects the shapes of fabric-formed rammed earth.

**Figure 8.** For a FR wall, rounded corners are easily produced (left), but for a TR wall, extra wooden strips should be installed within the rigid formwork to chamfer the corner (right).

created with fabric formwork to mitigate the impact of wind, rainfall and flood. This is very different from rigid formwork that requires extra frames to produce chamfered corners, since sharp corners are very fragile and easily broken (see Figure 8). Furthermore, the undulated pattern of fabric-formed rammed earth is not only aesthetically attractive, but also potentially more resilient to rainwater by enabling it to drain easily, as evidenced by the way the pattern of the vernacular mud houses of Musgum has served to drain rainwater (Alexander, 1964).

### Density and compressive strength

Rammed earth has a higher density than cob or adobe due to being built with higher compaction. Cob is made by stacking up lumps of clay, while adobe is usually produced in a mould by hand. Since they are produced by low compaction and a great amount of water is needed to increase workability, they have low density that makes them vulnerable to the penetration of rainwater. In contrast, rammed earth is built with high compaction, which reduces the gaps between soil particles where water could penetrate; therefore, it has enhanced water-resistance (Houben and Guillaud, 1994). Moreover, it is expected that the density of rammed earth is further increased by the use of fabric formwork by extracting excessive moisture and air through the permeable fabric.

The higher compressive strength of fabric-formed rammed earth can be deduced based on a comparative test conducted by Al Awwadi Ghaib and Górski (2001), which showed that fabric-formed concrete has a greater compressive strength than steel-formed concrete. An appropriate pore size of fabric increases compressive strength by holding fine particles of cement and sand, but releasing excessive water. This shows that the permeability of fabric serves to increase the strength of fabric-formed concrete by reducing the water-to-cement (w/c) ratio. A test to compare the compressive strength and density of FR and TR will be conducted as the next project of the author's research.

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## **Conclusion**

Fabric-formed rammed earth technology has been developed and researched by considering architectural, socio-cultural, material-driven and technical factors. This multi-disciplinary approach is essential to provide a sustainable housing solution in emergencies. As explained earlier, the response of international humanitarian agencies faced severe limitations and problems because it was implemented with a 'one-size-fits-all' approach and a focus on providing temporary shelter. As an alternative approach, fabric-formed rammed earth technology was tested in order to consider how the construction process of creating sustainable housing for flood-affected populations can become a tool to empower them, and how local materials are closely linked with a sense of belonging and local people's skills.

The comparative tests and design proposal have shown that the use of locally-available resources and a simple construction process may increase the chance to involve local people in the construction. There are more areas to explore further such as the flexibility of fabric potentially helping to create flood-resilient forms and aesthetic details. The work done to date suggests that fabric-formed rammed earth has great potential as flood-resilient low-technology and more tests and projects will be ongoing exploring its potential.

## **Acknowledgements**

The author wishes to express her great appreciation for the full support of her father, Gyu Gun Lee, for the opportunity to continue to develop her research in South Korea while the architectural school in Edinburgh was closed for two years due to the pandemic. Without his support, it would have been impossible to conduct any of the tests introduced in this paper.

## **Image credit**

The credit for all the images in this paper belongs to the author, Scarlett Lee.



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