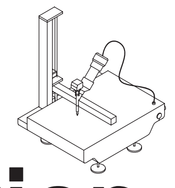
ceramics

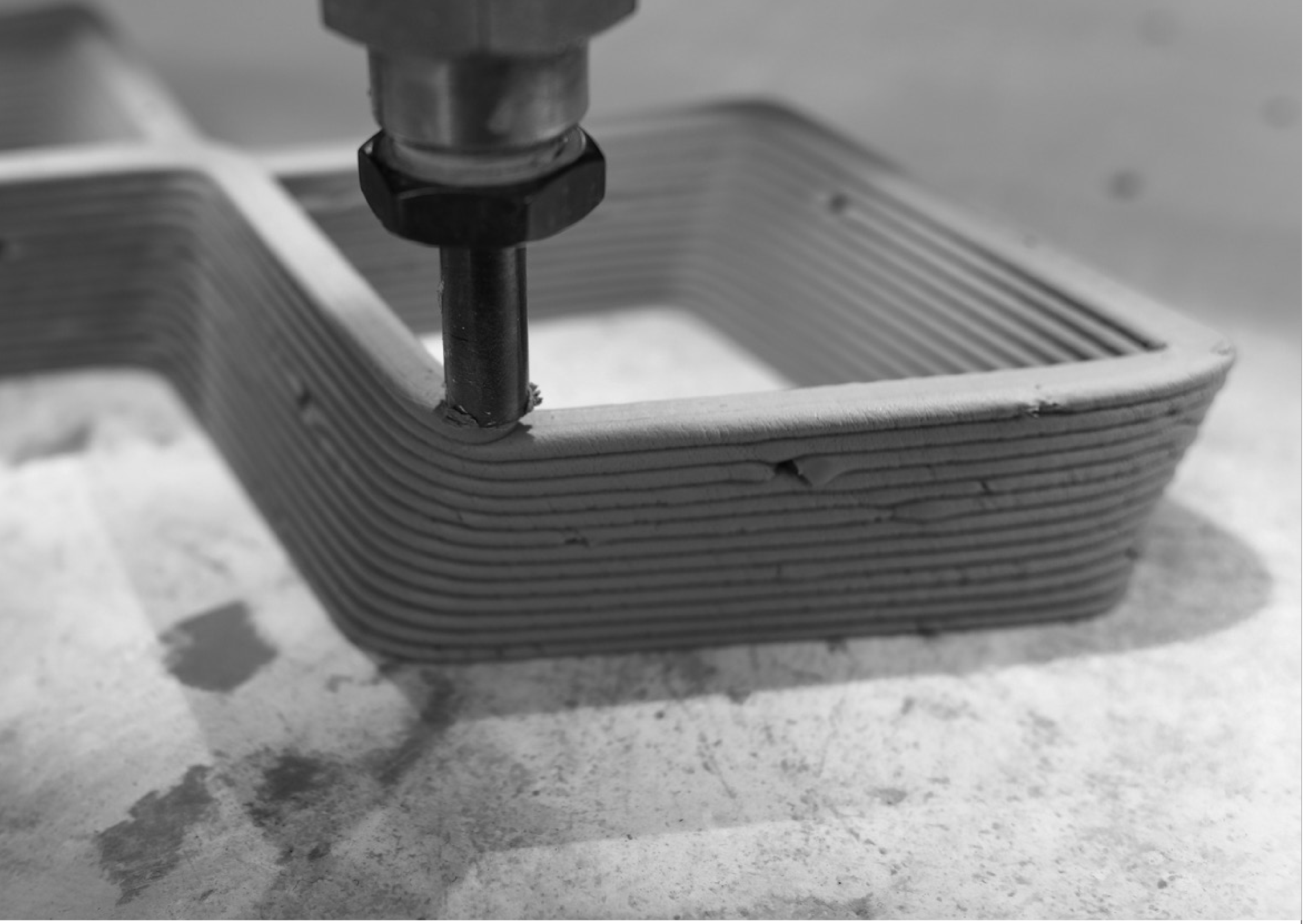
additive manufacturing

INTRODUCTION 02

One of the first references to the potential of Additive Manufacturing (AM) in Architecture arise in the mid-1990s by Mitchell and McCullough (1997)[1] under the term “Incremental Forming”. Often referred as  3D printing, AM consist on the production of objects by the successive addition of layered material, proposing a sustainable and a very cost effective method due to the fact that material is deposited only at the places required, by opposition to subtractive processes or traditional casting and molding techniques which, in addition to revealing a high degree of waste of raw material, do not allow customisation.

The advent of AM opened new areas of research in architectural design, building materials and in the building industry. Moreover when combined with computational design and simulation tools their potential is exponential, namely by enabling a broad geometrical freedom that can result from specific design requirements, design optimisation and challenging functions.

Regardless the debate between the direct application of AM on site and the production of discretized architectural components for subsequent assembly on site, the commercialization of houses built through AM is already a reality. Just as AM was



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highlighted as a key technology that accelerated the transformation of the manufacturing industry towards Industry 4.0, in a horizon of 5 to 10 years the increasing of successful integrations of AM in the building industry will operate a revolution in the built environment strategies of development.

A first set of experiments in AM for the building industry were mainly focused in materials such as concrete.[2] Ceramic materials are a natural resource with unique properties whose application goes back to the prehistoric age, to the first attempts of man providing his own shelter. Features such as hardness, density, durability and the possibility of having a vast number of shapes and finishes provide the application of this material in buildings all over the regions of the world. AM in ceramic materials can result in a compromise between a high performance material and the execution of complex geometries, impossible to obtain by any other production process, or by traditional methods.[3]

For these reasons the KERAMOS R&D project, an exploratory project under the framework of the MIT-Portugal Program, envisaged to contribute to the integration of ceramic materials and natural clay-based composites materials in AM processes. The project aimed to explore the AM of Innovative and Multifunctional Ceramic Products for Architectural Systems, encouraging the tailoring of their multiple properties—material, formal and functional—regarding a more sustainable built environment.

The project gathered a multidisciplinary team — architects, engineers and physicists — and took advantage of the fruitful cooperation between Lab2PT —The Landscape, Heritage and Territory Laboratory, the Design Institute of Guimarães, the Advanced Ceramics R&D Lab, the Institute for Polymers and Composites, the DONE Lab — Advanced Manufacturing of Products and Tools, and the Functional Coatings Group and Biofilm Group.

For that end the research encompassed a set of objectives and milestones regarding the different stages of the project.

1 Mitchell, W., McCullough, M. (1997). Digital Design Media. New York: John Wiley & Sons, Inc.

2 Khoshnevis, B. (2004). Automated construction by contour crafting--related robotics and information technologies.

3 Cruz, P.J.S., Knaack, U., Figueiredo, B., & Witte, D. De. (2017). Ceramic 3D printing – The future of brick architecture, Proceedings of the IASS Annual Symposium 2017. A. Crisfield, Non-linear Finite Element Analysis of Solids and Structures. Volume 2: Advanced Topics. (2nd ed.). New York: Wiley, 2017.

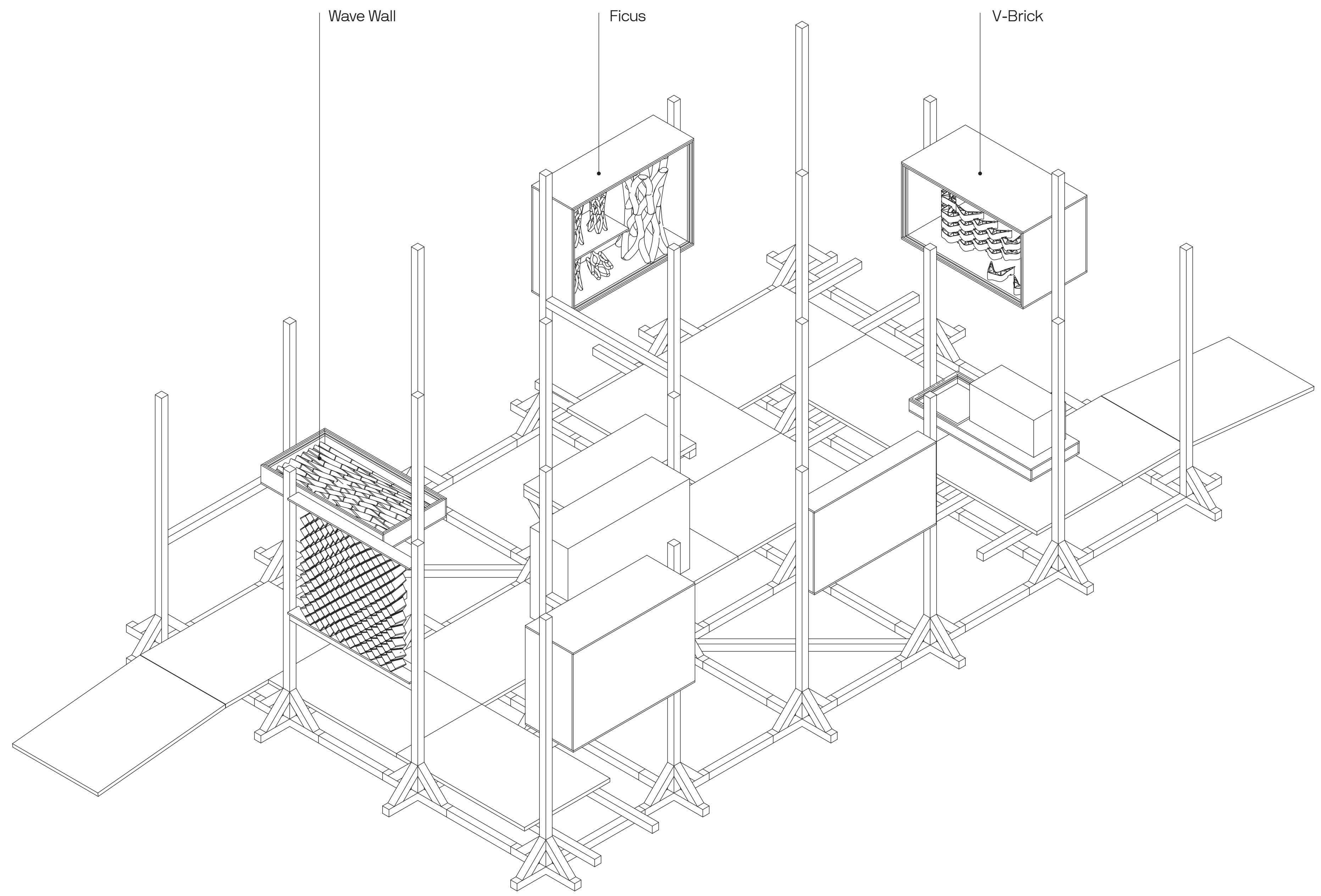
OBJECTIVES

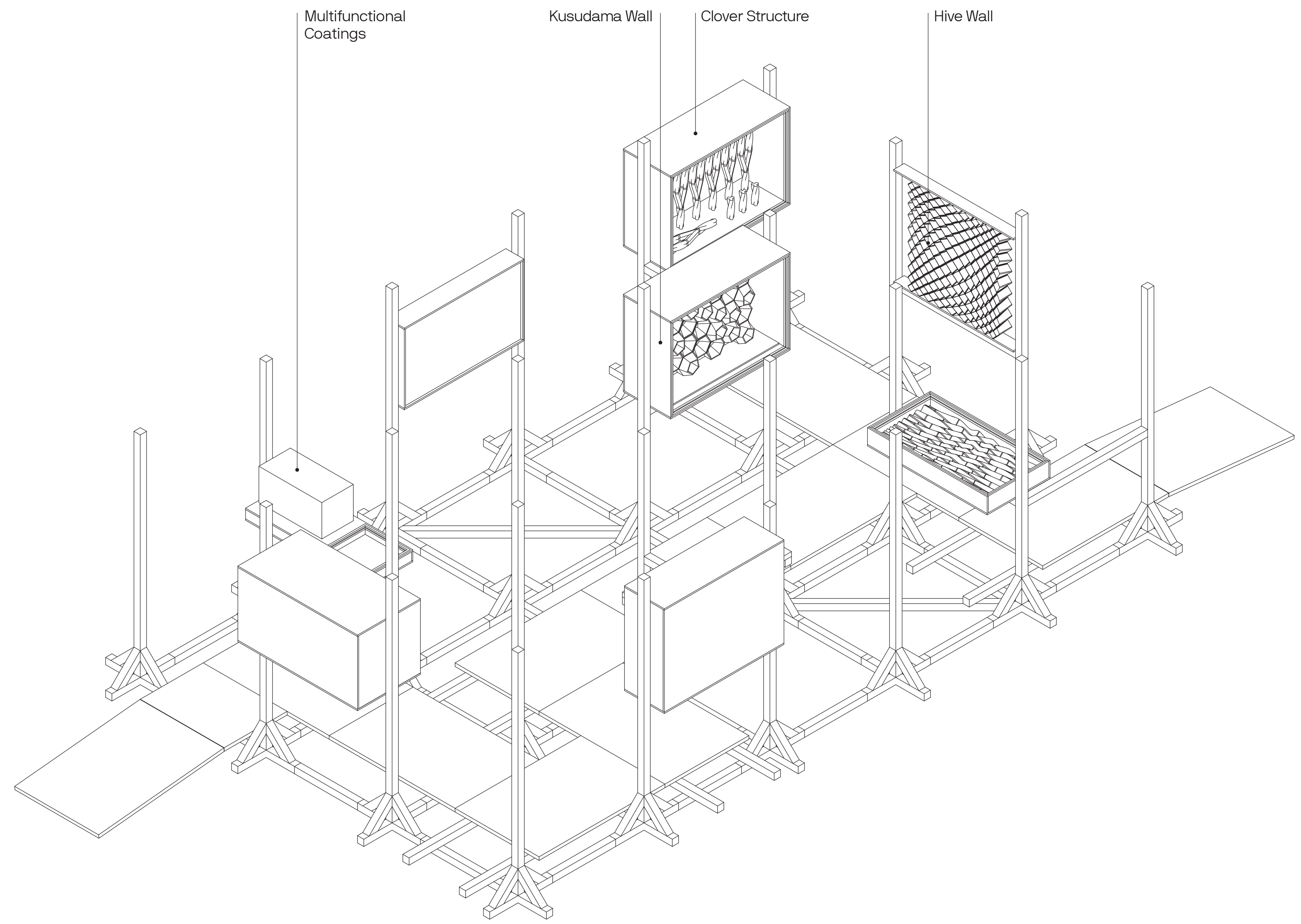
number	description
1	The integration of digital AM techniques in the architectural design and production processes of ceramic and hybrid architectural components.
2	The expansion of functionalities of ceramic components, beyond its traditional architectural uses, proposing new constructive systems with more sustainable and durable performances.
3	The application of magnetron sputtered coatings with multifunctional characteristics able to provide the mechanical stability and desired functional proprieties such as antifouling, anti-scratch and self-cleaning to architectural components.

MILESTONES

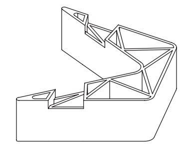
name	description
atlas	The Atlas propose a knowledgeable and structured compilation of architectural projects and researches with a regard on contemporary ceramic architectural products that seek multifunctional systems. This review on the use of ceramic architectural product is an open document to future additions and further developments, and will be a starting ground and stepping stone for new researches.
work	The main goal of the project was to explore the AM of ceramic elements, the design of customised fitting components & the use of multifunctional coatings. For this purpose the research team produced a set of design explorations and prototypes centred on the customisation of ceramic and hybrid cladding components. In addition, a set of sputtering tests with different coatings were performed. And also the testing of specimens produced with composite materials that combine ceramic with cellulose, metal and glass.
share	A workshop, an exhibition and the communications presented in specialised conferences were the main occasions for sharing the KERAMOS project outputs with the academic community and a broader group of interested parties. The two days' workshop (March 28–29) allowed to share the main knowledge of the project—the advent of ceramic AM, the use of computational models to define architectural systems, hybrid and composite elements, mechanical connections and fittings, surface treatments and coatings, the architectural applications of AM ceramic components—and the exhibition SHARE: Innovative and Multifunctional Ceramic Products, that took place at Azurém Campus of the University of Minho in Guimarães (June 11–July 1), permitted to disseminate the main outcomes to a greater audience.

Axonometric views of the layout of the exhibition SHARE — Innovative and Multifunctional Ceramic Products





PROTOTYPES 08

This section is dedicated to the presentation of prototypes  that have been developed in the scope of the KERAMOS R&D project 2018-19, but also in the context of previous researches conducted at the Advanced Ceramics R&D Lab, since 2016, that grounded subsequent investigations.

WAVE WALL

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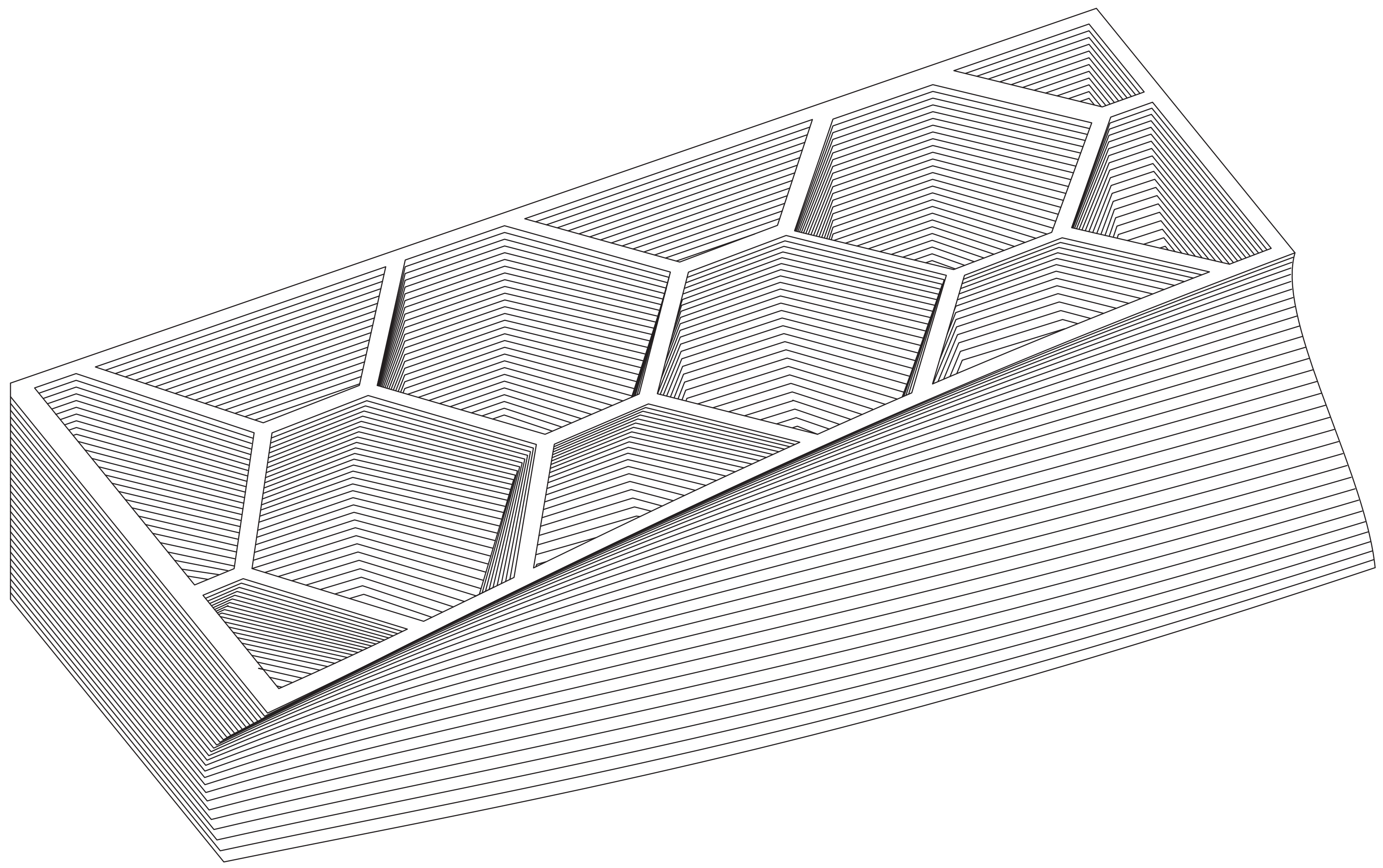
TEAM Paulo J.S. Cruz and Bruno Figueiredo (coordination); João Carvalho (design and development); Samuel Ribeiro (development and technical support). **SCOPE** ACLab Research, Master Thesis (MiArq, EAUM).

Wave Wall consists in a computational model and AM prototype that proposes a system of ceramic components for facade cladding. Wave wall has the specificity of formally exploiting the maximum degree of vertical curvature that stoneware extrusion is able of performing without collapsing.

The internal structural pattern was studied to be the most efficient as possible, allowing to correlate the heat conduction between the two exposed faces and their mechanical performances. For this end several patterns were considered and for all of them were defined some variables that can be parametrically controlled, such as the number of cells, in U and V directions, the thickness of the cells walls, and the patterns ability to adapt or not to the external shape of the brick.



S-BRICK

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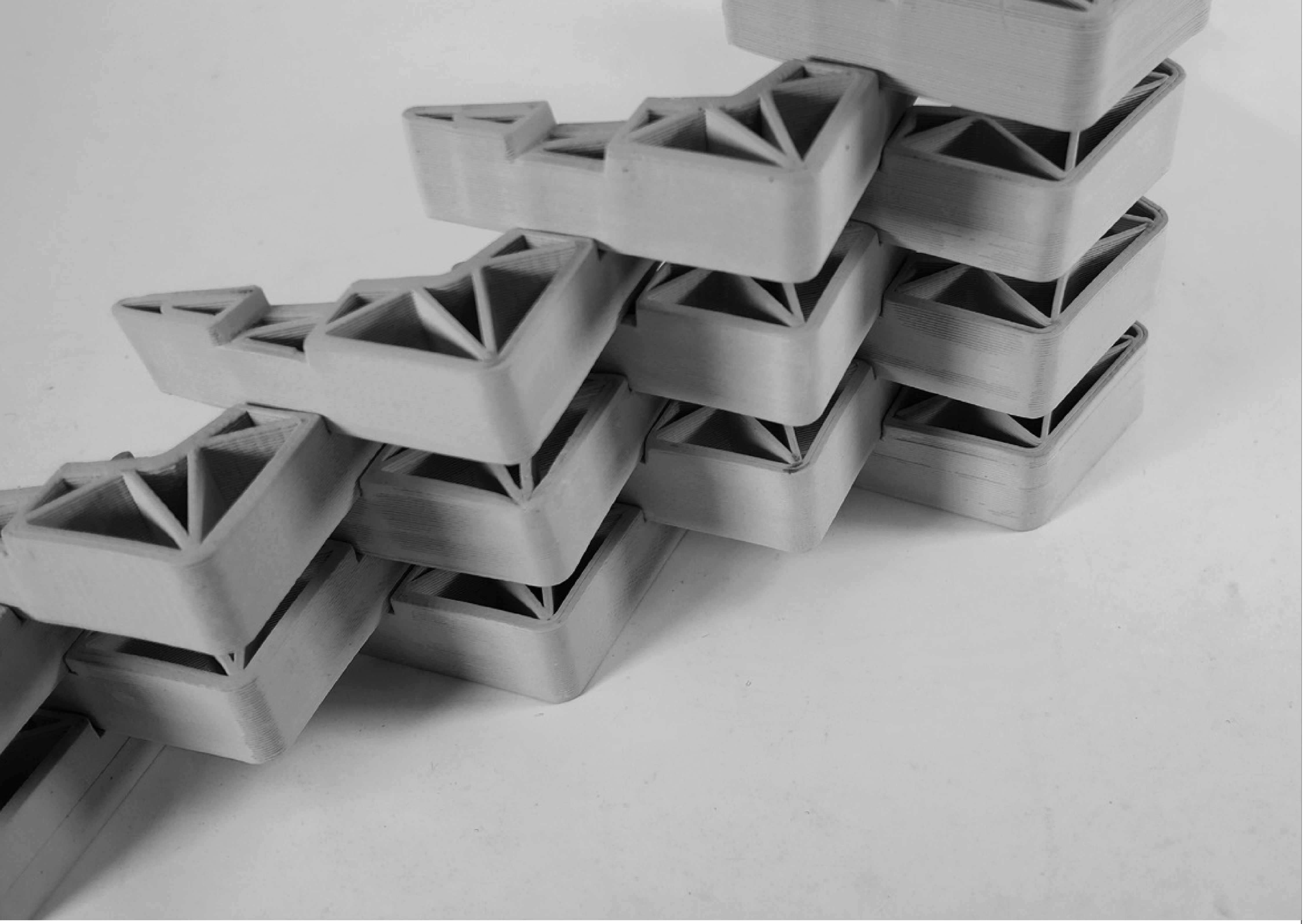
TEAM Paulo J.S. Cruz, Bruno Figueiredo (coordination); Patrícia Ferreira, Inês Tavares (design, EAUM); João Carvalho, Samuel Ribeiro (development and technical support).
SCOPE ACLab Research, Formas e Técnicas do Digital (MiArq, EAUM).

S-Brick prototype explores the design of bricks whose two larger faces are composed by double curved sinusoidal surfaces. It also takes advantage of AM for the customisation of the bricks inner structure by testing s-shaped curved configurations.

These features allow its layering to be done in two directions resulting in walls with different design and functions. If the bricks are assembled in the extrusion direction it might result in an opaque wall with a corrugated pattern. If layered lying down a ventilated sunscreen wall is obtained. In this solution the sinusoidal profile also facilitates the connection between the different layers of bricks.



V-BRICK

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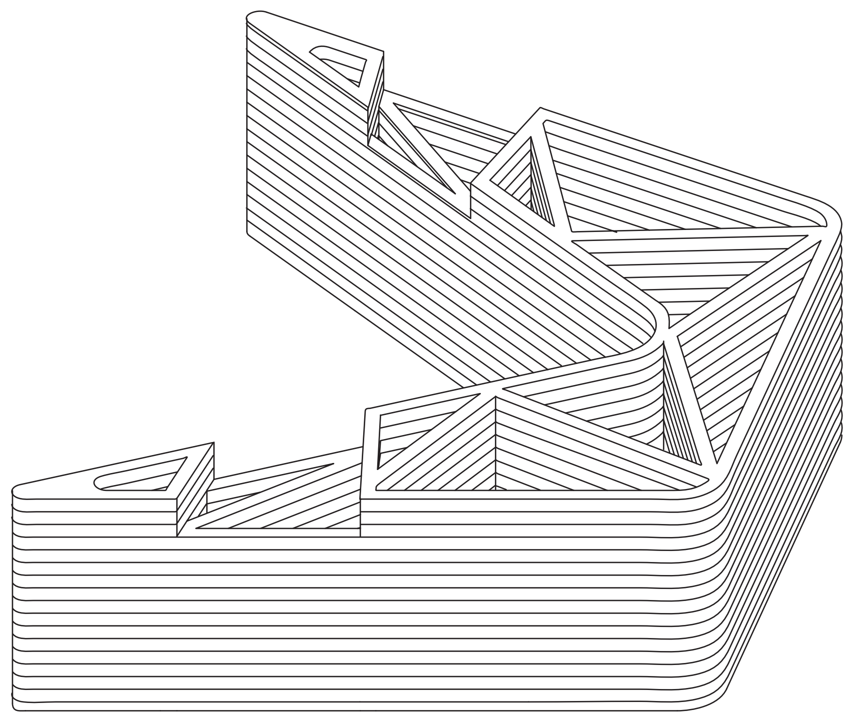
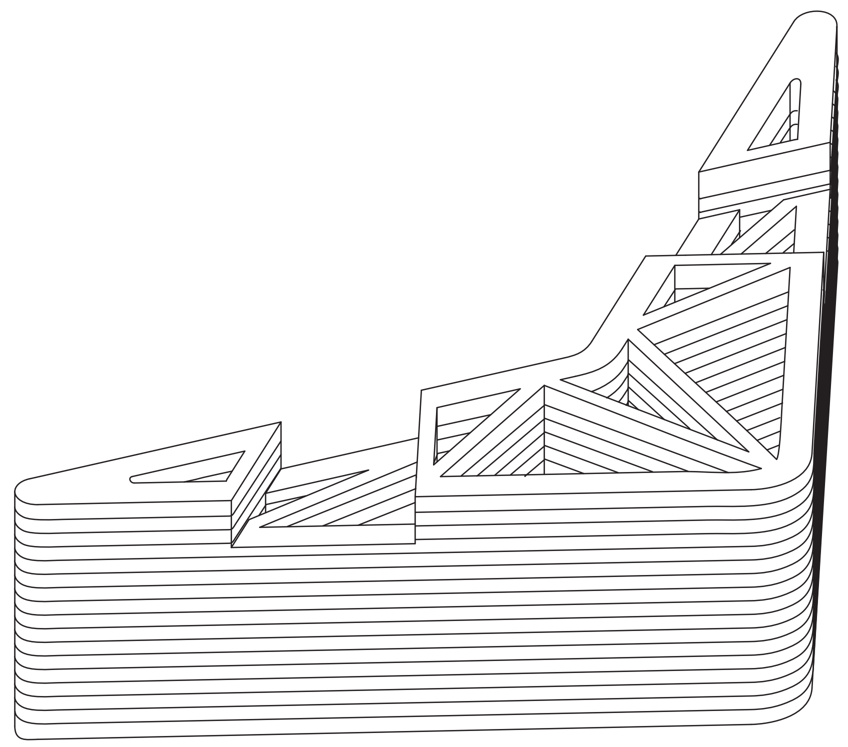
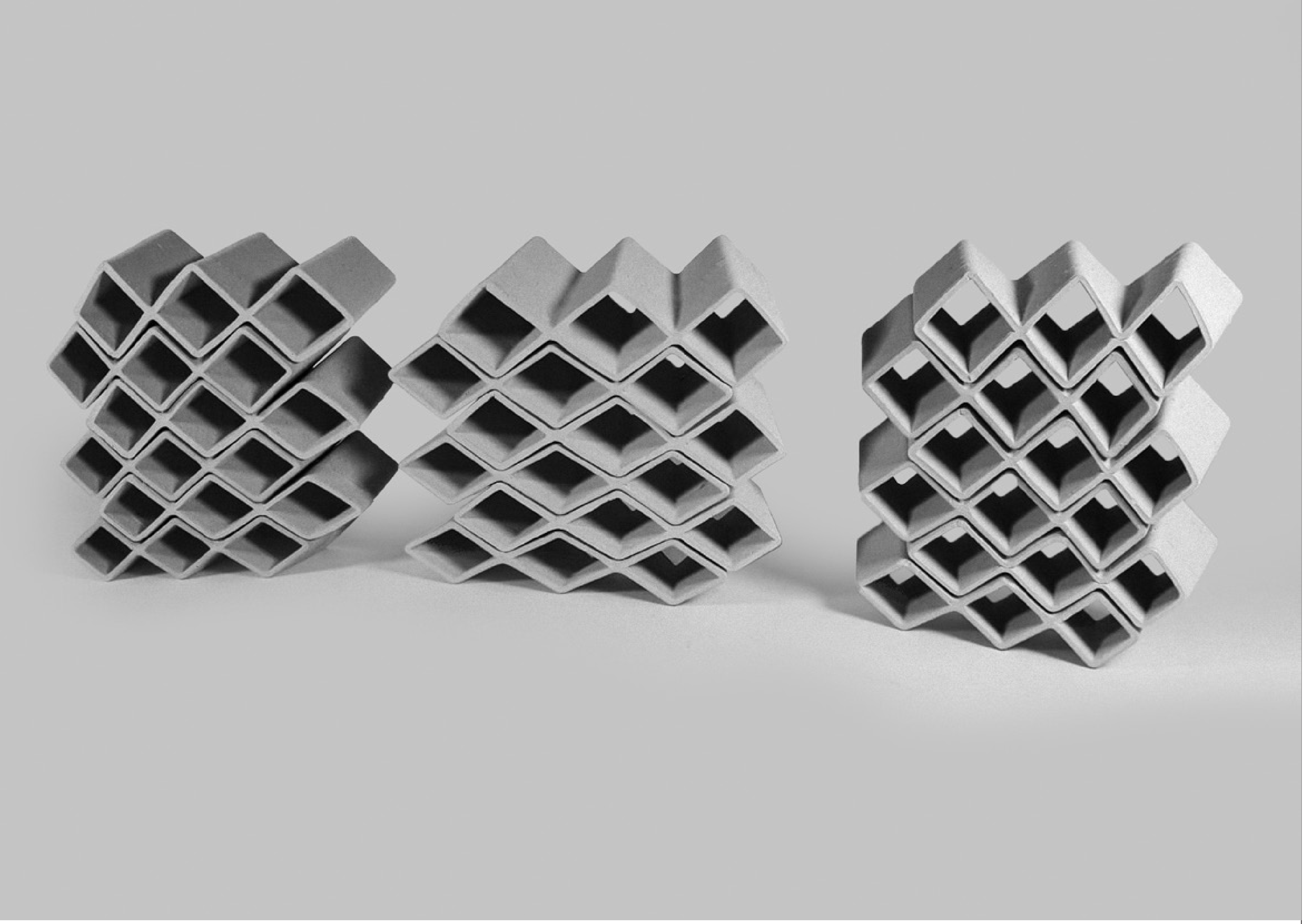
TEAM Paulo J.S. Cruz, Bruno Figueiredo (coordination); João Moreira, Luís Ferreira (design and development); Samuel Ribeiro (technical support). **SCOPE** ACLab Research, Formas e Técnicas do Digital (MiArq, EAUM).

V-Brick Wall project aimed to explore the discretization of architectural structures, such as walls, in ceramic blocks through the use of parametric design tools and AM processes. The focus was mainly on the development of innovative design solutions for the joints and interlocking strategy for a free-form design approach.

To augment the morphological freedom degree, two block types were developed: block A—allowing the construction of linear walls — and block B—enabling walls rotation of 60°. It was proposed a truss-like internal structure to increase the bricks structural strength, but also to optimise the process of continues material deposition that is performed in AM. Finally, an experimental design for a pavilion was created and a section of the V-Brick Wall was manufactured and assembled.







HIVE WALL

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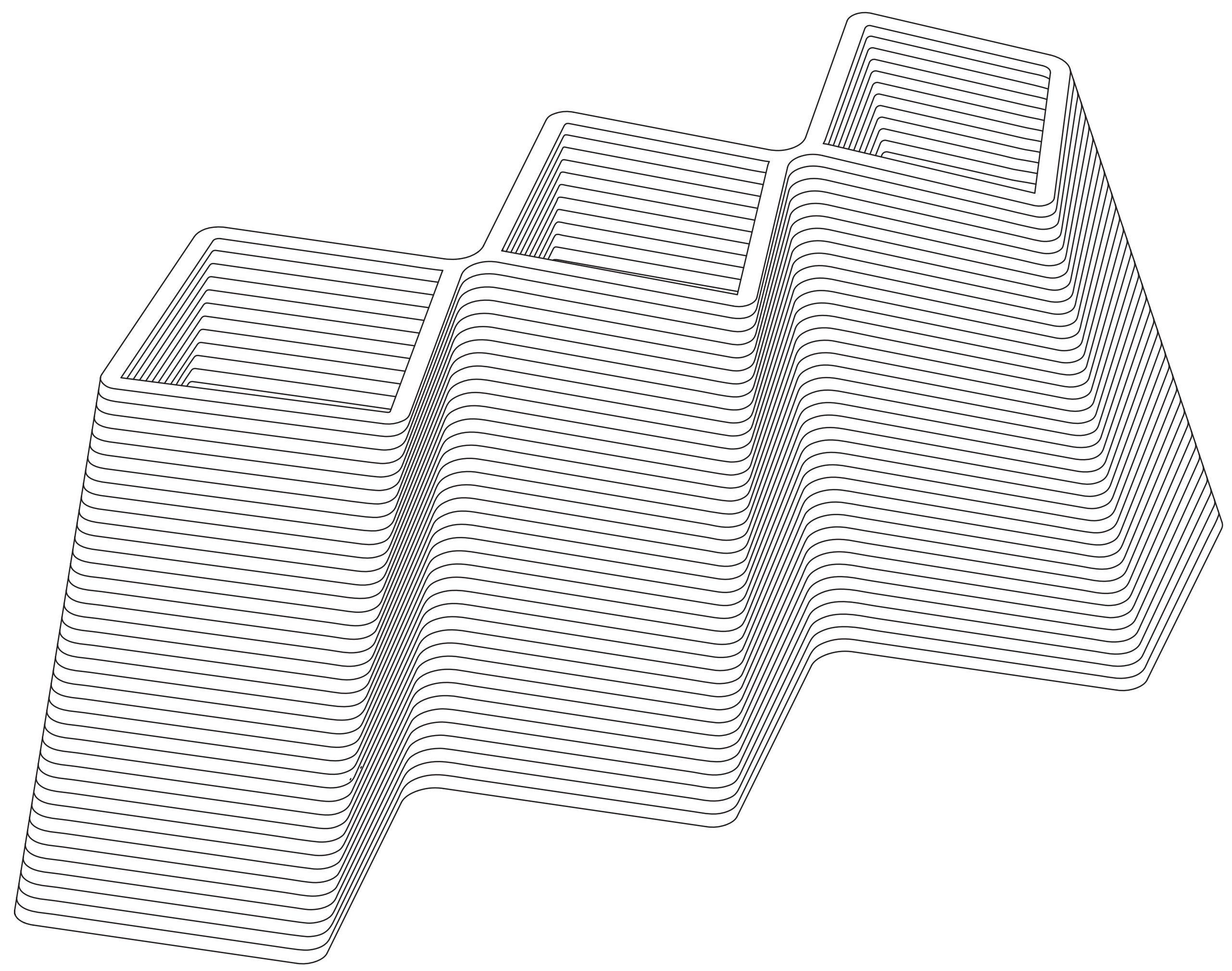
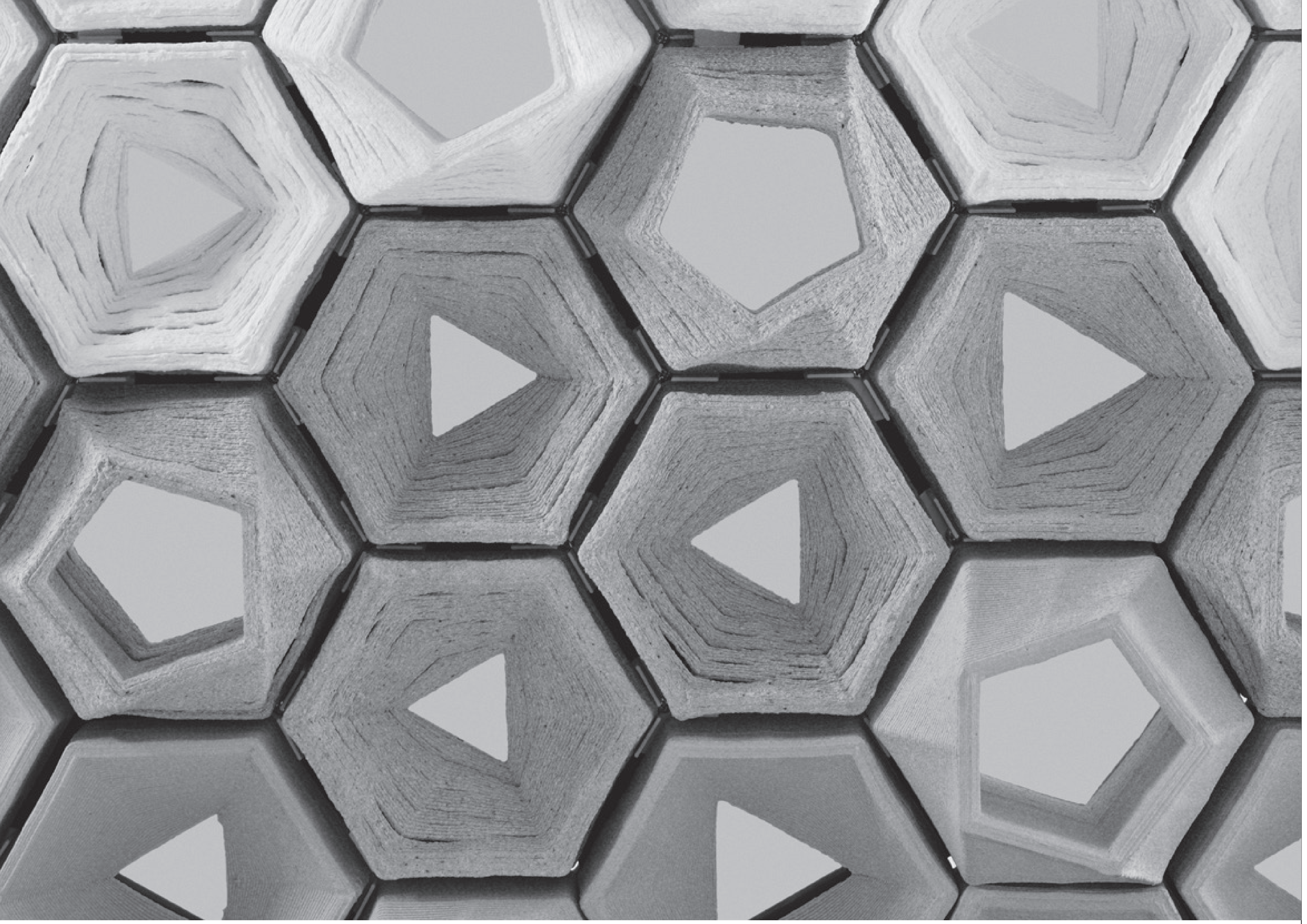
TEAM Paulo J.S. Cruz, Bruno Figueiredo (coordination); João Moreira (design); Samuel Ribeiro, João Carvalho, João Ribeiro (development and technical support). **SCOPE** KERAMOS R&D project & ACLab Research.

Hive Wall experiments the capabilities of AM processes to demonstrate the potential of architectural application of non-standard ceramic components for facade cladding. The challenge was to define a system for ventilated walls in which the size of the openings is customised allowing wider or narrower openings in accordance to the need of ventilation, shadowing or desired visual constrains. The blocks apertures and geometry are composed by three non-uniform truncated pyramids produced with stoneware. The assembly is done by horizontal layering that is facilitated by the trimmed formal configuration of the bricks that result in a stable interconnecting and docking system.

The prototype corresponds to a section of approximately one square meter, composed by 57 bricks of 10 cm depth, in which the central point corresponds to the maximum opening of the wall, which progressively decreases towards its limits.





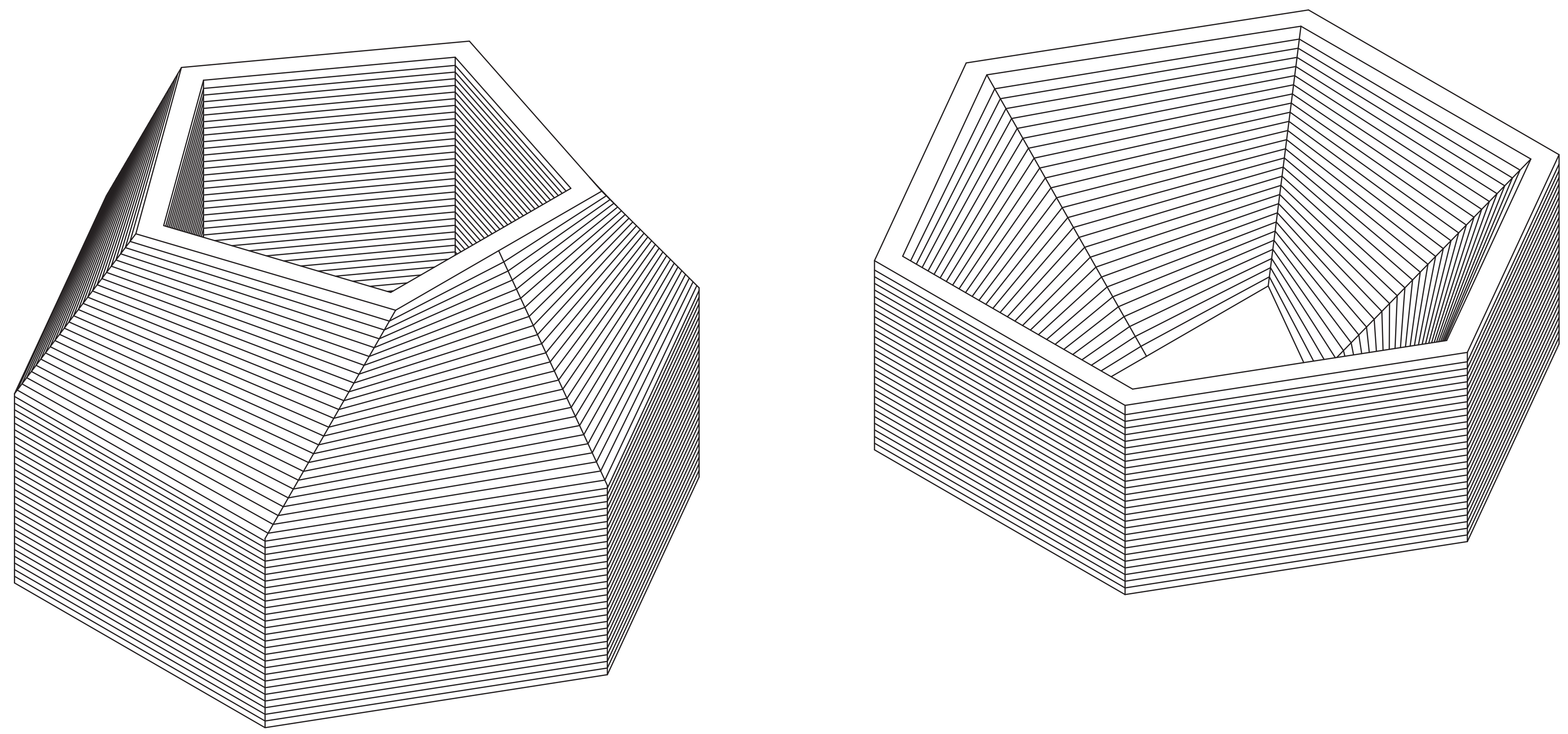
KUSUDAMA WALL 18

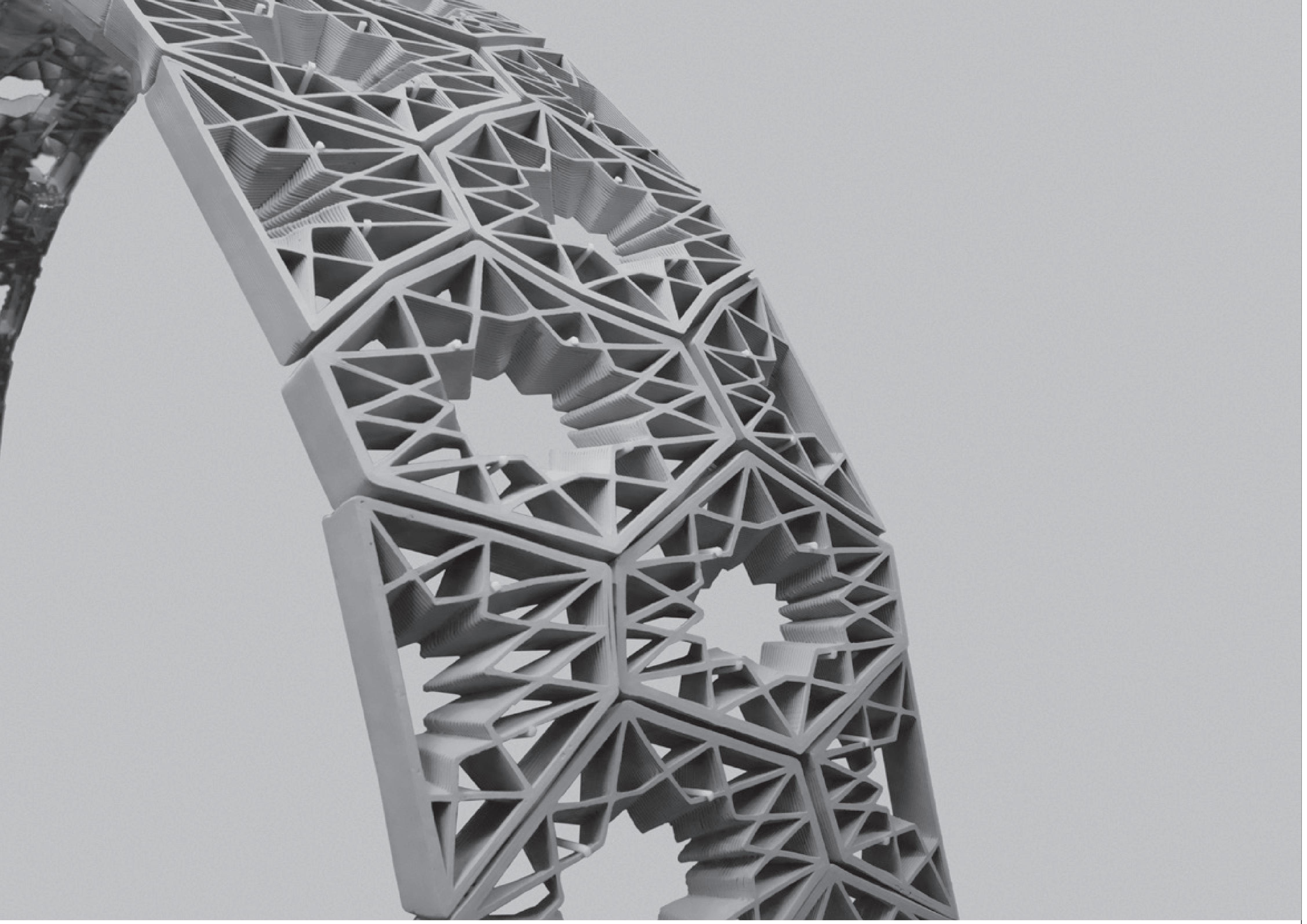
TEAM Paulo J.S. Cruz, Bruno Figueiredo (coordination); Tatiana Campos (research, design & development); Samuel Ribeiro (technical support).
SCOPE KERAMOS R&D project, ACLab Research, Master Thesis (MiArq, EAUM).

Kusudama wall prototype resulted from a research that aimed to explore the use of cellulose to produce architectural components by AM.

After an initial evaluation of 3D printed specimens produced with cellulose and composite materials mixing different percentages of cellulose with different percentages of water, starch, sawdust and ceramic paste, a set of mixtures was selected in order to produce a reliable prototype wall that expressed the different behaviour and tectonic of those materials—the Kusudama wall.

The design solution was achieved by the use of a parametric design model, envisaging a customised set of hexagonal blocks. Two types of blocks were made from a regular hexagonal grid, one consisted in a triangular interior opening and a second one consisted in a pentagonal interior opening.





HEXASHADE

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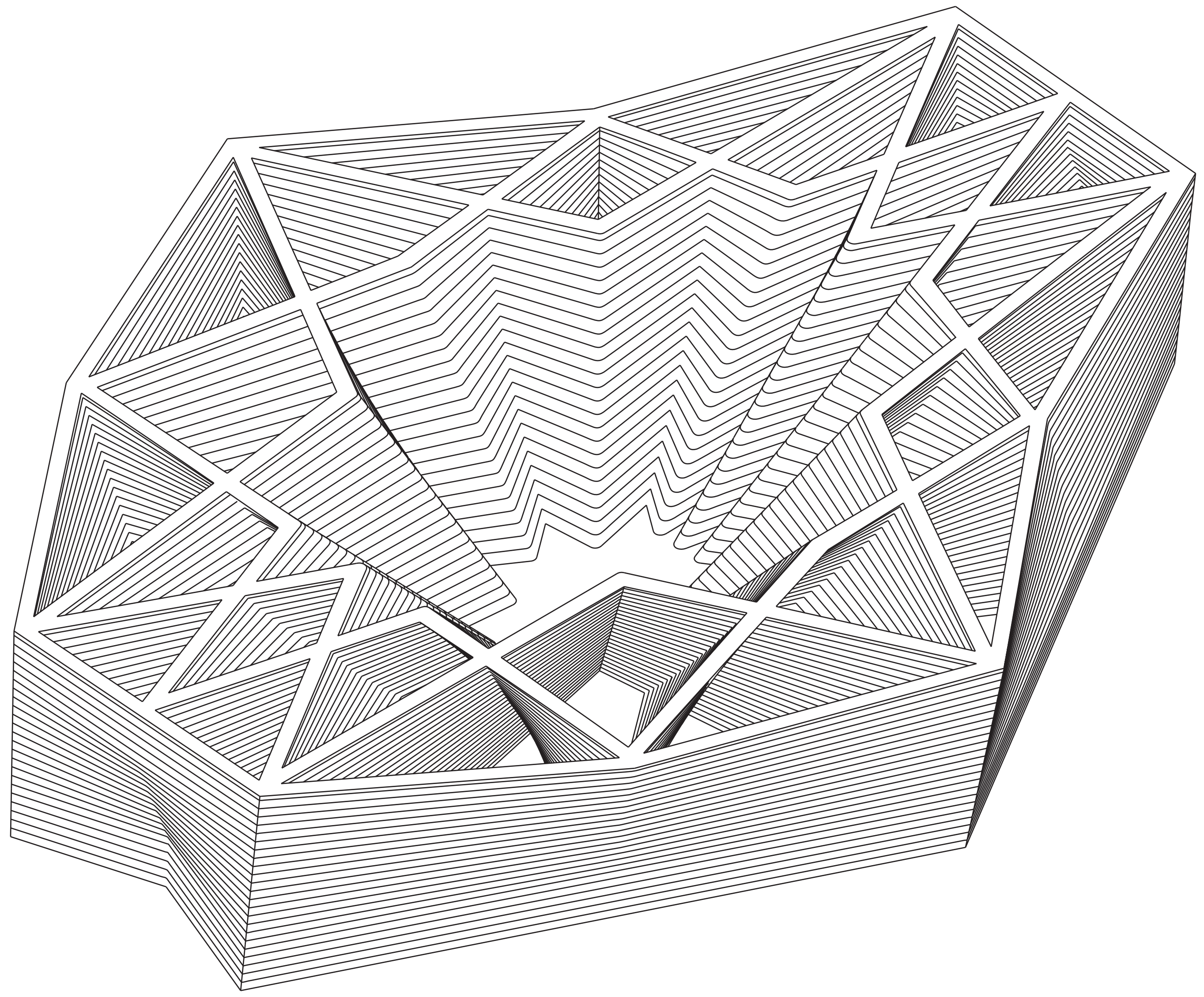
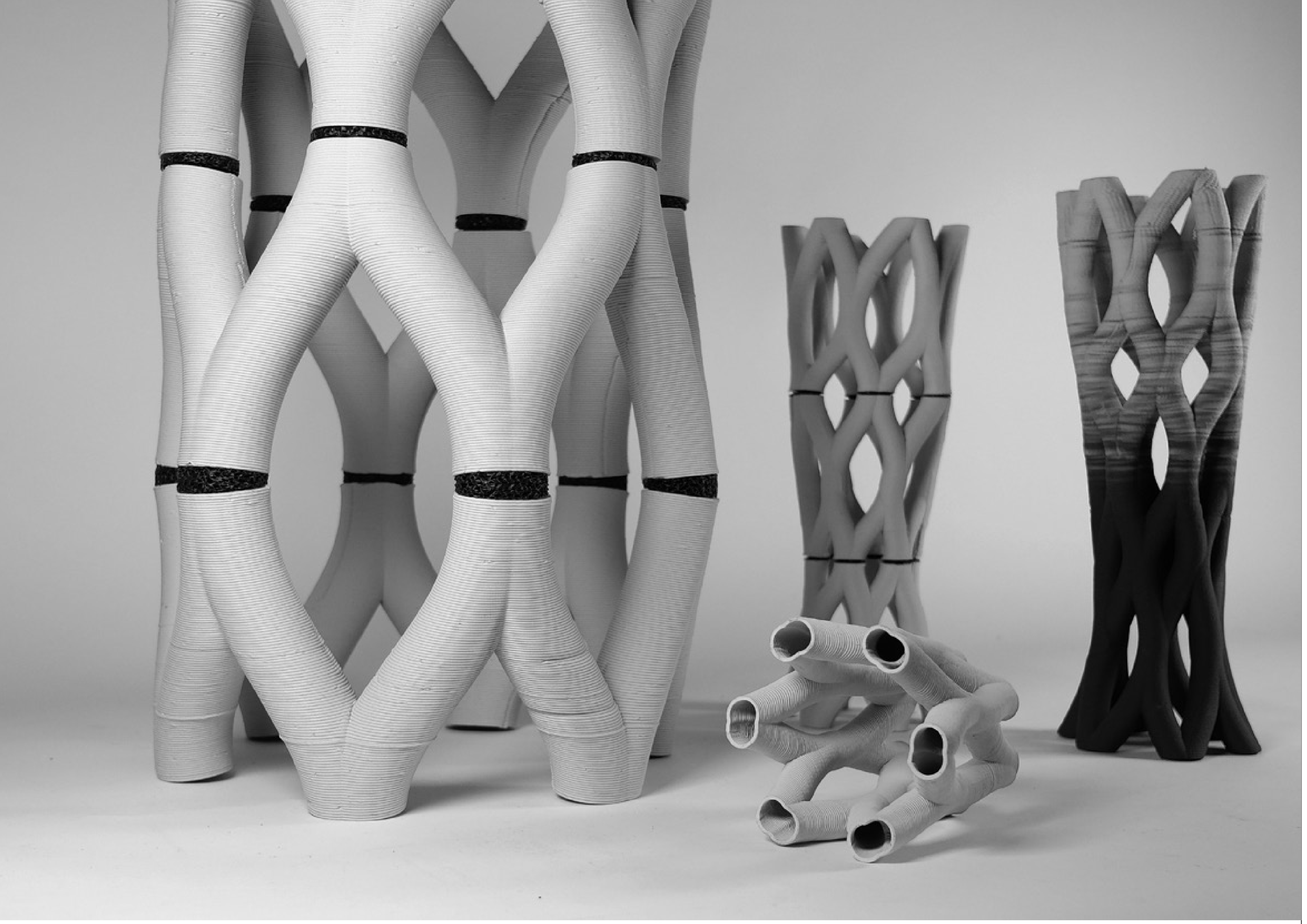
TEAM Paulo J.S. Cruz, Bruno Figueiredo (coordination); João Carvalho (research, design & development); Samuel Ribeiro (technical support).
SCOPE KERAMOS R&D project, ACLab Research, Master Thesis (MiArq, EAUM).

Hexashade prototype explores the use of hexagonal ceramic blocks for the construction of a vault shading system whose geometry and internal structure are defined according to solar incidence.

Based on hexagonal blocks, the optimisation takes place through the geometric variation of the internal structure of the blocks. The design process is mediated by a computational model, taking into account the sun incidence data, resulting in a system that adapts the internal geometry of each one of the blocks by their relative position in the set, making them more or less permeable depending of the space/time ratio that we want to shade.





FICUS

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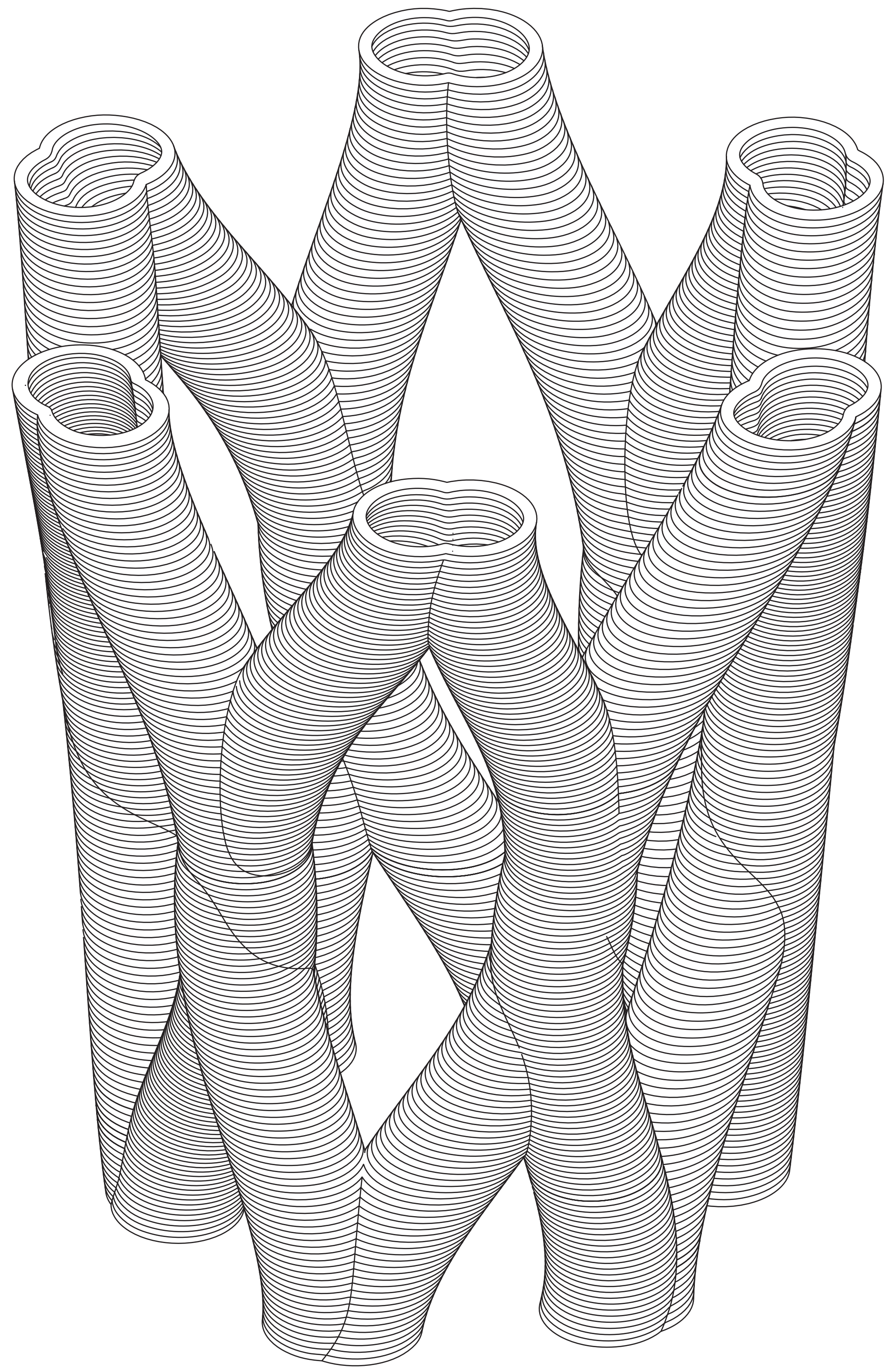
TEAM Paulo J.S. Cruz, Bruno Figueiredo (coordination); João Moreira (research, design & development); Samuel Ribeiro (technical support). **SCOPE** KERAMOS R&D project, ACLab Research, Master Thesis (MiArq, EAUM).

The Ficus project seeks to develop a system of reticulated, customised and optimised structural components, —a column system—based on previously defined premises. Entirely mediated by computational design, the research implements not only structural and optimisation analysis strategies, but also mimetic formal features of nature. This process allowed to define a model that adapts its formal attributes, depending on its assumptions and material constraints, resulting in the generation of a set of solutions that better respond to the proposed design problem.



CLOVER STRUCTURE

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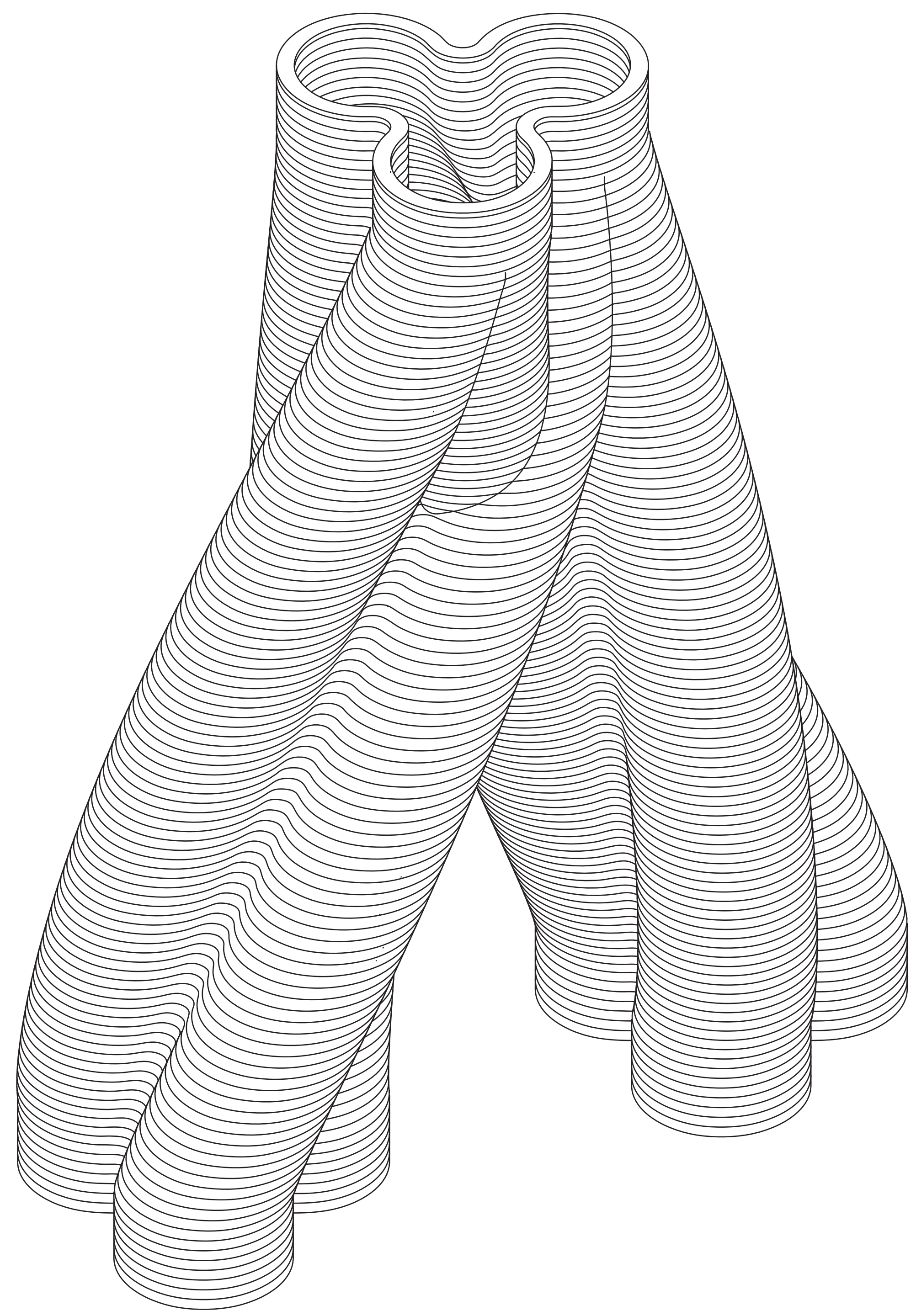
TEAM António Pontes and Paulo J. S. Cruz (coordination); Álvaro Sampaio, Ana Rita Gonçalves, Bruno Figueiredo and João Carvalho (research, design and development).
SCOPE KERAMOS R&D project, Done Lab research, ACLab Research.

The Hybrid Clover Structure is composed of ceramic and polymeric material tubular components, by means of AM. Polymeric part works as the fitting element.

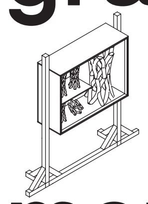
The main goal of this prototype was to study the integration of polymeric materials on ceramic architectural systems as fitting element, considering the behaviour of ceramics.

This polymeric element works as a counterweight to all deformations that occur during the production phases, namely drying and firing, making possible the connection between to pieces that doesn't match perfectly, as well avoiding the contact between two ceramic surfaces that may lead to cracks.



EXHIBITION 26

The exhibition SHARE—“Innovative and multifunctional ceramic products” presented the main outputs of the project KERAMOS—“Additive Manufacturing of Innovative and Multifunctional Ceramic Products for Architectural Systems”, an exploratory project supported by the MIT—Portugal Program.

The exhibition  took place in the first weeks of summer 2019 at the lobby of Building 01 at the Azurém Campus of the University of Minho in Guimarães.
The exhibition expressed the multidisciplinary of the KERAMOS project by presenting a wide range of specimens and prototypes that demonstrate the potential of the architectural application of ceramic components produced by additive manufacturing and boosts the commercial and industrial attractiveness of KERAMOS products.

Photography by
Carlos Lobo


OBJECTIVE 3.
The application of magnetron sputtered coatings with
innovative and multifunctional characteristics that able
to provide mechanical stability and desired functional
proprieties such as antifouling, anti-scratch and
self-cleaning to architectural components.

PRINCIPAL CONTRACTOR & HOST INSTITUTION

Universidade do Minho

PARTICIPATING INSTITUTION

Instituto Design Guimarães

Advanced Ceramics R&D Lab

RESEARCH UNIT

lab2pt

ADDITIONAL RESEARCH UNITS

CF-UM-UP

IPC Institute for Polymers and Composites

SUPPORT

DONE Lab

SMF

FCT Fundação para a Ciência e a Tecnologia

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