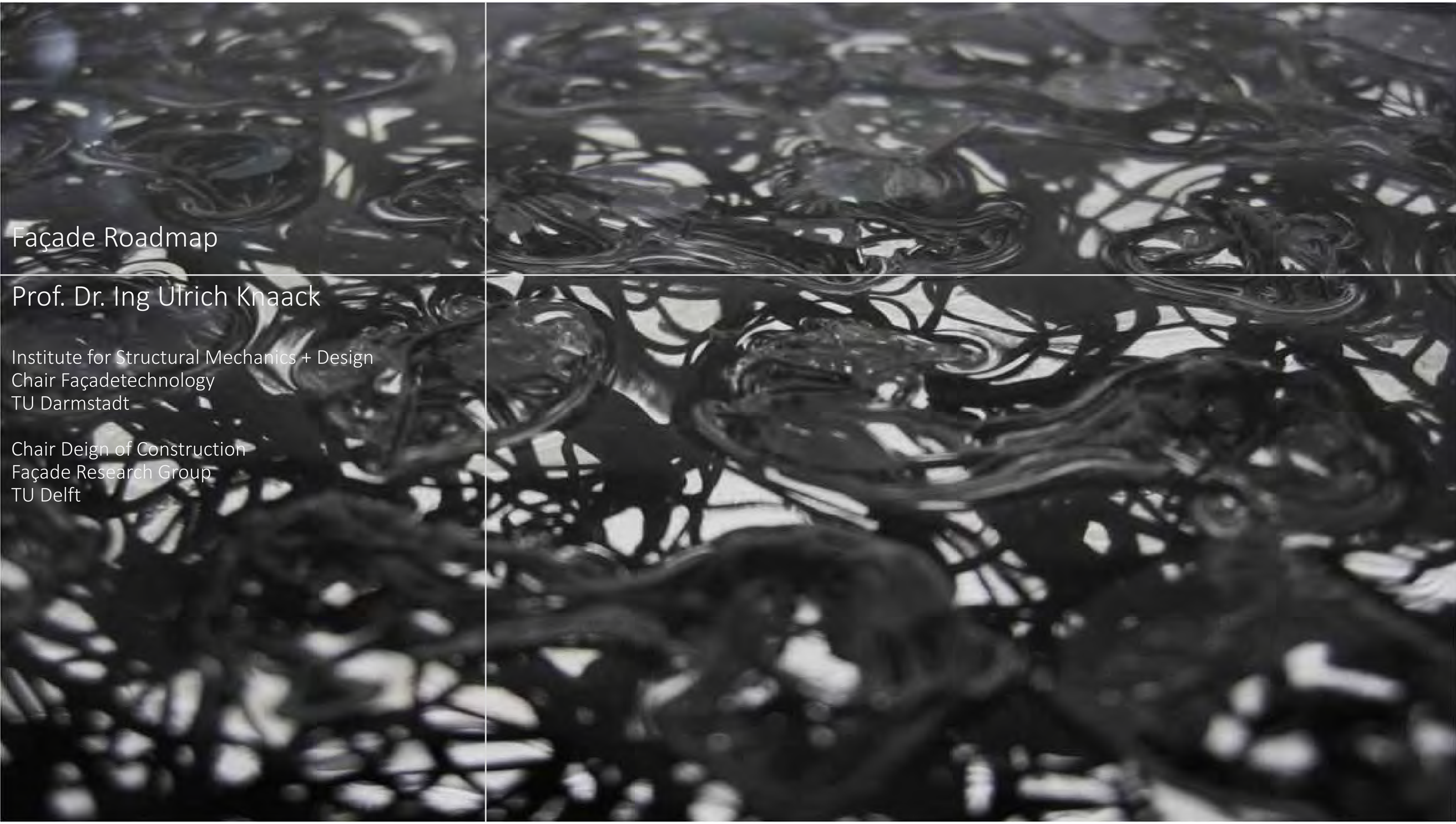


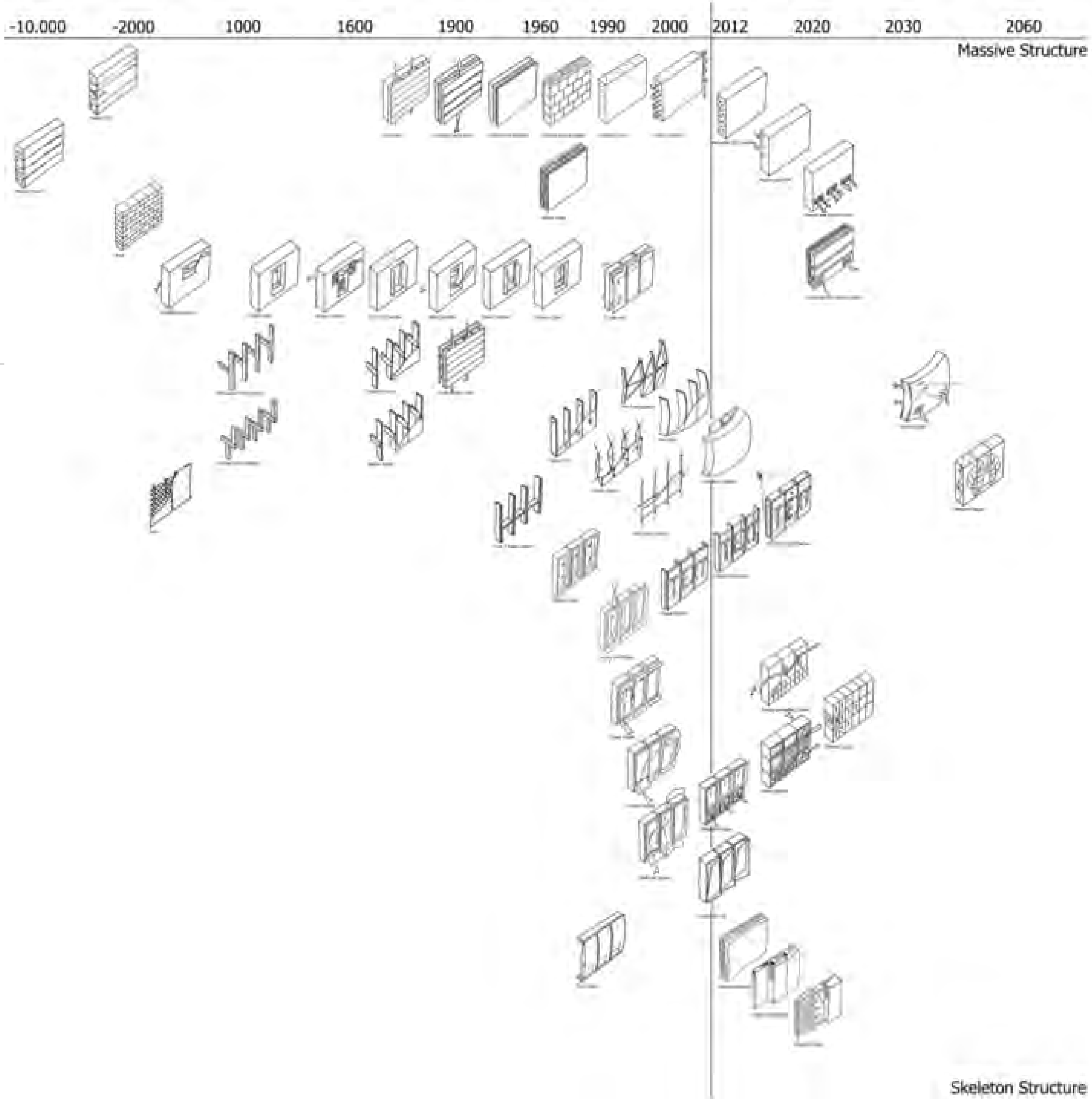
Façade Roadmap

Prof. Dr. Ing Ulrich Knaack

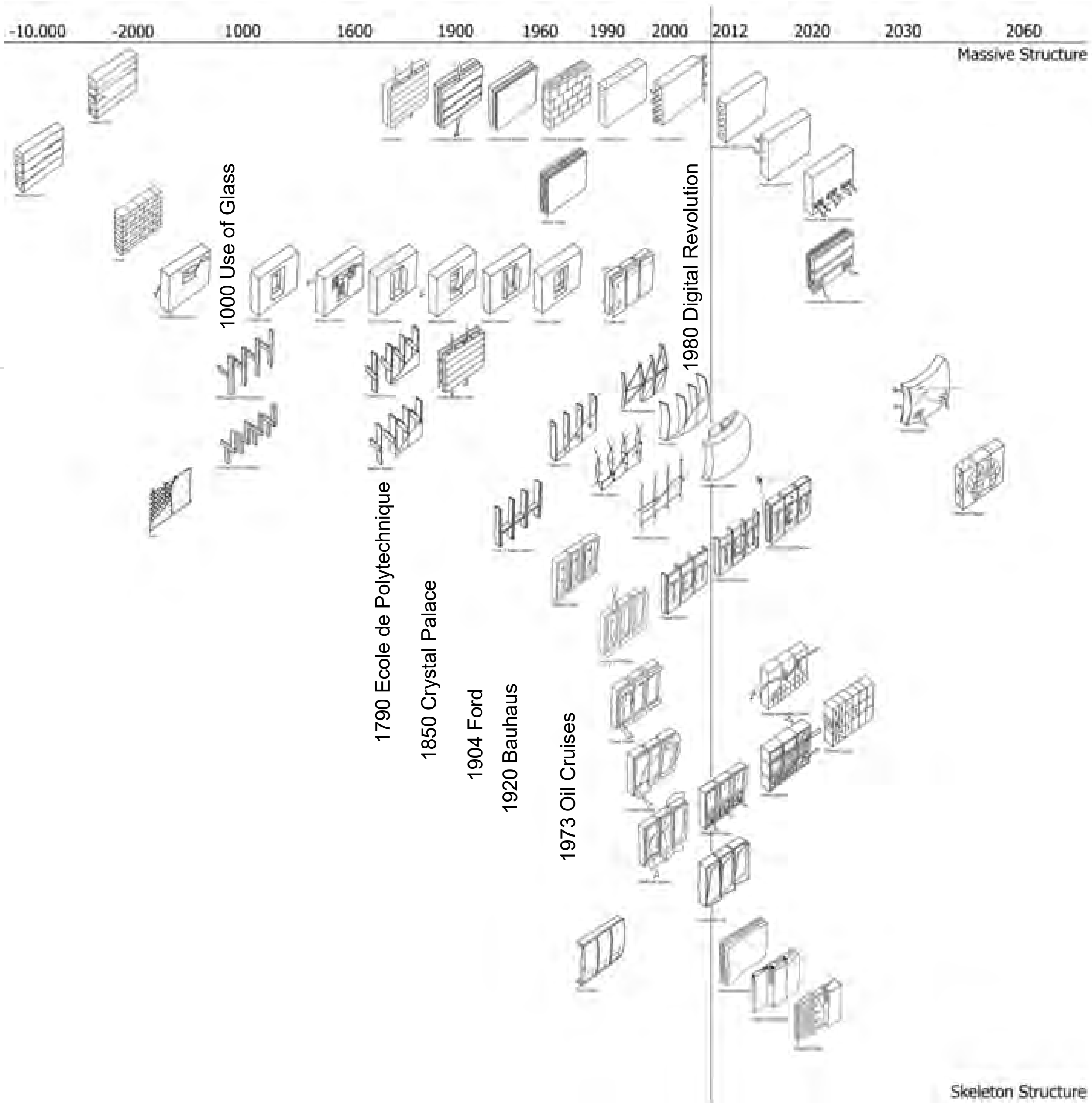
Institute for Structural Mechanics + Design
Chair Façadetechnology
TU Darmstadt

Chair Deign of Construction
Façade Research Group
TU Delft

Façade Roadmap

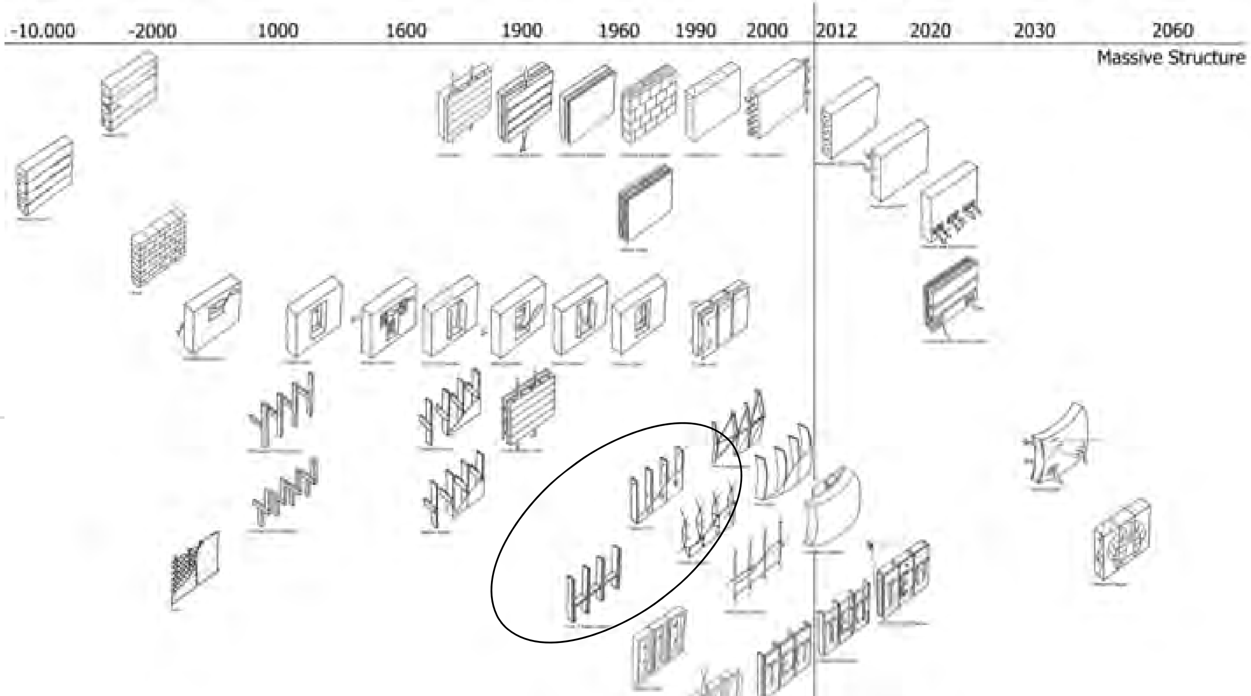


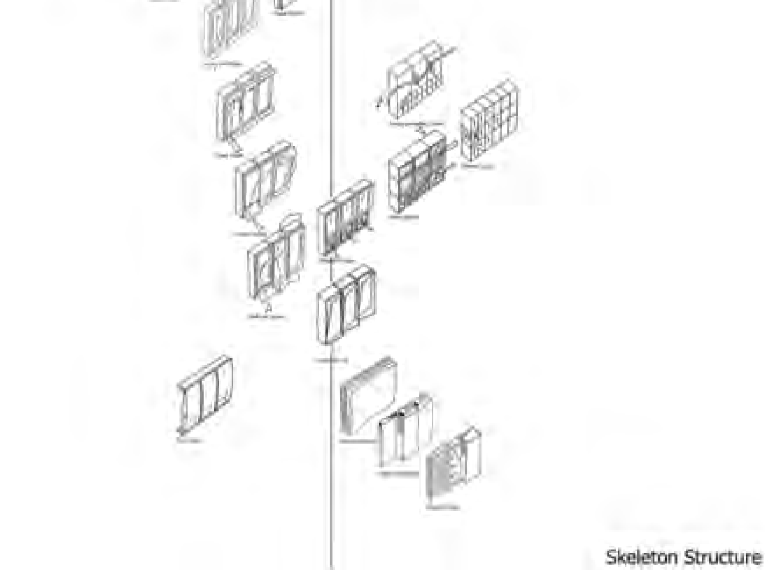
Influences



-10.000
-2000
1000
1600
1900
1960
1990
2000
2012
2020
2030
2060
Massive Structure
1000 Use of Glass
1790 Ecole de Polytechnique
1850 Crystal Palace
1904 Ford
1920 Bauhaus
1973 Oil Cruises
1980 Digital Revolution
Skeleton Structure

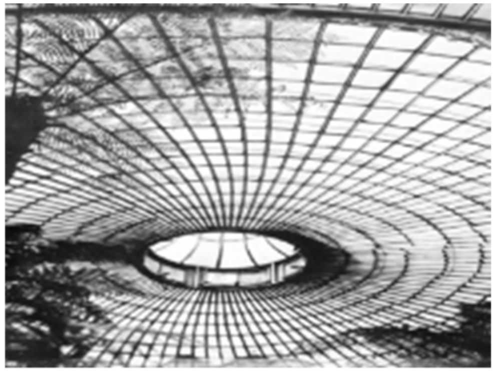
Façade Roadmap

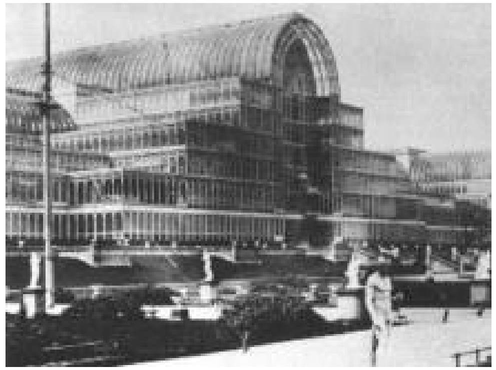




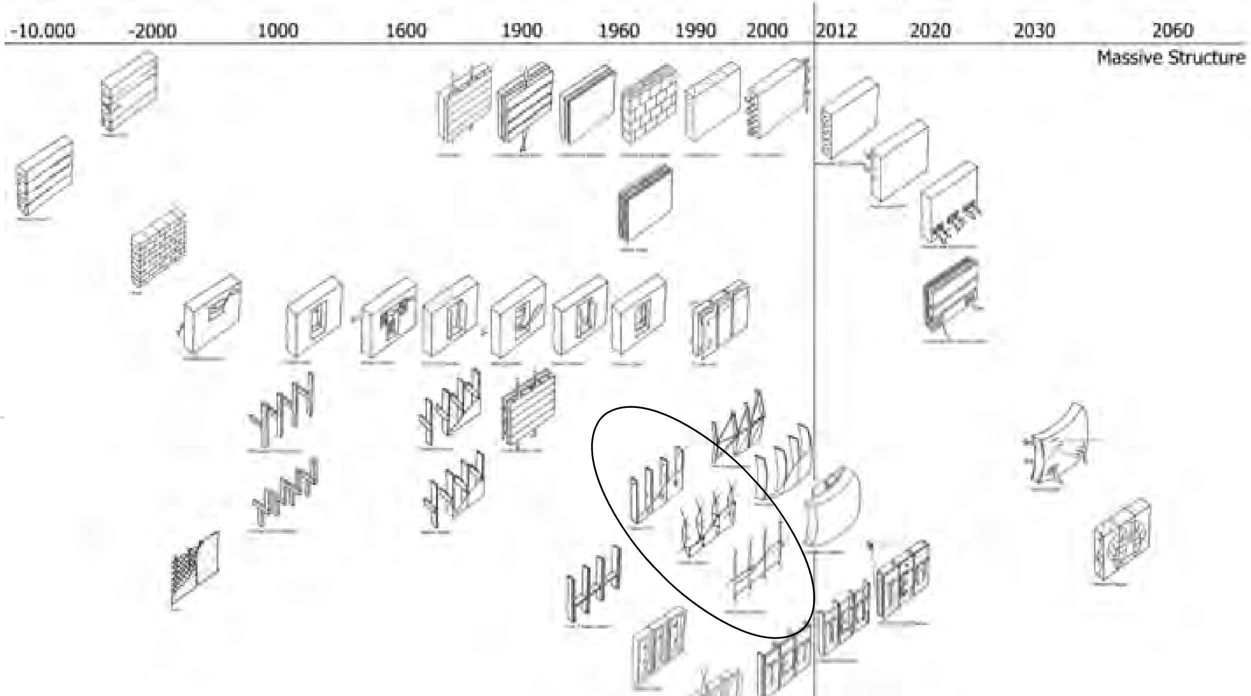
Kew Gardens

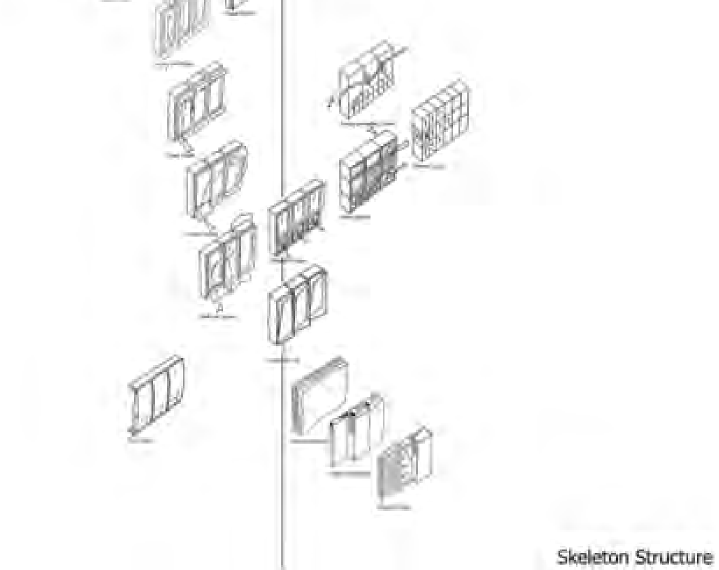
first generation structural glass @1840





Façade Roadmap

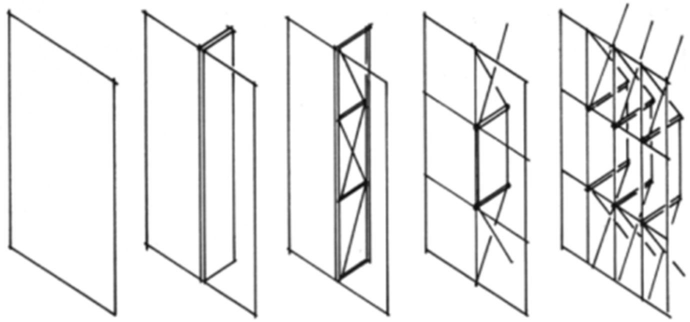




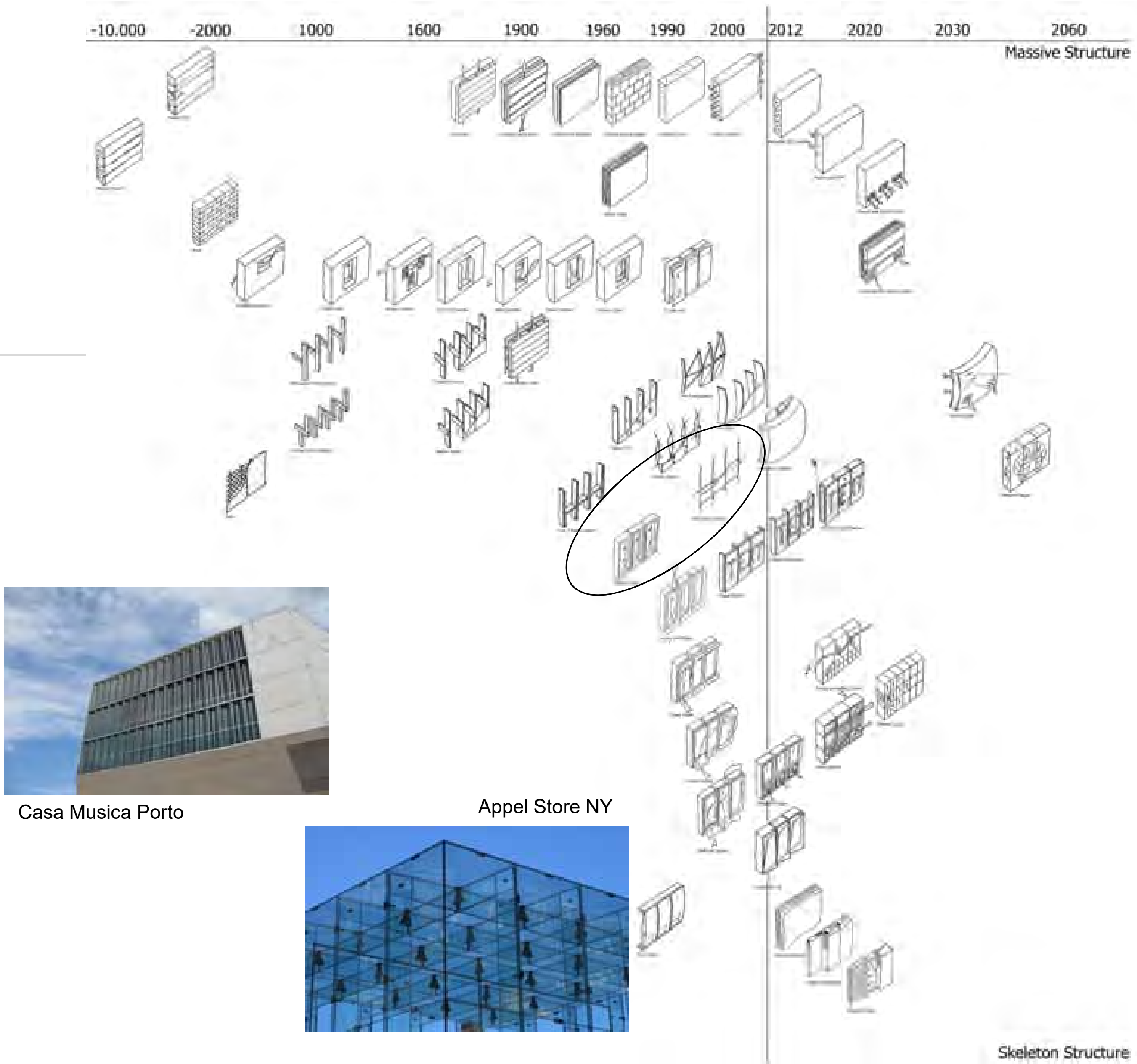

Kew Gardens

Parc de la Vilette


second generation
structural glass @ 1980



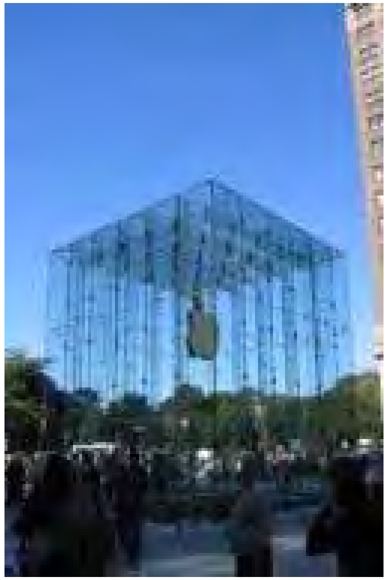
Façade Roadmap



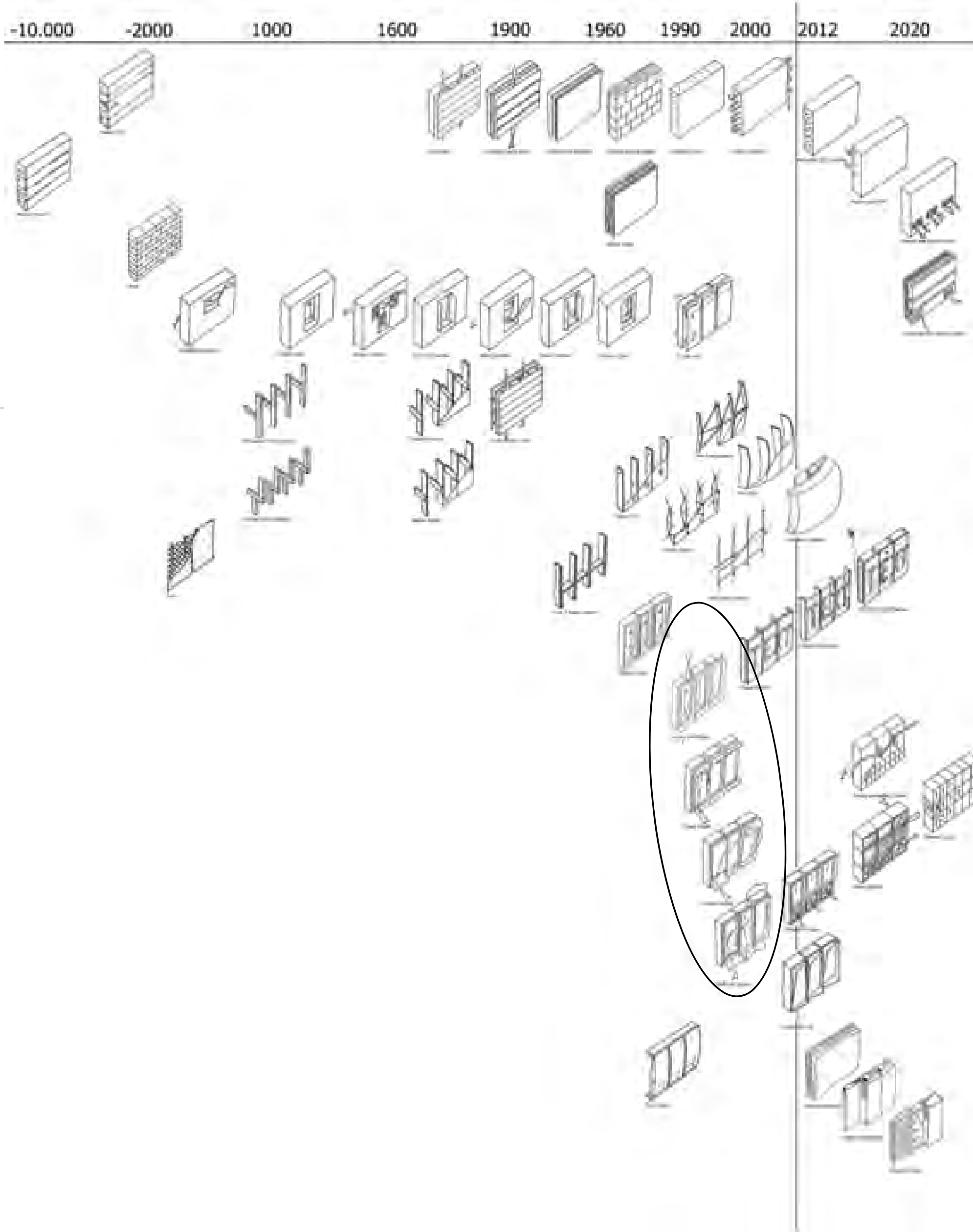
Casa Musica Porto

Appel Store NY

Third generation
structural glass @2015

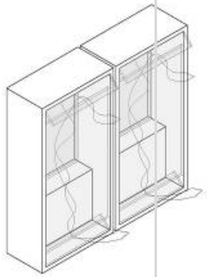


Façade Roadmap

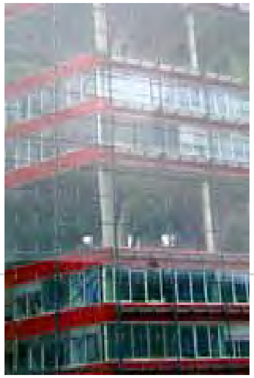


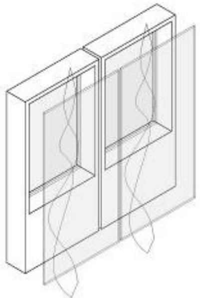
Stadttor Düsseldorf

Façade Roadmap
double facades @ 2000

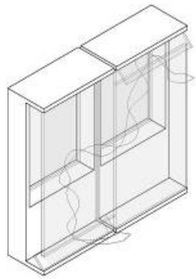


boxed window facade

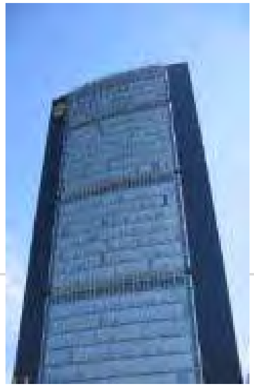


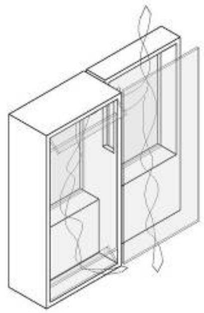


second skin facade

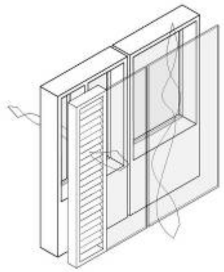


corridor facade

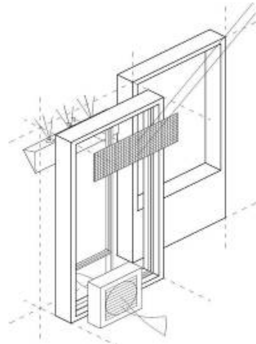




chimney boxed window facade

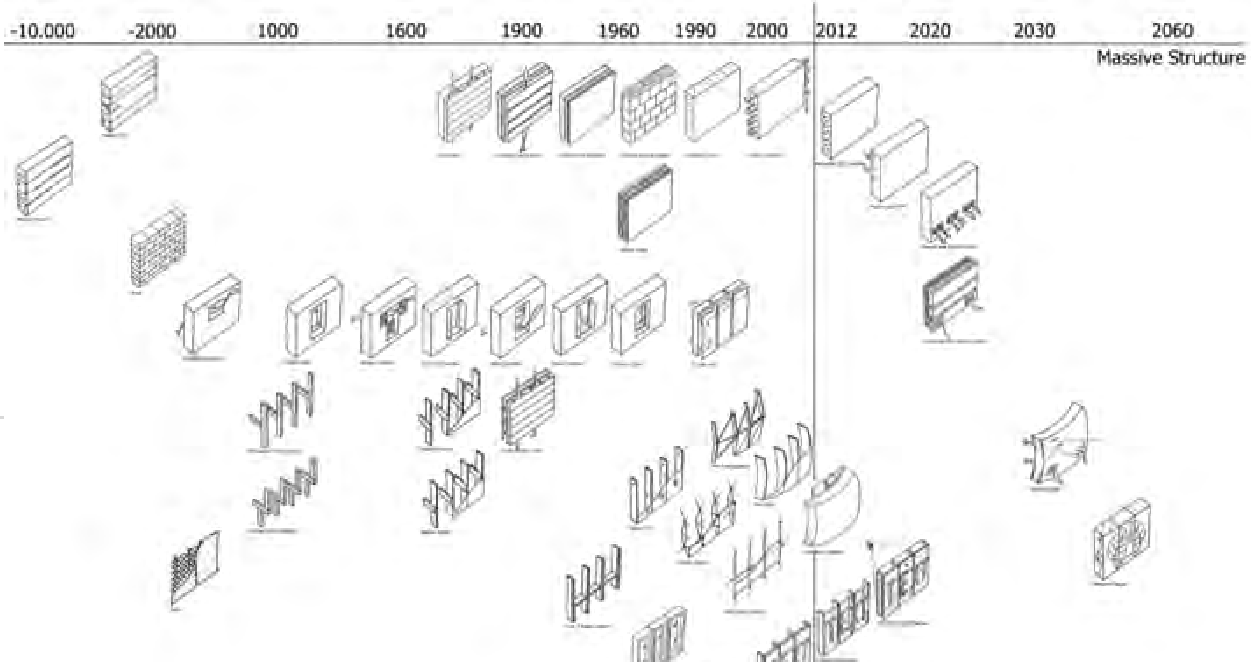


alternating facade



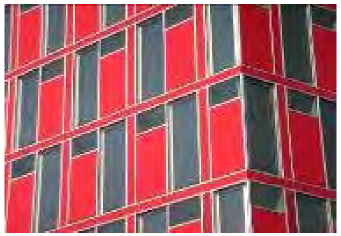
component facade

Façade Roadmap



Post Tower Bonn

Capricon Düsseldorf



Façade Roadmap
Component façade @ 2010

Posttower Bonn

T-motion facade

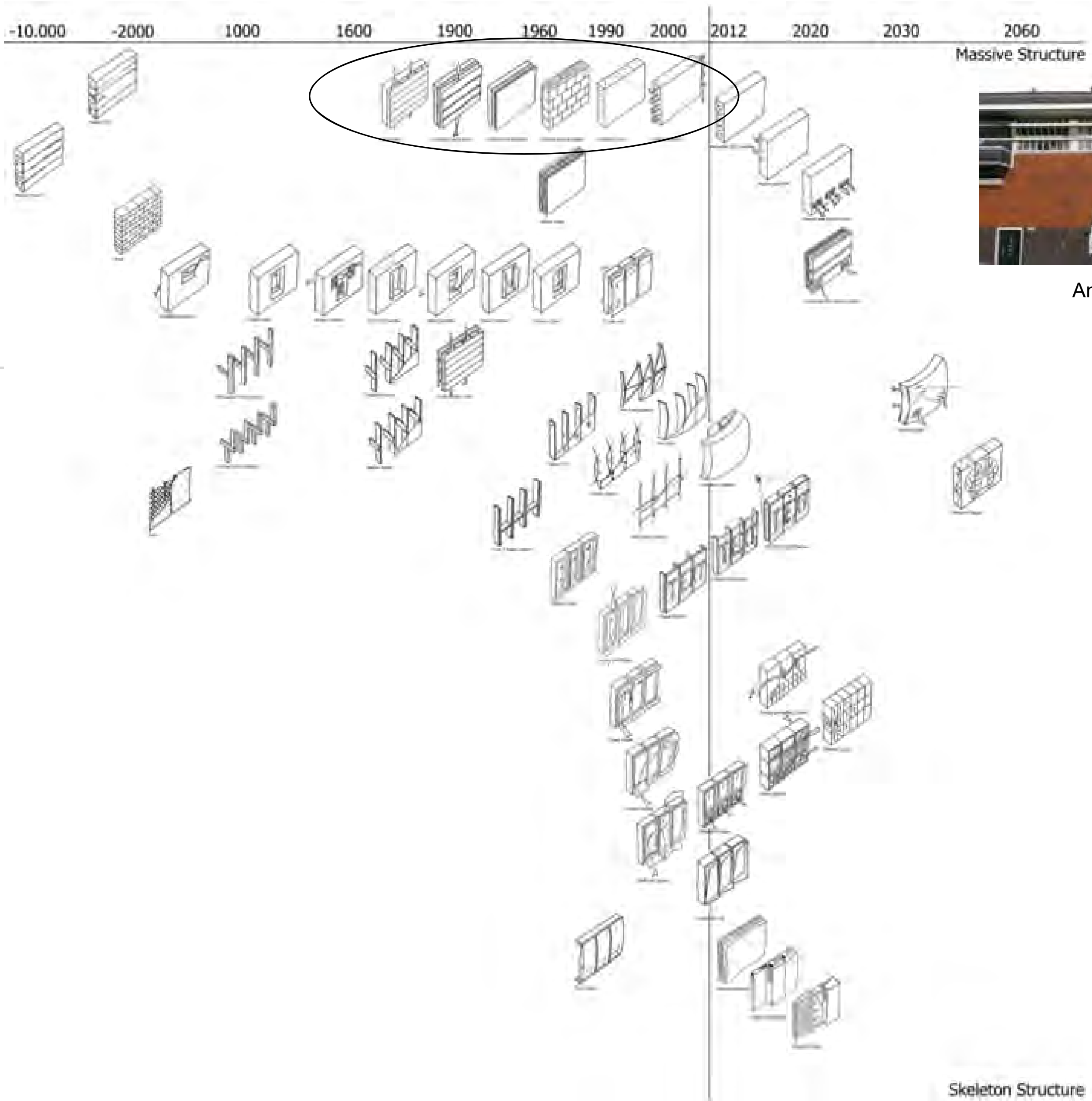
Capricon Düsseldorf

SmartBox

E² Fassade

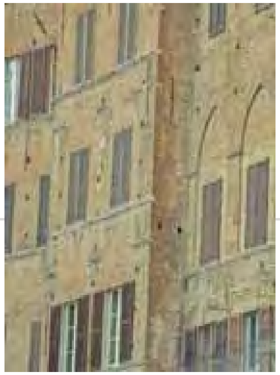
NEXT Facade

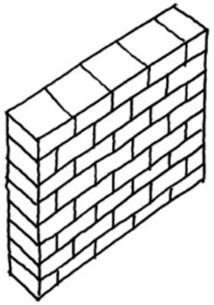
Façade Roadmap



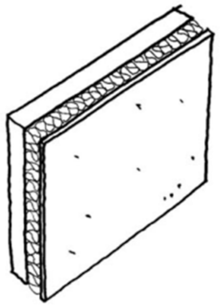
Amsterdamer Schule

solid construction to layered solid construction

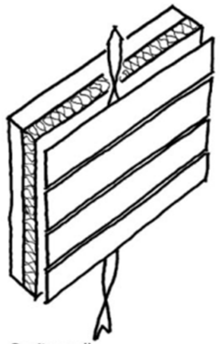




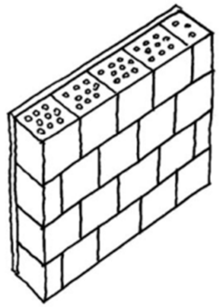
Brick



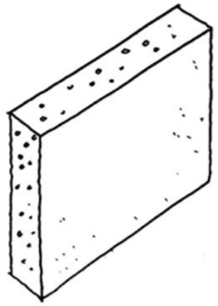
Massive insulated



Cavity wall

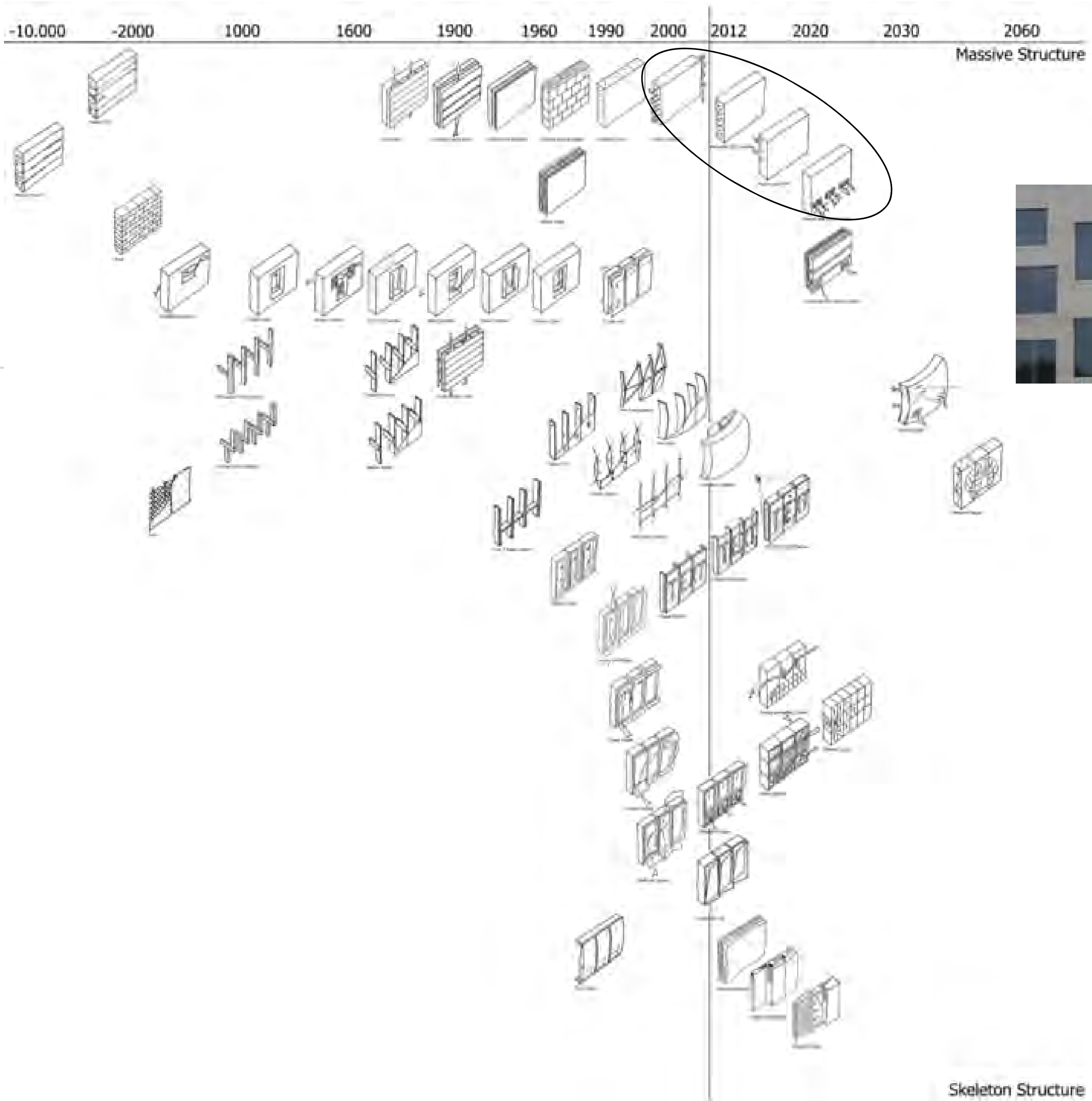


Massive brick insulated



Monolithic block

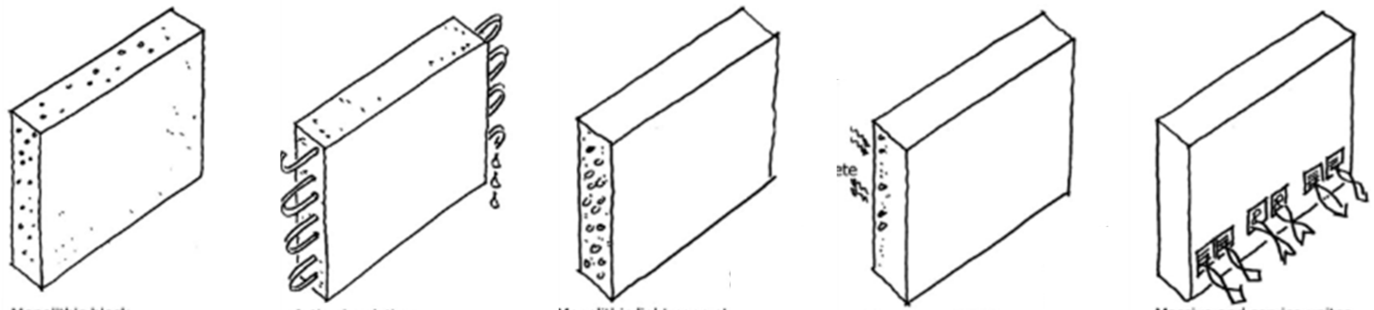
Façade Roadmap



Design School Essen

Façade Roadmap
solid function integrated construction



Façade Roadmap

Design School Essen - SANAA / Tokyo

in collaboration with
Mathias Schuller - Transsolar and
Holger Techen - Bollinger und Grogmann

Façade Roadmap

Design School Essen - SANAA / Tokyo

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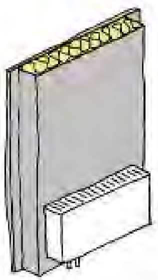
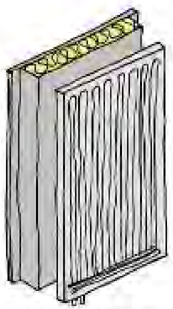
Façade Roadmap

facade heating / cooling panel

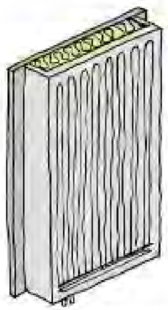
by Marcel Bilow / 2007



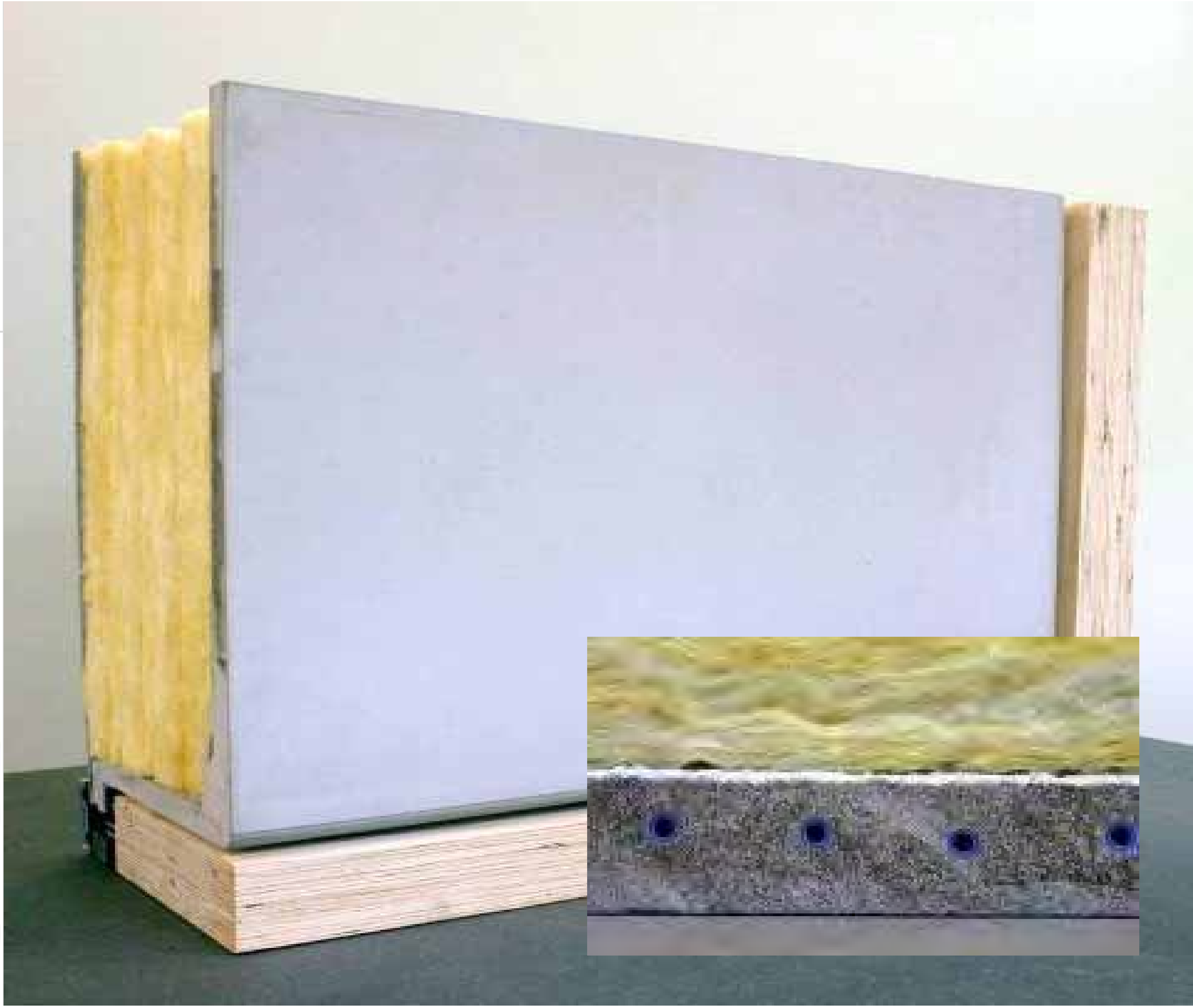
Panel mit vorgesetztem Heizkörper



Paneel mit Flächen-heizung additiv



Flächenheizkörper bildet Teil des Paneels

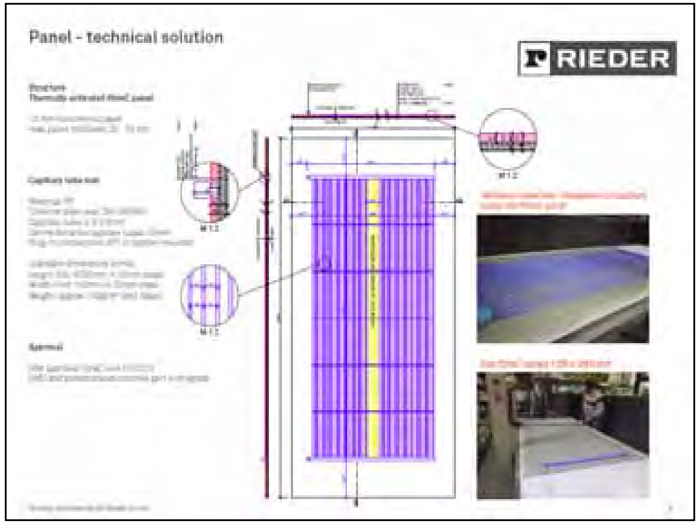


Façade Roadmap

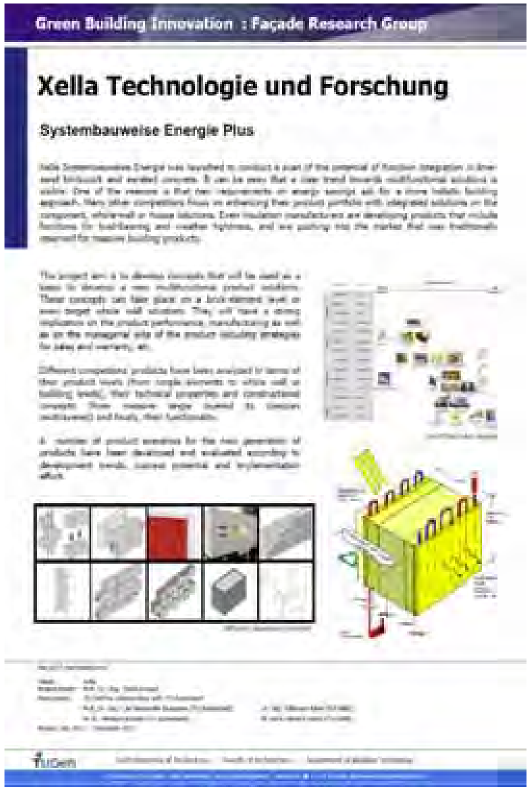
Jackbox: integrated sandwich construction

HS OWL / 2007

Façade Roadmap

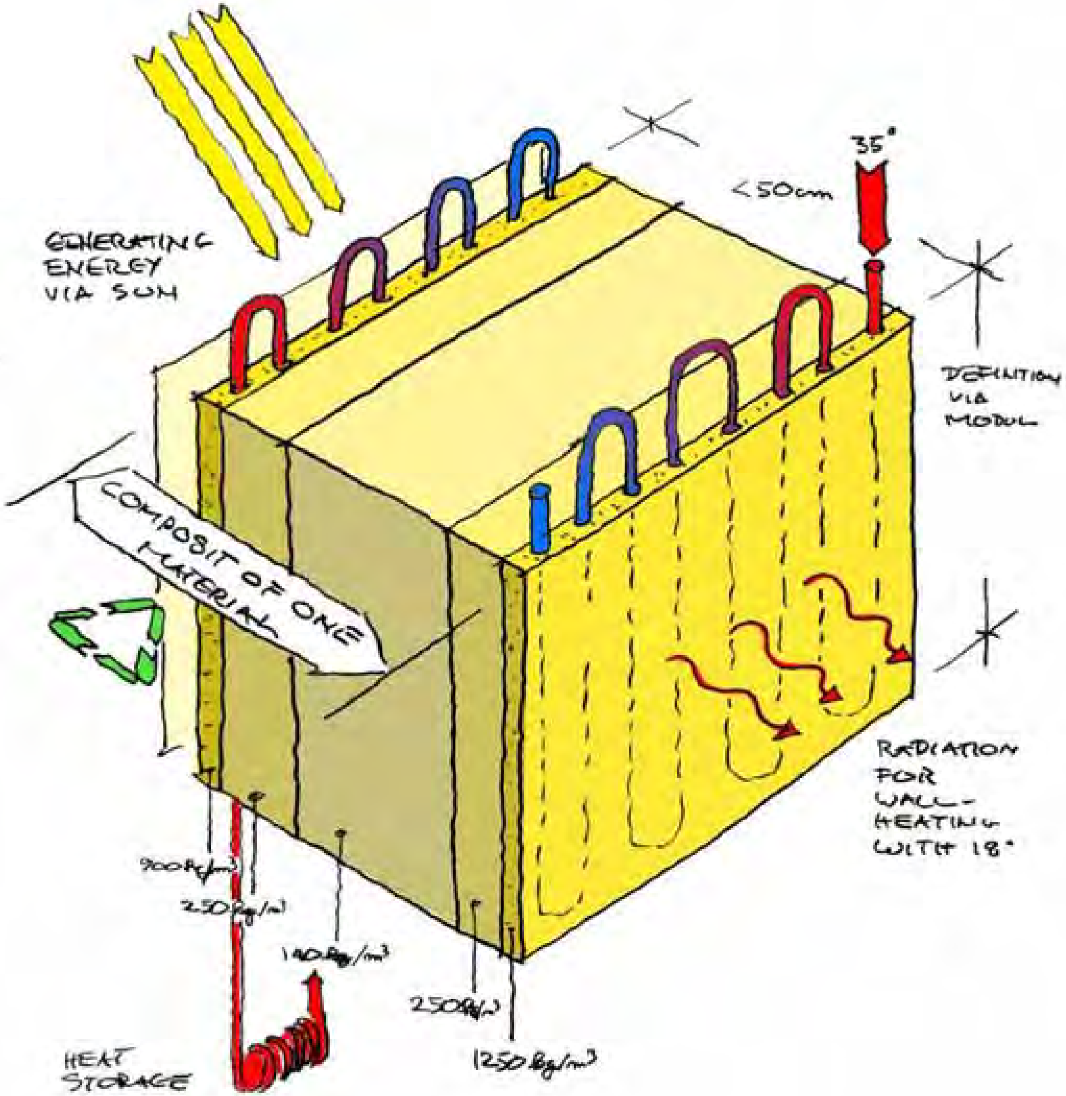


Façade Roadmap


Green Building Innovation : Façade Research Group

Xella Technologie und Forschung

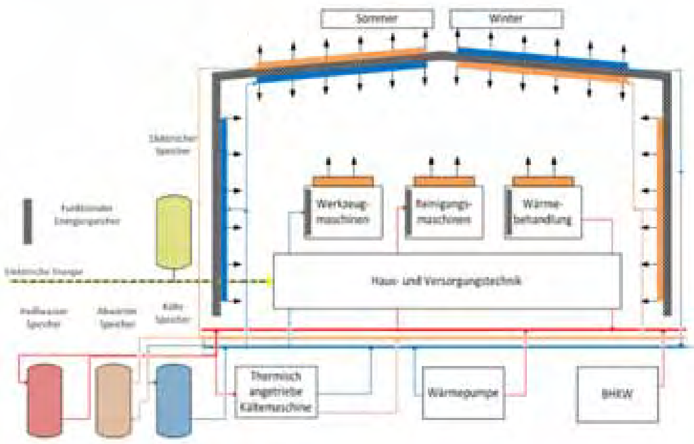
Systembauweise Energie Plus



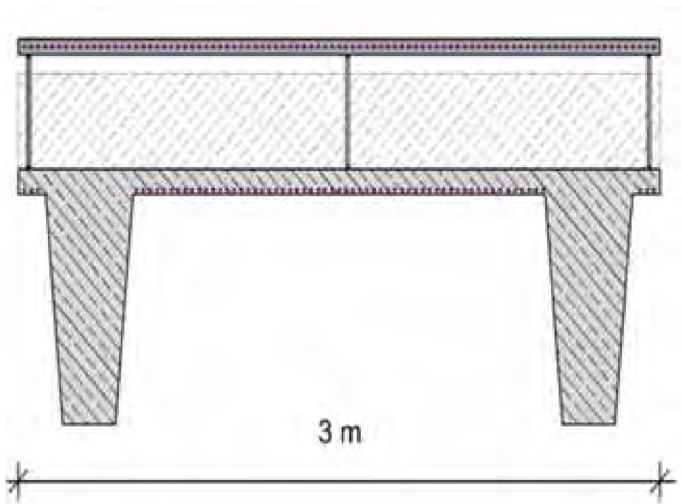
Façade Roadmap

ETA Factory / Tu Darmstadt

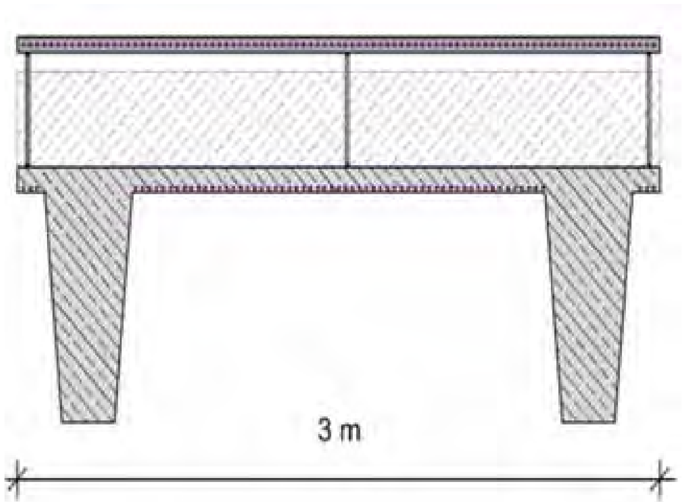
Prof Dr. Jens Schneider,
Prof Dr. H. Gerecht,
Prof Dr. E. Abele / TU Darmstadt
Prof. J. Eisele
Prof A. Joppin

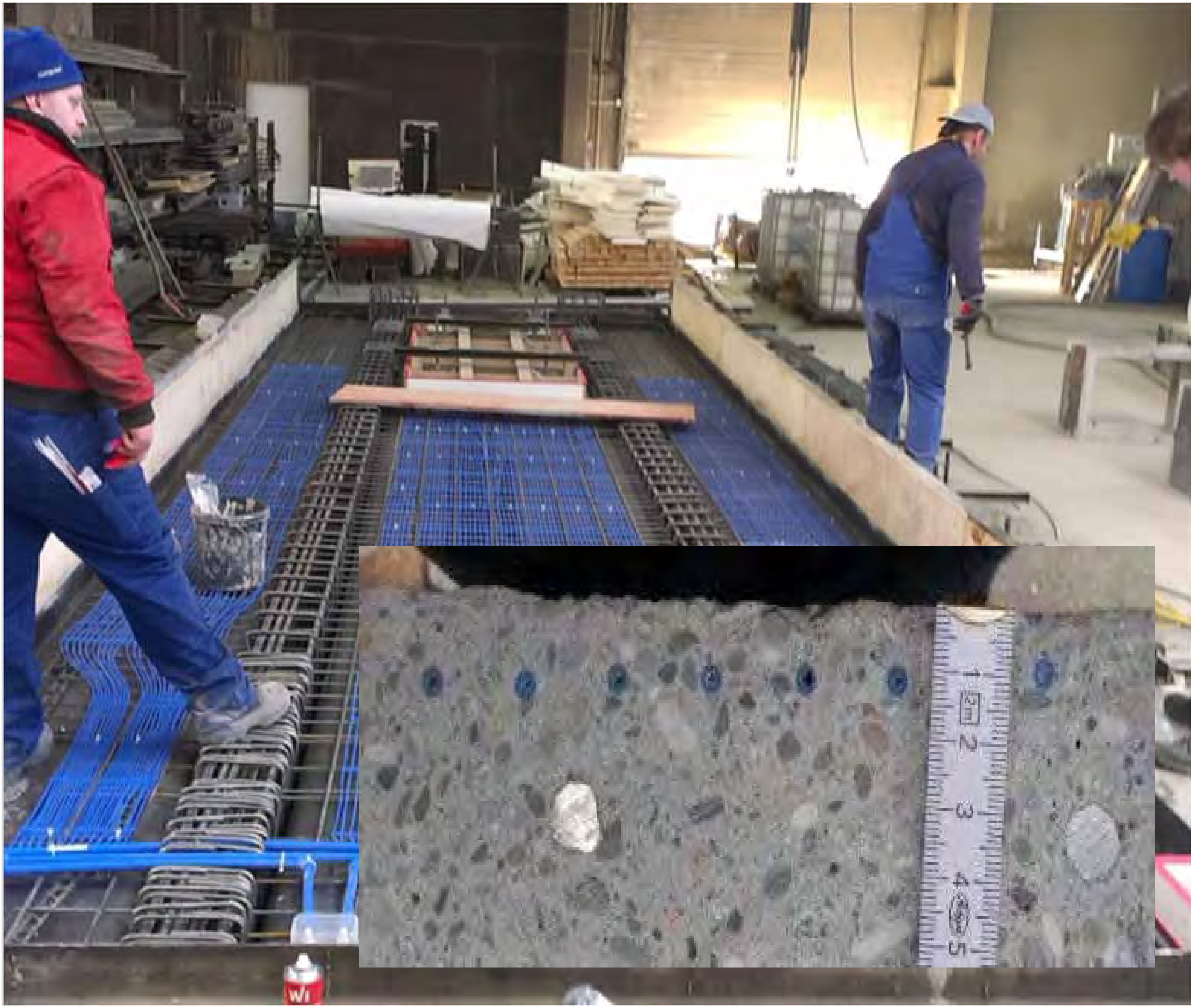


Façade Roadmap

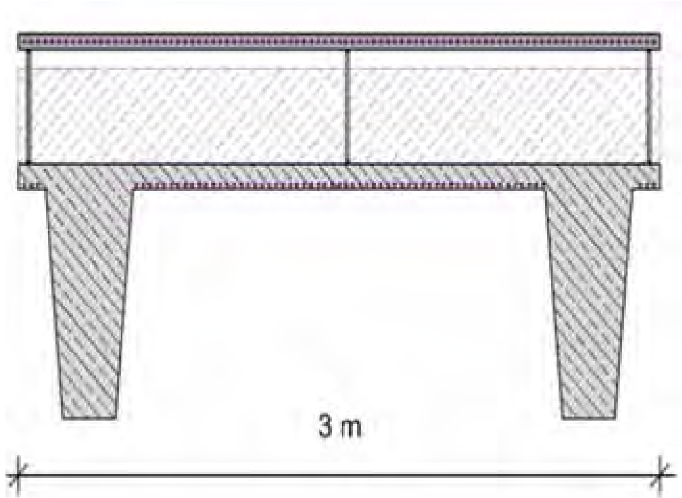


Façade Roadmap

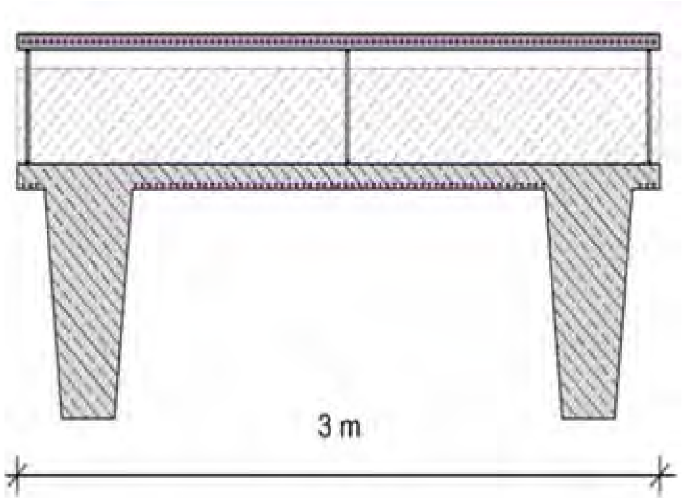


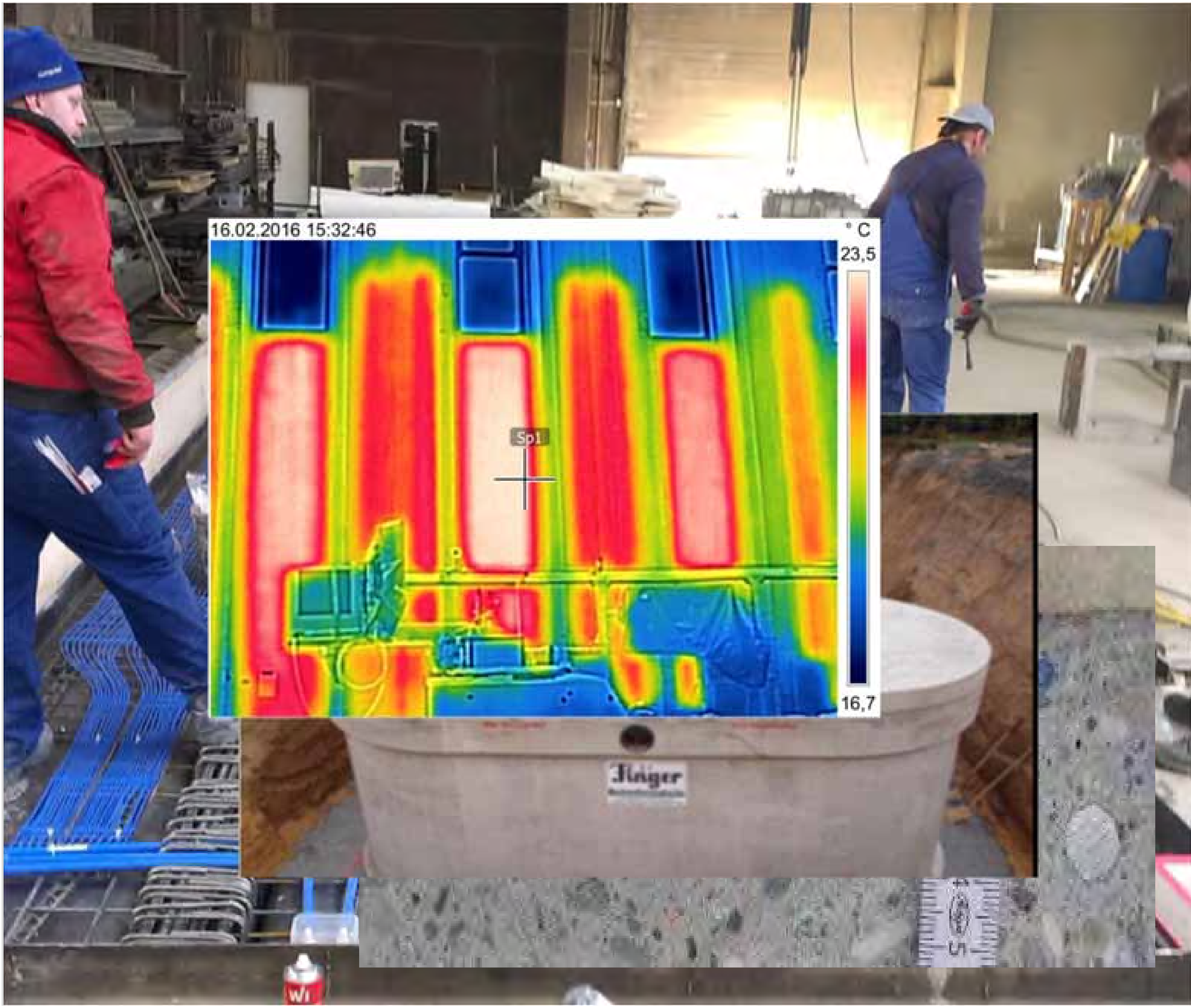


Façade Roadmap



Façade Roadmap





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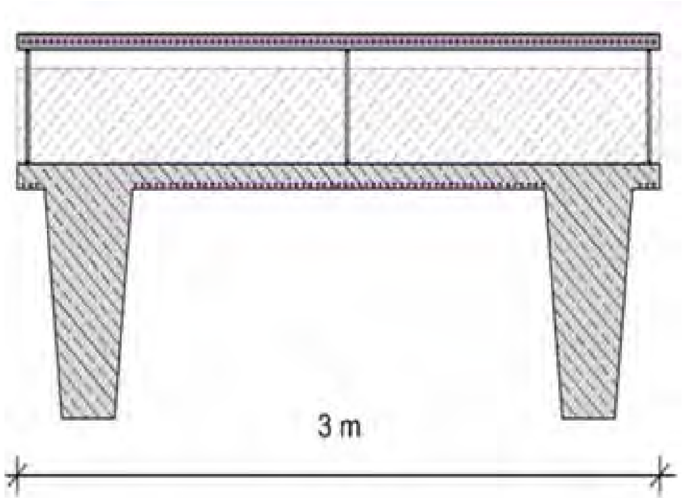
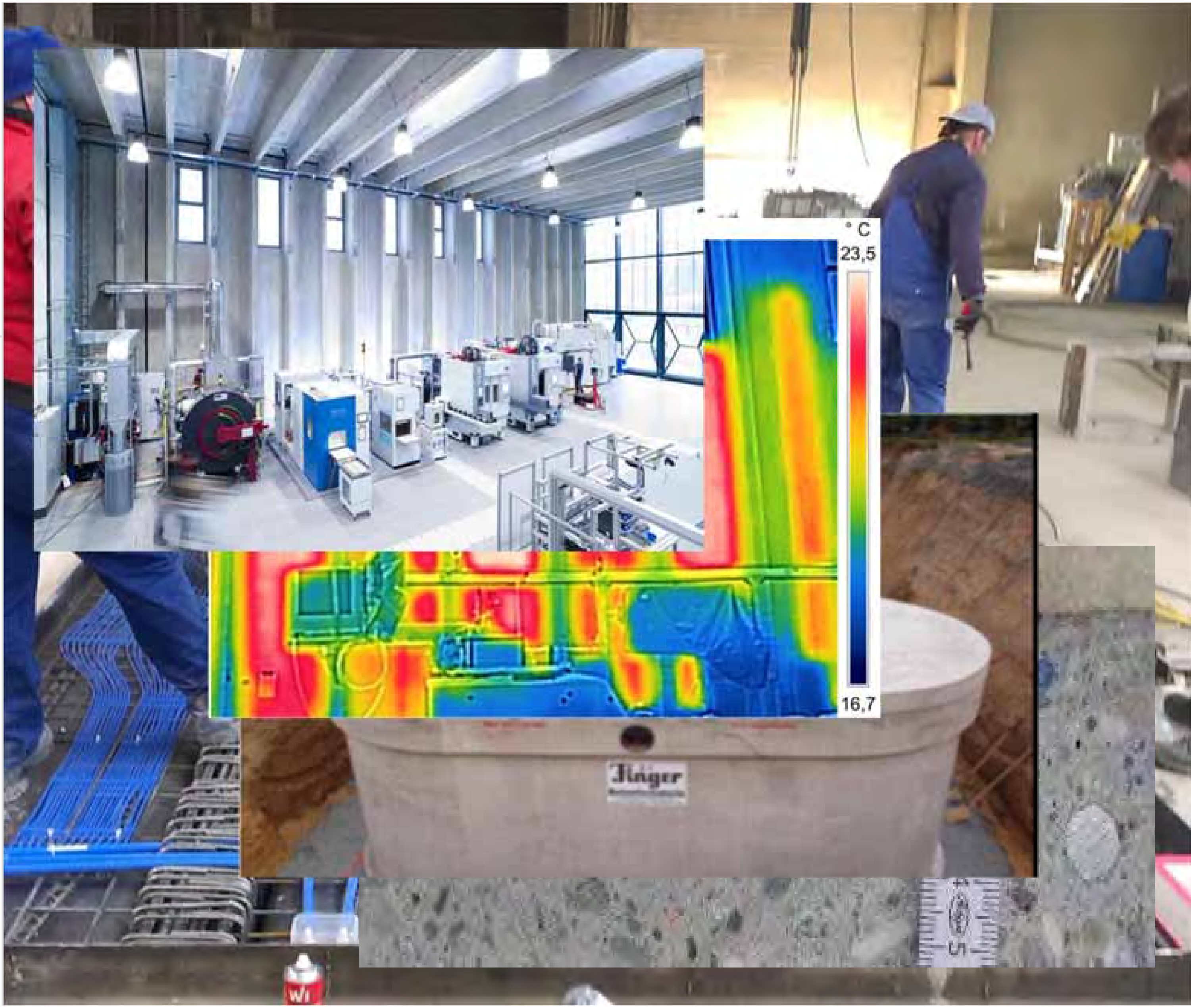
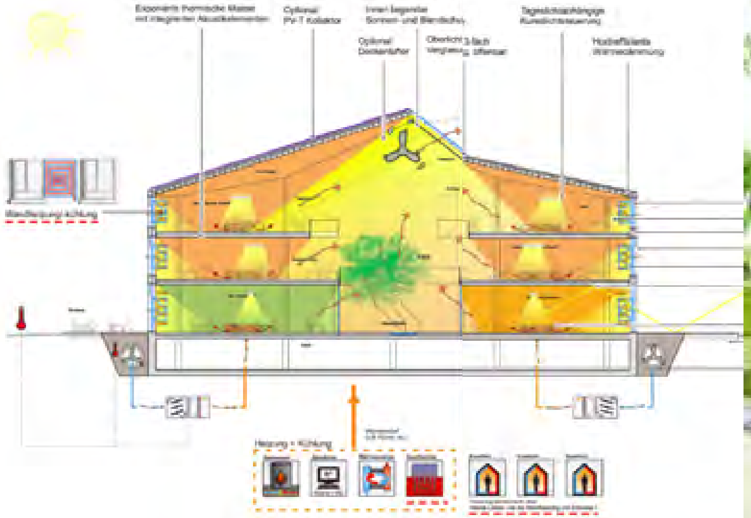




Façade Roadmap

Alnatura / Darmstadt

Studio 2050 mit Transsolar und Knipper Helwig



Façade Roadmap

Façade Roadmap

Green Building Innovation: Façade Research Group

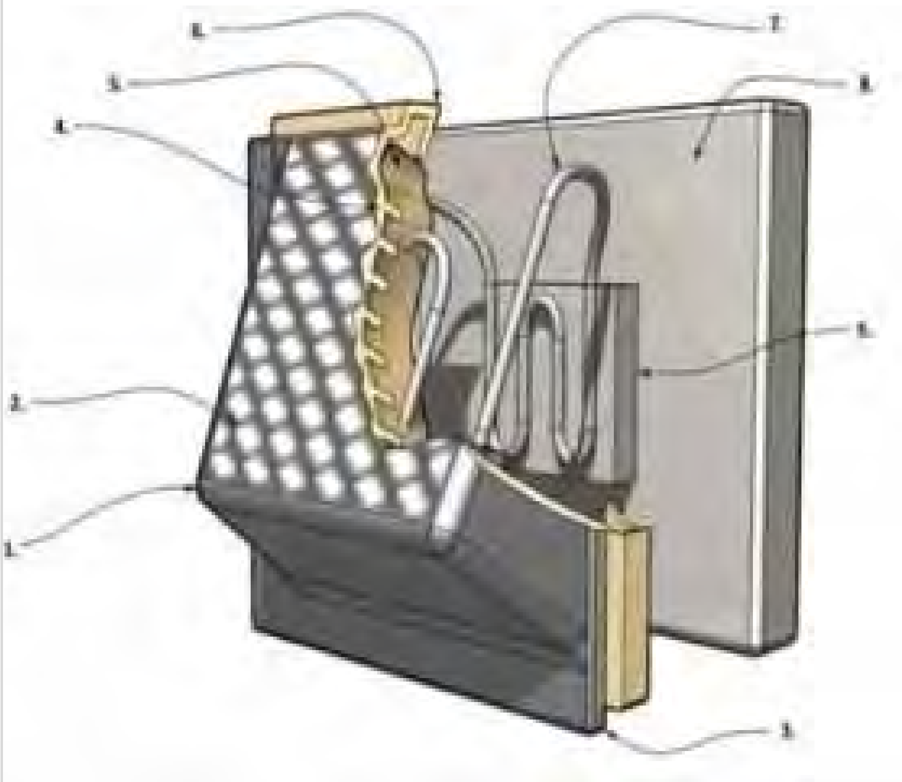
Advection Based Adaptive Building Envelopes:

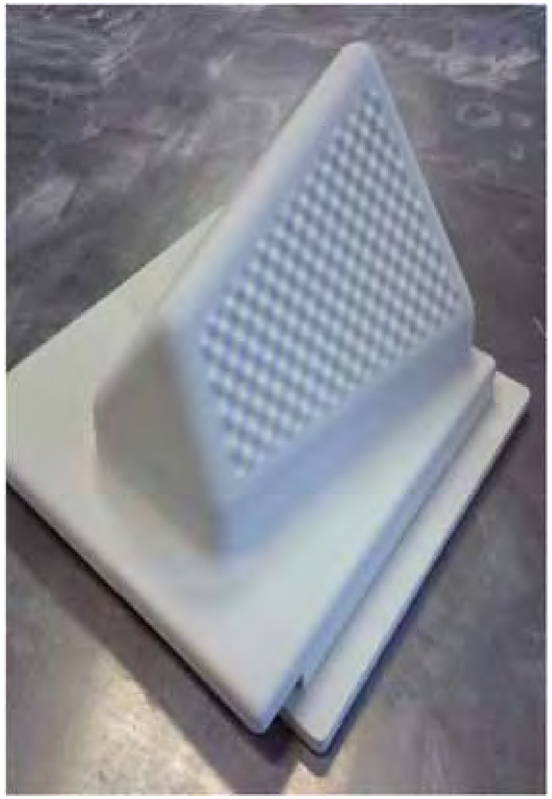
Component surface morphology and entropy management of a ceramic building facade

The Advection Based Adaptive Building Envelope is a ceramic based cladding system optimized to work with local climate conditions, absorbing or reflecting solar radiation by using variable surface morphology, colour and material properties, while vectoring energy via phononic advection. The ABABE is designed to use this multivalent strategy to absorb, release and redirect heat or coolth to conserve energy by managing entropy production.

Value Proposition of Managing Entropy Production

Building Envelope as Energy Transfer Function





Façade Roadmap

Green Building Innovation: Façade Research Group

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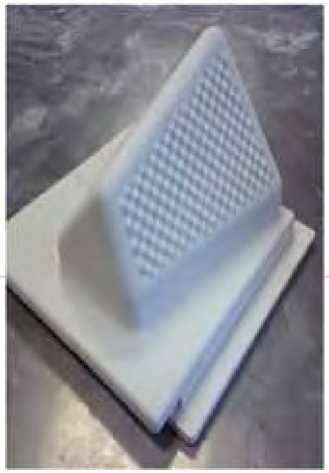
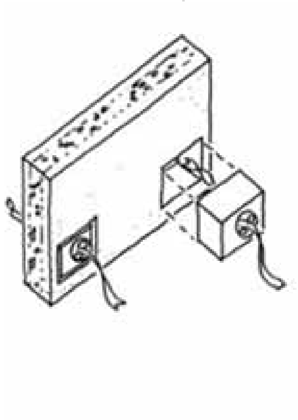
Value Proposition of Managing Entropy Production

Building Envelope as Energy Transfer Function

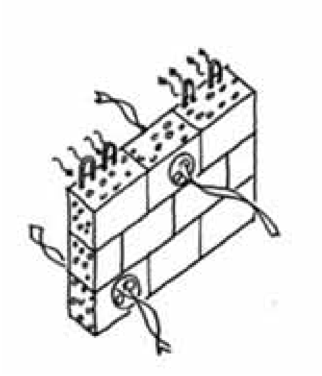
TU Delft Delft University of Technology Faculty of Architecture Department of Architectural Engineering & Technology

Façade Roadmap

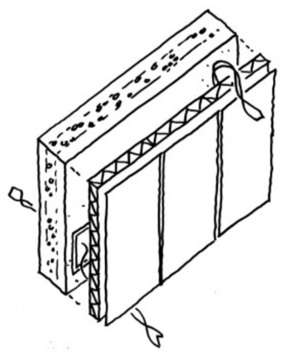




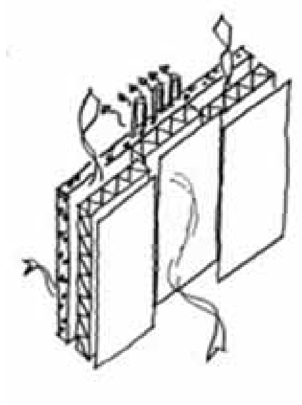
Single layered light massive enveloper with services integrated



Full services and energy collection integrated in light massive enveloper

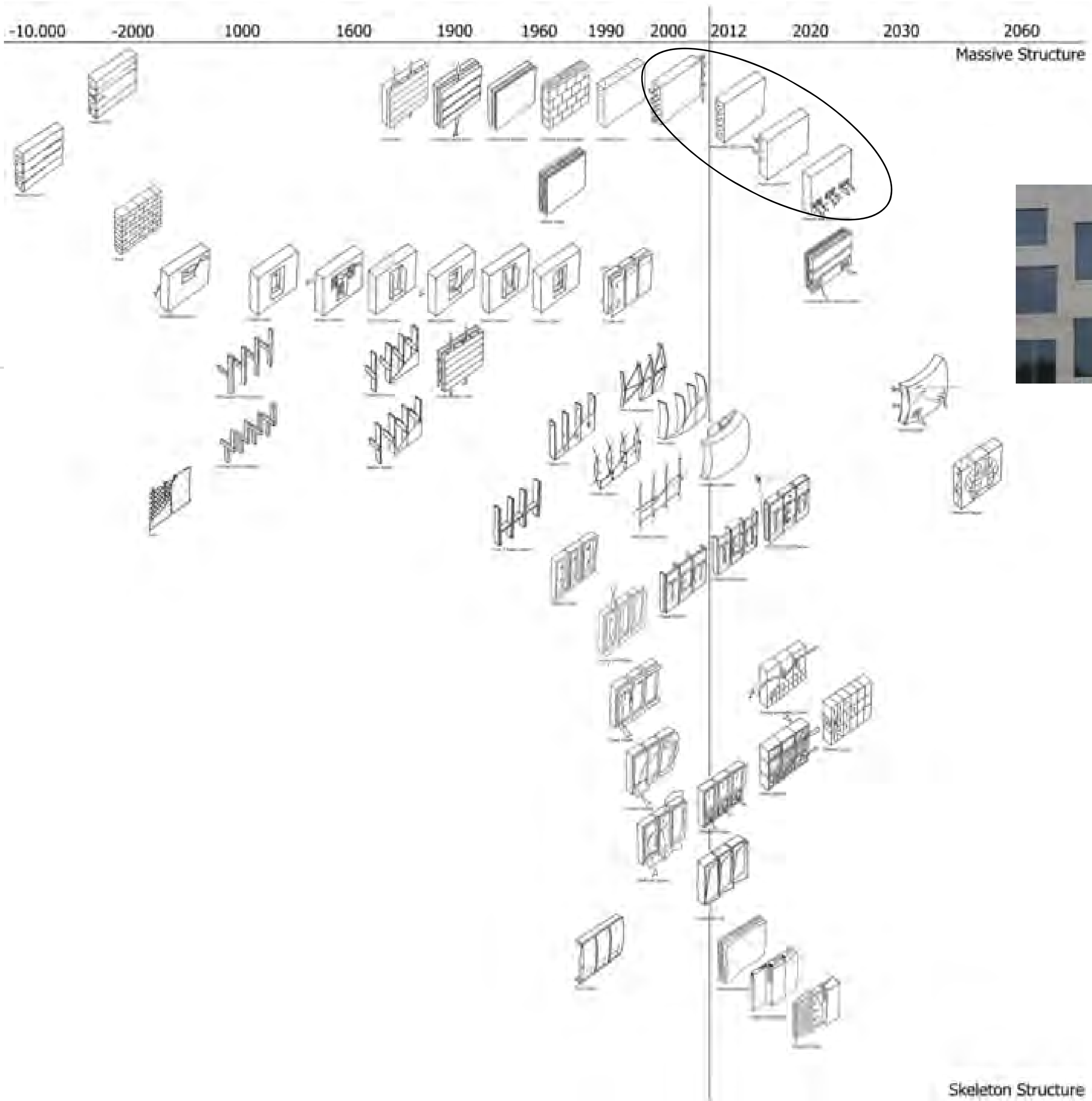


Light massive envelope with separate and demountable cladding



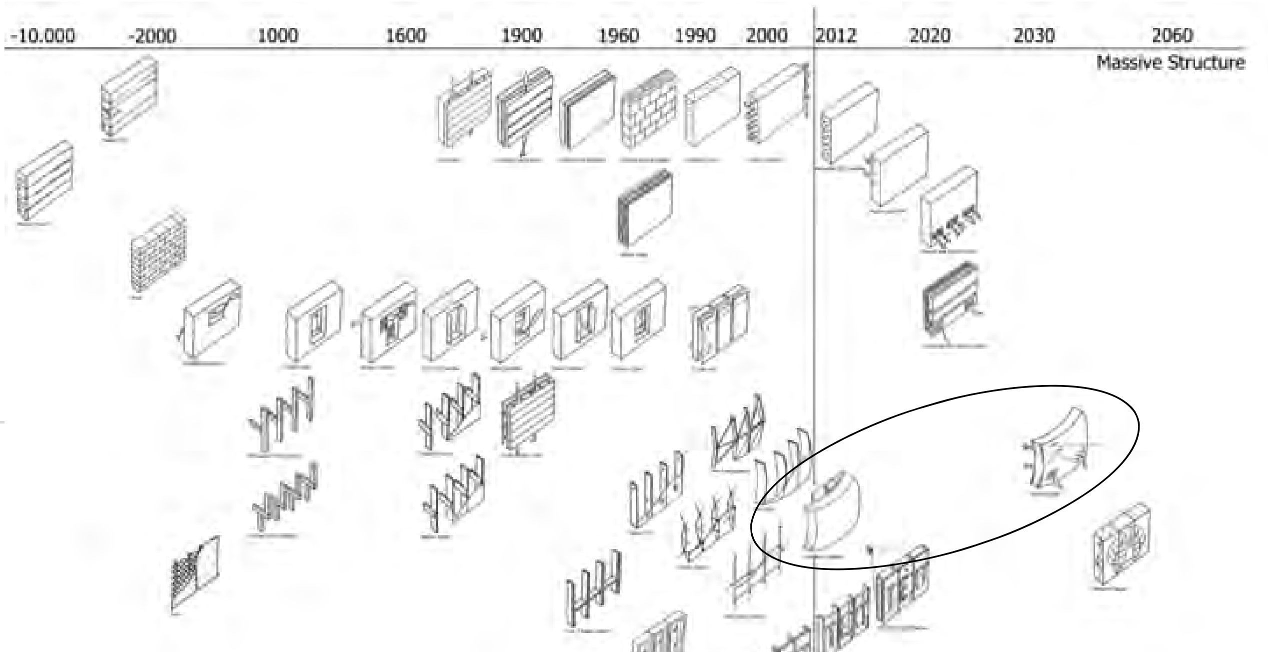
Light and fully demountabel massive envelope

Façade Roadmap



Design School Essen

Façade Roadmap




Additive Manufacturing

Polymeers

Metal

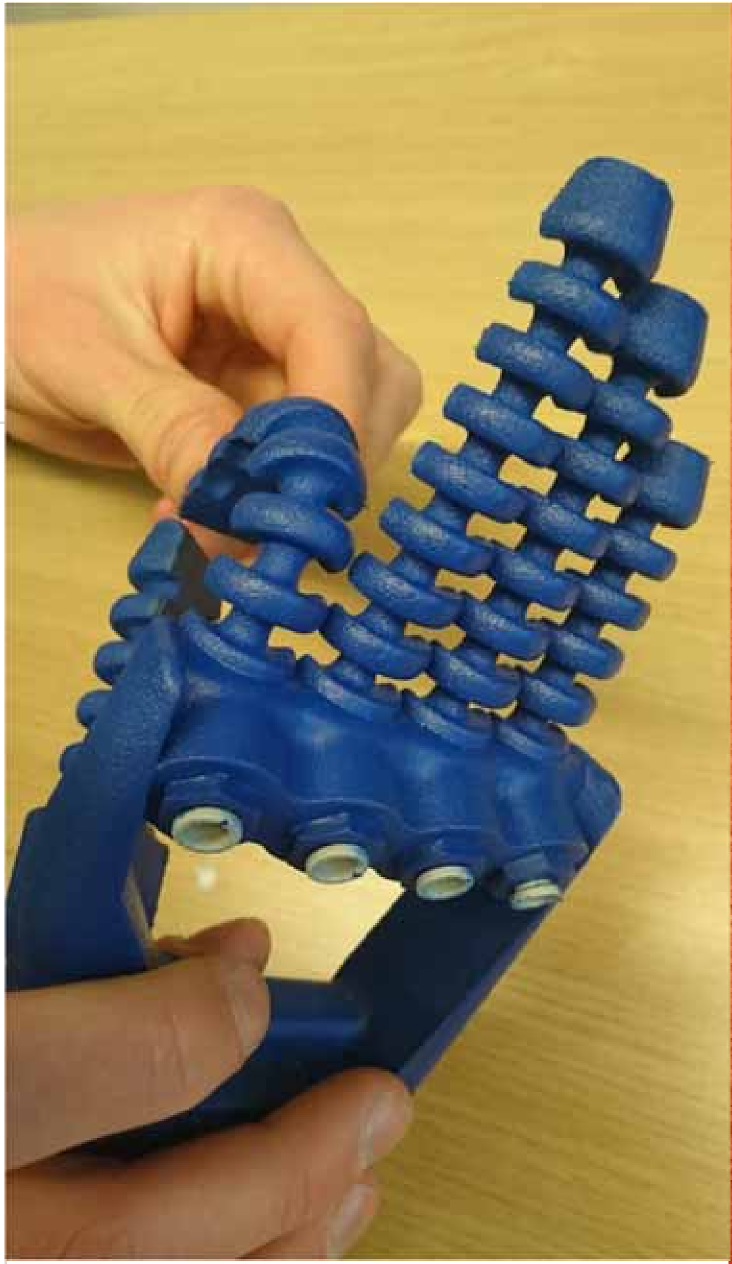
Concret

Ceramic

Glass

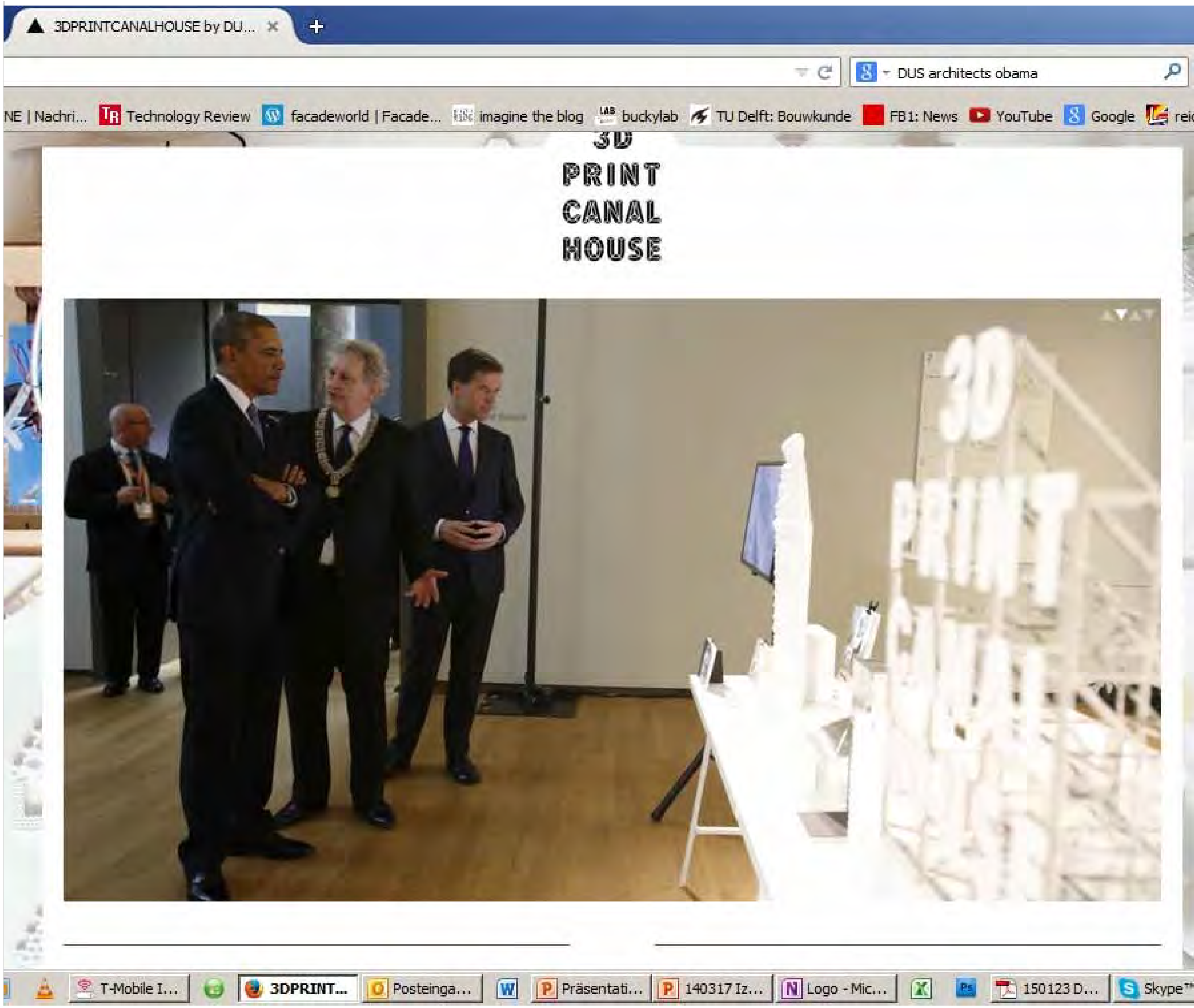
Wood / Paper

Additive Manufacturing

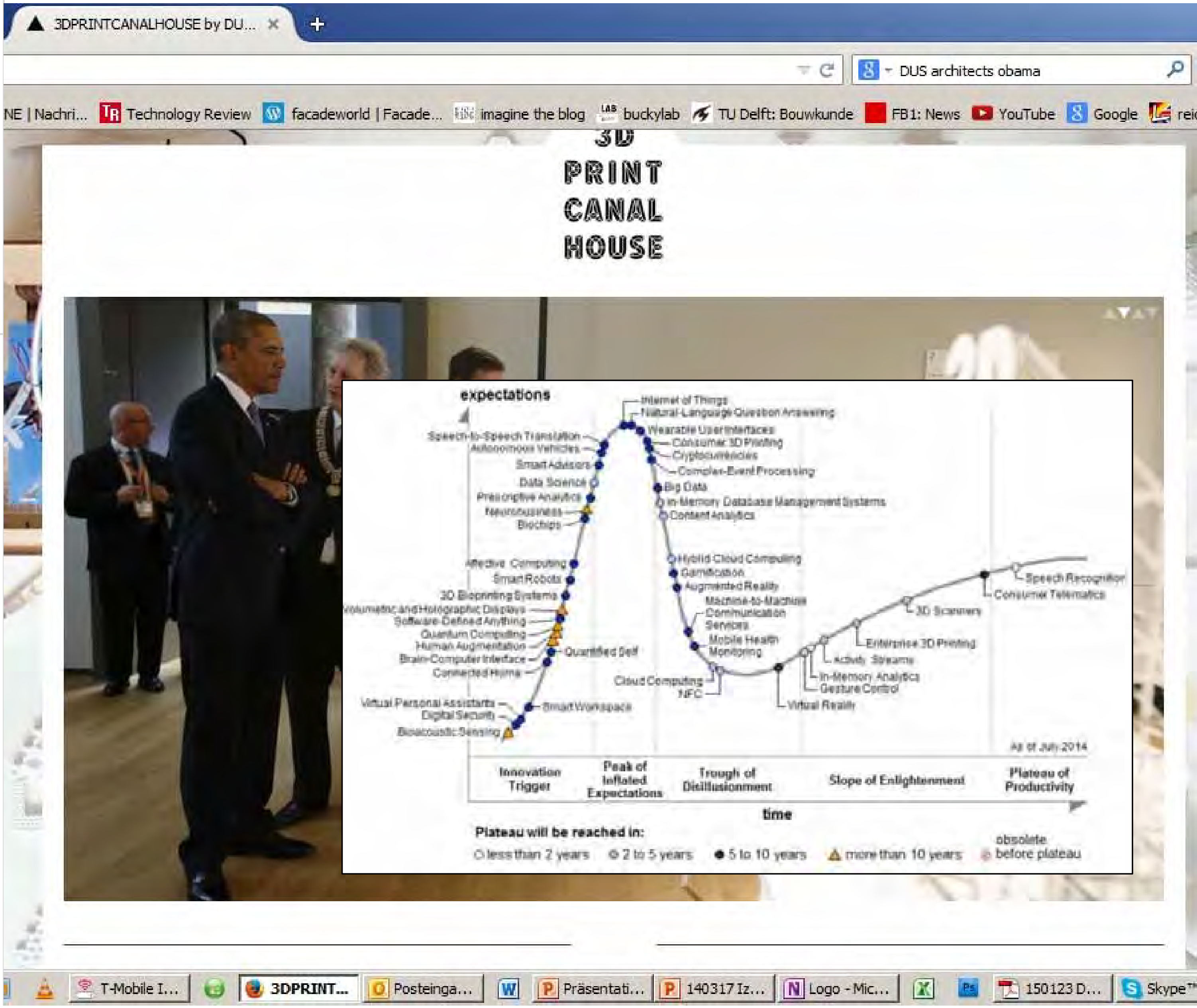


Additive Manufacturing

Additive Manufacturing

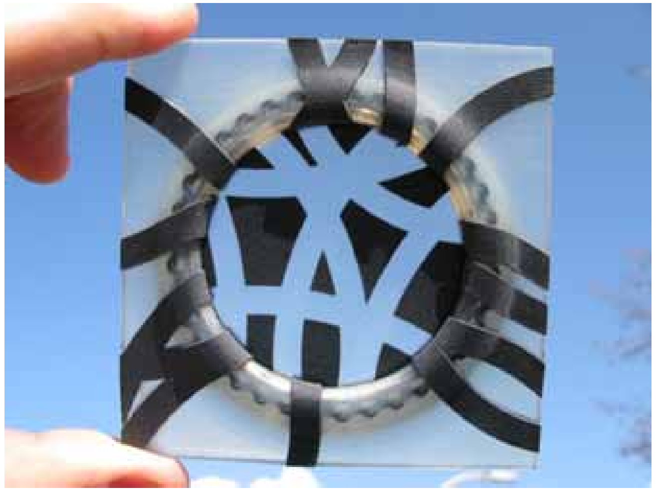


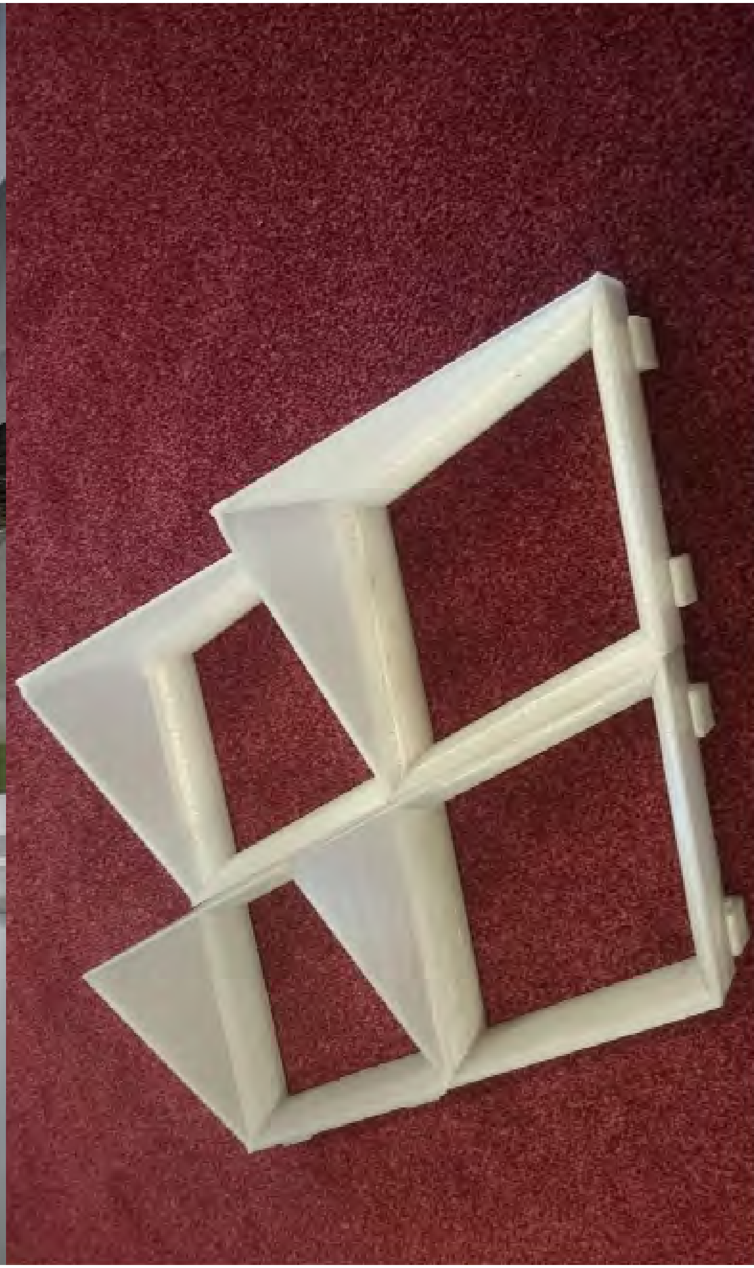
Additive Manufacturing



Additive Manufacturing

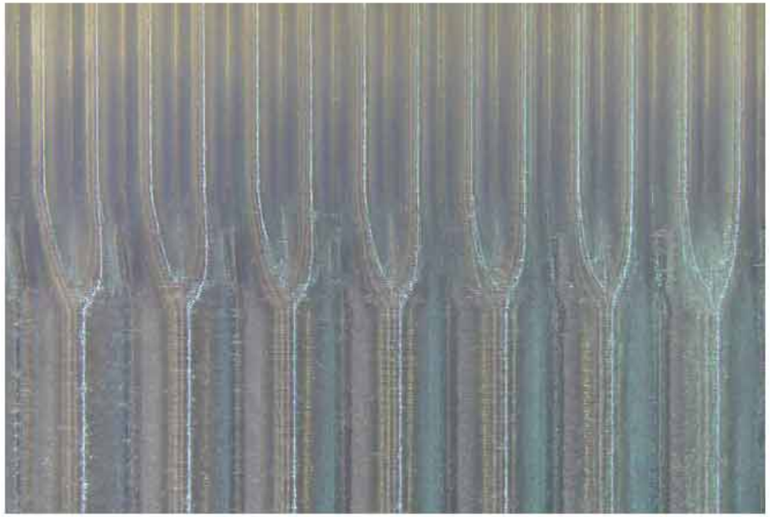
Sunnhading / TU Darmstadt - TU Delft

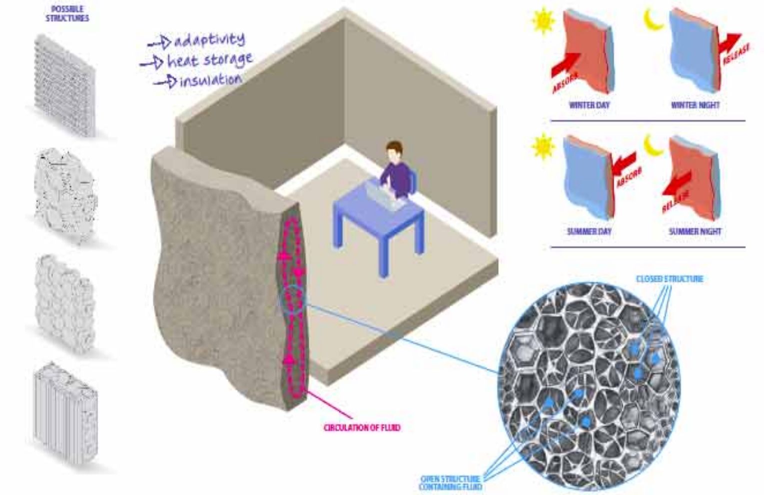




SPONG3D LHP2016

3D printed facade system enabling movable fluid heat storage





Spong3D is an adaptive 3D printed facade system that integrates multiple functions to optimize thermal performances according to the different environmental conditions throughout the year. The proposed system incorporates air cavities to provide thermal insulation and a movable liquid (water plus additives) to provide heat storage where and whenever needed. The air cavities have various dimensions and are located in the inner part of the system. The movable liquid provides heat storage as it flows through channels located along the outer surfaces of the system (on the indoor and outdoor faces of the façade). Together, the composition of the channels and the cavities form a complex structure, integrating multiple functions into a singular component, which can only be produced by using an Additive Manufacturing (AM; like 3D printing) technology.

The aim of this research is a proof of concept of Spong3D. Spong3D is an adaptive façade system that controls the heat exchange during the year between the interior and exterior conditions of the building. It incorporates two sub-systems. The first system consists of a porous inner core with air cavities to provide thermal insulation. The second one contains a series of outer channels that enable the flowing of liquid. The liquid acts as movable thermal mass to provide adaptive heat storage. Based on necessity, the liquid can be transferred from one side of the façade to the other to absorb and release the heat. The overall adaptive system proposes an integrated component fabricated with additive manufacturing.

The development of the proof of concept was organized according to sub-goals. First, the research aimed at understanding and quantifying the thermal potentials of the 3d printed porous structures; enhancing their capacity for thermal insulation and heat storage. Moreover, the research discovered additional needed properties, specifically issues related to the 3D printing process, such as flow resistance, water tightness, structural robustness and printing time for production. Finally, the research investigates the effects of the façade system in a room environment.

The optimization of thermal performances occurred through an iterative, cyclical process. Several samples with different geometric configurations of porous structures were designed and tested in order to maximize thermal insulation, allow appropriate heat absorption in the liquids, minimize the flow resistance, achieve acceptable water tightness and minimize the production time.

An adaptive façade system that controls the heat exchange during the year.

In order to design the test-samples, preliminary choices were made by taking into account that the porosity of the material determines the thermal resistance of the façade. The higher the porosity,

The models were produced with 3D printing, using PETG, a transparent material with relatively low thermal conductivity.

the less solid (and conductive) material there is, and therefore higher thermal resistance. Thus, the first set of samples was based on ordered cellular structures like polyhedra, which performed well for thermal criteria and structural robustness, but caused challenges with regard to the printing process. In order to reduce the time required for the printing process and the risk of possible failures during production, the size of the cells were then scaled in all directions except the ones related to the heat transfer perpendicular to the facade. The size of the insulating cavities in that direction was constrained to 15 mm in order to prevent internal convection since this would cause the thermal resistance to be reduced. As such, the geometry was adjusted to create smoothly curved cavities that remain 15 mm only in the direction of the heat transfer but are larger in the other two directions. This adjustment showed positive results not only reducing the printing time, but also to creating a stiff, yet lightweight structure. Moreover, the smoothness of the geometry allowed for a more stable printing process.
The external layer (where the liquid flows) requires water-tightness and a fluid shape of the channels to allow for minimal pressure drop and uniform flow. Several samples with different configurations were tested for flow resistance and the best performing shape was selected. The current shape of the channels is inspired by natural configurations that transfer fluids such as blood vessels, the veins of leaves and three dimensional bionic structures. Though further investigation is needed, the current shape is promising with regard to the circulation of the liquid. The channels should also allow for appropriate heat absorption into the liquid. To accommodate this need, the current models were produced with Fused Deposition Modelling (FDM) printing, using PETG, a transparent 3D printing material that has relatively low thermal conductivity. Further investigations may consider the calibrated combination of translucent and dark materials.
To control the movement of the liquid through the overall system, each façade panel consist of two external layers that integrate two reversed pumps for water circulation. The water can be stored in a tank in the center of the panel. In a cooling situation, the liquid is first placed on the inside to absorb internal heat gain and is then pumped to the outside layer to discharge the heat to the cool night sky. In the alternative case, for heating purposes, the liquid is placed outside to absorb any solar heat gain during daytime and is then pumped to the inside to release this heat inside the building. The pumps are also connected with the water tank to store the water inside the tank when necessary.

The structural behavior of the overall system was analyzed by investigating the impact of the wind load to the façade panel and calculating the deformations. The result is a curtain wall system that transfers the loads to the main structure of the building. The structural analysis did not reveal major structural challenges. However, deeper studies on the structural behavior of the 3D printed material are required especially when considering extreme thermal conditions and durability.

Finally, the thermal impact of the overall system on a room was simulated. The investigation focused on two scenarios, a summer day and a sunny winter day. Energy simulations showed that a cooling rate of 25 W/m2 could be obtained during typical summer conditions. This is more or less equivalent to 50% of the internal heat gains in a conventional office environment. Similarly, 4.8 kWh of thermal energy could be harvested for a typical 12 m2 office space on a sunny winter day, which accounts for approximately 70% of the typical corresponding heating demand.

A large 1:1 (full scale) prototype was produced. One important aspect of this research was to study the feasibility to produce a façade panel within particular time constraints. This was one of the main challenges that influenced the design and the production process. The design process prioritized configurations that have low printing time and specific settings were applied to ensure a speedy printing process. The production process occurred in collaboration with KIWI Solutions. The investigation of the 3D printing technology was based on the latest available production technologies, using 3D printers for larger objects and innovative materials.

In conclusion, the main outlook of this research is a proof of concept for a façade system that can adapt its thermal behavior to different environmental conditions, regulate the temperature inside the building and reduce the environmental impact through innovative production technologies. Despite the challenges faced so far, the project showed promising results regarding the development of tailored products with complex shapes by using 3D printing technology. In the case of Spong3D, it was possible to successfully generate a façade system with high complexity that achieves high levels of thermal comfort. Additionally, by using 3D printing technology the project uses material resources more strategically and minimalizes waste material throughout the production process.

Delft University of Technology
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dr. ir. arch. **Martin Tenpierik**, dr. ing. **Thaleia Konstantinou** MSc.,
Prof. Dr.-Ing. **Ulrich Knaack**

Eindhoven University of Technology
ir. **Arno Pronk**, Prof. Dr.-Ing. **Patrick Teuffel**, **Arthur van Lier**, **Rens Vorstermans**, **Elina Dolhamade**, **Marie de Klijn** MSc.,
ir. **Roel Loonen**, prof. dr. ir. **Jan Hensen**

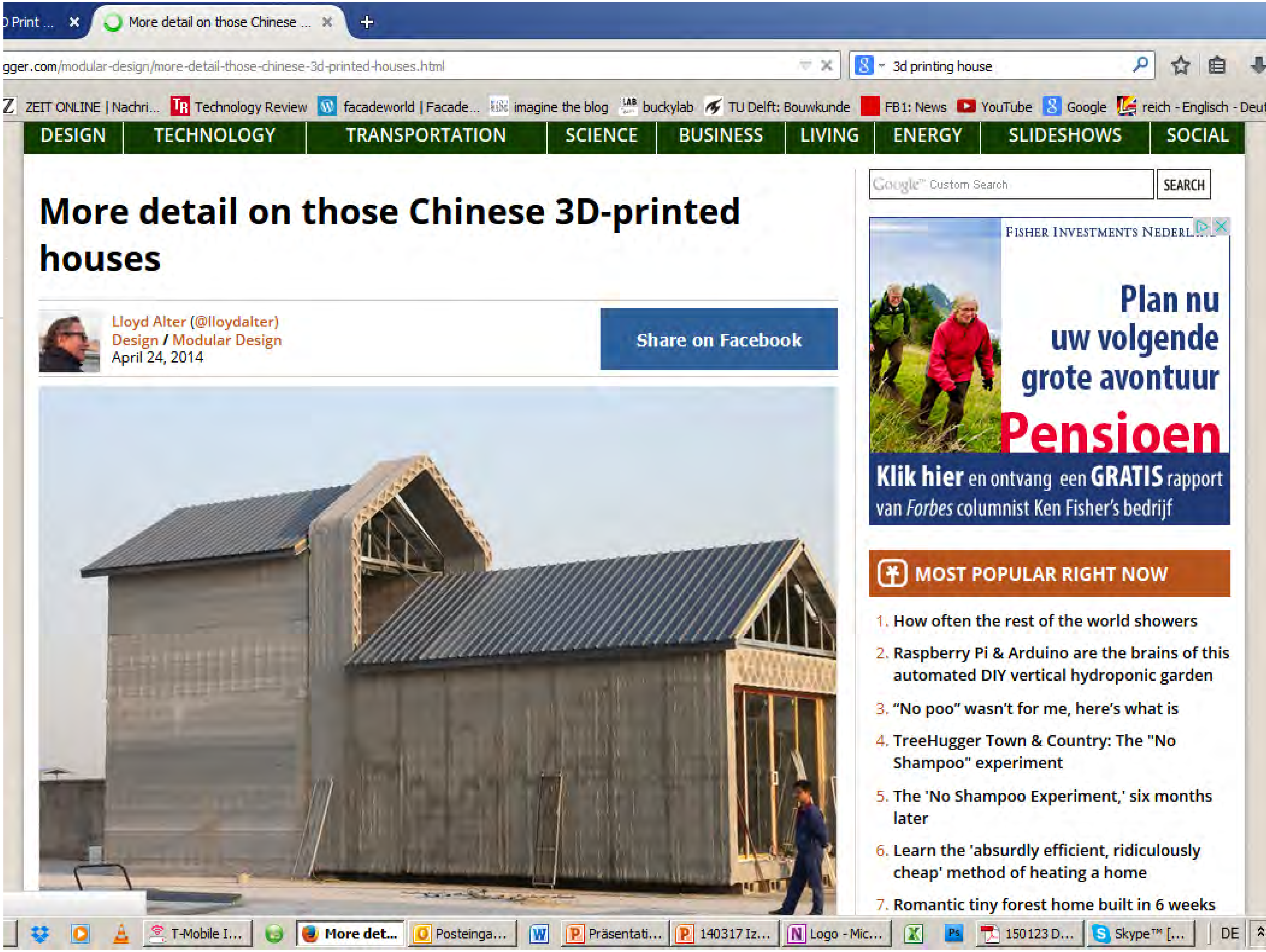
KIWI Solutions
Dick Vlasblom

Additive Manufacturing

Maria Valentini / TU Delft

Additive Manufacturing

Additive Manufacturing



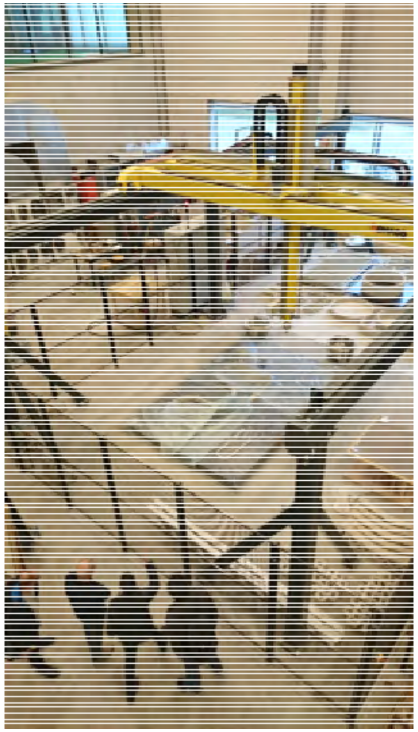
Additive Manufacturing

Reinforced 3D printed concrete Bridge
TU Eindhoven

3D Printed Concrete Bridge
IAAC

Additive Manufacturing

TU Eindhoven



Additive Manufacturing

Erno Langenberg / Amsterdam

Additive Manufacturing

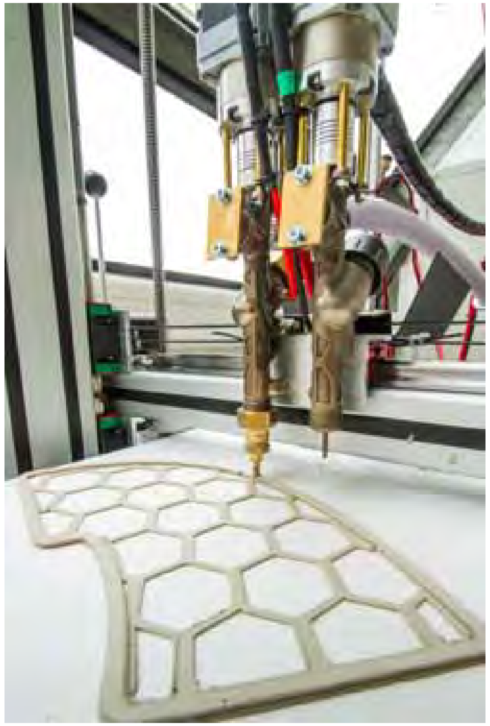
CITA / Copenhagen

Additive Manufacturing

HKU / Hong Kong

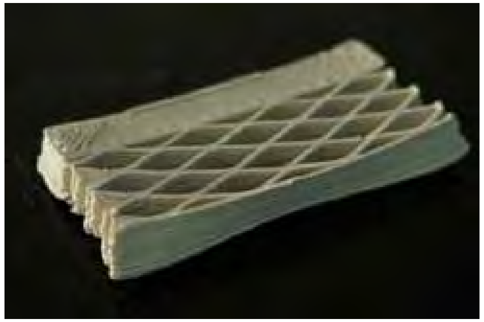
Additive Manufacturing

Dennis de Witte / TU Darmstadt



Additive Manufacturing

Dennis de Witte / TU Darmstadt



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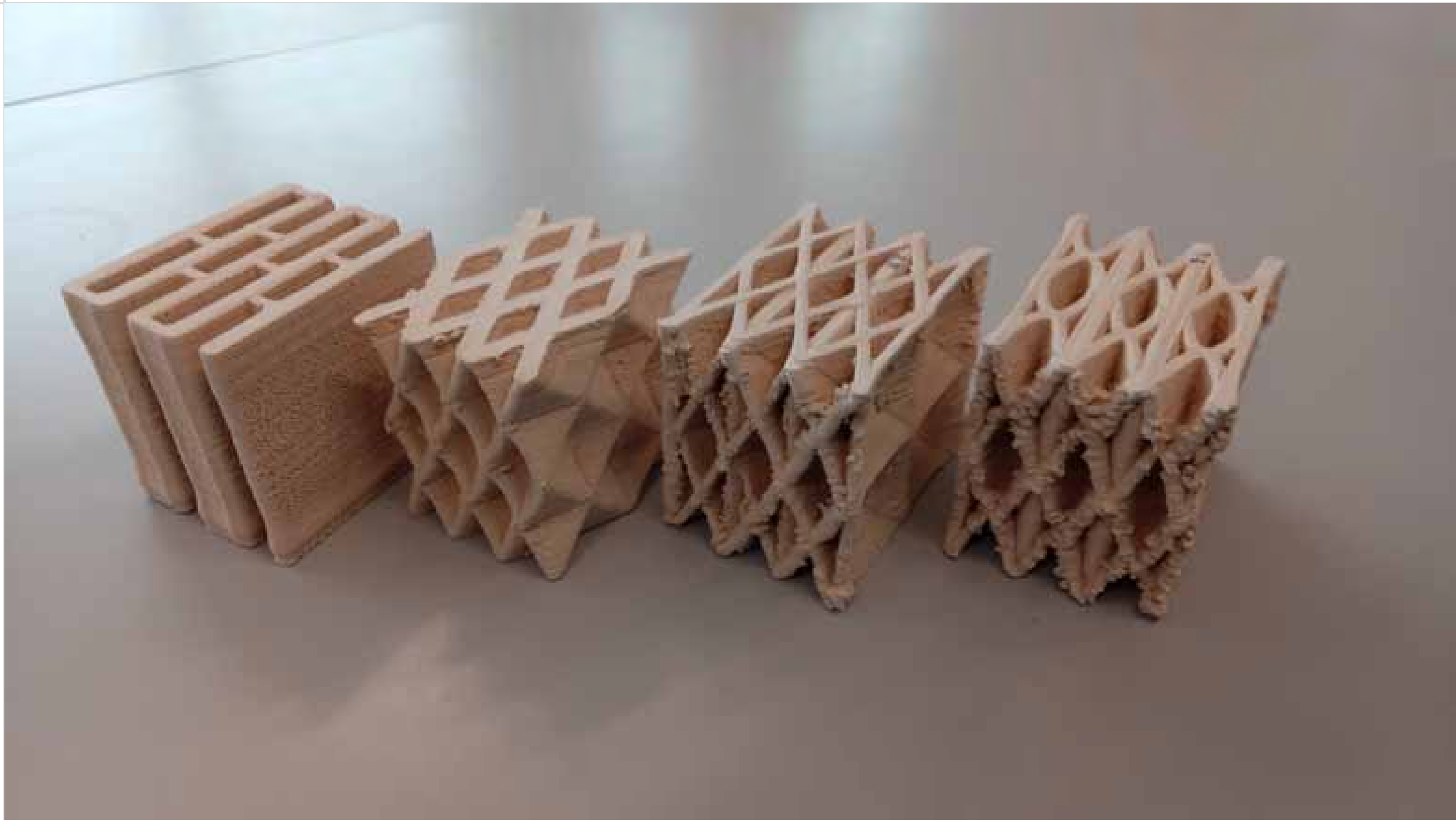

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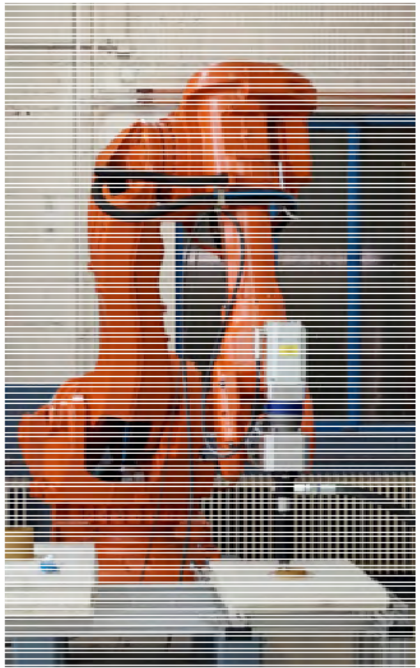

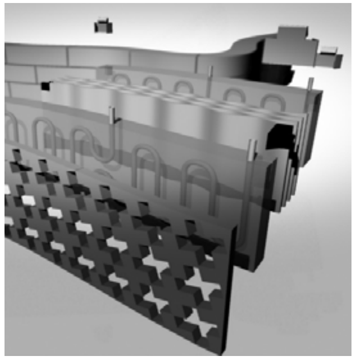

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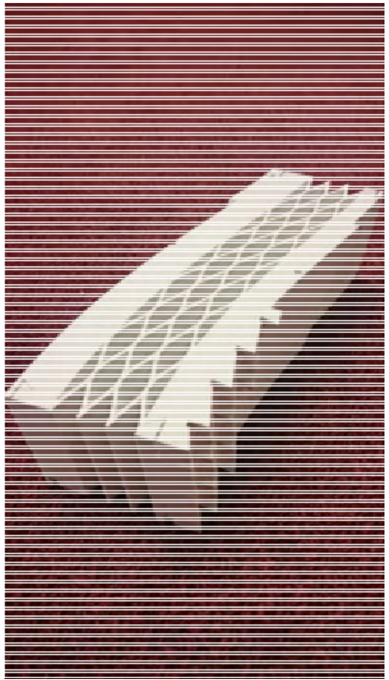
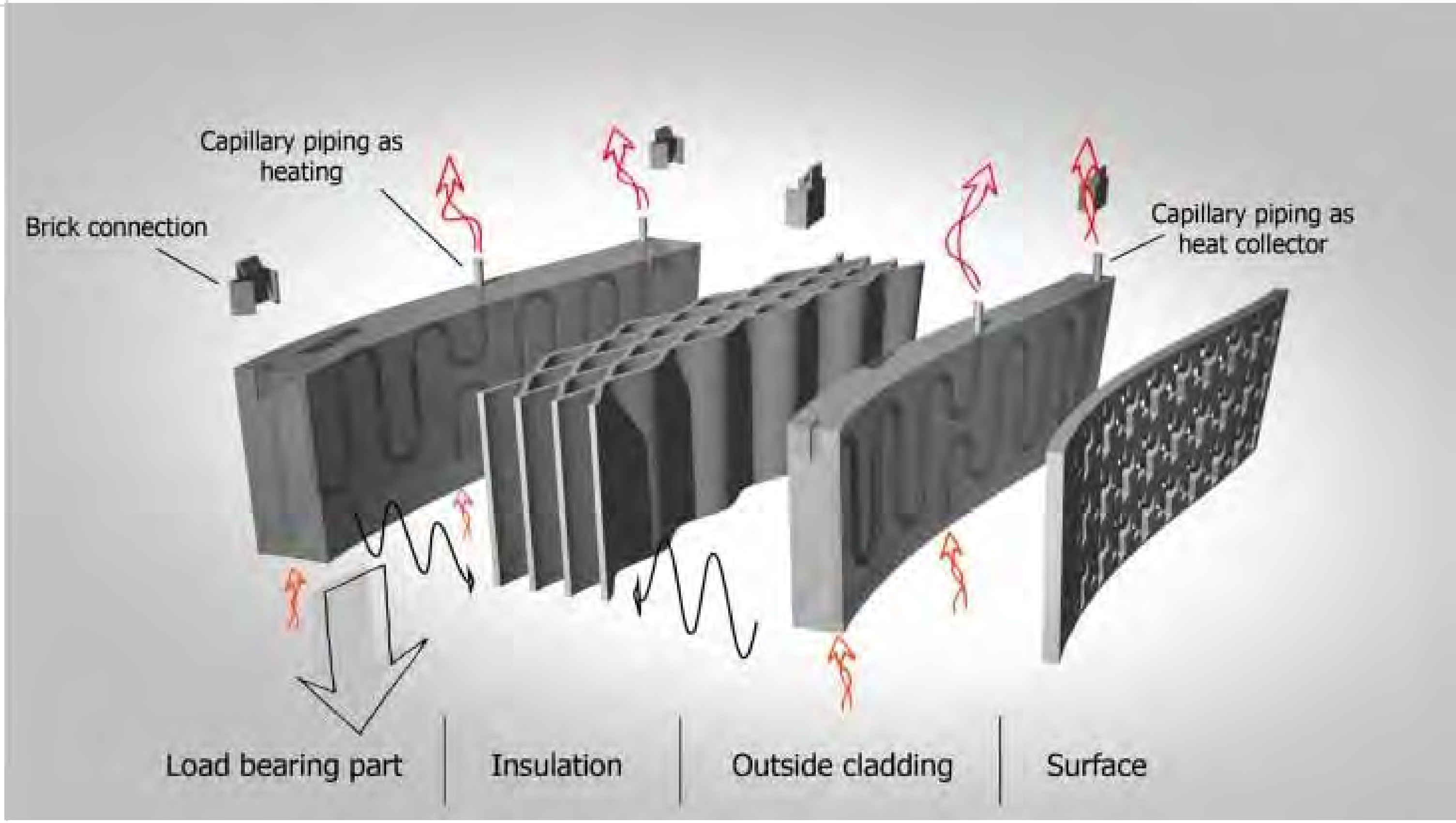
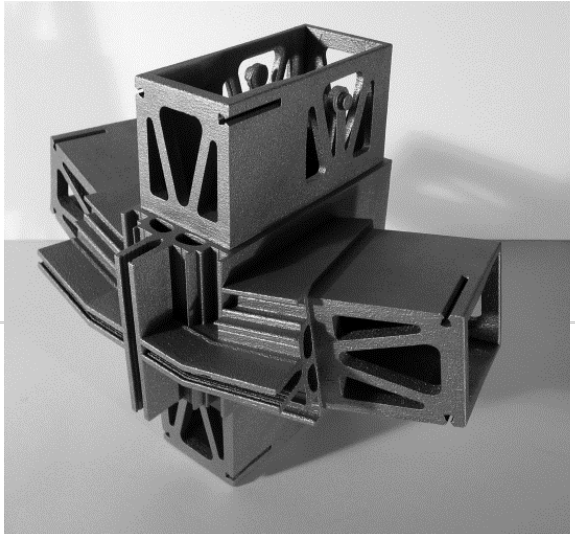
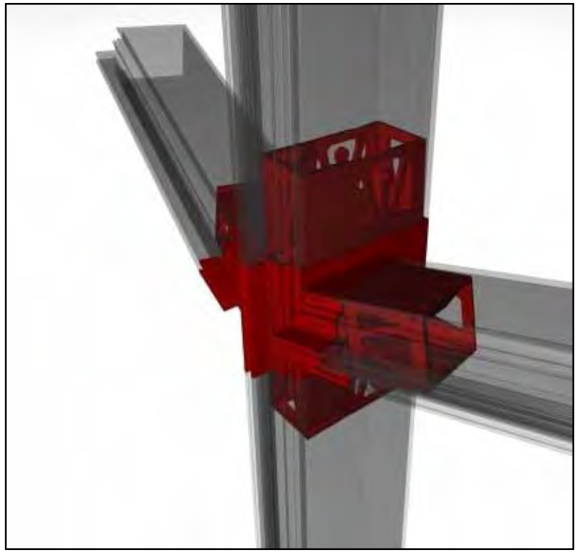




Additive Manufacturing

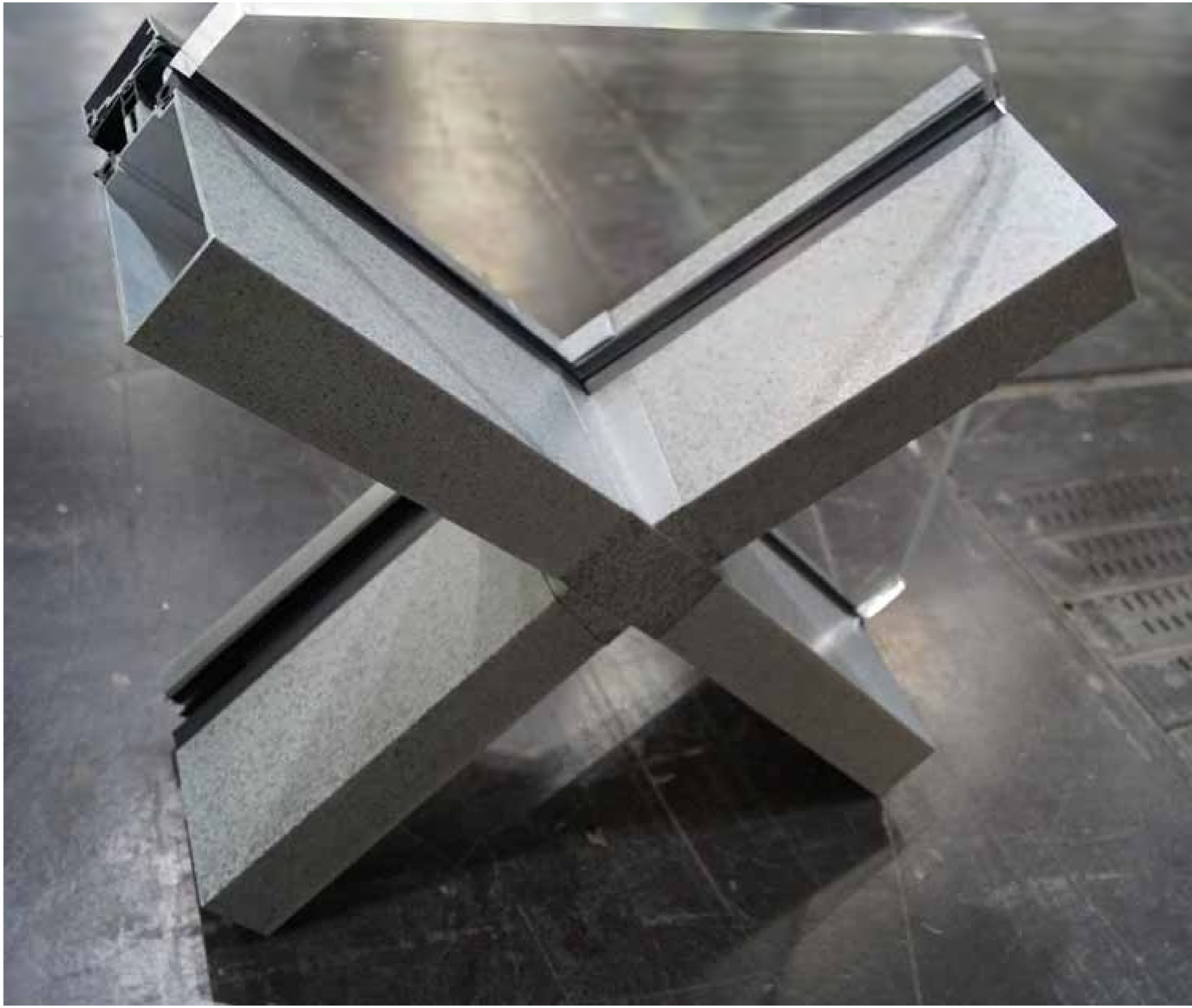
Holger Strauss / TU Delft





Additive Manufacturing

Holger Strauss / TU Delft

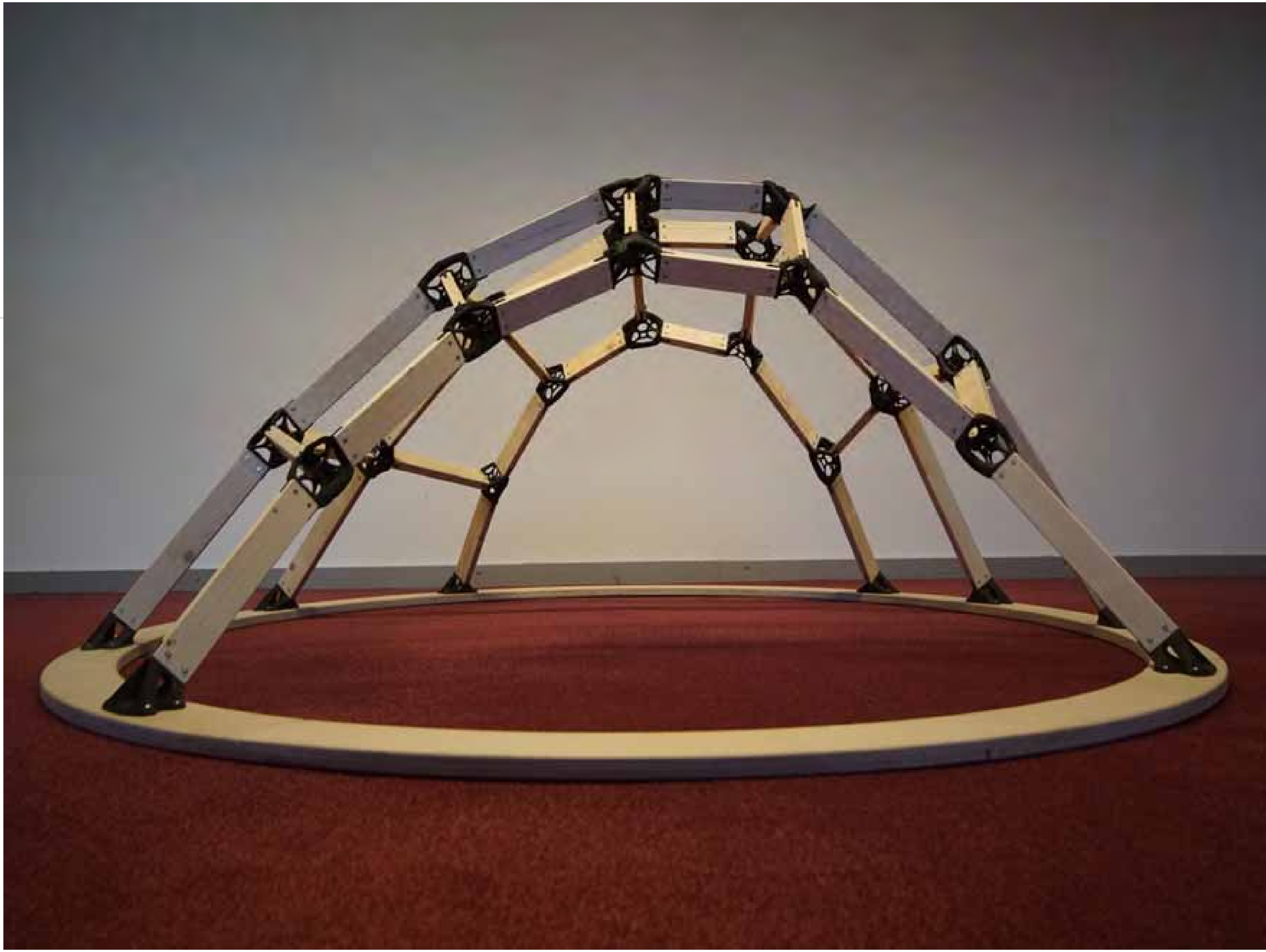


Additive Manufacturing

Bayu Prayudhi / TU Delft

Additive Manufacturing

Bayu Prayudhi / TU Delft



Additive Manufacturing

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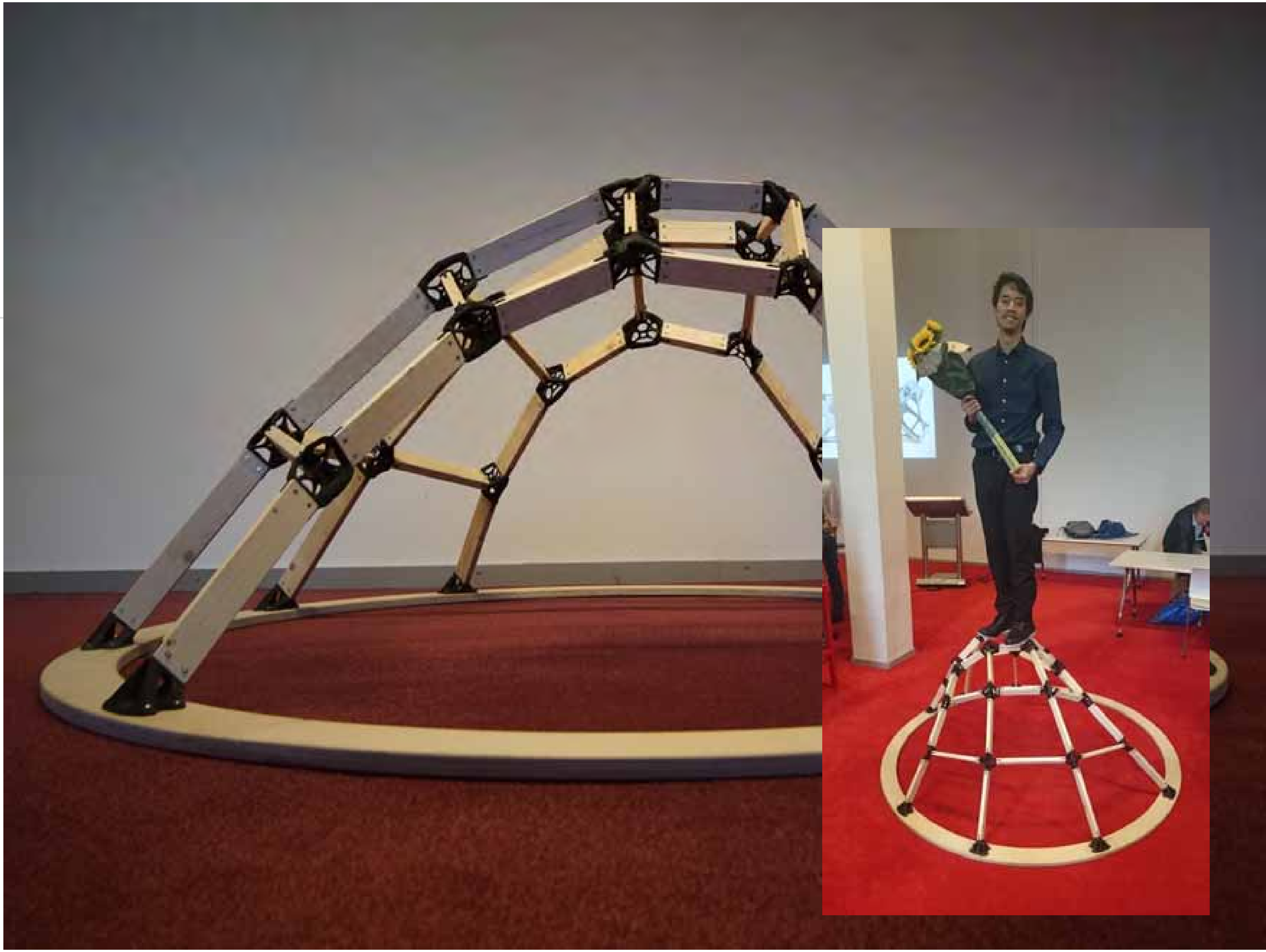


Additive Manufacturing

Alamir Mohsen / TU Darmstadt

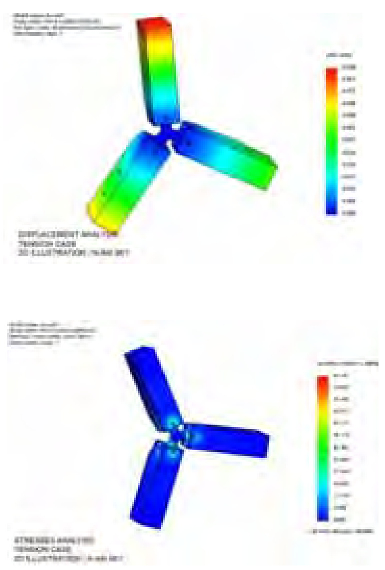
N-AM

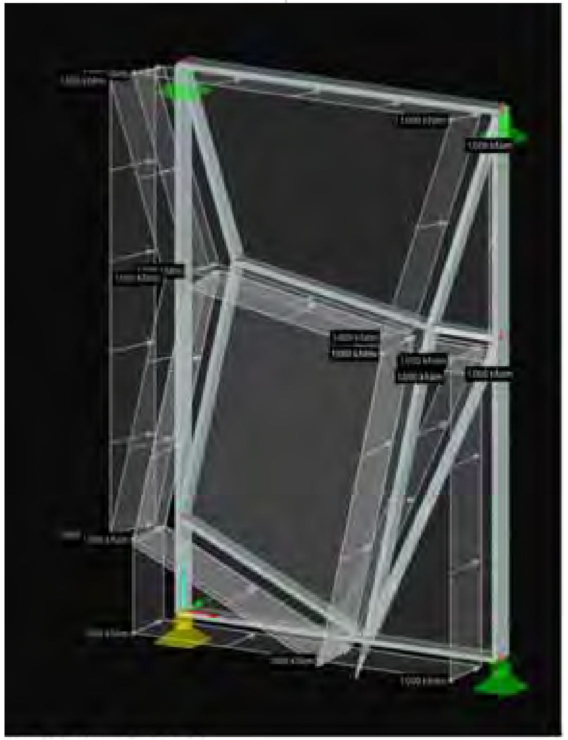
The Future of Advanced Building Skin

ISM+D

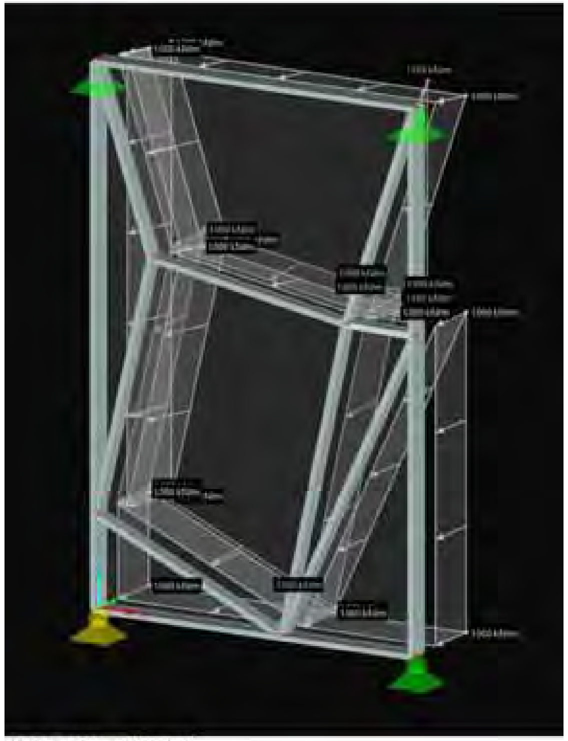
Additive Manufacturing

Alamir Mohsen / TU Darmstadt

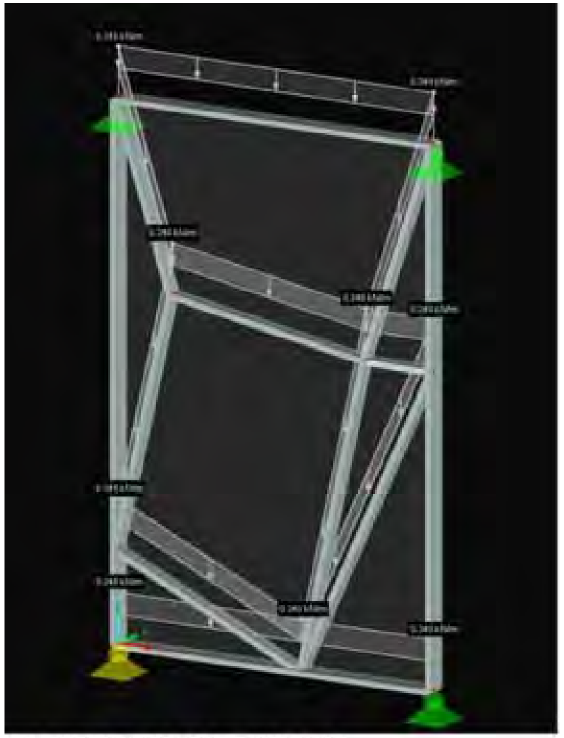




WIND LOAD - PRESSURE



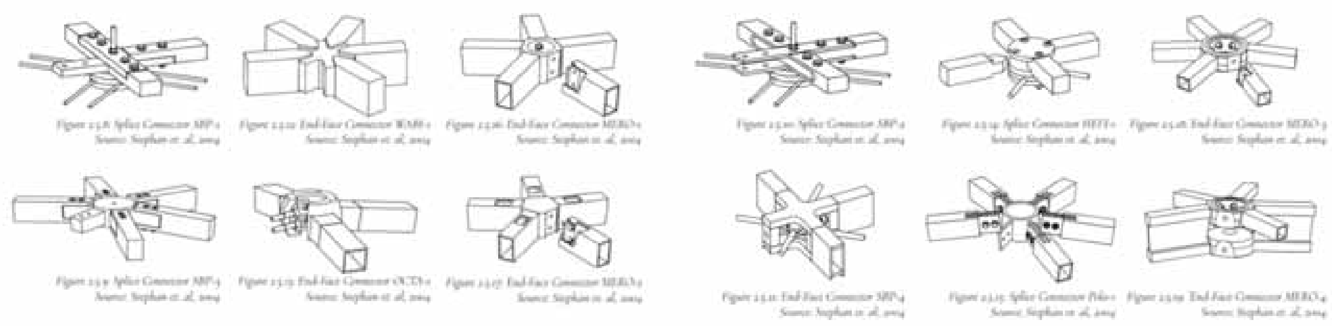
WIND LOAD - SUCTION



DEAD LOAD - WEIGHT OF GLASS PANELS

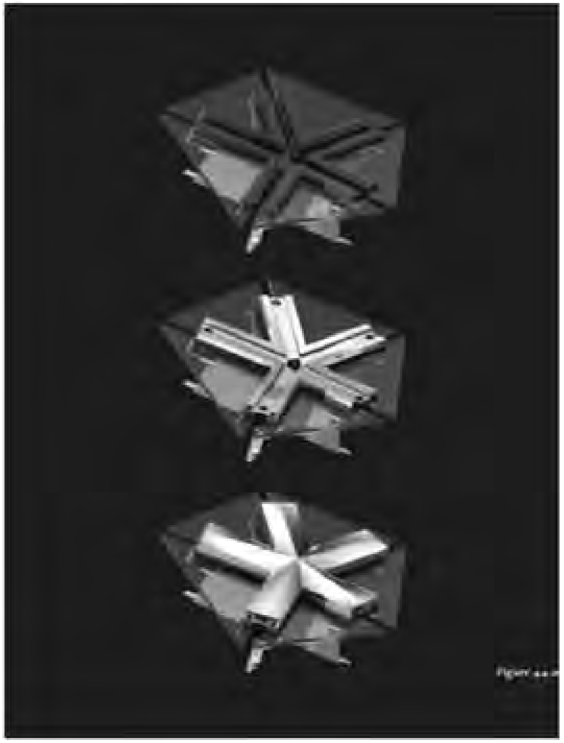
Additive Manufacturing

Seminar Fassadentechnik 2 + Alamir Mohsen /
TU Darmstadt



Additive Manufacturing

Lia Trabationi / TU Delft – with ODS / Jansen



Additive Manufacturing

MX3D / Amsterdam

Additive Manufacturing

MX3D / Amsterdam

Additive Manufacturing

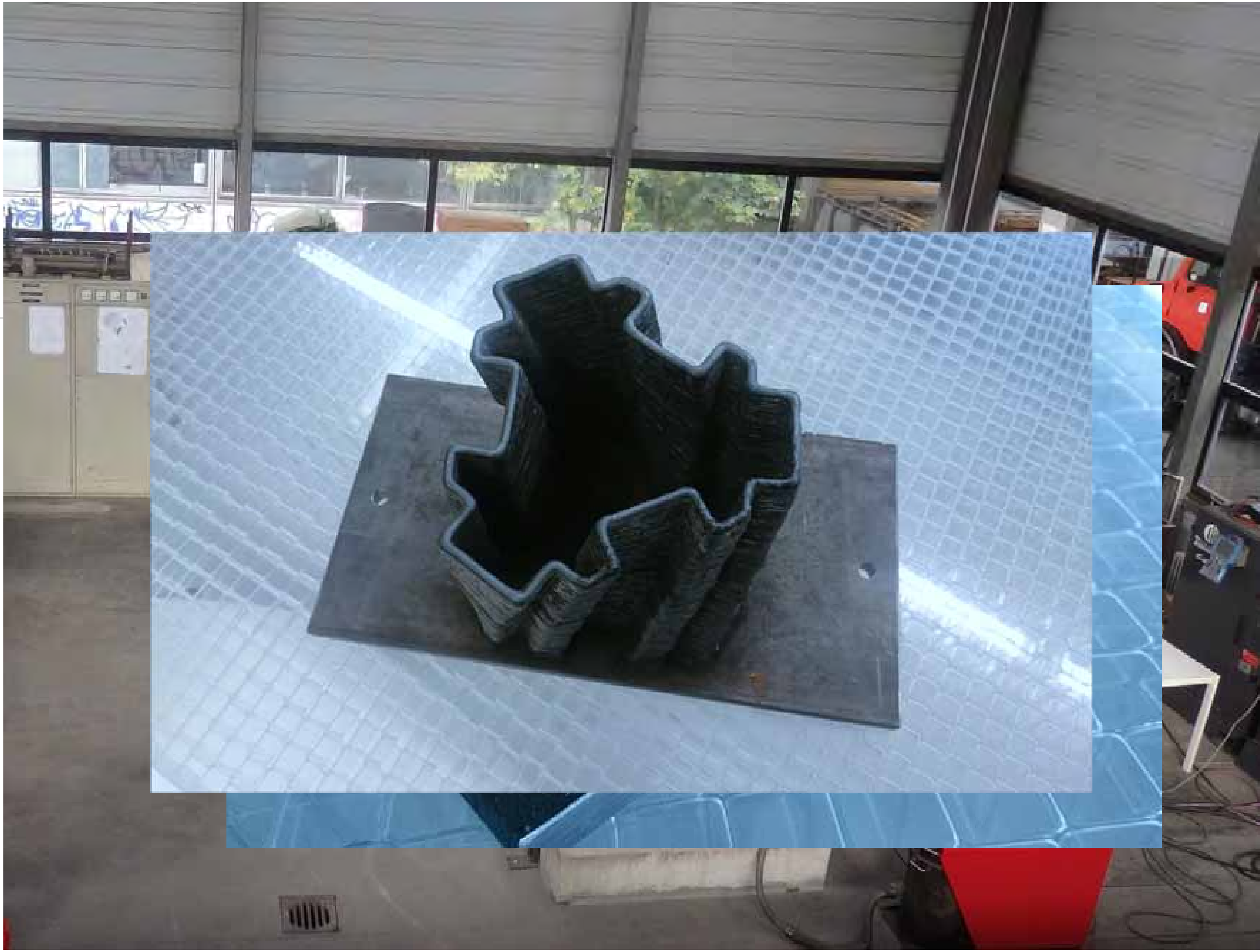
ISMD + ISFW / TU Darmstadt

Additive Manufacturing

ISMD + ISFW / TU Darmstadt

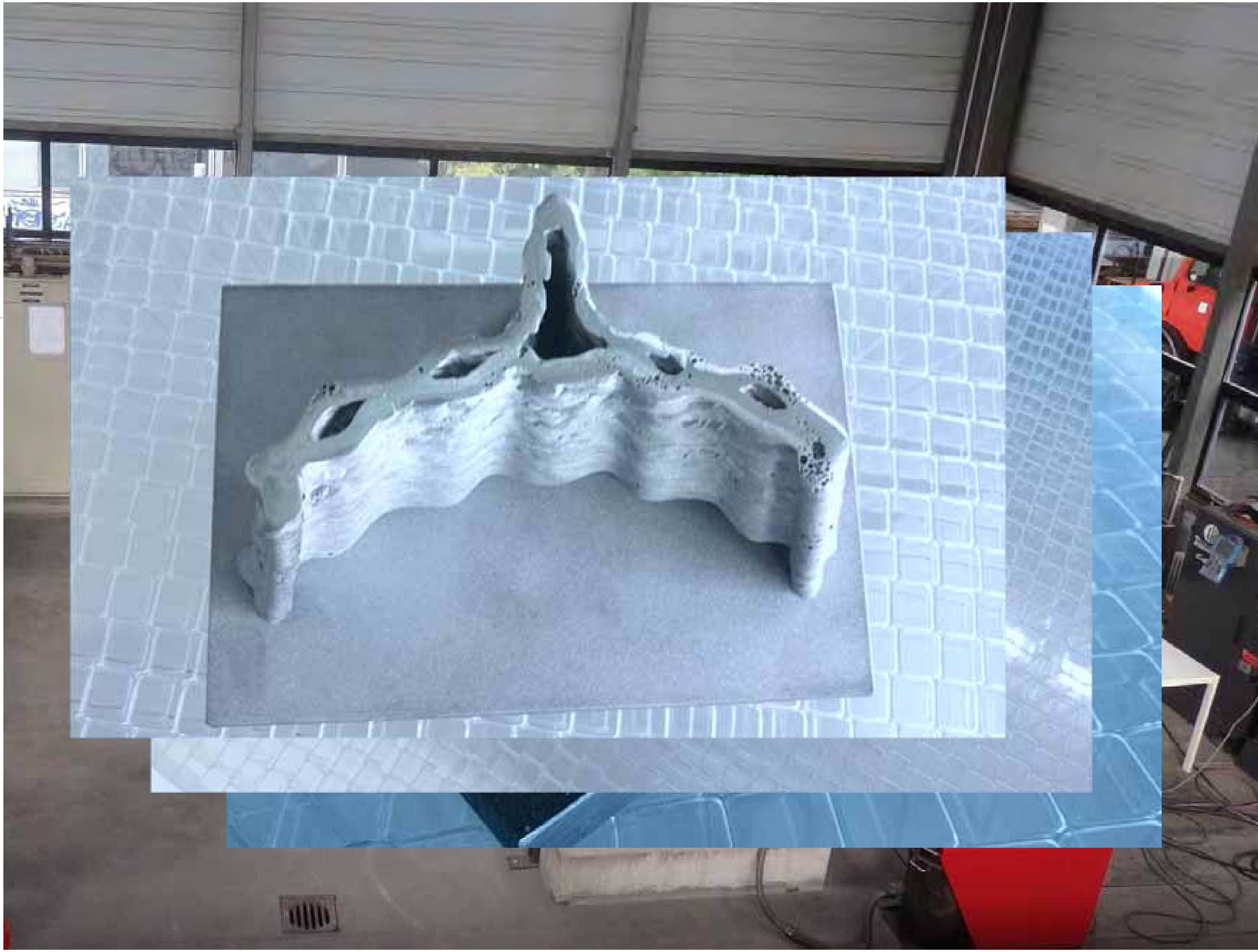
Additive Manufacturing

ISMD + ISFW / TU Darmstadt



Additive Manufacturing

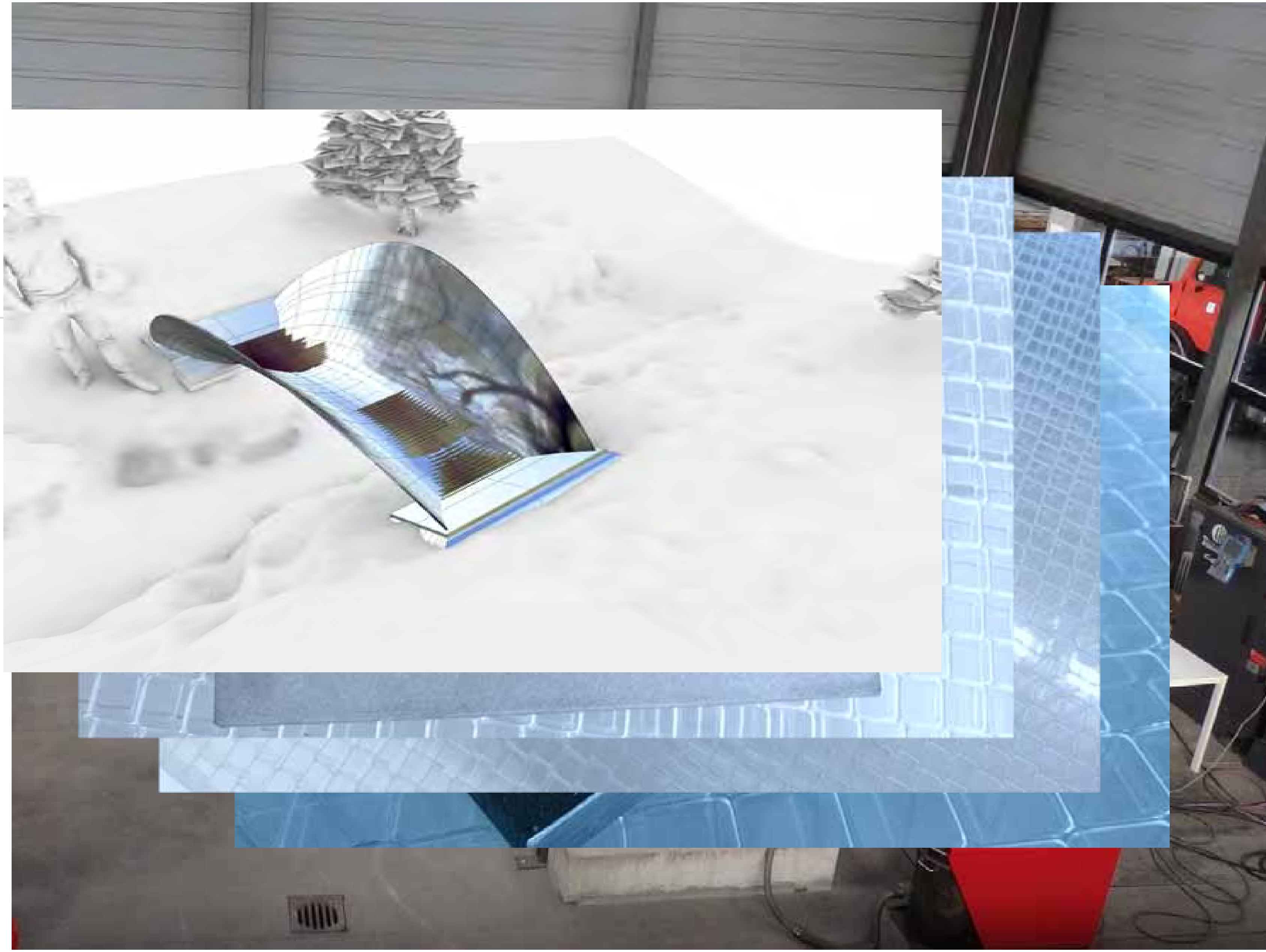
ISMD + ISFW / TU Darmstadt



Additive Manufacturing

ISMD + ISFW / TU Darmstadt


Robotic Wire-Arc Additive Manufacturing (W.A.A.M) in Construction



Additive Manufacturing

ISMD + ISFW / TU Darmstadt

Additive Manufacturing

Lisa Rammig / TU Delft + EOC

Green Building Innovation: Façade Research Group

ADDITIVE GLASS MANUFACTURING

The potential of additively fabricated glass connections for façade applications

During the past two decades Additive Manufacturing (AM) which can be defined as the layered production from a 3D file, has been enhanced from a prototyping tool used mainly for product development to a fully independent production method.
Whilst the direct fabrication of materials such as plastics or metals is by now a sophisticated technology, the additive fabrication of glass, perhaps one of the most fascinating building materials, is almost unexplored.

Additive Manufacturing

MIT

3-D Printing Breaks the Glass Barrier

Researchers have cracked the challenge of printing glass through a nozzle.

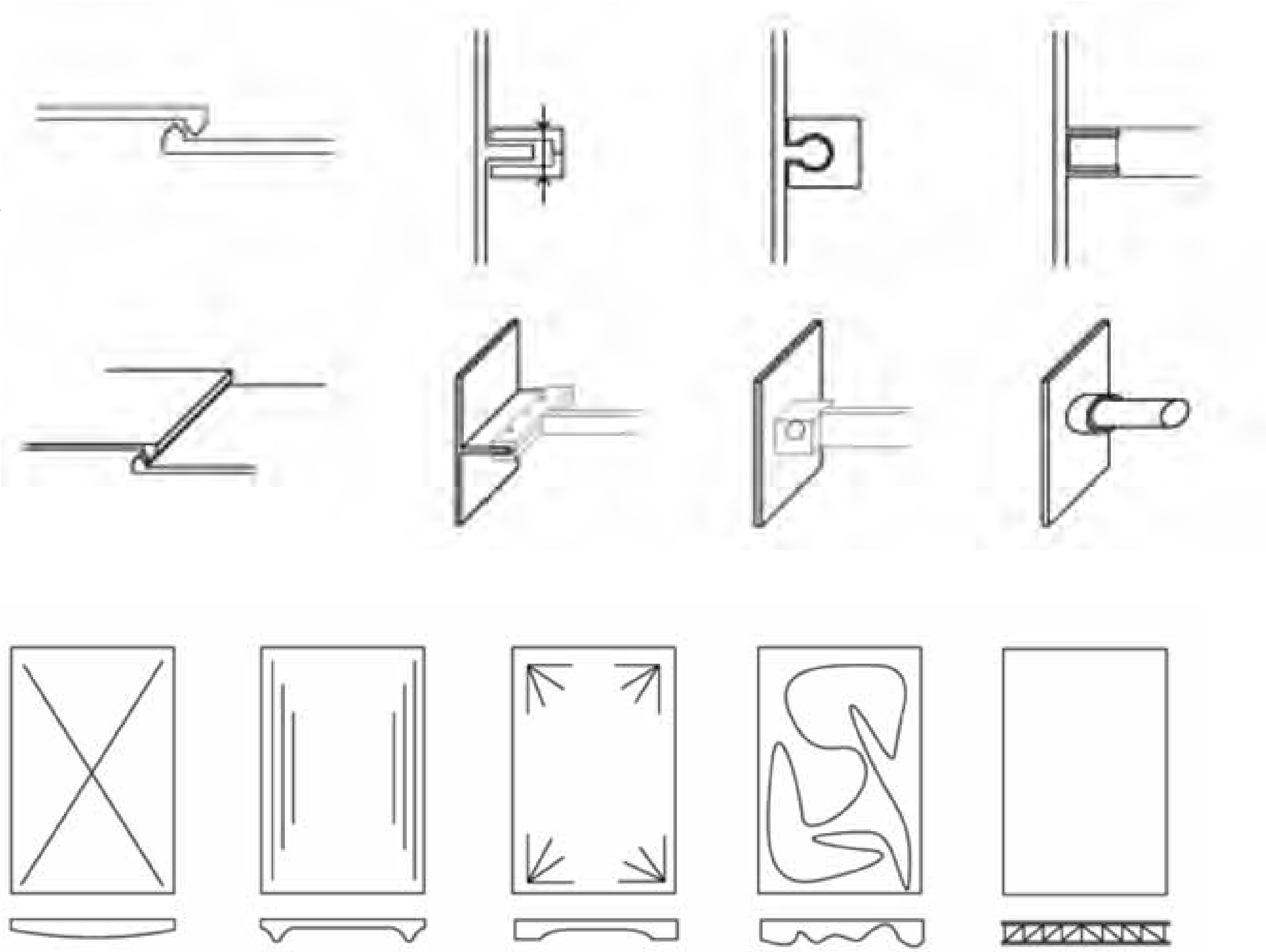
Additive Manufacturing

ISMD + MPA / TU Darmstadt


ADDITIVE MANUFACTURING WITH GLASS FOR APPLICATIONS IN THE BUILT ENVIRONMENT

Additive Manufacturing

ISMD + MPA / TU Darmstadt

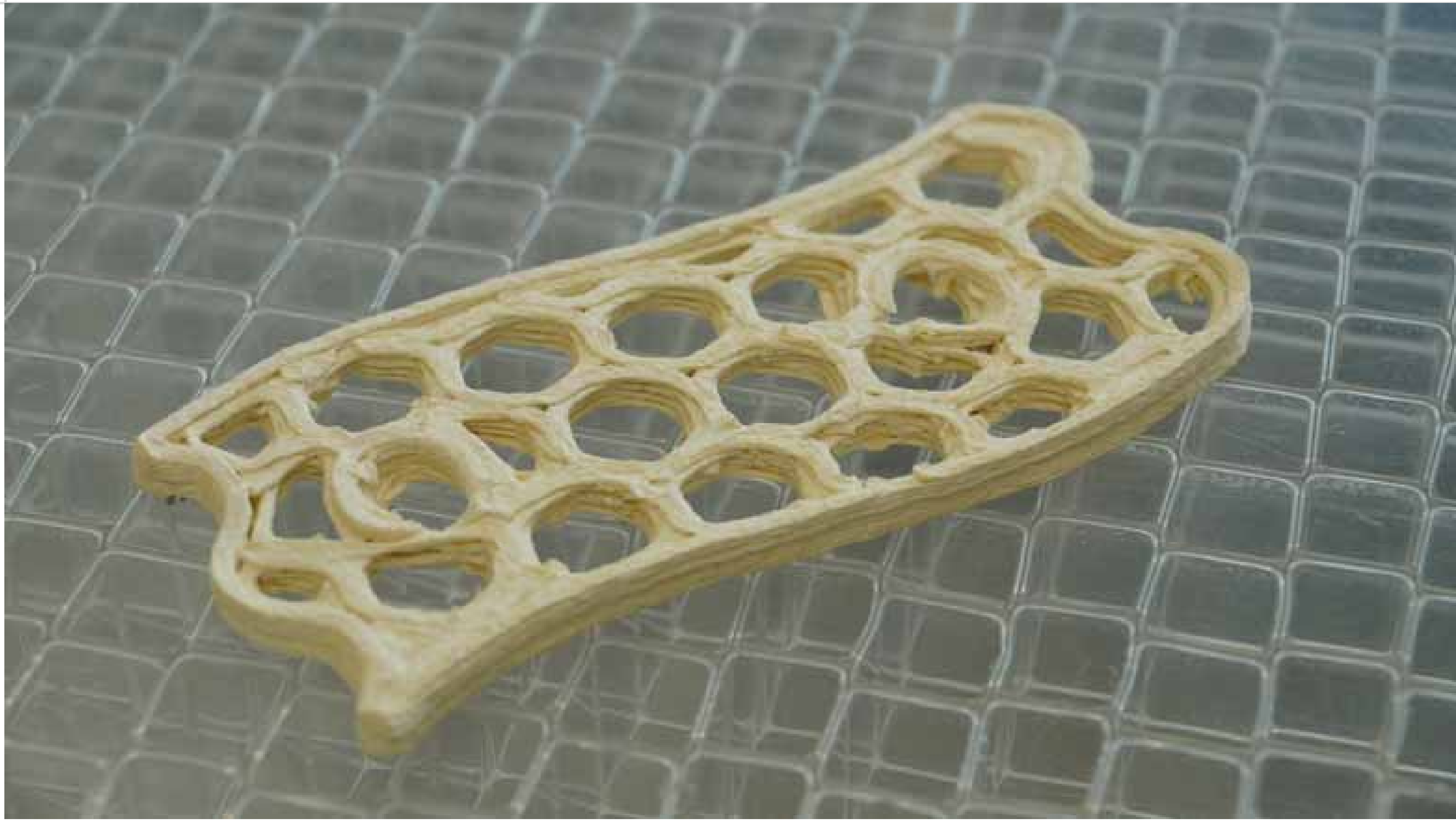


Additive Manufacturing

Next steps: adaptive Polymeere

Additive Manufacturing

Next steps: paper - BAMP Team / TU Darmstadt



Additive Manufacturing

Next steps: paper –
Seminar Fassadentechnologie + Dunia Ahag /
TU Darmstadt

Additive Manufacturing

Next steps: Wood / MSc T. Liebrand / TU Delft

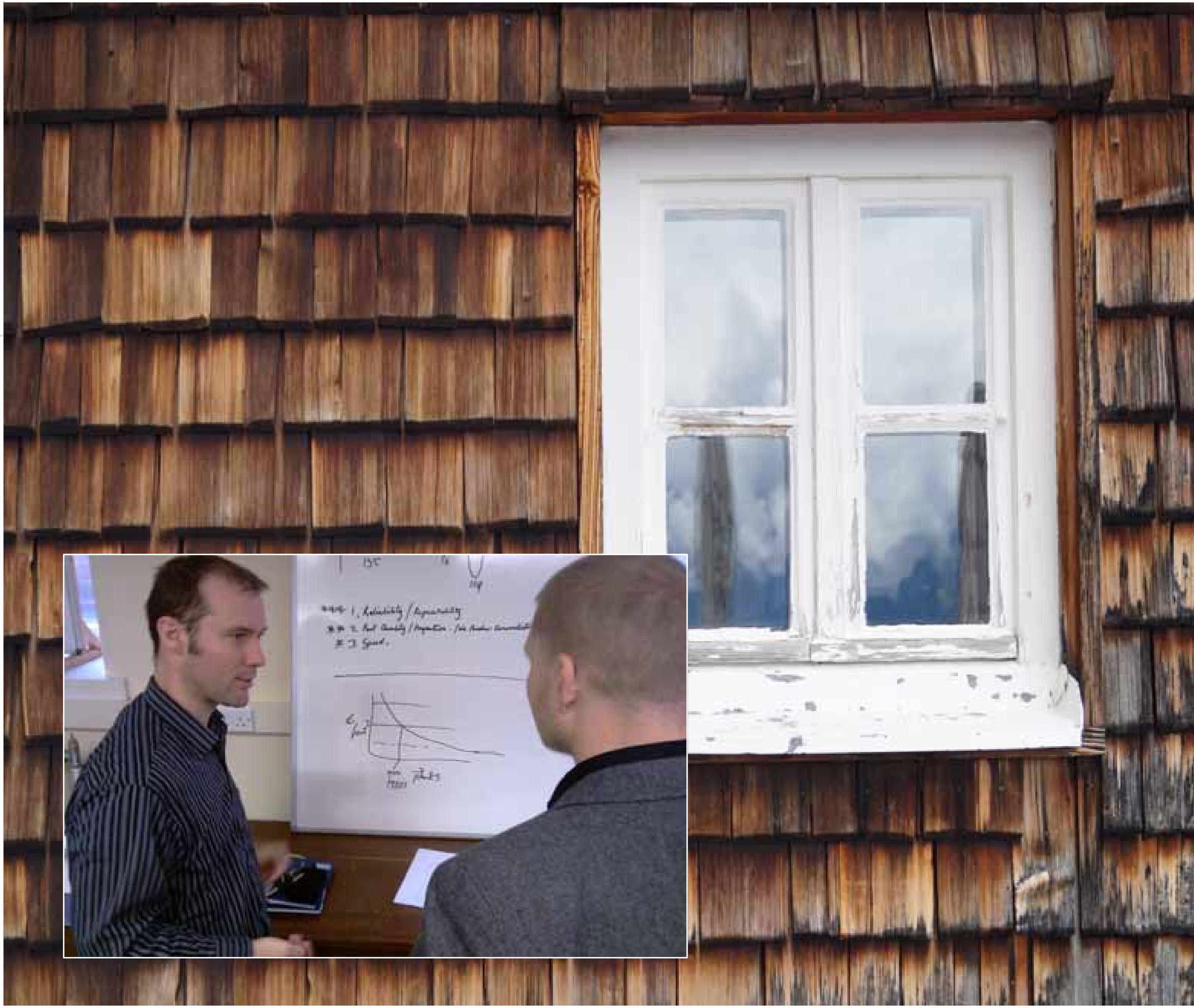
Additive Manufacturing

construction oriented versus function oriented thinking

Additive Manufacturing

construction oriented versus function oriented thinking

Potential for a new craftsmanship: local and low investment



Additive Manufacturing

construction oriented versus function oriented thinking

Potential for a new craftsmanship: local and low investment

The solution for refurbishment: parts and missing technology

Additive Manufacturing

construction oriented versus function oriented thinking

Potential for a new craftsmanship: local and low investment

The solution for refurbishment: parts and missing technology

Adaptive building envelopes: integrated technologies

Additive Manufacturing

Polymeers

Metal

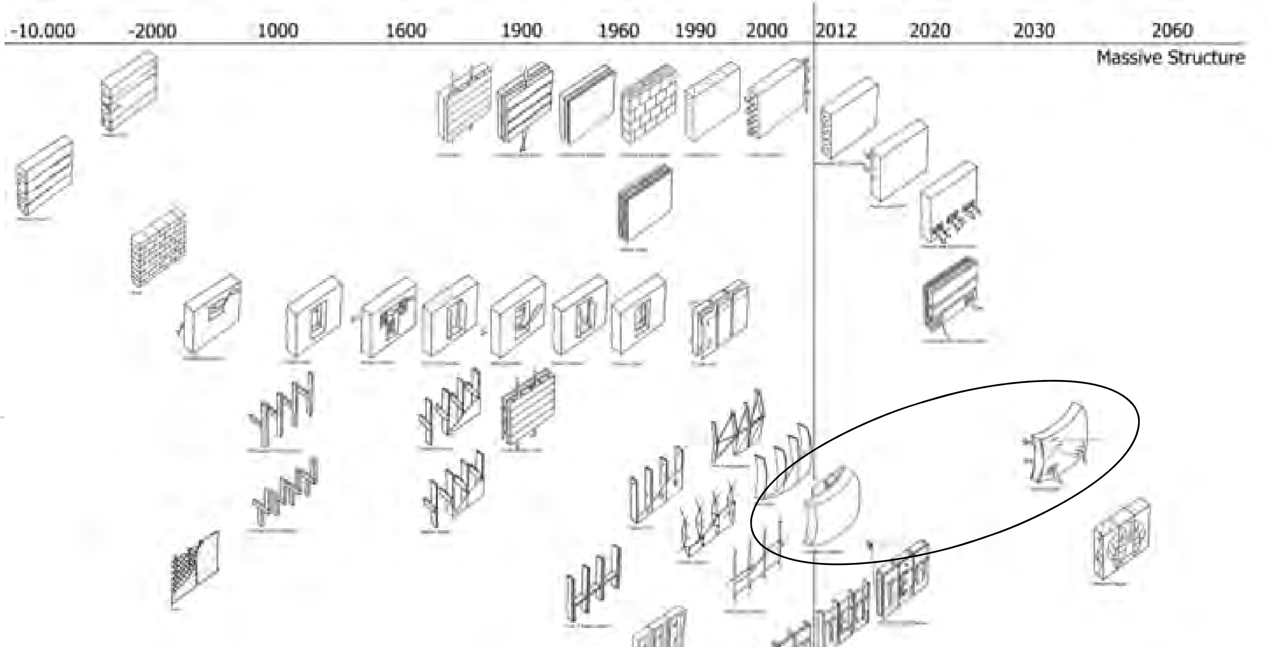
Concret

Ceramic

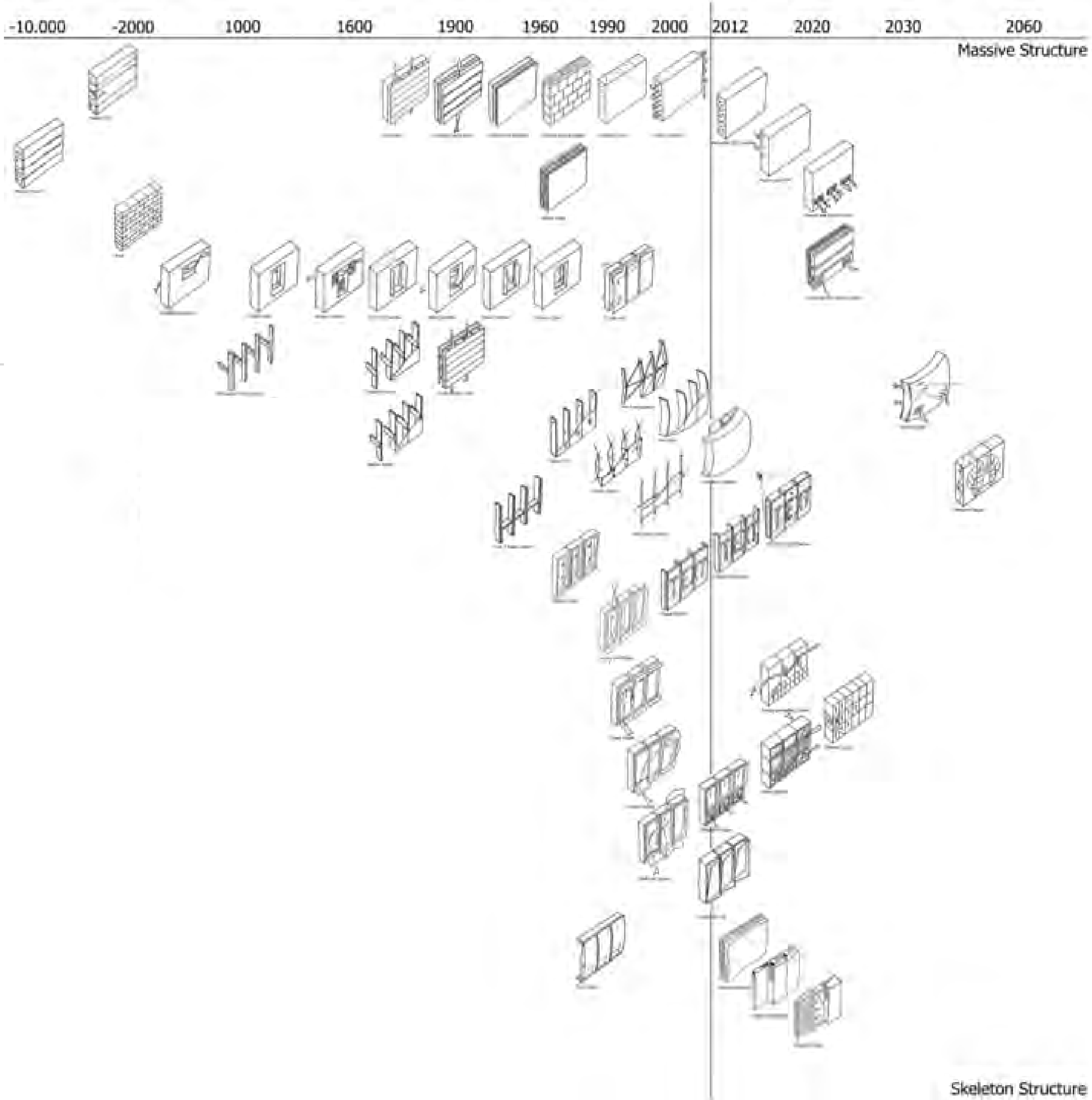
Glass

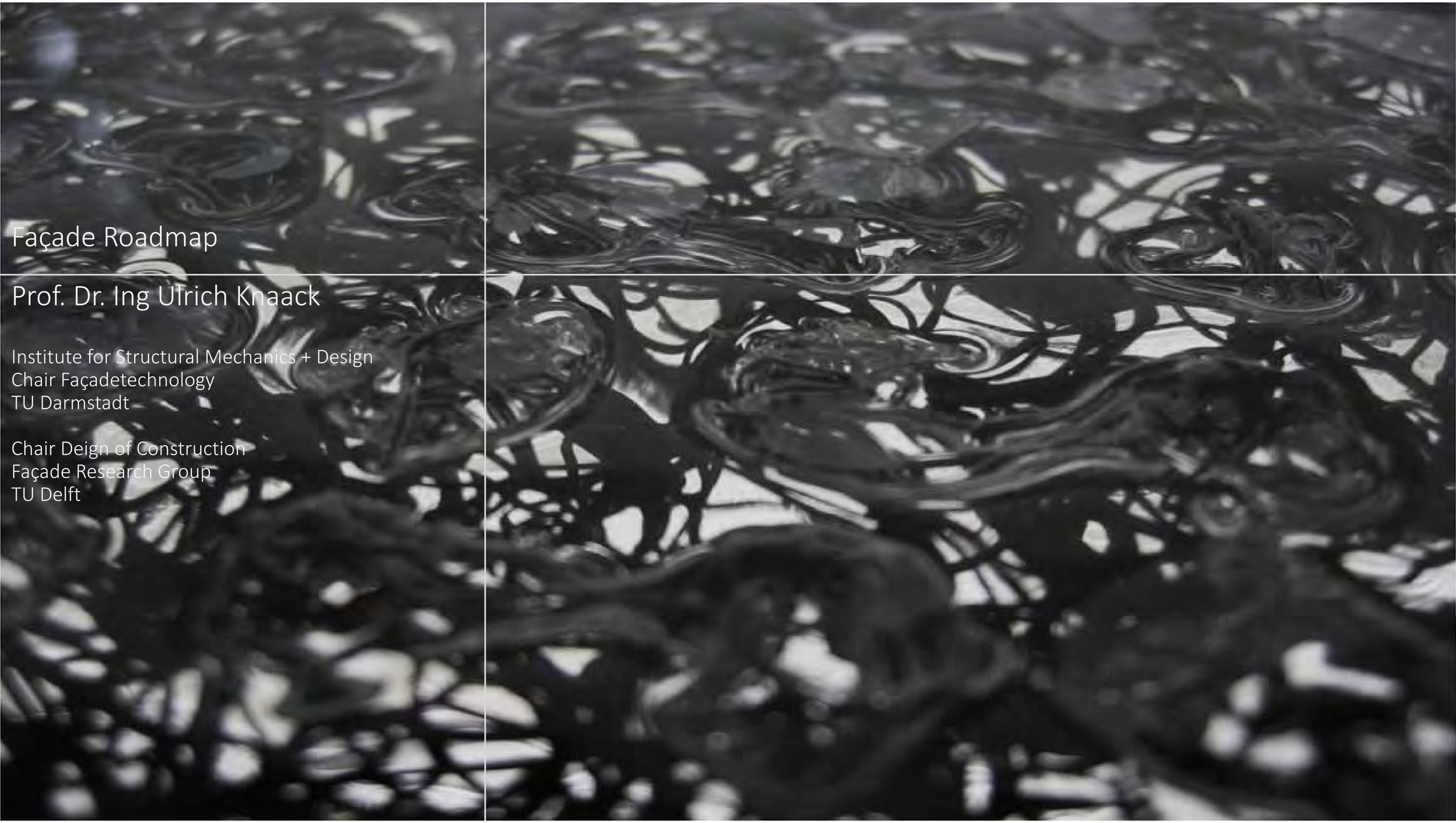
Wood / Paper

Façade Roadmap



Façade Roadmap





Façade Roadmap

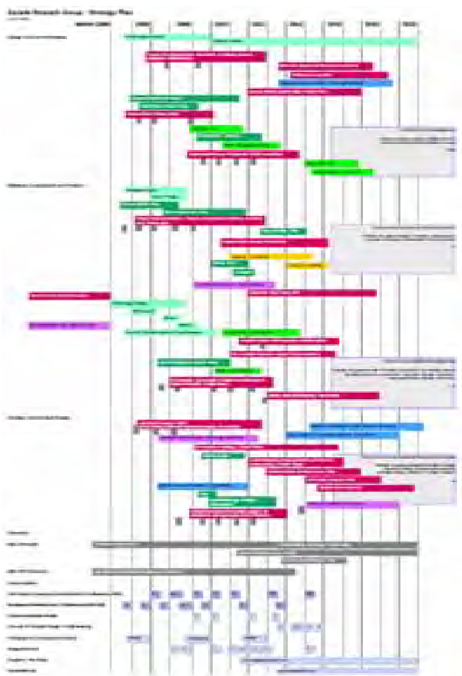
Prof. Dr. Ing Ulrich Knaack

Institute for Structural Mechanics + Design
Chair Façadetechnology
TU Darmstadt

Chair Deign of Construction
Façade Research Group
TU Delft

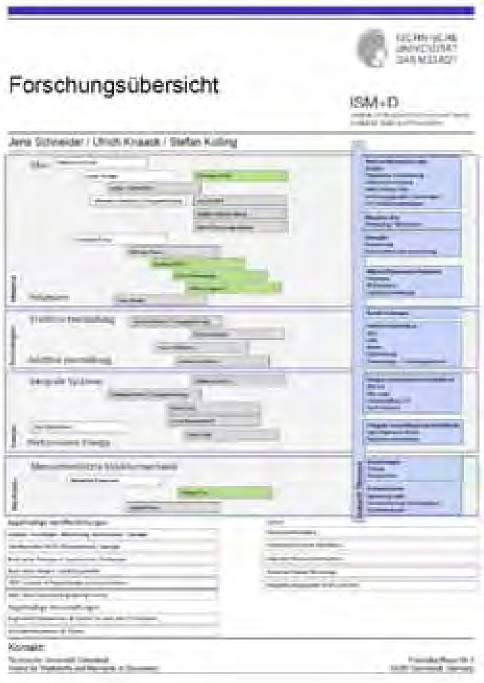
Architectural Facades & Products / Research Group TU Delft

Prof. Dr. Ing. Ulrich Knaack
Prof. Dr. Ing. Tillmann Klein



Institute for Structural Mechanic + Design / TU Darmstadt

Prof. Dr. Ing. Jens Schneider
Prof. Dr. Ing. Ulrich Knaack



Valorisation

-South Danish University Odense / Denmark *
-TU Delft / The Netherlands *
-CWTC + University of Bristol / United Kingdom
-Hochschule OWL / Germany *
-TU Darmstadt / Germany *
-Hochschule Luzern / Swiss
-Uni Innsbruck + Bolzano / Italy
-Universidad del Pais Vasco - San Sebastian + University of Madrid / Spain
-ITU Istanbul / Turkey *
-Lisbon / Portugal

Valorisation

TU Delft / The Netherlands

MSC Program Building Technology
Subtract Façade Design and Engineering
Cooperation with the Dutch Façade Association

TU Darmstadt / Germany

MSC Program Civil Engineering
Subtract Glass and Façade Structures

MASTER PROGRAM ARCHITECTURE, URBANISM, AND BUILDING SCIENCES, TRACK BUILDING TECHNOLOGY – DELFT

UNIVERSITY	Delft Technical University
FACULTY	Faculty of Architecture, Department Architectural Engineering + Technology
DEGREE / LANGUAGE	M.Sc. / English
DURATION	2 Years / 4 Semesters
SPECIALISATIONS	Accredited focus
ADMISSION FOR	B.Sc
KEY CONTENTS	Building_Newton
COORDINATORS / TEAM	Prof.Dr. Ulrich Knaack, Dr.-Ing. Tillmann Klein, ir. Arie Bergsma

PROFILE

The Building Technology track is one of the five tracks within the Architecture, Urbanism and Building Sciences master program. Within this track, students can specialize on Façade Design. The track focuses on research, technological design and innovation, dealing with the newest technology and interacting with the current market. This program offers a balance between applied research and design of buildings and building elements.

It encompasses a broad spectrum of engineering and architectural design skills that lead to one of the dominant professions of the future: the sustainable designer. The emphasis of this programme is on the design of innovative and sustainable building components and their integration into the built environment.

What you will learn
Through focusing on structural, façade and climate design, students learn how to contribute to smart buildings that are sustainable, comfortable and environmentally intelligent. This programme stands out internationally because of its integration of architectural design with technical disciplines, filling the niche between architecture and engineering. Rather than focusing on one or two specialisations, students investigate the whole breadth of building technology, looking at climate design, façade design and structural design, producing designers that know how engineers work.

Prospective students must show both technical and architectural skills, interest and understanding. The programme is well suited to architectural graduates looking to strengthen their technical qualifications and those with a technical background that want to strengthen their design abilities.

JOB PROSPECTS

Building technology graduates and façade specialists are in high demand as the construction industry is lacking designers that bridge this gap between the architectural and engineering disciplines. Given that graduates can make decisions based on calculations and integrate them into architecture, they can direct structural engineers and manage complex processes. Graduates are sought after for architectural offices, engineering offices and specialised façade manufacturers.

Graduates of the Building Technology programme can expect to find generalist and specialist positions in engineering and architectural firms, and excellent opportunities in the business supply, contracting and project development sectors. Others opt to begin their own businesses or to pursue further studies at the doctoral level.

MASTERPROGRAM GLASS & FAÇADE STRUCTURES – DARMSTADT

UNIVERSITY	Technische Universität Darmstadt
FACULTY	Faculty of Civil and Environmental Engineering
DEGREE / LANGUAGE	M.Sc. / English
DURATION	2 Years / 4 Semesters
SPECIALISATIONS	Civil Engineering with a focus on Glass and Façade Engineering
ADMISSION FOR	B.Sc
KEY CONTENTS	Façade materials, structural performance
COORDINATORS / TEAM	Prof. Dr. Ulrich Knaack, Prof. Dr. Ing. Jens Schneider

PROFILE

As part of the Civil Engineering track of the Faculty of Civil and Environmental Engineering MSc program a specialisation of façade engineering is made available. Within this track, students can specialize on Façade Engineering. The track has a broad intake with a standard civil engineering MSc program and is focusing in the specialisation "glass + façade structures" at materials, structural and computational engineering as well as facades and glass construction. Problem solving at an engineering level, combined with a close understanding of technical and physical parameters of facades are in the focus of the education. Engendering and design skills are trained in an project oriented program. The program is closely linked to research within the faculty and interacts with the partner programs within the European network.

What you will learn
Façade as one of the most complex parts of a building act as the border of indore and outdoor environment. An education to engineer the requires a deep understanding of the mechanical, material and building physics related aspects. In this program these aspects are integrated in theoretical and experimental courses. Project related parts of the programm will train the understanding of engineering and design processes.

JOB PROSPECTS

Civil engineering graduates do have a large variety of job opportunities: working in the engineering and construction industry as well as being active in the manufacturing industry are general opportunities. But due to the lake of skilled people in the façade industry the specialization "Glass and Façade Structures" will allow alumni's to become active as specialist in consulting, engineering and manufacturing / construction within the field of façade.

Graduates of the "Glass and Facades structure" program can expect to find engineering or specialist positions in engineering or manufacturing firms as well as contracting and project development sectors. The program also allows to continue further studies at the doctoral level.

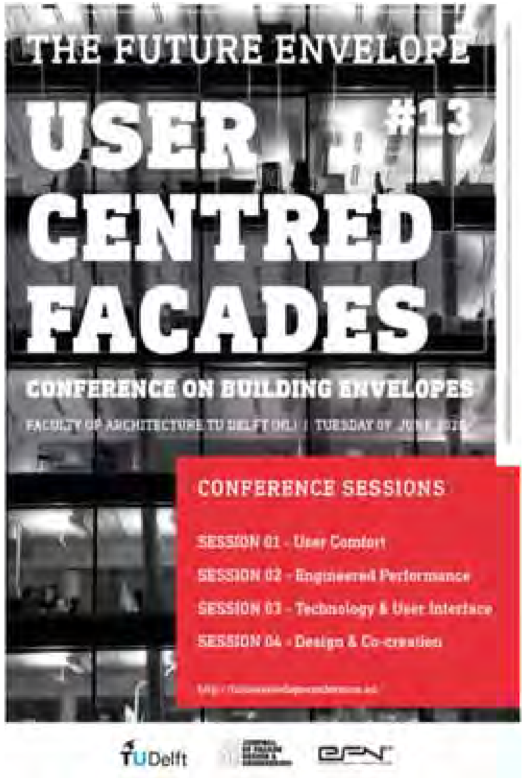
Valorisation

The Future Envelope / Delft

PowerSkin / BAU München

BE-AM / FormNEXT Frankfurt

glass technology live / Düsseldorf



Valorisation

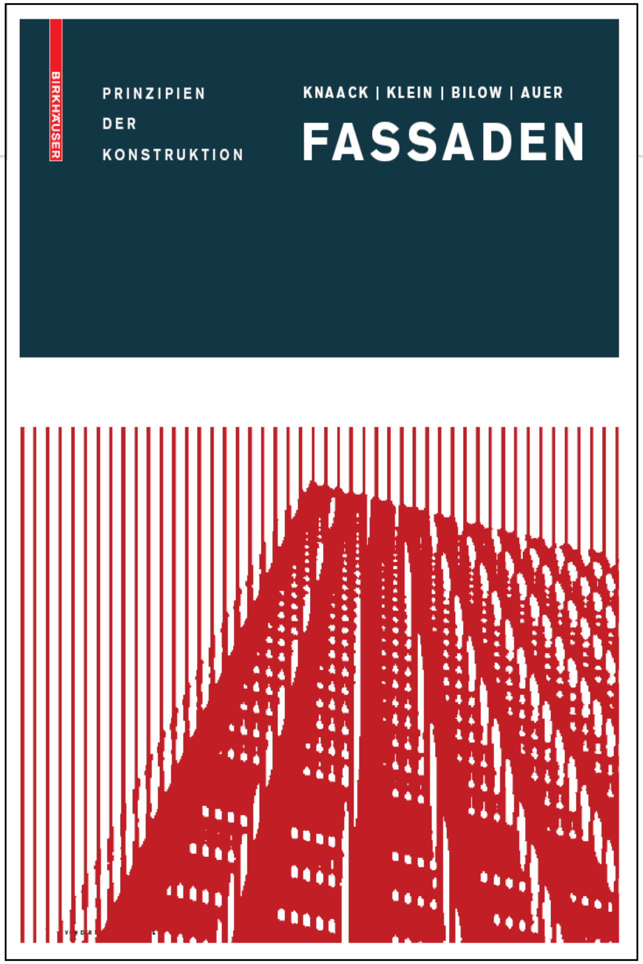
Books

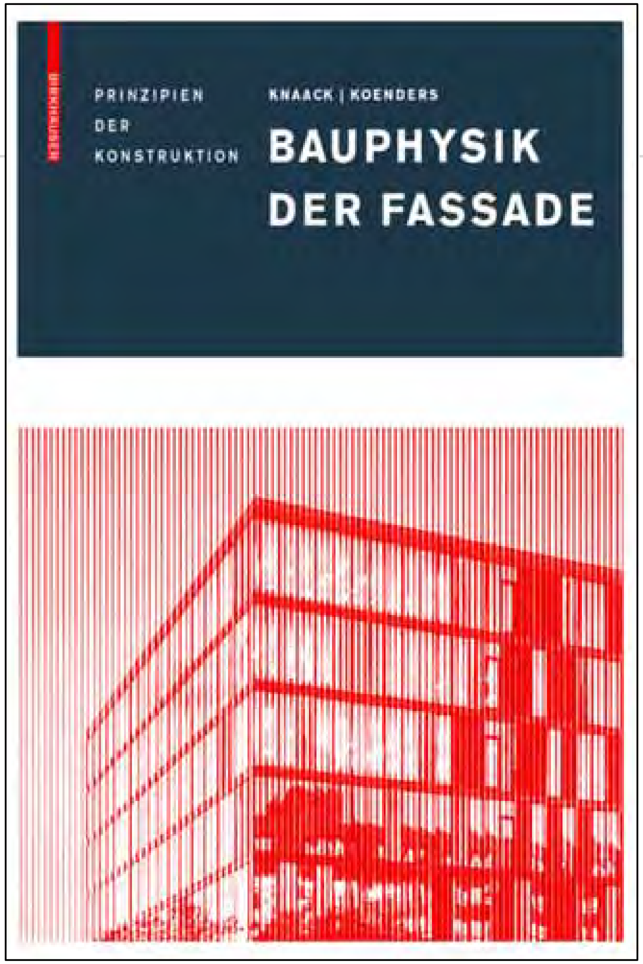

Green Building Innovation : Books Façade Research Group

Principels of Construction

Educational Book Series
Birkhäuser – Basel, Boston Berlin

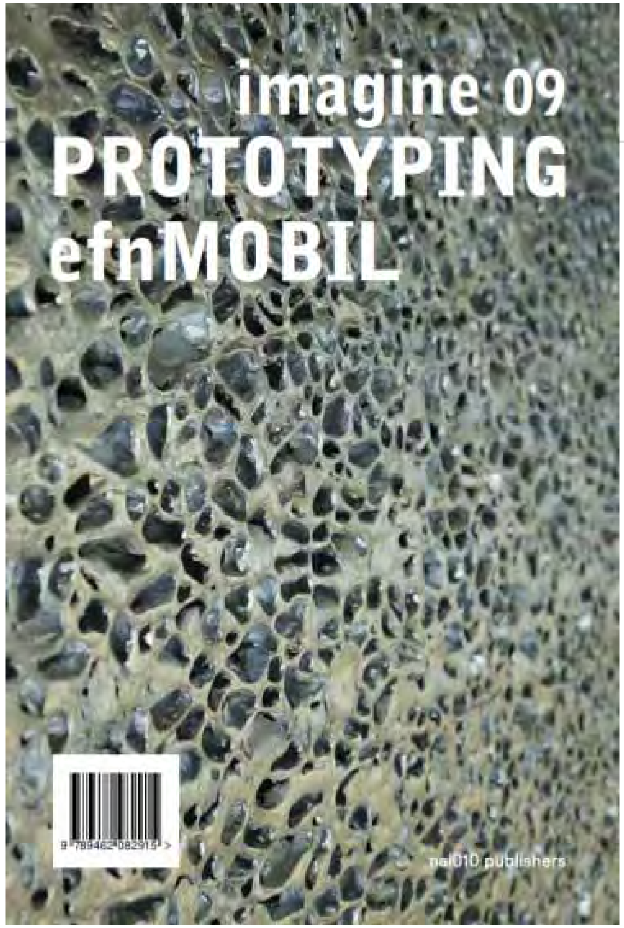
Principles of *Construction* is a educational book series which provides young professionals and students with systematic structured principle knowledge of building technologies.





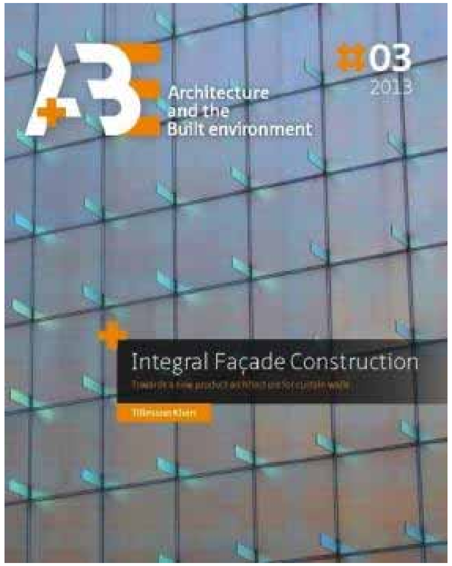
Valorisation

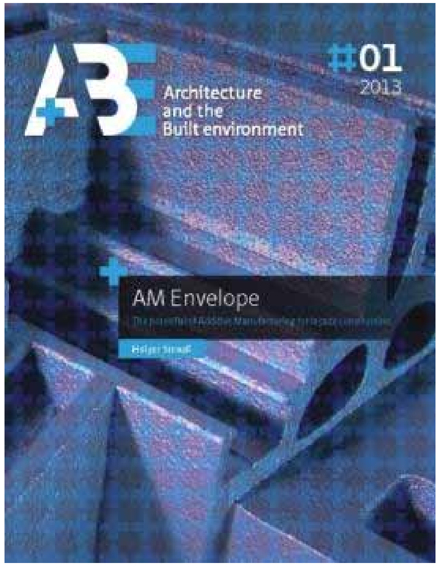
Books



Valorisation

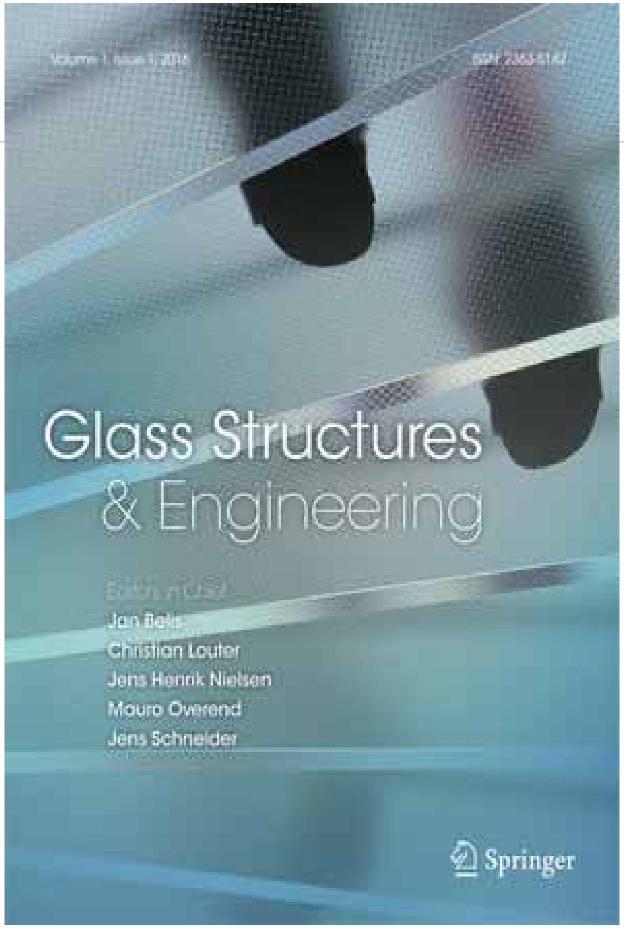
PhD´s
TU Darmstadt: Springer
TU Delft: BKBOOKS – open access





Valorisation

Journals
Glass Structures & Engineering / Springer
Journal of Façade Design & Engineering / BKBOOKS – open acess



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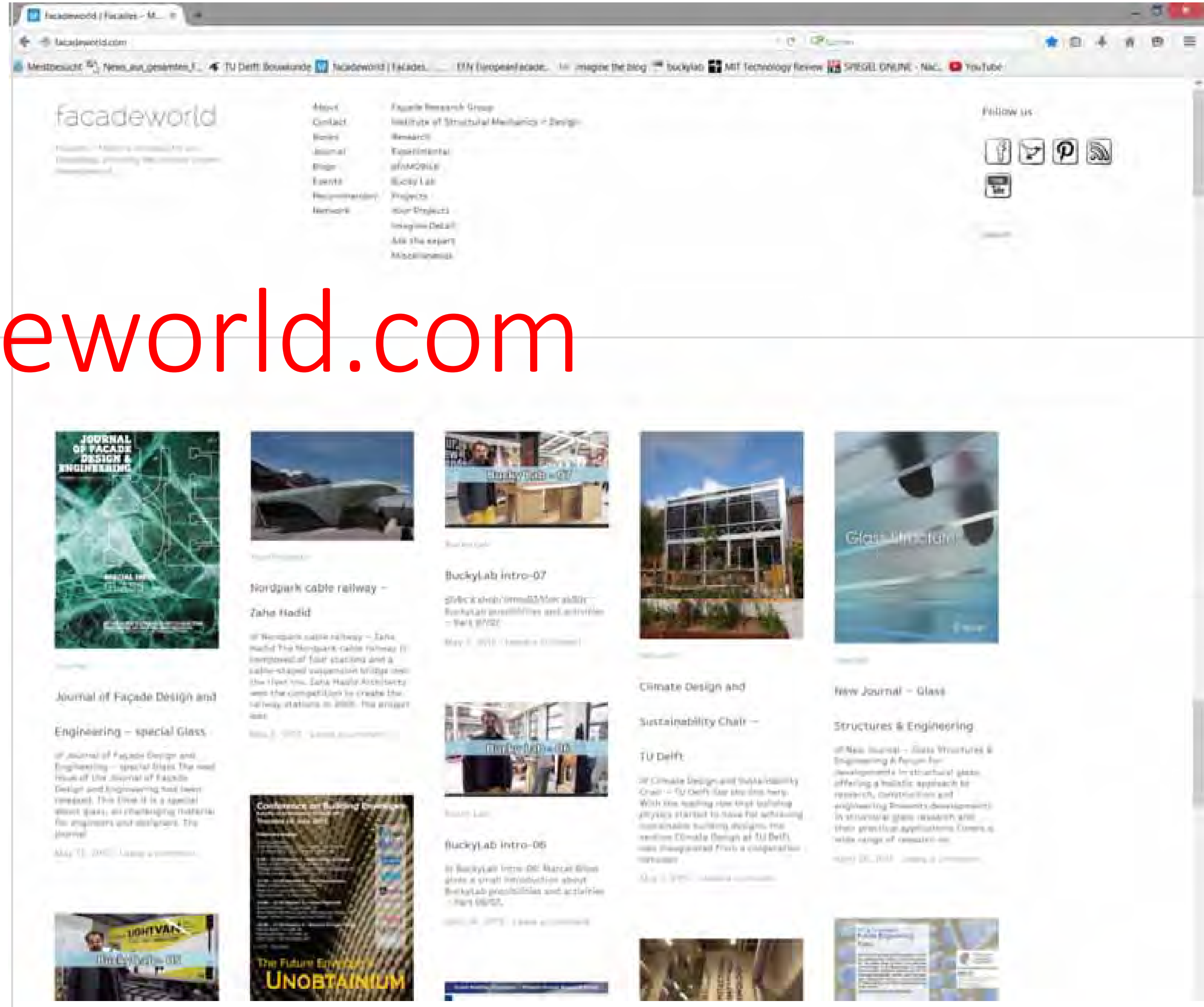

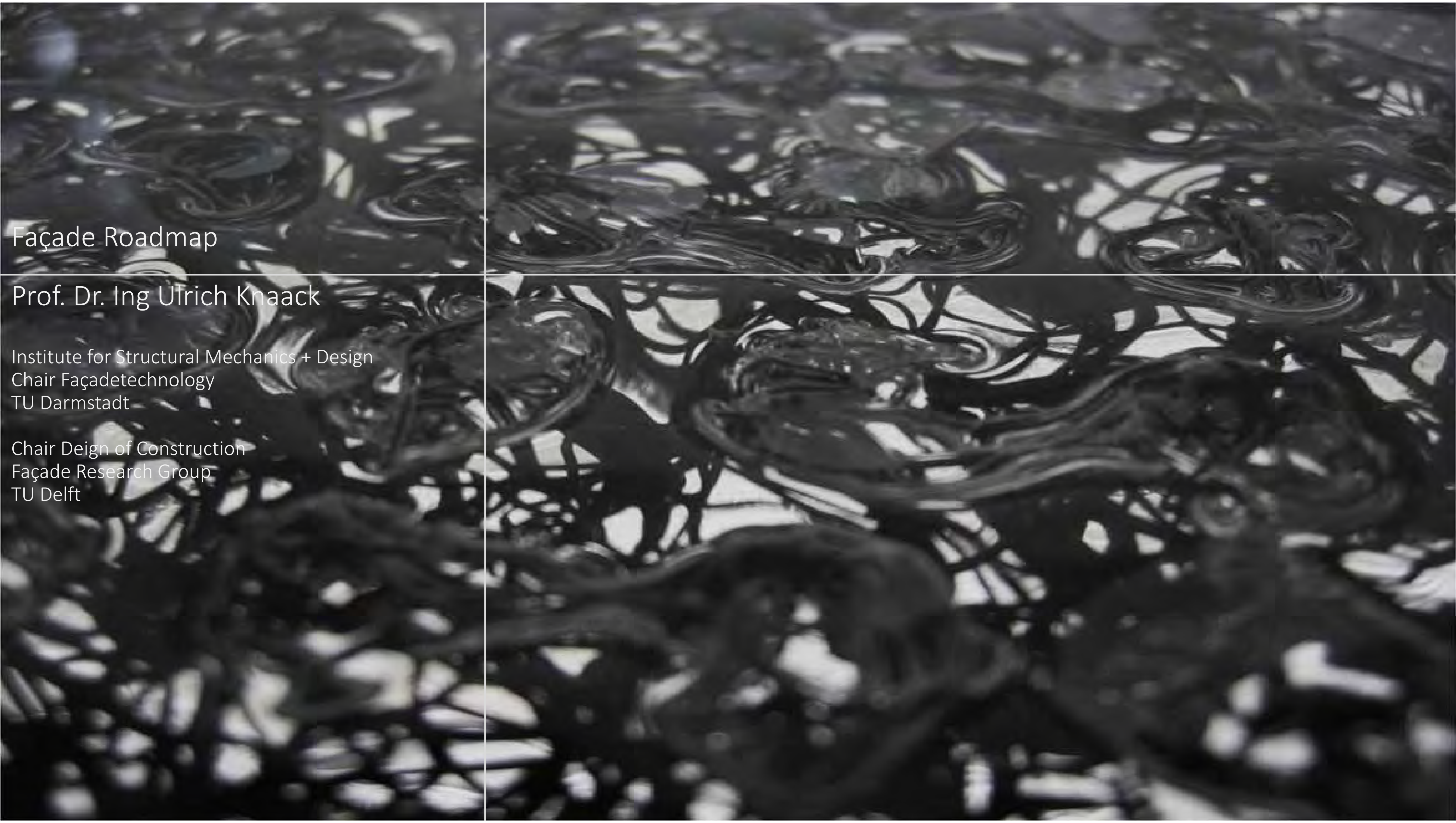

Façade Roadmap

Prof. Dr. Ing Ulrich Knaack

Institute for Structural Mechanics + Design
Chair Façadetechnology
TU Darmstadt

Chair Deign of Construction
Façade Research Group
TU Delft