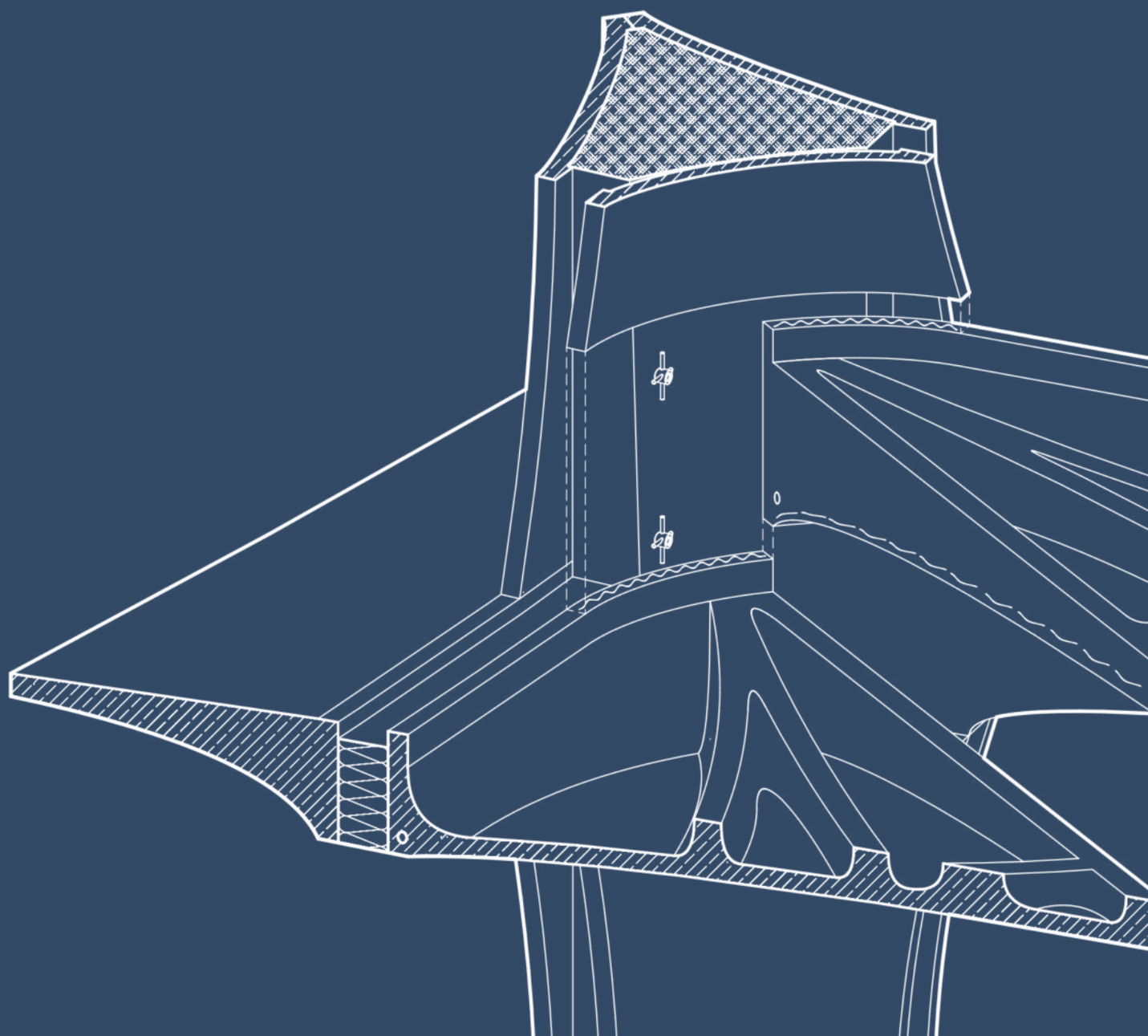
FROM ADDITIVE MANUFACTURING TO ARCHITECTURE



FROM ADDITIVE MANUFACTURING TO ARCHITECTURE

AN EXPLORATIVE DESIGN PROJECT IN COOPERATION OF
TU MÜNCHEN & TU BRAUNSCHWEIG

From Additive Manufacturing to Architecture

An explorative design project in cooperation of
Technische Universität München &
Technische Universität Braunschweig

In association with
Additive Manufacturing in Construction
AMC TRR 277

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BACKGROUND & MOTIVATION

„From Additive Manufacturing to Architecture“ (AMtoARC) is a new cross-location teaching format in the context of the Collaborative Research Center TRR 277 Additive Manufacturing in Construction (AMC). The AMC was established by the Technische Universität Braunschweig (TUBS) and the Technische Universität München (TUM), in 2020, investigating large-scale Additive Manufacturing (AM) as a new key technology for tomorrow‘s construction. The research is based on the hypothesis that AM can combine the advantages of artisanal construction and craft, namely individualized and non-standardized manufacturing, with the advantages of industrial mass production, namely precision and cost-efficiency. With the so-called concept of „mass customization“, new degrees of freedom in design and higher material efficiency in construction can be achieved, mainly because material can be applied only where it is structurally and functionally needed. The AM methods investigated within the AMC are fundamentally material-agnostic, and 3D printing with a wide variety of building materials such as steel, concrete, clay, as well as fibre-reinforced polymers and wood is being explored. What methodically unites this diversity of materials is a focus on material-process interaction; In digital construction, materials and the manufacturing process are no longer understood as separate entities, but are always considered in relation to each other. Moreover, the AMC`s research is essentially interdisciplinary and goes beyond purely technological investigations. Not only material-process interactions are investigated, but also simulation and modelling, structural design, and the integration of AM in the overall construction ecosystem.

Currently, research on fundamental design approaches, such as those using new AM technologies in an architectural context, is not being addressed in the AMC‘s established network, not least because architectural quality is difficult to quantify and difficult to classify in a scientific context due to its ambiguous value. However, with the overarching goal of installing AM as a key technology in the sustainable transformation of the architecture, engineering and construction sector, architects and planners in particular should be involved in both research and implementation to ensure the transfer of research to real-world applications. In addition, the integration and application of novel technologies requires a rethinking of the sequential process of design, engineering, and construction; that is, a novel holistic approach is required that combines expertise from different disciplines in early design phases to be able to make informed design decisions. For these reasons, the AMtoARC format is installed in teaching in the form of an architecture design studio to explore and test this new integrated approach for the first time with both architecture students and AMC researchers. The methodological focus of this studio is on the inversion of the traditional design process: Rather than starting from a material- and building process-agnostic design that is further detailed and engineered, and made “buildable” as the planning progresses, the studio embraces AM processes as one fundamental starting point for the architectural design and thus integrates it into the earliest conceptual stages of the design process. By understanding AM technologies and processes as a main design driver, AMtoARC encouraged architecture students to creatively explore and investigate the possibilities of AM for a future digital building culture that is highly sustainable, productive and resource efficient.

The format was carried out across universities for the first time in the 2022 summer semester as a collaboration between Prof. Dr. Kathrin Dörfler (Professorship of Digital Fabrication) and Prof. Florian Nagler (Chair of Design and Construction) from TUM, as well as Prof. Helga Blocksdorf (Chair of Construction), Prof. Dr. Norman Hack (Professorship of Digital Construction) and Prof. Dr. Harald Kloft (Institute of Structural Design) from TUBS. The students developed designs for an inner-city residential building, focusing on the development of an intelligent construction configuration and a resilient apartment typology. The challenge for the students was to develop designs that harmonize the architectural program including the factors of flexibility, spatial openness, and climatic quality, while respecting and incorporating the requirements and constraints of the selected AM technology in terms of durability, material justice, resource efficiency and an intelligent fabrication workflow.

On the basis of the design studio in the 2022 summer semester, a specialization and in-depth investigation was offered in the subsequent 2022/23 winter semester, in which the designs were further developed and detailed within smaller and dedicated interdisciplinary teams for the production of so-called Collaborative Demonstrators at 1:1 architectural scale, in particular for the AMC’s evaluation for the 2nd funding period. For this purpose, the previously developed design ideas were optimized and adapted to their feasibility by architecture students in cooperation with the scientific researchers of the AMC with regard to the selected AM processes. The resulting demonstrators were then produced in cooperation with the scientific researchers of the AMC in both the laboratories of TUM and TUBS, and selectively with associated industrial partners.

The „From Additive Manufacturing to Architecture“ Studio will be repeated regularly in the 2nd funding period of the AMC, with the aim of this pilot format to jointly research an architectural language for the building technologies of tomorrow in interdisciplinary team settings ranging from architecture, materials science, mechanical engineering and building informatics.

Kathrin Dörfler & Norman Hack
04/2023


DEMAG

TEACHING CONCEPT & DESIGN TASK

This project entails students investigating the prospects and opportunities of AM technologies in the field of architecture and design. Subjects such as materiality, structure, thermal features or building comfort are explored using an experimental case study approach for the design for a mixed-use building on the Ägidienmarkt in Braunschweig, Germany, employing various new AM methods which are being developed at both TUM and TUBS. Challenges with respect to sustainability are addressed, considering multiple aspects in the fabrication process for building construction that balance durability, material appropriateness, and resource efficiency with flexible, spacious playability, and translating into design concepts.
In joint kick-off sessions at TUBS and TUM, academic researchers from the AMC introduce the students to the process technologies that are being developed in the A-projects. As part of two presentation days scheduled throughout the semester, they serve as a body of scientific experts evaluating the targeted feasibility of the students' design proposals within their technologies. Small-scale experimental studies during the design phase allow to investigate formal design options, structural efficiency, as well as functionality of the building‘s materials. During the AMC Summerschool in July 2022, students eventually present their final research projects to the entire AMC Board, which evaluates the projects regarding their elaboration into real-scale demonstrators.

Focusing on multidisciplinary collaboration, the project aims to facilitate the following teaching and learning aspects for students and academic researchers:
· Reflection toward one's own disciplines, awareness for typical thinking in one‘s own discipline, and identification of the demand for one‘s own expertise and capabilities for other disciplines
· Work in heterogeneous teams, to encourage an appreciation for other skills and perspectives
· Proactive and self-directed learning, e.g. practicing to deal with ambiguous topics and to explore the relationship of technical developments with ethical and societal topics.
· Project-based and experimental learning: Developing competences in solving questions by applying theoretical knowledge in an experimental approach.

Site - The Ägidienmarkt is one of the medieval marketplaces in Braunschweig‘s city center. It has been the social and economic center of the Altewiek in the Middle Ages, nowadays it is situated in between the Magniviertel and the Aegidienviertel separated by the city ring road. The Ägidienmarket has been named after the Aegidienkirche and the associated Aegidienkloster with the pottery market as its most important area. Today the Ägidienmarkt is experienced as a abondoned space within a heterogeneous, but historically grown inner city structure. The expansion of the road infrastructure after the World War II has resulted in the construction of the so called City Ring, which nowadays transects the historical market square, leaving relicts of the city‘s former sub-center. By establishing a new buliding structure addressing the urgent need of residential space, the underappreciated site has the potential of being reactivated and reinterpreted as part of the city‘s structure.

Program - The spatial program contains a market hall for the ground floor representing a reminiscence to the original purpose of the site.
The program organization on site requires the preservation of at least one of the existing trees and its integration during the design process. The upper floors are intended to provide space for residential typologies and community areas. The residential concepts can range from multigernerational living to shared appartements typologies and micro-apartments. The design development has to be in continuous dialogue with the AM method and its current capabilities following the idea of explorative design: To understand and to integrate the fundamental technical principles of AM processes and to investigate sustainable architectural approaches for future long-term use.

Conceptual Purpose - The project „From Additive Manufacturing to Architecture“ addresses two main topics. Firstly: an architectural and structural design using AM methods and therby: new perspectives for the execution of massive building structures. Secondly: Typologies of mixed-use and residential uses capable to change over the next decades and to interact with the building structure.

„Are you are seeking flexibility?
Keep on building your walls of stone.“
Luigi Snozzi, Parole Nr. 12

Luigi Snozzi is arguing flexibility with a solid, inflexible material. The intention is to emphasize on robust, yet smart grids and structures to host a variety of functions throughout their lifecycle. The goal of sustainablity results from a wide range of factors which also this design project addresses, focusing on long lasting structures, efficently manufactured with AM technologies.

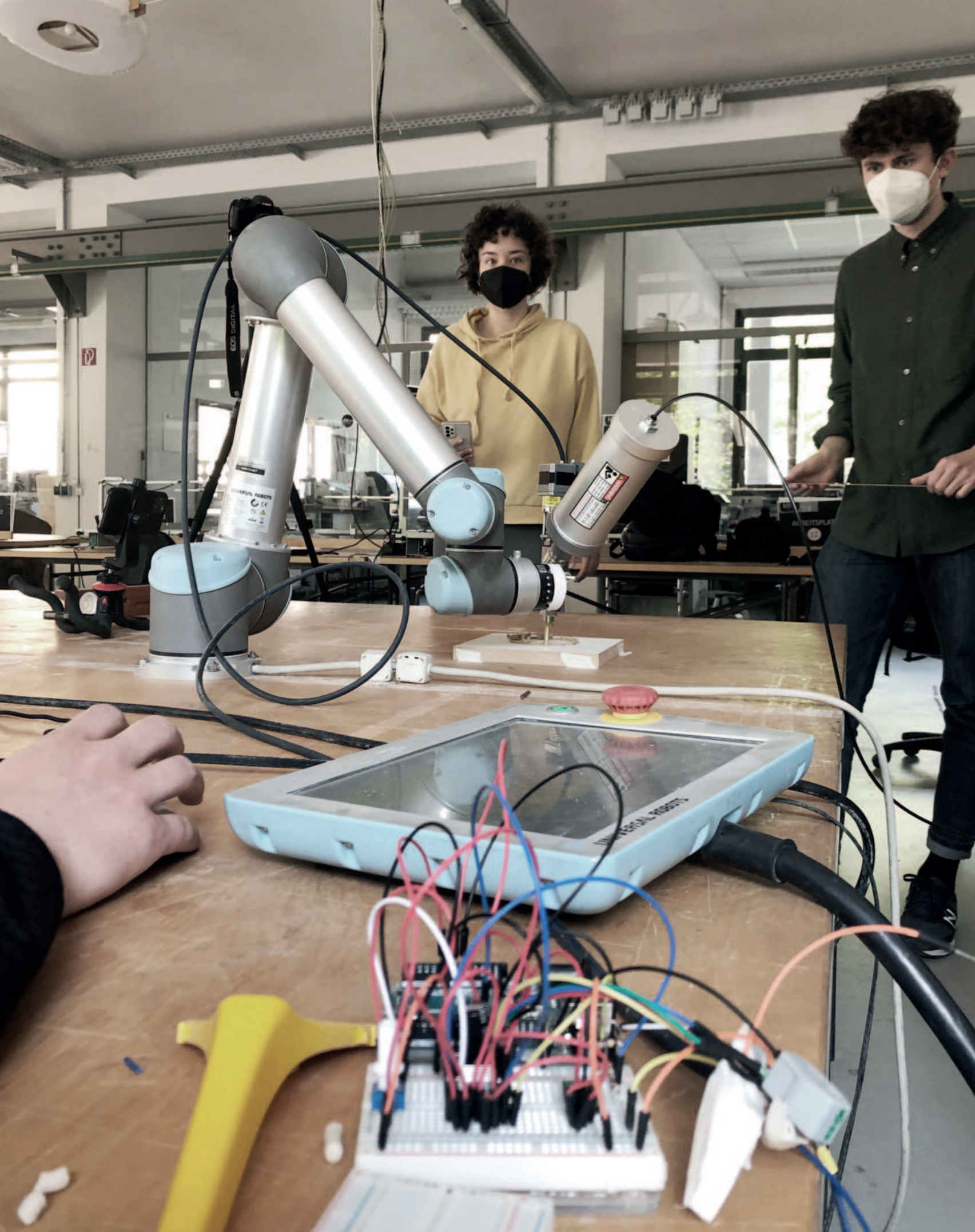
Julia Fleckenstein, Anne Niemann,
Philipp Rennen & Moritz Scheible

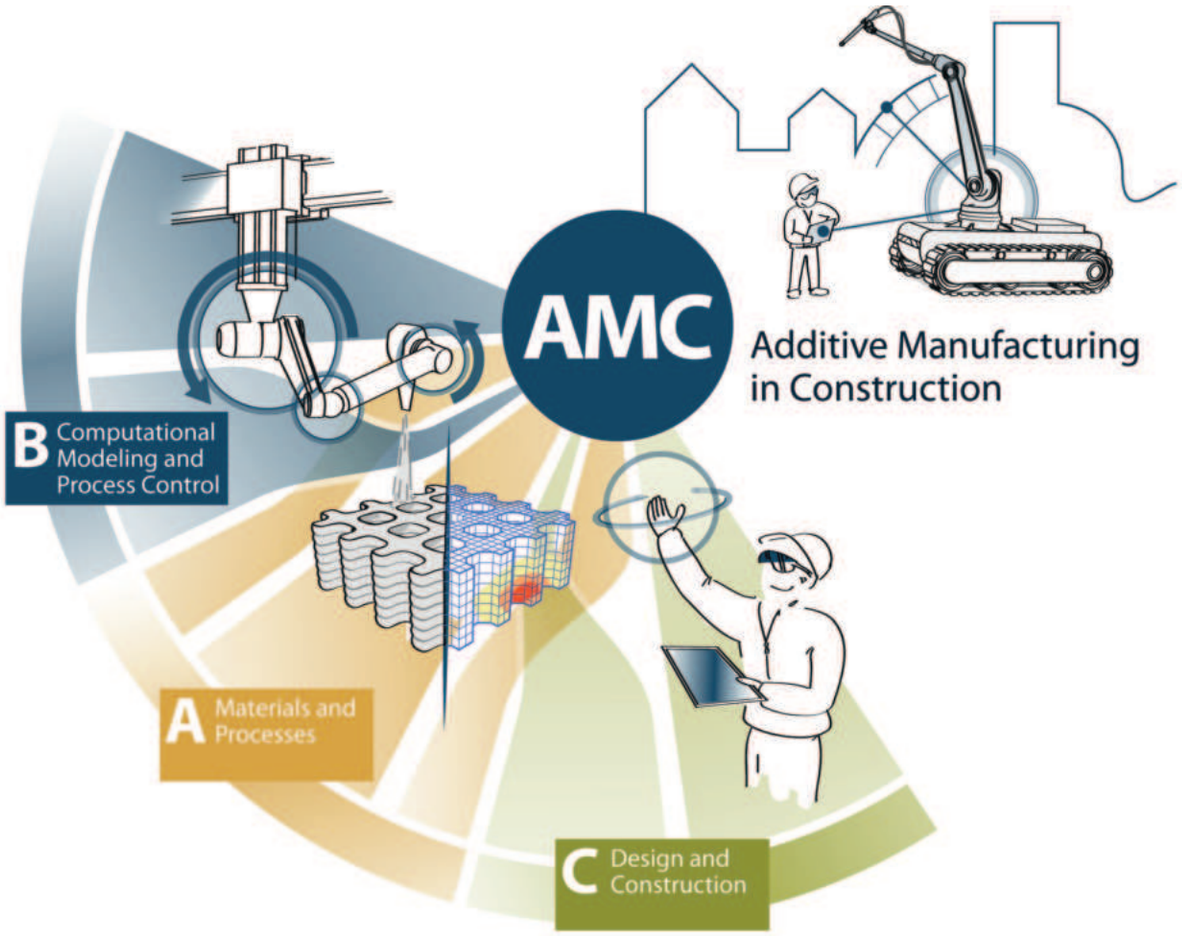
Figure 1 / Left side / Project excursion at Digital Building Fabrication Laboratory (DBFL) / ITE / TU Braunschweig

Figure 1 / Top / Black plan of Braunschweig city center /
Project site marked as red triangel
Figure 2 / Right side / Image of the project site at Ägidien-
markt in Braunschweig / view from eastern boardwalk

Figure 1 / Top / Diagram of the holistic design approach
Figure 2 / Right side / Site plan of Ägidienmarkt, Braunschweig / Project site is located in the center of the plan

Figure 1 / Top Left side / Project excursion at Ägidienmarkt Braunschweig
Figure 2 / Top Right side / Presentation of A03 „Near Nozzle Mixing“ at TU München AMC Lab
Figure 3 / Right side / „Hackathon“ introduction exercise at TU Braunschweig model workshop


UNIVERSAL ROBOTS
UNIVERSAL ROBOTS


AMC
Additive Manufacturing in Construction
B Computational Modeling and Process Control
A Materials and Processes
C Design and Construction

ADDITIVE MANUFACTURING IN CONSTRUCTION AMC TRR 277

The Challenge of Large Scale - The SFB/Transregio TRR 277 aims to examine Additive Manufacturing (AM) as a novel digital manufacturing technology for the construction industry in an interdisciplinary, cross-location research project. In Additive Manufacturing, the production of building components is achieved solely by a digitally controlled layer-by-layer material application, without mould making or forming processes. This approach represents a paradigm shift to the manual construction processes, which are characterised by traditional, predominantly craft-based techniques. As a result, productivity in the construction industry has stagnated for decades. In addition, these manual techniques foster a rather simple component design and thus inefficient use of materials. Against the background of the enormous demand for resources in the construction industry, this methods of constructing contributes significantly to global CO2 emissions.

The objective of the proposed TRR 277 is to explore the fundamentals for implementing Additive Manufacturing in Construction (AMC). Automated additive material application enables the construction of buildings with a high degree of design freedom and a resource-efficient use of materials. In order to fully exploit this potential, structural design, material behaviour and manufacturing processes must be fundamentally rethought and, above all, must interact. While additive manufacturing technology is already being used for serial production in other industries, there are still fundamental challenges to be solved when transferring it to the construction industry: First, the transfer of AM technologies to the large scale of construction; second, the necessary material and process diversity, which is determined by the complex functional requirements of a building; and third, the required high degree of individualization and flexibility in construction. These challenges give rise to complex research questions on materials, process engineering, control, modelling, design and construction, which are investigated by interdisciplinary teams of scientists from the fields of civil and mechanical engineering.

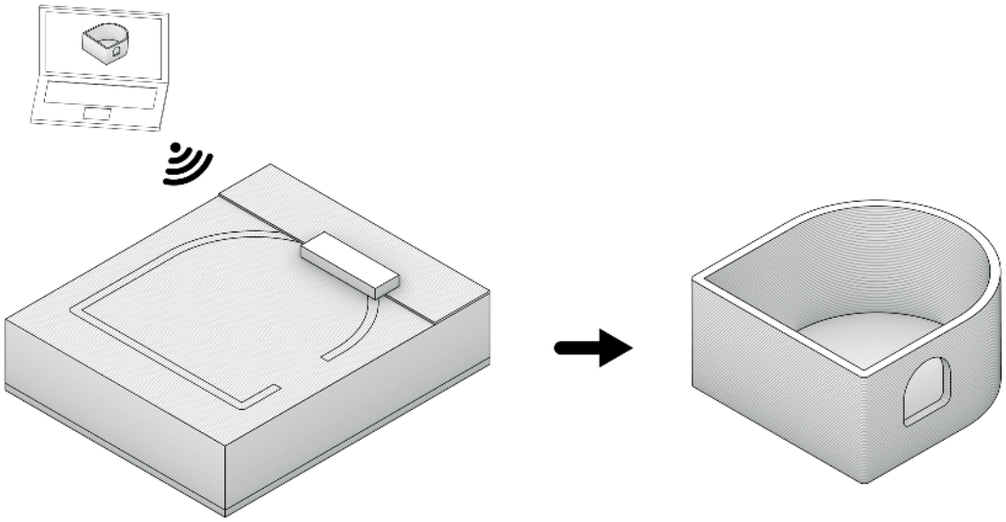
The work programme of TRR 277 is guided by two fundamentally new research approaches:
1. Combinations of materials and processes. As a central topic of the research program, material and process coordination are considered as inseparable units in additive manufacturing. In project area A, innovative material and process combinations for Additive Manufacturing will be researched and brought to a new logic of form. All A-projects follow a novel integrative approach, investigating structural design, material behaviour and manufacturing processes as inseparable components within an interdisciplinary framework. For this it is essential to open up the material- and process combinations from the outset and not to restrict them to individual materials and/or processes. The project area B aims to ensure robustness and full automation of additive manufacturing processes by providing feedback and numerical simulation capabilities to the A projects.
2.The seamless digitalisation in the building industry. End-to-end digitization is of crucial importance for the successful introduction of additive manufacturing in the construction industry. Focus Area C “Design and Construction” is therefore researching the digital interfaces to the upstream planning processes as well as the downstream processes of construction from the very beginning. The interaction between digital models and physical objects forms the methodological link of TRR 277 and is the basis for the networking between project areas A, B and C. The networking across the project areas is realized by the continuous production of large scale demonstrators and their digital twins.

The TU Braunschweig and the TU München share many years of experience in interdisciplinary and cross-location research on additive manufacturing in the construction industry. The excellent research infrastructure available at both universities and the complementary expertise form the basis for the research program and promote the strategic development of both universities. TRR 277 promises a high degree of national and international visibility and, together with other national research initiatives, aims to make an important contribution to the digitalization of the construction industry.

https://amc-trr277.de/trr-277-mission/about-amc/

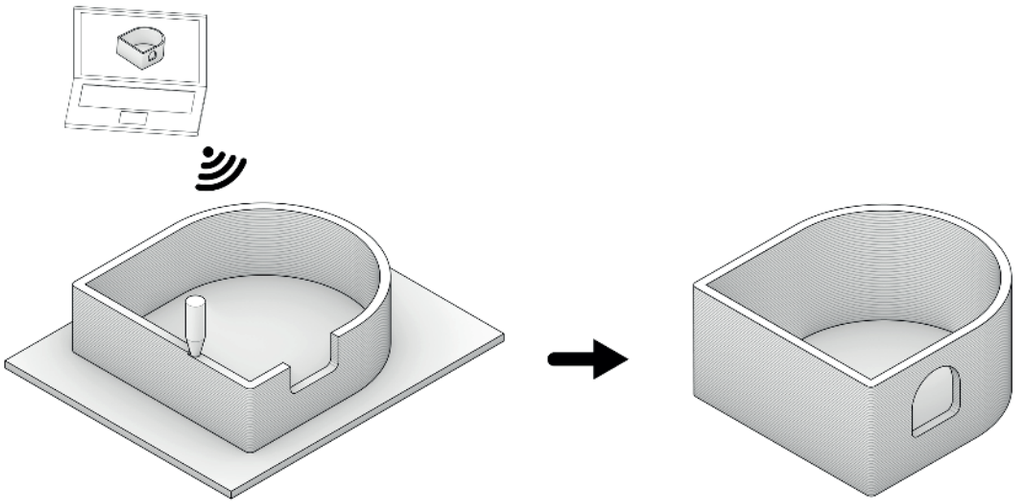
Figure 1 / Left side / Process scheme of AMC TRR 277
research topics and application scenarios

PARTICLE-BED 3D PRINTING



	Activation	Intrusion	Fusion
Concrete	A01	A02	
Timber		A08	
Steel			A06

DEPOSITION 3D PRINTING



	Extrusion	Shotcrete	Reinforcement	Fusion
Concrete	A03	A04		
Fibre			A05	
Steel				A07

Figure 1 / Top / Particle Bed 3D Printing Techniques / Associated A-projects of the AMC TRR 277
Figure 2 / Bottom /Deposition 3D Printing Techniques / Associated A-projects of the AMC TRR 277

ADDITIVE MANUFACTURING PRINTING TECHNOLOGIES

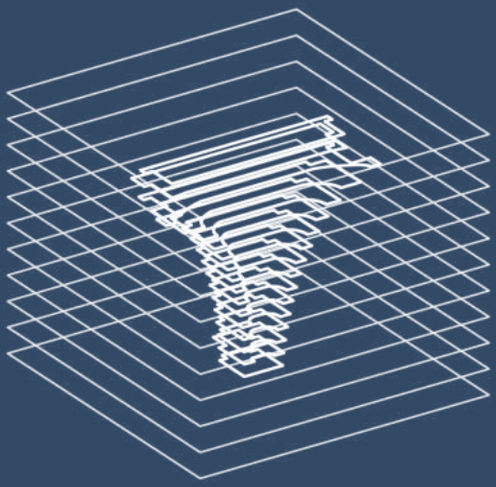
The students utilized processes of two primary 3D printing categories, namely Particle-Bed 3D Printing (PB3DP) and Deposition 3D Printing (D3DP), as the basis for their architectural concepts. These processes served as design drivers for their projects. During the excursions to TU München and TU Braunschweig, the AMC researchers provided an in-depth overview of the capabilities of each of their method, its specifications, and the current state of research in insider talks, ultimately enabling the students to gain a deeper understanding of the underlying principles, constraints, and potentials of AMC.

Particle-Bed 3D Printing (PB3DP) is an AM method, where dry particles are deposited in thin layers within a print bed and selectively bonded with a liquid. After the printing process, the non-bonded particles are removed from the print bed, the so-called de-powdering process. The printing resolution varies according to the material being applied, mainly defined by the particle size. As such, the resolution can be in the range of mm-precision. Regarding its integration with construction, the process is highly suitable for prefabrication purposes, owing to the necessity of print beds. The process enables the creation of a wide range of intricate free-form geometries with extremely high precision, with a crucial constraint being that particles are enclosed within closed-cell geometries.
Digitally generated building models serve as input geometry for the printing process, enabling the AM of highly differentiated building elements. With the use of computational structural and functional optimization, material can be placed only where it is structurally and functionally necessary, without the need for scaffolding and formwork.
However, this process also comprises challenges such as the development of specialized materials with the necessary strength and durability or the capacities of large-scale printers to manufacture building elements at a reasonable speed and cost. Both depending on the printer size and its building space and also in regards of subsequent transportation, the architectural designs require partitioning and segmentation.
Based on the AMC A-projects, the students conducted research primarily on three distinct processes and materials utilized in PB3DP. These processes include the activation of concrete using water intrusion (A01), or a liquid binder like cement intruded into dry aggregate (A02), as well as the selective binding of wood chips using adhesives (A08). Additionally, the use of the A06 project focused on powder bed fusion of metals, was explored for large-scale building applications.

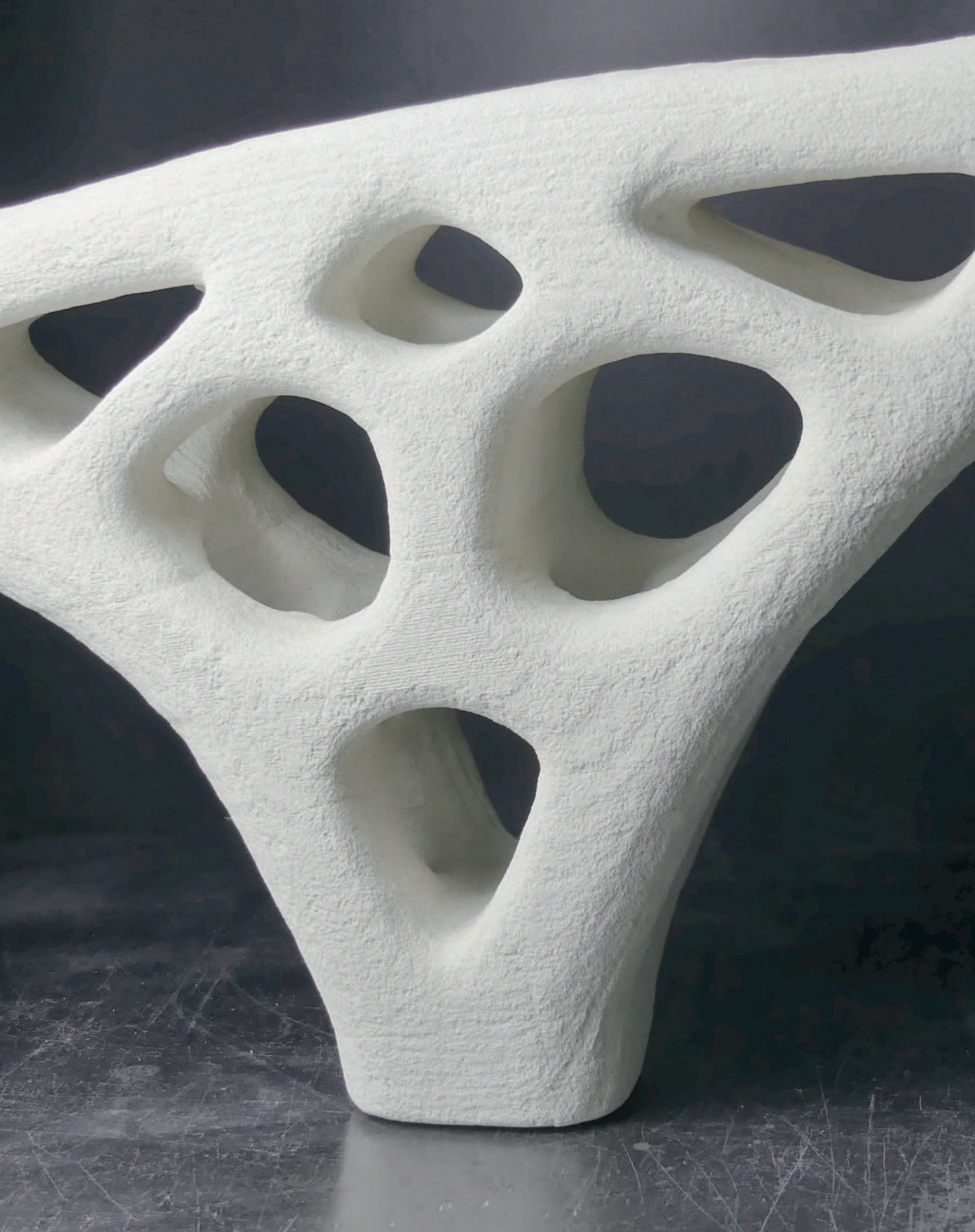
Deposition 3D Printing (D3DP) is an AM method, where material is directly deposited in layers. D3DP of concrete is often used for in-situ building construction, using large-scale printer setups and specific concrete mixtures to build structures layer by layer. The material mixture being extruded through a nozzle can contain reinforcing fibers or other additives to improve the strength and durability. The process comprises three main manufacturing phases, (1) conveying the material to the nozzle, (2) depositing a strand through a printing nozzle, and (3), layering material without further formwork or supporting structures.
This allows for the fabrication of objects both for new and within existing contexts, depending on the printing system used, which can be both stationary or mobile. Like PB3DP, digital models serve as input data for the printing process. Since the material is applied in layers in free space, the layering process is constrained by attributes such as overhangs. In comparison with PB3DP, the resolution is typically lower, however, it allows for the creation of closed-cell geometries encapsulating air spaces.

Based on the AMC A-projects, the students explored the materials concrete, fiber, and steel, whereby concrete is either extruded using a near nozzle mixing system (A03) to meet the demands of processability and pumpability during the printing process; and deposited using the Shotcrete 3D printing (A04) process, adopting fundamental principles of the traditional sprayed concrete process. Project A05 develops strategies to integrate textile reinforcement in the deposition process to surpass the limited tensile strength of unreinforced components. In the direct energy deposition process (A07), metal material is melted directly onto surfaces, fusing materials together.

Julia Fleckenstein, Kathrin Dörfler
Teaching Team from AMtoARC



DESIGN PROJECTS ON PARTICLE-BED 3D PRINTING



PARTICLE-BED 3D PRINTING BY SELECTIVE CEMENT ACTIVATION

MATERIALS AND PROCESSES

Particle-Bed 3D Printing by Selective Cement Activation (SCA) – Particle Surface Functionalisation, Particle-Bed Compaction and Reinforcement Implementation. This project focusses on high-resolution particle-bed 3D printing of reinforced cementitious composites as a novel technology in the construction industry. To pioneer the understanding of governing mechanisms affecting the material-process interaction, basic interdisciplinary research addressing particle surface functionalisation, tailoring of particle size distribution, particle-bed compaction, liquid intrusion, interparticle and interlayer bonding, active structural build-up control of the matrix, high precision geometries as well as reinforcement integration will be conducted.

RESEARCH TEAM

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Contributors
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Dr.-Ing. Inka Mai
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ASSOCIATED DESIGN PROJECTS

Breuer X AM
Mia Düpree & Mareen Fechner
Technische Universität München

AMC TRR 277 PROJECT

A01

BREUER X AM

MIA DÜPREE &
MAREEN FECHNER
TU MÜNCHEN

This project investigates experimentally differentiated monomaterial prefabricated building elements that employ computational design methods together with climateinformed design principles using SCA as AM technology. Marcel Breuer‘s IBM Research Center in LaGaude, France serves with its monomaterial building elements and its integration of load-bearing functions and sun protection as design inspiration. Consequently, a mixed-use building with circumferentially arrayed, tailored, self-shading building elements has been proposed to explore the design scope that Breuer was excluded by the limitations of the fabrication methods of his time, to transform it within the customizable fabrication capabilities available today.

A01
This project was selected to be further investigated for the A01 demonstrator due to its potential to showcase the AM of bespoke, functionally graded building elements tailored to site-specific features.

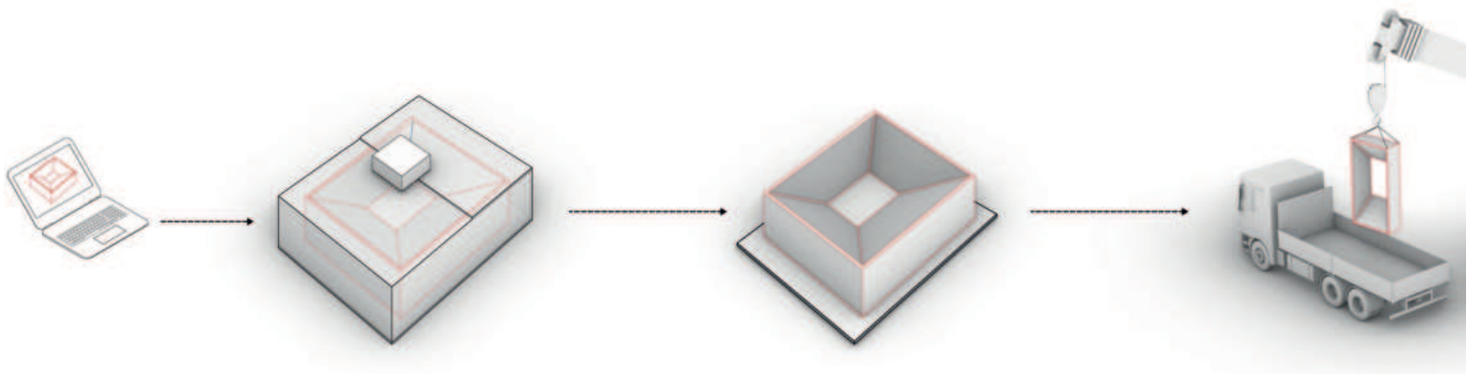


Figure 1 / Left side / Exterior perspective Ägidienmarkt
Figure 2 / Bottom / Fabrication and assembly preparation of 3D printed facade structure elements

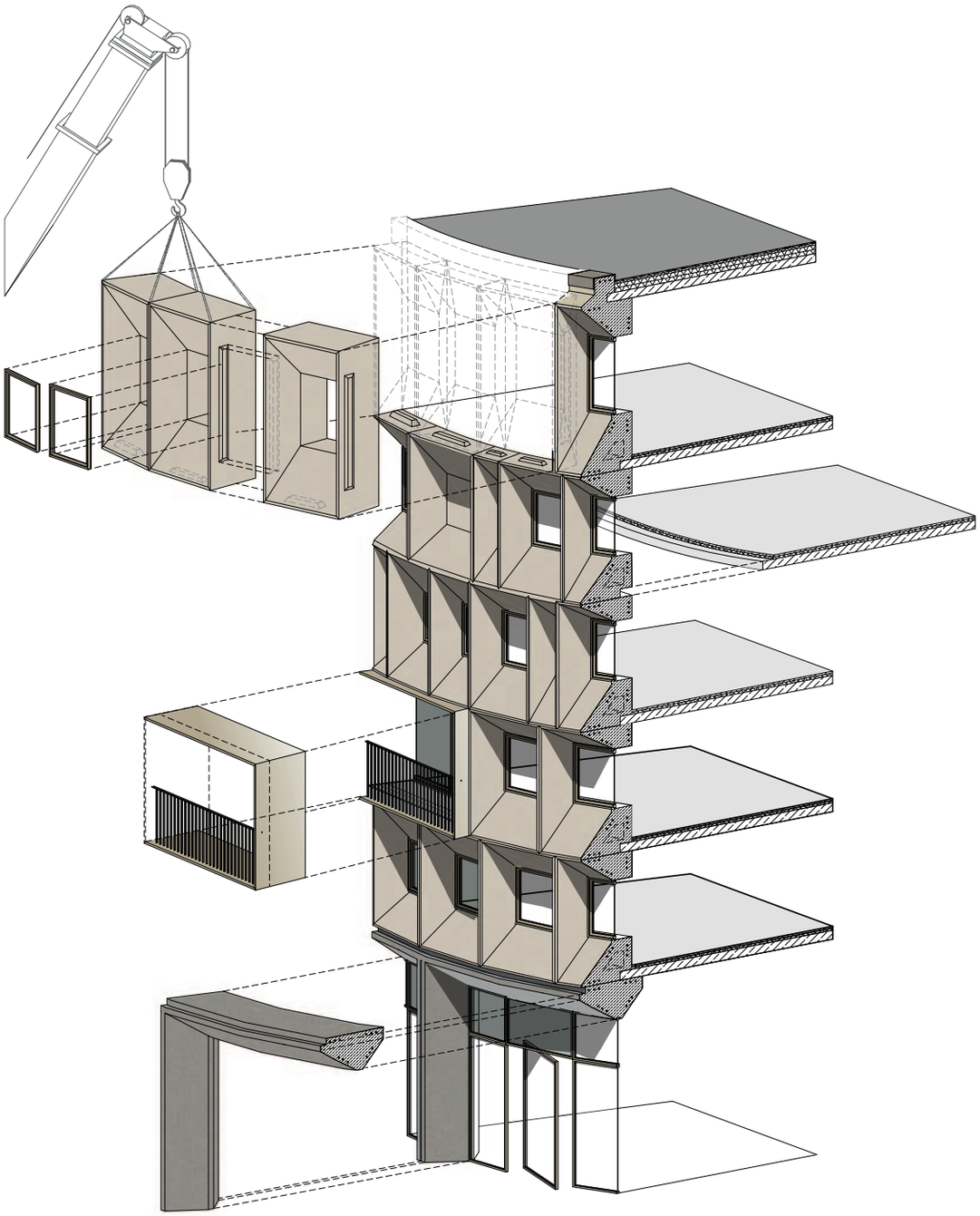


Figure 1 / Left side / Isometric view of facade section proposing the assembly on site
Figure 2 / Right side / Clay model of a composition of building elements

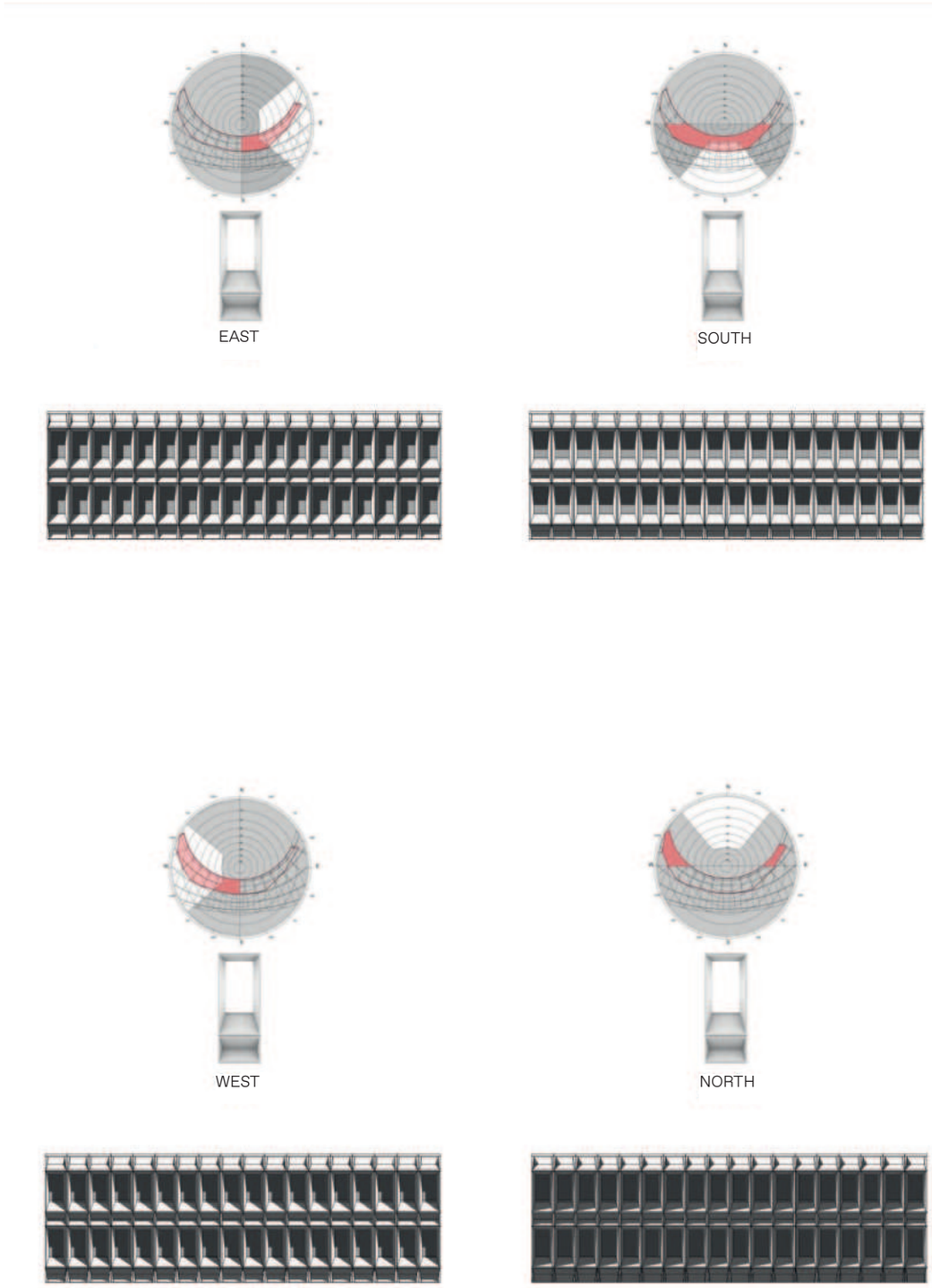


Figure 1 / Original facade of the IBM Research Center in La Gaude, France designed by Marce Breuer with solar control shading mask (Bertagna, Piccioni and D'Acunto, 2023)

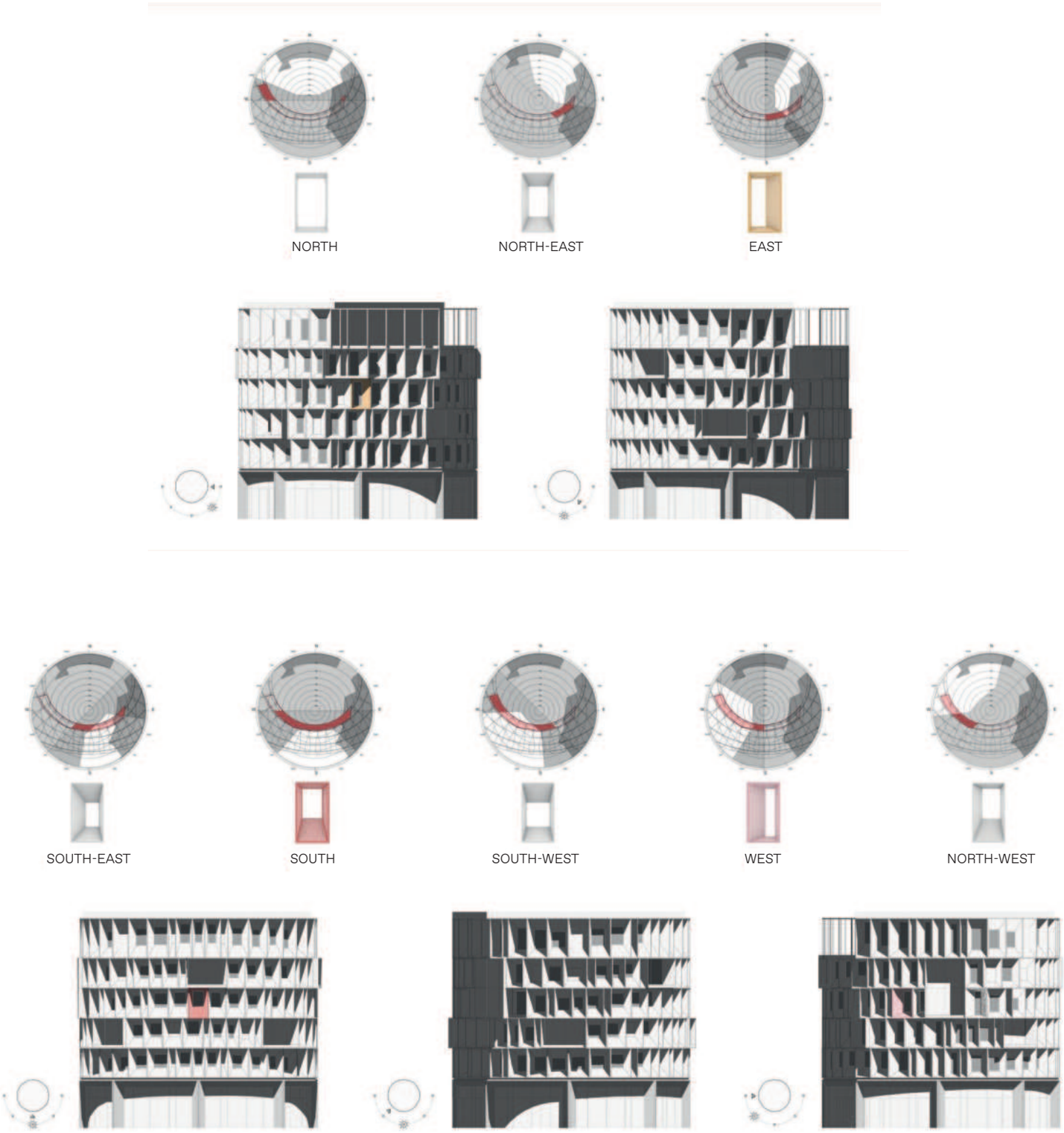


Figure 2 / Adapted facade due to the solar control for all eight directions

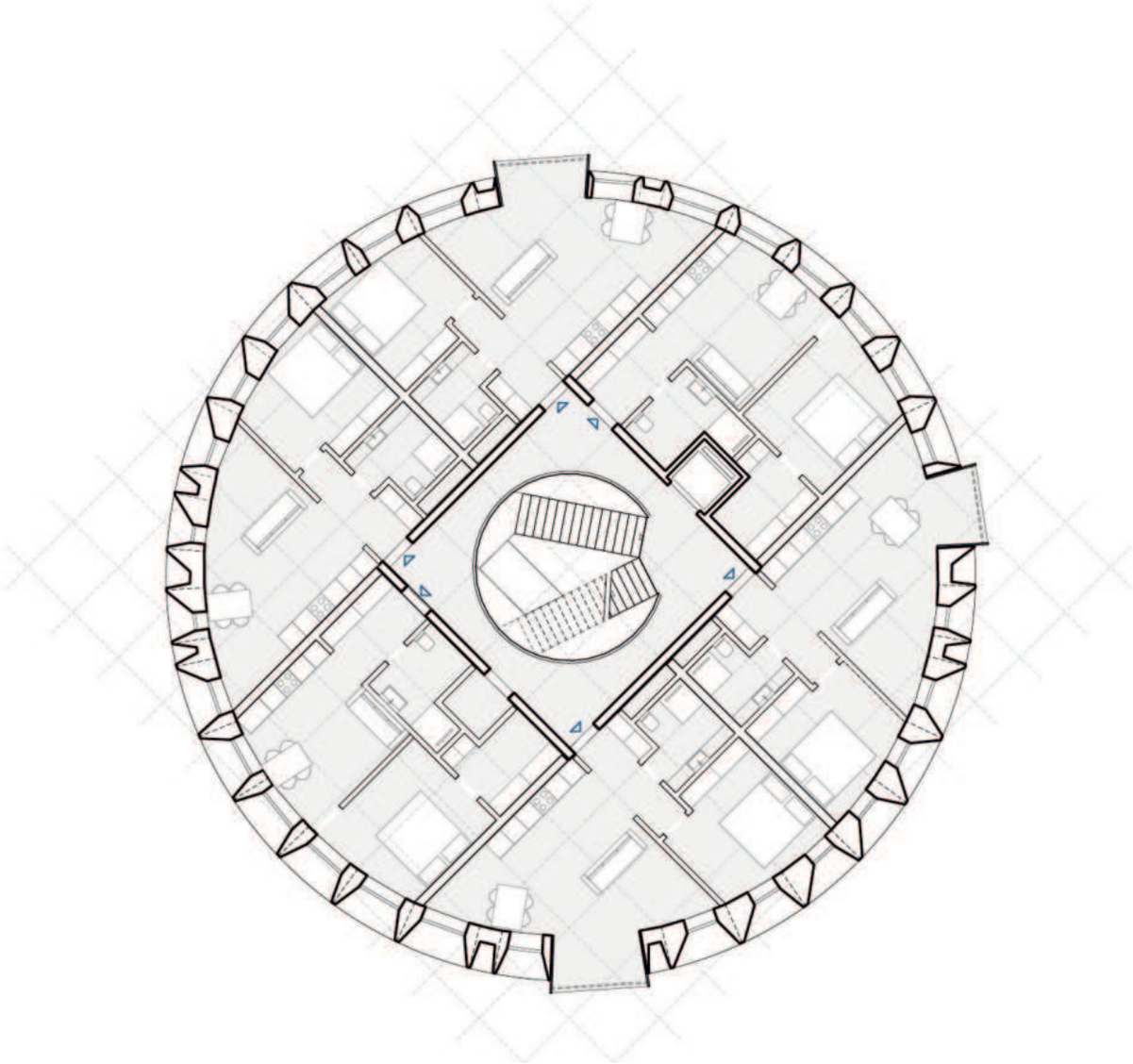
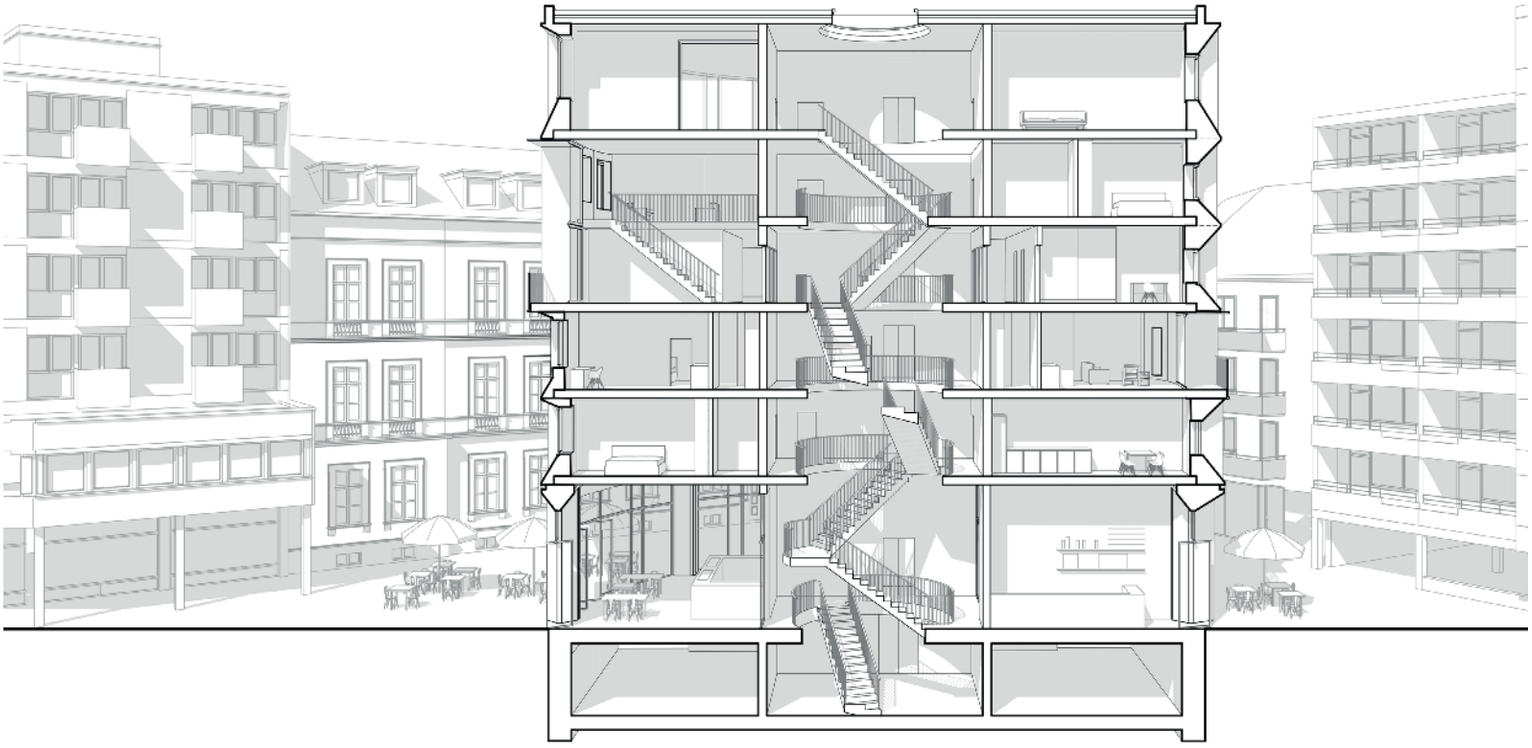
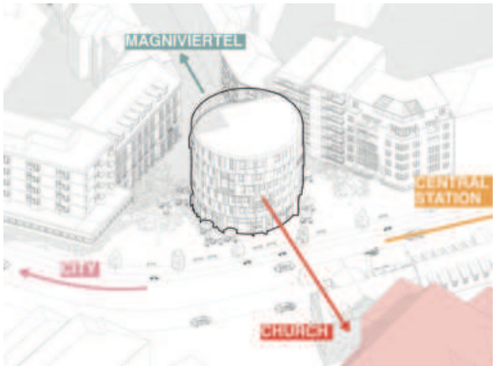
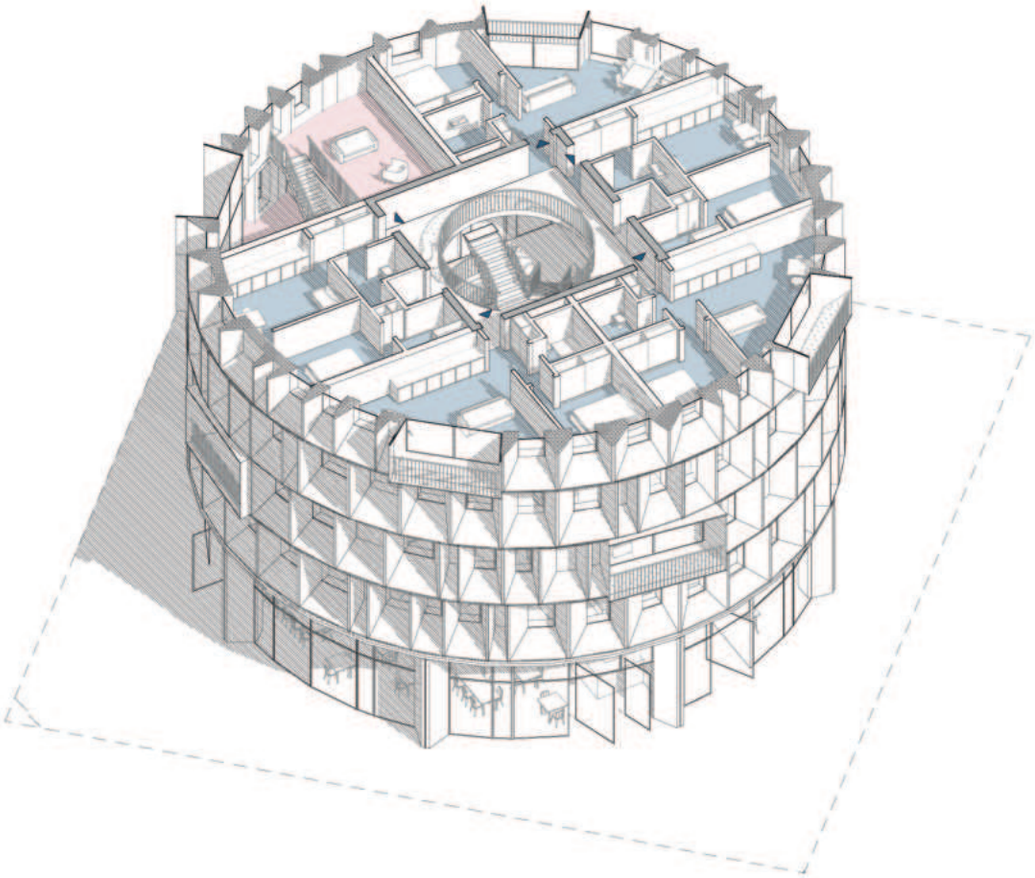


Figure 1 / Left side / Standard floor plan
Figure 2 / Top right side / Axonometrical section
Figure 3 / Bottom right side / Urban context




MAGNIVIERTEL
CENTRAL STATION
CITY
CHURCH



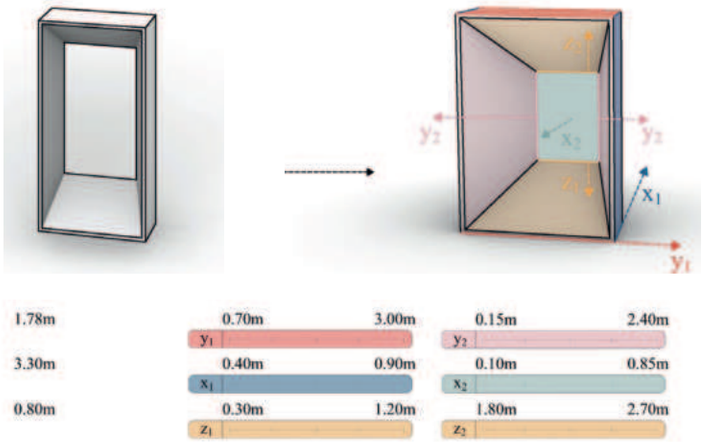


Figure 1 / Top / Isometric view and horizontal section of facade configutation and standard floor plan
Figure 2 / Bottom / I Transformation parameters of Breuer's building elements into site-specific self-shading building elements
Figure 3 / Right side / Facade elevation in detail

PARTICLE-BED 3D PRINTING BY SELECTIVE CEMENT PASTE INTRUSION

MATERIALS AND PROCESSES

Particle-Bed 3D Printing by Selective Cement Paste Intrusion (SPI) – Particle Surface Functionalisation, Particle Synthesis and Integration of WAAM Reinforcement. Selective paste intrusion (SPI) is a particle-bed-based additive manufacturing technology in which aggregates are spread in thin layers and bonded by cement paste. To qualify SPI for structural concrete elements, the inclusion of reinforcement is mandatory. The innovation introduced here is that reinforcement will be implemented simultaneously in the SPI process using Wire and Arc Additive Manufacturing (WAAM). Different active and passive cooling strategies, e.g. particle surface functionalization and the synthesis of new particles, will be developed to deal with the high temperatures during WAAM.

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Stone-Timber
David Meister & Fabian Schnieder
Technische Universität München

AMC TRR 277 PROJECT

A02

PLAYING WITH BLOCKS

AMBER ALVAREZ &
ELKE MEIERSONNE
TU MÜNCHEN

„Playing with blocks“ explores traditional compression-dominant design principles for interlocking, large-scale, custom building components. Within the scope of the SPI method as AM technology, this project proposes prefabricated monomaterial design assemblies that meet both structural and thermal requirements at feasible wall thicknesses. Using lightweight aggregates with the potential of low thermal conductivity for the particle-bed 3D printing allows unbounded material to serve as insulation material. Enclosed cavities within the component and its structural behavior are therefore capable of fulfilling both, thermal and structural requirements. Assembled on site post-tensioning cables tie the building assembly to the floor slabs.

A02
This project is dedicated to be further developed as A02 demonstrator due to its capability to provide bespoke strategies of monomaterial interlocking and compression dominant building elements.

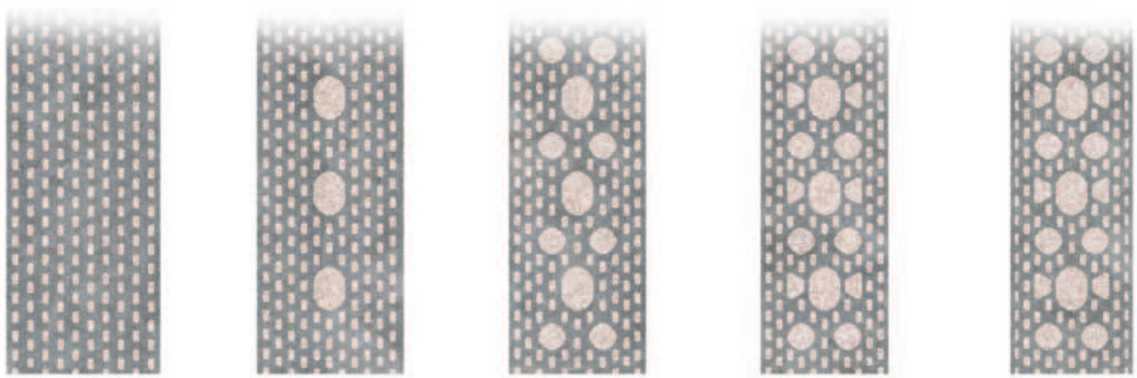
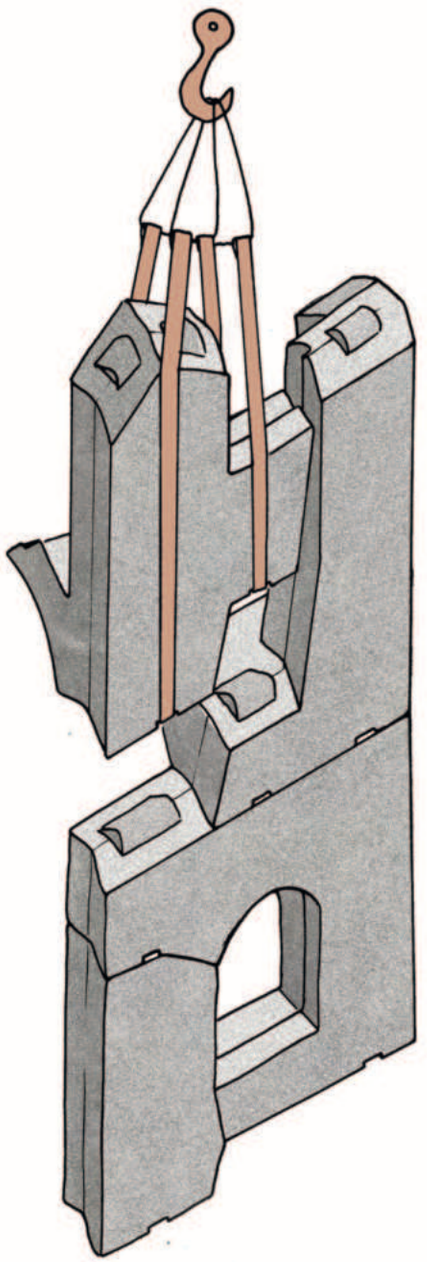


Figure 1 / Left side / Close-up drawing of the building facade vizualizing the concept of interlocking building elements
Figure 2 / Rigt side / Variations of wall constructions displaying different grades of density and insulation



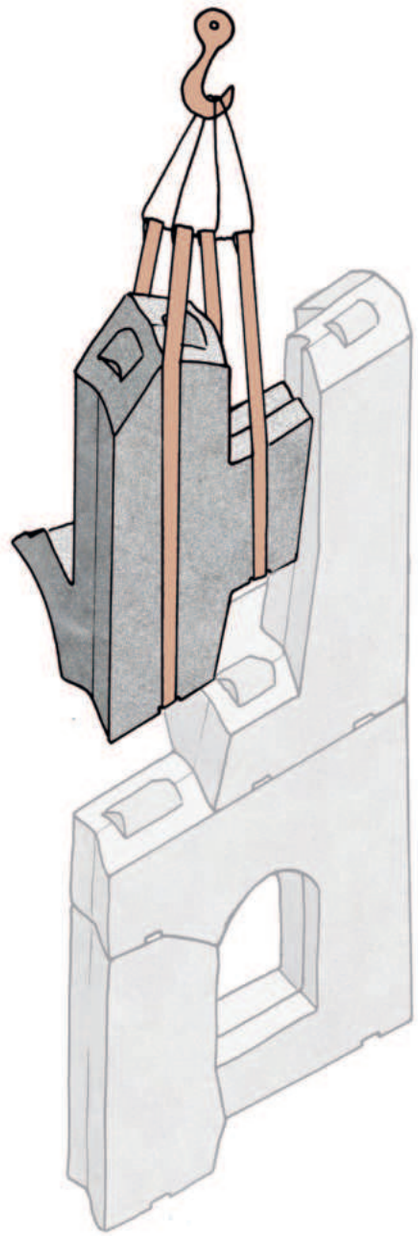


Figure 1 / Left side / Isometric view proposing the assembly the transportation and assembly on site
Figure 2 / Right side / Building section of the market space introducing the internal thermal structure of the elements

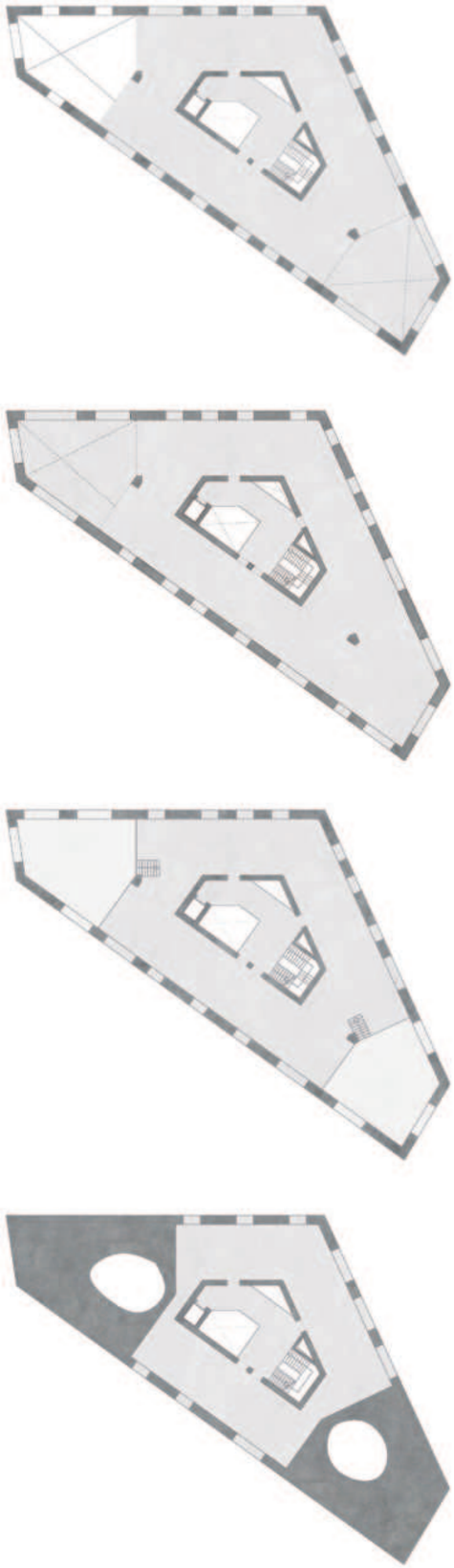
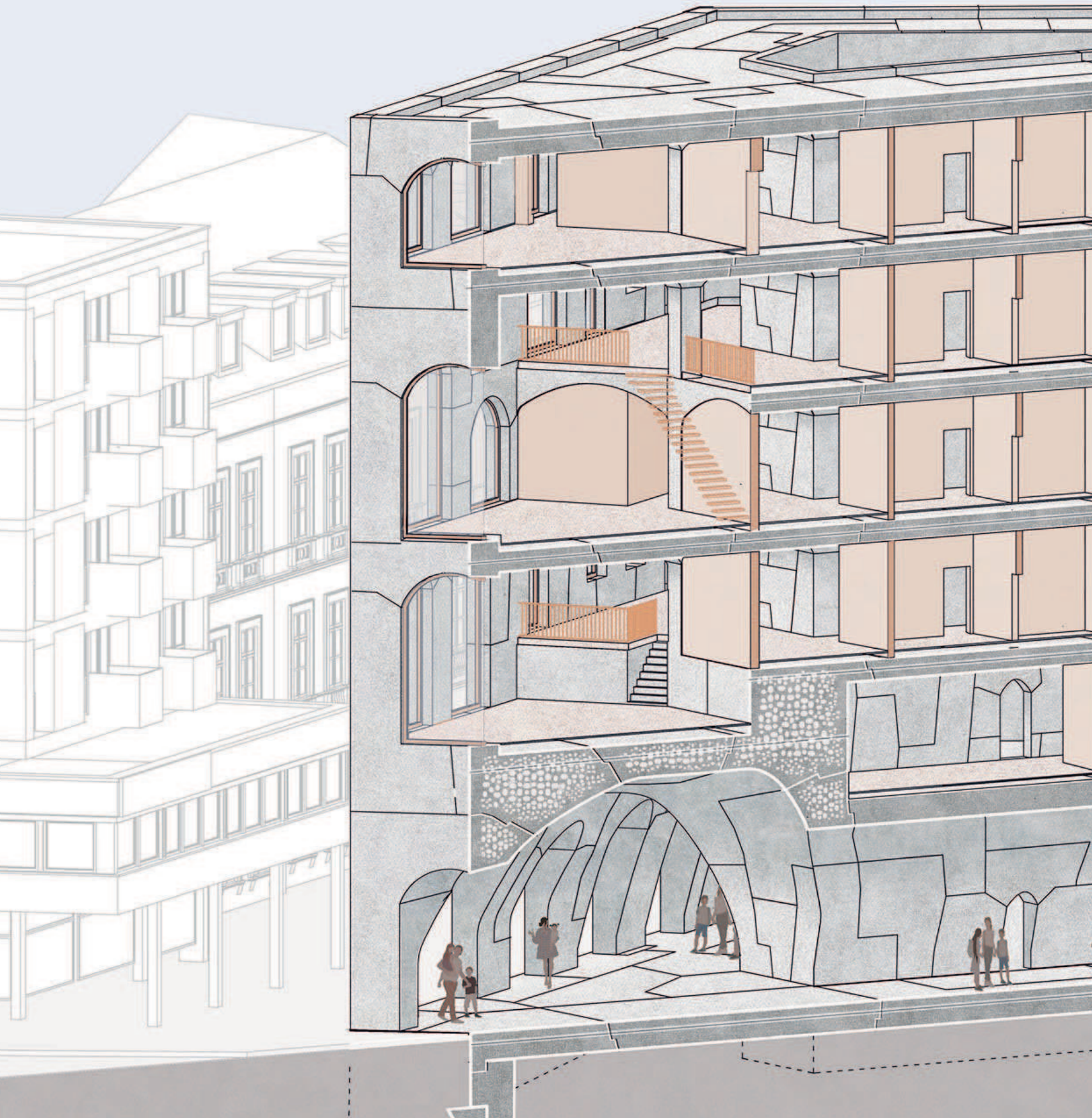
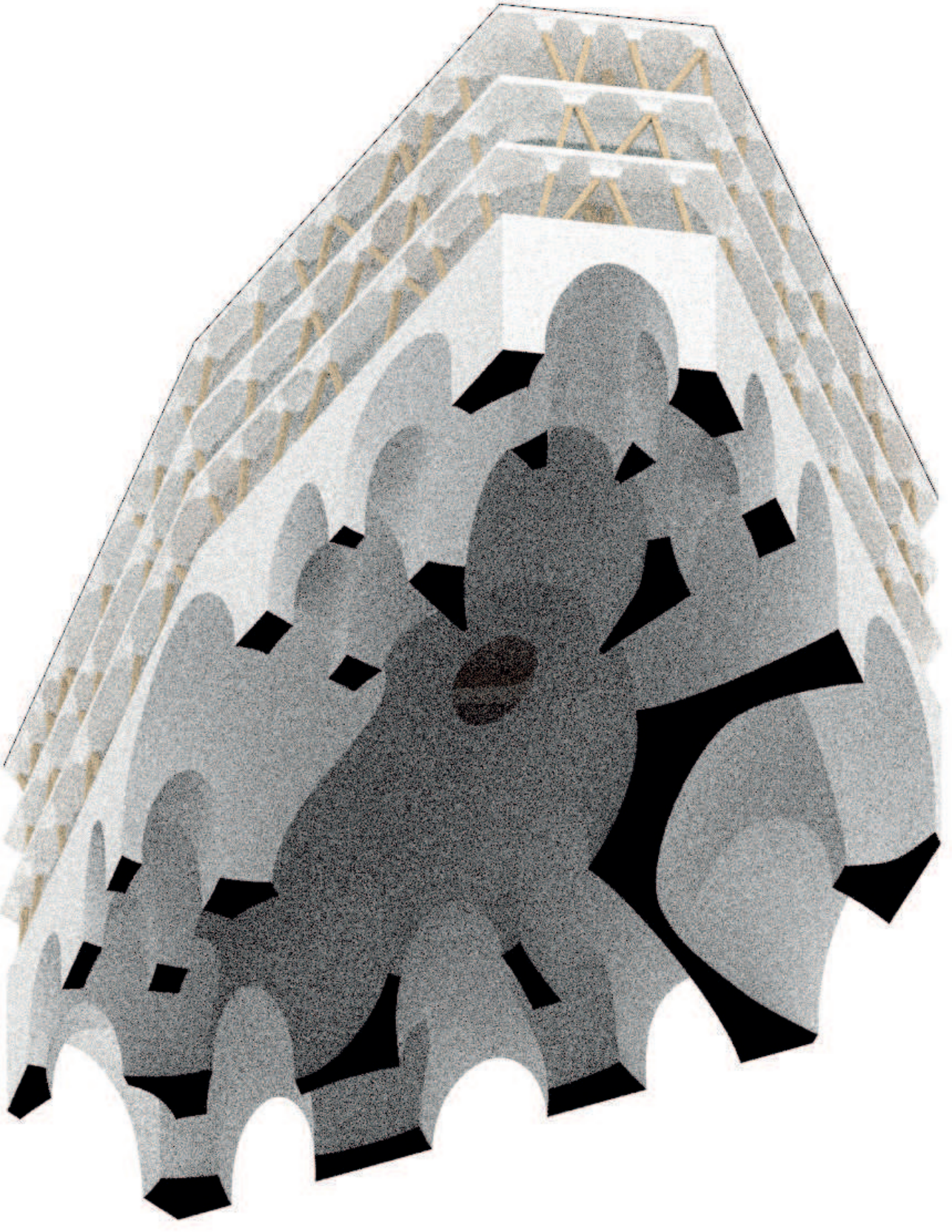


Figure 1 / Left side / Building floor plans introducing split double levels with the main core in the center
Figure 2 / Right side / Axonometrical building section





STONE TIMBER

DAVID MEISTER &
FABIAN SCHNEIDER
TU MÜNCHEN

New technologies with historical craftsmanship have been combined in this project, transforming traditional wood-stone construction techniques into SPI with timber. The proposed market hall on the ground floor is fabricated with SPI transitioning into a SPI-timber hybrid structure for the residential stories above. The position of the beams is defined following three structural zones across the building. The beam's inclination angle follows the vaults of the market hall, along which the beams rotate tangentially up to 35°. The shape of the bespoke vaulted structure of the market hall returns in its shape as slightly vaulted floor slabs joining the wooden structure.

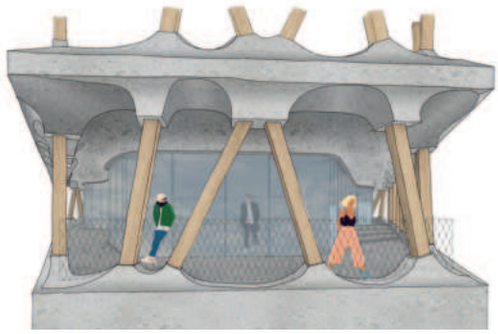


Figure 1 / Left side / Section from below into the market place
Figure 2 / Right side / Perspective of the construction principle with the vaulted SPI floor slabs accommodating the vertical timber beams

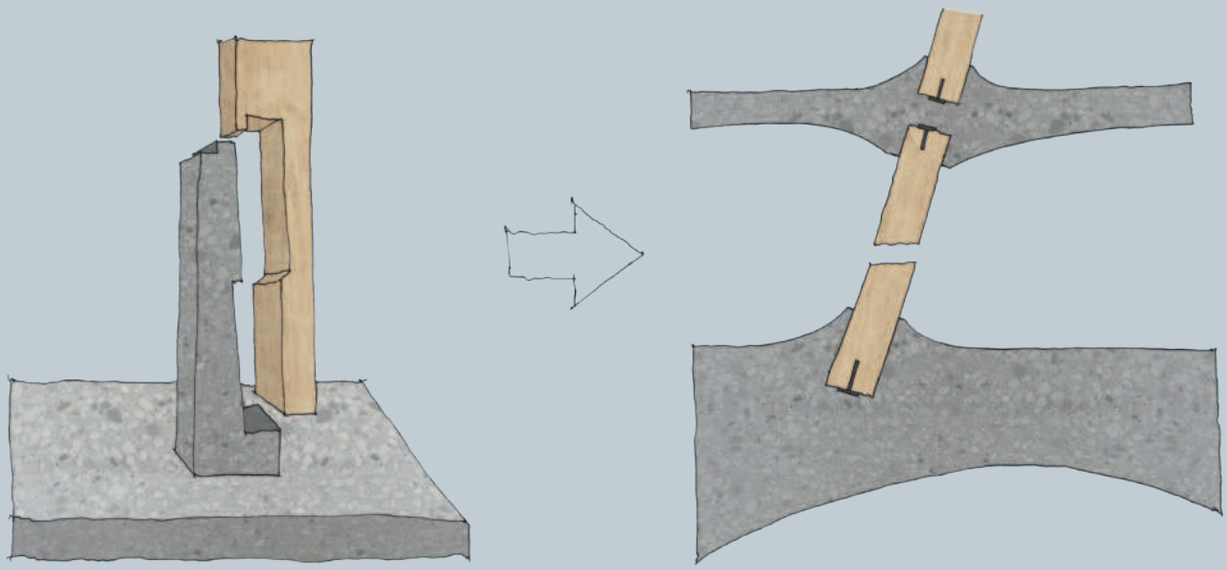
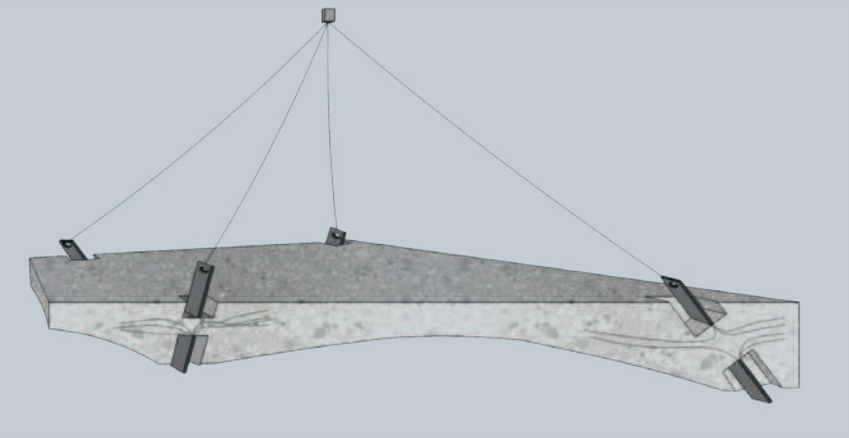
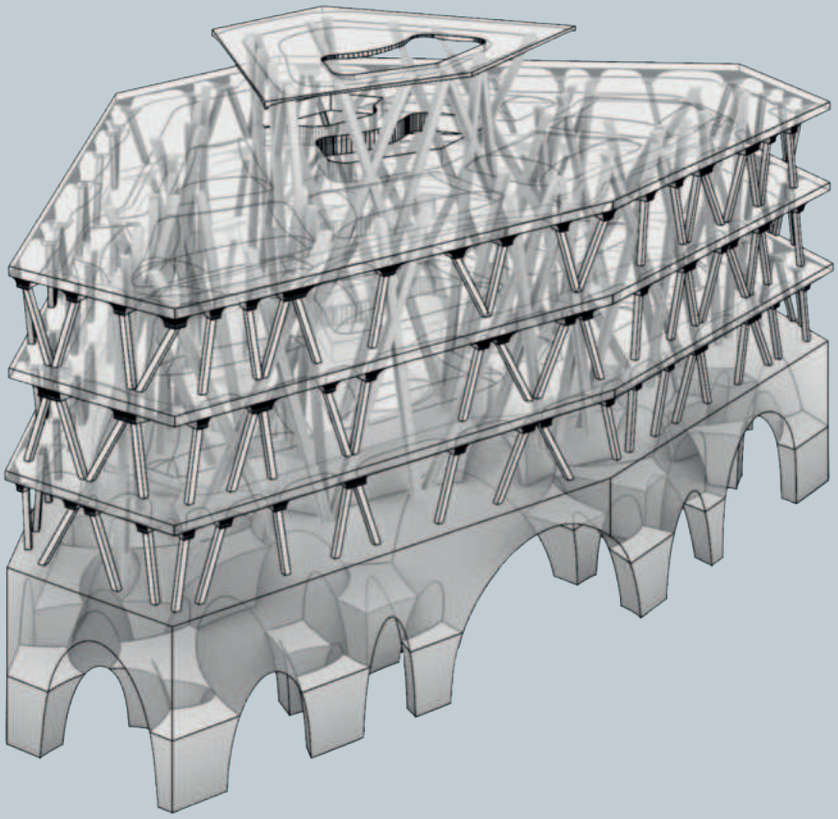


Figure 1 / Top left side / Construction method of the three main building structures
Figure 2 / Bottom left side / Transformation of traditional wood-stone constuction techniques into SPI floor slaps, SPI and timber
Figure 3 / Top right side / Transportation and on site assembly strategy of large scale building components
Figure 4 / Bottom right side / Axonometry of the design proposal





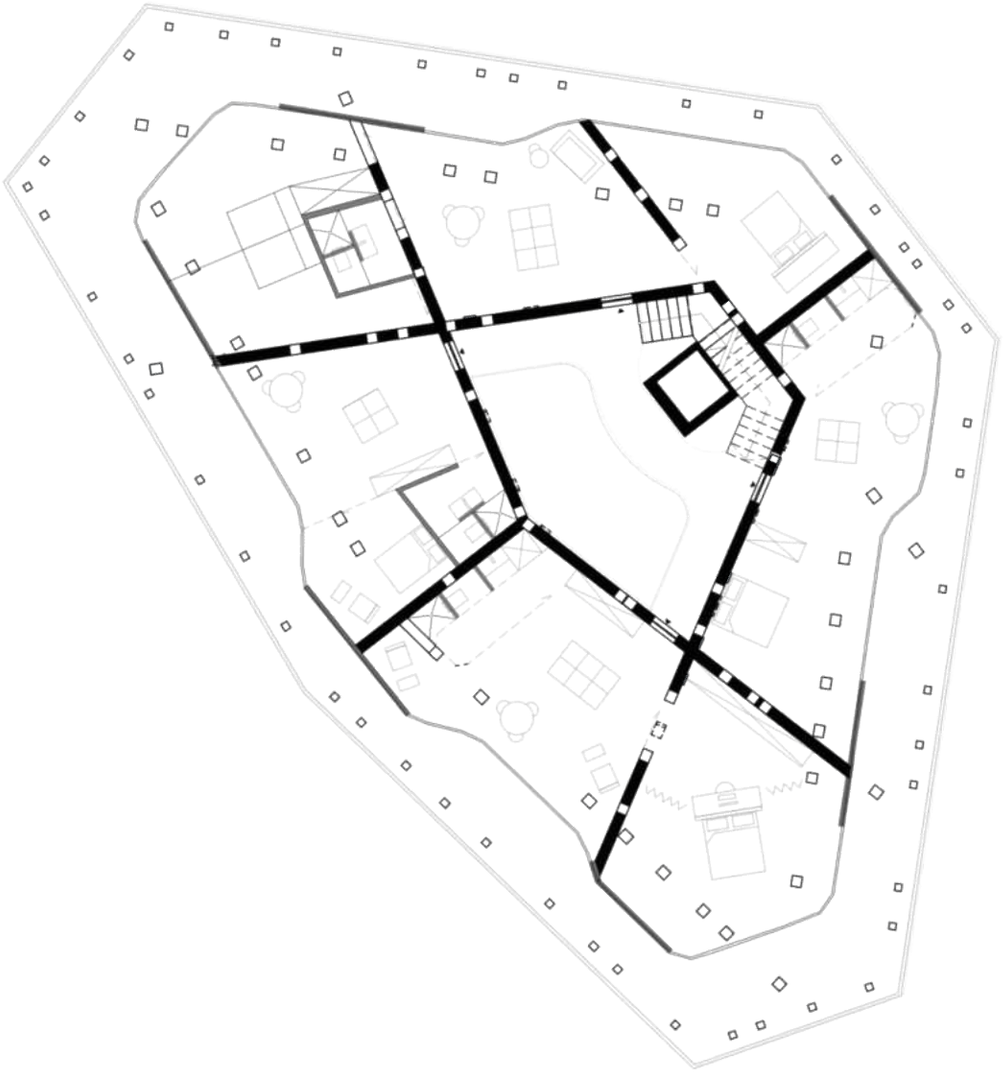


Figure 1 / Left side / Floor plan
Figure 2 / Right side / Explosion drawing showing the various construction materials being

LASER POWDER-BED FUSION OF STEEL ELEMENTS FOR CONSTRUCTION

MATERIALS AND PROCESSES

Laser Powder-Bed Fusion (LPBF) of Steel Elements for Construction – Basics of Design and Mechanical Resilience. This project aims to explore and evaluate the factors influencing the manufacturing of safe and durable structural steel elements by Powder Bed Fusion of Metals using a Laser Beam (PBF-LB/M). Thereby, the PBF-LB/M process, the post-treatment, and the geometrical aspects in terms of microstructure and mechanical properties will be investigated and correlations determined. In the first funding period, it is focused on analyzing small-scale specimens and complex facade elements with multiaxial stress states. Based on the results, a first methodology for a qualified Additive Manufacturing (AM) design of safe and durable structural steel elements will be derived.

RESEARCH TEAM

Project Leaders
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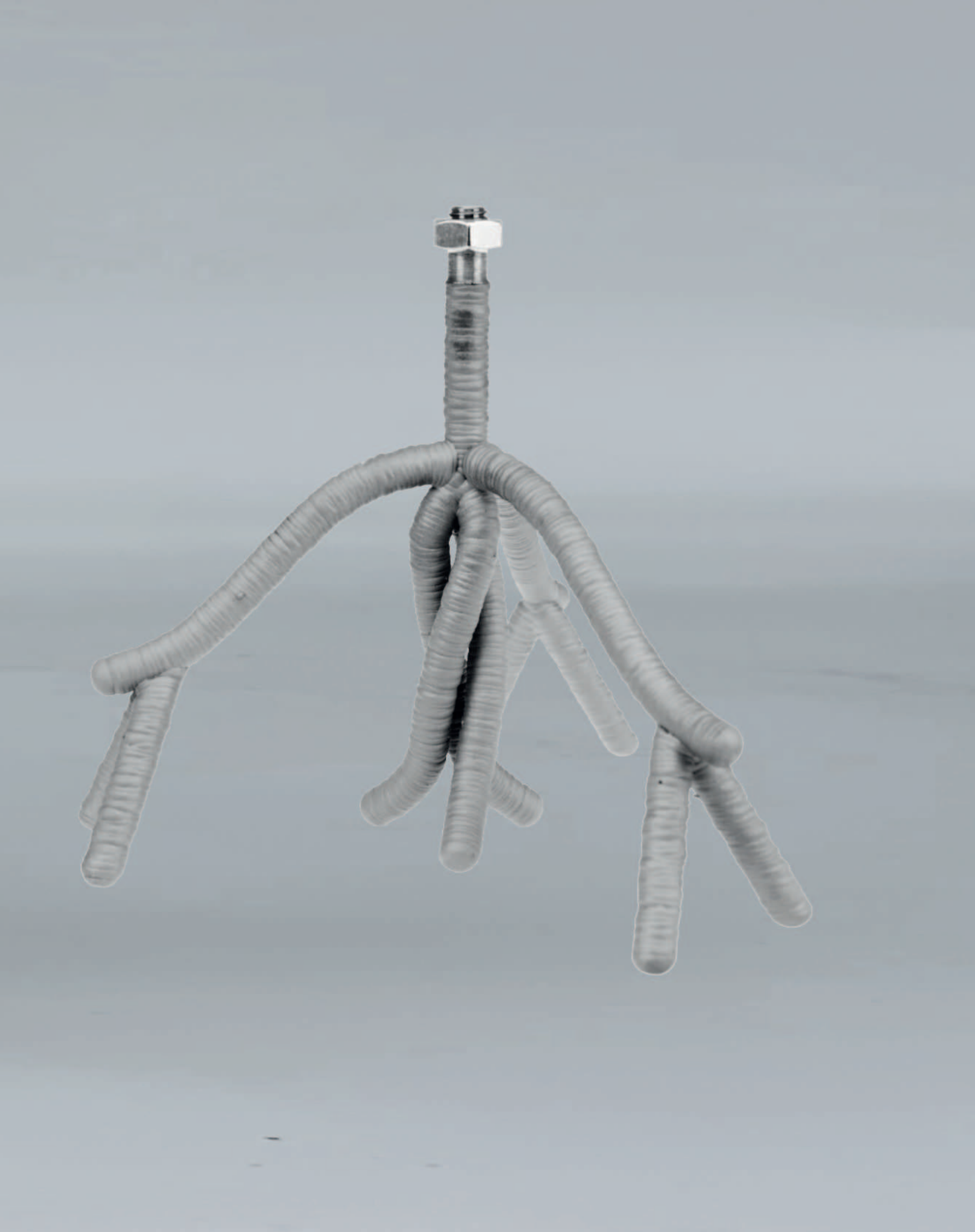
M. Sc. Dorina Siebert
M. Sc. David L. Wenzler

ASSOCIATED DESIGN PROJECTS

Hold on, timber!
Shi Zhan & Tianpu Zhou
Technische Universität München

AMC TRR 277 PROJECT

A06



WIRE & ARC ADDITIVE MANUFACTURING

MATERIALS AND PROCESSES

Project A07 investigates structural design, WAAM methods and component testing of complex, large-scale, individualized steel components. The objective is to connect conventionally manufactured steel components and semi-finished products with additively manufactured, complex steel components, like connection nodes or anchorage structures for concrete. The research program is based on innovative design and manufacturing methodologies that take both additive manufacturing parameters and material properties into account. The evaluation of the WAAM components follows a novel test method, which considers potentially anisotropic component behavior, surface topographies, geometric irregularities and residual stresses in addition to the relevant material properties.

RESEARCH TEAM

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M. Sc. Johanna Müller
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ASSOCIATED DESIGN PROJECTS

Hold on, timber!
Shi Zhan & Tianpu Zhou
Technische Universität München

AMC TRR 277 PROJECT

A07

HOLD ON, TIMBER!

SHI ZHAN &
TIANPU ZHOU
TU MÜNCHEN

This project investigates AM strategies for the pre-fabrication of a load-bearing structure from reused wood elements with bespoke metal joints using WAAM or SLM as AM technology. The structural system is based on the principle of structural reciprocity, composing a spatial configuration with unclear structural hierarchy, and is generated by an optimization algorithm allowing minimizing the material waste and maximizing the short stock elements usage. AM methods such as WAAM or SLM enable connections between beam elements of different angles and different cross-section in three dimensions. The combination of metal joints strengthens and extends the properties of timber structures, creates a dry-joint structural system and allows components to be easily disassembled and replaced.

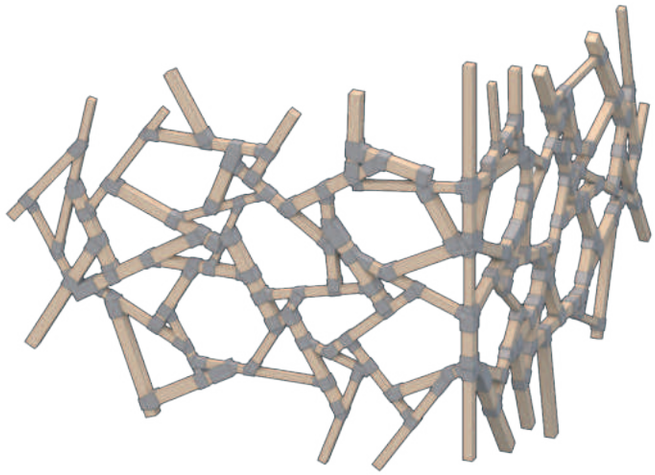
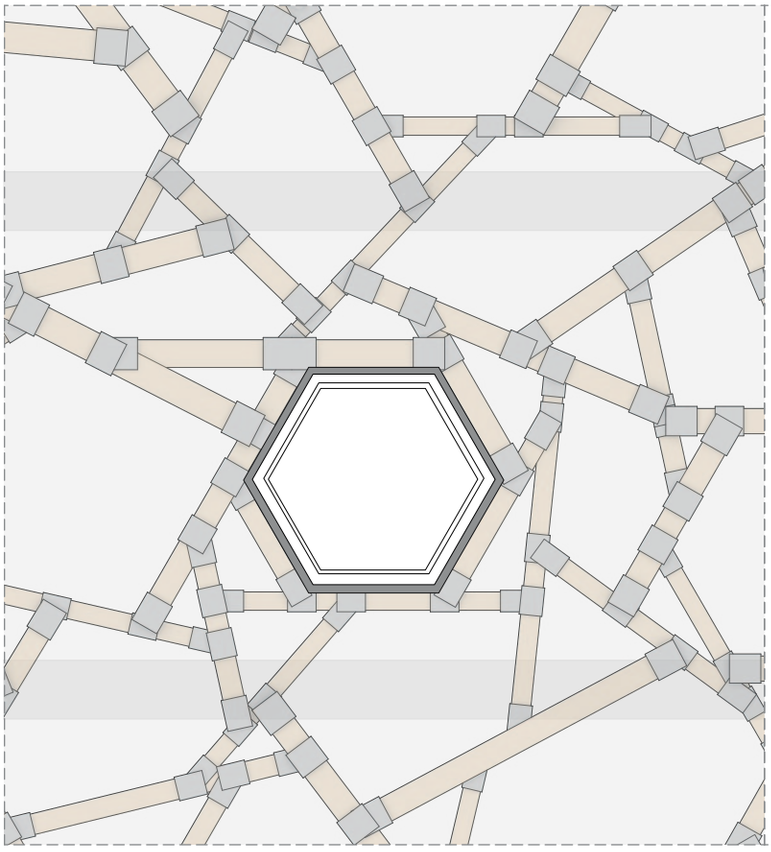


Figure 1 / Left side / Night view into the translucent building
Figure 2 / Bottom / Principle of wood-steel joints



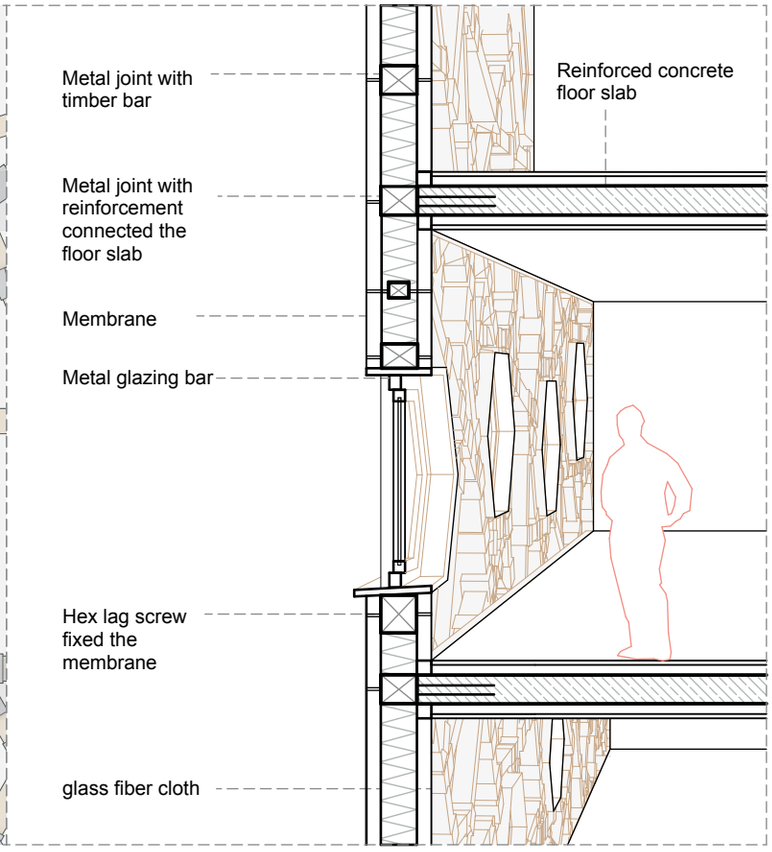
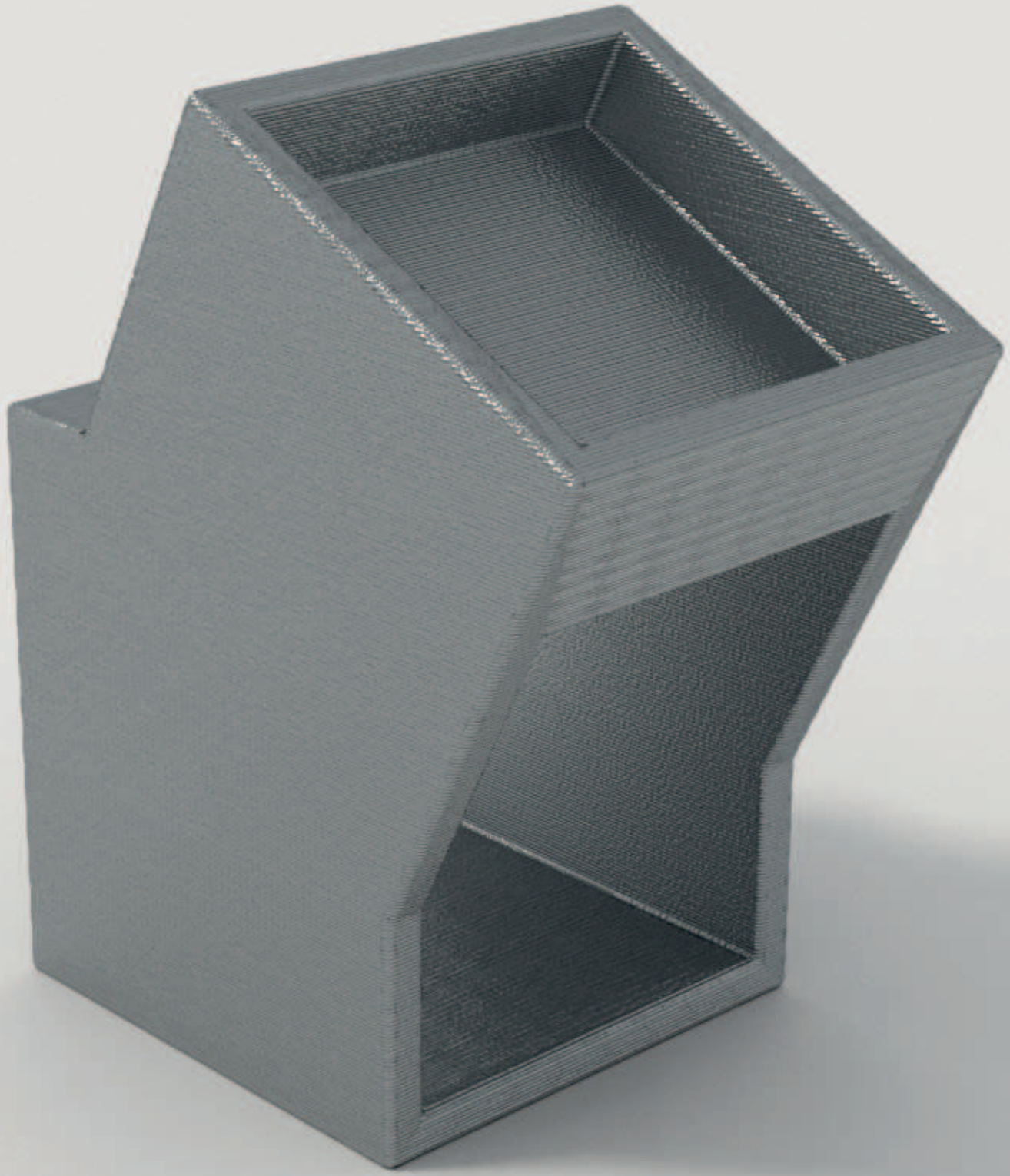
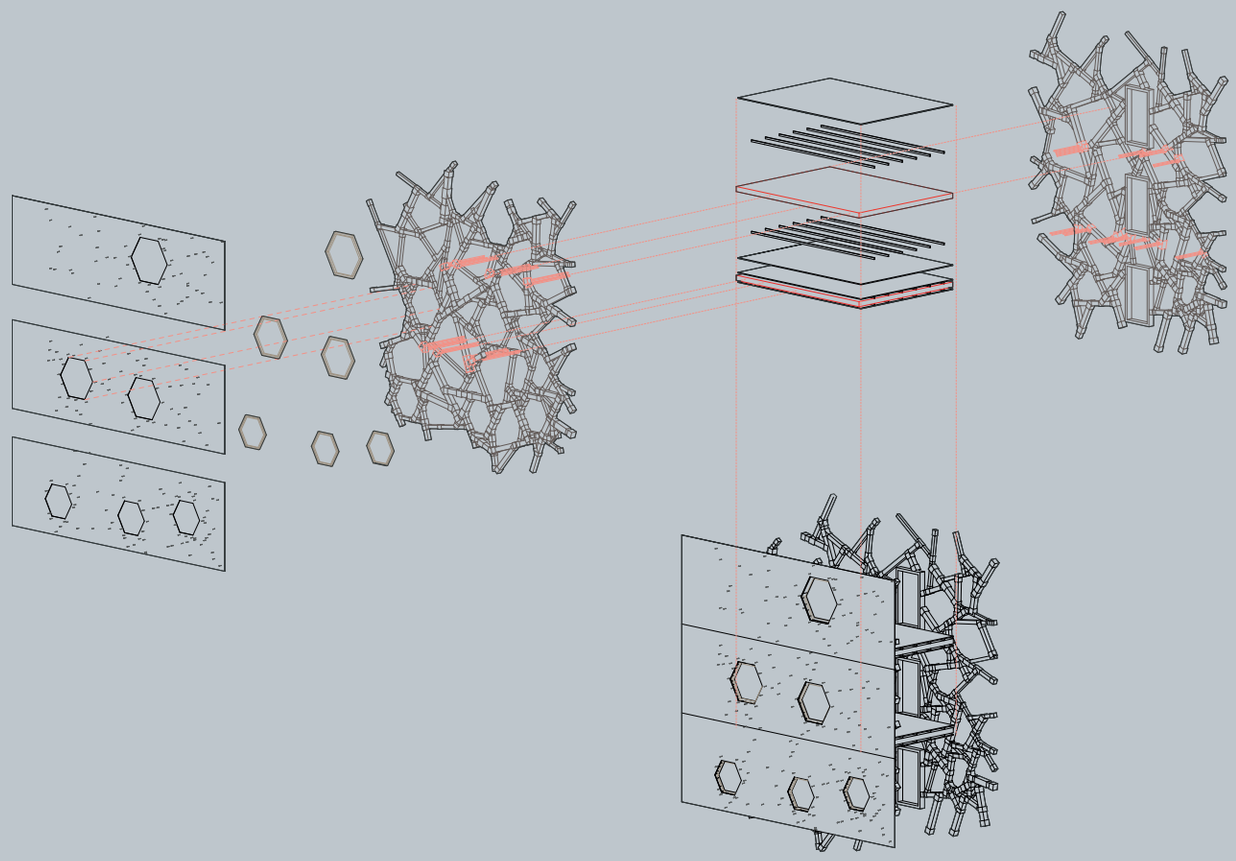


Figure 1 / Left side / Close-up view and perspective section through the building facade introducing the structural configuration
Figure 2 / Tailored metal joint





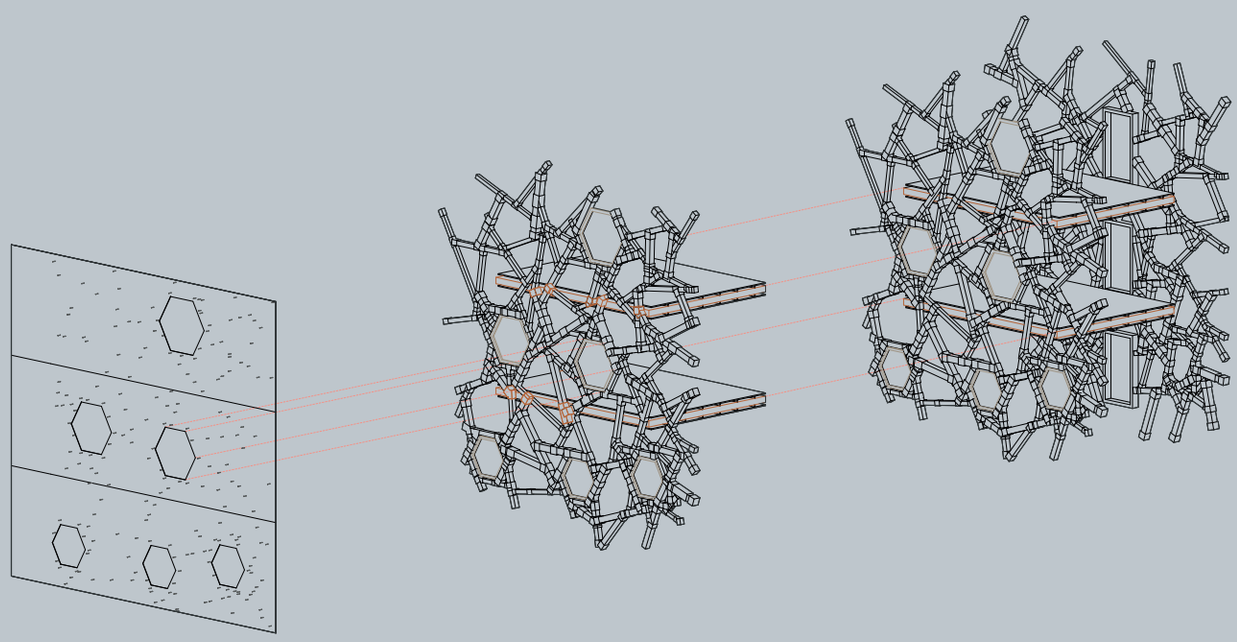


Figure 1 / Left side / Explosion drawing of the building system
Figure 2 / Right side / Axonometric drawing

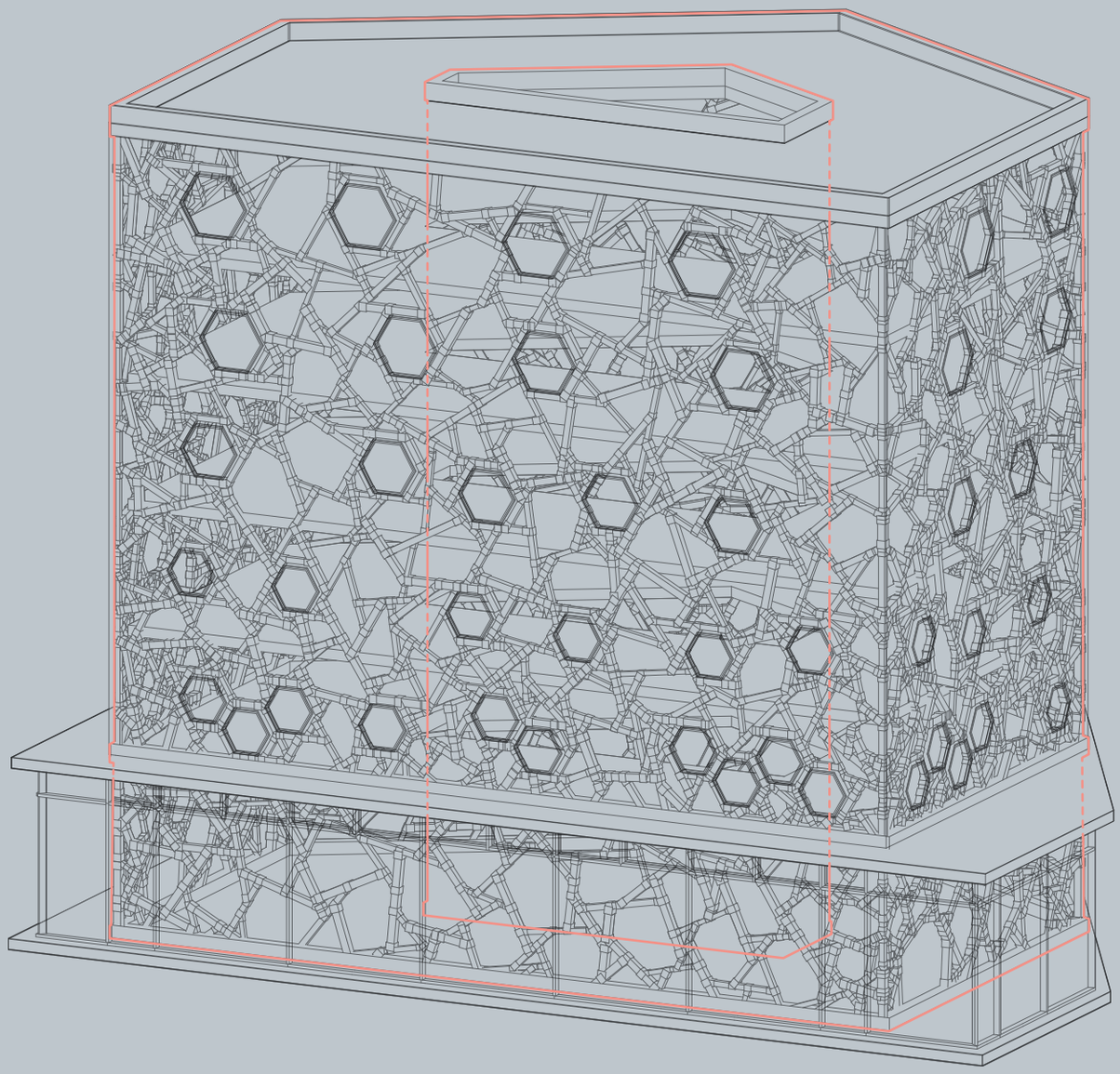
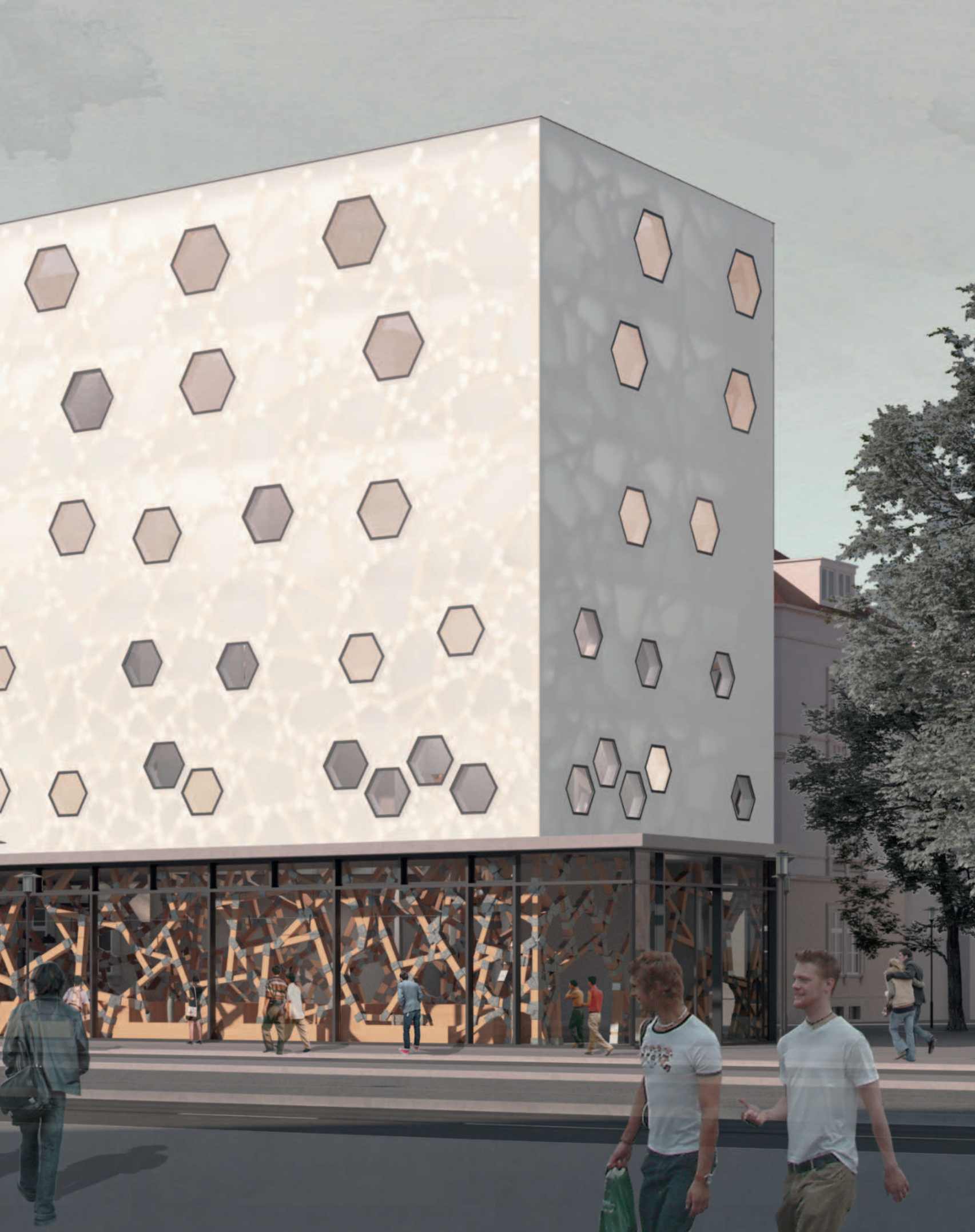


Figure 1 / Top left side / Standard floor plan
Figure 2 / Right side / Perspective view



LARGE PARTICLE-BED 3D PRINTING

MATERIALS AND PROCESSES

Large Particle 3D Concrete Printing Using Recycled Concrete Aggregates
The Large Particle 3D Concrete Printing (LP3DCP) process is a form of additive manufacturing born out of the idea of particle bed extrusion. The basic principle behind it works similar to already well researched additive manufacturing methods like gypsum 3D printing. Aggregates are being laid out flat to a growing formwork and selective binder, in this case cement, is being applied. In comparison to other additive manufacturing processes the LP3DCP gives designers a greater freedom of form, since unbound aggregates can work as a support structure for layers sitting on top. With aggregates being laid out beforehand things like recycled particles can be integrated, which can give the LP3DCP manufacturing a chance of making concrete more sustainable.

RESEARCH TEAM

Project Leaders
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Prof. Dr. Harald Kloft
Prof. Dr.-Ing Dirk Lowke

Collaborators
M.Sc. David Böhler
M.Sc. Jan-Phillip Zöllner

ASSOCIATED DESIGN PROJECTS

The renewed potential of a formal language
Philip Nünning
Technische Universität Braunschweig

THE RENEWED POTENTIAL OF A FORMAL LANGUAGE

PHILIP NÜNNING
TU BRAUNSCHWEIG

This project investigates in a large particle bed printing setup (LP3DCP) spraying shotcrete onto and between recycled coarse particles recycled from demolished buildings. Due to the geometric freedom derived from the particle bed setup the design proposes resource-efficient, arched, monolithic facade elements. Furthermore, the design focuses on applying a minimum of reinforcement by adapting the major structural load to compressive forces. This enables the building design to meet the formal possibilities of AM technologies allowing the additive manufacturing of functional integrated monolithic elements for e.g. orientation-dependent shading, insulation and drainage.

This project was selected for the further development within the research project „Large Particle Bed 3D Printing“.

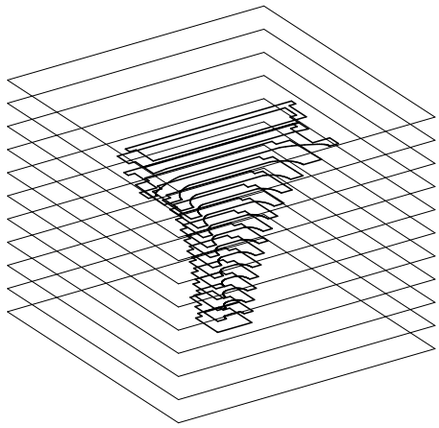


Figure 1 / Left side / Exterior perspective of design proposal from western standpoint in Mandelnstraβe
Figure 2 / Right side / Scheme of Large Particle Bed 3D Printing process

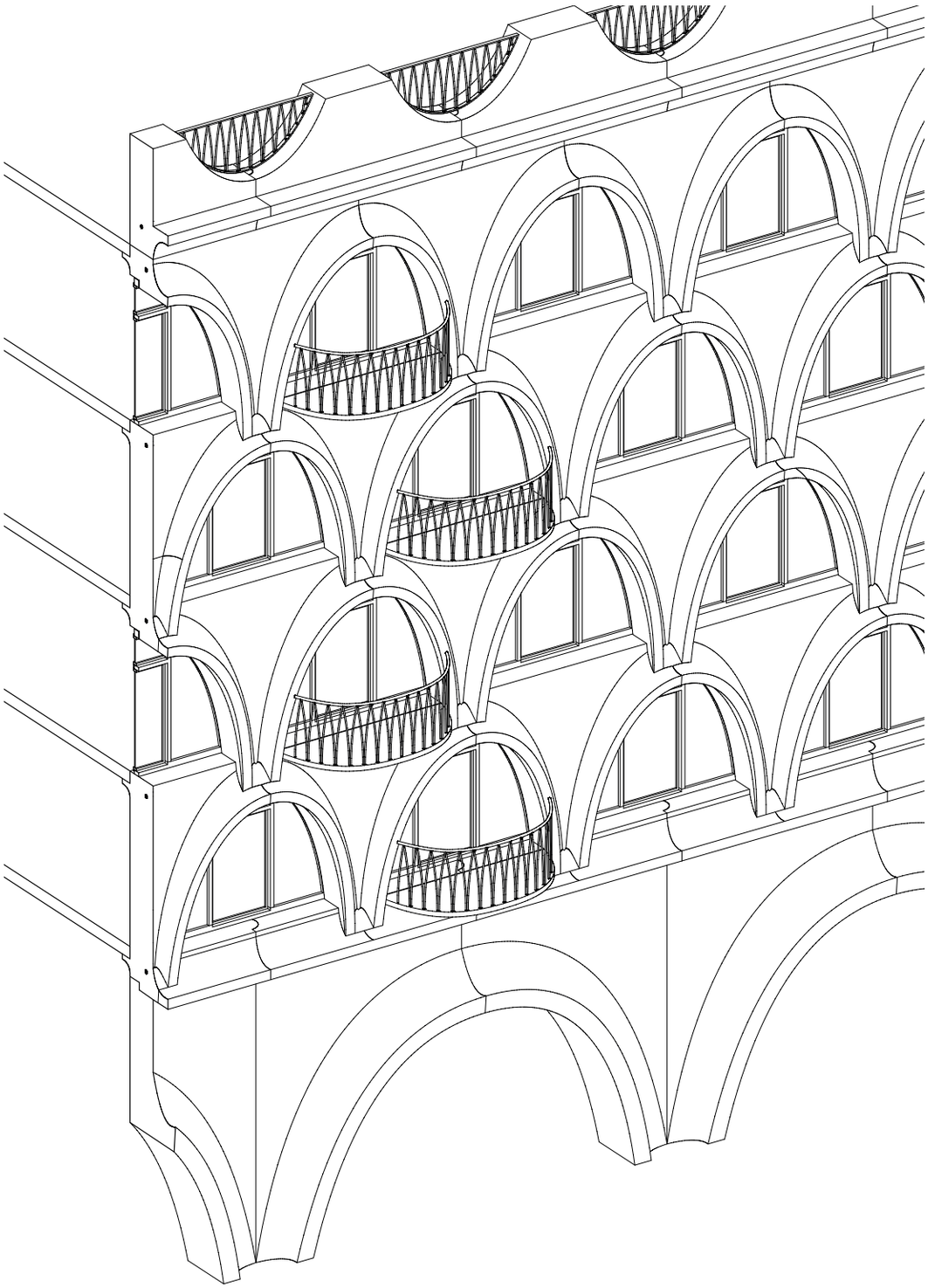


Figure 1 / Left side / Isometric view of facade construction typology
Figure 2 / Right side / 3D Rendering of 3D Printed facade and structural element before assembly

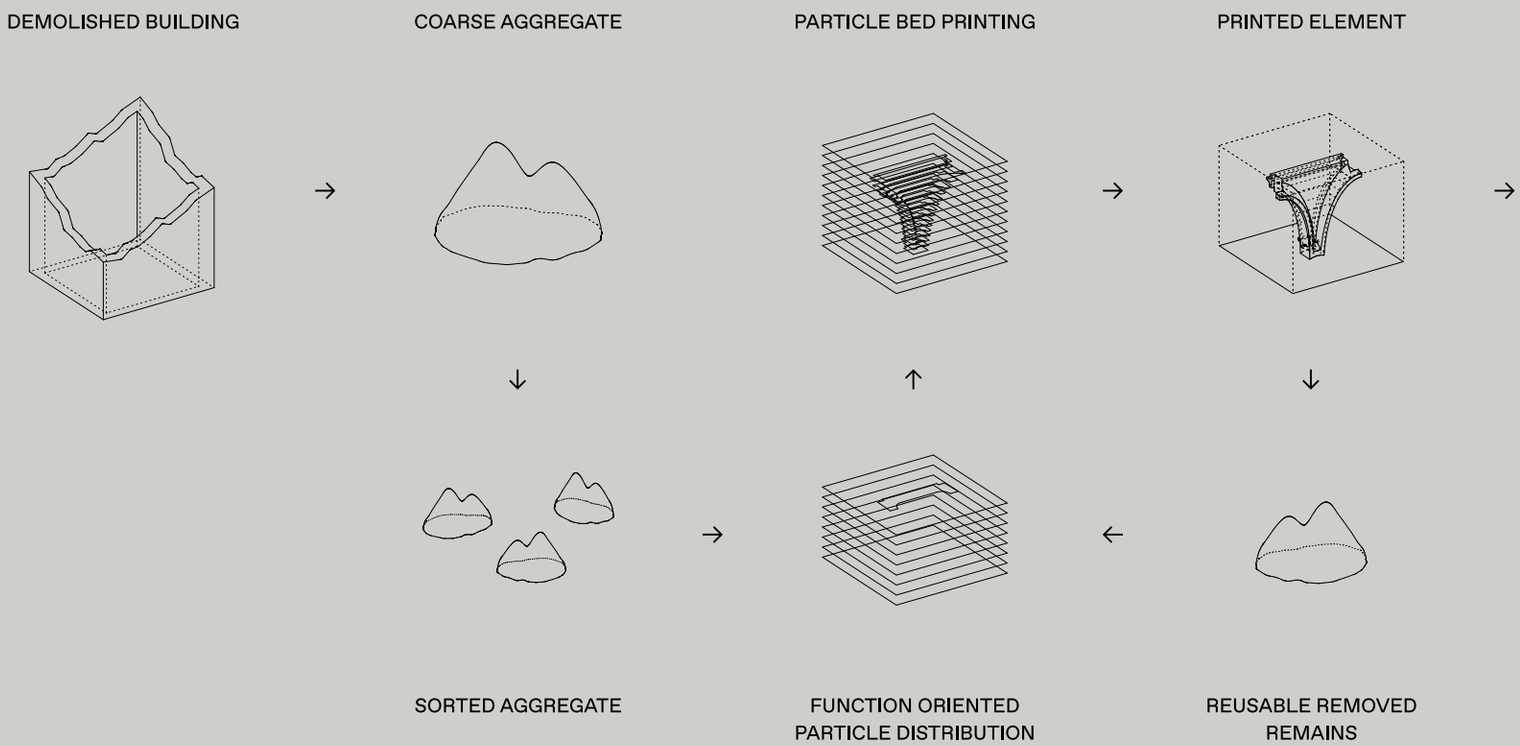
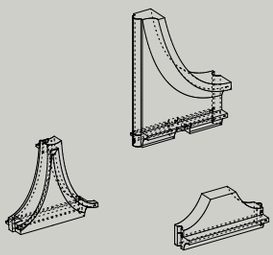
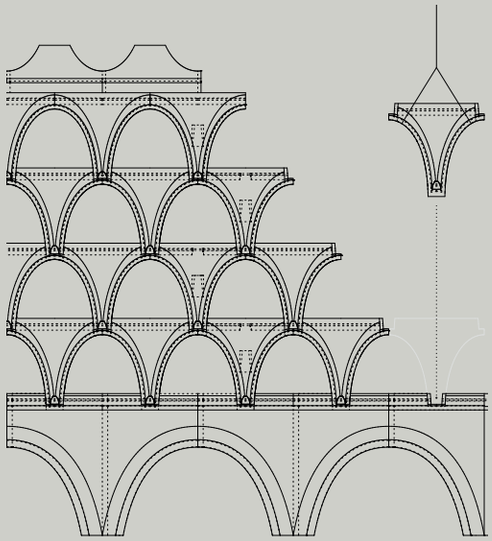


Figure 1 / Left side / Scheme of preparation and fabrication process
Figure 2 / Right side / Construction and assembly method of 3D printed elements

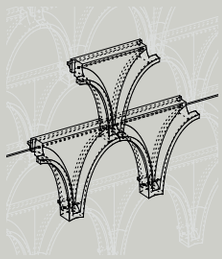
PRINTED ELEMENTS



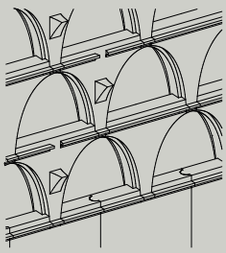
ASSEMBLY ON SITE



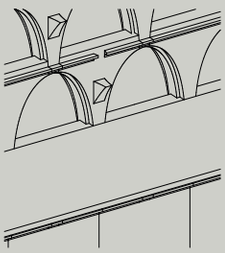
TENSILE JOINTING



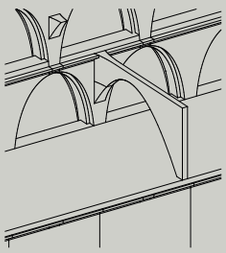
TENSILE JOINT WALL



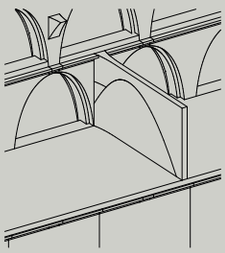
TIMBER CLAY CEILINGS



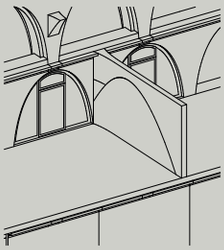
ARCHED BRACING WALLS



PRINTED CLAY FILLING



WINDOW ELEMENTS



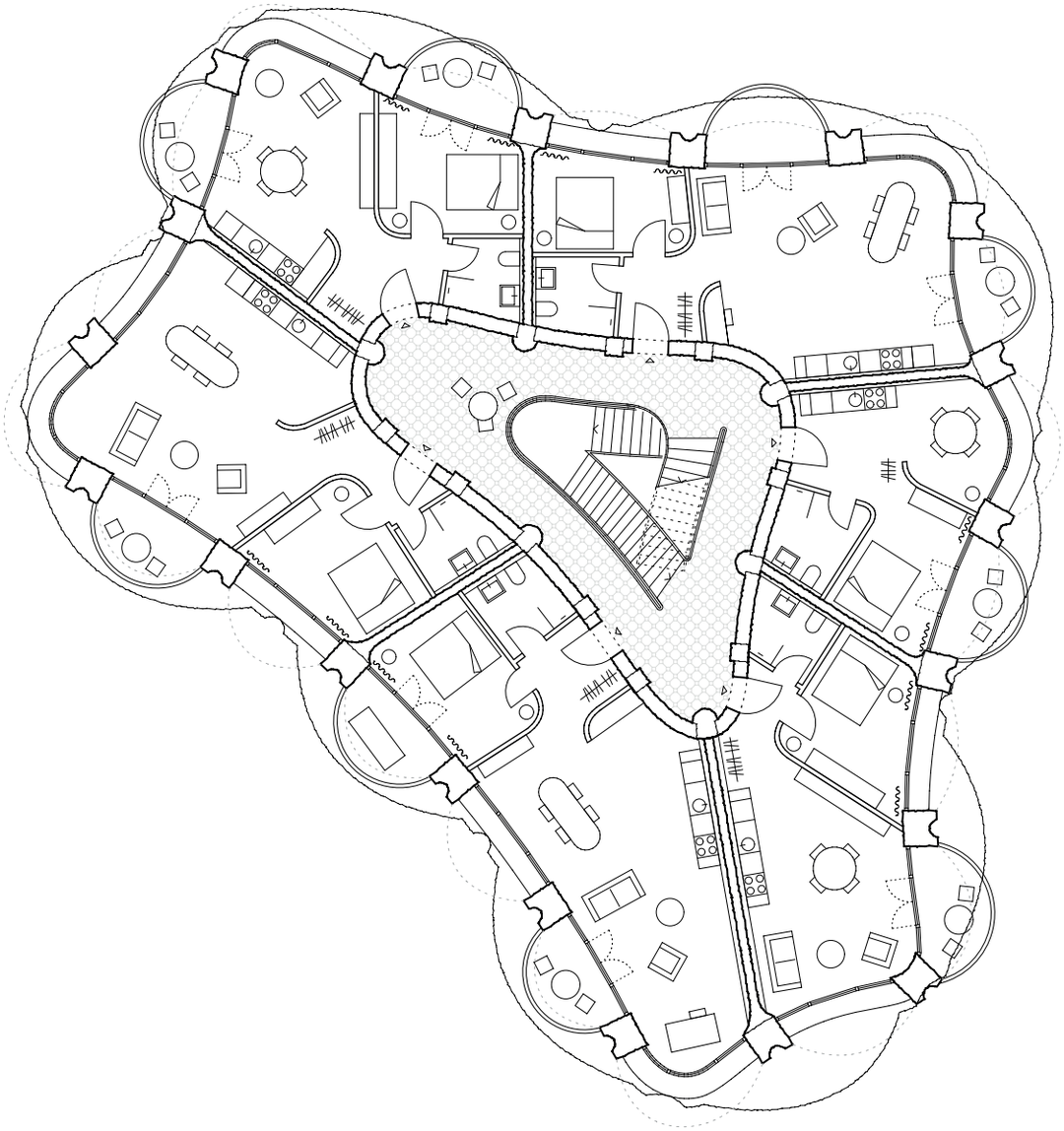
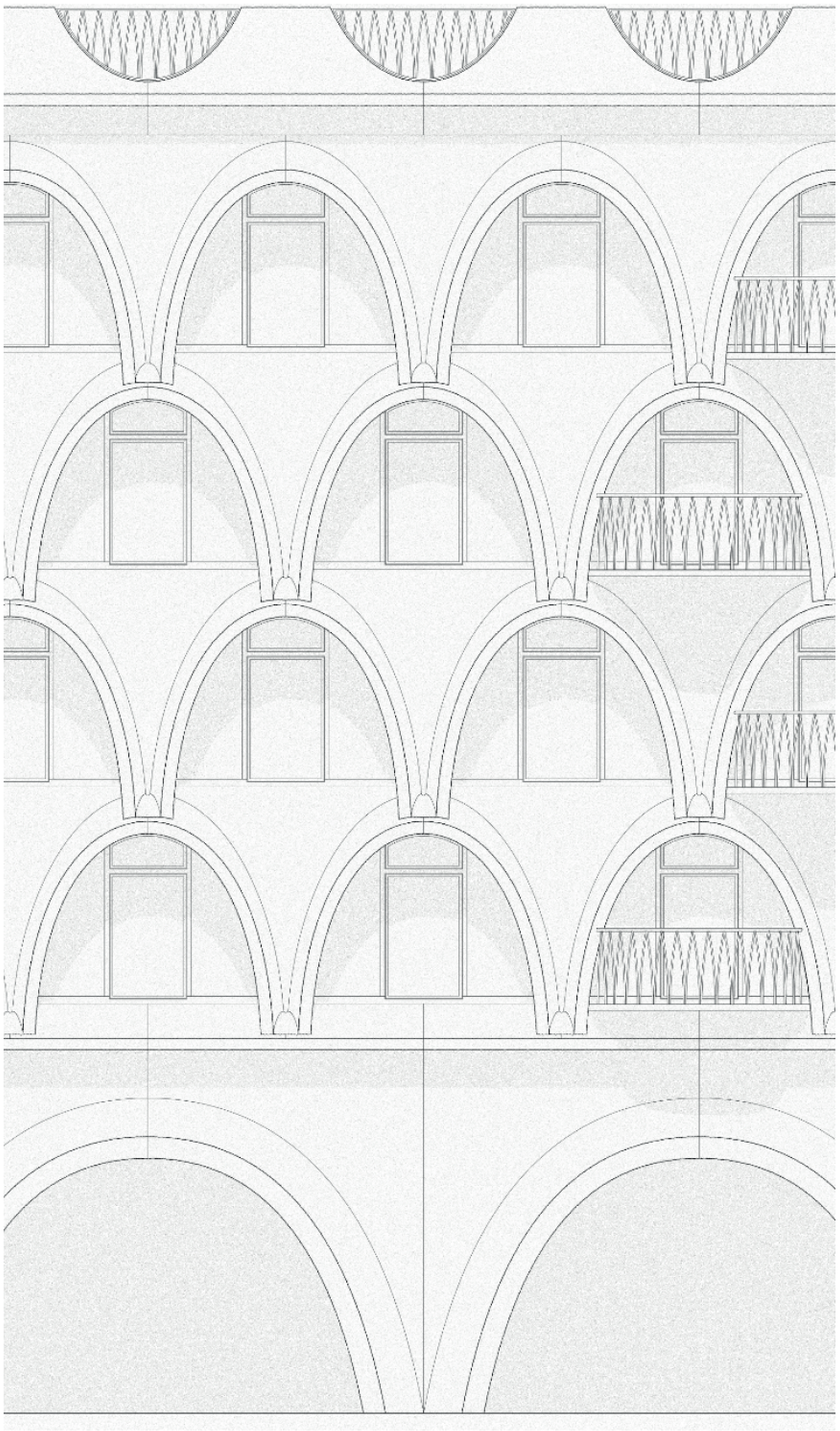
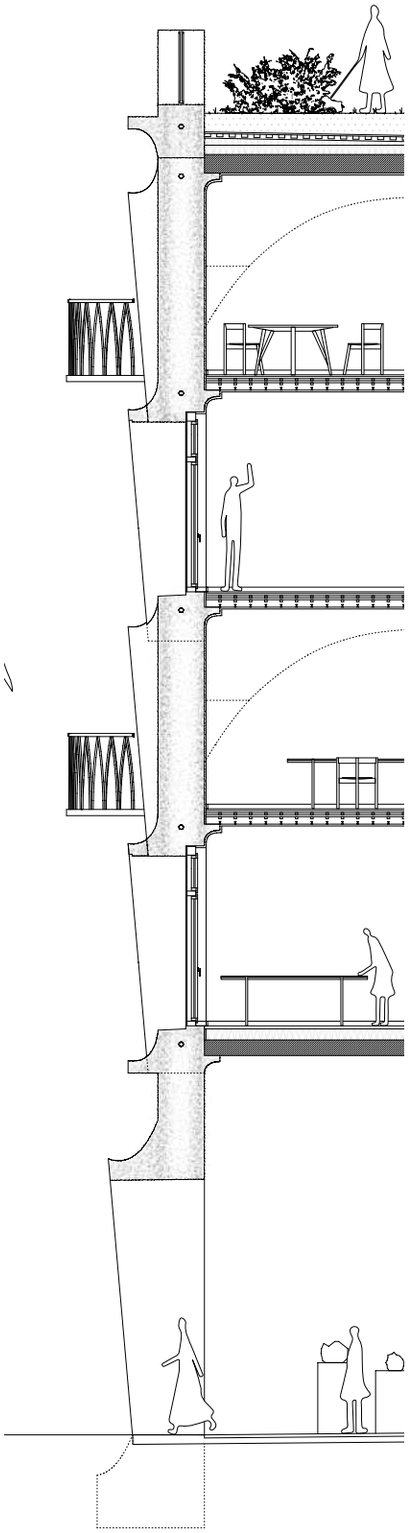
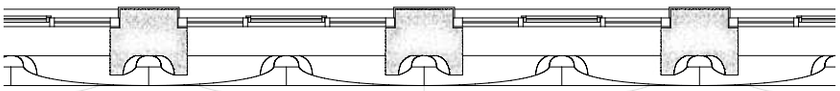


Figure 1 / Left side / Standard residential floor plan
Figure 2 / Right side / Facade section and elevation







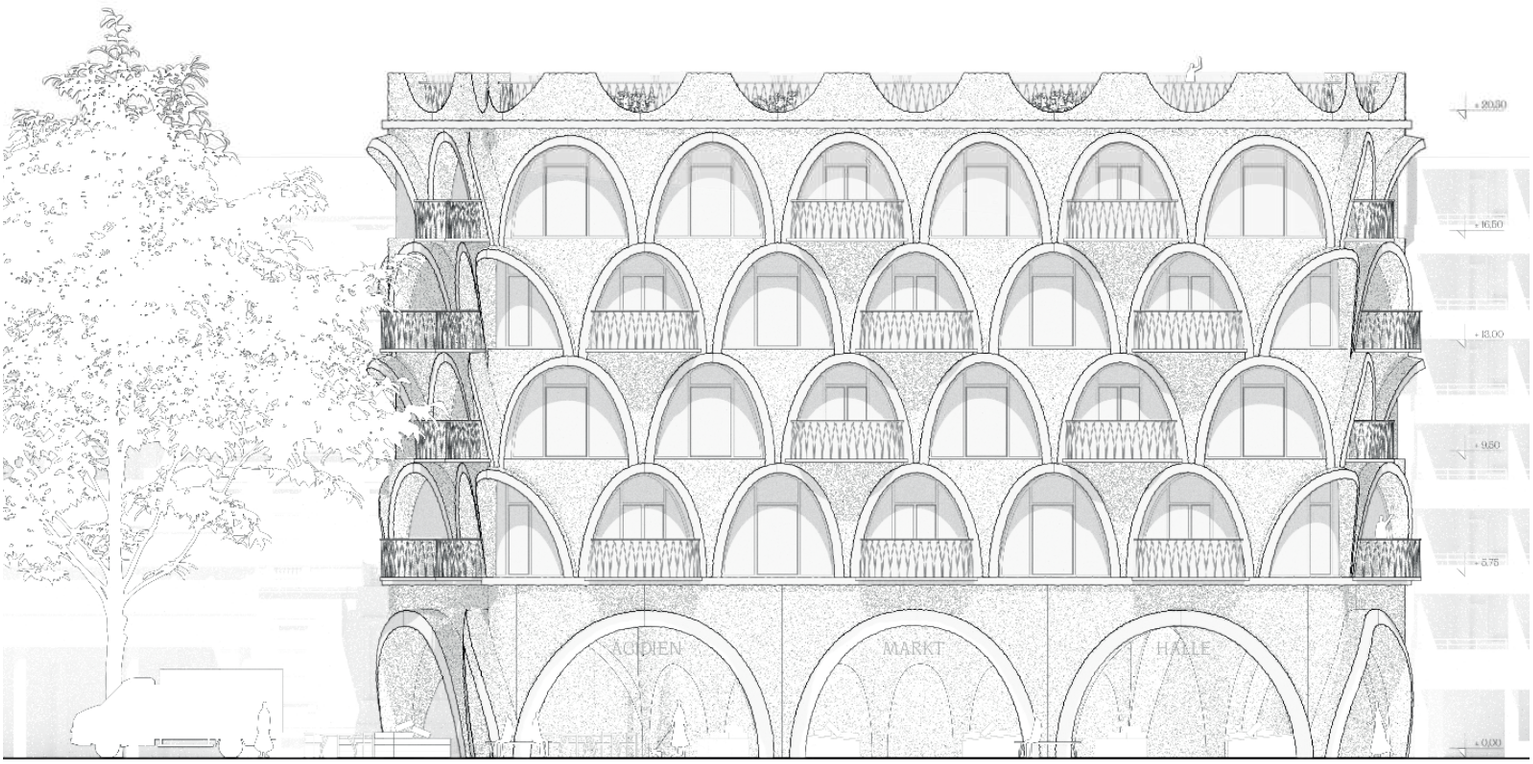
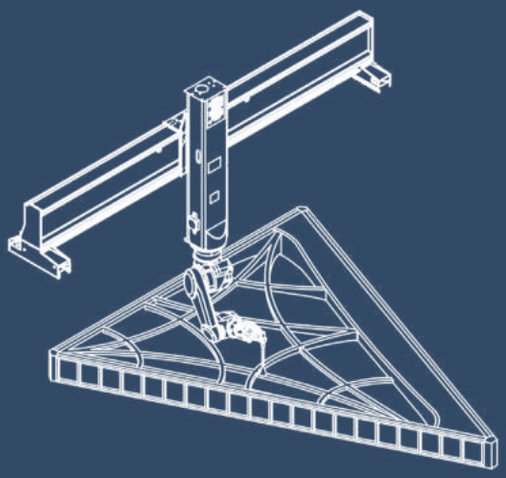
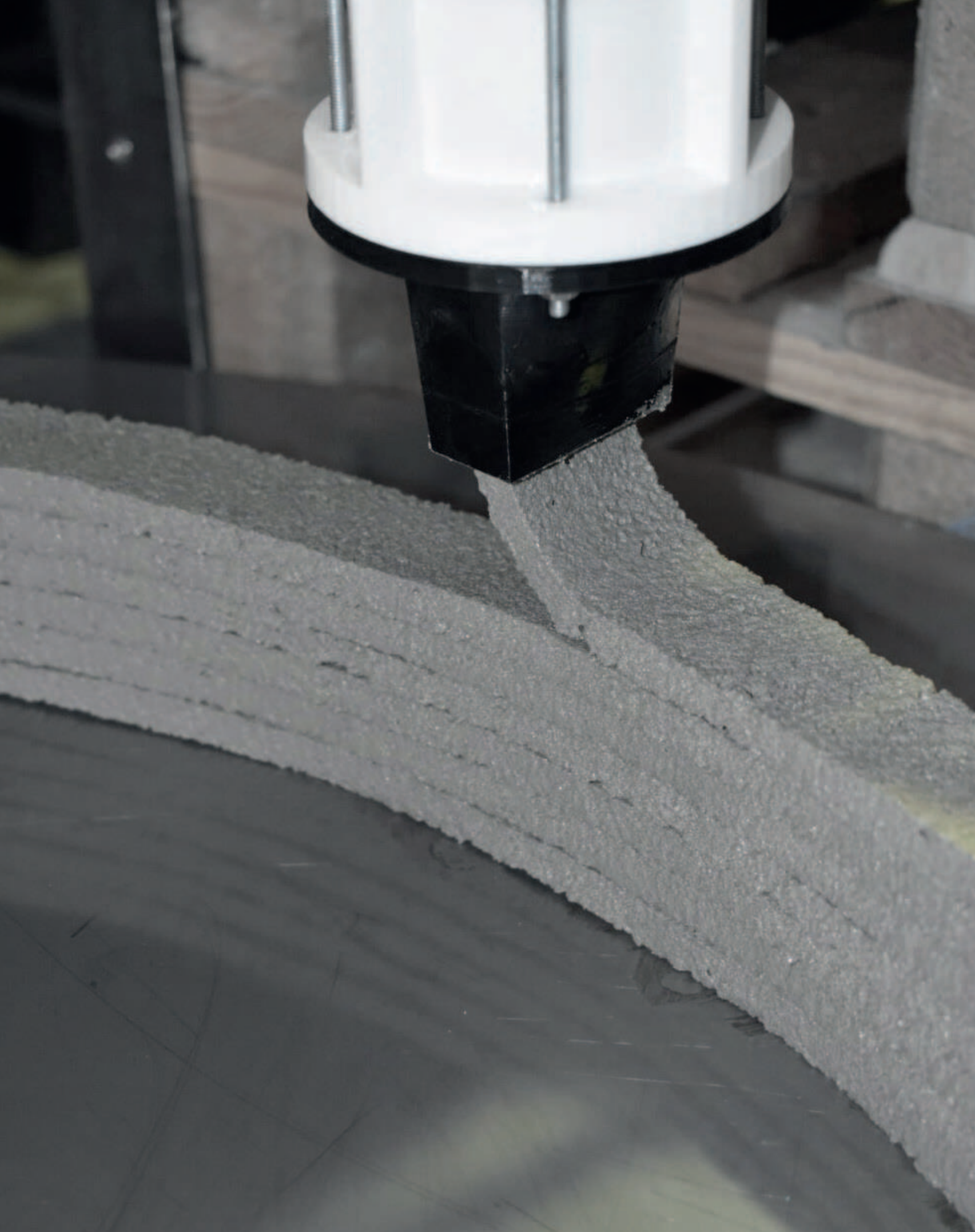


Figure 1 / Left side / Elevation West
Figure 2 / Right side / Interior perspective of residential use



DESIGN PROJECTS ON DEPOSITION 3D PRINTING



EXTRUSION OF NEAR-NOZZLE MIXED CONCRETE

MATERIALS AND PROCESSES

Extrusion of Near-Nozzle Mixed Concrete –Individually Graded in Density and in Rate of 3D Fibre Reinforcement. The gradation of material properties in concrete extrusion allows more efficient use of resources and multifunctional design of components, but represents a particular challenge in pump-based extrusion systems. Therefore, an innovative near-nozzle mixing system, called gradation ready extruding system (GRES), is being developed in A03 which enables immediate gradation of the material properties. This allows to locally extrude different materials ranging from normal to lightweight concrete. Furthermore, the short conveying distances for the fresh concrete facilitate the extrusion of e.g. more sustainable materials that cannot be processed in previous extrusion systems due to impeded workability compared to normal 3D printing materials. The combination of multi-material printing with an automated vertical rebar insertion strives for high performance as well as a precise adjustment of material properties to the local needs and thus for a more sustainable material use.

RESEARCH TEAM

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Contributors
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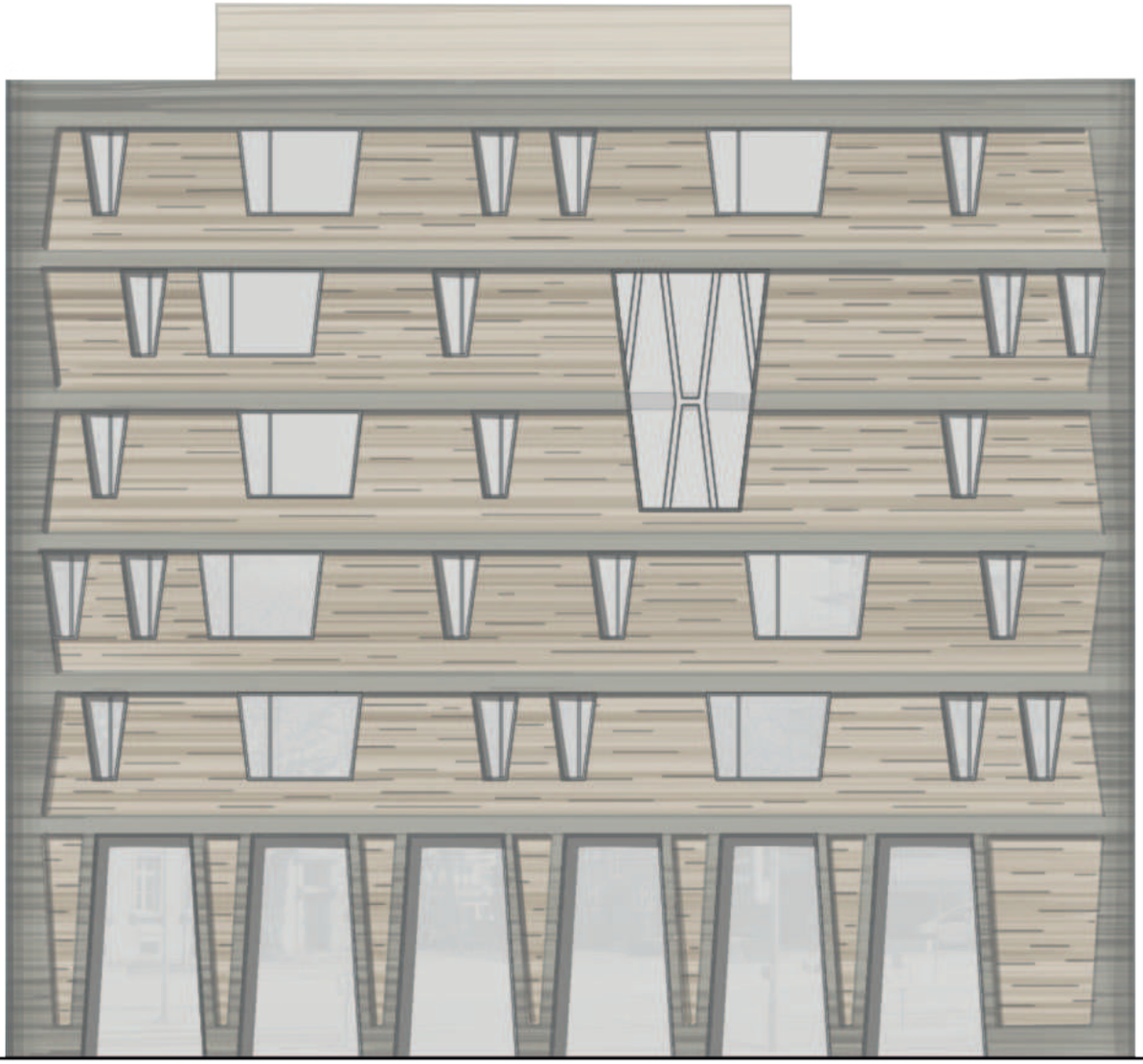
Dipl.-Ing. Stephan Kessler
Dr.-Ing. Thomas Kränkel

ASSOCIATED DESIGN PROJECTS

Marriage battle of two materials
Luisa Durst & Mauritz Renz
Techische Universität München

AMC TRR 277 PROJECT

A03



~~BATTLE~~ MARRIAGE OF TWO MATERIALS

LUISA DURST &
MAURITZ RENZ
TU MÜNCHEN

The project aims for a simple construction with a dual nozzle system with clay and concrete, using the advantages of each material to compensate for the limitations of the other. Through the simultaneous printing process of both materials, each layer serves to support the other allowing geometric freedom. The on-site production of the vertical elements is supplemented with prefabricated horizontal elements. Here, the concrete takes over the load transfer and, as a pure compression structure, can dispense with reinforcement. Furthermore it provides erosion protection for the clay. The clay serves as a thermal envelope and offers the possibility of component activation. This is made possible by a hexagonal, printed structure, which also reduces the material consumption.

A03
This project was awarded for the further research of the A03 demonstrator to develop a workflow for a synchronized printing process of two concrete mixtures at different aggregate sizes using the near-nozzle mixing setup.

Dual Nozzle Printing

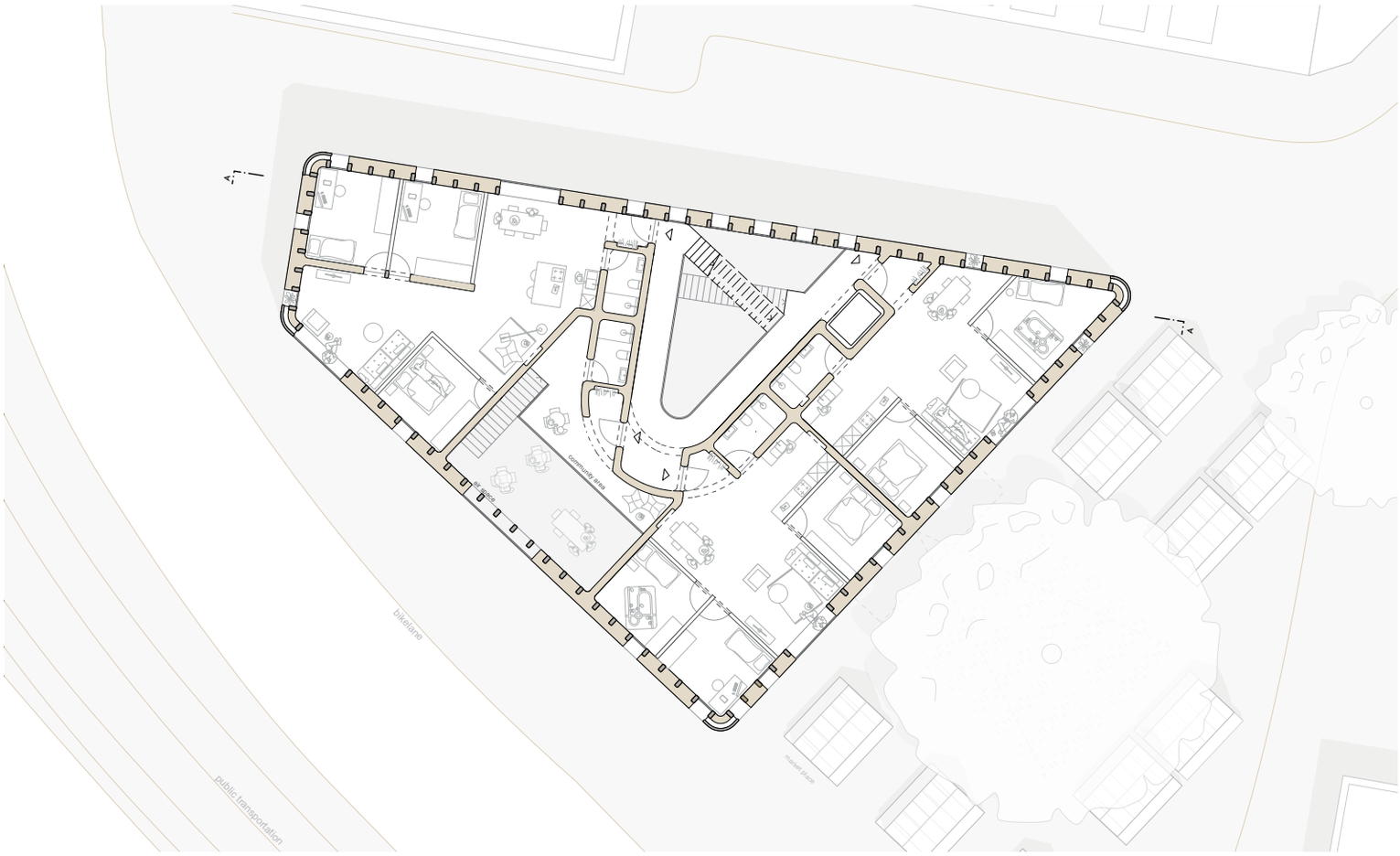
Mutual Support

Possible Compex Geometries

Extreme Overhangs

Optional and simple Removal of Clay

Figure 1 / Left side / Street view drawing
Figure 2 / Bottom / dual nozzle printing concept



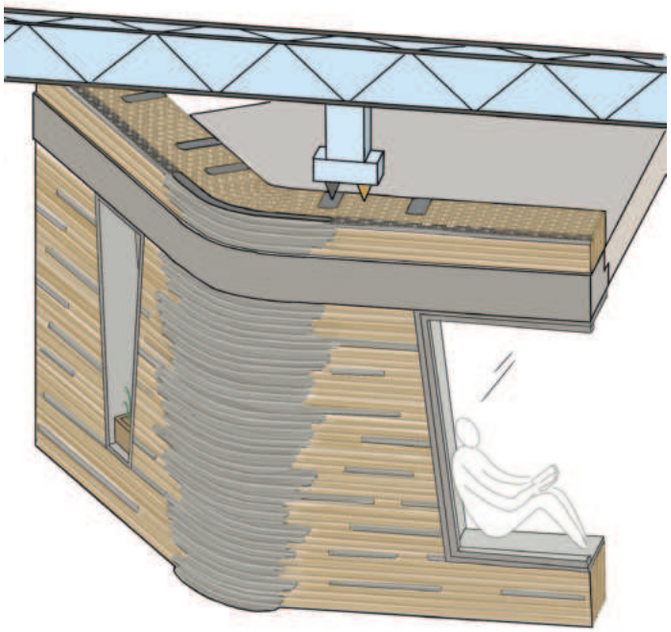
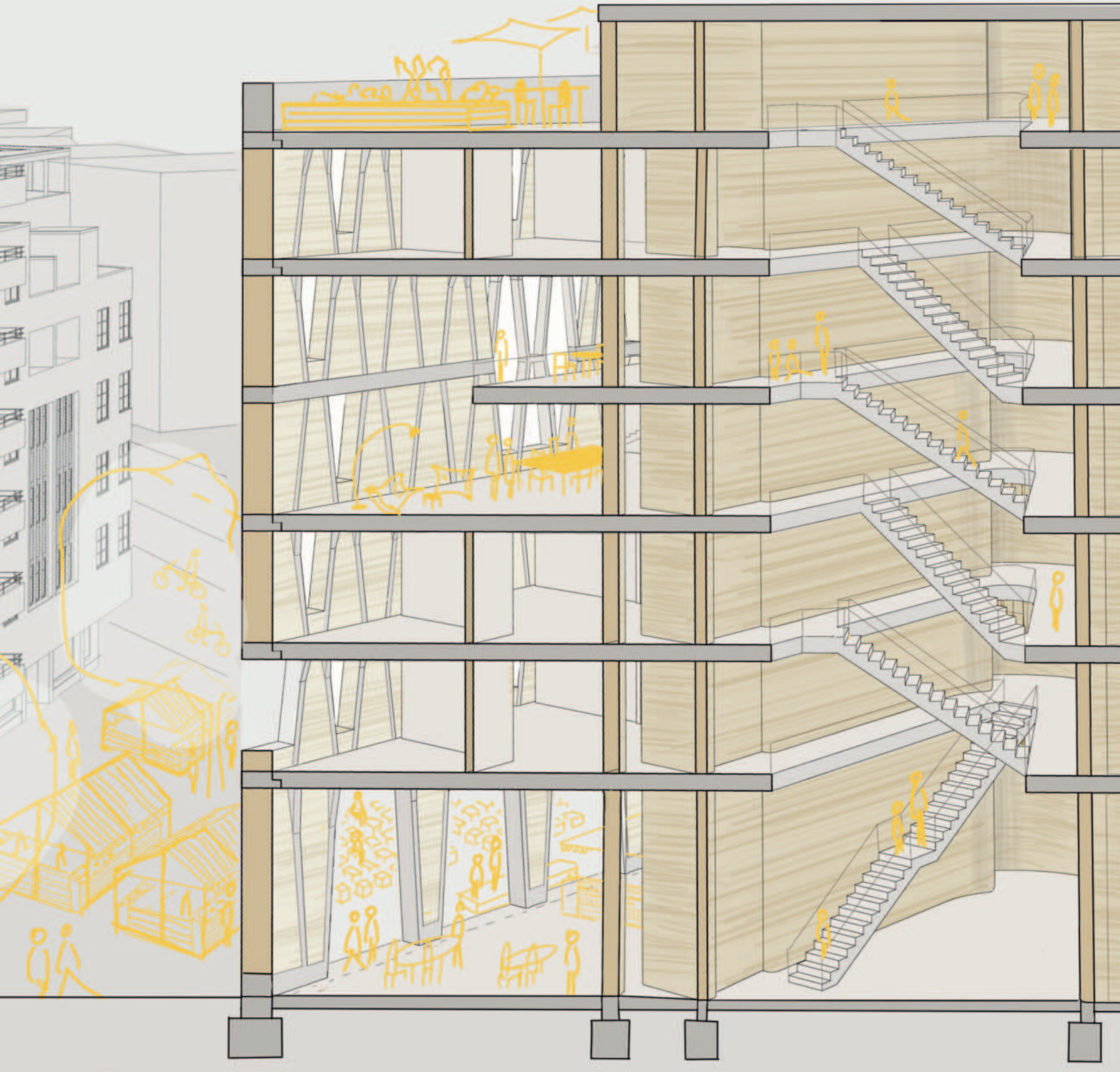


Figure 1 / Top left side / Floor plan
Figure 2 / Bottom left side / Isometric view of dual nozzle printing process
Figure 3 / Perspective section through the building




STÄUBLI

INTEGRATED ADDITIVE MANUFACTURING PROCESSES FOR REINFORCED SHOTCRETE 3D PRINTING

MATERIALS AND PROCESSES

Integrated Additive Manufacturing Processes for Reinforced Shotcrete 3D Printing (SC3DP) Elements with Precise Surface Quality. Within this project, basic research on various SC3DP strategies, materials, tools and methods will be conducted with regard to enhanced material and process control, reinforcement integration, surface quality and automation. To that end, different reinforcement materials in combination with suitable reinforcement manufacturing and integration concepts will be investigated based on force-flow optimised reinforcement alignment. Besides, design strategies as well as material and process control will be investigated in detail. Furthermore, tools and strategies for precise control of the surface quality and geometric resolution of SC3DP elements are subject of research. Finally, strategies, materials and tools elaborated within the project will be synergistically combined and validated at large scale.

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Urban carpet
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Treedimension
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AMC TRR 277 PROJECT

A04

URBAN CARPET

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Based on the outline of the traditional market square, a rectangular plane structure is erected above the entire area. Depending on the use on top or below the area, the plane is shaped to create space for uses, to provide elevations and to ensure access and egress to the area. Likewise the shaping serves the stability. The surface is supported by a total of eight columns, which always make up a low point of the construction, while higher areas are created in between. Instead of conventional formwork technology, textile formwork can be used to achieve the desired shape. In this case, the so-called Knitcrete technology was chosen. In the first step a formwork skin from sheep's wool is knitted using a CNC knitting machine. The prefabricated sheets can then be piled together and easily transported to the construction site. On site, the Knticrete formwork is assembled and stretched. For this purpose, there is a frame that creates the tension of the formwork skin. In order to avoid unwanted deformations, the textile is additionally supported with inserted metal rods, which run from support to support. The first layer of formwork structure is followed by a thin and light fixing layer. Various coating materials such as polymers, gels, foams and cementitious materials can be used for this purpose. To save weight, a material-saving layer is then applied using air cushions, which form air pockets through layers of fabric. This allows the amount of material to be significantly reduced. On top of this comes another full-surface layer of Shotcrete. Directly after the printing process, the fiber reinforcement - optimized according to the force distribution - is tacked onto this first layer of concrete. The final layer is another full-surface layer of concrete. This is smoothed by a milling machine, and as soon as the concrete has cured, all stressing devices are removed. The final result is a thin concrete support structure with the textile formwork still visible on the underside.

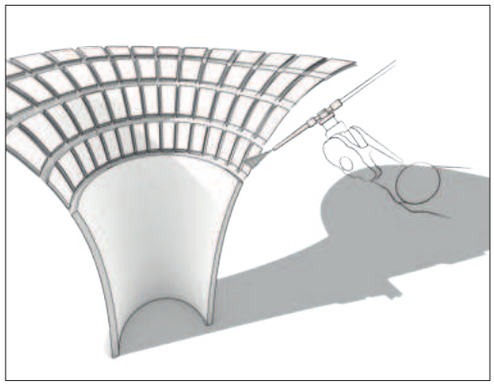


Figure 1 / Left side / Perspective West from Mandelnstraβe
Figure 2 / Right side / Shotcrete printing method on textile formwork sheet

Figure 1 / Top / Site plan
Figure 2 / Right side / Top view of site model

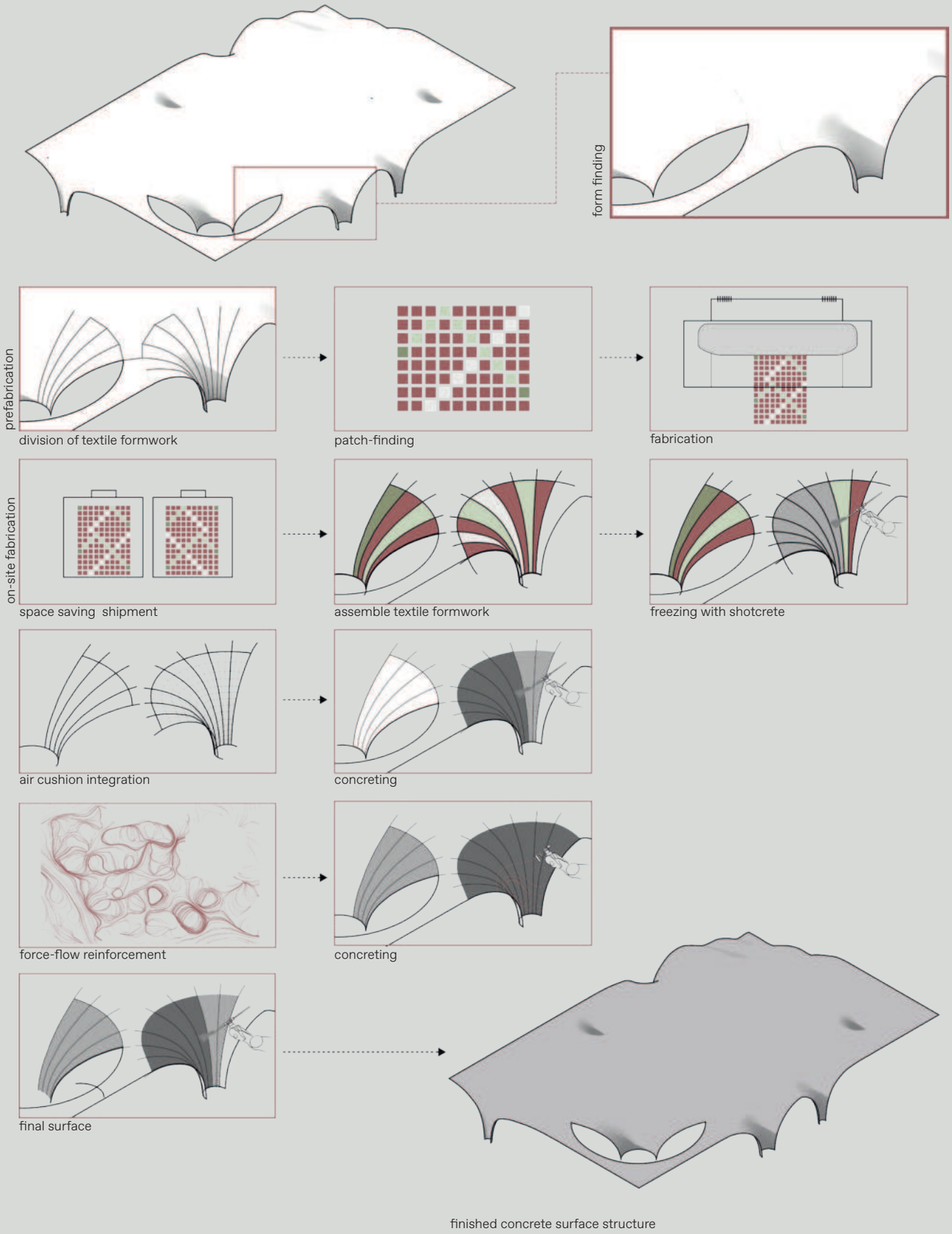
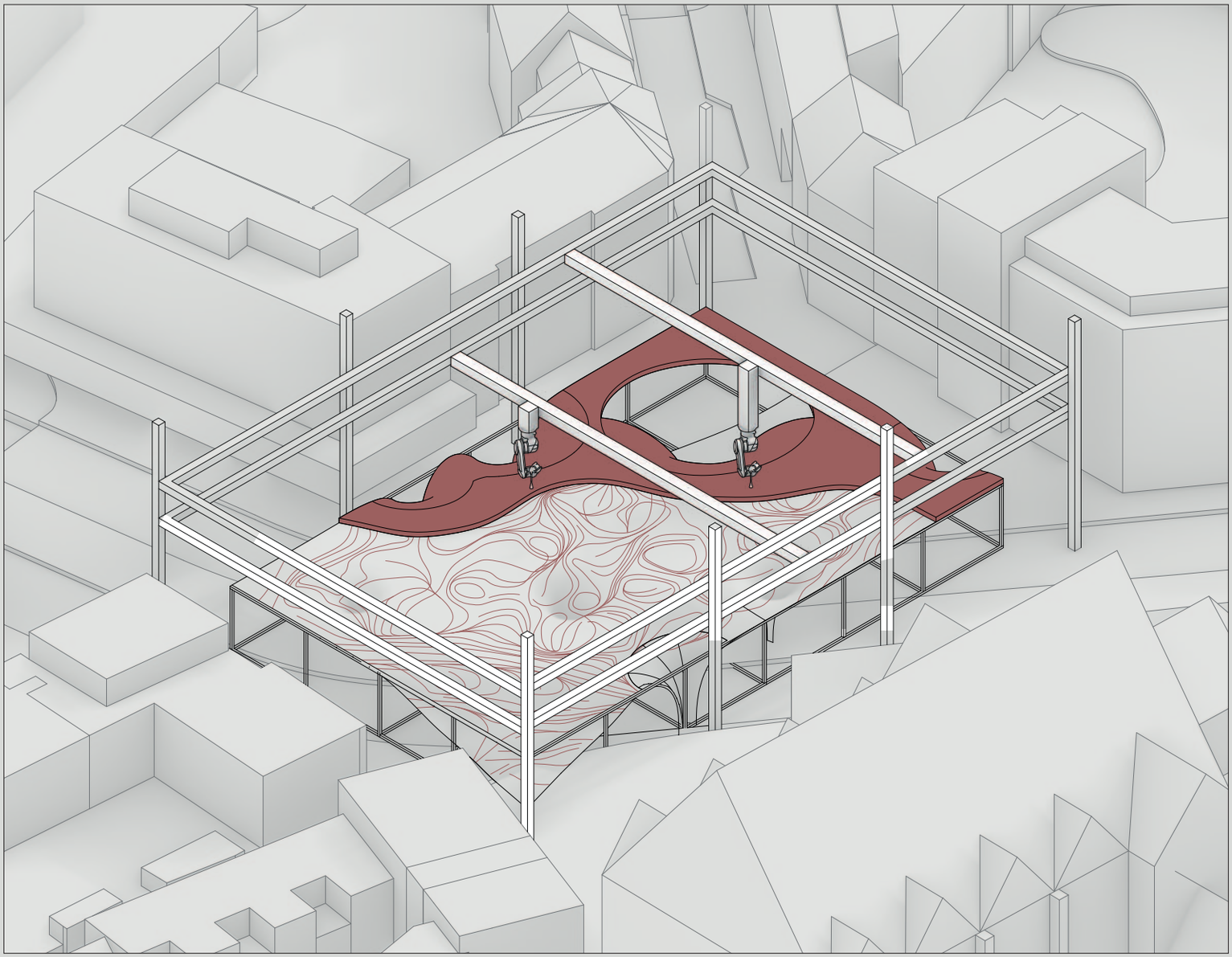
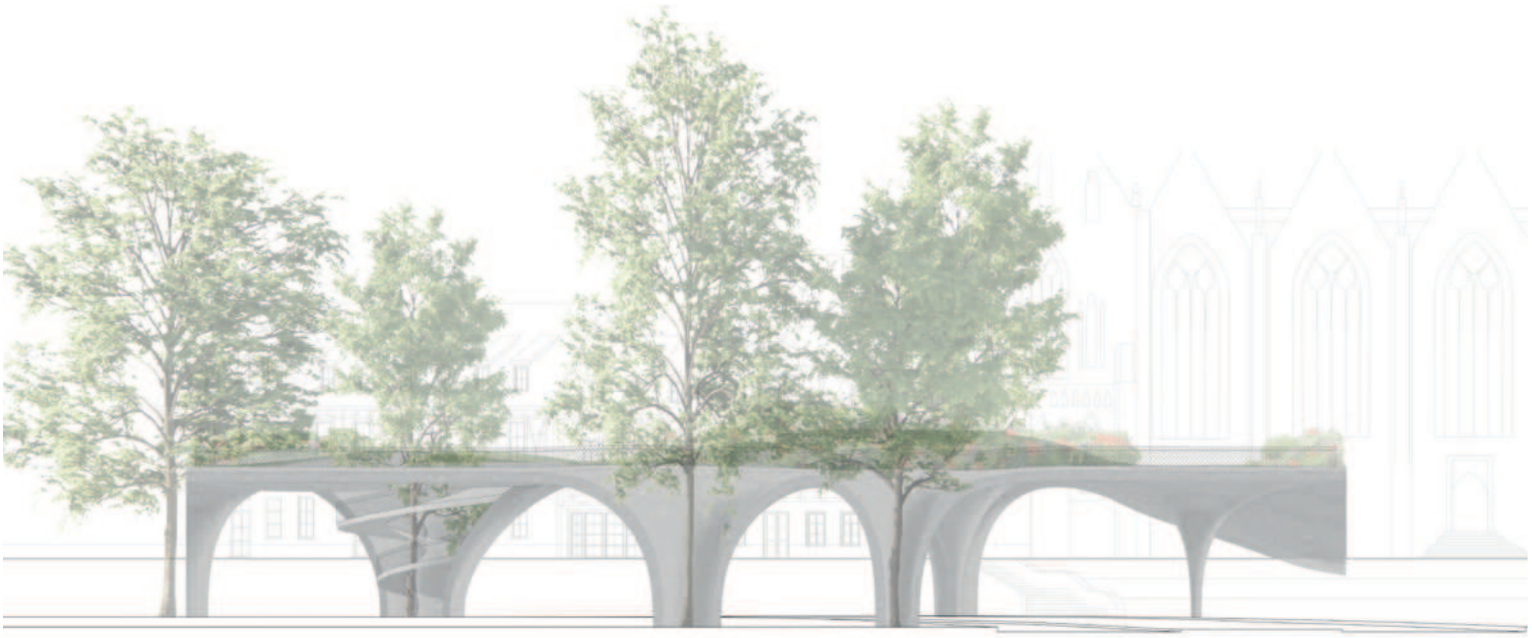


Figure 1 / Top / Parametric planning, fabrication and on-site assembly process
Figure 2 / Right side / On-site robotic fabrication setup





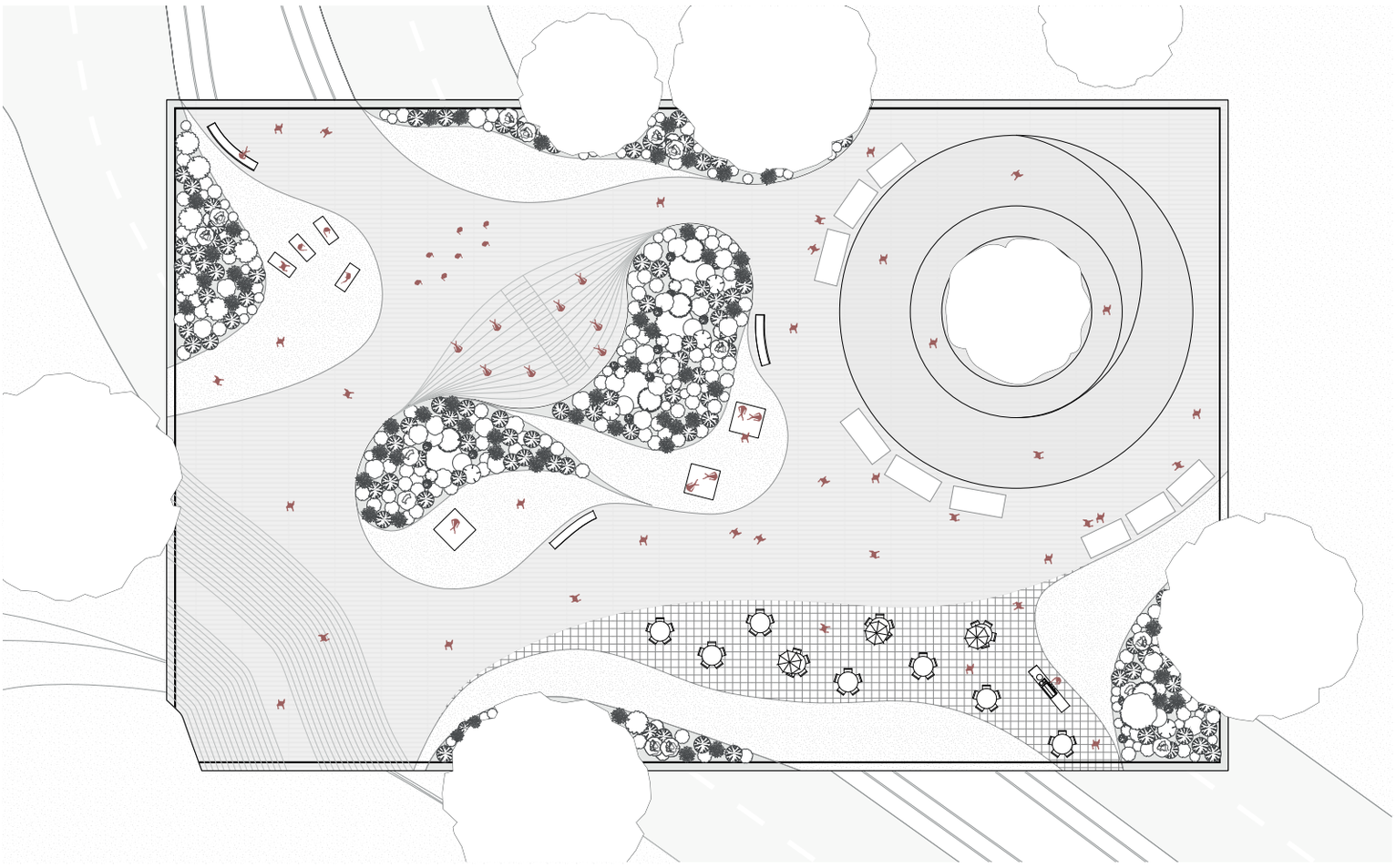
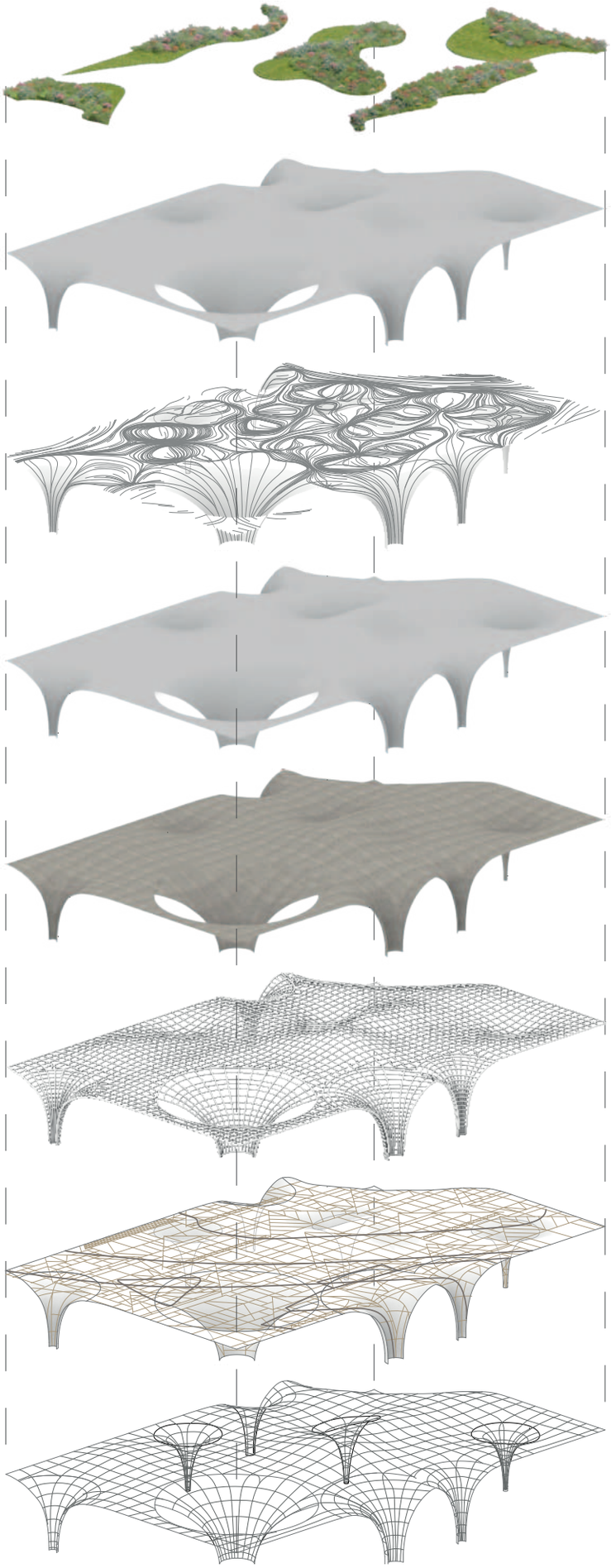


Figure 1 / North elevation
Figure 2 / Bottom / Floor plan of upper level
Figure 3 / Right side / Isometric view of construction layers, forceflow diagram and structural grid



TREEDIMENSION

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The building volume is placed as solitaire in the center of the original area of the Ägidienmarkt. The building does not reference to the surrounding buildings or the street. It stands in such a way that it can be seen from Mandelnstraβe, but does not block the view of the Ägidienkirche. The newly designed bicycle path passes underneath the building. The first floor and top floor are designed to be open and accessible for the public. They function as a complement to the plaza spaces, allowing the building to integrate naturally into the plaza without interfering too much with the plaza level.
The supporting structure is developed out of the requirement for a minimal footprint on the square. On the first floor, there are three large columns, which split twice to form three columns each in the vertical course of the building. The diameters of the columns thereby become smaller from the bottom to the top. The structure followst he conceptional logic of tree branches. A triangle with reinforced reinforcement is formed in the floor slabs between the columns. This allows any bending stresses to be absorbed. The complete supporting structure does not require load-bearing walls and is fully braced by the diagonal elements of the columns.
The columns are manufactured additively with the Large Particle Bed 3D printing Method. Vertical reinforcement is integrated using the WAAM technology. Floor slabs with optimized ribs are to be printed from concrete using the Shotcrete process. Reinforcement will be welded by a Mesh Mould robot. All components will be prefabricated on site and then positioned and installed by crane.

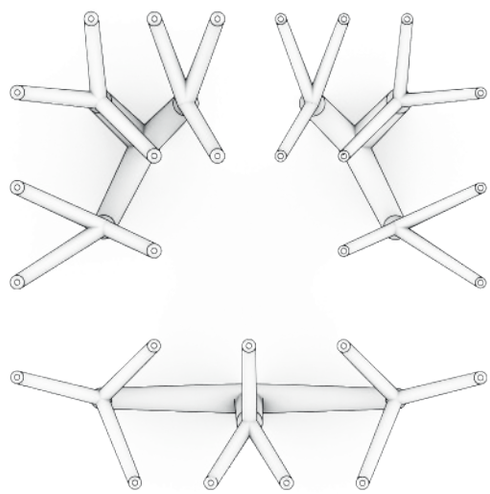


Figure 1 / Left side / Exterior perspective north facade
Figure 2 / Right side / Top perspective of tree-like load bearing structure

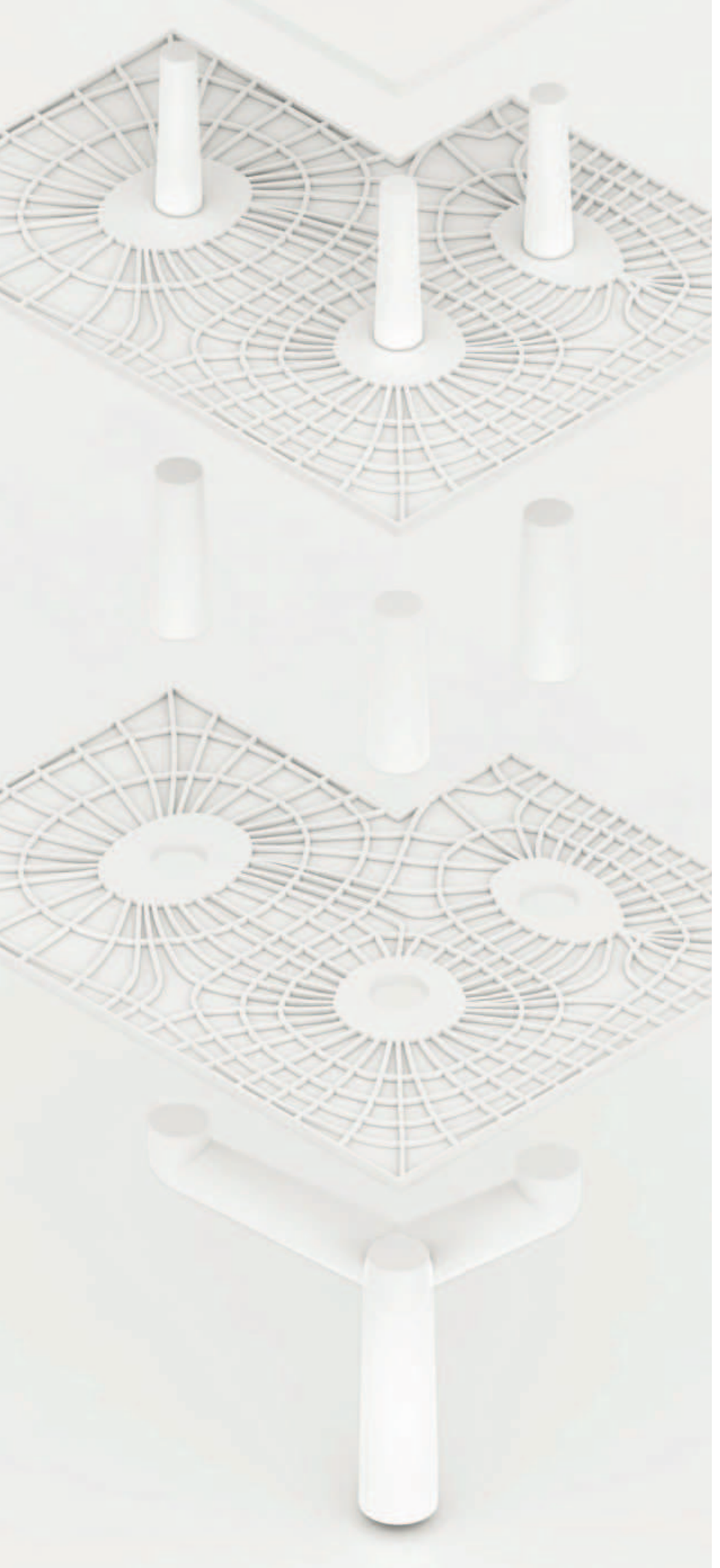
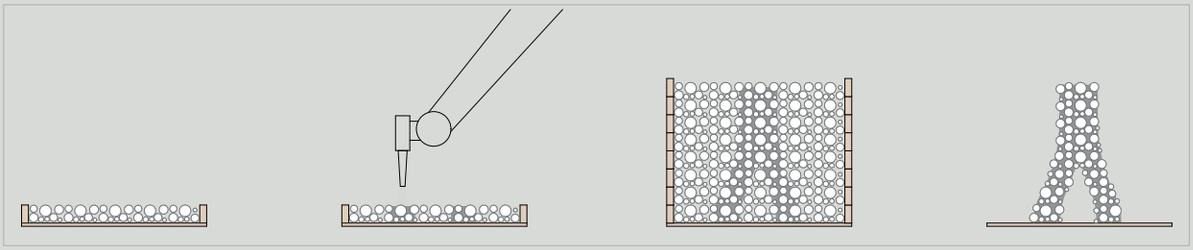
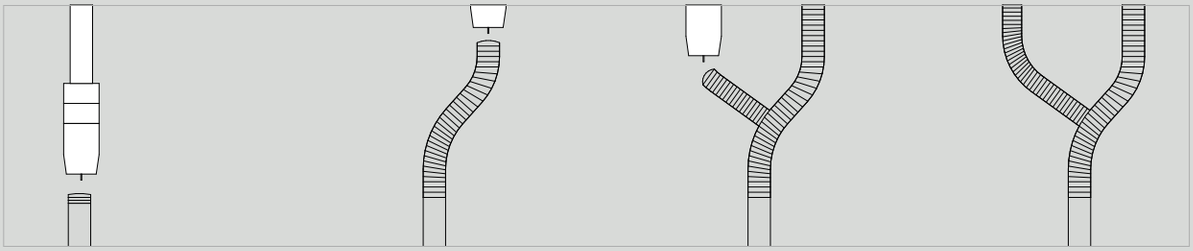


Figure 1 / Left side / Isometric view of structural stacking / Treelike columns combine with forceflow optimised ceilings
Figure 2 / Right side / Model of building structure and facade

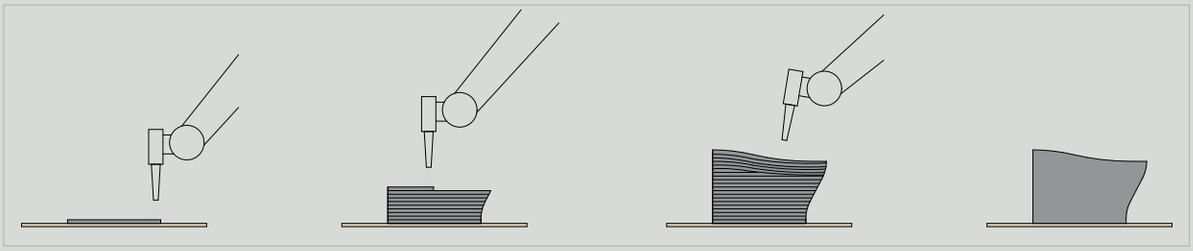
Large particle bed 3D Printing



Wire and arc additive manufacturing



Shotcrete 3D printing



Mesh mould roboter

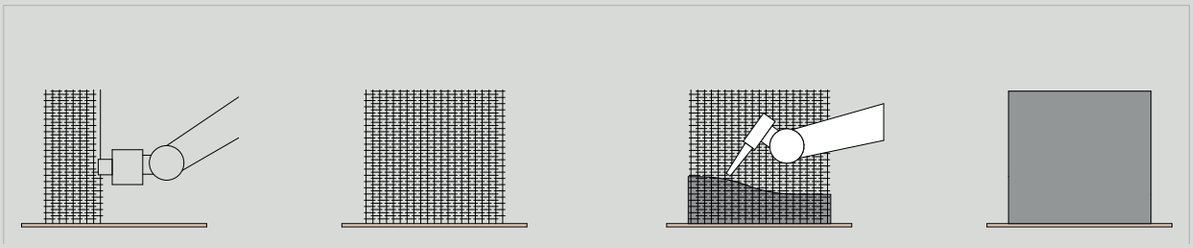
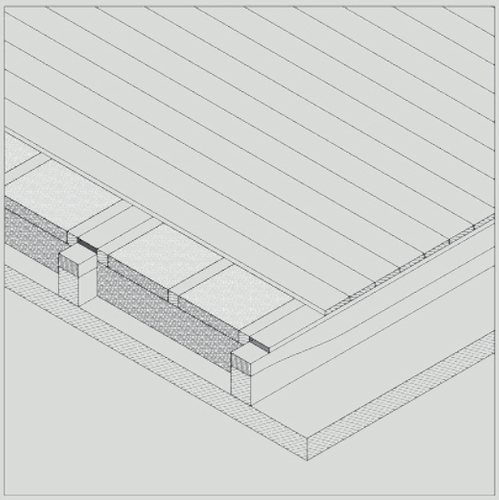
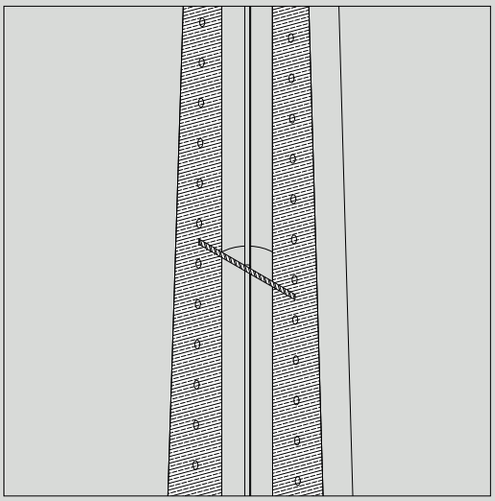
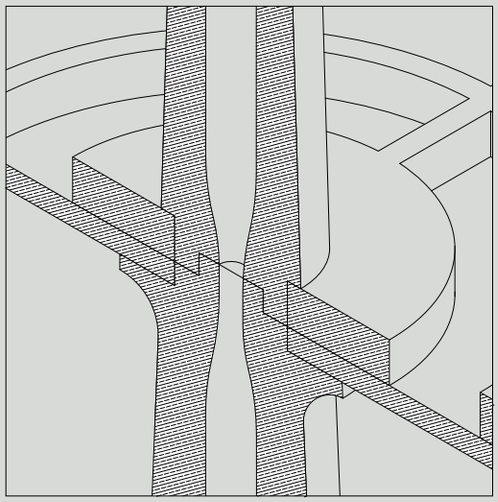
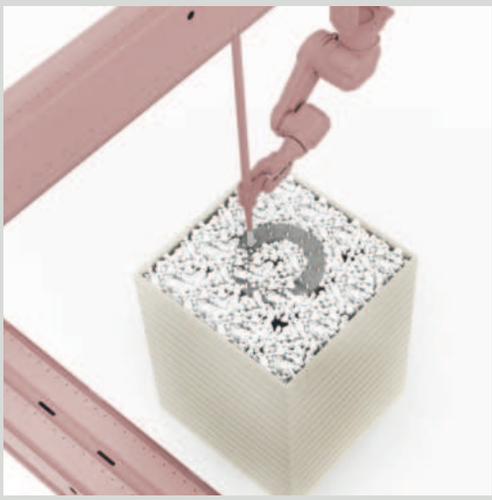
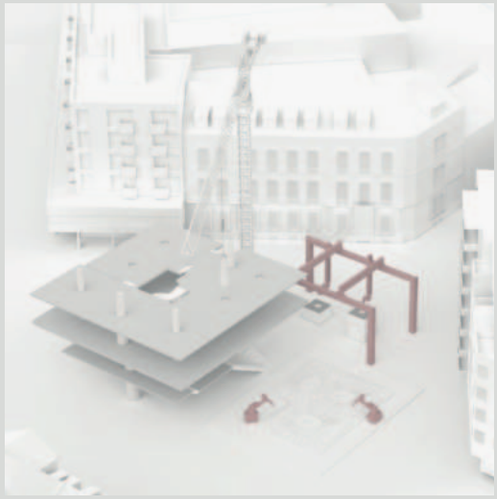


Figure 1 / Left side / 3D Printing technologies applied in the design proposal
Figure 2 / Right side / Construction layers of standard ceiling construction / Joints of pillars and ceilings / 3D printing technologies for on site fabrication / assembly set up on site



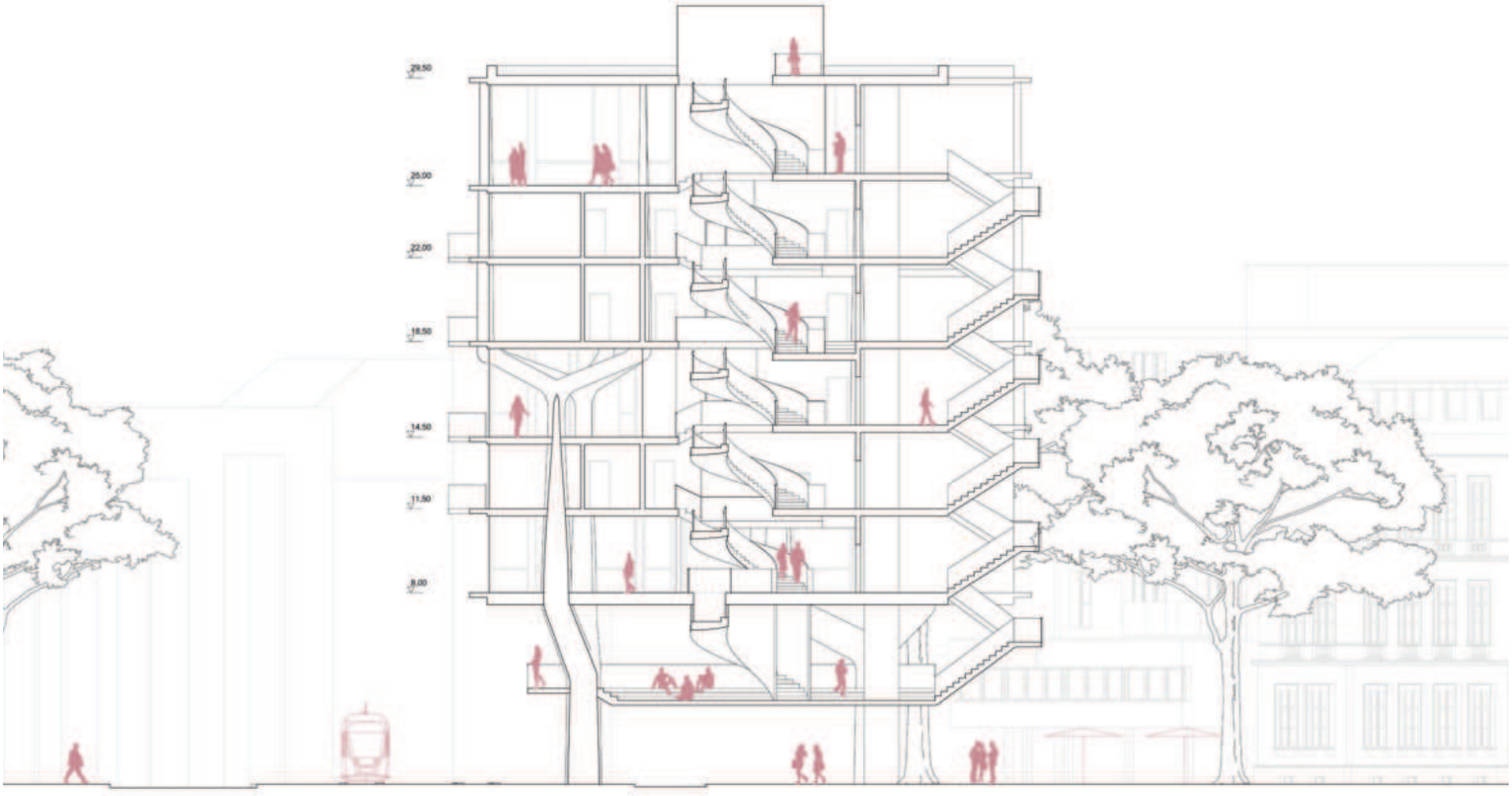
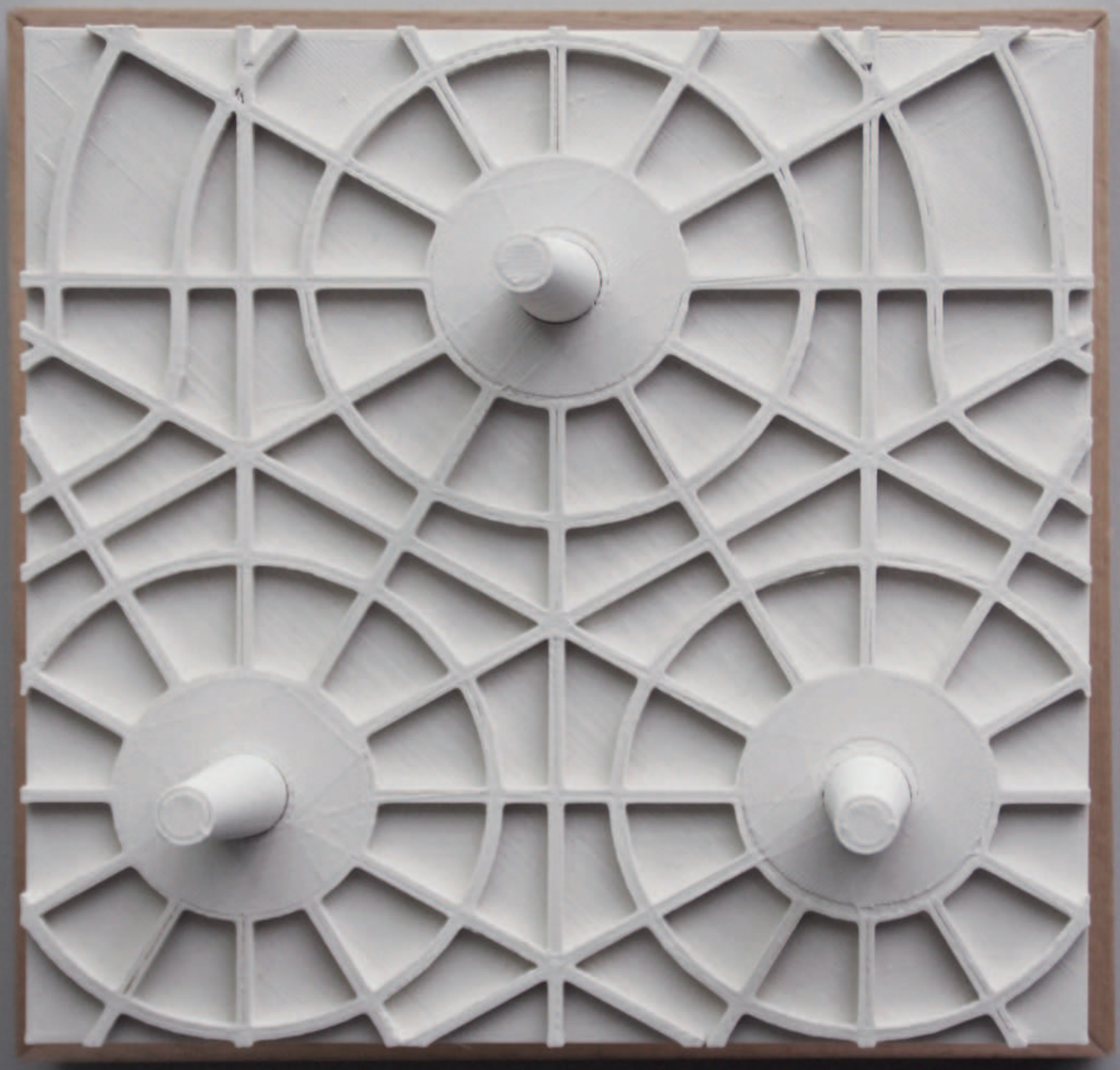


Figure 1 / Left side / Vertical section
Figure 2 / Right side / Top view of structural ceiling model



INTEGRATION OF INDIVIDUALIZED PREFABRICATED FIBRE REINFORCEMENT IN ADDITIVE MANUFACTURING

MATERIALS AND PROCESSES

Integration of Individualized Prefabricated Fibre Reinforcement in Additive Manufacturing with Concrete. One of the biggest challenges in 3D printing with cementitious materials is the integration of reinforcement. As 3D-printed, unreinforced concrete components can only compensate for limited tensile forces, their range of applications is confined to predominantly compression-stressed components and thus the structural potential of 3D-printed parts remains unrealized. The aim of this project is to develop textile-based reinforcement strategies for additive manufacturing with concrete and to utilize the advantages of textile reinforcement (e.g. corrosion resistance and material flexibility) for the production of material-efficient, individualised structures.

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ASSOCIATED DESIGN PROJECTS

Shelltonics
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AMC TRR 277 PROJECT

A05

SHELLTONICS

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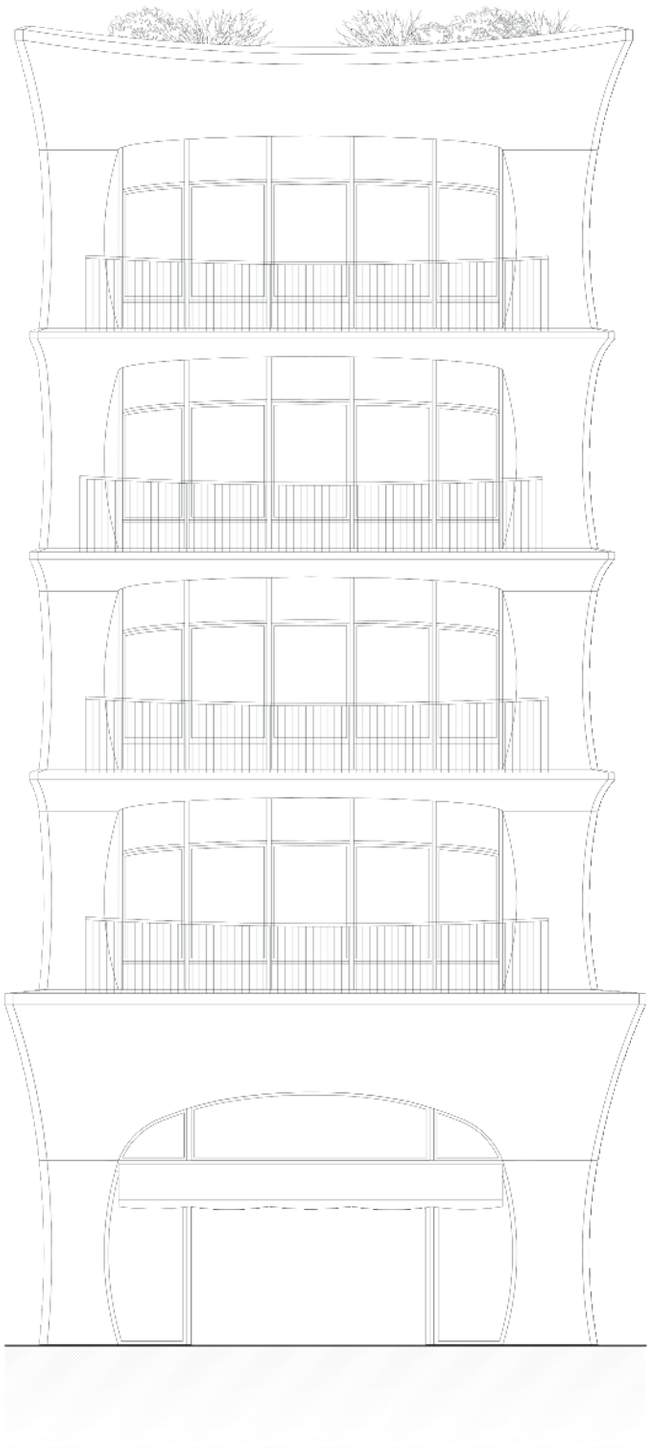
This design address the material efficiency of the shell and its potential to effectively transfer loads to the ground. Therefore, this approach is exploiting vaulted ceilings and columns, composed of three shells that are mutually self-bracing providing a free architectural layout. Lightweight timber structures seperate the spaces from each other. The integration of custom freeform fibre reinforcement facilitates the reduction of concrete material used, provides an ultralightweight support structure, and enables a significant degree of design freedom. Due to transportation constraints, the shells are separated into segments for prefabrication that can than be assembled on site with dry joints.

A04/A05
Shelltonics was selected for the further elaboration of the A04/A05 demonstrator to showcase the AM of large-scale building components being composed of a column, a wall and the vaulted ceiling with bracing ribs.

Figure 1 / Left side / Exterior perspective south
Figure 2 / Right side / Model of fibre-winded reinforcement frame



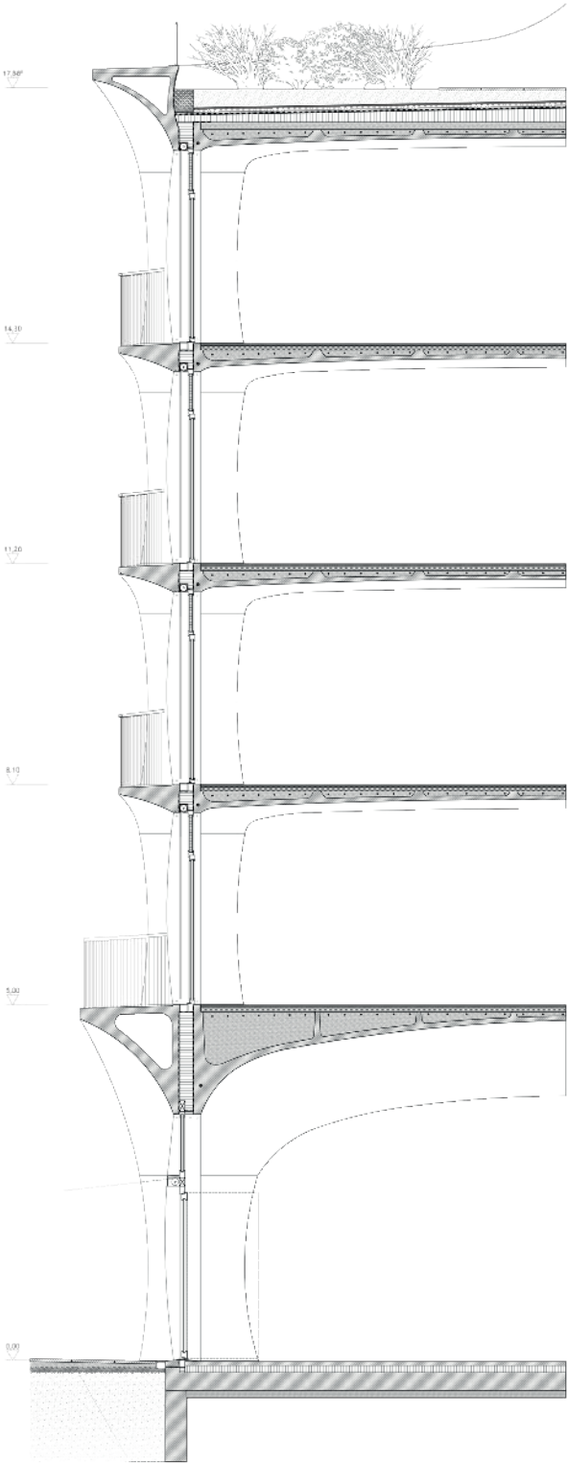
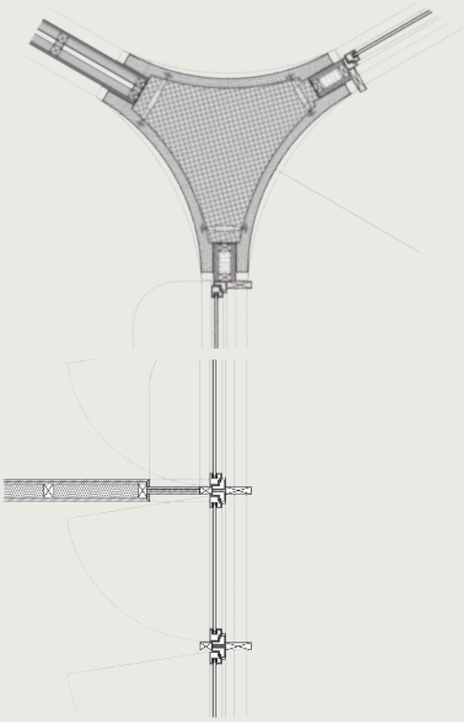


Figure 1 / Left side / Facade elevation and vertical section
Figure 2 / Right side / Working model of material-efficient, forceflow optimizied column shape



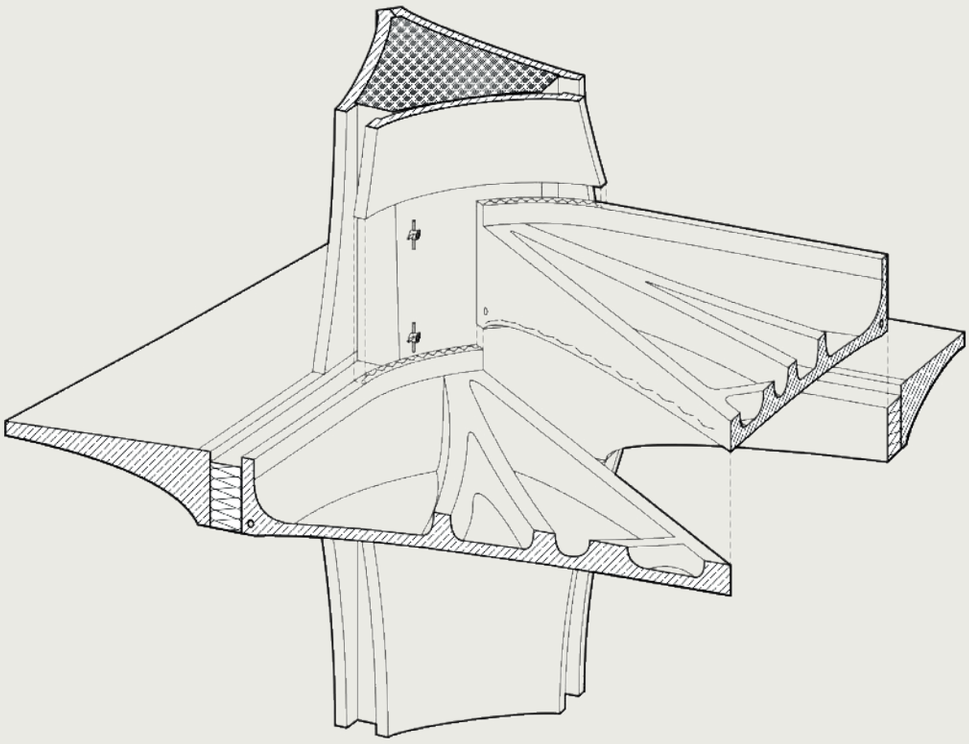
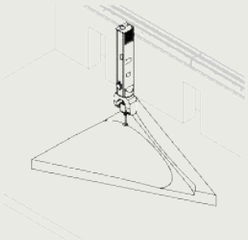
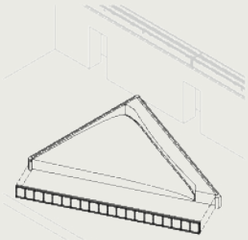


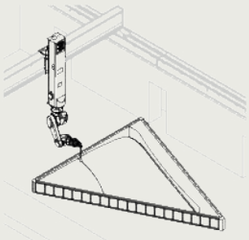
Figure 1 / Top / Horizontal detail sections of columns and wall joints
Figure 2 / Bottom / Isometric view of structural knot combining facade, column and ceiling elements
Figre 3 / Right side / Scheme of digital fabrication process



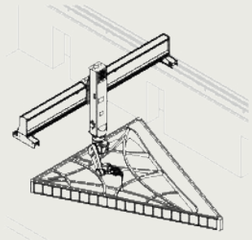
S1 milling of wax-formwork



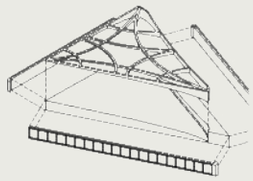
S2 building the formwork



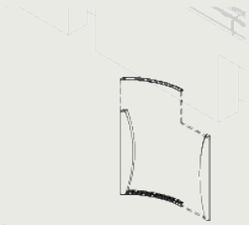
S3 shell shot-creting



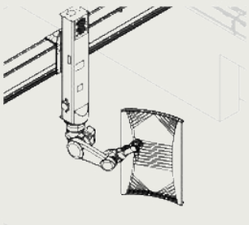
S4 rib shotcreting



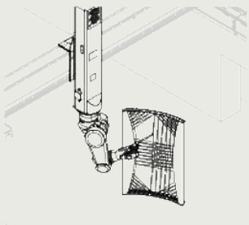
S5 stripping of formwork



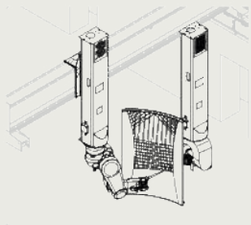
D1 assembling frame



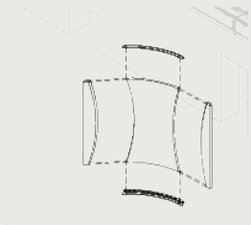
D2 winding first layer



D3 winding second layer

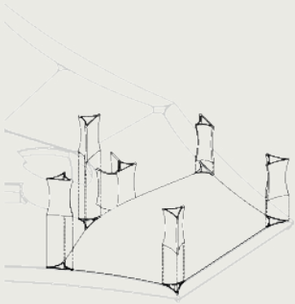


D4 shield printing



D5 stripping the frame

D6 assembling column



B1 placing columns

B2 placing vault sections

B3 tensioning edge-cabel

Figure 1 / Top / Isometric view of primary construction layers
Figure 2 / Right side / Structural model

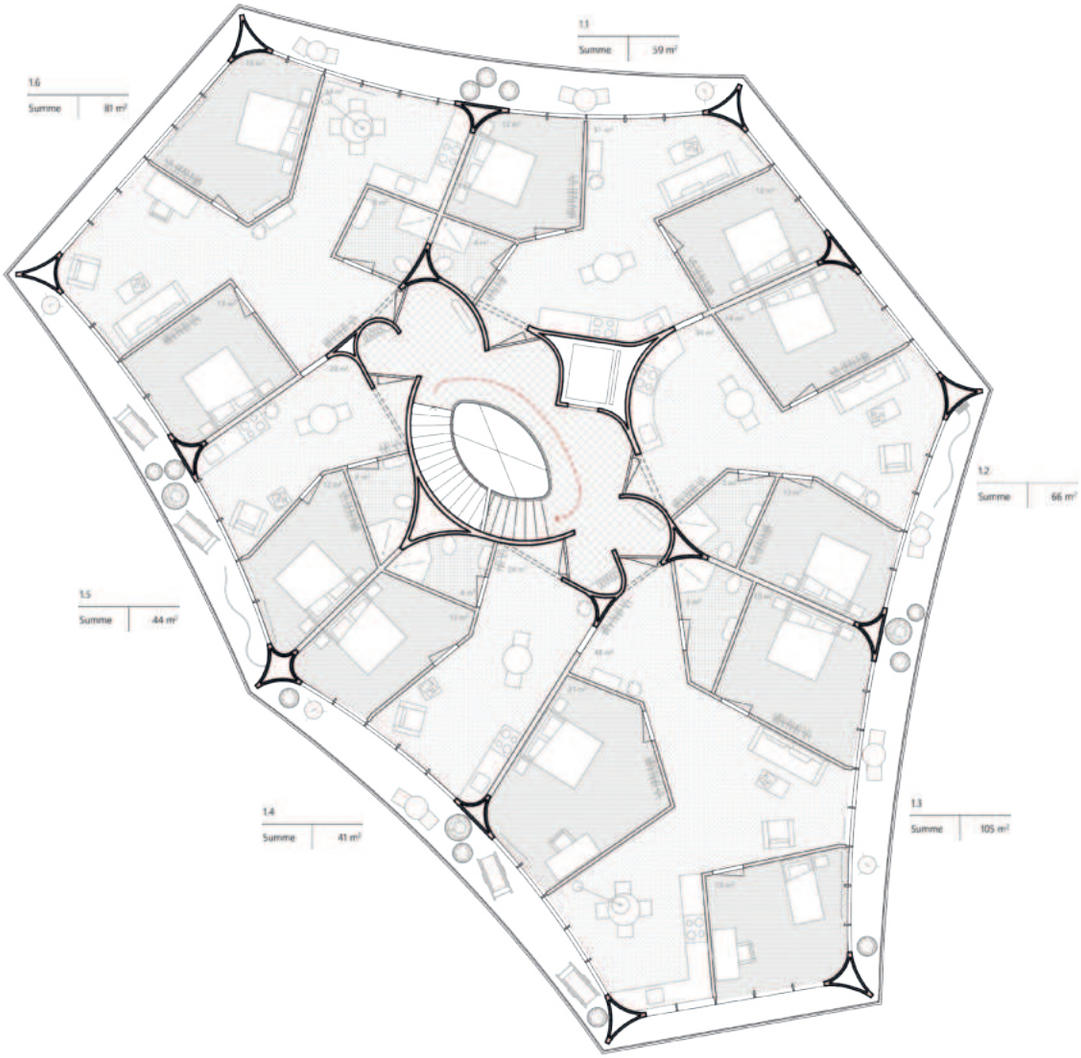


Figure 1 / Top / Standard residential floor plan
Figure 2 / Right side / Interior perspective of ground floor market space

PRINCIPLES OF MOBILE ROBOTICS FOR ADDITIVE MANUFACTURING IN CONSTRUCTION

MATERIALS AND PROCESSES

This research examines the architectural implications of mobile robotics for AM in construction and develops methods for their implementation. The material deposition method of clay and concrete extrusion is used to investigate AM strategies for mobile robots. By implementing advanced sensor and control solutions, autonomous localization and precise manipulation techniques for mobile AM are explored with the aim of manufacturing large building components whose size exceeds the robot's static workspace. Additionally, this research aims to provide scalability to AM processes by examining the use of multiple robots to cooperate on individual manufacturing jobs.

RESEARCH TEAM

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Positive substraction
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AMC TRR 277 PROJECT

B05

POSITIVE SUBSTRACTION

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This experimental project is a building design composed of two core concepts: a negative clay cast on the first floor and a clay-printed façade placed above it, but both fabricated exclusively with AM technologies. 3D-printed converging clay domes serve as a mold to shape the ground-floor market hall, which is casted with concrete and washed off after setting. The recycled clay is being re-used to fabricate the façade of the residential building above. To protect the residential facade from weathering, it is being coated with spray plaster.

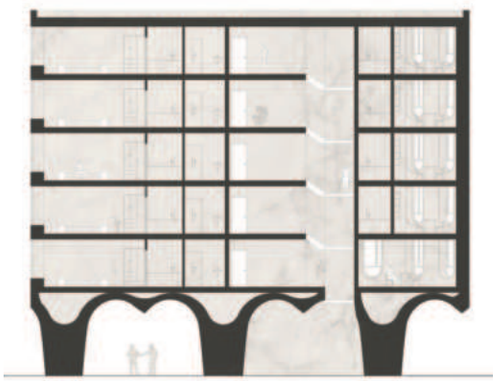

Figure 1 / Left side / Working model of clay- and force-flow-formed vault elements
Figure 2 / Right side / Vertical section of structural concept with form optimised vaults carrying the upper stories

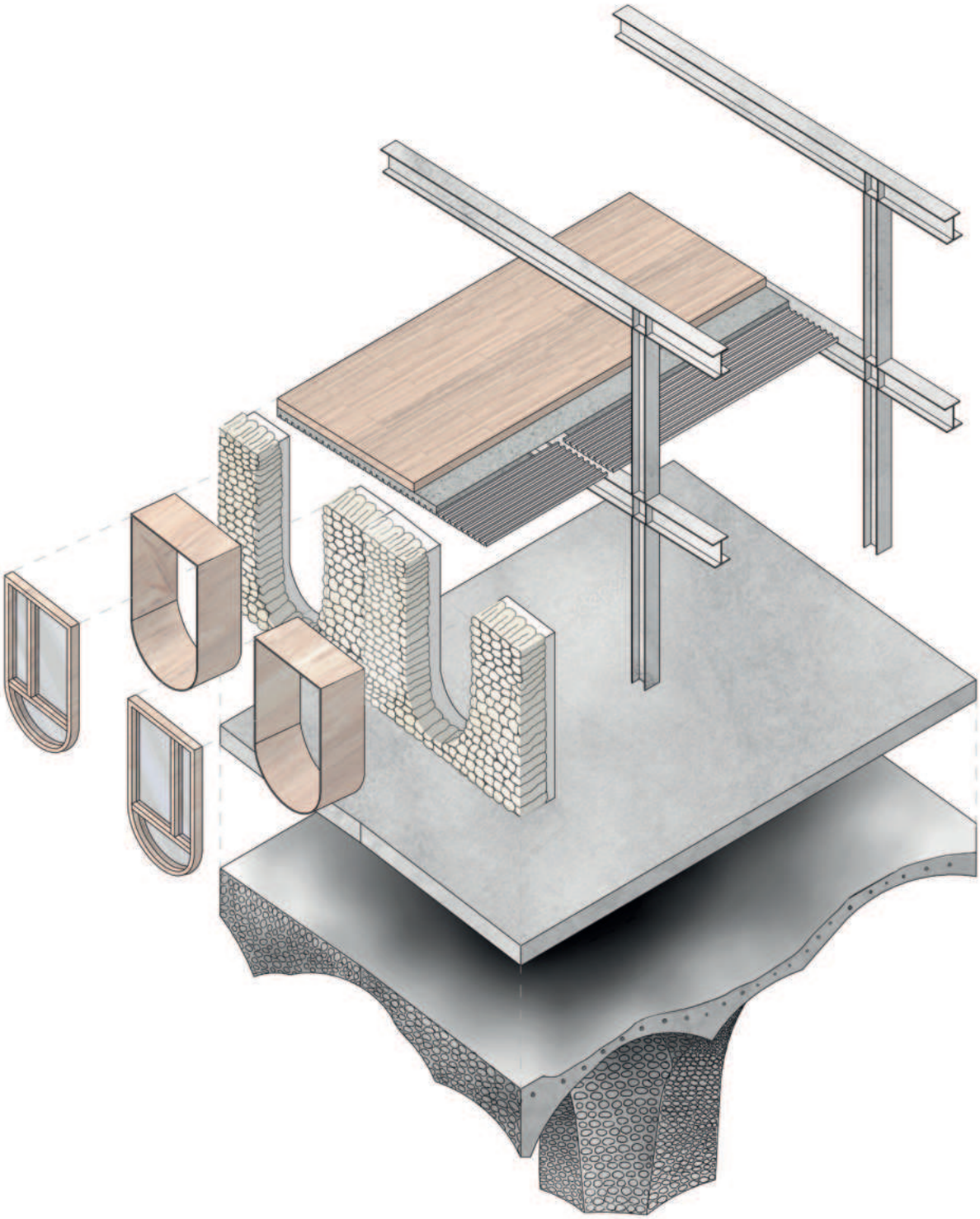

Figure 1 / Left side / Isometric explosion drawing of the different building components
Figure 2 / Right side / Interior perspective of market space


STAUBLI

ROBOTIC FABRICATION OF RAMMED EARTH ELEMENTS

MATERIALS AND PROCESSES

The research project „Robotic fabrication of rammed earth elements“ aims to develop an applicable, robotic manufacturing process for rammed earth components. Rammed earth is an ancient building technique used since 8000 years. The technique is based upon layered compaction of earth in a formwork by using a manually driven wooden tamper. Today formwork technology has improved and pneumatic tampers have replaced traditional hand tampers. However, the process is still manual in nature, which leads to inefficiencies compared to other building materials and techniques. In contrast to concrete, where stability depends on a chemical reaction, rammed earth gains its fundamental stability merely from the compaction process. Therefore, a formwork is only needed, where compaction takes place immediately. In contrast to the traditional technique, the objective in this research project is the development of an actively moved formwork and a compaction tool that is mounted as an end effector to a robot.

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ASSOCIATED DESIGN PROJECTS

Rammed architecture
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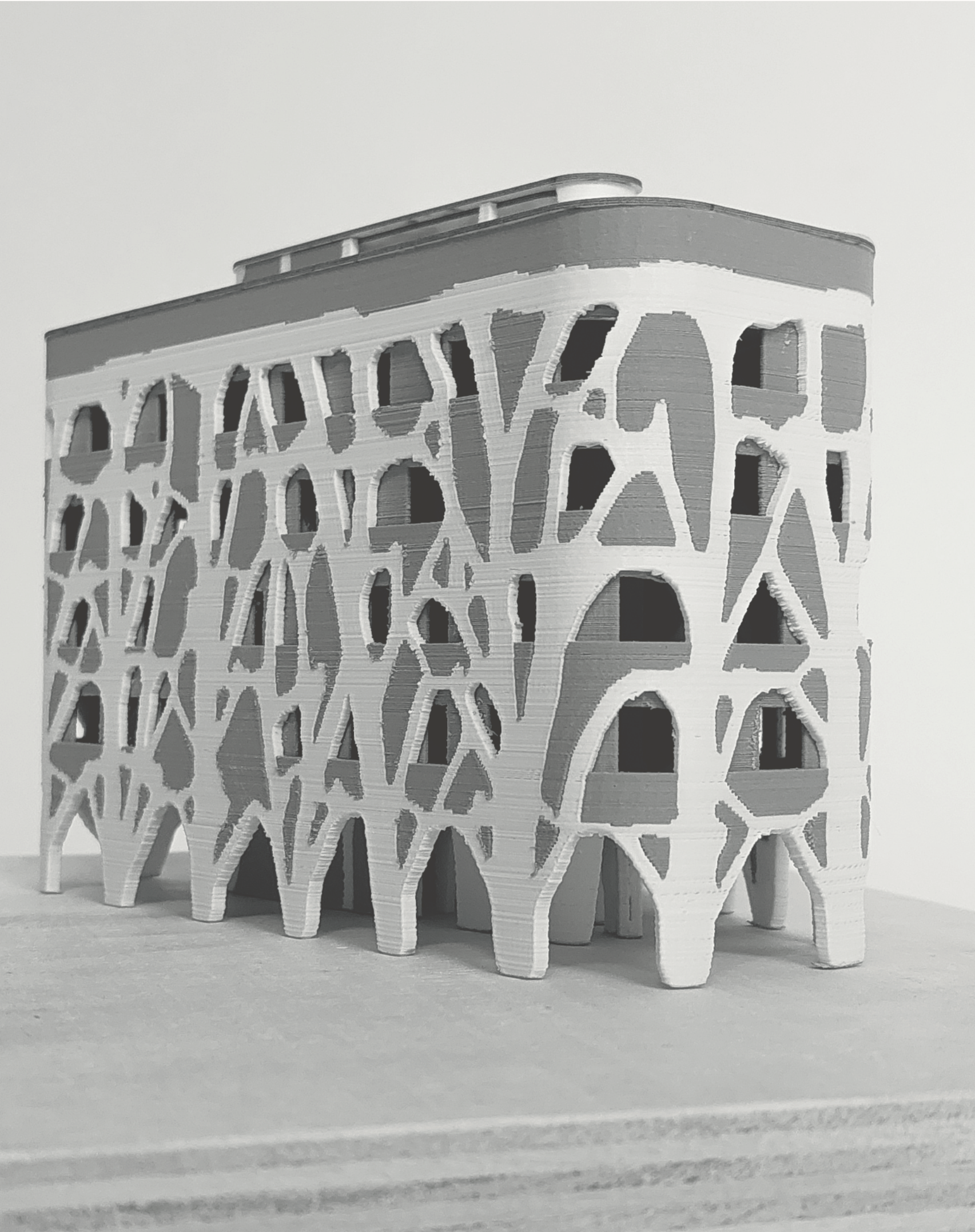

RAMMED ARCHITECTURE

GABRIELA KIENBAUM &
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TU BRAUNSCHWEIG

The building concept explores a differentiated nozzle mixing system allowing to combine clay, concrete and lightweight clay within a robotic ramm process. Rammed earth comprises the building envelope and acts as formwork for integrated load -bearing structures of rammed concrete. For the insulation of the building a layer of lightweight clay serves for insulation purposes. The load-bearing building structure derived from a computational workflow features a streamlined force flow enabling the non-load-bearing structure to be fabricated with rammed earth and to provide space for openings such as windows or doors.

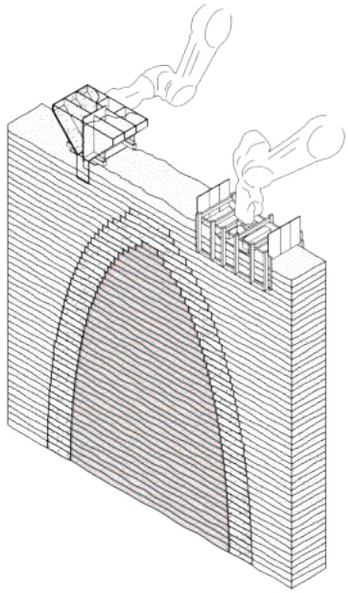


Figure 1 / Left side / Exterior perspective view of 3D printed working model
Figure 2 / Bottom right side / Sketch of robotic rammed earth technology

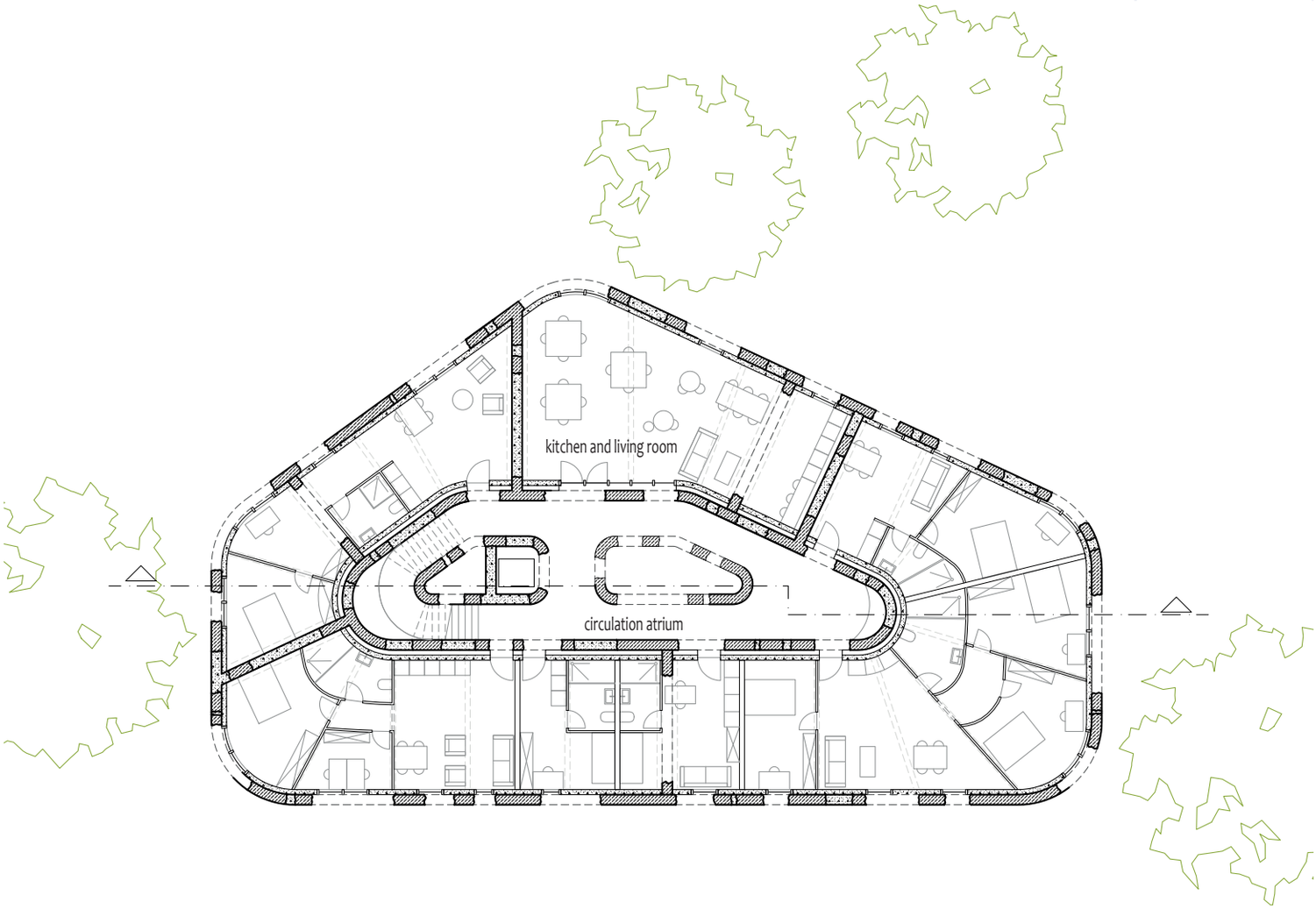
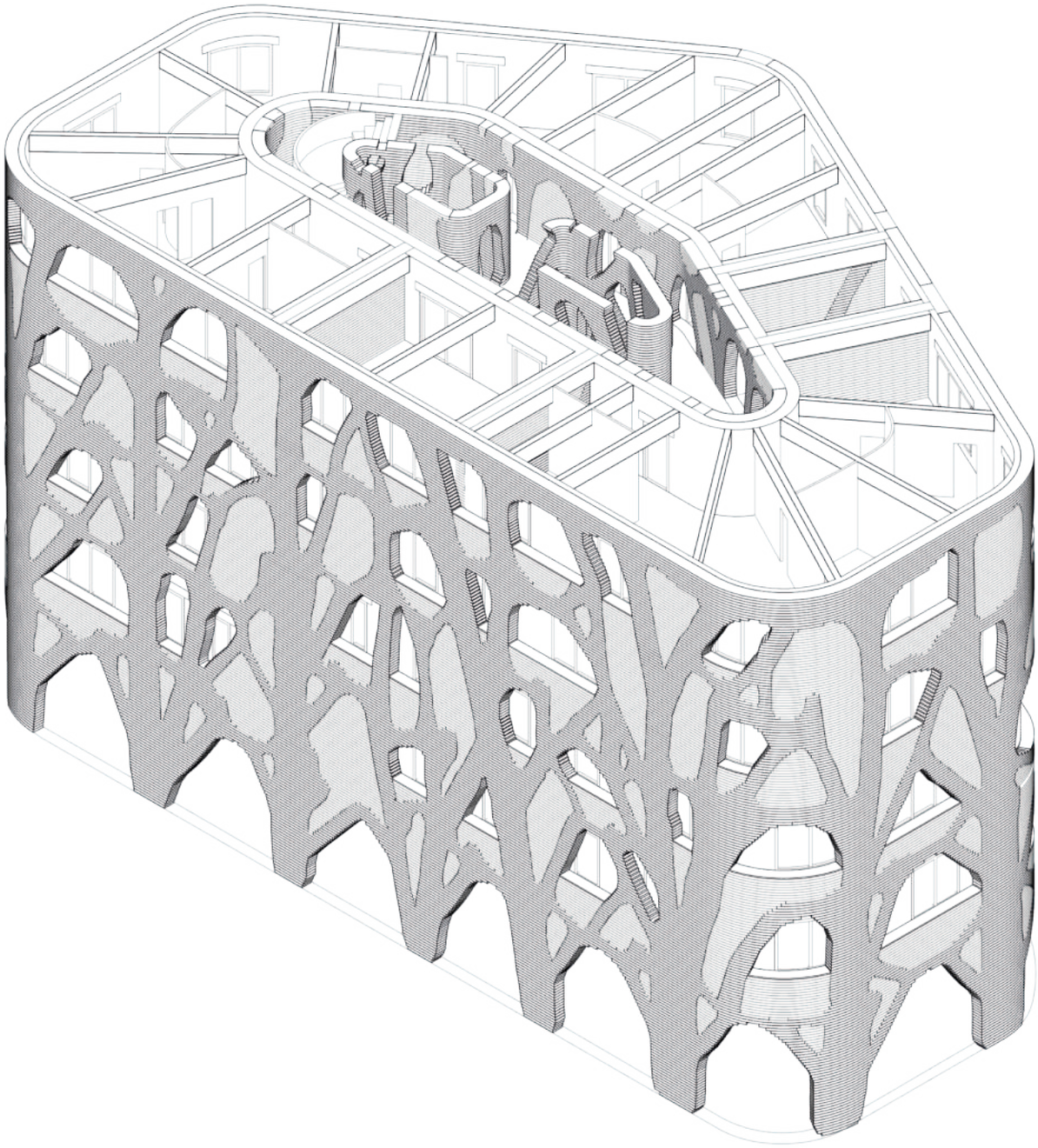


Figure 1 / Left side / Standard floor plan
Figure 2 / Right side / Axonometric view of building structure



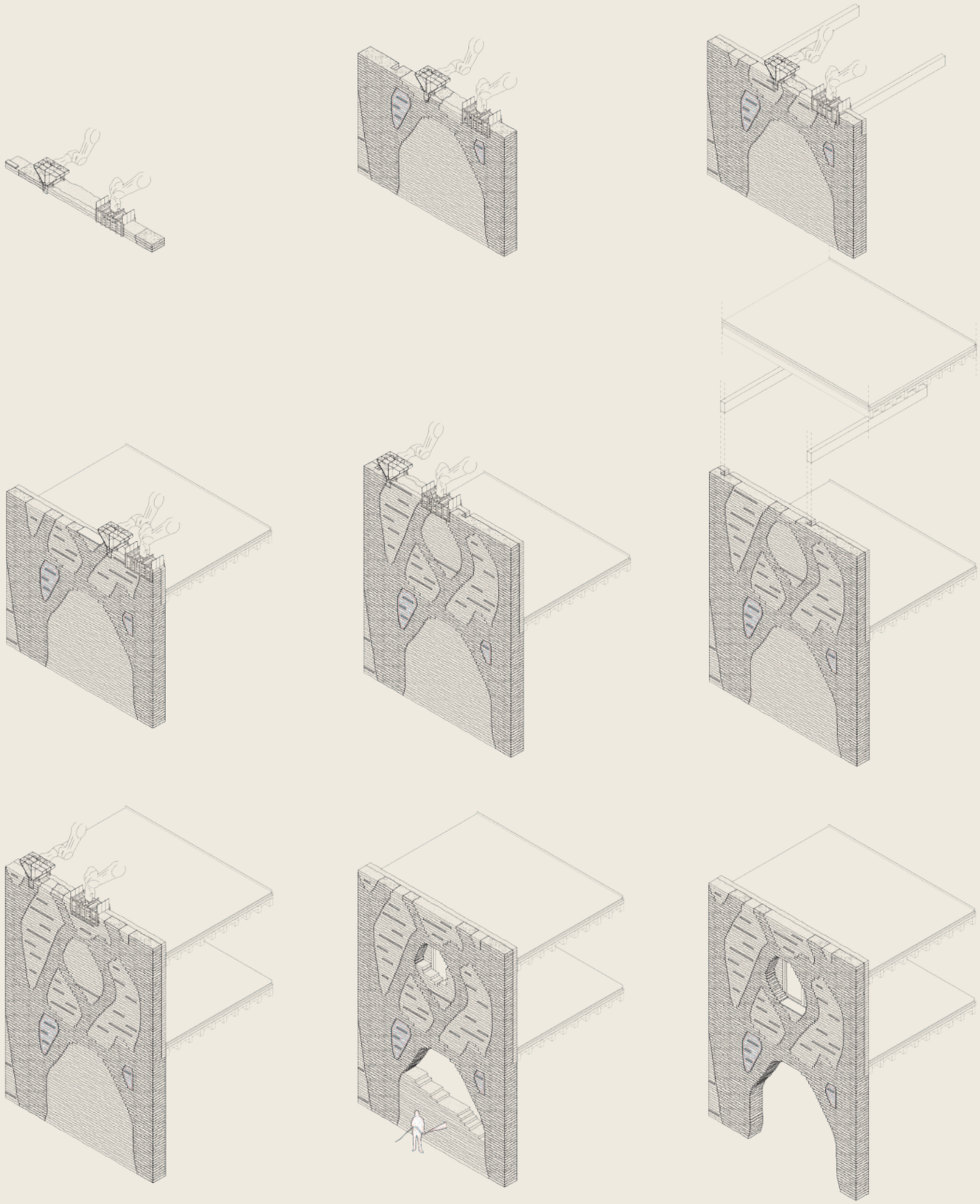
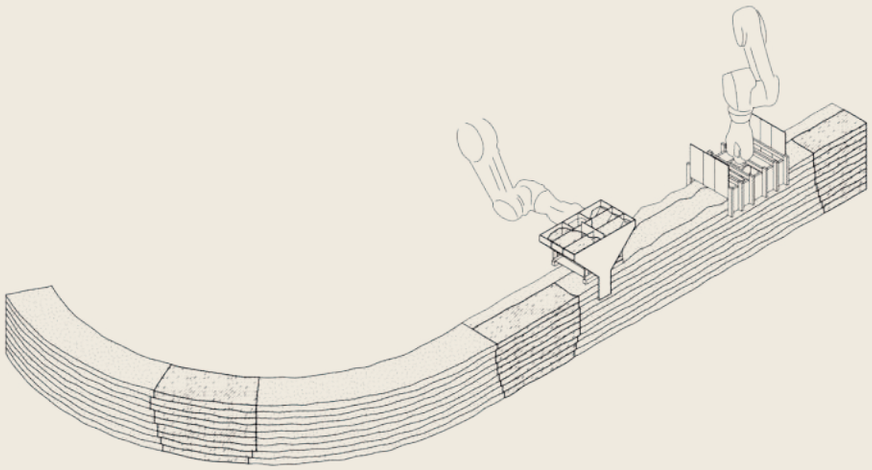
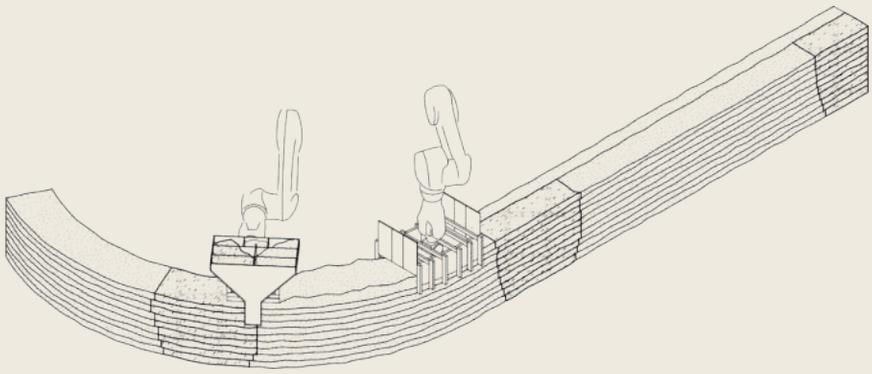
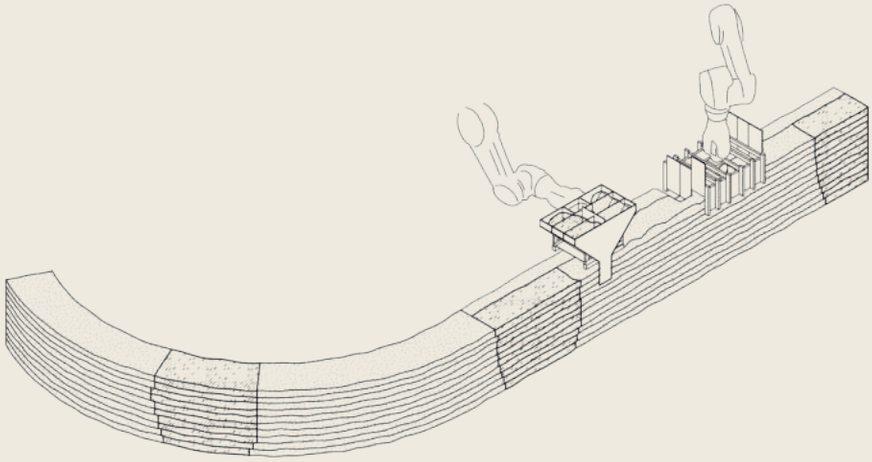


Figure 1 / Left side / Construction method with robotic rammed earth and on-site assembly
Figure 2 / Right side / Manufacturing setup for curved wall elements







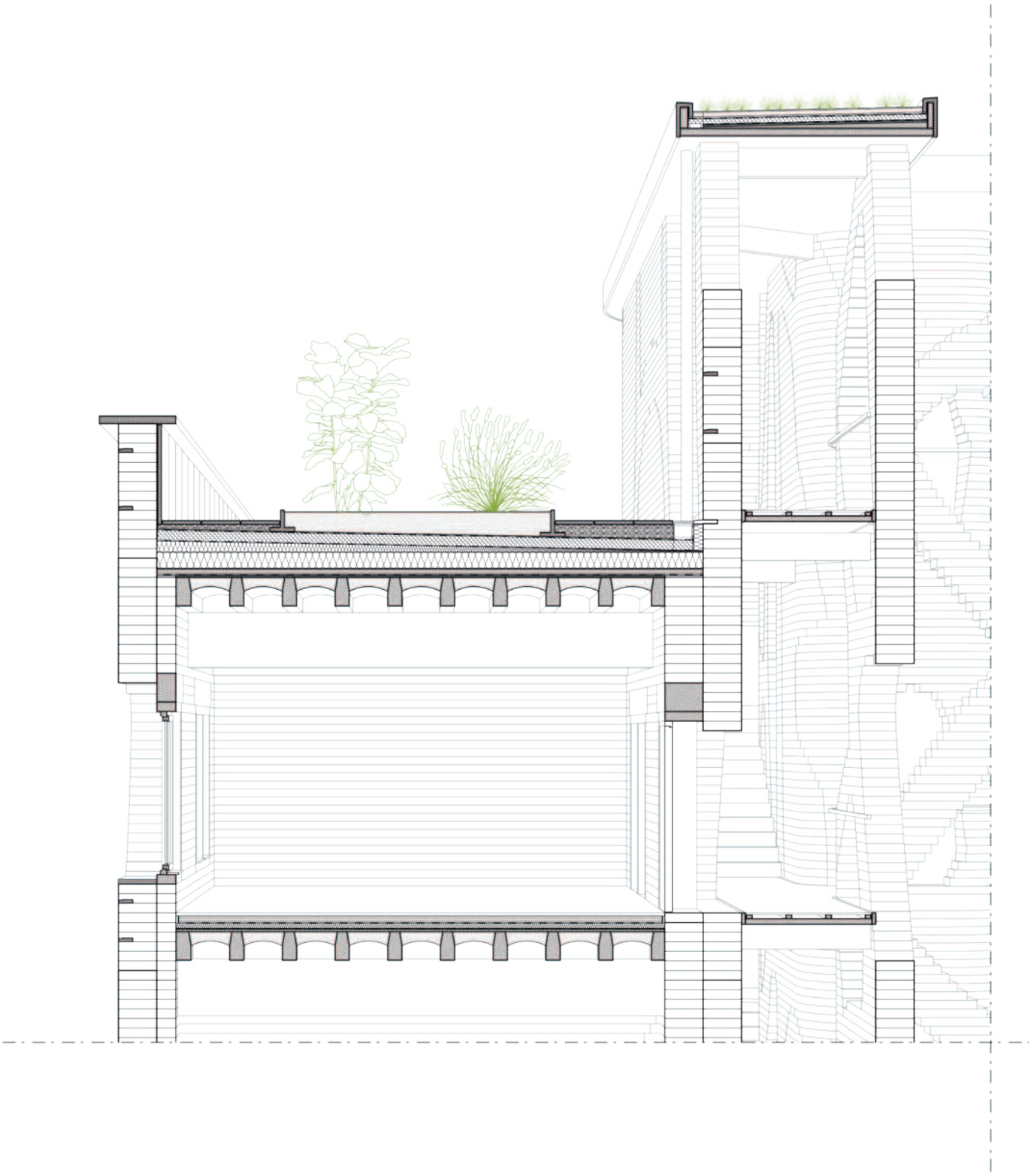


Figure 1 / Left side / Perspective detail section of core, roof and regular level
Figure 2 / Right side / Material model of earth and concrete combined wall elements

SUMMER SCHOOL

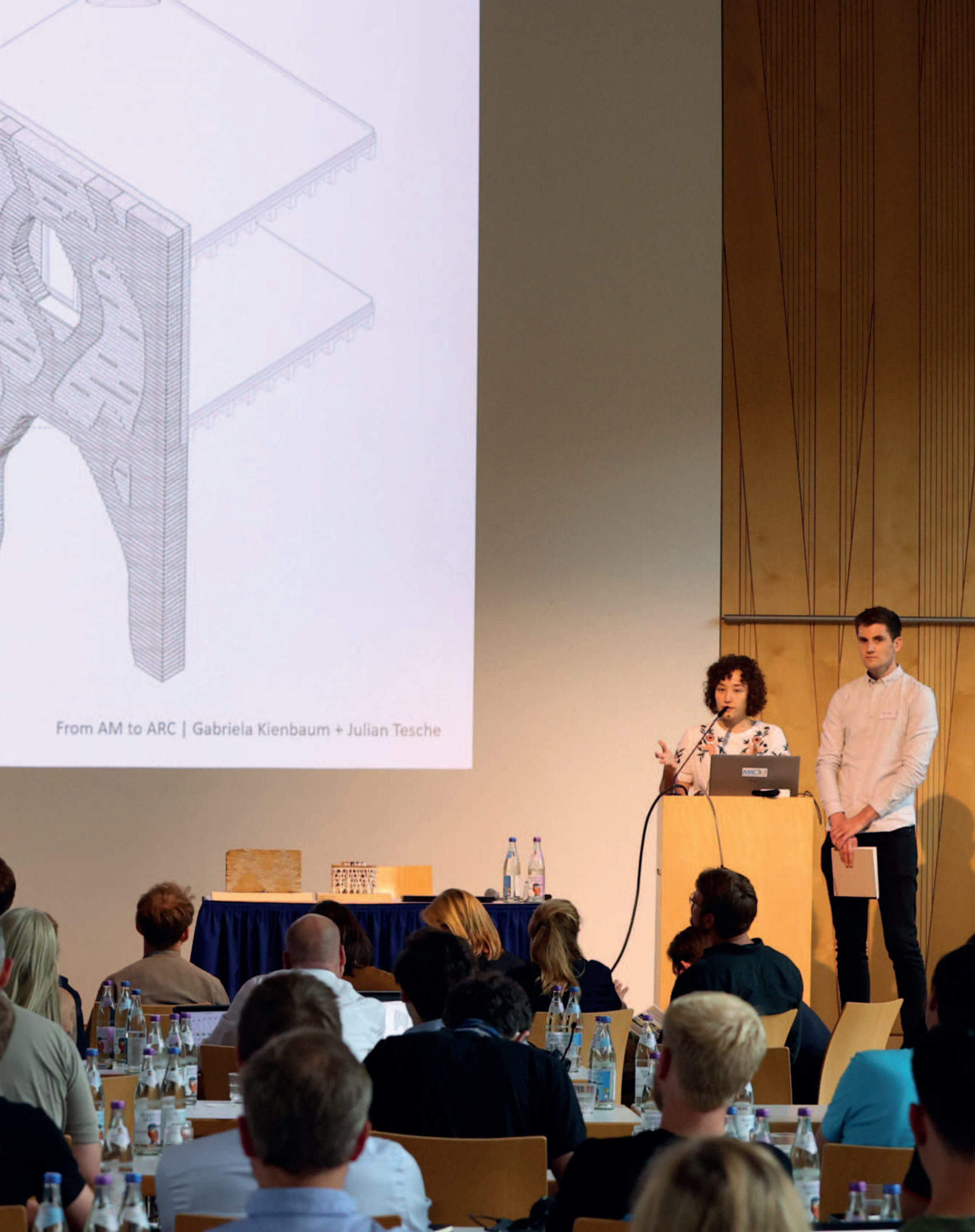
The Collaborative Research Centre Transregio TRR 277 Additive Manufacturing in Construction (AMC) met at the end of July for an intensive research exchange at Lake Ammersee. For one week, the Haus der Bayerischen Landwirtschaft was home to 80 AMC scientists and their guests. Among them were students from the cooperating universities TU Braunschweig and TU München as well as the Venture Lab. The five days of the Summer School brought a breeze of fresh air to the AMC and motivated the researchers for the upcoming second phase of the overall project. This year's AMC Summer School took a look back at the research highlights achieved so far as well as a look into the future. Here the focus was also on the question: how can additive manufacturing techniques be implemented and integrated in buildings in concrete terms? But the near future should also play an important role at this AMC meeting. Next year, the Collaborative Research Centre will be reviewed by the German Research Foundation (DFG). The so-called second phase of the AMC and the setting of priorities were discussed intensively among the researchers.

But first, university students of the cooperation seminar "From Additive Manufacturing to Architecture" succeeded in inspiring our scientists with creative and innovative ideas. In their final presentation, the students showed designs which integrate methods of additive manufacturing right into the construction process of a residential building. Aspects of these designs are now to be implemented and built in reality. In particular, they are to be used for a collaborative demonstrator, i.e. exhibits on which the techniques and possibilities of additive manufacturing can be demonstrated in a comprehensible and vivid way on a large scale. This collaborative demonstrator will be a central element of the DFG's review in 2023. How could one present scientific research results any more clearly than with a tangible object?

The scientists worked in small working groups and workshops on answers to the question how each sub-project can contribute to the collaborative demonstrator and to the second project phase. These intensive discussions often went on late into the evening. But the personal get-together of many scientists was also respected by a joint hike to Kloster Andechs and swimming breaks to cool off a bit in the nearby Lake Ammersee. An evening lecture by the Venture Lab of the TU München completed the programme of Summer School 2022. Dr.-Ing. Sascha Schwarz from the Venture Lab Additive Manufacturing and Christos Chantzaras, TUM Venture Lab Built Environment presented challenges and opportunities of scalability of research results by examples of founding one's own company and/or collaborating with commercial enterprises. Developing a business idea with researchers, finding partners from the industry or even having a dedicated space to get together for the first time are all smaller and larger challenges in the desire to found a company. The TUM Venture Lab offers suitable concepts and an experienced network of experts who help to take the leap into self-employment and build a bridge between researchers and industry. Will some of our scientists become founders? We will see in the next few years, but who they would have to approach to do so, they do know now.

"So much drive, so much dynamic, so many inspiring ideas that I have experienced here in the last few days! I am thrilled and I wish that we can take this energy for the preparations of the Collaborative Demonstrator and into the 2nd phase. This energy shows me what we and our Collaborative Research Centre are really capable of achieving: a contribution to changing the world of construction. We can prepare the way for more sustainable, resource-saving and design-oriented construction," says Prof. Dr Kathrin Dörfler, co-spokesperson of the AMC, in her closing words for the AMC Summer School 2022.

https://amc-trr277.de/amc-summer-school-2022/


From AM to ARC | Gabriela Kienbaum + Julian Tesche

REFLECTION & FORECAST

From the moment the AMC – namely Katrin Dörfler, Harald Kloft and Norman Hack – opened their laboratories in München and Braunschweig to us, we felt honoured and excited to join forces with them to cooperate in developing the teaching programme 'From Additive Manufacturing to Architecture'.

During our own efforts to set up the research map for the freshly launched Institute of Construction (IKON), it became clear that concrete as a building material, and in particular cement production, has presented and still presents significant unresolved issues. Even the latest and award-winning technologies in cement substitution involve a significant amount of carbon capture.[1] From an ecological standpoint, it follows that these technologies require close scrutiny. In this respect, understanding Additive Manufacturing as material-agnostic appears to have promising prospective consequences. A synergic second path is to deploy concrete only at its capacity limits and in its thinnest shapes. Taking these two parameters, the analogy in the development of the material usage of concrete would be akin to that from the 'pottery market' to 'porcelain'.

Keeping in mind the obvious danger of 'technification', as manifest in Material Cultures,[2] and vice versa the potential to combine ecological materials with the benefits of robotics, the symbiosis represents an ideal opportunity to embed experienced architects in Additive Manufacturing research and to tie them into the explorations required the field. To spin the porcelain metaphor further, the collaborative energy we invest in current ongoing research is the proverbial 'butter' in which the white gold was packed to survive the transport routes in former times. While the first generations of digital development focused on the challenge of advanced geometry, the present driving force is the urgency of *how to treat nature differently*. This shifts the hypotheses that the technology itself will become the main motor within the process of design and construction from machine back to man. Artificial Intelligence would be a prime example, and would seem to present obvious challenges in this regard, although as expressed in the dialogue between the structural engineer Manfred Grohmann and the media theorist Friedrich Kittler: There is still no algorithm without an idea.[3]

While teaching concepts provide a greater freedom to explore, the reality in planning is to equally test constructive hypotheses. In the face of the pressing threats of climate change and resource depletion, the international conference 'Constructive Disobedience' at TU Braunschweig hosted in September 2022 by Katharina Benjamin, Matthias Ballestrem and myself has shown the serious endeavours by the community of practitioners to pursue and elaborate relevant design experiments in building practice. Importantly, the focus of the event lay in showcasing methodological approaches to constructive experimentation and knowledge production through singular and particular architectural projects. In this regard, the conference addressed a specific type of design-based research encapsulated in the opening statement: 'Whereas experimental design juggles with dependent and independent variables, to the extent that the setting allows a reliable forecast about the result; and whereas artistic experiment uses variants to select, mostly intuitively, the best solution; the constructive experiment, on the other hand, consists of both.'[4] Through these scientific exchanges and in other ongoing formats like the design-based doctoral programme at the TU Berlin, the institutional and intellectual ceilings between architecture and technical and digitised research can be broken down to the mutual benefit of both, allowing practice-based architects to inscribe themselves and their knowledge into applied research and thus together rethink the core principles of architecture as a profession.[5]

Based on methods and academic rigor, there should be no innate trepidation about genuinely evaluating the architectural qualities of a range of solutions, all the while accepting that the solutions and the paths by which they are arrived at are heterogeneous. Taking the aspects of fabrication within the developing rules of the AMC as the starting point for architectural design, it could also be argued that they concomitantly articulate clear requisites for teaching experimental design, as characterised by: 1. using a framed setting, 2. an immersion in alterations between conscious and unconscious actions, and 3. producing a series of options.[6] In essence this process of experimental design via constructional experimentation towards explorative teaching as a research format[7] requires extending the complexity to a further level.

In distinction to a design task with many potential answers, the climate crisis presents the dimensions of a 'wicked problem', as famously formulated by Rittel and Webber.[8] There is therefore an obvious and urgent need to radically regenerate the building sector, as for instance most recently outlined by the structural engineer Christoph Gengnagel.[9] In this sense, considering the imminently finite timescale humankind is facing, the decisions we make today are clearly 'one-shot-operations'.[10]

→

To return to the teaching and learning process, the challenges described above call for new interlinkages between researchers from all disciplines. The concept of explorative teaching breaks with common and standardised design teaching methods. How we design (the spatial qualities of the built artefact) and what we design with (materials, processes and simulation techniques) are two inseparable aspects of our future activities as architects and engineers. Substantial sustainability only emerges when all these factors are combined into a complex whole.

The project 'From Additive Manufacturing to Architecture' successfully demonstrates how to integrate innovative research approaches to the design- and construction-planning processes into masters' student projects from the very outset. The resulting architectural and technical findings were subsequently critically reflected upon within the scientific spectrum of the AMC TRR 277. Explorative teaching as a research format thereby promotes the interaction of technology and design, and transfers individual inventions into a coherent overall construct. The holistic questions that come to light in the course of an architectural conception alter the perspective within the research work. The engineering part of the research team discovered new, unexpected and fruitful challenges in the realisation process, especially in the in-depth phase. This iterative circle strengthens the whole development in both directions. In turn, the scientific findings supplied the research team's architectural positions with a broad spectrum of new procedures and techniques leading to sustainable architecture within the planetary boundaries. As such, we are convinced that the motto for future research developments should perforce be: 'From Additive Manufacturing to the Realm of Architecture.'[11]

Helga Blocksdorf
04/2023

[1] See, for example, Seratech Cement website, https://www.seratechcement.com.
[2] *Material Cultures: Material Reform – Building for a Post-Carbon Future* (London: MACK, 2022), 66–9. [3] 'Despite all our evolutionary algorithms, computers or algorithms create nothing autonomously of their own accord.' Friedrich Kittler, Mannfred Grohmann and Anne Kockelkorn, 'Morphogenese und freier Wille', *Bauwelt* 44 (2011), 7–11, here 7: https://www.bauwelt.de/dl/736965/bw_2011_44_0006-0011.pdf.
[4] Helga Blocksdorf, 'Conference Introduction – Constructive Disobedience', Staatstheater Braunschweig, 15 September 2022, https://constructive-disobedience.com.
[5] See Matthias Ballestrem and Lidia Gasperoni, *Epistemic Artefacts: A Dialogical Reflection on Design Research in Architecture* (Baunach: Spurbuchverlag, 2023). [6] Matthias Ballestrem, 'Experimentelles Entwerfen: Methoden des kontrollierten Kontrollverlusts', in Christophe Barlieb and Lidia Gasperoni (eds.), *Media Agency: Neue Ansätze zur Medialität in der Architektur, ArchitekturDenken*, vol. 10 (Bielefeld, Germany: transcript Verlag, 2020), 145–60, here 147: https://doi.org/10.14361/9783839448748-008.
[7] Bob Sheil, 'Position Bob Sheil über Explorative Lehre', in Achim Menges and Jan Knippers (eds.), *Architektur, Forschung, Bauen: ICD/ITKE 2010–2020* (Basel: Birkhäuser, 2021), 100–101.
[8] Horst W. J. Rittel and Melvin M. Weber, 'Dilemmas in a General Theory of Planning', *Policy Sciences* 4 (1973), 155–69. Reprinted in Horst W. J. Rittel, *Thinking Design: Transdisziplinäre Konzepte für Planer und Entwerfer*, ed. Wolf D. Reuter and Wolfgang Jonas (Basel: Birkhäuser, 2013), 20–38. [9] Christoph Gengnagel, 'Zur Notwendigkeit einer radikalen Regeneration', *Protocol 13: Adrenalin: Magazin für Architektur im Kontext* (2023), 114–17.
[10] Rittel, *Thinking Design*, 30.
[11] In this respect, Louis Kahn differs between 'the marketplace', which we could read as the building sector without any architectural quality, and architecture: 'But the most important thing to teach is to know that architecture has no presence. You can't get a hold of architecture. It just has no presence. Only a work of architecture is presented as an offering to architecture.' Louis I. Kahn, *Silence and Light* (Zurich: Park Books, 2013), 32–3.

CREDITS

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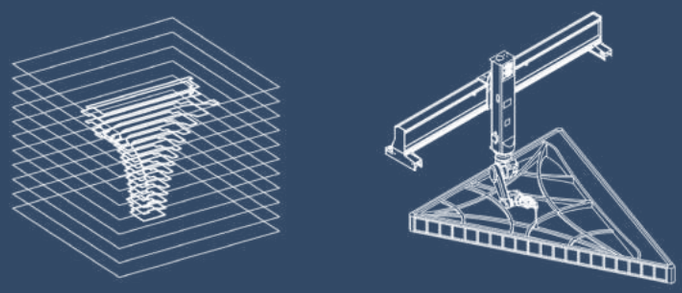

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