TT Professorship Digital Fabrication
Department of Architecture
Technical University Munich

Simple Slabs

Design and Robotic Fabrication of Timber-Exposed Floor Slabs

Design Studio 2019/2020

TT Professorship Digital Fabrication
Prof. Dr. sc. ETH Kathrin Dörfler

Department of Architecture
Technical University Munich

In collaboration with:

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Chair of Architectural Design and Construction
TUM Department of Architecture

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Chair of Timber Structures and Building Construction
TUM Department of Civil, Geo and Environmental Engineering

2019/2020


[1]The Sequential Wall, Gramazio Kohler Research, 2008

[1]Gramazio Kohler Research, ETH Zurich, 2008

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schedule

Tuesday 15.10.	10:00-12:00h, Room Nr. 4119	Input Lectures 'Robotic Fabrication' by Kathrin Dörfler 'Einfach Bauen' by Tilmann Jarmer 'Timber-Composite Constructions in Architecture' by Markus Lechner
Tuesday 15.10.	14:00-16:00h, Room Nr. -1730	Introduction of Research Task, Visit of the Robot Lab
Friday 25.10.	7:30 - 19:00h	Excursion to müllerblaustein Holzbauwerke & Züblin Timber
Tuesday 29.10.	09:00-12:00h, Room Nr. 4119 14:00-17:00h, Room Nr. -1730	Breakfast with presentation of the research topics Basics of Robotic Fabrication - Seminar 1

Tuesday 05.11.	09:00-12:00h, Room Nr. -1710 14:00-17:00h, Room Nr. -1730	Basics of Robotic Fabrication - Seminar 2 Simple Slab - Concept Presentations
Tuesday 12.11.	14:00-17:00h, Room Nr. -1730	Simple Slab - Deskcrit
Tuesday 19.11.	09:00-12:00h, Room Nr. -1710 14:00-17:00h, Room Nr. -1730	Basics of Robotic Fabrication - Seminar 3 Simple Slab - Deskcrit
Tuesday 26.11	09:00-12:00h, Room Nr. -1710 14:00-17:00h, Room Nr. -1730	Basics of Robotic Fabrication - Seminar 4 Simple Slab - Midterm Presentation 1

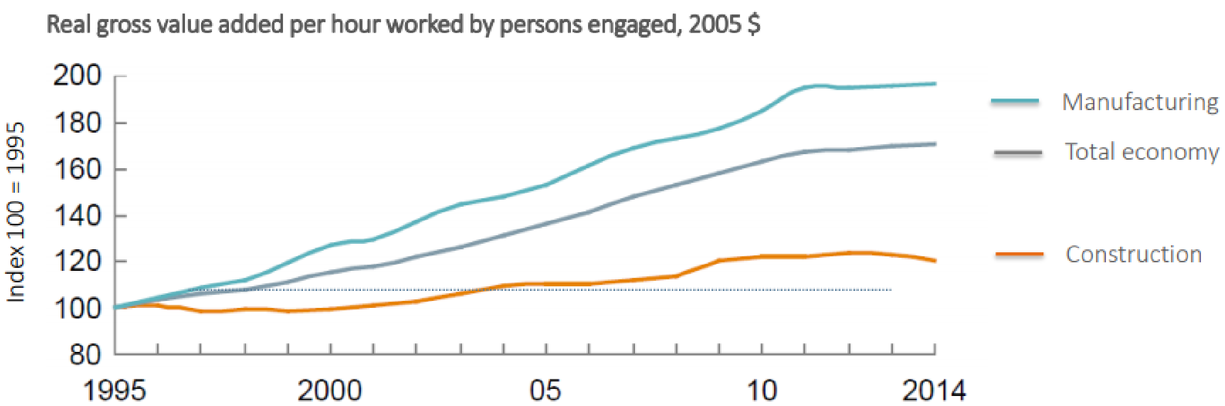
Tuesday 03.12.	09:00-12:00h, Room Nr. -1710 14:00-17:00h, Room Nr. -1730	Basics of Robotic Fabrication - Seminar 5 Simple Slab - Deskcrit
Tuesday 10.12.	09:00-12:00h, Room Nr. -1710 14:00-17:00h, Room Nr. -1730	Basics of Robotic Fabrication - Seminar 6 Simple Slab - Deskcrit
Tuesday 17.12.	09:00-12:00h, Room Nr. -1710 14:00-17:00h, Room Nr. -1730	Basics of Robotic Fabrication - Seminar 7 Simple Slab - Midterm Presentation 2

Tuesday 14.01.	09:00-12:00h, Room Nr. -1710 14:00-17:00h, Room Nr. -1730	Basics of Robotic Fabrication - Seminar 8 Simple Slab - Deskcrit
Tuesday 21.01.	09:00-12:00h, Room Nr. -1710 14:00-17:00h, Room Nr. 1730	Basics of Robotic Fabrication - Seminar 9 Simple Slab - Deskcrit
Tuesday 28.01.	14:00-17:00h, Room Nr. 2050	Simple Slab - Final Presentation

Resources are finite. By 2050, there will not be enough sand and steel to build with the same consumption of concrete as we do today. The demand for mineral raw materials in Bavaria alone is currently around 150 million tonnes, of which around 130 million tonnes are sand, gravel and bulkheads for the construction industry - and the trend is rising. Even seemingly everywhere available resources such as sand will be scarce in the future, as seen by a local example of the gravel pit by the company Glöckle in Grafenrheinfeld in Bavaria, which must be closed in the next 5 years as their resources are exhausted.

[2]https://www.br.de/nachrichten/bayern/der-kampf-um-kies-und-sand,RRUbS63

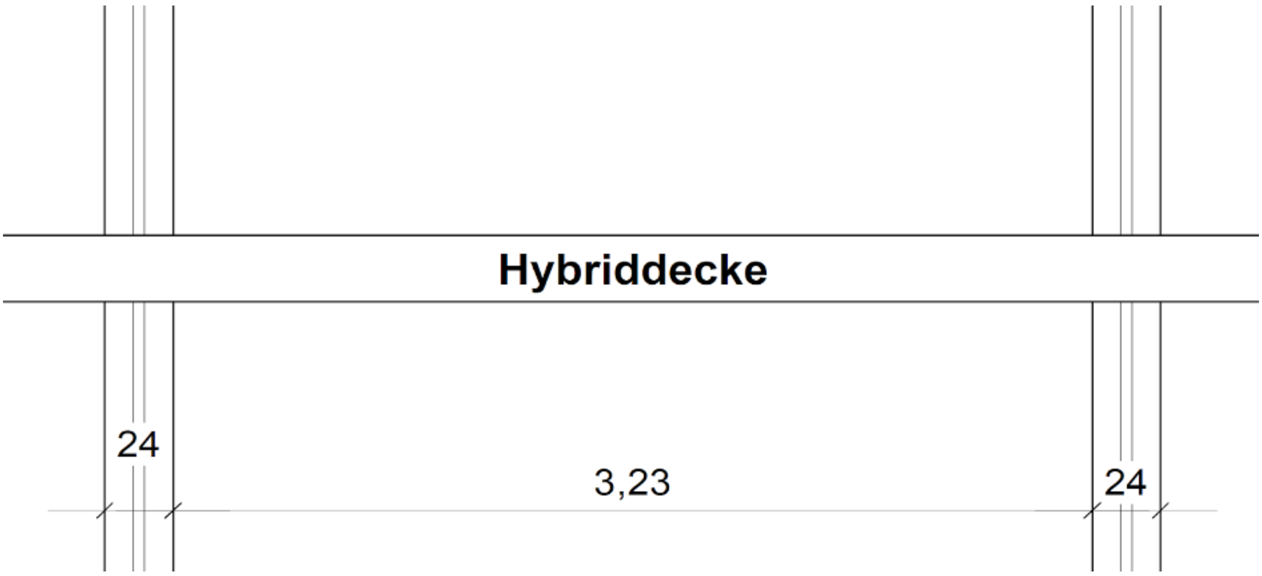
On top of this, the construction sector is facing a constant stagnation in its productivity rate, almost half the one of the manufacturing industries. This is directly linked to the low level of digitization in construction. In the face of our growing earth population, we are irresponsibly using material and resources, scratching the earth's surface. It is time to fundamentally rethink the design and construction of buildings that we, as designers, can and must directly influence.



[3]The productivity rate of the construction sector is stagnating since 1995, while the productivity of the manufacturing sector has almost doubled in the same period

[2]https://www.br.de/nachrichten/bayern/der-kampf-um-kies-und-sand,RRUbS63
[3]https://medium.com/datadriveninvestor/the-role-of-ai-in-construction-sector-891cff096fd1

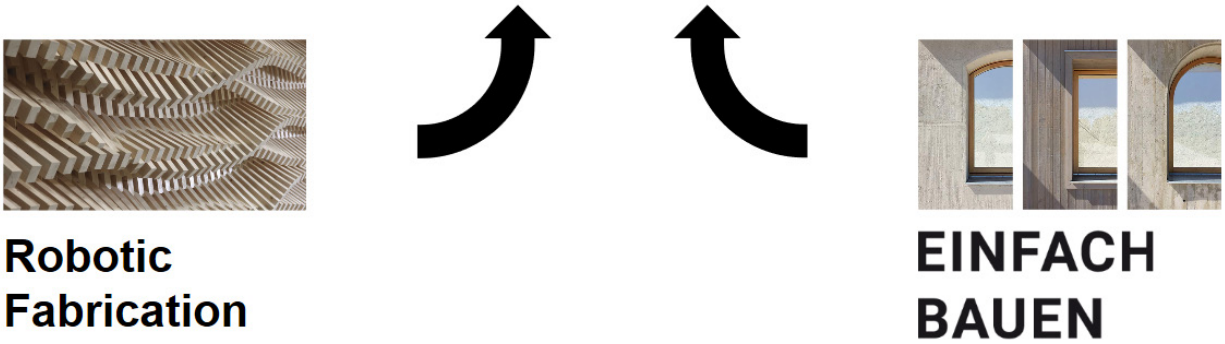
[4]Floorplan of the Case Study: Student Homes Garching



[5]Section A of the Case Study: Student Homes Garching

[4]"Einfach Bauen" - Chair of Architectural Design and Construction, Prof. Florian Nagler
[5]"Einfach Bauen" - Chair of Architectural Design and Construction, Prof. Florian Nagler

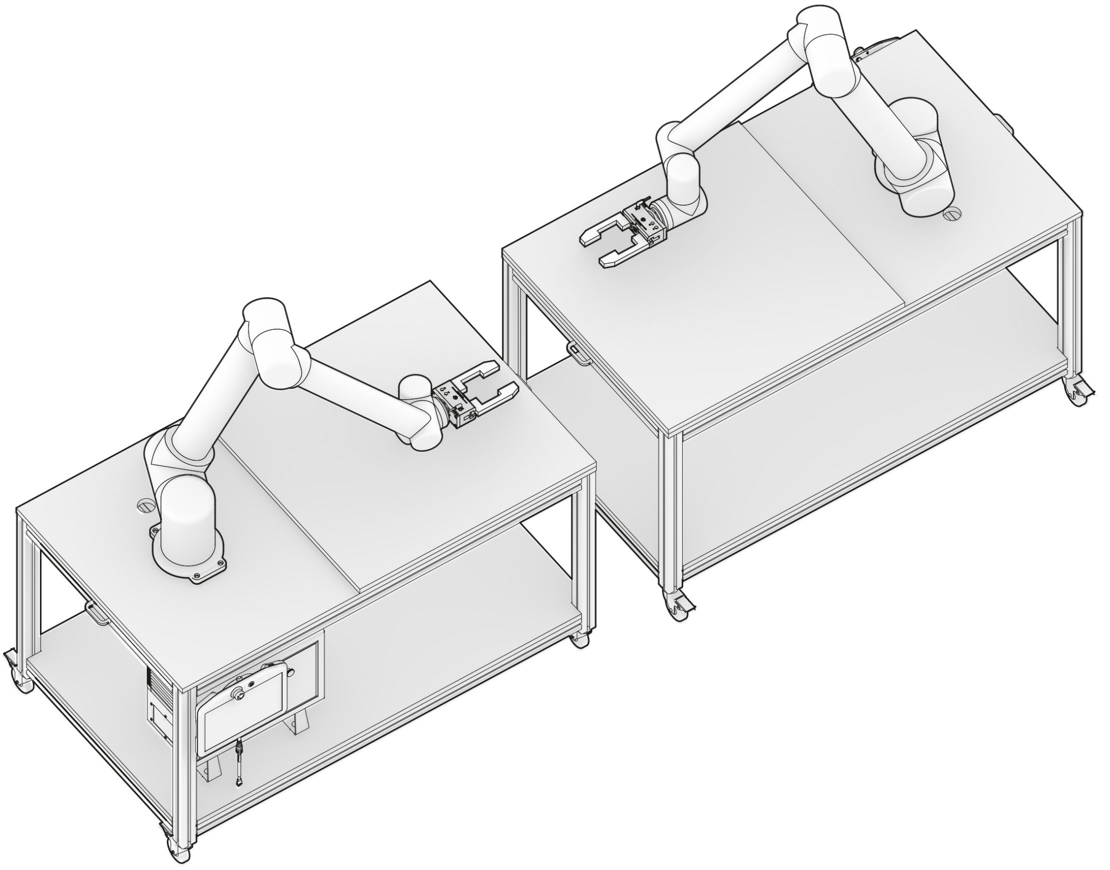
Motivated by these facts, this design and research studio aims to explore how computational design and new robotic fabrication technologies can lead to more efficient building construction and thus reduce the use of raw materials. The studio is contextually embedded into the research „Einfach bauen“ of the Chair of Architectural Design and Construction. Here, monolithic material systems are investigated to replace conventional resource intensive layering of various different materials for building components and envelopes.



[6]Simple Slab - Design and Robotic Fabrication of Timber-Exposed Floor Slabs

One of the “Einfach bauen” research buildings - a student home in Garching, Munich area - will serve as a case study for this studio (see image 4 and 5). For this building, we will explore and develop different design and robotic fabrication solutions for hybrid timber-exposed concrete floor slabs as a resource-efficient alternatives to conventional reinforced concrete slabs, and also explore their inherent process-distinct materiality and architectural expression. Throughout the studio period, an expert from the Chair of Timber Structures and Building Construction will give valuable instructions and feedback on the design proposals and prototypes.

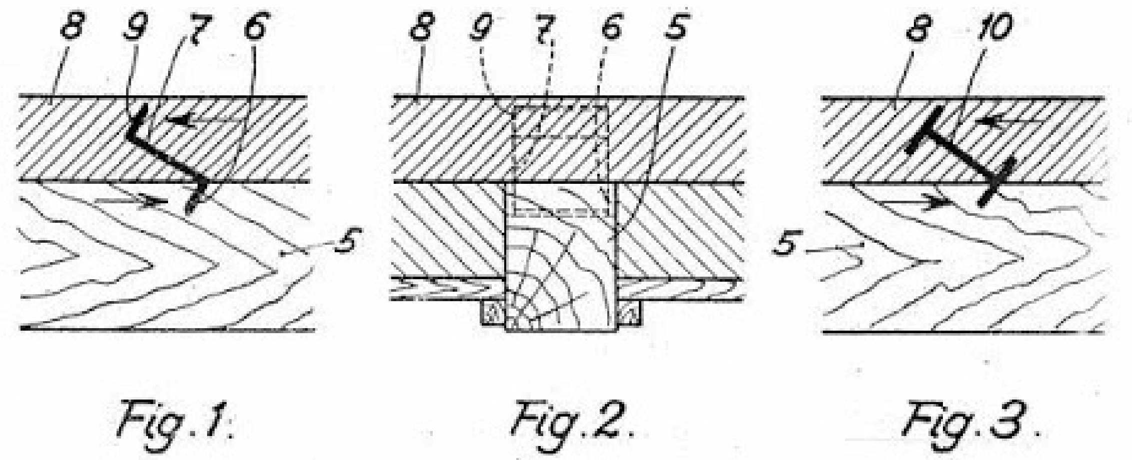
[6]Afab Diagram: Gramazio Kohler Research, ETH Zurich, 2015 and “Einfach Bauen” - Prof. Nagler



[7]Isometric view of the current robot set-up of two UR10s

[7]Afab

First, we will research and learn both from examples from the past, such as the patented system by Otto Schaub from the year 1939, and from present examples, such as the robotic timber assembly for prefabricated timber modules, GKR, ETH Zürich, 2018.



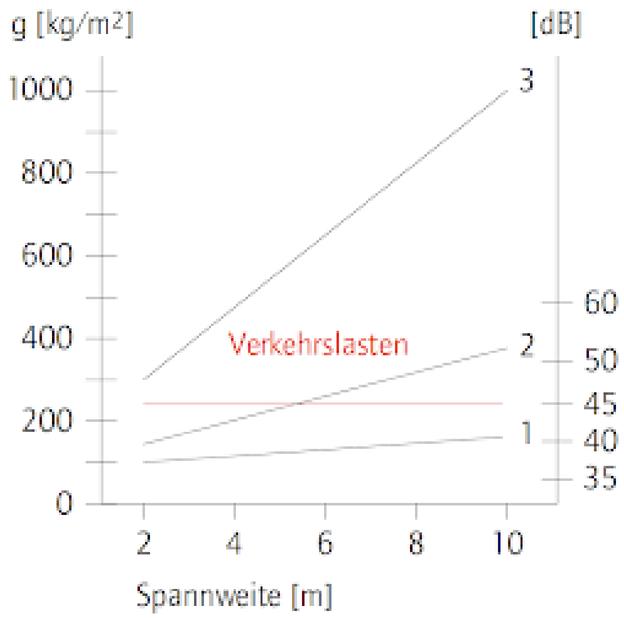
[8]Patented system for wood-concrete floor systems by Otto Schaub, 1939

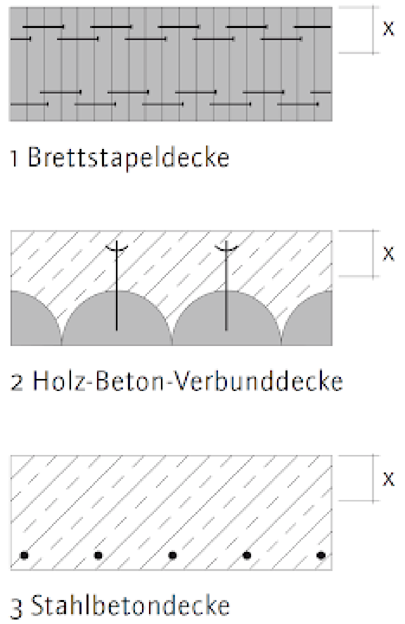
[9]Robotic timber assembly for prefabricated timber modules, GKR, ETH Zürich, 2018

[8]http://www.forum-holzbau.com/pdf/39_IHF2017_Jeitler_Augustin.pdf p.4
[9]https://www.holzmagazin.com/technik/1852-neues-holzbau-verstaendnis

Then, based on drawings and hand-built models we will develop constructive principles and translate them into a digital design and fabrication workflow. With lightweight robots, we will pursue assembly tests and prototype various design solutions at model scale of around 1:4.

We will methodologically explore how geometrical designs and new technologies can result in lighter constructions, saving in the consumption of raw materials, while at the same time our goal is to fulfill building requirements such as sound insulation, optimized indoor climate by storage mass, or optimum load capacity.





[10]Comparison of dead weight to span and acoustic damping behavior
[11]Massive- und hybrid - construction in comparison, x = pressure zone

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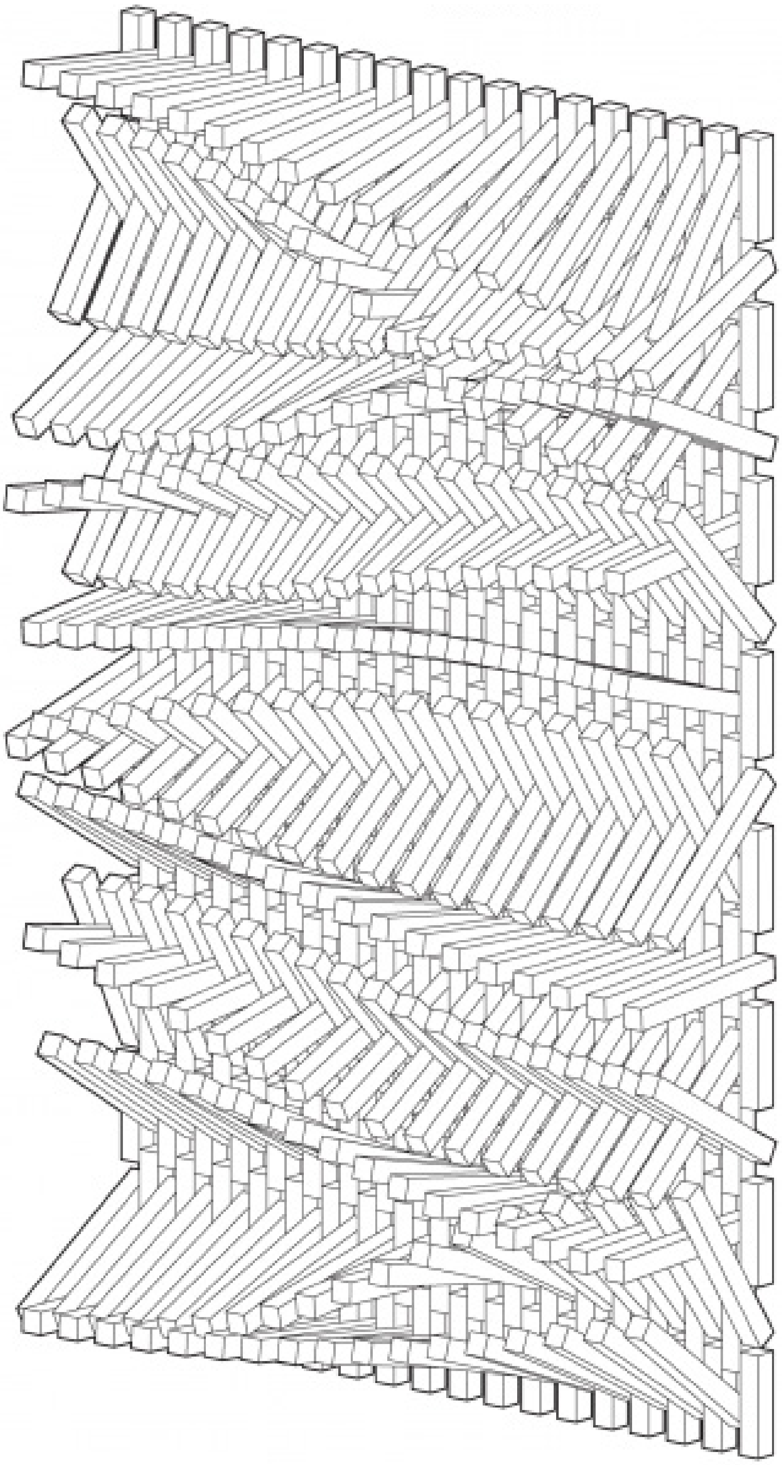
[10]http://www.proholz.at/zuschnitt/45/nachgefragt/
[11]http://www.proholz.at/zuschnitt/45/nachgefragt/



[12]The Sequential Wall, Gramazio Kohler Research, 2008

[12] Digital Materiality in Architecture, Gramazio & Kohler, Lars Müller Publishers, 2008

Digital Materiality in Architecture
Gramazio & Kohler
Lars Müller Publishers, 2008

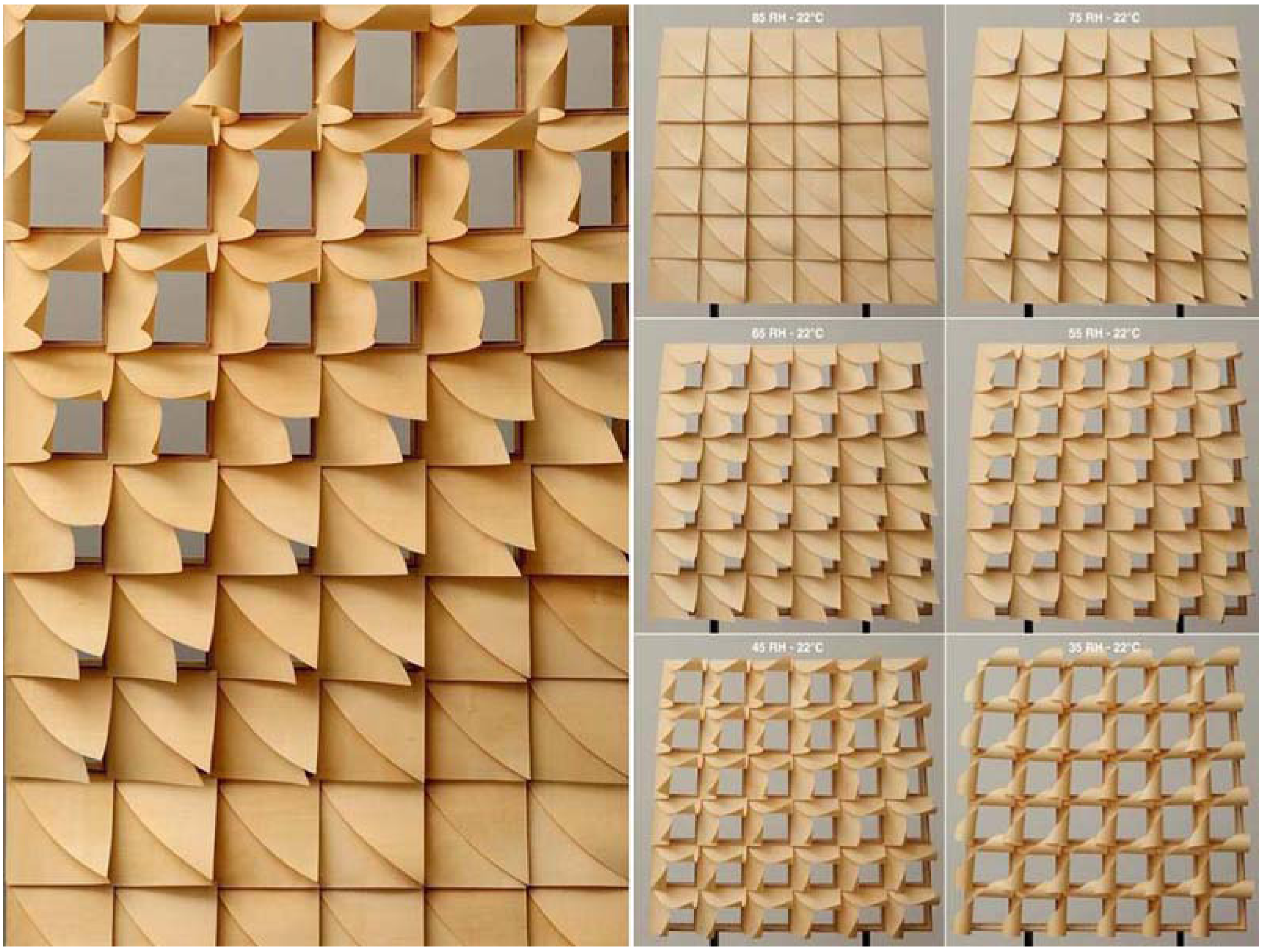
Digital Materiality

We use the term digital materiality to describe an emergent transformation in the expression of architecture. Materiality is increasingly being enriched with digital characteristics, which substantially affect architecture‘s physis. Digital materiality evolves through the interplay between digital and material processes in design and construction. The synthesis of two seemingly distinct worlds-the digital and the material-generates new, self-evident realities. Data and material, programming and construction are interwoven. This synthesis is enabled by the techniques of digital fabrication, which allows the architect to control the manufacturing process through design data. Material is thus enriched by information; material becomes „informed." In the future, architects‘ ideas will permeate the fabrication process in its entirety. This new situation transforms the possibilities and thus the professional scope of the architect.

Sensuality of Digital Order

Digital materiality leads to a new expression and-surprisingly enough, given the technical associations of the term „digital"- to a new sensuality in architecture. Digital and material orders enter into a dialogue, in the course of which each is enriched by the other. Digital materiality is thereby able to address different levels of our perception. It is characterized by an unusually large number of precisely arranged elements, a sophisticated level of detail, and the simultaneous presence of different scales of formation. Despite its intrinsic complexity, we experience and understand it intuitively. Digital materiality addresses our ability to recognize naturally grown organizational forms and to interpret their internal order. Its expression is novel, but not alien. Digital materiality is not rooted solely in the material world and its physical laws such as gravity, or in material properties. It is also enriched by the rules of the immaterial world of digital logics, such as its processual nature or calculatory precision. Digital orders intensify the particularities of materials. Materials do not appear primarily as a texture or surface, but are exposed and experienced in their whole depth and plasticity. Even familiar materials-such as bricks, which have been known for over 9000 years-appear in new ways.

For the observer, a tension spans the intuitively understandable behavior of a material and the design logic, which may not be immediately obvious. The logic can be sensed, but not necessarily explained. This obscurity seduces our senses, sending them on a voyage of discovery and inviting us to linger and reflect.



[13]Biomimetic Responsive Surface Structures

[13] Performance Based Architecture Achim Menges, Arch+188, 2008

Performance Based Architecture
Achim Menges
Arch+188, 2008

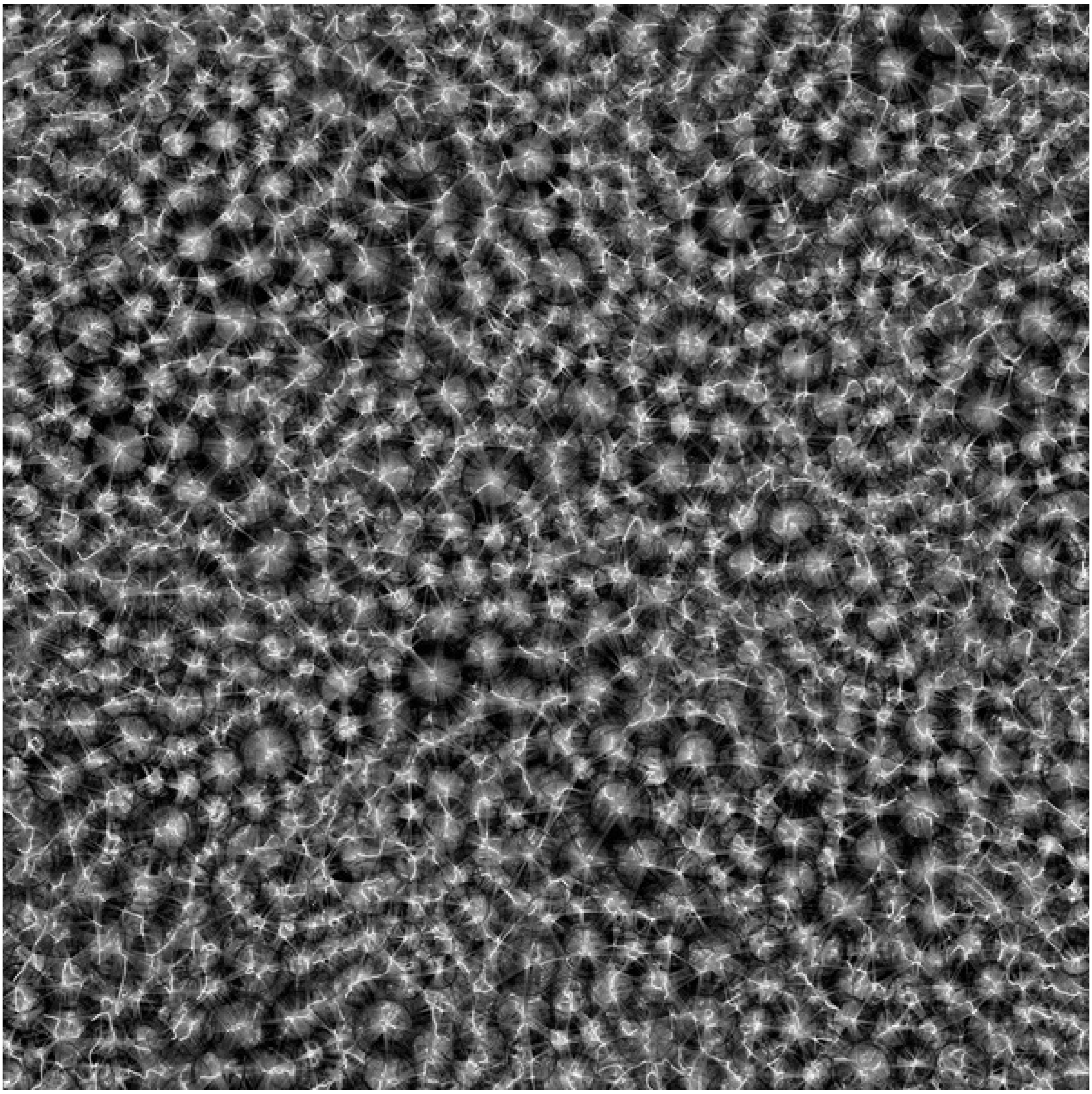
Nie zuvor war eine kritische Betrachtung und grundlegende Revision unserer tradierten Vorstellungen und festgefahrenen Definitionen von Architektur und Bauen so notwendig wie heute. Nie zuvor waren die Chancen einer solchen Infragestellung aufgrund eben jenes technologischen Fortschritts so günstig wie heute.

Wenn wir die Potenziale des Rechners nicht im Abstreifen aller formalen und konstruktiven Constraints sehen, sondern das computerbasierte Arbeiten als die Möglichkeit begreifen, eine enge Schnittstelle zwischen dem virtuellen und dem realen Raum zu schaffen, wenn wir die Beschaffenheit der materiellen Welt nicht als zu überwindend betrachten, sondern in ihren Logiken und Zwängen neue Wege erschließen, dann bedarf es einer Entwurfsmethodik, welche die tradierte Hierarchie von Form und Konstruktion durch einen Prozess integraler Formgenerierung und Materialisierung ersetzt. Wenn wir den Rechner nicht nur als besseres Zeichenwerkzeug benutzen, sondern die Herstellungs- und Fügungslogiken direkt an der Schnittstelle von CAD/CAM-Technologien einbetten, können wir jene Konstruktionsmethoden hinter uns lassen, die sich auf das Auswählen und Verteilen von Norm- und Gleichteilen im Raum beschränken. Wenn wir die Anpassung an Umweltbedingungen nicht als nachgeordnetes Optimierungsverfahren begreifen, sondern durch kontinuierliche Rückkopplung und analytische Verfahren in einen generativen Entwurfsprozess einbetten, wird die Modulierung von Raumklima, Licht, Schall zum integralen Bestandteil der Umweltgestaltung. Performance ist keine Frage der Anwendung von Lehrbuchprinzipien, sondern der räumlichen Differenzierung.

Nie zuvor hatten wir eine so große Chance, Architektur jenseits des Irrglaubens an eine totale räumliche und klimatische Kontrolle in der performativen Wechselwirkung von Material, Struktur und Umwelt zu entfalten. Nie zuvor hatten wir so gute Voraussetzungen, Architektur jenseits des repräsentativen Selbstzwecks tektonischer Objekte als differenzierte und reichhaltige Lebensräume zu konzipieren.

Nie zuvor hatten wir das technologische Potenzial, den Menschen und seine Umwelt in den Mittelpunkt einer alternativen Vorstellung von Nachhaltigkeit zu stellen. Woran es fehlt, ist ein intellektuelles Verständnis dieser ungeahnten Möglichkeiten und entsprechende, alternative Entwurfsansätze. Dies ist Ziel und Zweck dieser Ausgabe.

Nie zuvor war die Erforschung und Entwicklung solcher Entwurfsansätze so relevant wie heute, denn nie zuvor wurde auf unserem Planeten mehr gebaut.



[14]Field Conditions Diagrams

[14]In Points + Lines, Field Conditions, Stan Allen, 1985

Field Conditions
Stan Allen
Points + Lines, 1985

From Object to Field

The term ‚field conditions' is at once a reassertion of architecture's contextual assignment and at the same time a proposal to comply with such obligations. 1 Field conditions moves from the one toward the many: from individuals to collectives, from objects to fields. The term itself plays on a double meaning. Architects work not only in the office or studio (in the laboratory) but in the field: on site, in contact with the fabric of architecture. ‚Field survey', ‚field office', ‚verify in field': ‚field conditions' here implies acceptance of the real in all its messiness and unpredictability. It opens architecture to material improvisation on site. Field conditions treats constraints as opportunity and moves away from a Modernist ethic- and aesthetics - of transgression. Working with and not against the site, something new is produced by registering the complexity of the given.

A distinct but related set of meanings begins with an intuition of a shift from object to field in recent theoretical and visual practices (Figs 1 and 2). In its most complex manifestation, this concept refers to mathematical field theory, to nonlinear dynamics and computer simulations of evolutionary change. It parallels a shift in recent technologies from analogue object to digital field (Fig 3). It pays close attention to precedents in visual art, from the abstract painting of Piet Mondrian in the 1920s to Minimalist and Post-Minimalist sculpture of the ‚60s. Post-war composers, as they moved away from the strictures of Serialism, employed concepts such as the ‚clouds' of sound, or in the case of Iannis Xenakis, ‚statistical' music where complex acoustical events cannot be broken down into their constituent elements.2 The infrastructural elements of the modern city, by their nature linked together in open-ended networks, offer another example of field conditions in the urban context. Finally, a complete examination of the implications of field conditions in architecture would necessarily reflect the complex and dynamic behaviours of architecture's users and speculate on new methodologies to model programme and space.
To generalise from these examples, we might suggest that a field condition would be any formal or spatial matrix capable of unifying diverse elements while respecting the identity of each. Field configurations are loosely bounded aggregates characterised by porosity and local interconnectivity. The internal regulations of the parts are decisive; overall shape and extent are highly fluid. Field conditions are bottom-up phenomena: defined not by overarching geometrical schemas but by intricate local connections. Form matters, but not so much the forms of things as the forms between things.

Field conditions cannot claim (nor does it intend to claim) to produce a systematic theory of architectural form or composition. The theoretical model proposed here anticipates its own irrelevance in the face of the realities of practice. These are working concepts, derived from experimentation in contact with the real. Field conditions intentionally mixes high theory with low practices. The assumption here is that architectural theory does not arise in a vacuum, but always in a complex dialogue with practical work.

Tutors

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Marton	Deme
Hareth	Ferhat
Alina	Götz
Muslima	Rafikova

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MüllerBlaustein Holzbauwerke
Industrial Partner

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CAD/CAM Specialist at Blumer-Lehmann AG

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TUM Department of Architecture

Prof. Florian Nagler
Professor at the Chair of Architectural Design and Construction
TUM Department of Architecture

Dominik Wowra
Head of Sales at MüllerBlaustein Holzbauwerke

Agenda

14:00 **Introduction**
Brief introduction on the Studio Topic by Prof. Dr. sc. ETH Kathrin Dörfler

14:15 **Talk**
By Ursula Frick: CAD/CAM Specialist for “Free Form” at Blumer-Lehmann AG, Switzerland

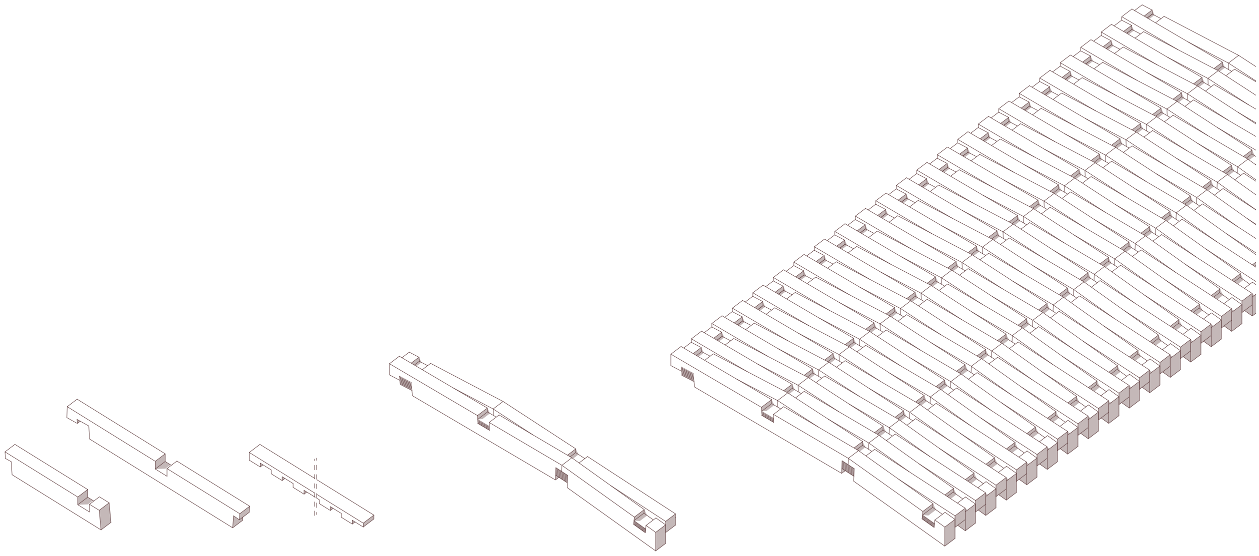
15:00 **Presentations**
Group 1: Begüm Saral, Muslima Rafikova and Chiara Saccomanno
Group 2: Ferhat Hareth
Group 3: Alina Götz
Group 4: Marton Deme and Julian Trummer

17:00 **Aperó**

projects

„Lift, Put, Lock“
Chiara Saccomanno, Muslima Rafikova, Begüm Saral

“Lift, Put, Lock” explores the potentials of a floor slab system which consists of both timber elements loosely connected via interlocking structures for the load bearing capacity, and a gravel filling for the sound-insulating and thermal mass capabilities. Via doing without rigid connections, this floor system is expected to behave like a sound damping structure, which, at the same time, is fully recyclable into its original state.



Elements - Connection - System

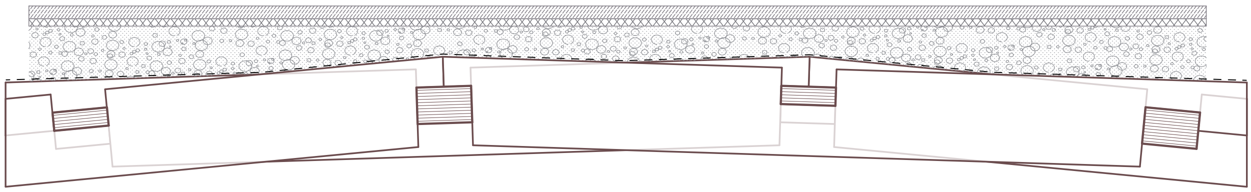
This project presents a framework for the design process of the structural system based on the reciprocal arrangement and interlocking behaviour of the structural elements. The goal of this research project was to develop a construction as well as a design process which would be driven by robotic fabrication logic and material capacities.

In the heart of the method is a Leonardo da Vincis practical reciprocal design for a self-supporting bridge. The project motivation lied in the design exploration and implementation of this system in a case study of building floor.

Despite the significant number of research contribution on reciprocal systems in general, these seems to be no research that would explore the the possibility of implementing this system for a building floor. For these reasons we have started to work on some mock-ups and finally come up with an idea of using the compound of timber slats as a static reciprocal structure and elastic heavy composite for a sound insulation properties.

Interior view

method



Floor

: 35 mm floating screed, on PE film
: 20 mm soft insulation boards
: 150 mm bound filling on trickle protection
: 240 mm x 140 mm framework

dead load g = 438, 7 kg/m2

Material system

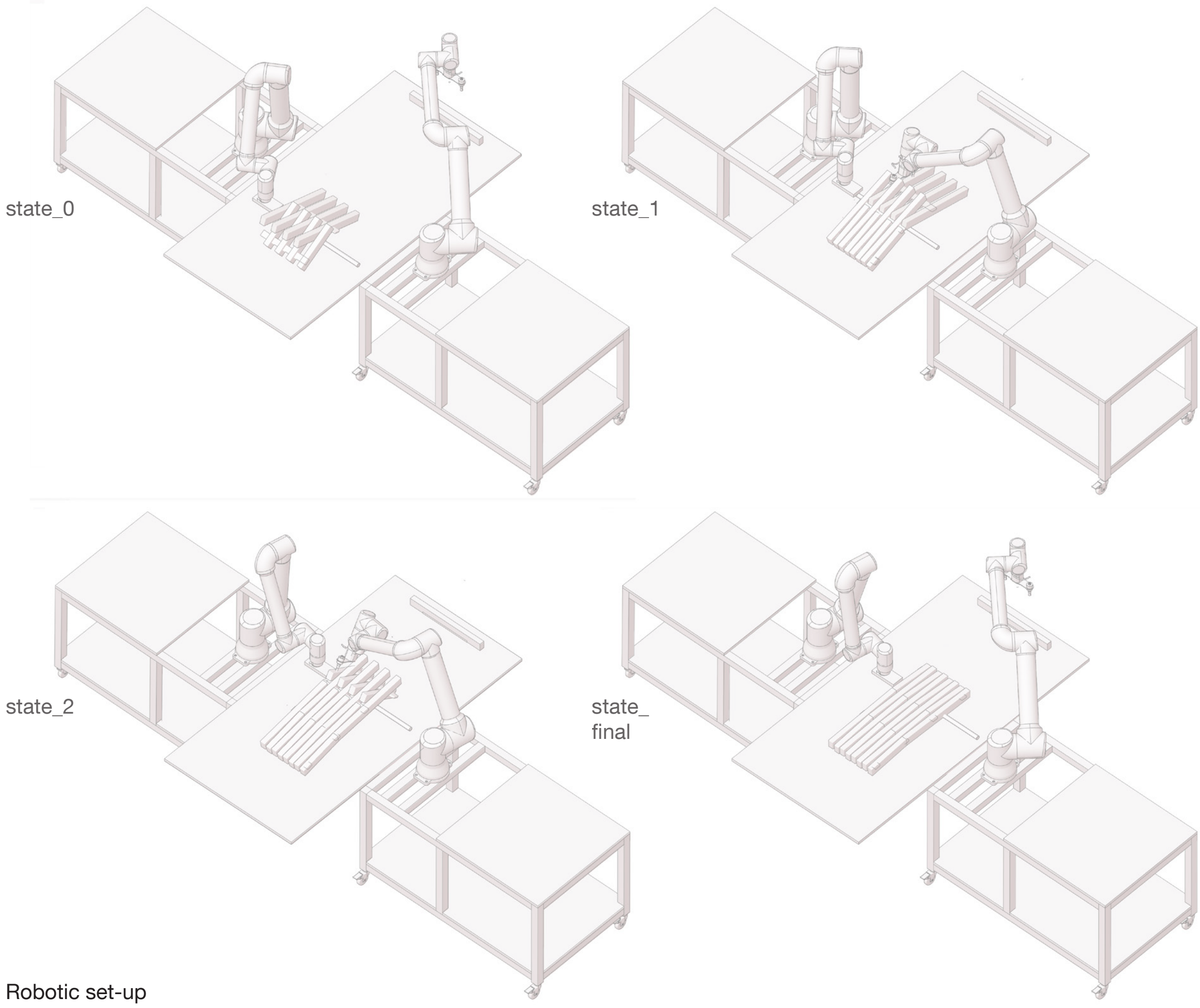
As long as all memeber scontribute to the load support and the expected slightly arched form of the slab produce no horizontal forces we used simple notched standard timber slats s in the recipcrocl pattern. Additionally, the final indulating surface of the slab helps to mitigate the floor vibration and behave as a sound-damping structure.
In order the structure to be load-bearing and at the same time fire-resistant we used spruce (240 x 140 x 2200 mm) as a main notched members and BauBuche (150 x 100 x 1000 mm) for a high load bearing capacity of the secondary structure. The complete structure consists of 46 layers and spans the 3,40 m to 6,50 m

Floor system

STATIC : use of simple standard timber segments in reciprocal pattern
benefit: 1. Arched form of the slab, no horizontal forces
2. All members contribute to the support of the load
3. Undulating surface helps to mitigate the floor vibration

MASS SOUND : elastic and heavy composite
Flexible chopping bound filling with latex milk , ex: StoPrefaColl SB / m‘ ≥ 360 kg/m2
benefit: extra levelling fill, mass for total weight and acoustics

FLOOR FINISH : floating screed on the soft sound insulation boards



Robotic set-up

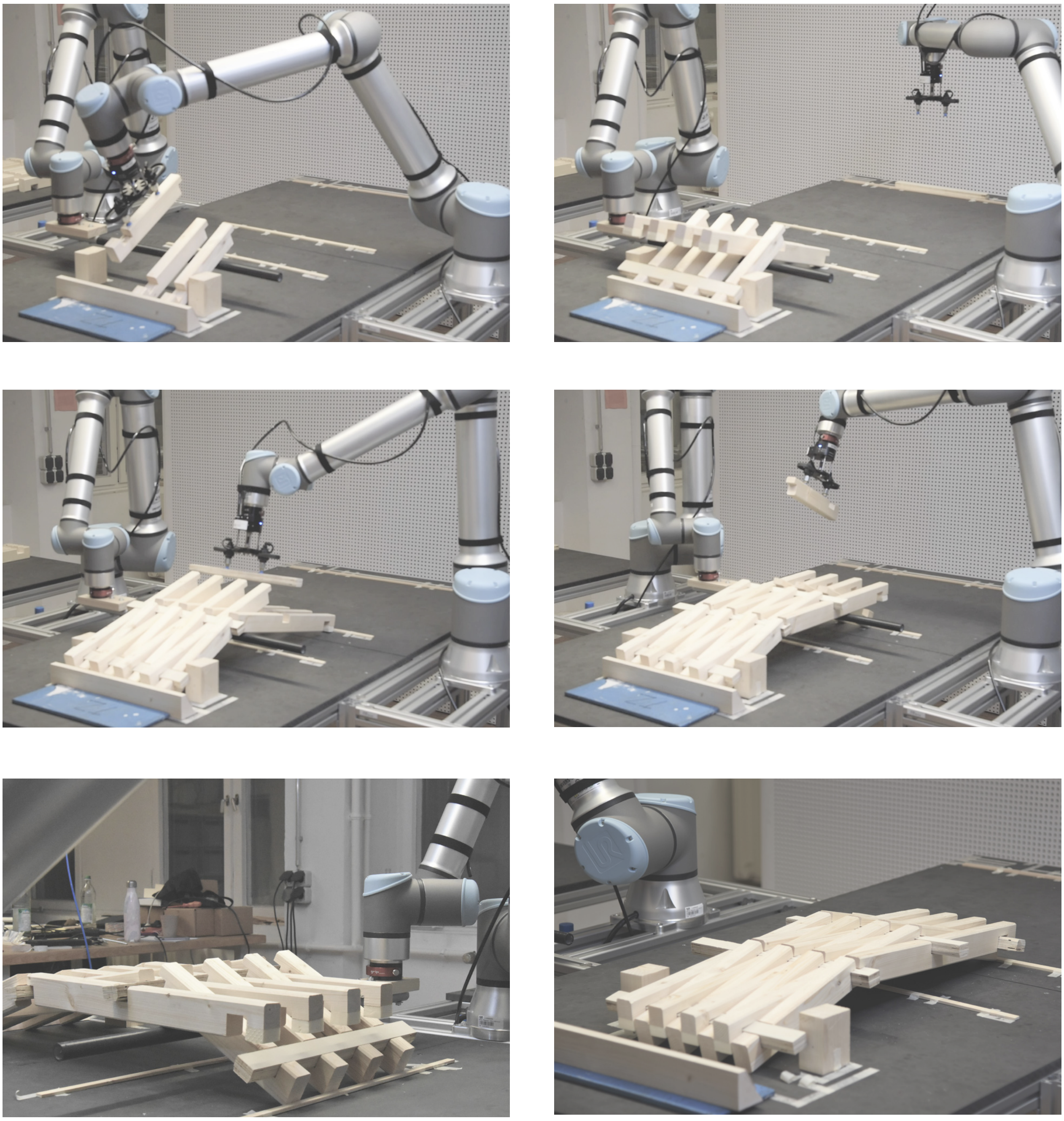
Assembly principle and robotic set-up

Two robot arms are used in the robotic set-up of our slab design. While one robotic arm is in charge of placing the timber elements to their corresponding locations within the use of double vacuum tips, second robot arm is in charge of moving the lifter, a long circular tube, that helps us to lift the model up and down.

The key motion of the assembly principle lies under the name of the project „lift-put-lock“. This motion is repeated three times in the case of our slab. These kinetic situations are called „states“. In each state the lifter robot arm starts by moving the lifter up and „lifts“ the structure up from one corner. Then the placer robot arm first places the horizontal elements. Due to the lifting, a cross space inbetween horizontal elements are created. The placer robot arm „puts“ the perpendicular element to this corresponding space. As the lifter robot arm moves the lifter back down, the structure „locks“ itself. Later on, the lifter arm moves to the side for the next state, repeating the same process.

Writing the script for the complex da Vinci inspired slab, considering the kinetic movement and the states, proved itself to be a challenge. We had deriven the design from a single curve, establishing the woven cross design, and creating the states from the situation based angles. The complexity of the geometry was later observed during the fabrication process as well.

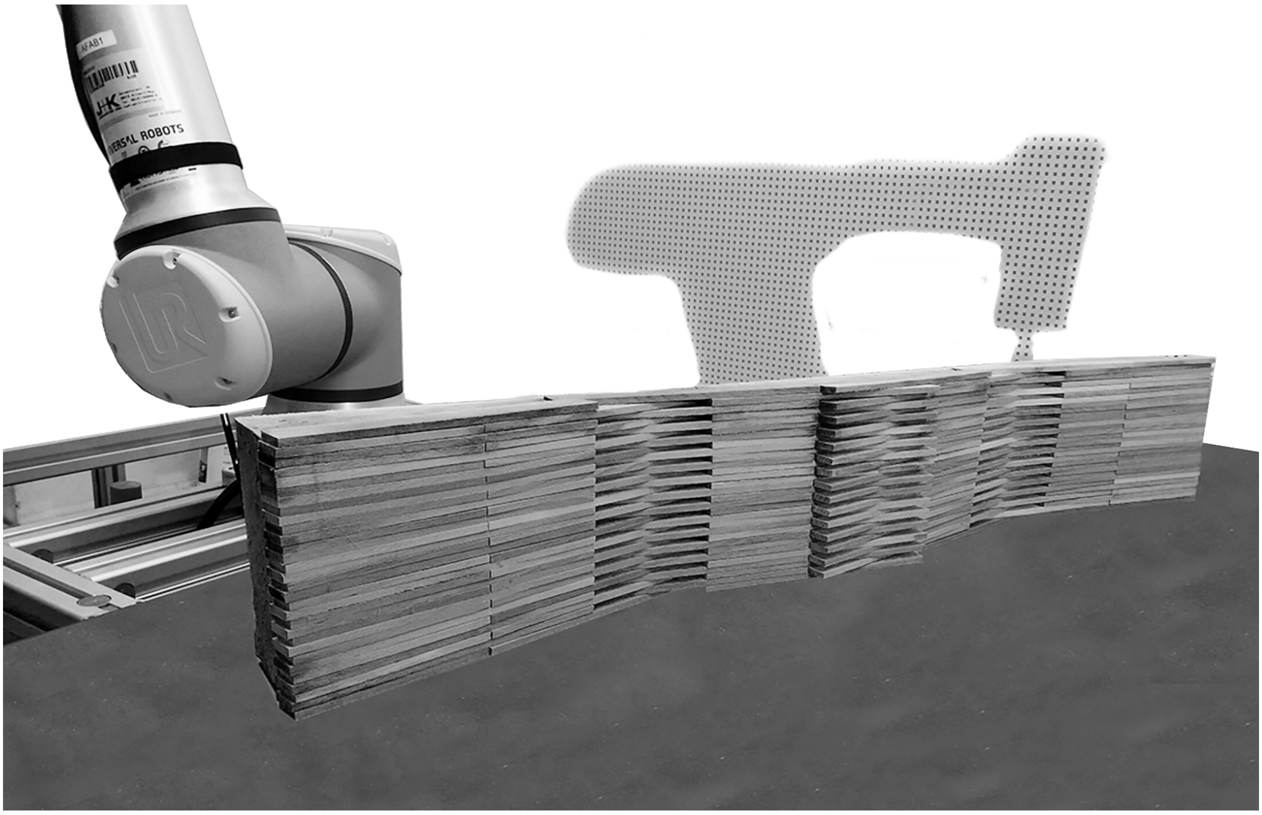
fabrication process and results



Fabrication Process

In the following fabrication process, we have built a 1:4 model section with the aid of two robot arms. The model dimensions were 80 cm to 27 cm, and three different elements have been used: long horizontal, short horizontal and perpendicular slats. We have carved notches on the horizontal elements, and prepared the perpendicular elements according to correct dimensions by taking some tolerances into account.

For the fabrication process, there was a need for a starting element to keep the timber elements in order, and blocks on the sides, in order to keep the structure in the correct position. Horizontal rodes fixed to the table were used in order to create friction for the elements that are placed with an angle.



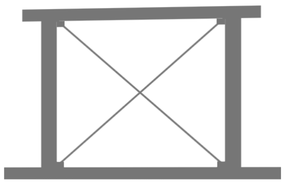
„Shifted - M“
Hareth Ferhat

The project is a research attempt to design a composite slab (concrete-wood) taking the student house in Garching, region of Munich as a case of study. SHIFTED-M comes in response to our greatest concern, which is to offer resource-efficient alternatives to conventional reinforced concrete slabs as well as to give it a particular architectural expression.

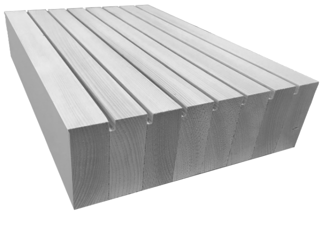
SHIFTED-M is experimenting a robotic fabrication attempt in order to develop a concept of a Timber-Concrete composite slab. The project uses the power and the flexibility of robotic Fabrication techniques to achieve a combination of design aspect, structural functionality and efficient use of materials by increasing their performance.

One of the main ideas of our studio is to explore how computational design and robotic fabrication technologies can lead to more efficient building construction.

Then, we had to compose with the physical and mechanical properties of materials (Timber and Concrete) with the aim of ensuring a functional structural result for our slab.

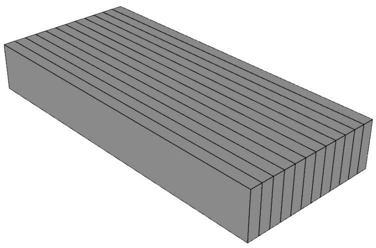


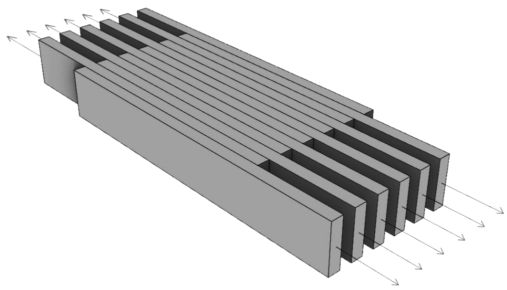
The main idea comes from the Brettstapel principle, a repetition of single piece of wood (glued or dowelled together). Our concept tends to go from the same idea, a multiplication of basic module but with experimenting new dispositions and sets.

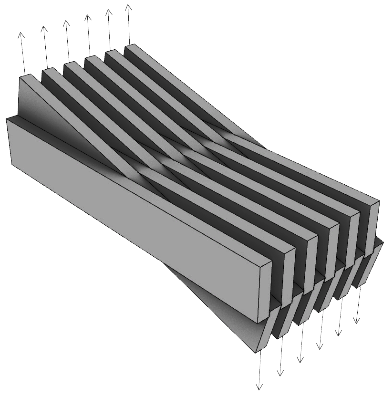


Brettstapel

Shifting and rotating the pieces against each others

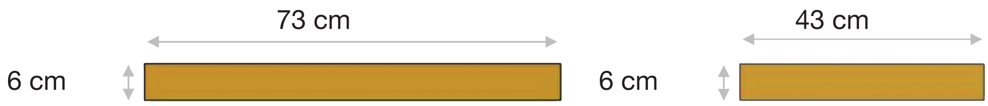




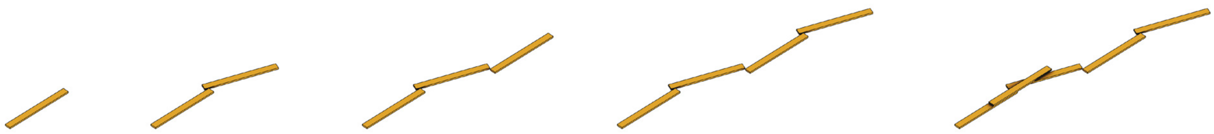


method

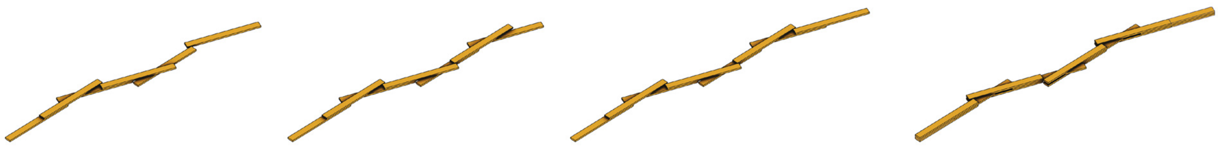
The sets, we are experimenting in this project, start from two simple timber elements of 73 cm and 43 cm length. The challenge of these very small wooden elements is how can we build the slab (3.23m*7m) based on their repetition.



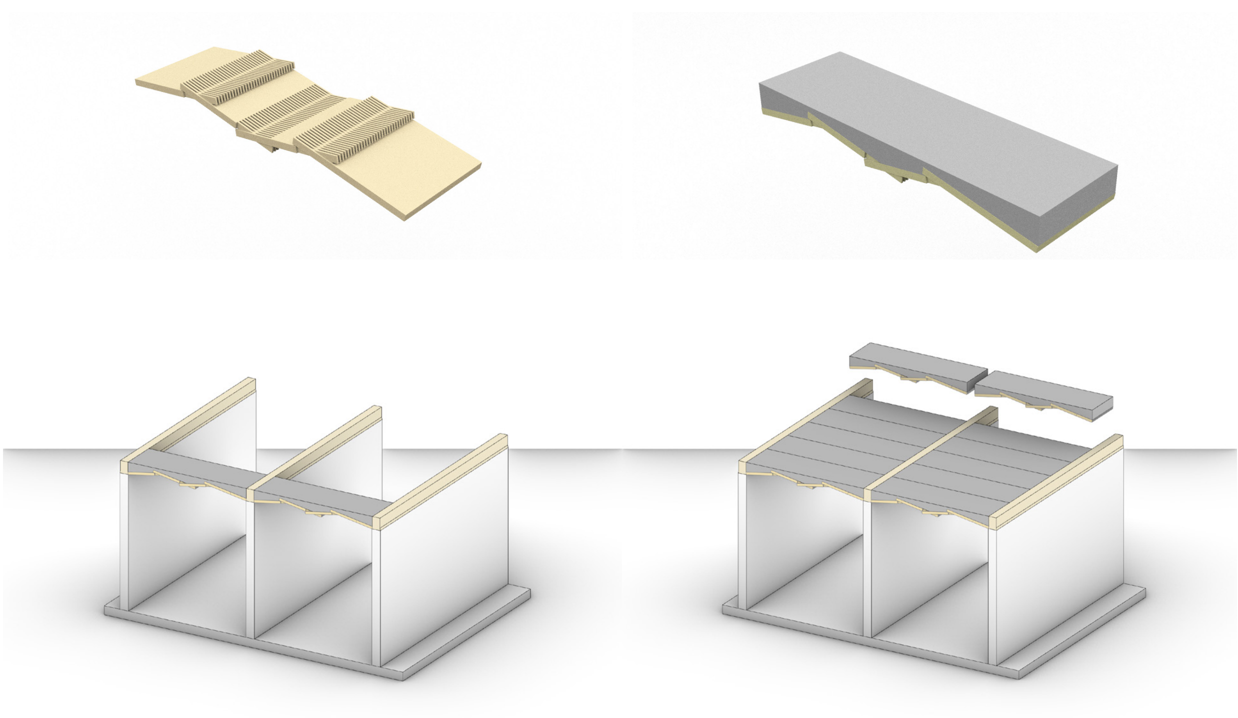
Shifting pieces in one layer



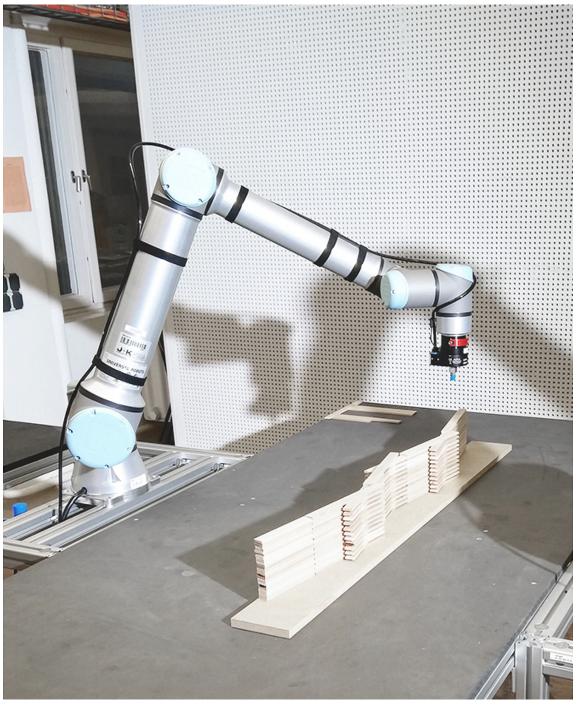
Shifting pieces on the next layer vertically



Building prefabricated panels (timber-concrete)



fabrication process and result

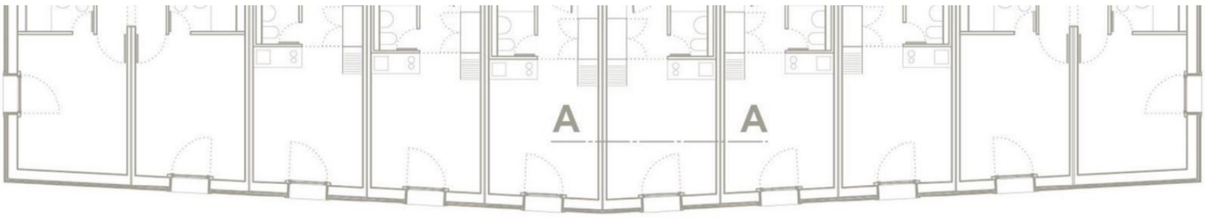


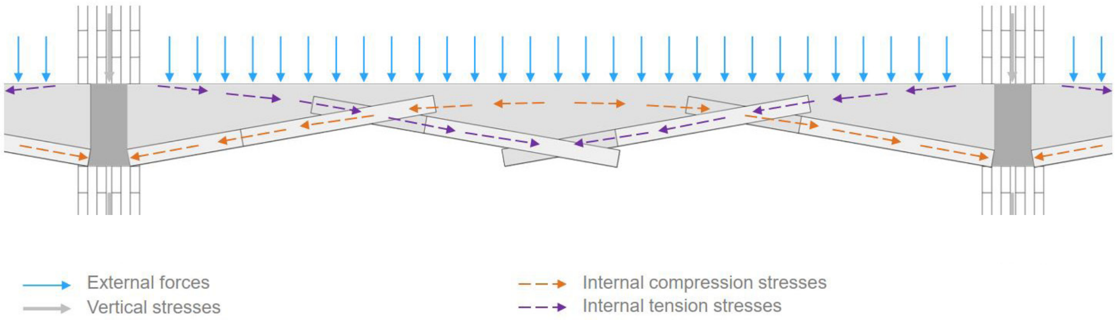
Fabrication Process

Adding the concretelayer

Finall Modell

The arch structural system

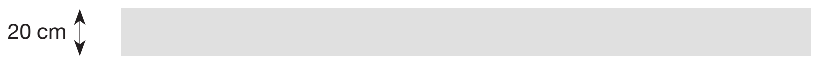




Quantifiable analysis

One of the major objectives of our concept is to reduce the use of limited resources materials (concrete and steel) and replace them with renewable materials (Timber), while achieving the same performance.

Full concrete slab



Concrete amount : 4.23 m^3
Steel amount : 0.25 m^3
Ratio S/C : 6 %

SHIFTED-M slab (timber-concrete)

Concrete amount : 3.51 m^3
Wood amount : 1,49 m^3
Ratio W/C : 14 %

Cooperative Flat Vault - view of student room

„Cooperative Flat Vault“
Alina Götz

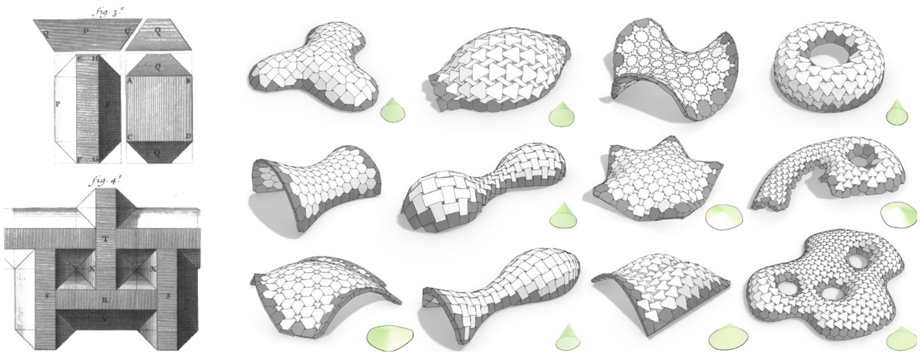
“Cooperative Flat Vault” explores the potentials of topological interlocking as concept for a floor slab system. Modules of same shape and size are assembled without binder or srews, just because of geometry attributes. Via doing without rigid connections, this floor system is expected to behave like a sound damping structure, which, at the same time, is fully recyclable into its original state.

Driving Idea

1. No need for a formwork
2. Universally applicable

Inspiration

In 1699 Joseph Abeille patented his ‘Flat Vault’ a planar assembly of truncated tetrahedron shaped stones. The topological interlocking was supposed to span without the curvature of a vault. The way the building blocks interlock refers to medieval vaults with keystones. The Flat Vault never became a successful construction system but scientists rediscovered it very recently.



Flat Vault of Joseph Abeille (left) - parametric studies of shape and size nowadays(right)

Objective

Using the concept of topological interlocking to buildt up the slab for a student room given by the assignment. The Objective is to explore the possibilities and limitations of the concept of topological interlocking considering a robotic set up with two robots and no formwork. Topological interlocking is a method to design the special shapes of the building blocks and the corresponding topologies of their assemblies such that no internal block can be removed from the assembly held by kinematic constraints imposed by its neighbors.

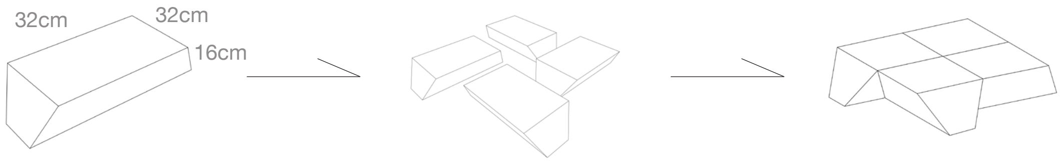
Advantages of topological interlocking

1. Tolerance to local failures
2. No connectors
3. Full recyclability
4. High energy dissipation
5. Sound absorb
6. hybrid composite possible

method

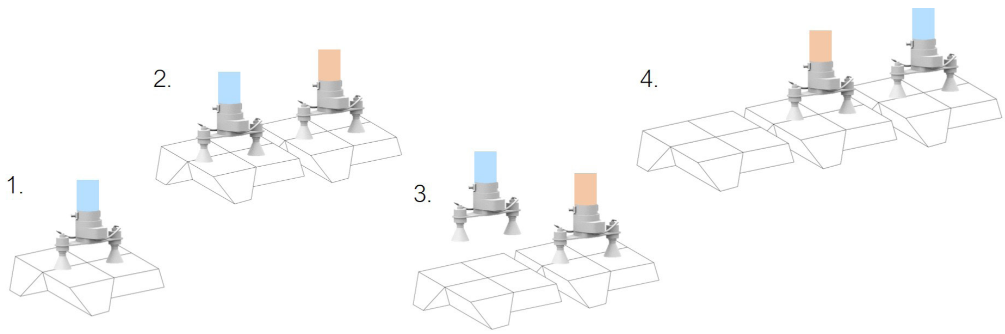
Assembly Method

Work around of formwork for mid-air build up



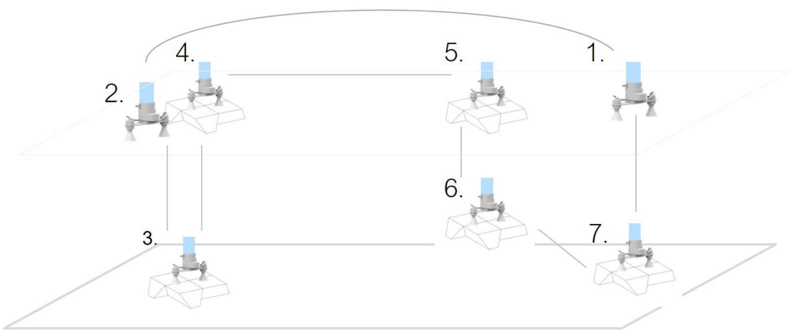
The assembly of the whole slab is typically with formwork and frame. Formwork can first be removed after last module is placed in the frame. To work around the formwork it was necessary to create a ring of four modules. Therefor in each direction to span there are two surfaces tilted in different directionsand the next module can interlock.

Two cooperating robots



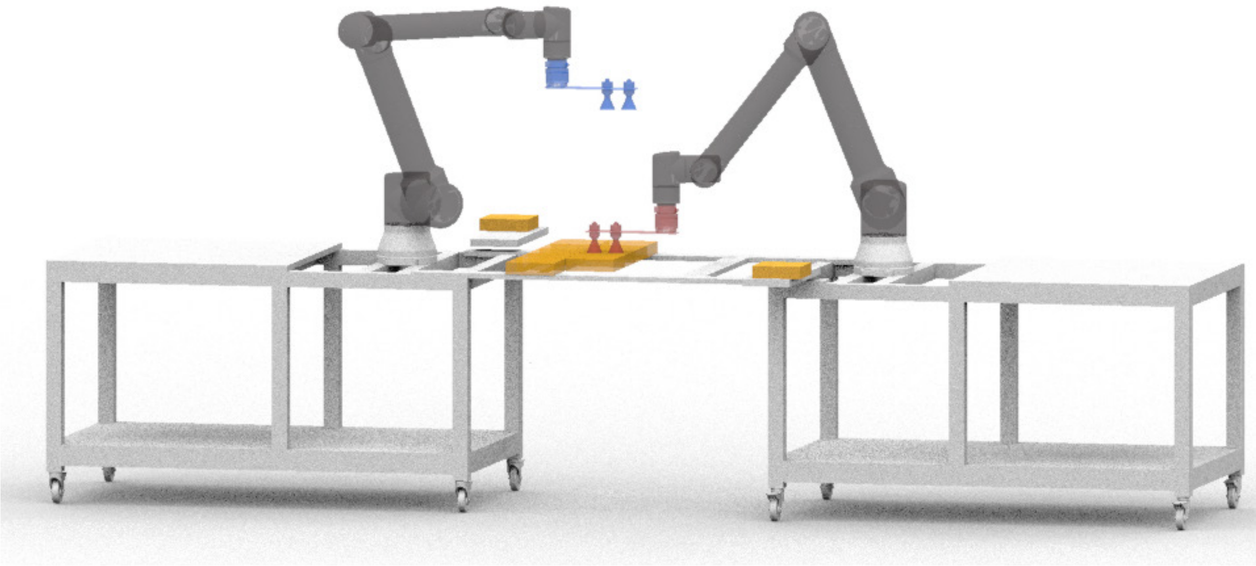
The princip of the workflow is that the first robot (blue) brings the first module. The first robot still holds the module, meanwhile the second robot (red) brings the second module. With the second module and considering the frame, the first modul ist stabilised and the first robot can release its module and can get the third module.

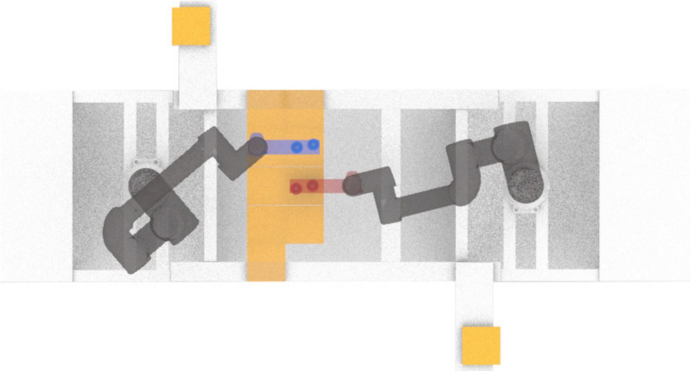
Robotpath

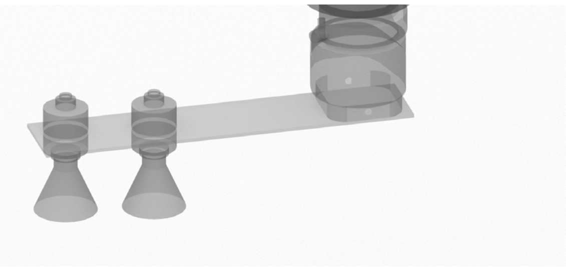


Considering the path starting with realesing the module, that is just hold, the first step is to get up to the safe level(1). The next point is at the safe level above the pick up area for the next module(2). Then the robot gets down, turns on the sucker to pick up the next modul(3) and gets back with the modul to the safe level(4). From there it moves to the aproach point on the safe level(5) . Then the robot gets down to the aproach point(6), which lays in an angel of 45 degree in x,y and z direction away from the end position. This is necessary to assembly the undercuts .And finally it slides the modul into final position(7).

Robot set up



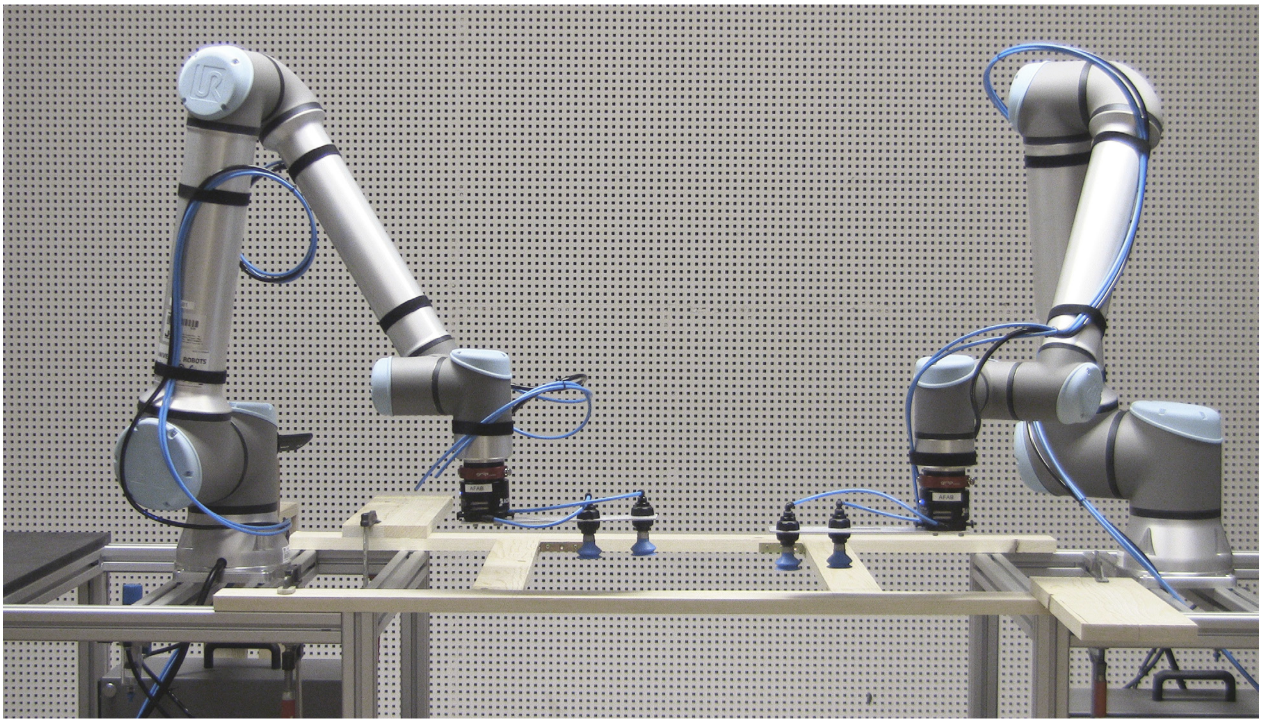


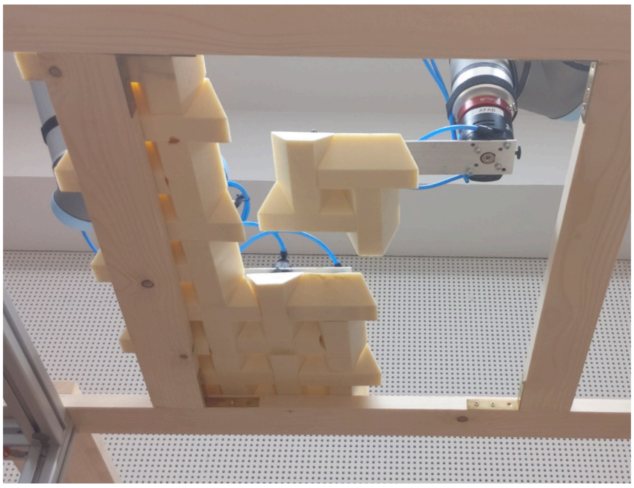


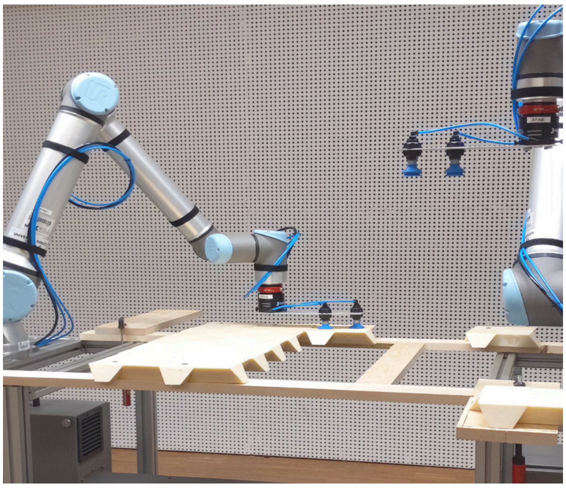
The frame was arranged between the two robots and the assembly direction was optimzied for no interference of the robots. The heads of the robots would collide by one holding a module, the other one bringing the next one. Therefore an extension of the sucker had to be buildt.

Programming in python/ grasshopper

The set up to control the robot was in rhino and grasshopper plug in. The coding was in Python and based on three parts, which where placed into a larger setup. The first part was to create the module and its trajectory with position, sucker attributes and speed details and also which robot to take. In the second part the information where edit to process them later into robot comands. Escpecially the coordinate system transformation and detaching of tool properties where programmed here. In the third part the robot comands where scripted. Overall the code was as generic as possible programmed, so little changes for example in the trajectory where made very easy.







1:1 Mockup

„Timber/Clay Hybrid“

Julian Trummer, Marton Deme

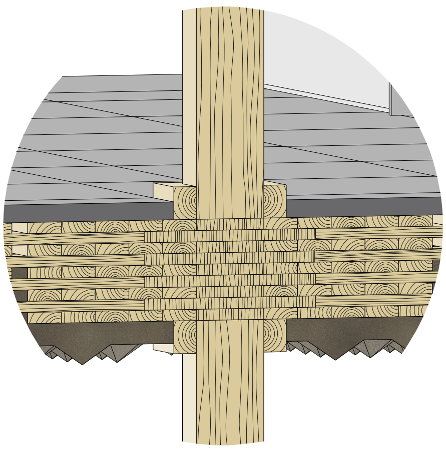
Timber/Clay Hybrid is a solution for a natural and simple low-cost ceiling construction that can meet high demands on static performance, fire safety and sound insulation. In addition, it promises to be a both cost-efficient and environmentally friendly solution that can be applied in any type of buildings.
The geometry can easily be assembled by robots and is based on current CLT technology though thanks to algorithmic optimization it requires only 50% of the amount of timber and 25% of the amount of glue compared to an ordinary CLT ceiling. A 1:4 model was built with the robots at Afab Lab.
The 1:1 mockup shown on the title image was developed and produced in cooperation with the Swiss Start-Up Oxara which is developing a clay mixture that while based on excavation material can be cast like concrete and does not need to be compressed.

Why we cannot possibly be happy with the status quo

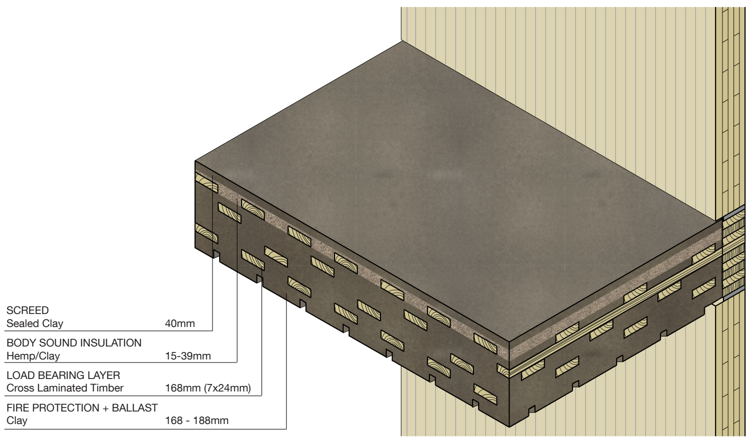
When timber ceilings have to meet high demands on sound and fire resistance, architects usually have only two options.
The first option is encapsulating the construction with fire protection boards. This does not only destroy the architectural character of the timber ceiling including its advantageous characteristics in respect to acoustics and interior climate, but leads to complicated, multi-layered constructions. Particularly considering that gypsum boards are commonly used in this mode of construction, reusability and recyclability are seriously compromised.
The second option is a timber-concrete composite ceiling. While this saves the architectural expression, the construction is expensive and complicated, slows down the whole construction process and requires over dimensioning and the use of concrete and steel, destroying most advantages of timber construction.
Neither of the two options can be considered satisfactory and the lack of efficient alternatives is a severe obstacle when it comes to providing sustainable alternatives to conventional construction methods.

Goals

Departing from the status quo, the student team set four goals:
1) Low carbon footprint, use of recyclable/decomposable materials only and zero waste.
2) A construction that would be universally applicable. Therefore, it has to meet high demands on the fields of fire resistance and sound insulation.
3) Easy automation of the production.
4) Visibility of the material and contribution to the interior climate.



Column Solution



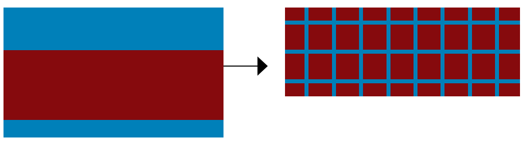
Sectional Axonometry

method

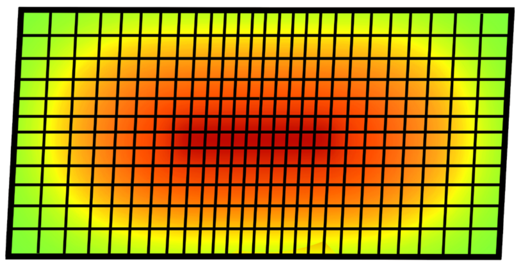
Concept

Both in order to reduce the number of layers by embedding functions in the load-bearing structure as well as to raise timber efficiency without increasing the ceiling height, we decided to work with an open timber grid. Timber elements would be placed wherever they would be statically most efficient while the voids allow for other functions to be embedded right in the loadbearing layer.
Particularly in the secondary span direction, shorter elements of varying widths can be used, allowing for the use of recycled timber. A computer algorithm was coded to evaluate the optimal design that can then be assembled by two robots in a factory. Compared to an ordinary CLT ceiling, less than half of the amount of timber and one fourth of the amount of glue are required.

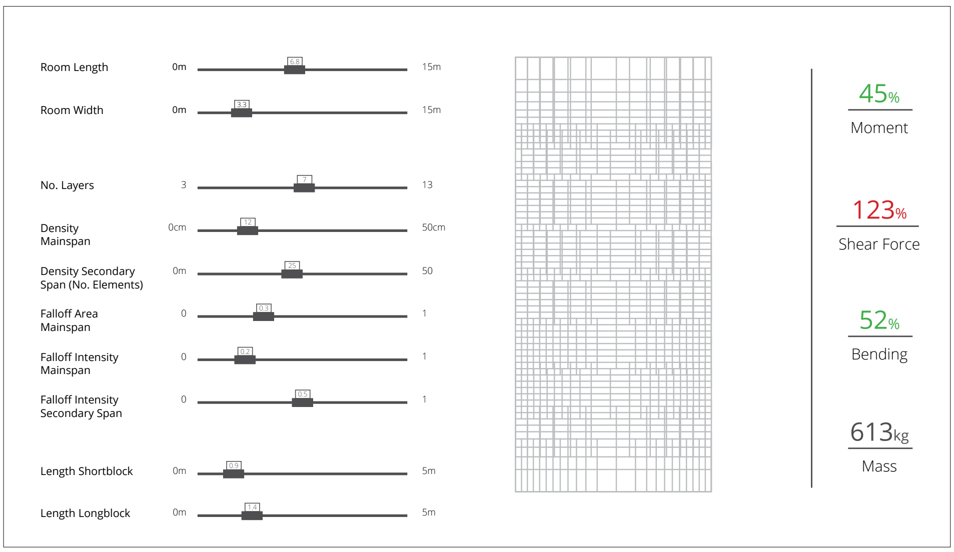
In order to create a spatial enclosure that protects against fire and insulates sound, the voids are filled up with clay. Only a layer of hemp-clay for minimizing body sound transfer as well as an uneven bottom negative for reducing/guiding cracks were introduced, keeping the overall complexity of the system low. The weight of the ceiling can be adapted over the clay mixture.
An exemplary ceiling was designed for the 3,2mx6,4m student room in the “Einfach Bauen” student dorm in Garching. It features a grid with seven layers, composed of standard 24x75 timber boards. The load-bearing timber construction weighs 27kg/m2, while the whole ceiling weighs 328 kg/m2 and is 267mm thick.



Embedding Functions in the loadbearing layer

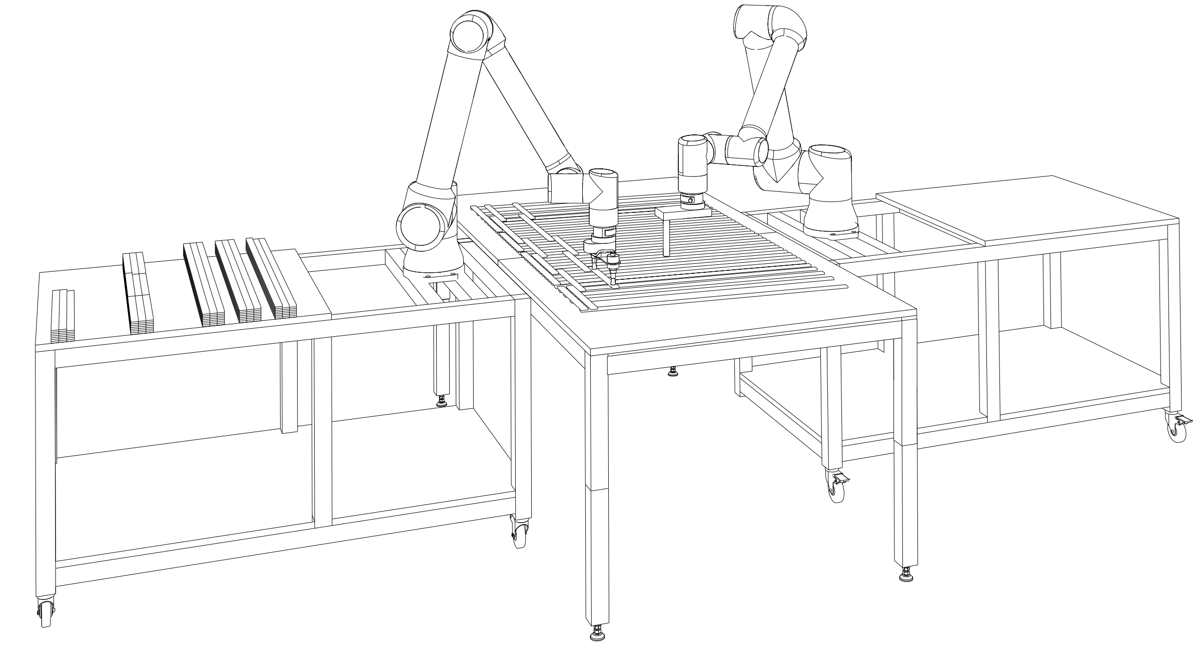


Tectonically optimizing the layout

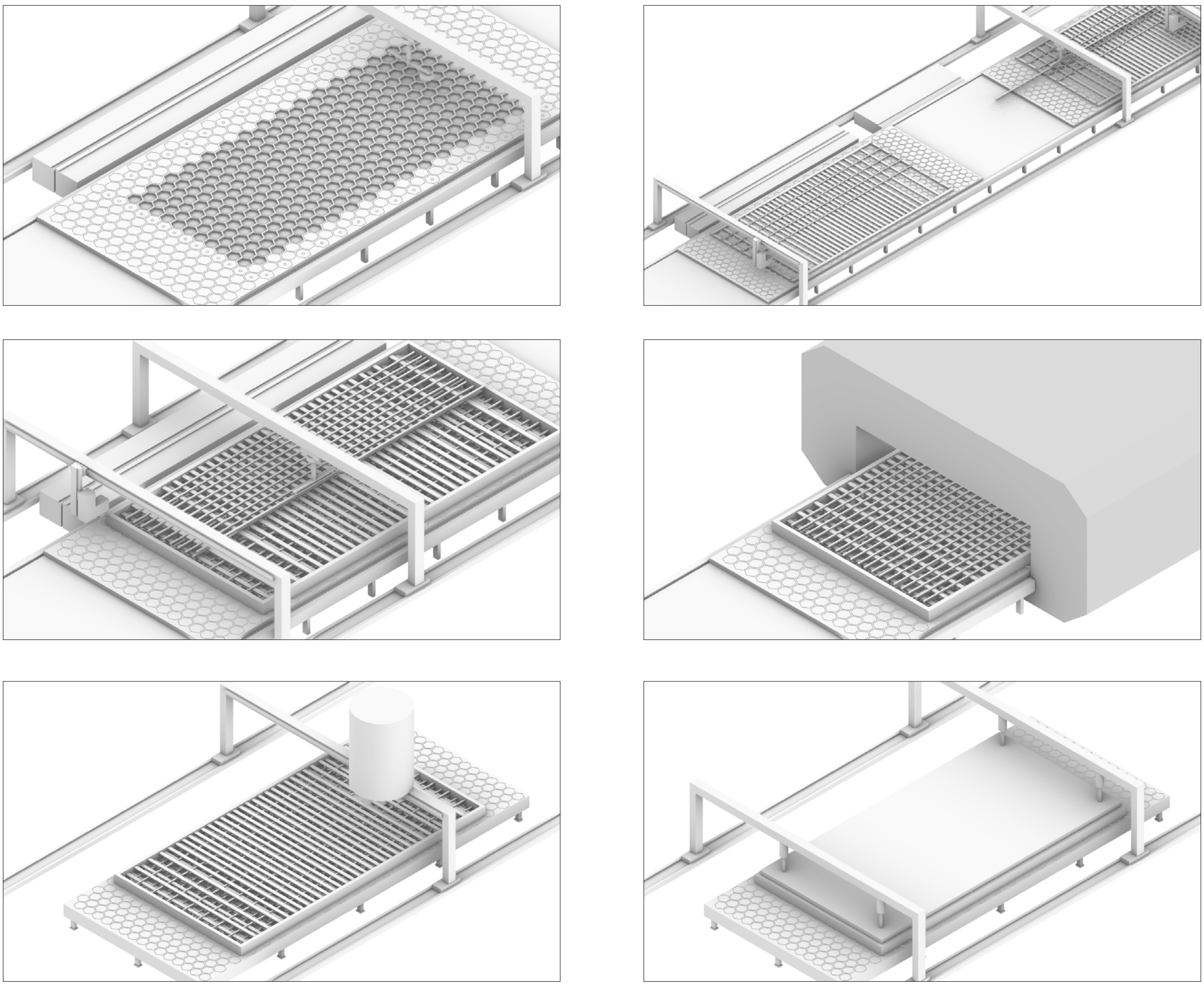


Optimization Algorithm

fabrication process and result



Afab Assembly



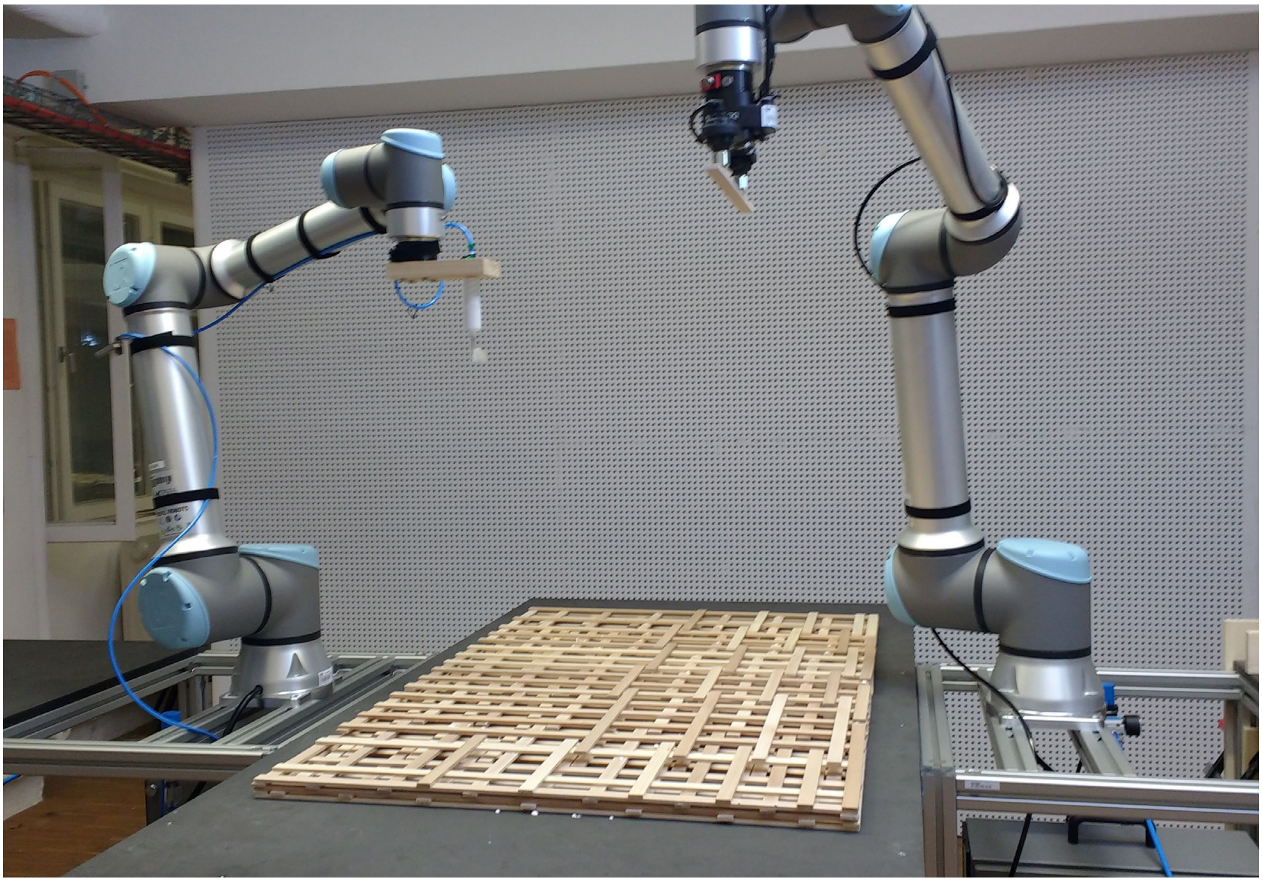
Envisioned Production Process

Prototyping

The load-bearing construction was assembled by two robots in 1:4. Two arms worked in synchronicity with one picking/placing timber sticks and the other one placing glue points. Shorter elements were used in the secondary span direction, showing the potential for implementing reused timber elements.
In addition, a 1:1 ceiling fragment was built together with start-up Oxara whose co-founder Thibault Demoulin travelled to Munich for this purpose. Oxara is an ETH-spinoff developing a clay mixture that does not need to be rammed. The mixture includes 100kg clay (acquired from a sand factory for whom this is a waste material), 150 kilos of aggregate, 1kg of straw and less than 100g of special minerals developed by Oxara to minimize cracks.
The mock-up will provide information on the potential cracking behaviour, drying time and the compound behaviour between timber and clay. While the cracking behaviour looks promising so far, the timber, despite not being protected in any way, did not take any damage in the casting process.
Concerning cracks it has to be noted that they would be more of an aesthetic than structural issue as the clay is not load-bearing and can hardly fall out. Considering the good repairability as well as the possibility of minimizing cracks by pre-stressing/pre-bending/reinforcing, it is very likely that an adequate solution can be developed. In order to observe the effects an uneven surface might have on the cracking behaviour, a second, smaller mock-up with a smooth surface was built.

Julian Trummer and Marton Deme

OXARA



Afab 1:4 Assembly

1:1 Mockup Casting Process

1:1 Mockup Side View

Interior Image

Production Process

The system can be produced in a prefabricated or semi-prefabricated way. The timber grid has to be assembled in the factory where it then goes into a CLT press before the lower layers of clay and the body sound insulation are casted with a vibrating table being used in order to spread the material evenly. In the prefabricated version, the clay floor is cast in the factory as well with only the sealing taking place on site, while in the semi-prefabricated version the floor is cast on site in order to ensure a seamless top surface. On construction sites with a great amount of built volume and sufficient free space, transportation cost can be minimized by establishing an on-site factory for the whole casting process, with only the timber grid being prefabricated.
Featuring easily automatable steps – pick & place, gluing, pressing and casting - the whole process can be automated already with the current state of technology, minimizing cost while maximizing speed and output. Mostly relying on casting processes, the assembly is possible without creating any waste.

LAYERS

SCREED Clay	40mm
BODY SOUND INSULATION + FILLING Hemp/Clay	15-39mm
LOAD BEARING LAYER Cross Laminated Timber	168mm (7x24mm)
FIRE PROTECTION + BALLAST Clay	168 - 188mm
	267mm

PROPERTIES

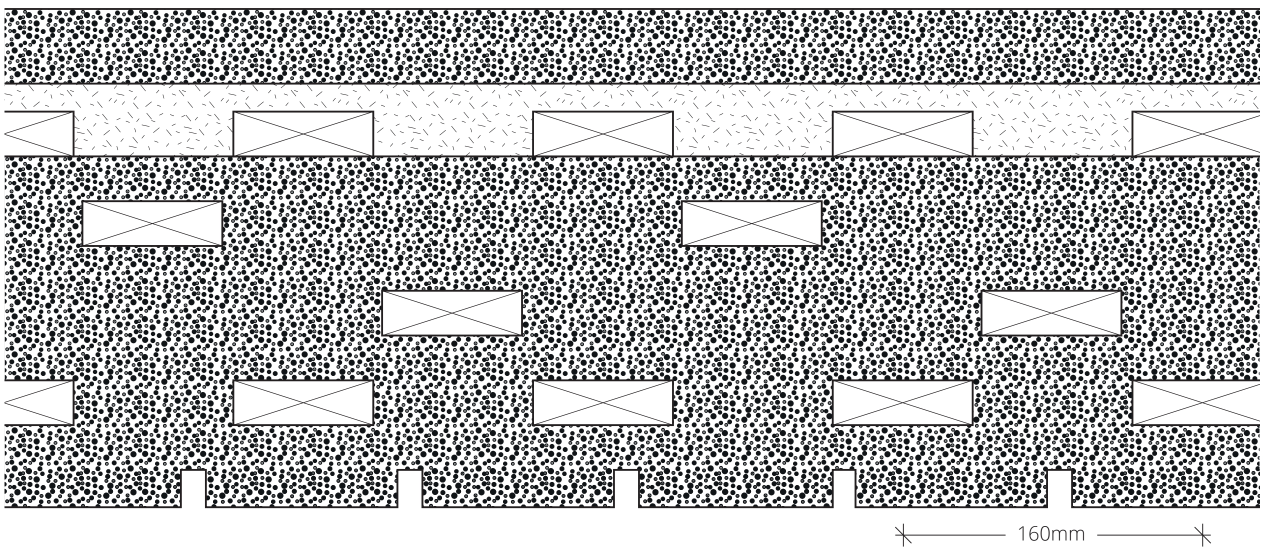
TIMBER BEAM FORMAT	24x75mm
WEIGHT LOAD BEARING	27 kg/m^2
WEIGHT TOTAL	328 kg/m^2
SOUND INSULATION	54 db
BODY SOUND INSULATION	51 db

STATICS (FEA)

FORCE APPLIED	4KN/m^2
UTILISATION MOMENT	37%
UTILISATION SHEAR FORCE	97%
BENDING	6.1mm

STATICS (Manual)
Under Ideal Conditions

FORCE APPLIED	4KN/m^2
UTILISATION MOMENT	22%
UTILISATION SHEAR FORCE	62%
BENDING	3,6mm



Detailed Section

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imprint

TT Professorship Digital Fabrication
Prof. Dr. sc. ETH Kathrin Dörfler

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Simple Slab - Design and Robotic Fabrication of Timber-Exposed Floor Slabs
TT Professorship Digital Fabrication - Department of Architecture - Technical University Munich