Terra-Ink

Additive Earth Manufacturing for Emergency Architecture

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Abstract

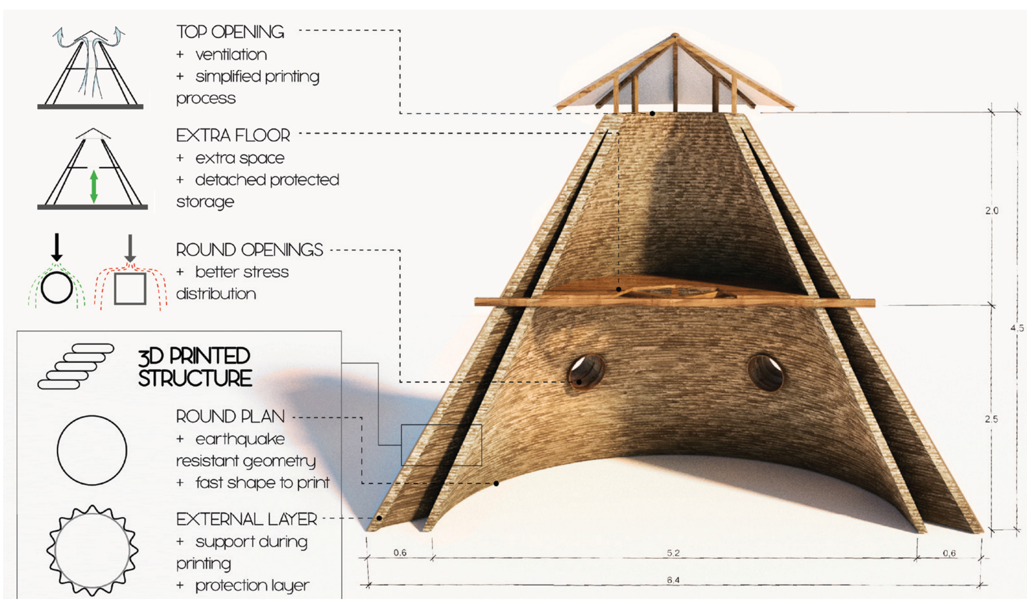
In recent years, natural disaster and military conflicts forced vast numbers of people to flee their home countries, contributing to the migration crisis we are facing today. According to the UNHCR, the number of forcibly displaced people worldwide reached the highest level since World War II. Post-disaster housing is by nature diverse and dynamic, having to satisfy unique socio-cultural and economical requirements. Currently, however, housing emergencies are tackled inefficiently. Post-disaster housing strategies are characterized by a high economic impact and waste production, and a low adaptability to location-based needs. As an outcome, low quality temporary shelters are provided, which often exceed by far their serving time. Focusing on temporary shelters suitable for the transitioning period between emergency accommodation and permanent housing, TERRA-ink addresses new construction methods that allow for time and cost efficiency, but also for flexibility to adapt to different contexts.

TERRA-ink aims to develop a method for layering local soil, by implementing 3D printing technologies. With the aid of such a construction system, the goal is to create durable structures that can be easily de-constructed once they served their purpose. The use of locally sourced materials in combination with additive manufacturing is investigated aiming at reductions in financial investments, resources and human labor, as well as at simplified logistics, low environmental impact and adaptability to different situations and requirements. Such a building system has the potential of combining low- and high-tech technologies, in order to facilitate a fully open and universal solution for large scale 3D-printing using any type of soil.

Keywords

soil, material, process, mixture, emergency, temporary, structure, extrusion

Preliminary studies were conducted to explore the potential for innovation in an emergency relief process. In practice, an emergency response is usually organized and divided in separate phases. Each phase addresses different problems and needs. A temporary shelter is meant to respond to an intermediate phase of the emergency, to facilitate the transition from emergency accommodations to more durable housing solutions. Therefore, a temporary shelter can be defined as a dynamic process more than a final product; a solution adaptable over time and easy to deploy and dismantle.

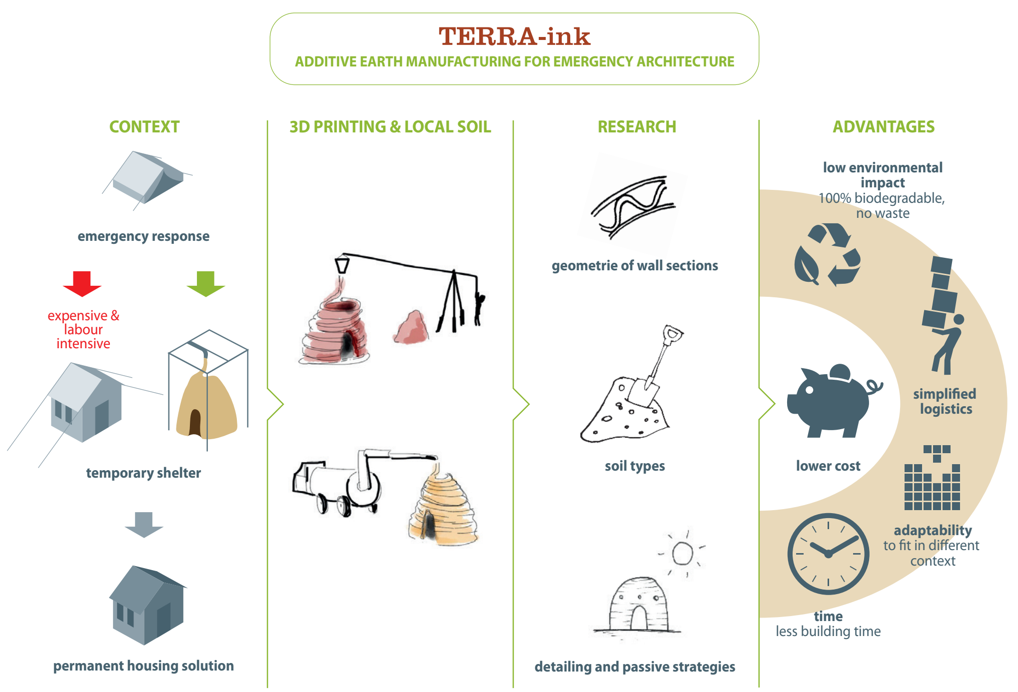


Aiming to increase the flexibility and adaptability of the process, the project examined the potential of a construction system based on the deposition of soil material, without relying on a specific technology or material recipe, but rather adjusting to the available resources. During the project, the use of both local materials and generic machineries was investigated. Soil material was studied focusing on the material properties of various mixtures in dry and wet conditions. Different mixtures (clay + aggregates) were considered, in order to define how various clay types and grain size affect the physical and mechanical properties of the material. Then, compression tests were conducted on dried soil samples. The results were used to define the compressive strength and other parameters for the structural analysis. The influence of additives and different kind of natural fibers (ex. straw, jute and hay) was confirmed to be an important aspect in the design of the mixture, as the fibers in the mix increase the tension resistance of the soil and reduce the shrinkage.

Besides studying the mechanical performance of dried soil, the project investigated the properties of the mixture when in fluid state. Its behavior was analyzed during the extrusion process used to deposit the material in layers. Parallel to the material studies, the project focused also on the hardware developments, since it also affects the extrusion process. More specifically, commonly available machineries are utilized in this project, in order to explore an alternative open-source solution for large scale 3d-printing that can be applied in all emergence situations. This approach offers simplified logistics and reduced costs, especially when compared with existing technologies such as robots or big commercial printers. An industrial clay pug-mill and a concrete mixer were tested to define the characteristics that allow a good extrusion of the material. By studying the interaction of the machines with the liquid soil mixture and its deposition, it was possible to define and highlight the main parameters that influence the correct design of a soil mix. The criteria of the extrusion quality are based on (1) material coherence and (2) extrusion speed rate. In particular, the material recipe had to be adjusted to achieve a more liquid mix to meet those 2 criteria. A good design of the mixture for 3dprinting application must achieve an appropriate balance between a smooth extrusion flow and control of deformation during the drying process.

Additionally, investigations were made on the design options, regarding the geometric configurations and structural behavior of the shelters. As a test case, a simple shelter design was analyzed to identify solutions using as little material as possible (simultaneously reducing the printing-time), but still achieving good structural stability.

Since curved shapes are generally faster to produce by 3D-printing, a simple round-shaped solution in plan was examined first. Compared to other geometries, round shapes offer also the additional benefits of being earthquake-resistant due to their symmetry in all directions. After defining the boundary conditions (such as maximum dimensions of printing area and structural properties, based on laboratory tests and literature) structural optimization was used to identify the optimum geometries. Due to uncertainties in the behavior of the printed material, the results are preliminary. Nevertheless, they indicated domes and cones as the most efficient shapes, minimizing tension stresses where soil is more vulnerable. Using simulations in a structural analysis software (Karamba in Grasshopper for Rhinoceros, McNeel), irregularities in the wall surfaces (such as openings) were examined in order to identify the limitations in dimensions and the best geometries for doors and windows. Using 1:1 scale printed samples, on-going tests aim at determining which geometries can be actually produced. In fact, the shape and geometries of the shelter are also a consequence of the printing process. During the deposition, the liquid material tends to deform and eventually settle under its own weight. When occurring in rather uncontrolled environments (such as on-site, where shelters are needed) the impact of this process can be high. The lack of stiffness and stability of the layer can be counteracted by its geometry. A flower shape layer deposition can drastically improve the stability of the overall structure, until the mixture is dry enough to withstand its own weight. For this purpose, a second external layer is printed in order to give extra support during the extrusion process and contribute to redistribute the stresses once the wall is dry. This external layer is also a useful protection against atmospheric conditions. The inner gap could provide benefits in terms of ventilation or can be filled with insulation material, depending on the local climate.



During the process, several small-scale tests were made. A 1:1 scale prototype of a wall portion is being realized as a proof of concept. The prototype will be used also to further test the geometries and the structural performances.

Though more research is necessary to develop the construction system, the current results show its potential of applicability. This direction indicates the plausibility for a significant change and improvement in the emergency relief field. Some of these potentials can be significant also beyond the case of emergency architecture. Besides that, the further benefits of soil as a building material are highlighted. Over the past centuries, soil was always used; but nowadays it is often underestimated or associated to modest constructions. Today, in combination with innovative technologies, it could be reconsidered and regain its relevance.