exploring tensile reinforcements, high-performance openings, and multi-material support systems in impact-printed clay structures

Research Framework

For several years, the ecologically friendly building material - earth, commonly used for thousands of years now, is gaining popularity, even in developed nations. Earth, as a building material offers numerous advantages in hot and dry temperature regions. Its peculiar texture and composition not only hold a great aesthetic appeal but contributes a lot to its physical and functional attributes.

COBB is a technique that checks most of the boxes of sustainable construction, viz. local materials, completely biodegradable, thus low carbon footprint. Where it lacks is the labor-intensive methodology of construction, and impact printing, a form of additive manufacturing, addresses exactly that. A lot of research has already been done into perfecting the parameters necessary to efficiently print structures with this technique. Some of these are cited further in the *State of the Art*. This research aims to push the technology further by looking into aspects such as performative architectural openings, intra-bullet and inter-bullet tensile reinforcements, and multi-material support systems as temporary structures and/or permanent architectural elements.

Research Hypothesis

How can computation help us design and fabricate – inter-layer tensile reinforcement, high-performance openings, and multi-material support systems in impact-printed clay structures on an architectural scale?

State of the Art

1. ***Gramazio Kohler Research**, Prof. Marco Hutter* (RSL - Robotic Systems Lab) *read more here*
2. ***RoboCob,** Ms. Madhavi Ojha* (IAAC-MAA_02 Thesis Project) *read more here*
3. ***Clay-manure building block**, Azerbaijan* (Local Cob Construction) (*reference*) *read more here*
4. ***Cement Room**, Anish Kapoor* (Art Sculpture) *read more here*

Research Objectives

The studies cited above, however, have debatably not reached a desired stage of resolution in the following aspects of fabrication, amongst others – *providing* ***openings*** *for such "impact-printed structures" ; a solution to provide* ***inter-layer reinforcement*** *to increase the overall tensile strength of the printed structure ; informed considerations for provision of permanent or temporary* ***supplementary structural elements***.

The research at ***ETH Zurich***$_1$ successfully managed to scale up this fabrication technique from experimentations in labs to a massive free-standing architectural wall 15m wide and 13m tall. ***RoboCob***$_2$ showed promising results for the use of conventional and composite timber sections, but only as permanent inserts to be used as architectural elements (eg. staircase landings) ; and not as temporary scaffolding. This research thus aims to explore –

> ***studying materials and/or material combinations suitable for inter-layer reinforcements in the aggregation ; studying possibilities of introducing temporary support structures to make fabrication more efficient; studying geometric configurations with respect to design architectural openings with/without permanent/temporary support systems (specific to respective support system), studying and/or designing interface connection details arising thereof, and other related parameters, all working towards providing structurally and environmentally optimized architectural openings in impacted-printed structures.***

A rather ambitious goal of this research would be to design an architectural space (preferably a house) proudly showcasing architectural openings at all scales, viz. openings that provide the passage of – air (micro), daylight (meso and macro), and humans (macro).

Research Methodology

The steps of this research go from some quick base-line experiments to familiarize with tools and materials at hand, also involving numerous digital and physical experiments working towards the objectives of this research.

For inter-layer reinforcement – This stage of the research involves studying behaviors of various materials, both natural and artificial, viz.- straw, natural fibers, etc. for their abilities to provide tensile reinforcement between layers of impact-printed clay. Naturally growing roots of suitable plants is also a technique suggested by the research done in ***RoboCob***$_2$.

For temporary and permanent support systems – This stage of research involves a lot of computation and fabrication experiments, testing various geometric configurations, arising from various support materials, viz.- bamboo, timber, etc. ; structurally and aesthetically.

For architectural openings – This stage of the research also involves a lot of computation and fabrication experiments, testing various geometries as architectural openings at micro, meso and macro scales; all this, considering temporary and/or permanent support systems if necessary.

Summing up – This stage of the research involves showcasing the findings of this research in the form of a dwelling for a typical family unit, also considering a suitable geographical and climatic context; with a possibility to fabricate a scaled-down version of the "house" and/or, fabricate an 'as close to full-sized' version of the part of the "house"

Research Takeaway

Thus, combining **natural, earth-based building material**$_3$ with timber or similar materials, and state-of-the-art **digital design** and **robotic fabrication** technologies, this research shows potential to change the perception of **sustainability** in ways more than one. It can also pave new models of automated robotic construction workflows and the potential of developing sustainable infrastructure in **remote and inaccessible areas**, at comparatively **minimized embodied energies**.

In addition to the **ecological value** this fabrication technique adds, it also shows potential to radically change the way we look at our **urgent housing requirements** – from perpetually existing **urban sprawls** to especially urgent **refugee crises** across the world.

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keywords *: additive manufacturing, robotic fabrication, impact printing, clay bullets, clay buildings, multi-material construction, openings, permanent and temporary frameworks, timber and clay, inter-material connections*

bibliography :

i. *Project Curiosity*
https://www.project-curiosity.com/experiment/robot-impact-printing-clay

ii. *Gramazio Kohler Research, Prof. Marco Hutter (Robotic Systems Lab – RSL)*
https://ethz.ch/content/dam/ethz/special-interest/baug/ibi/ibi-dam/documents/Presentation%20info%20event_HS2021_long.pdf

iii. *Gramazio Kohler Research, Prof. Marco Hutter (Robotic Systems Lab - RSL)*
https://gramaziokohler.arch.ethz.ch/web/e/lehre/374.html
MAS DFAB: Rapid Clay Formations (Brunnen)
https://gramaziokohler.arch.ethz.ch/web/e/lehre/434.html

iv. *MAS DFAB: Rapid Clay Formations (Rio)*
https://gramaziokohler.arch.ethz.ch/web/e/lehre/399.html

v. *Tecla House*
https://en.wikipedia.org/wiki/Tecla_house

vi. *Azerbaijan, Clay-Manure building block*
https://www.123rf.com/photo_100866766_building-material-from-a-mixture-of-manure-and-clay-it-is-used-in-the-construction-of-buildings-in-t.html

vii. *The Impact of Advanced Construction Technology on Refugee Shelters*
https://bfemu.journals.ekb.eg/article_139431.html