2022 Lisbon Architecture Triennale
University Competition Award

Flying Earth

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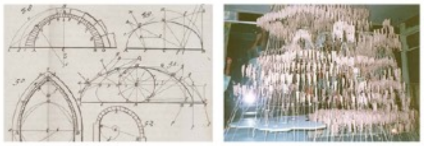
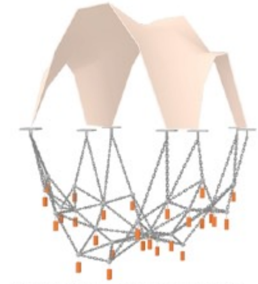
Introduction

Between the geological earth and the rubble turned ground, architecture happens. It is in the cycles that happen between those two moments that the Flying Earth proposal is developed. Addressing the Trienalle challenges, it explores how the Earth's most sourceable matter may provide the human being with an infinitely available and carbon-free material, contributing to an alignment with the current circular economy paradigm.

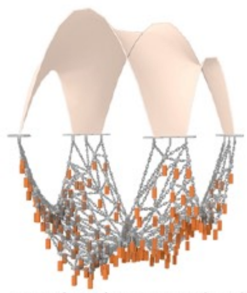
Earthen materials, such as adobe bricks, fired clay or stone, are relevant to construction as they exhibit physical properties such as high levels of compressive resistance, thermal inertia and index of reusability. With the wit of men these materials have been tamed to fly using their own weight to shape arches and vaults overtime, with increasing complexity and efficiency, also supporting the creation of a variety of forms from amorphous to modular. The Flying Earth proposal aims at achieving circularity and reducing the carbon footprint of construction by proposing a novel building production system to encourage the use of earthen materials in architecture. In the age of climate change, it is decisive to give a new opportunity for employing traditional and sustainable earthen materials in architecture, and thus fight the disastrous emissions caused by the building construction industry and its insistence in concrete and steel-based systems.



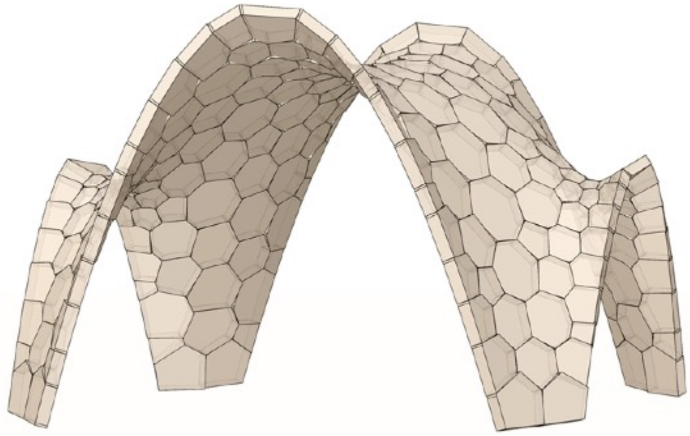
Frézier's treaty on stereotomy and
Gaudi's stereofunicular models.

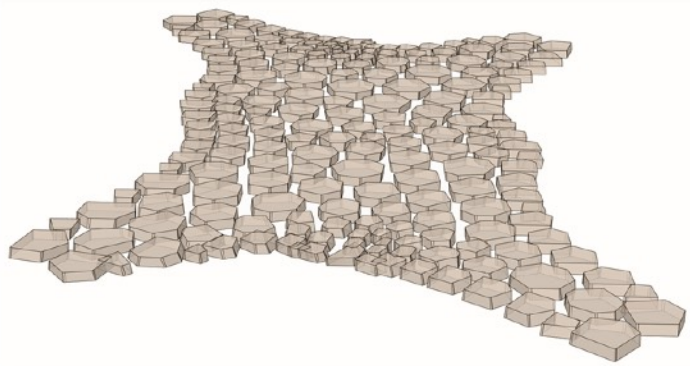


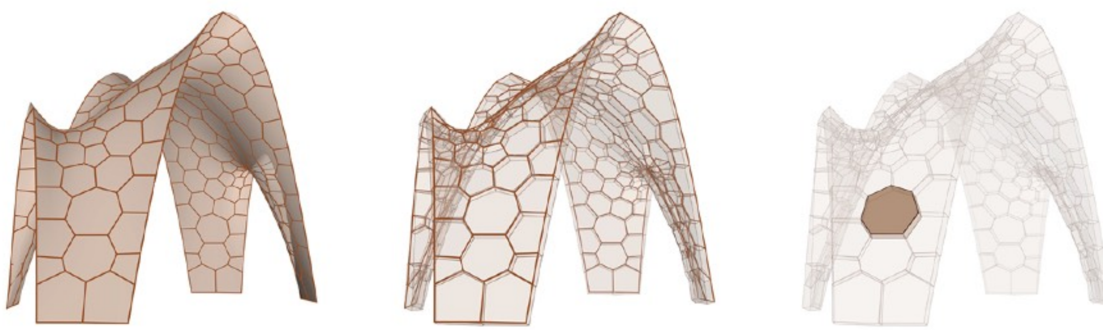
Simplified chain network for
explanation purposes.



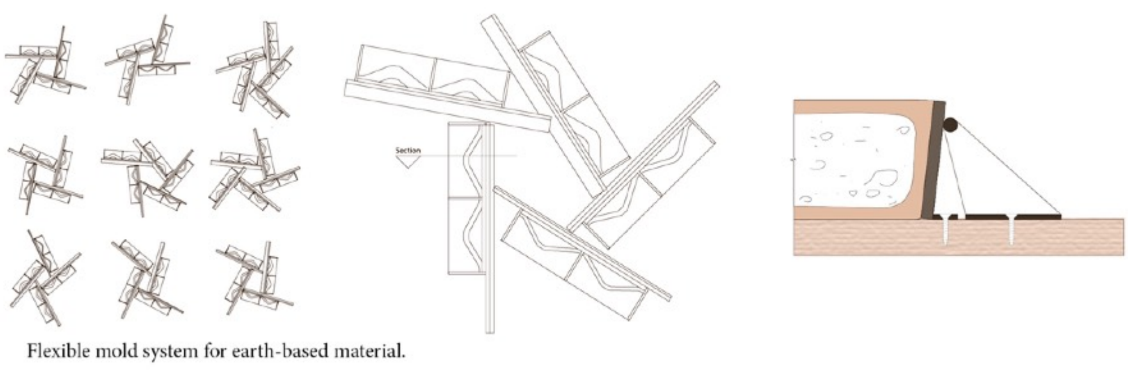
Complete chain network, achieving
geometry curvature continuity.







Surface subdivision and discretization into building blocks.



Flexible mold system for earth-based material.

Reviewing Earthen Materials

Earth bricks, (or sun dried bricks, mud bricks) are a construction material used since the dawn of building. The first known vaults were built with earth bricks in Mesopotamia (Oates 1973), revealing how flexible and strong this material is. Earth built architecture can be found in extensive areas of the globe, as attested by Houben and Hubert (1994). This traditionally used material has also been subject of research and application by modern architects, as is the case of Hassan Fathy. The two basic pillars of his thinking were the use of local materials and understanding architecture as a social project. In his book, *Architecture for the Poor* (Fathy 2000), he wrote that the building materials are under our feet: it is the earth that has always been the basic building material in this region. His approach is fully in line with the circular economy and locality.

Currently, earthen materials are gaining a new relevance to address the urgent needs for a more sustainable and energy efficient construction. When assessing its life cycle, locally sourced raw earth has a low negative environmental impact. Traditionally used in hot and dry climates, it protects building interiors from overheating. For example: untreated and unfired adobe blocks decompose in the process of erosion and return to the soil. Recognizing these advantages, renowned architects are driving their attention to earthen materials, such as Foster + Partners (2015), Renzo Piano Building Workshop (2020), Francis Kéré (Fernández-Galiano, 2018), Gramazio and Kohler (2021), to produce the entire building or just parts.

Research and Innovation at the DFL

Building with earth assumes many approaches, all sharing the common property of strong compression resistance. Stereotomic design is one of them, traditionally relying on cut stone to build arches or vaults. A rebirth of stereotomy, or Stereotomy 2.0, has been announced and researched in recent years (Fallacara and Barberio 2018). This interest in discrete, prefabricated elements capable of replacing heavy carbon tensile resistant beams is accompanied by a renewed interest in stereo-funicular structures, whose design is now driven by powerful computational tools.

The DFL has been conducting research in this topic at FAUP for more than 6 years. The research group has been developing a vision of an increasingly stereo-funicular, discrete architecture (Azambuja Varela, 2020) while providing an integrated model for the fabrication of these building structures. With the overall idea of waste reduction, a system of reusable and reconfigurable moulds was developed to successfully cast uniquely shaped blocks which, when juxtaposed, create compressive working structures. These blocks may be fabricated of any pourable material, and while low carbon concrete mixtures can be used, we suggest earth compositions as raw material. This whole process is fostered by digital technologies from the design and analysis phase to the mould production process. Previous research at the DFL have used a robotic arm to inform and fabricate the geometry of these reusable moulds (Azambuja Varela and Sousa, 2018, 2019), creating a sort of elision between high tech digital fabrication and low tech material making.


Prototype of earth voussoirs vault, as proposed to be installed in CCB/Garagem Sul.

This vault is demonstrative of the structural efficiency and geometric freedom of earth architecture.

While robotic arms have been the larger drive of architectural digital fabrication, other different digital technologies are emerging, like Augmented Reality (AR). Being a technology that affords a visualization experience that overlaps digital and physical information it has become widespread in many fields, like medicine, engineering, commerce or entertainment. Placing a virtual product in a real environment is becoming ubiquitous practice, with AR technologies being harnessed by the end user, without any priori knowledge or skill. Recognizing these features and its potential, the DFL has looked into this technology as an opportunity for continuing and innovating his research on stereotomy construction with earthen materials.

The Flying Earth project

The Flying Earth project submitted to the Lisbon Architecture Triennale 2022 aimed at exploring the innovative potential of earth in architecture by deploying a novel and highly sustainable production process based on AR technology. To demonstrate that, the DFL wanted to present a 1:1 scale installation (Image 1) built with earthen components for the University Competition Exhibition. As a complement, various speculative architecture designs (Image 2) would also be featured in graphic panels, documenting possible applications of the production system to rethink and envision possibilities for building elements, such as slabs, roofs, vaults or stairs. Those designs were thought to be developed through public workshops in order to engage a wider audience.

The Design

The design for the installation consisted in a four legged vault large enough for people to walk beneath. Featuring horizontal point symmetry, it is composed only of earth voussoirs leaning against each other in a continuous stereo-funicular surface composed of four arches in its perimeter. This sculptural object would showcase the formal and structural possibilities of a stereotomic earth construction.

In addition to the proposed vault, a series of other architectural scenarios were investigated to unveil the potential of this construction system. The first example features a building whose facade and inner structure is made of earth blocks arranged in arches, configuring a contemporary expression to the proposed architecture. Another situation features a slab system with a slight curvature, lending a centrality to the room; this system was generated algorithmically and automatically adapts to the shape of each room, allowing for a flexible design tool. Finally, a stair system was also devised, following the principle of avoiding heavy carbon materials such as steel or cement; the stair develops along an extended arch, where the steps are actually voussoirs, part of the structure itself.

Production

For the production of the Flying Earth project, we chose clay as an earth-based material that is easy to mould and unmould. The clay material resulted with smooth surfaces when contacting the surfaces of the mould components. The material dries when it is exposed to air without the need for burning or heating. The unmolded and cured clay blocks also provide strength for the potential compression of vault-like forms.

The stereotomic nature of the Flying Earth project and its variable components required different techniques and technologies to produce the parts and assemble the structure. First, to produce 207 unique voussoirs, it is proposed one flexible mould system that can be customized to produce many different blocks (Image 3). The flexible mould is constituted from metal plates that can be carefully positioned and angled to prepare different configurations to mould each earthen block. The intended moulds could be created using blueprints, annotated angles and a variety of carpentry tools, but it would become time-consuming and potentially innacurate.

So, instead of looking for automated processes through robotic technologies, the Flying Project turned to explore the potential of AR technologies to empower human capabilities and complete that task. The fabrication and assembly relies on the Hololens 2 headset that enable us to deal with complex designs and fabrication tasks. During this augmented fabrication process, we take advantage of the headset's ability to superimpose digital data over physical reality, allowing craftsmanship to handle the design and fabrication processes rather than just visualizing them.

The use of AR technology coupled with the flexible and reusable mould system allows the production flow of multiple components without generating waste. Together with the earthen nature of the construction materials, this yields sustainable building blocks which are the basis of our proposed architecture: an architecture which is inspired by history, rooted on local conditions and human capabilities, featuring shapes that follow natural forces and are free from carbon footprint impact.

Environmental impact

Environmental life cycle assessment (LCA) has become a valuable tool to evaluate construction processes and buildings in order to understand its impact on sustainability. One of the main differences of LCA and previous evaluation methods is its focus on the whole cycle of materials, from extraction to its end usage and future application; this brings the concept of circularity, a continuous path of material application that reduces waste to a minimum. Although only a few studies have enumerated the environmental impacts of earthen building materials (including the LCA of adobe bricks (Christoforou et al. 2016), rammed earth (Treloar et al. 2011), and earthen plasters (Morela et al. 2001)), a clear idea on the relevance of these materials is postulated by Ben-Elon et al. (2019): “Earthen building materials offer an environmentally sustainable alternative to conventional materials because they are locally available, minimally processed, and waste-free.”

This set of images shows outcomes of the workshop, where stereotomic earth is explored as a multifaceted structural and expressive material.

Final remarks

Although it is understood that building with sustainable materials is a main contemporary challenge of architecture, earthen materials, while being acknowledged as a material widely used globally and spanning civilisations, are yet to enter the list of widely used materials in the contemporary construction industry standards. This research shows how novel applications with earth can empower this material to be used in much more architectural situations than the standard bearing wall. By looking into the history of stereotomic stone construction, a transfer of knowledge was applied to earth, by transforming this shapeless material into geometric blocks. Future architecture can benefit from this approach by using earth in structural elements such as load bearing facades, slabs or stairs, while benefiting from the exposed finish of this natural material.

Earth construction must be brought closer to an industrial scale so that the gap between earth construction and contemporary architecture can be continuously narrowed. With this general objective in mind, this research still has big challenges to overcome, and a set of actions can facilitate this task. Augmented reality, although quickly becoming ubiquitous, is still in its infancy, and new technologies and modes of usage might foster its usage, such as collaborative AR assisted workers working in the same object, or a more seamless flow of data between AR sets and the main model. Earth molded blocks must be tested within larger scale experiments, to attest its viability in real world scenarios, as well as different typologies of challenges.

The presence in the Lisbon Architecture Triennale 2022 was thus an opportunity to advance the research on more flexible and sustainable modes of design and construction with earth materials. By promoting emergent tectonics, fostering the use of locally sourced materials and empowering human capabilities, the Flying Project can be an illustration of the New European Bauhaus principles of aesthetics, sustainability and inclusion.

Acknowledgments

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Image captions

Image 1. Sousa et al., Flying Earth project, 2022, Porto, Portugal © FAUP-DFL.

Image 2. Sousa et al., Stereotomic architectural scenarios, 2022, Porto, Portugal © FAUP-DFL.

Image 3. Sousa et al., Design and fabrication process of Flying Earth, 2022, Porto, Portugal © FAUP-DFL.