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

The Next Big Thing

Symposium
"High Performance Building Envelopes"

¤ The Dutch government aims for a **climate-neutral built environment in 2050**. Renovation of the existing building stock is essential in realizing this ambition as the market needs to prepare for delivering 200,000 high performance renovations per year. This requires, among others the development of affordable renovation solutions, enabling the transition toward a fully sustainable energy supply and a fast renovation process.

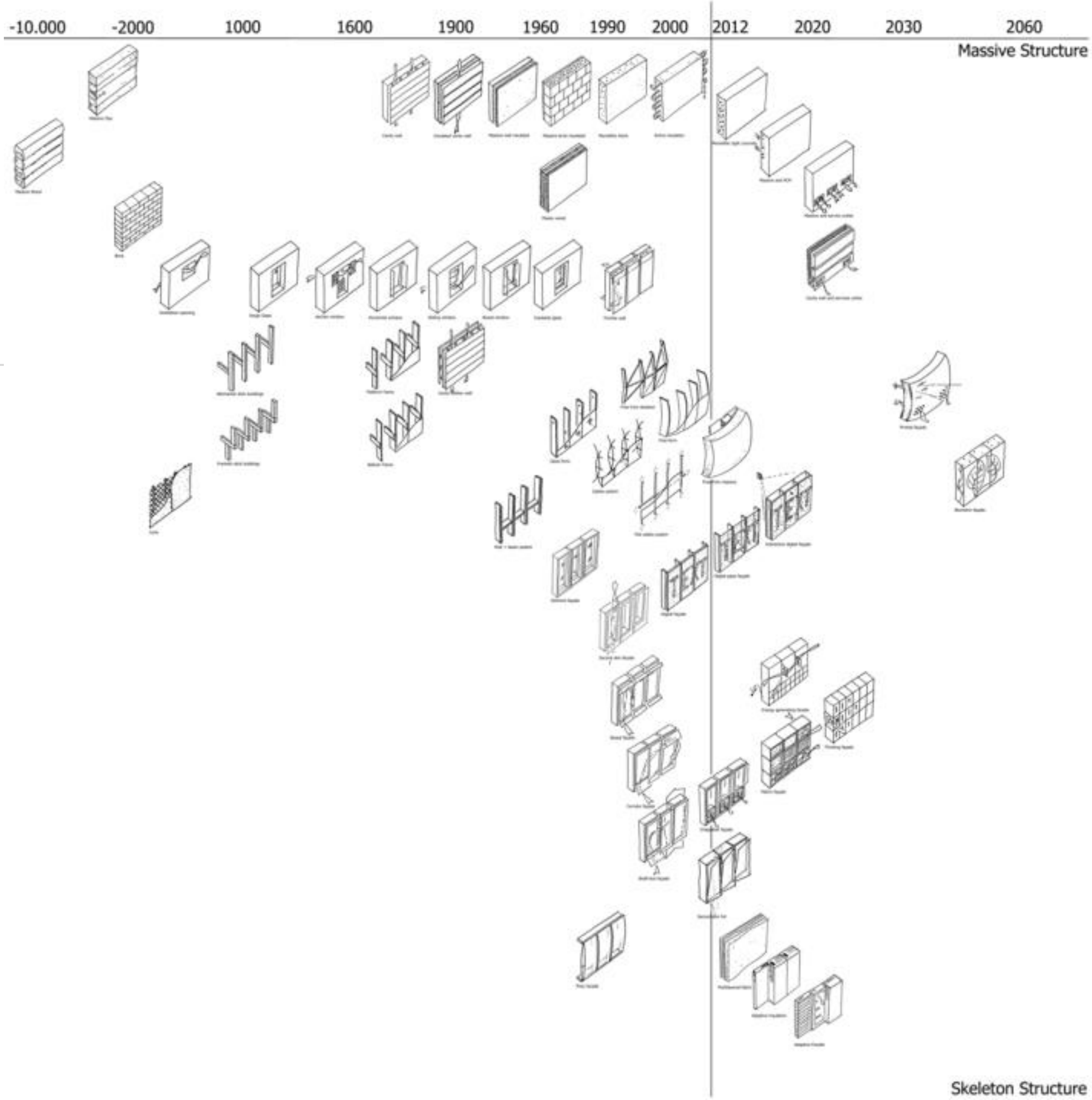
¤ Adapting the building envelope is an important element for this transition. This implies improving the **thermal performance of the envelop** (lower energy losses through better insulation, better windows, etc.) as well **actively utilizing the envelop for the production of renewable energy**.

¤ Various smart solutions for the building envelope were developed in the last couple of year and the key question is: **how can we scale up these projects** to contribute **to delivering 200,000 high performance renovations per year**?

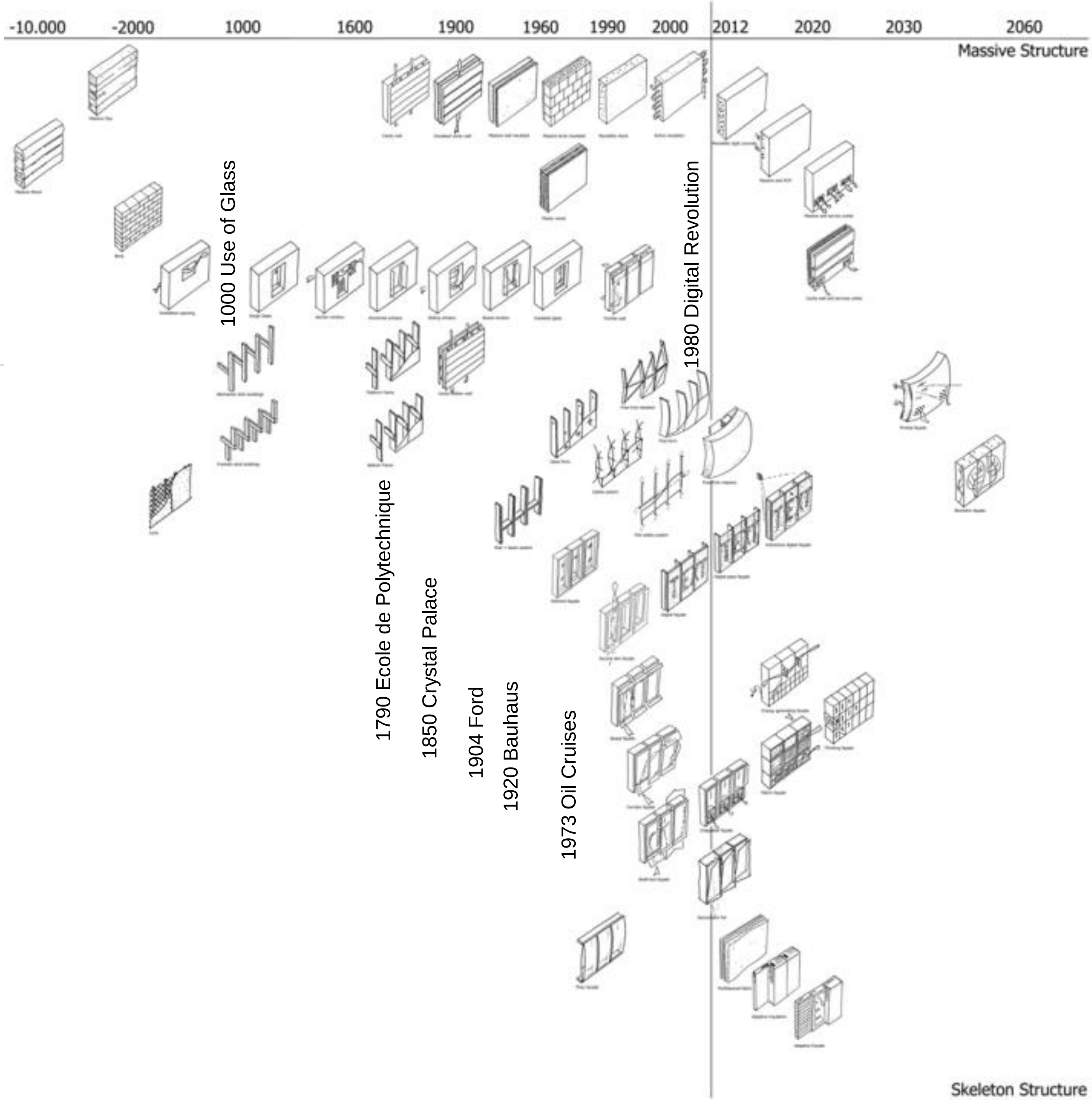
¤ At this symposium we will discuss:

o What are promising concepts and developments?
o What is needed to scale up these concepts?
o Which innovations are needed to reduce costs?
o How can robotisation and digitization contribute to development of affordable renovation?
o What process innovation do we need in the construction chain?

Façade Roadmap

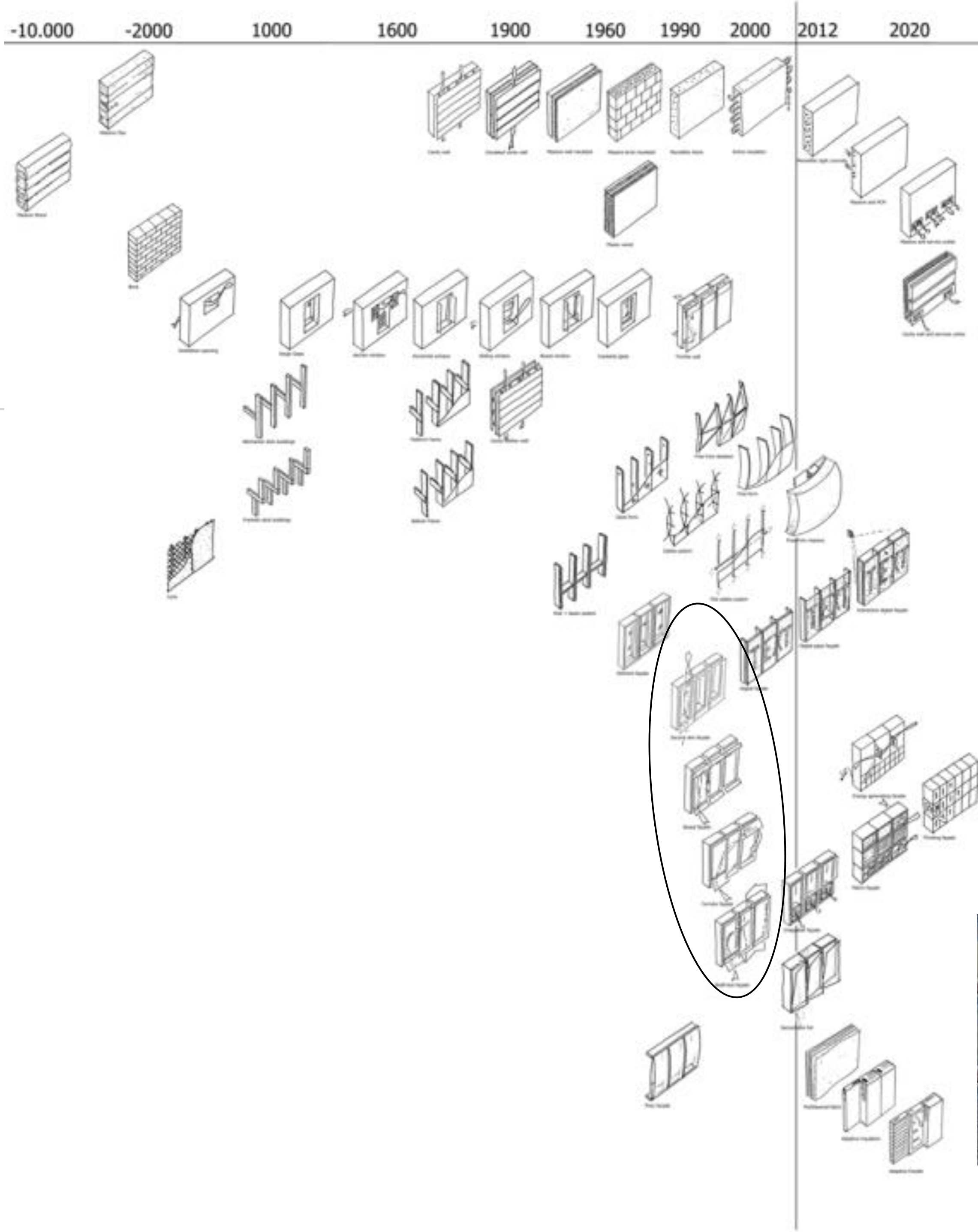


Influences



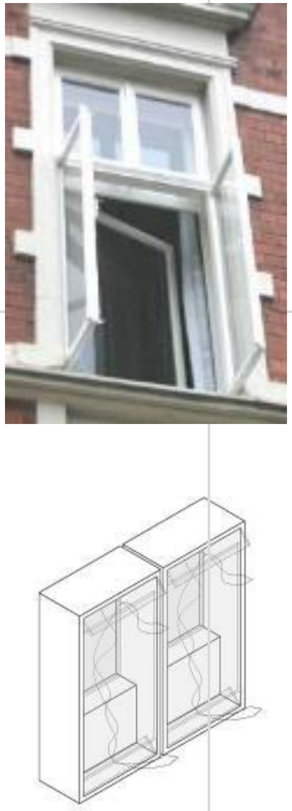
-10.000
-2000
1000
1600
1900
1960
1990
2000
2012
2020
2030
2060
Massive Structure
1000 Use of Glass
1980 Digital Revolution
1790 Ecole de Polytechnique
1850 Crystal Palace
1904 Ford
1920 Bauhaus
1973 Oil Cruises
Skeleton Structure

Façade Roadmap

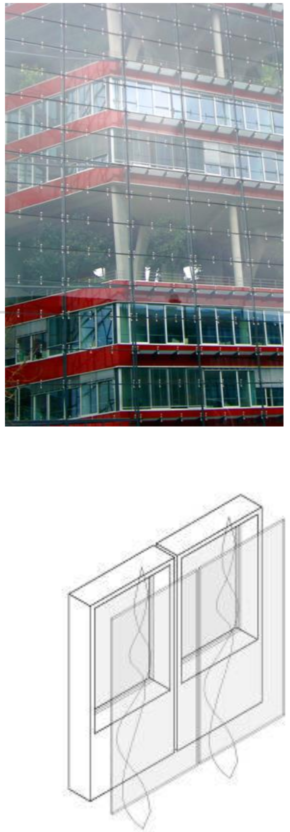


Stadttor Düsseldorf

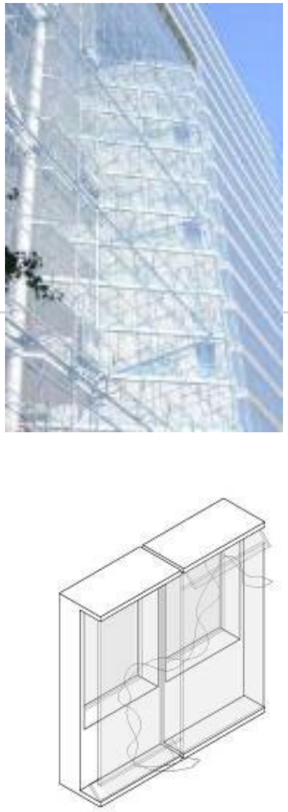
Façade Roadmap
double facades @ 2000



boxed window facade

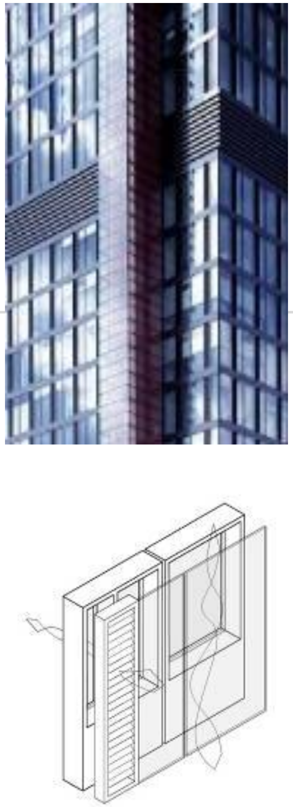


second skin facade



corridor facade

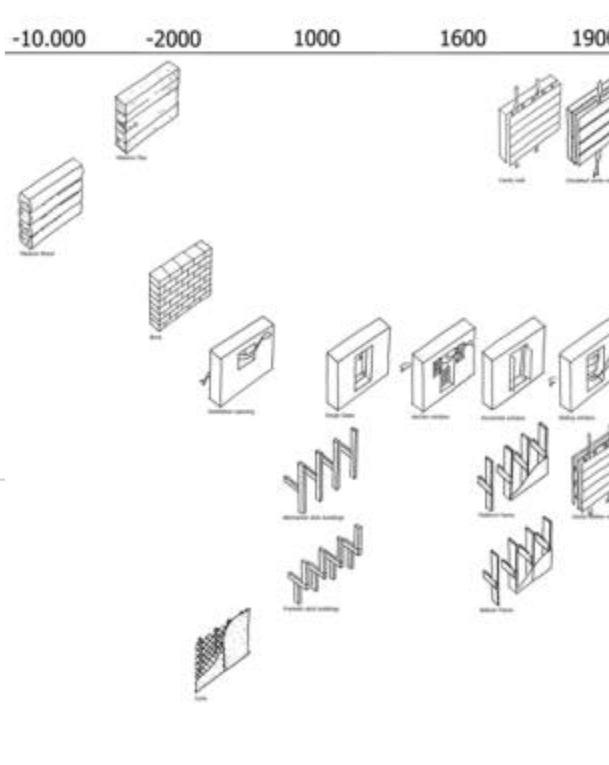
chimney boxed window facade

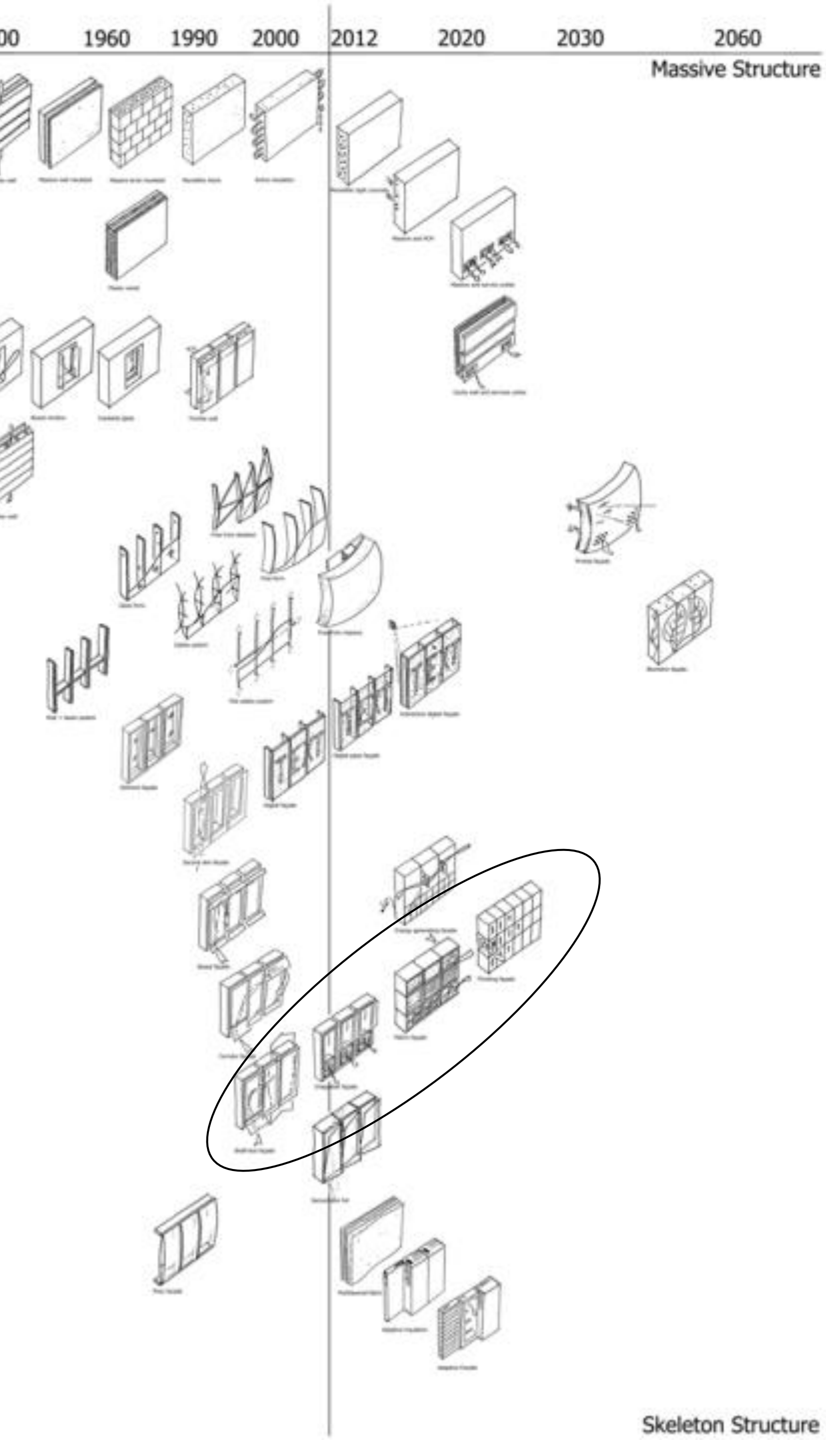


alternating facade

component facade

Façade Roadmap





Post Tower Bonn

Capricon Düsseldorf

Façade Roadmap
Component façade @ 2010

Posttower Bonn

T-motion facade

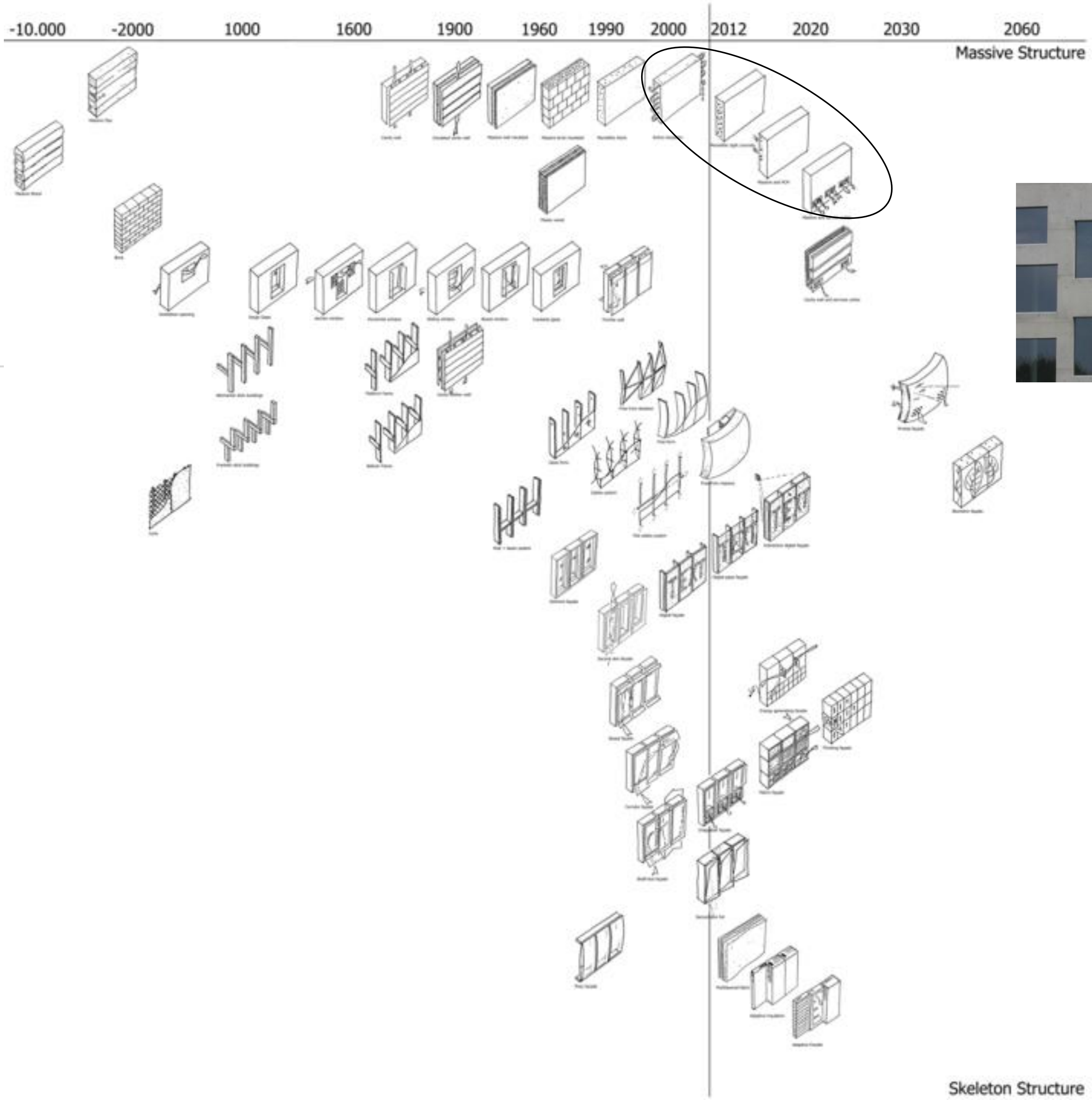
Capricon Düsseldorf

SmartBox

E² Fassade

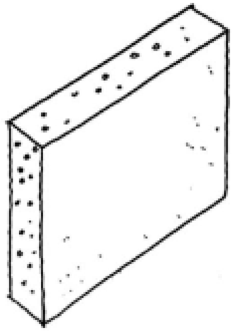
NEXT Facade

Façade Roadmap

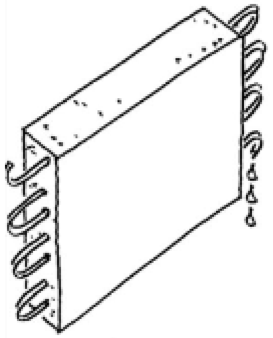


Design School Essen

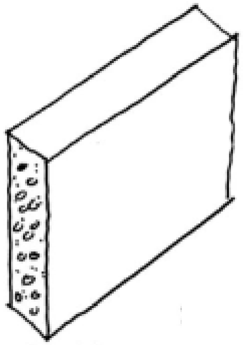
Façade Roadmap
solid function integrated construction



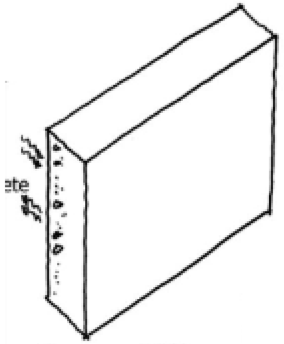
Monolithic block



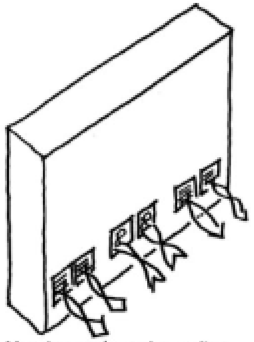
Active insulation



Monolithic light concreti



Massive and PCM



Massive and service unites

Façade Roadmap

Design School Essen - SANAA / Tokyo

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

Façade Roadmap

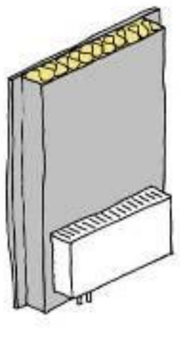
Design School Essen - SANAA / Tokyo

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

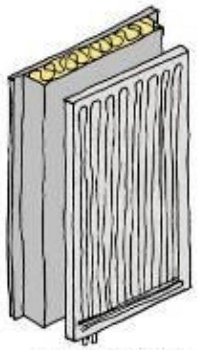
Façade Roadmap

facade heating / cooling panel

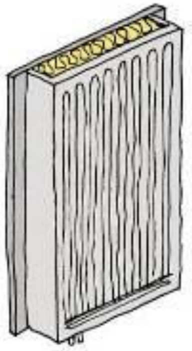
by Marcel Bilow / 2007



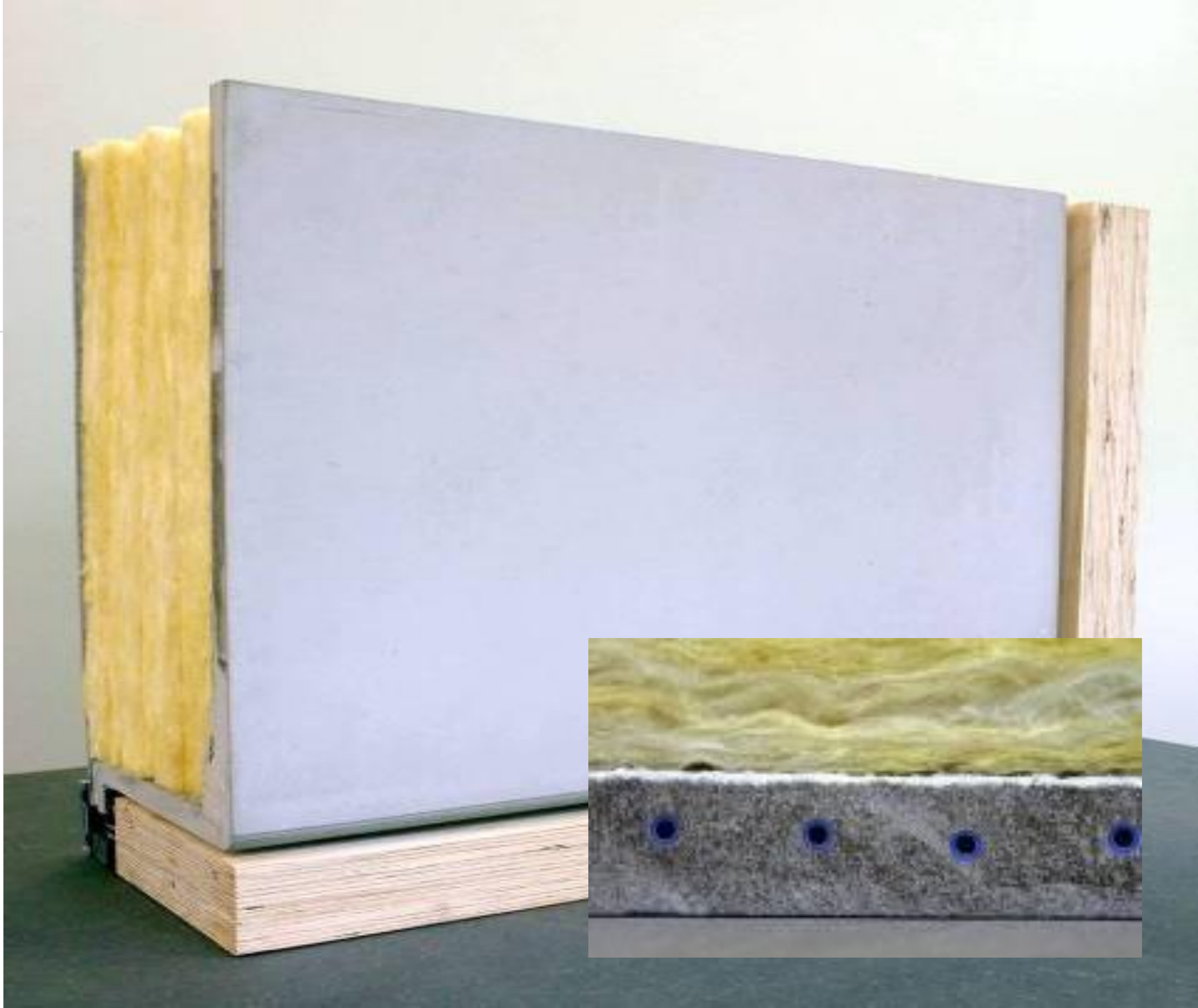
Panel mit vorgesetztem Heizkörper



Paneel mit Flächen-heizung additiv



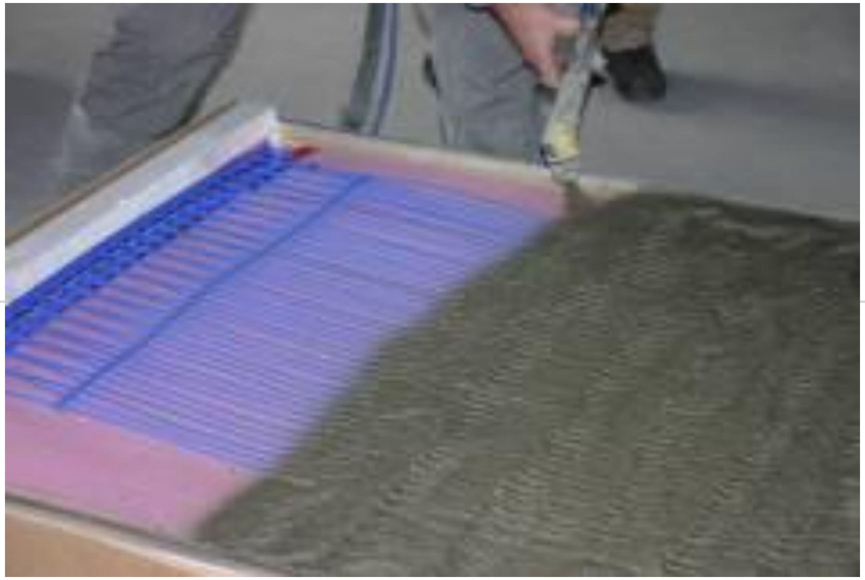
Flächenheizkörper bildet Teil des Paneels



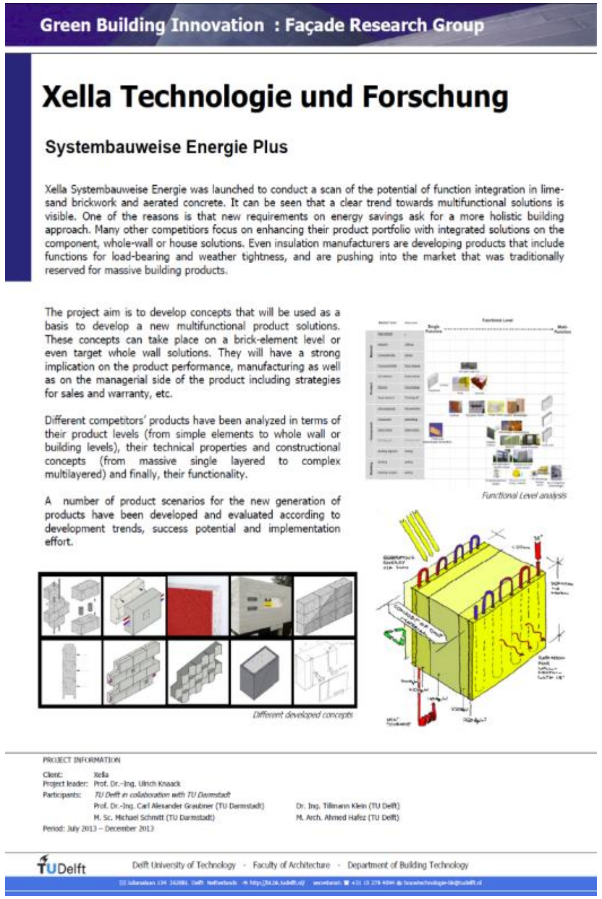
Façade Roadmap

Jackbox: integrated sandwich construction

HS OWL / 2007



Façade Roadmap


Green Building Innovation : Façade Research Group

Xella Technologie und Forschung

Systembauweise Energie Plus

Xella Systembauweise Energie was launched to conduct a scan of the potential of function integration in lime-sand brickwork and aerated concrete. It can be seen that a clear trend towards multifunctional solutions is visible. One of the reasons is that new requirements on energy savings ask for a more holistic building approach. Many other competitors focus on enhancing their product portfolio with integrated solutions on the component, whole-wall or house solutions. Even insulation manufacturers are developing products that include functions for load-bearing and weather tightness, and are pushing into the market that was traditionally reserved for massive building products.

The project aim is to develop concepts that will be used as a basis to develop a new multifunctional product solutions. These concepts can take place on a brick-element level or even target whole wall solutions. They will have a strong implication on the product performance, manufacturing as well as on the managerial side of the product including strategies for sales and warranty, etc.

Different competitors' products have been analyzed in terms of their product levels (from simple elements to whole wall or building levels), their technical properties and constructional concepts (from massive single layered to complex multilayered) and finally, their functionality.

A number of product scenarios for the new generation of products have been developed and evaluated according to development trends, success potential and implementation effort.

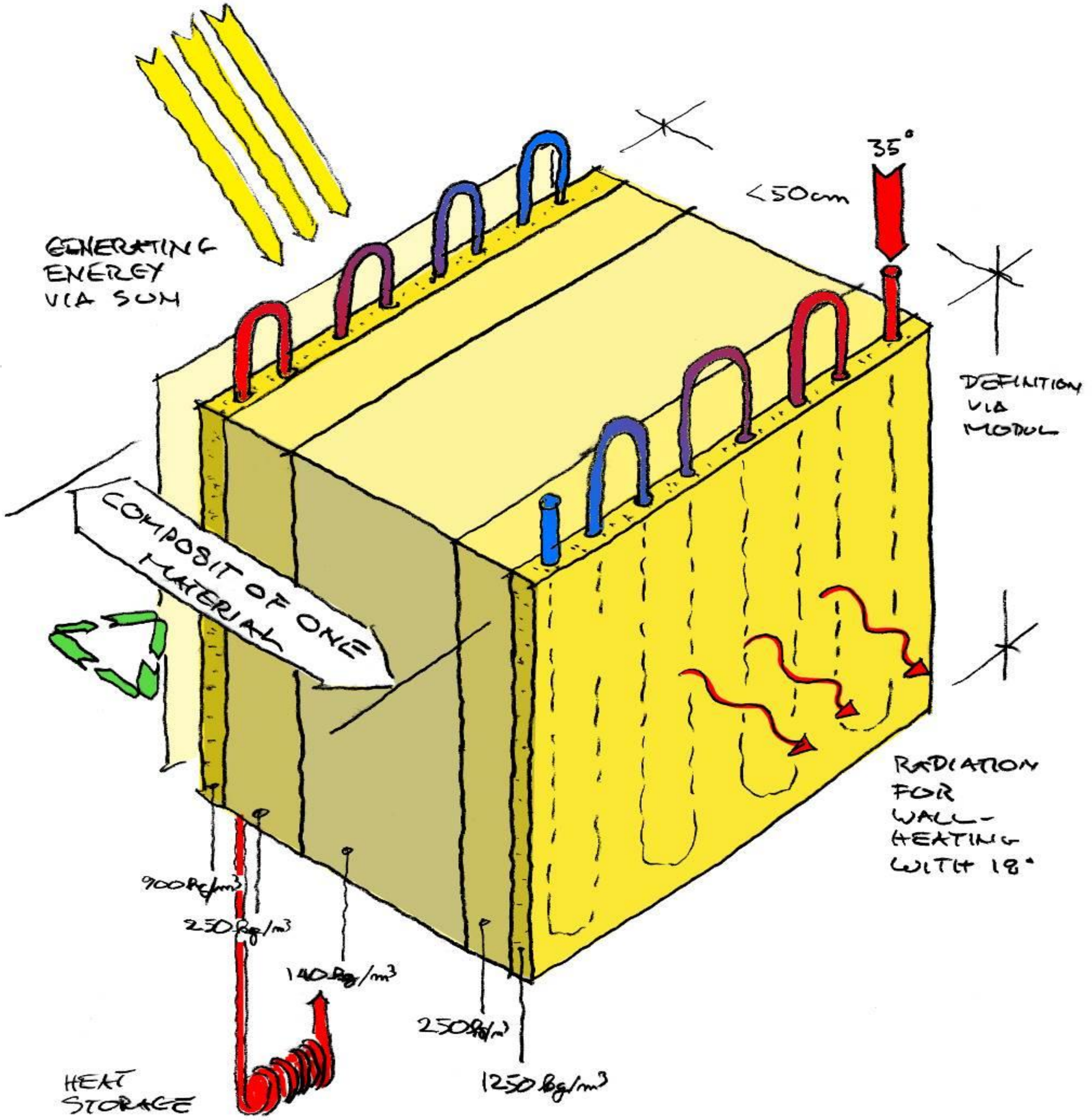
Functional Level analysis

Different developed concepts

PROJECT INFORMATION

Client: Xella
Project leader: Prof. Dr.-Ing. Ulrich Knaack
Participants: *TU Delft in collaboration with TU Darmstadt*
Prof. Dr.-Ing. Carl Alexander Graubner (TU Darmstadt) — Dr. Ing. Tillmann Klein (TU Delft)
M. Sc. Michael Schmitt (TU Darmstadt) — M. Arch. Ahmed Hafez (TU Delft)
Period: July 2013 – December 2013

TU Delft — Delft University of Technology · Faculty of Architecture · Department of Building Technology



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 phronetic 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
If ABABEs transport energy usefully in response to the dynamic loads of climate and occupation, then by controlling thermal transfer, in both time and length scales by vectoring phronetic advection, ABABEs will reduce the typical peaks and valleys of energy consumption associated with conventional building envelope typologies.

Building Envelope as Energy Transfer Function
The characterization of the building envelope as a transfer station for the capture, transformation, storage and distribution of energy is based on an ecological model of entropy management through the building matrix; it reframes the typical approaches of energy mitigation or conversion that can be characterized as derived from the First Law of Thermodynamics (e.g., conservation of energy) to Second Law of Thermodynamics (e.g., entropy generation).

Bioanalytic Design Principles
The first principles of counter current heat exchange (e.g., rete mirablis), and surface modulation (e.g., caruncle), are directly related to thermoregulation across species (e.g., turkey vulture, lamnid sharks, etc.) and climates (e.g., hot and arid, continental, etc.) and provide a research platform from which to investigate the potential for the performance design of a multivalent envelope system. The principle of counter current heat exchange is the management of entropy through an advective working fluid. The principle of surface modulation is the control of the rate of energy gain or loss due to exposures. By linking these two principles together in the design of a facade component, we can show significant effects on the energy profiles of the affected thermal zones, as well as propose the facade as a functioning ornament whose morphology reflects its use.

1. Molded tile geometry for optimal winter solar collection, 2. Textured solar collection surface for improved solar heat gain. 3. Overlapping geometry for rainscreen water shedding. 4. Ceramic fins on interior tile surface for improved heat transfer to phase change cavity. 5. Phase change material collection cavity. 6. Lapping tile geometry for clipping to modular track cladding system.7. Heat transfer loop for conduction to thermal storage bank. 8. Thermal storage bank. 9. Thermal transfer switching connection to thermal storage bank for seasonal performance control. Credit: Jason Vollen, Kelly Winn, CASE.

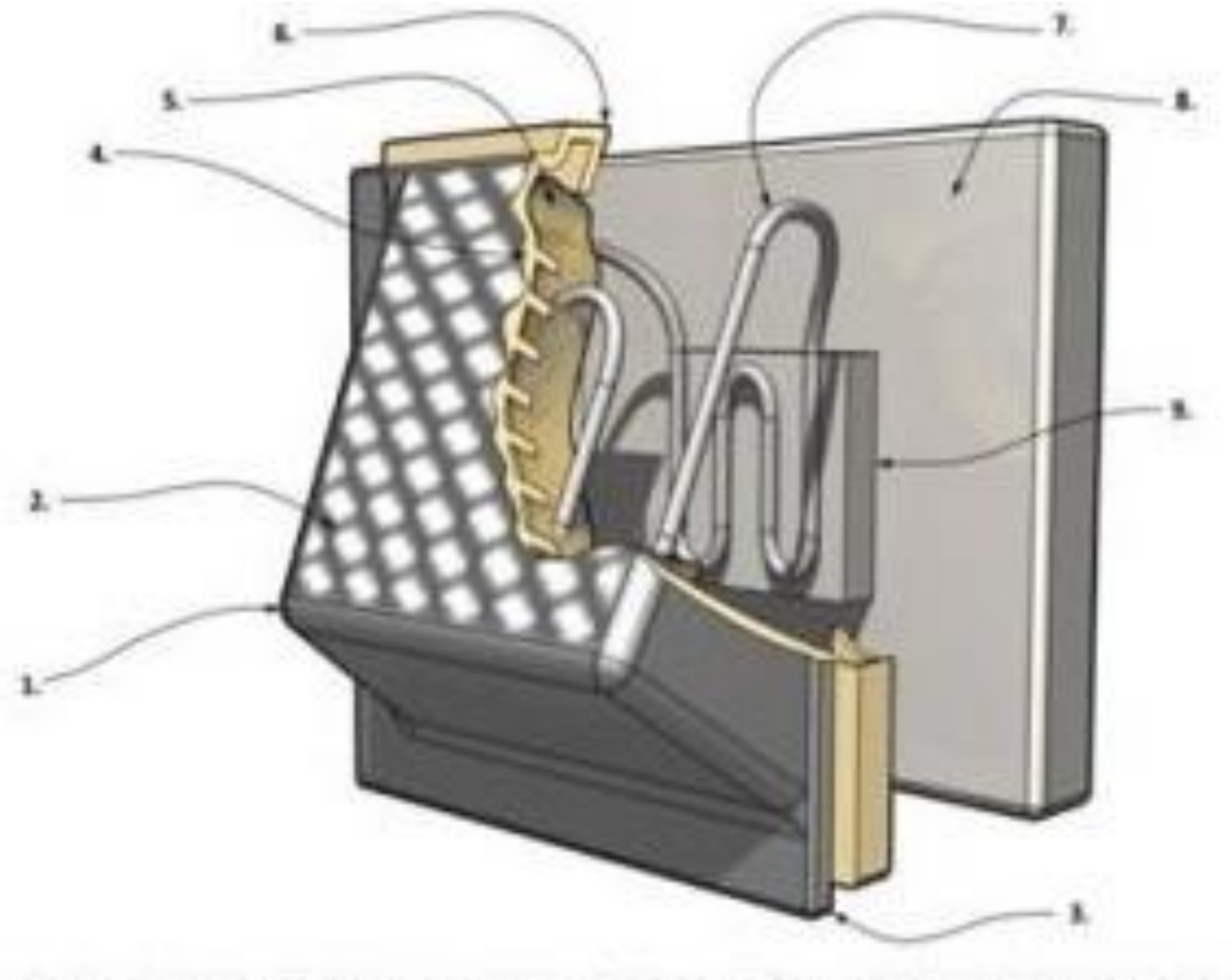
Stoneware slipcast prototype showing competent level morphology changes. Credit: Jason Vollen, Kelly Winn, CASE.

PROJECT INFORMATION
PhD Researcher: Jason Oliver Vollen, RA
First Mentor: Prof. Dr. Ing. Ulrich Knaack
Prof. Dr. Ing Tillmann Klein
Period: 2013-16

RELATED PUBLICATIONS

- *Knaack, U. and T. Klein, The Future Envelope 1: A Multidisciplinary Approach, IOS Press. (2008).*
- *Xu, X. and S. Van Dessel (2008). "Evaluation of a prototype active building envelope window-system." Energy and Buildings 40(2): 168-174*

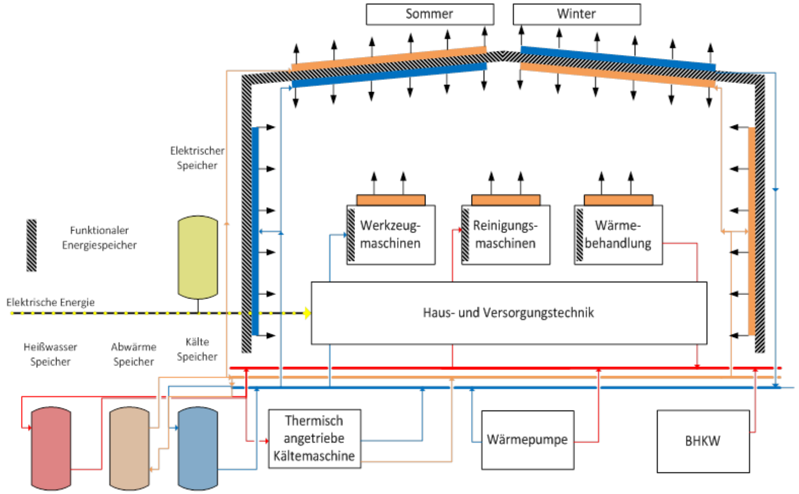
TUDelft Delft University of Technology - Faculty of Architecture - Department of Architectural Engineering & Technology
Julianalaan 134 2628BL Delft Netherlands http://bt.bk.tudelft.nl/ secretariat: +31 15 278 4094 bouwtechnologie-bk@tudelft.nl



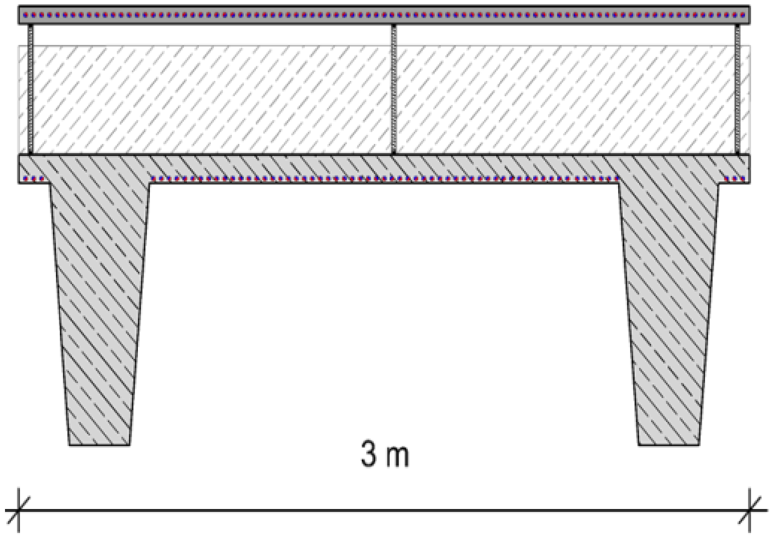
Façade Roadmap

ETA Factory / Tu Darmstadt

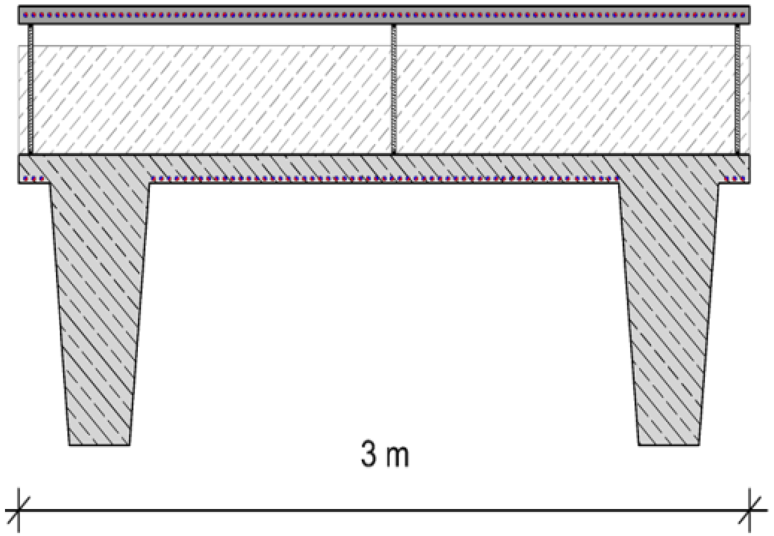
Prof Dr. Jens Schneider,
Prof Dr. H. Gerecht,
Prof Dr. E. Abele / TU Darmstadt
Prof. J. Eisele
Prof A. Joppin

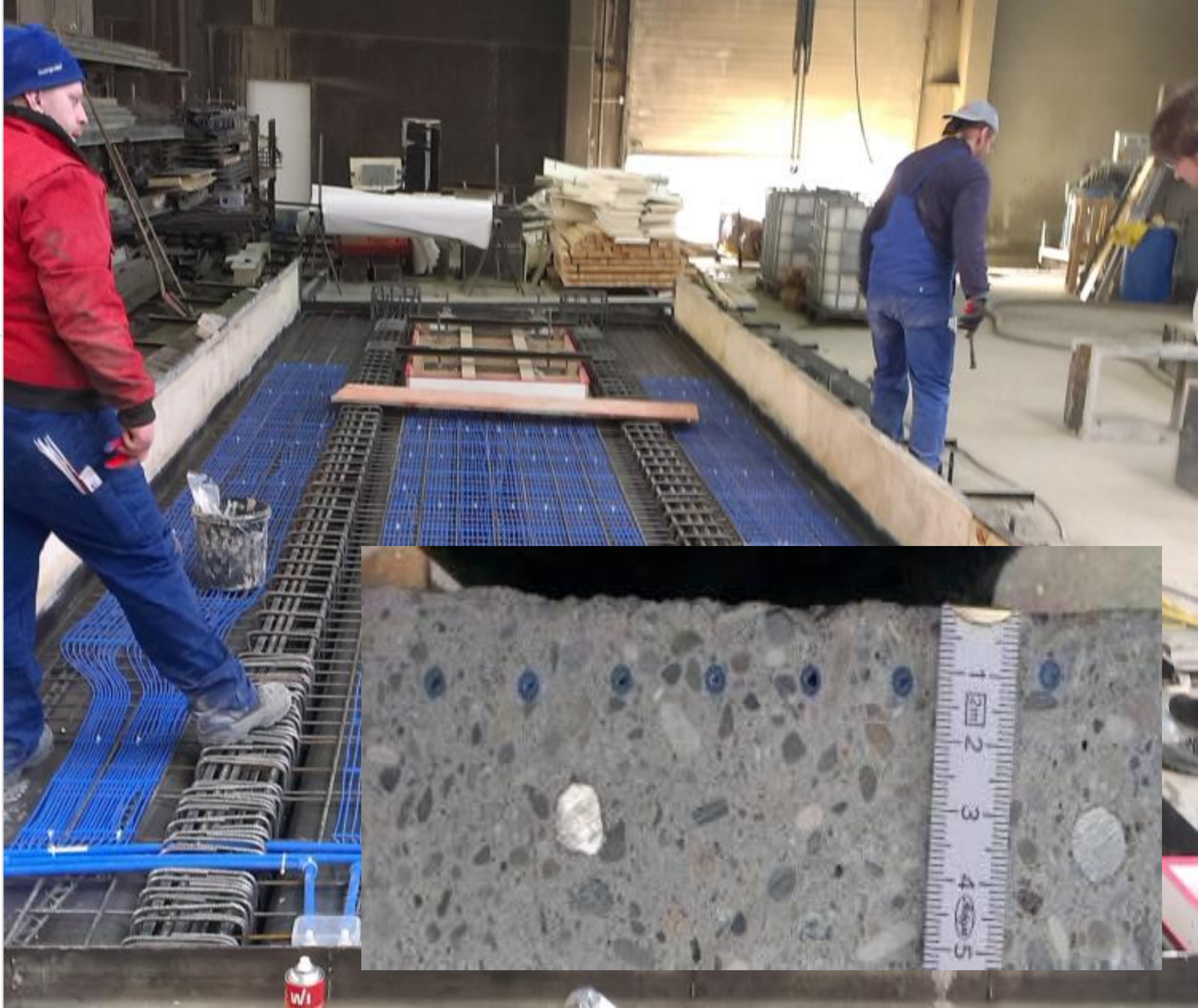


Façade Roadmap

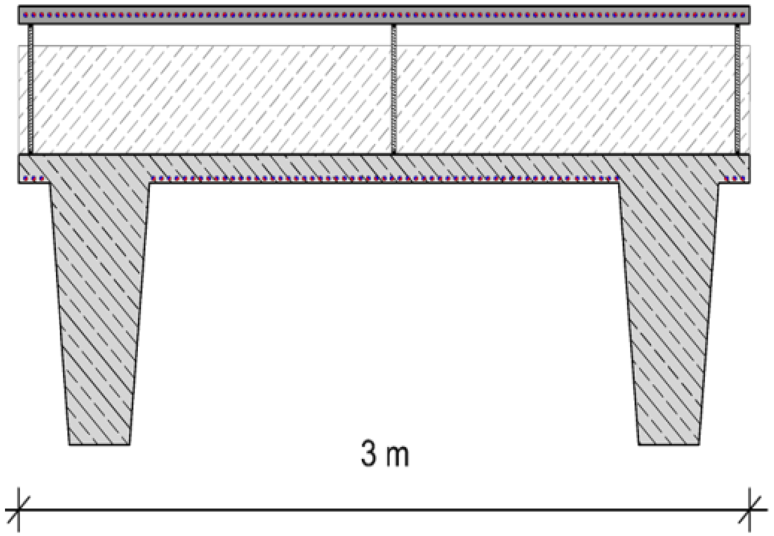


Façade Roadmap

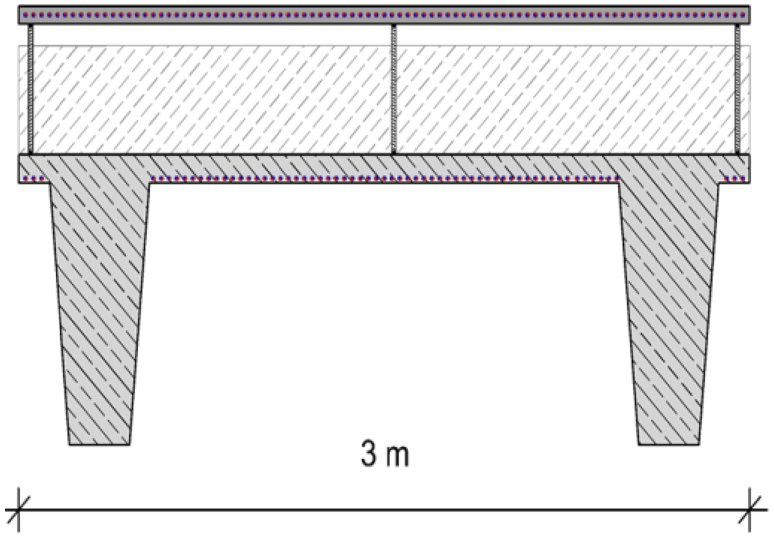


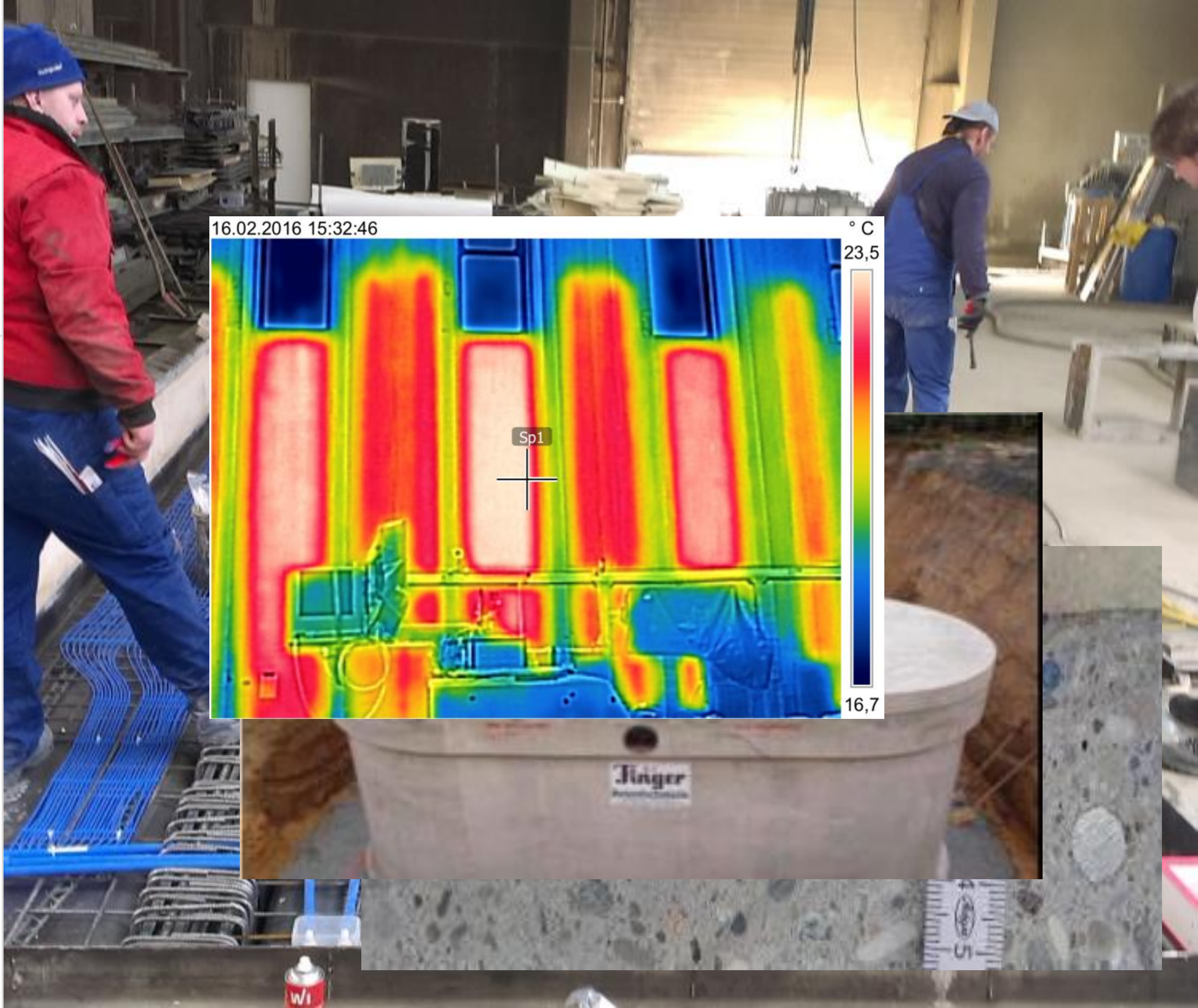


Façade Roadmap

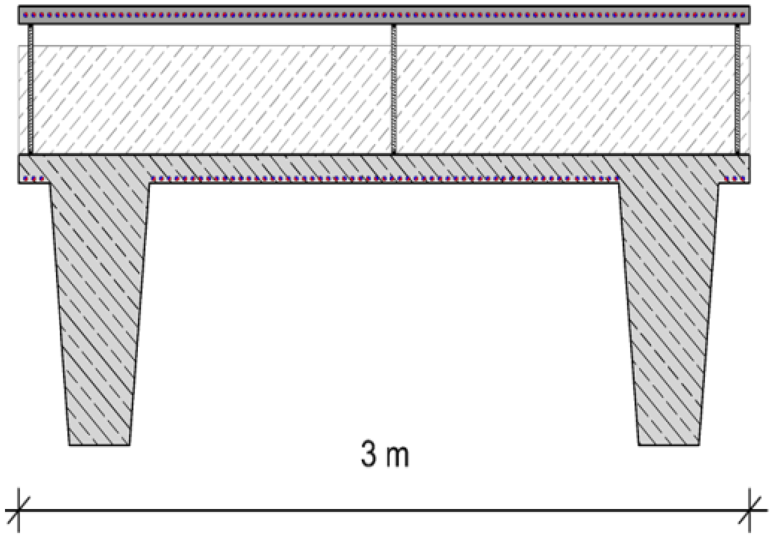


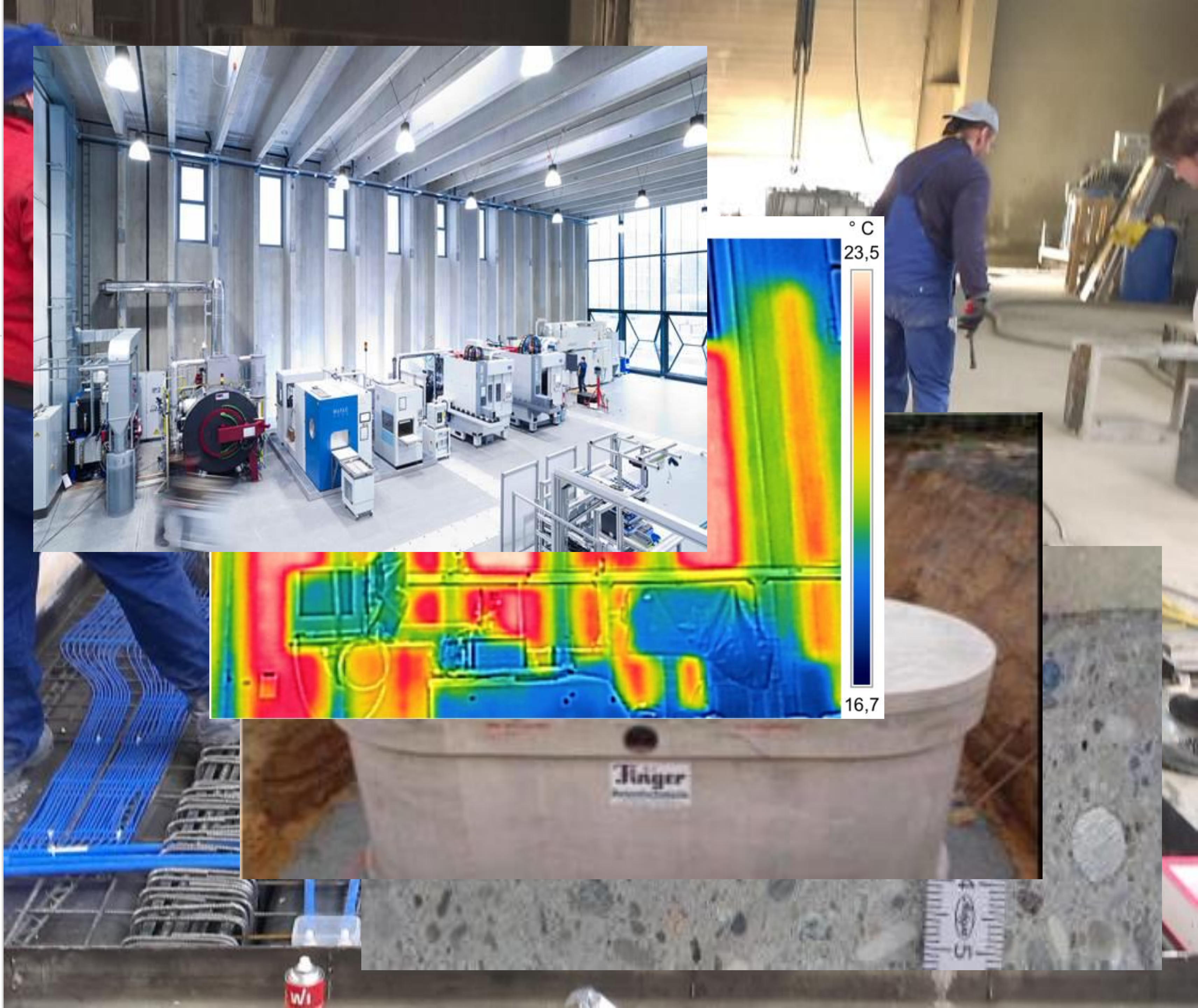
Façade Roadmap





Façade Roadmap

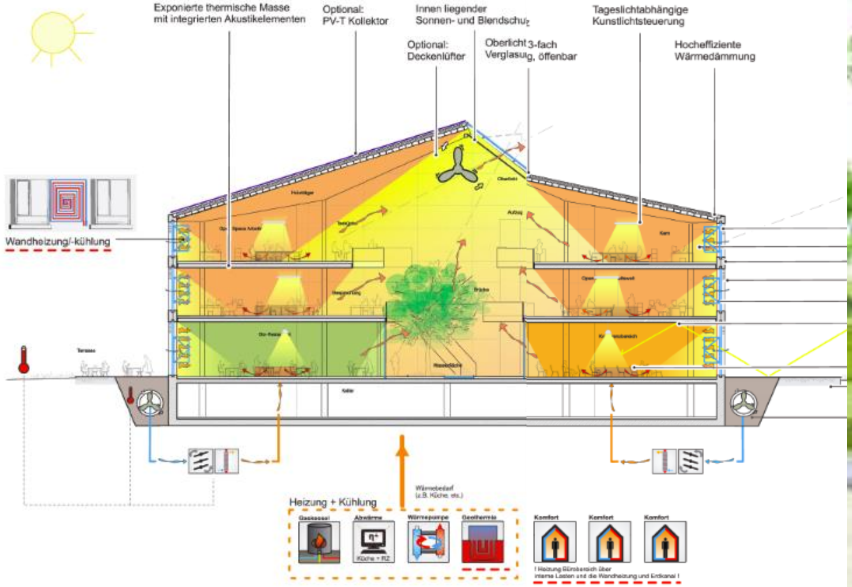




Façade Roadmap

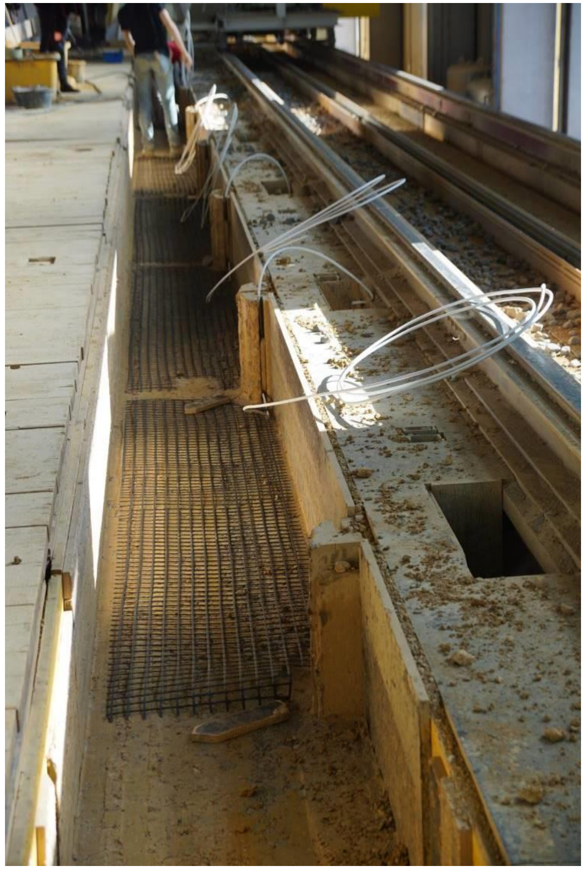
Alnatura / Darmstadt

Studio 2050 mit Transsolar und Knipper Helwig

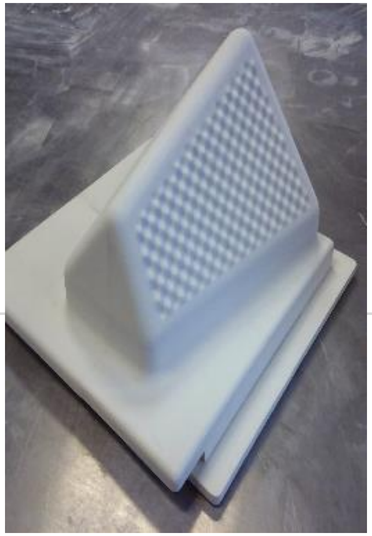


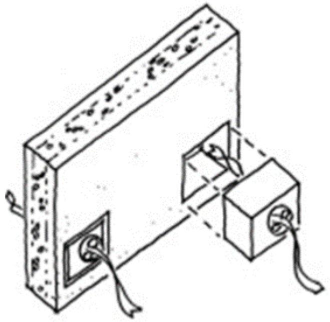
Façade Roadmap

Façade Roadmap

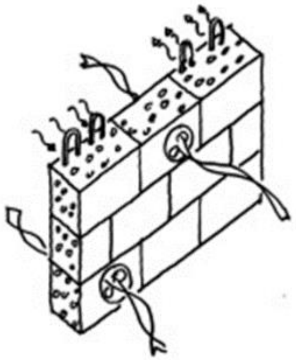


Façade Roadmap

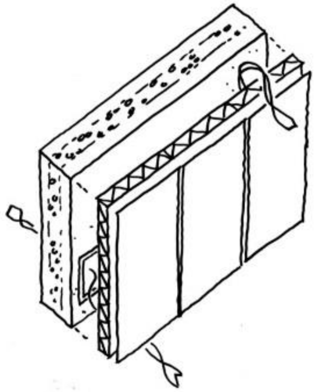




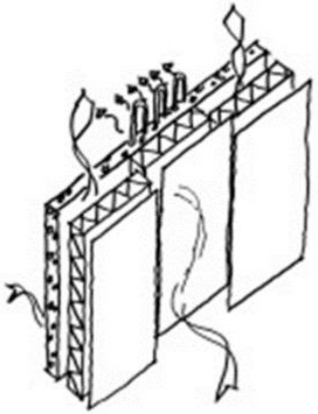
Single layered light massive enveloper with services integrated



Full services and energy collection integrated in light massive enveloper

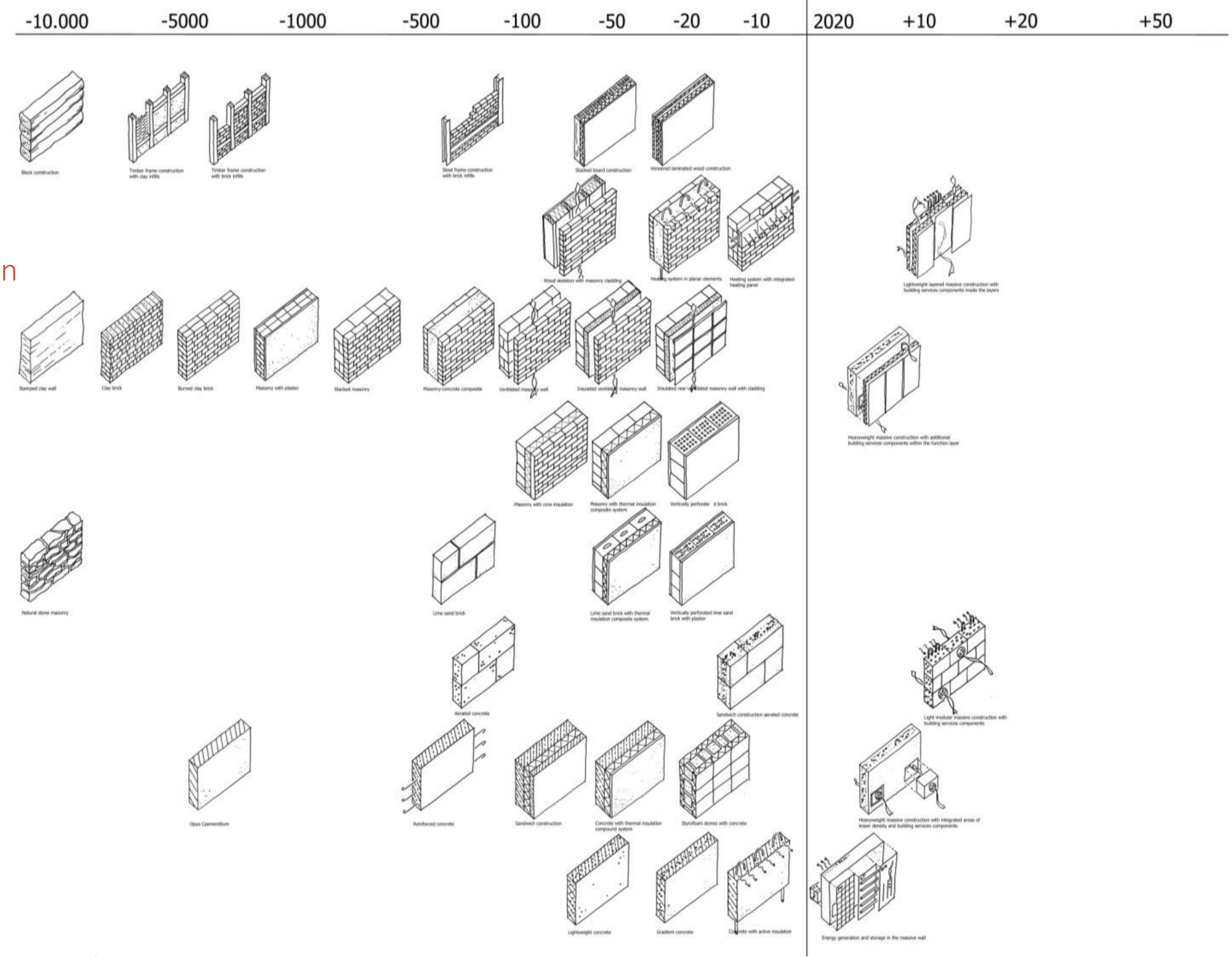


Light massive envelope with separate and demountable cladding



Light and fully demountabel massive envelope

Façade Roadmap Solid Construction



Symposium “High Performance Building Envelopes”

¤ The Dutch government aims for a **climate-neutral built environment in 2050**. Renovation of the existing building stock is essential in realizing this ambition as the market needs to prepare for delivering 200,000 high performance renovations per year. This requires, among others the development of affordable renovation solutions, enabling the transition toward a fully sustainable energy supply and a fast renovation process.

¤ Adapting the building envelope is an important element for this transition. This implies improving the **thermal performance of the envelop** (lower energy losses through better insulation, better windows, etc.) as well **actively utilizing the envelop for the production of renewable energy**.

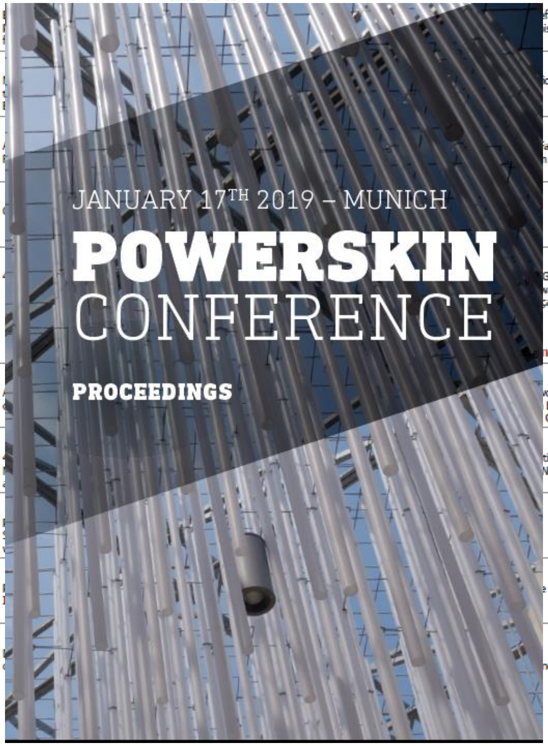
¤ Various smart solutions for the building envelope were developed in the last couple of year and the key question is: **how can we scale up these projects** to contribute **to delivering 200,000 high performance renovations per year**?

¤ At this symposium we will discuss:
o What are promising concepts and developments?
o What is needed to scale up these concepts?
o Which innovations are needed to reduce costs?
o How can robotisation and digitization contribute to development of affordable renovation?
o What process innovation do we need in the construction chain?

Powerskin 2019

ENVIRONMENT ROOM C 61			ENVELOPE ROOM C 62 a			ENERGY ROOM C 62 b		
Session I Chairman Prof. Dr.-Ing. Ulrich Knaack			Session I Chairman Prof. Dr.-Ing. Jens Schneider			Session I Chairman Prof. Dipl.-Ing. Thomas Auer		
11:30 - 11: 50			11:30 - 11: 50			11:30 - 11: 50		
Auxetic Structures and Advanced Daylight Control Systems	Ph.D. Yun Kyu Yi	University of Illinois at Urbana-Champaign USA	Bio-inspired Transparent Microfluidic Platform as Transformable Networks for Solar Modulation	Asst. Prof. Ph.D. Mark Alston	University of Nottingham UK	Three Case Studies of a Prefabricated Window Element for Refurbishments	M.Sc. Vesna Pungercar	Technical University of Munich GER
11:50 - 12:10			11:50 - 12:10			11:50 - 12:10		
The Plug-n-Harvest Façade: A Second Skin with Active and Passive Components	M.Sc. Verena Dannapfel	RWTH Aachen University GER	Market Survey of Timber Prefabrica-ted Envelopes for New and Existing Buildings	Ph.D. Annalisa Andaloro	European Research Academy ITA	Fluidglass – The Energy Efficient Glass Façade	Prof. Dr.-Ing. Jochen Stopper	Technical University of Ap-plied Sciences Rosenheim GER
12:10 - 12:30			12:10 - 12:30			12:10 - 12:30		
Façades: Past, Present and Future – Marking 50 Years of Continuos Development	Ph.D. Justin Furness	FAECF UK	Automated Digital Workflows for Façade Detailing and Manufacturing	Dipl.-Ing. Martin Manegold	Imagine Computation GER	Active Moisture Control of Façades by Smart Ventilation System	Dr. Thomas Löwenstein	Deutsche Amphibolin-Werke GER
12:30 - 12:50			12:30 - 12:50			12:30 - 12:50		
Impacts on the Embodied Energy of Rammed Earth Façades During Production and Construction Stages	M.Sc. Lisa Nanz	Technical University of Munich GER	One-and-a-Half Skin Glass Façade	Prof. Dr. Alberto Raimondi	Università di Roma Tre ITA	A Study on the Impact of Climate Adaptive Building Shells on Indoor Comfort	M.Sc. Adele Ricci	University of Bologna ITA
12:50 - 13:10			12:50 - 13:10			12:50 - 13:10		
Comparative Overview on LCA Software Programs for Application in the Façade Design	M.A. Rebecca Bach	RWTH Aachen University GER	4D-Adaptive Textile Building Skin	M.Sc. Jan Serode	RWTH Aachen University GER	Reliability and Performance Gap of Whole-Building Energy Software Tools in Modelling Double Skin Façades	M.Sc. Elena Catto Lucchino	Norwegian University of Science and Technology NOR
Session II Chairman Prof. Dr. Alberto Raimondi			Session II Chairman Prof. Dr.-Ing. Frank Wellershoff			Session II Chairman Prof. Dr.-Ing. Madjid Madjidi		
14:00 - 14:20			14:00 - 14:20			14:00 - 14:20		
Novel Technologies to Assure As-Designed Solutions for Energy-Efficient Refurbishment Scenarios	Ph.D. Benedetta Marradi	University of Pisa ITA	ArKol – Development and Testing of Solar Thermal Venetian Blinds	Dipl.-Ing. Paul-Rouven Denz	Priedemann Facade-Lab GER	A Simulation-Based Framework Exploring the Controls for a Dynamic Façade with Electrochromic Glazing	Ph.D. Abolfazl Ganji Kheybari	TU Kaiserslautern GER
14:20 - 14:40			14:20 - 14:40			14:20 - 14:40		
SMP Prototype Design and Fabrication for Thermo-Responsive Façade Elements	Assoc. Prof. Jungwon Yoon	University of Seoul KOR	4dTEX – Exploration of Movement Mechanisms for 3D-Textiles Used as Solar Shading Devices	Prof. Dipl.-Ing. Claudia Lüling	Frankfurt University of Applied Sciences GER	Optimization of Twisted Vertical Louvers Based on Artificial Neural Networks	B.Sc. Liu Siwei	South China University of Technology CHN
14:40 - 15:00			14:40 - 15:00			14:40 - 15:00		
Materiality and Embodied Carbon Considerations in Contemporary Curtainwall Systems	Ph.D. Mic Patterson	Façade Tectonics Institute USA	Parametric Poetry - Integrated Solutions for Complex Geometries with Structure and Skin	M.A. Ragunath Vasudevan	Schneider + Schumacher Design & Computation GER	Parameters to Design Low-Tech Strategies	Dipl.-Ing. Elisabeth Endres	Ingenieurbüro Hausladen GER
15:00 - 15:20			15:00 - 15:20			15:00 - 15:20		
Adaptive Bricks: Potentials of Evapora-tive Cooling in Brick Building Envelopes to Enhance Urban Microclimate	Dr.-Ing. Philipp Molter	Technical University of Munich GER	Parametric Penrose Tiling – Innovative Exterior Shading Skins	Ph.D. Wilfried Laufs	Laufs Engineering Design GER	Trombe Curtain Wall Façade	Prof. Dr. Andreas Luible	Lucerne University of Applied Sciences and Art CHE
15:20 - 15:40			15:20 - 15:40			15:20 - 15:40		
A Visual Digital Tool to Assist the Concept Design of Façades	Ph.D. Giovanni Zemella	Arup UK	Development of a Holistic Performan-ce Approach for Façade Design	M.Sc. Sinem Kültür	Bahçeşehir University TUR	3D Heat Transfer Analysis: A Parametric Tool for Designers	M.Sc. Alessandro Baldini	Eckersley O'Callaghan UK

Powerskin 2019

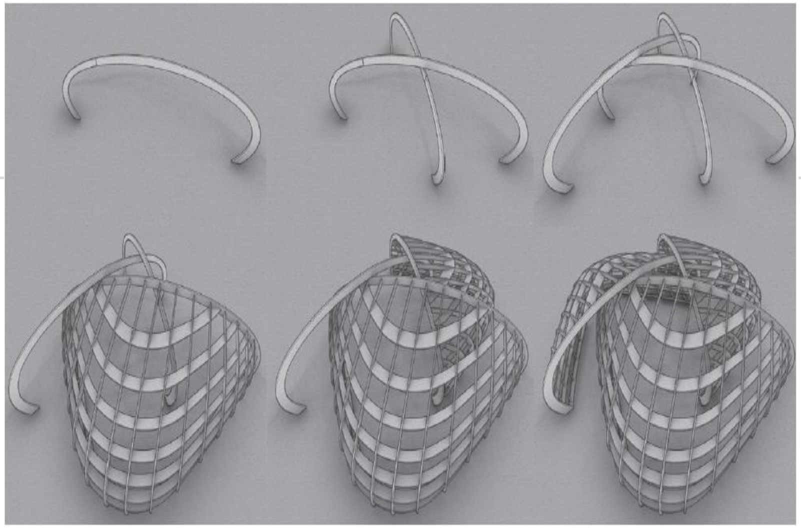


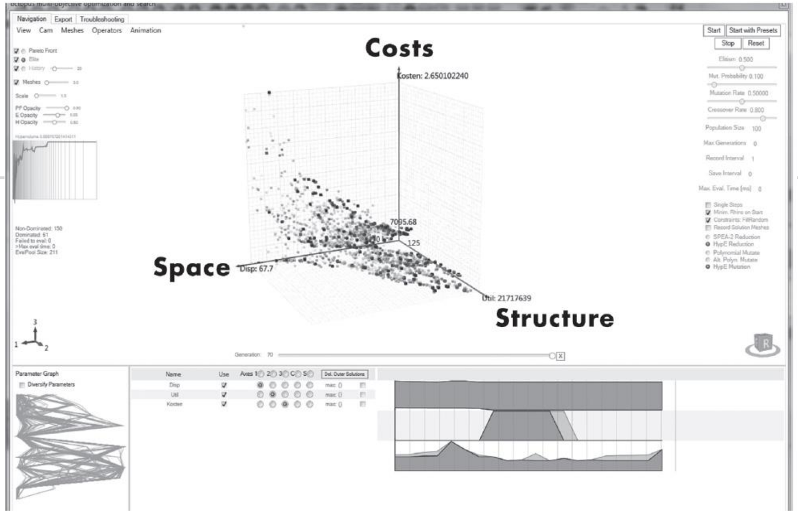
Session Envelope

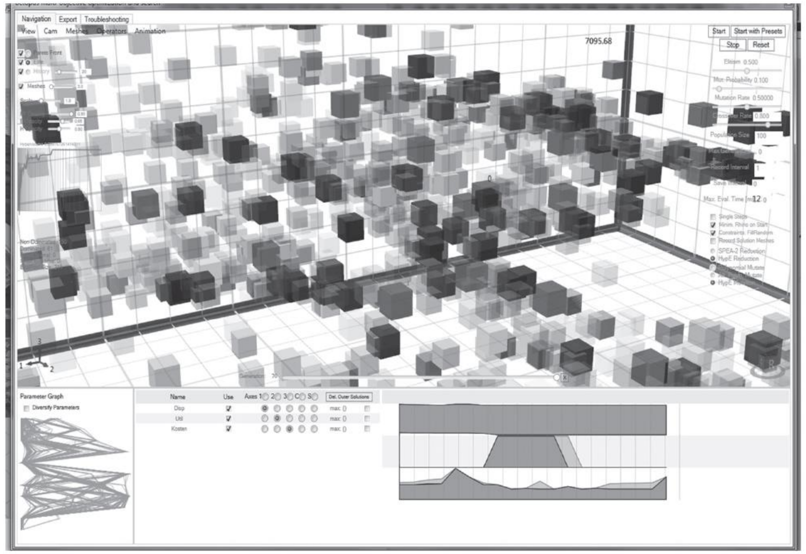
Parametric Poetry-Integrated Solutions for Complex Geometries with Structure and Skin

Ragunath Vasudevan[1], Till Schneider[2], Kai Otto[2], Klaus Bollinger[3], Andreas Rutschmann[3]

schneider+schumacher Design & Computation GbR, Frankfurt am Main, Germany, email: ragunath.vasudevan@schneider-schumacher.de
schneider+schumacher Planungsgesellschaft mbH, Frankfurt am Main, Germany
Bollinger+Grohmann Ingenieure GmbH, Frankfurt am Main, Germany





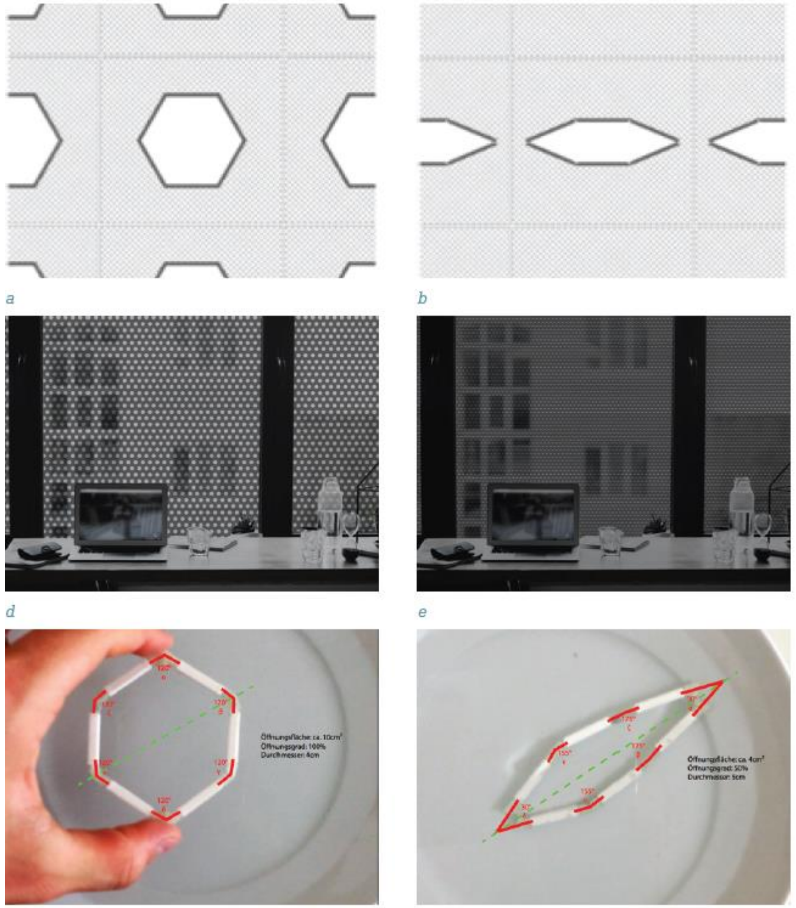


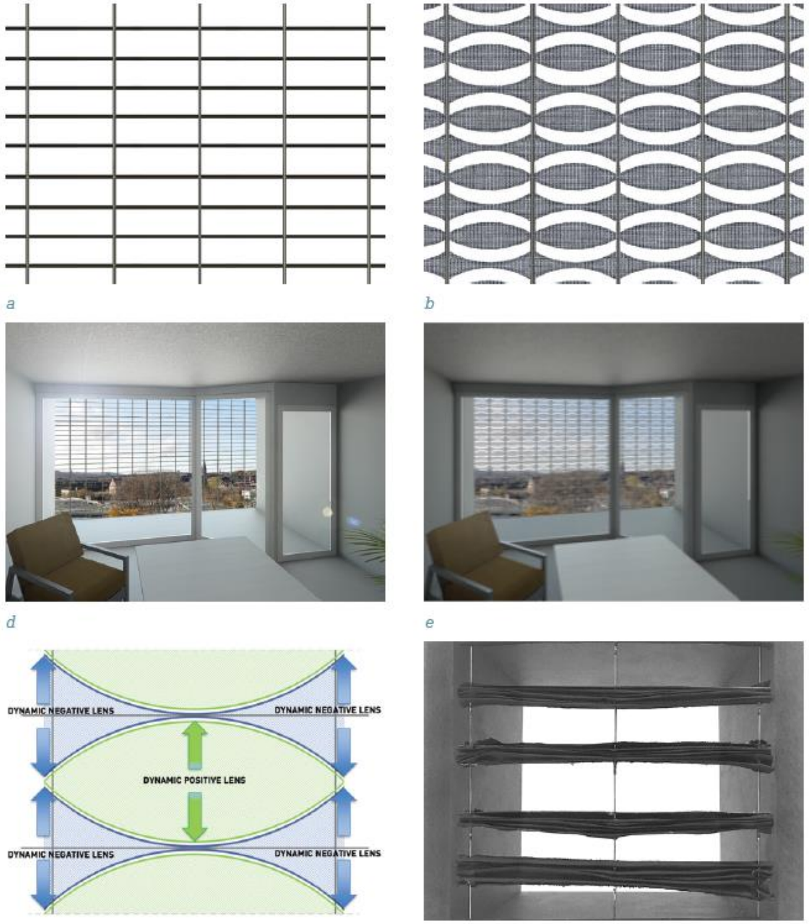
Session Envelope

4D Adaptive Textile Building Skin

Jan Serode[1], David Schmelzeisen[2], Philip Engelhardt[3], Sabine Baumgarten[4], Tibor Lohmann[4], Thomas Gries[2]

Institut für Textiltechnik (ITA), RWTH Aachen University, Aachen, Germany, email: jan.serode@ita.rwth-aachen.de
Institut für Textiltechnik (ITA), RWTH Aachen University, Aachen, Germany
Institute of Building Technology (GBT), RWTH Aachen University, Aachen, Germany
Clinic of Ophthalmology, RWTH Aachen University, Aachen, Germany



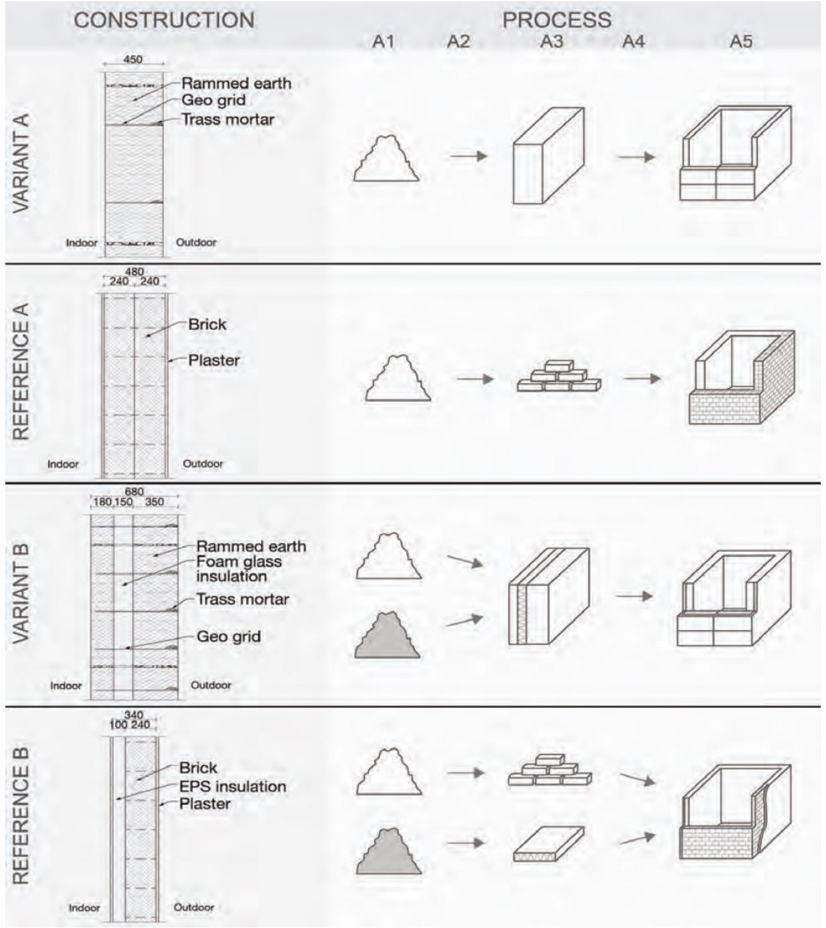


Session Environment

Impacts on the Embodied Energy of Rammed Earth Façades During Production and Construction Stages

Lisa Nanz[1], Martin Rauch[2], Thomas Honermann[2], Thomas Auer[1]

Chair of Building Technology and Climate Responsive Design, Technical University of Munich, Munich, Germany, lehrstuhl.klima@ar.tum.de
Lehm Ton Erde Baukunst, Schlins, Austria

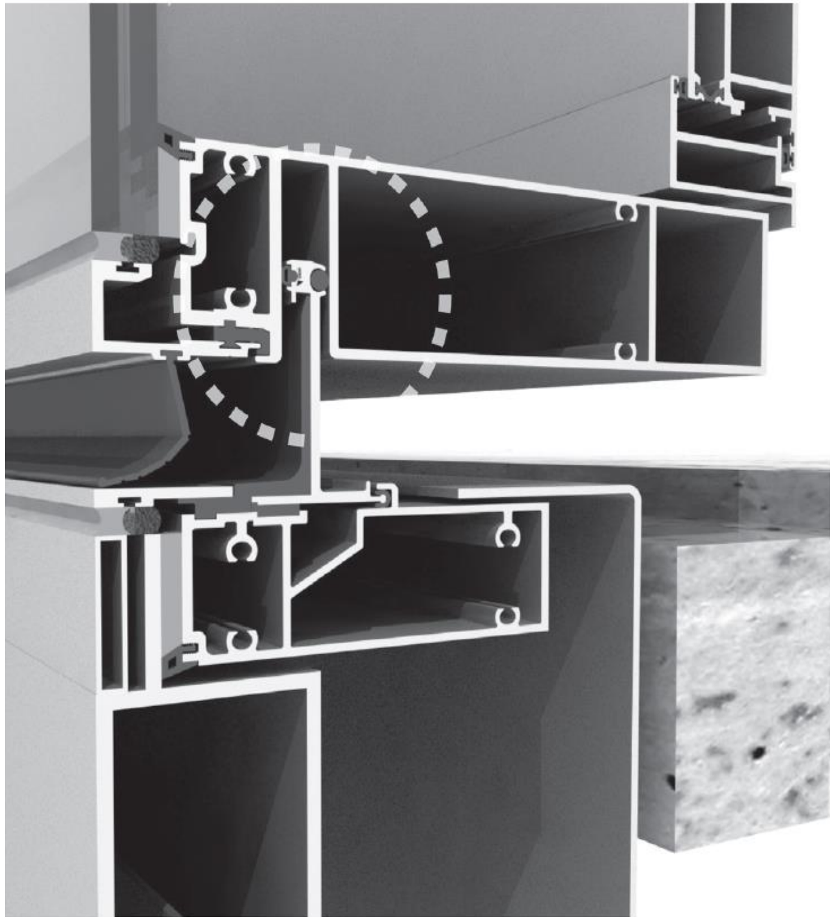


Session Environment

Materiality and Embodied Carbon Considerations in Contemporary Curtainwall Systems

Mic Patterson, PhD, LEED AP (BDC)[1]

Schüco-USA, Façade Tectonics Institute, Simi Valley, Canada, email: mpatterson@façadetectonics.org



4TU.Bouw
center of excellence for the built environment

TU Delft Delft University of Technology

TU/e Technische Universiteit Eindhoven University of Technology

UNIVERSITY OF TWENTE.

WAGENINGEN UNIVERSITY & RESEARCH

The next big thing - facades

RESEARCH 2014 – 2017

Lighthouse Projects
PDEng Projects
Research to Reality Projects

4TU.Bouw
center of excellence for the built environment

TU Delft Delft University of Technology

TU/e Technische Universiteit Eindhoven University of Technology

UNIVERSITY OF TWENTE.

WAGENINGEN UNIVERSITY & RESEARCH

The next big thing - facades

RESEARCH
2014 – 2017

Lighthouse Projects
PDEng Projects
Research to Reality Projects

RESEARCH TO REALITY
4TU.Bouw 2014 – 2017

EXPLORATION OF BUILDING INTEGRATED PHOTOVOLTAICS

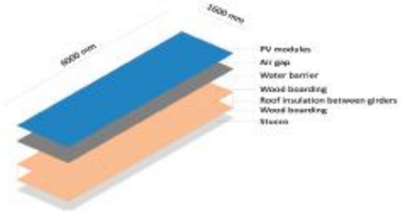
Applied solar cell in the BIPV field test.

EXPLORATION OF BUILDING INTEGRATED PHOTOVOLTAICS

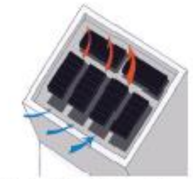
Within the EU, covering the whole life cycle of buildings, about 50% of extracted materials and 50% of all energy is consumed in the built environment. To lower collateral environmental impact, the EU has set a target to realize 27% energy efficiency improvement, 30% share of renewable energy, and 40% CO_2 emission reduction by 2030. This has been translated in legislation that by the end of 2020, all new buildings have to be nearly Zero Energy Buildings (nZEB).

To realize a nZEB, two measures are typically applied, entailing a decrease of operational energy demand, mainly by adding building components such as insulation packages, and an increase of energy generation, mainly by adding or integrating energy generating devices. Consequently, material related environmental impact might create a collateral disproportionate burden, which is not well addressed in current assessment methods.

The aim of this research is to develop a framework for environmental impact assessment of Building Integrated Photovoltaic rooftop solutions, expressed in the claim on carrying capacity, based on theoretical data and collected data from a BIPV field test. The objective is to apply the framework to a BIPV field test and to develop an optimized BIPV rooftop element for this specific case based on assessment and possibly ranking of a generated set of alternatives.



BIPV rooftop field test roof element.



BIPV rooftop field test with indicative ventilation.

BIPV rooftop field test in The District of Tomorrow.

Eindhoven University of Technology
M.J. Ritzen

Zuyd University of Applied Sciences
R. Rovers, Z.A.E.P. Vroon

TNO
C.P.W. Geurts

NWO

CONVECTIVE CONCRETE

CONVECTIVE CONCRETE

Convective Concrete is about a research-driven design process of an innovative thermal mass concept. The goal is to improve building energy efficiency and comfort levels by addressing some of the shortcomings of conventional building slabs with high thermal storage capacity. Such heavyweight constructions tend to have a slow response time and do not make use of the available thermal mass effectively. Convective Concrete explores new ways of using thermal mass in buildings more intelligently. To accomplish this on-demand charging of thermal mass, a network of ducts and fans is embedded in the concrete wall element. This is done by developing customized formwork elements in combination with advanced concrete mixtures. To achieve an efficient airflow rate, the embedded lost formwork and the concrete itself function like a lung.

The use of thermal mass is usually considered as an effective strategy for achieving energy efficient building designs with high thermal comfort levels. This is normally done by applying construction types with high thermal storage capacity (e.g. concrete) on the inside of the thermal insulation layer. Such heavyweight constructions have a slow response time. This thermal inertia helps to flatten temperature peaks, but the slow response is not advantageous at all times. Due to a lack of control possibilities regarding when and how much energy to exchange between interior zones and the constructions with thermal mass, these dynamic effects may also increase heating and cooling energy demand during intermittent operation or can cause unwanted discomfort, either due to too cold surface temperatures when the building is already occupied on winter mornings,

or because the accumulated heat can sometimes not be sufficiently released, leading to potential indoor overheating issues in summer. Another shortcoming of thick concrete slabs is that only a small part of the heavyweight material (usually the first few centimeters) plays a role in storing thermal energy effectively. This is a missed opportunity.

Water as Transport Medium

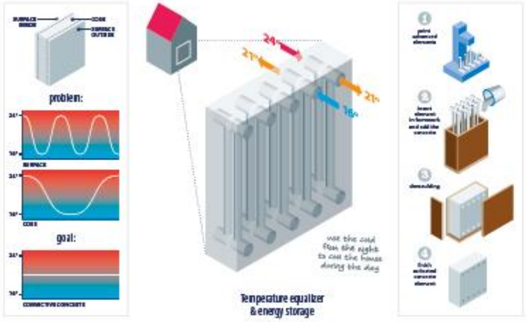
Convective Concrete initially targets the residential building market. The goal is to mitigate residential overheating during summer periods by reducing the temperature of constructions through active heat exchange between the building construction (hollow-core concrete slabs) and cool outside air at night. Even though air has a relatively low volumetric heat storage capacity compared to e.g. water, it is used as a transport medium in this project, because of:

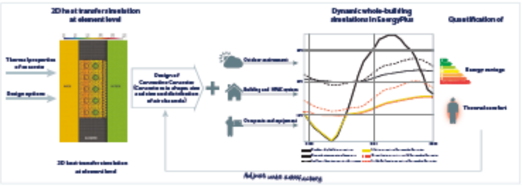
- Its widespread availability at favorable temperatures
- Can be combined with earth tubes
- Easy construction and installation process: plug-and-play
- Provides standalone elements that do not need to be connected to additional systems
- Can function passively without mechanically forced convection due to the buoyancy effect
- No risk of leakages, punctures or frost damage
- Low weight and therefore less structural requirements

To accomplish the on-demand charging of thermal mass, a network of ducts with attached fans, needs to be embedded in the concrete wall element. The fans act as back-up to the buoyancy effect to ensure a sufficient amount of air flowing through the wall. This is done by developing customized formwork elements in combination with advanced concrete mixtures.

Additive Manufacturing (AM) is researched, because it is a good method for this kind of rapid prototyping. Customized and free-form parts can be produced easily. AM of lost formwork differs from the approach of direct concrete printing, but allows for a traditional processing of the concrete itself. To benefit most from AM as production technology, the free-form and customized parts needed for the Convective Concrete are printed in wax, using Fused Deposition Modeling (FDM), an AM process based on material extrusion, that can be melted after the concrete is hardened. The building volume and resolution of FDM printers can be adapted to the desired size and layer thickness easily. However, for the first prototypes wax casting was used.

To achieve an efficient convective flow, the embedded lost formwork and the concrete itself should function like a lung. The convection takes place with separate pipes on both sides of the concrete's core to increase the charge/discharge of the thermal storage process with help of fans, in the event of lack of buoyancy effect and with the help of valves, to control when the slabs are ventilated. There will not be any openings through the slabs themselves, because that would cause thermal bridges. The concrete mixture with matching characteristics (density, porosity and lambda value) will be fabricated on the basis of input from computational simulations.





Delft University of Technology
Dennis de Witte MSc.,
prof.Dr.-Ing Ulrich Knaack

Eindhoven University of Technology
Marie de Klijn-Chevalerias MSc.,
ir. Roel Loonen,
prof.dr.ir. Jan Hensen

G.tecz
Dr.-Ing Gregor Zimmermann

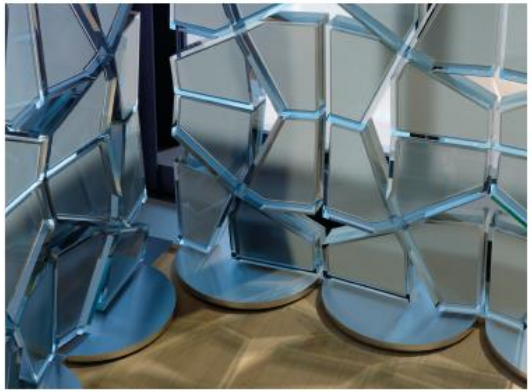
Results

As soon as the outcomes of the simulations match the physical models, parametric models can be designed, after which optimized internal formwork for the Convective Concrete can be printed and the façade and internal walls can be applied in the built environment. The final product can be in the form of a prefabricated concrete slabs, but also in the form of the inserts itself that is are placed embedded in the on-site built formwork.building volume and resolution of FDM printers can be adapted to the desired size and layer thickness easily. However, for the first prototypes wax casting was used.

To achieve an efficient convective flow, the embedded lost formwork and the concrete itself should function like a lung. The convection takes place with separate pipes on both sides of the concrete's core to increase the charge/discharge of the thermal storage process with help of fans, in the event of lack of buoyancy effect and with the help of valves, to control when the slabs are ventilated. There will not be any openings through the slabs themselves, because that would cause thermal bridges. The concrete mixture with matching characteristics (density, porosity and lambda value) will be fabricated based on input from computational simulations.

As soon as the outcomes of the simulations match the physical models, parametric models can be designed, after which optimized internal formwork for the Convective Concrete can be printed and the façade and internal walls can be applied in the built environment. The final product can be in the form of a prefabricated concrete slabs, but also in the form of the inserts itself that is are placed embedded in the on-site built formwork.

DOUBLEFACE



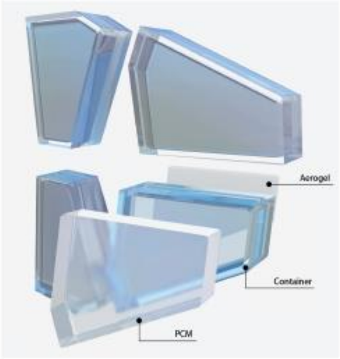
DOUBLEFACE

The DoubleFace project aimed at developing a new product that passively improves thermal comfort of indoor and semi-indoor spaces by means of lightweight materials for latent heat storage, while simultaneously allowing daylight to pass through as much as possible. Specifically, the project aimed at designing and prototyping an adjustable translucent modular system featuring thermal insulation and thermal absorption in a calibrated manner, which is adjustable according to different heat loads during summer- and wintertime. The output consists of a proof of concept, a series of performance simulations and measurement and a prototype of an adjustable thermal mass system based on lightweight and translucent materials: phase-changing materials (PCM) for latent heat storage and translucent aerogel particles for thermal insulation.

The system is based on an innovative approach to thermal principles of Trombe walls. As compared to traditional Trombe walls, the system is about five times lighter than traditional Trombe walls to avoid structural overloads in buildings; is translucent in order to benefit from daylight; and is adaptive in order to calibrate the thermal effects.

Lightness and translucency are achieved by means of the applied materials. Instead of using heavy and opaque materials like concrete, a novel application of PCM and aerogel is proposed. Several products and technical systems are currently available on the market for applying PCM by integrating them into walls, containers, or ventilations systems or in facades. Double Face proposes a system based on interior design elements, taking advantage of the dynamic behaviour of PCM as well as its appearance. As such, the system is also meant to contribute to aesthetical design criteria in the design of interiors. The elements are translucent; are meant to be located in front of a (full) glass façade, where the largest heat impact from outside happens to be; and can be developed into various design options for new buildings as well as retrofitted into already existing buildings. Additionally, the system is adaptive to enhance the thermal benefits. Exposing thermal mass to winter solar radiation (passive heat gain) and protecting it from the summer one (passive cooling) and therefore acting as thermal buffer. This happens by rotating the elements towards the source of incoming heat or the sink for heat release. In winter, the PCM side would face the exterior and be thermally charged during the day by the low winter sun. During night times, oriented towards the interior, it releases the accumulated heat. In summer, during the day in combination with external sun shading, it would store the heat from interior heat loads and during the night release this heat to the outside environment by means of night ventilation, thus acting as a cooling plate.

The research process started with a wide inventory of existing PCM; an analysis of their properties; and a consequent short-list of selected materials. For each of the selected PCM, digital simulations were conducted to analyse the thermal behaviour. They were conducted for single layers of PCM in various thicknesses; and for combinations of two layers, one of PCM in various thicknesses and one of translucent insulation, also in various thicknesses. The translucent insulation was simulated as a layer of Aerogel; and as a system of cavities trapping air within a translucent 3D printed material. Based on the digital simulations, the system of layers was pre-dimensioned for a total thickness of 7cm (5 cm PCM, 1 cm aerogel and 1 cm container wall thickness). Several samples (17x17x7cm) were made for a number of selected PCM. These samples were tested in the laboratory for Building Physics at Eindhoven University of Technology for their thermal behaviour; and at Delft University of Technology for their light transmittance. The measurements



Delft University of Technology
dr.Arch. Michela Turrin,
dr.ir. Martin Tenpierik,
ir. Paul de Ruiter, ir. Wilfried Meijer,
dr.ir. Willem van der Spoel,
Carlos Alfredo Chang Lara

Eindhoven University of Technology
dipl.-ing. Florian Heinzelmann,
prof.Dr.-Ing. Patrick Teuffel,
ing. Wout van Bommel

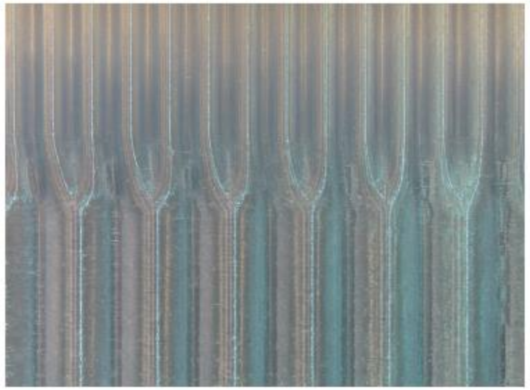
allowed for fine-tuning the dimensions as well as for narrowing down the list of selected materials. As a result, PCM thickness was reduced to 4 cm. Furthermore, using the measured properties as input, simulations of the thermal behaviour of a standard room equipped with this Trombe wall system were run in DesignBuilder to study several variations including PCM layer thickness, insulation layer thickness, extra cavities and percentage of holes in the wall. These simulations showed that an opening percentage of roughly 10% was ideal for this Trombe wall system. Because of the limitations of simulating the rotation of the wall panels, a new simulation model was developed in Matlab/Simulink. These new simulations, which included the rotation, showed that the adjustable Trombe wall system leads to an energy reduction of roughly 40% as compared to the 'no Trombe wall situation'.

Parallel to the research, several design alternatives were drafted, based on the thermal principles. For this project, one design option was chosen to be developed and prototyped. The option shows the potential of exposed technical systems contributing to aesthetical design criteria within interior design, while remaining within feasibility constraints to realize a prototype within the timeline of the project. To realize the prototype, the translucent container for the layers of PCM and insulation, additive manufacturing was considered initially, to cope with the complexity of the form. A number of tests were made by 3D-printing translucent PLA and PET via the rather cost effective filament fused deposition modelling (FDM) method. However, considering the challenge of obtaining translucent parts that have high structural strength and maximum light transmittance without the need of falling back to expensive 3D printing techniques (like Stereolithography), additive manufacturing was later used only to produce moulds to cast transparent resin, in order to get a more glass-like appearance. An option for a laser-cut transparent sheet of Perspex was developed, leading to satisfactory results as well.

The thermal behaviour of the prototype is now being measured using heat-flow sensors and thermocouples at Delft University of Technology. Additionally, further performance simulations are being run in order to model the behaviour of the modular and adaptive system under different climate conditions and in various room environments. Current simulations include fine-tuning of the rotation schedule of the elements to orient the insulation according to contingent conditions (day/night – winter/summer).

The ambitions of the team include tuning this prototype and exploring other design alternatives, for which further development and testing are intended. Several companies have been contacted during the process especially regarding existing PCM and their architectural applications.

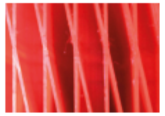
SPONG3D

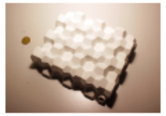


SPONG3D

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.





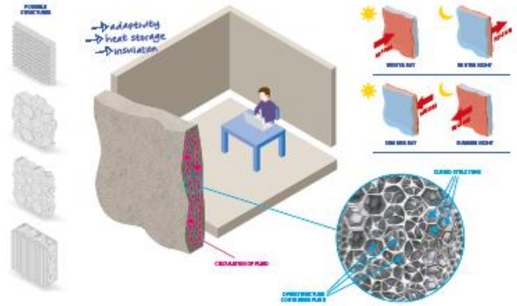
The development of the proof of concept was organized according to sub-goals. First, the research aimed at understanding and quantifying the thermal potentials of the 3d printed porous structures; enhancing their capacity for thermal insulation and heat storage. Moreover, the research discovered additional 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 to maximize thermal insulation, allow appropriate heat absorption in the liquids, minimize the flow resistance, achieve acceptable water tightness and minimize the production time. 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 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 polyhedral, which performed well for thermal criteria and structural robustness, but caused challenges regarding the printing process. To reduce the time required for the printing process and the risk of possible failures during production, the size of the cells was 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 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 regards 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 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
ing. Maria Valentini Sarakinioti MSc.,
dr.MArch. Michela Turrin,
MArch. M. Teeling, ir. Paul de Ruiter,
Mark van Erk,
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, Bas Vorstermans,
Elise Dolkemade, Marie de Klijn MSc.,
ir. Roel Loonen, prof.dr.ir. Jan Hensen

KIWI Solutions
Dick Vlasblom

DOUBLE CURVED 3D CONCRETE PRINTING

DOUBLE CURVED 3D CONCRETE PRINTING

It is no secret that there have been some great advances in the realm of concrete additive manufacturing. However, one of the major drawbacks of this fabrication technique is that the elements must be self-supporting during printing. While most other additive manufacturing materials can overcome this by using a secondary printed support structure, alternative strategies must be developed for materials such as concrete.

This 4TU project explores the possibilities of combining concrete additive manufacturing with a temporary support surface. By printing on a free-form surface, more intricate geometries can be realized. Several potential applications have been outlined, however the principle focus is combining concrete additive manufacturing and casting. The end result is a partially-printed pavilion using a completely digital design-to-fabrication workflow.

Although additive manufacturing (AM) is a fabrication technique which has been around for the past 20 years or so, it is only now that we are starting to see its applications emerge into the built environment. Whilst metals, plastics and other composite materials are also being explored for their use in the Built environment, it is concrete that shows great potential for large-scale additive manufacturing. Concrete Printing techniques already allow for the rapid fabrication of large-scale structures with minimal material waste, as already exhibited by Winsun and the fabrication of 1,100 Sqm Apartments in Jiangsu, China.

Whilst this does indeed allow for the rapid fabrication of concrete structures, most elements printed remain as 2.5D rather than 3D. This is due to the fact that extruded material must be self-supporting during printing in order to avoid collapse, imposing somewhat of a geometrical restriction. Most other printing materials can overcome this by printing a temporary support structure, however this is not the case with fluid materials such as concrete. Instead, a temporary surface is proposed as a means of support to printed concrete.

The adaptable mould developed at TU Delft served to provide such a surface. Consisting of a silicone surface connected to a bed of adjustable pins, double-curved surfaces can be produced in a similar fashion to milled surfaces. The main difference being that no material waste is generated since new surfaces are defined by adjusting the pin-bed. Prior to the 4TU Project, this system was used for casting free-form concrete panels. The combination 3D concrete printing and an adaptable mould resulted in a hybrid manufacturing technique consisting of two complimentary fabrication techniques.

Three Potential areas of research were identified through this combination. Firstly, the potential for fully-printed concrete panels. For this, It is proposed to use differential growth algorithms to generate print paths over any given surface. The second potential identified was the printing of structural ribs following stress-lines to provide reinforcement to panels. However, the chosen theme was a combination of 3D Printing and casting concrete. In this, complex geometries are defined by printing a boundary into which concrete is cast. The advantage to this approach is that complex, free-form concrete panels can be realized without the need for complicated moulding systems.

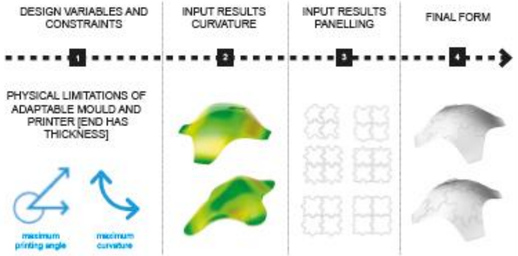
Design Overview

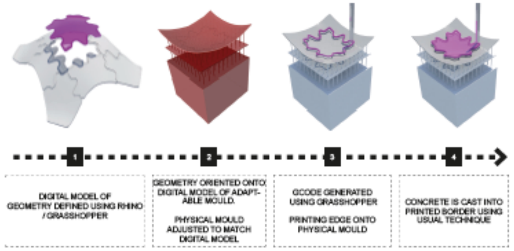
In order to study the proposed manufacturing concept, a shell structure consisting of complex interlocking geometry was designed and printed. The basic principle of realizing the design consists of first creating a digital model of the structure using parametric design tools. Each individual panel is then digitally oriented onto an adaptable mould and G-code is generated by dividing splines that define the perimeter of the object. Once the physical mould is adjusted to match the digital mould, the Gcode is sent to the printer and the geometry is printed. Finally, concrete is cast into the printed shape and left to cure for 24 hours after which it is demoulded.

Fabrication Process

Both the 3D Printer and adaptable mould have their own set of physical limitations. Thus, a number of variables and constraints were set by studying the two technologies. Firstly, the maximum slope angle on which concrete can be printed was found to be 40 Degrees, after which material had a tendency to curl up and distort. This value was used to limit the maximum curvature of the form-found shell structure. Due to the printer's incapability to print right angles, a minimum turning radius was also determined and was used to generate the tessellations for printed geometry. The end result is a 2.5 m x 2.5 m shell with a maximum slope of 35 degrees and minimum turning radius of 150 mm, consisting of a total of 9 Print-And-Cast panels.

In order to have a design process which consists out of one single file from design to fabrication, a custom g-code generator was created using Grasshopper 3D. This was also necessary because slicing techniques used in traditional additive manufacturing could not be used since a later-wise approach was not used. Instead, the geometry is defined as a spline and is divided into a number of points depending on curvature of the curve. These points are then expressed in terms of their relative co-ordinates and communicated with the Printer. An additional bespoke script was generated to take into account collisions of the Printer Nozzle with the Surface.





This was required because printing was not done perpendicular to the surface meaning that the physical nozzle had a tendency to collide with steep surfaces. The way this was corrected was by determining the intersection between the nozzle and surface at every co-ordinate and raising the point such that no intersections occurred. The corrected print path is then defined by interpolating the raised points which is then converted into G-Code.

Final Structure

The final structure is printed in a single print pass taking approximately 20 minutes to complete as shown in the image below. After the individual panels are printed, plasticizer is mixed in with printed concrete and cast inside the panels. These are left to cure for 24 hours and demoulded as an inverted shell structure. This is later temporarily propped up and held together through mortar joints.

Delft University of Technology
dr.ir. Roel Schipper,
Chris Borg Costanzi MSc.

Eindhoven University of Technology
dr.ir. Freek Bos,
Zeeshan Ahmed MSc.,
Rob Wolfs MSc.

Challenges and Conclusions

The project was limited to a relatively small 2.5 m x 2.5 m shell structure and the geometries printed were kept relatively simple to focus on refining the design process. However, given that the physical constraints of the printing process have been established it is easily imaginable that scalability and increase of geometrical complexity can be achieved if boundary conditions are maintained. Moreover, the project focused on combining printing and casting, however other directions such as generating print paths which follow stress-lines could serve as future areas of research using the same basic design process.

OPTIMISING 3D CONCRETE PRINTING

OPTIMISING 3D CONCRETE PRINTING

The application of new Computer Aided Manufacturing (CAM), digital fabrication and additive manufacturing techniques in the construction industries is expected to bring major change to these industries. Driven by a foreseen reduction of construction time and labor cost, simplification of logistics and an increase of constructible geometrical freedom, many experiments are performed both at academia and in practice.

Beyond these economical and architectural objectives, digital fabrication in construction can be used to reduce the environmental footprint of the industry. The increased level of control offered by digital fabrication enables the use of advanced computational optimisation techniques. With these optimisation techniques buildings can be designed which, for instance, combine an optimal thermal performance with a minimum use of materials, while still complying with all codes and standards.

To fully utilise this potential of digital fabrication, the capabilities and limitations of the manufacturing process need to be taken into account during optimisation. By combining the concrete 3D printing knowledge of Eindhoven University of Technology, the optimisation expertise of the BEMNext lab at Delft University of Technology and software development by White Lioness technologies, the 'Optimising 3D concrete printing' Lighthouse project has made the first steps towards more knowledge on integrated optimisation and manufacturing.

Context

Additive Manufacturing (AM) techniques are employed to overcome limitations of traditional manufacturing in terms of precision and/or constructability and allow for application of digital fabrication on a multitude of scales and materials. The difference between an object on a designer's screen and the physical, manufactured artifact can be orders of magnitude smaller with an additive manufacturing powered process in comparison to a conventional manufacturing process.

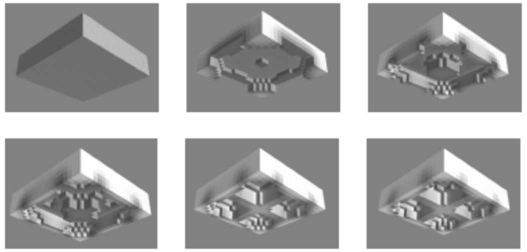
It is this narrowing of the gap between computational design and physical artifact which enables better use of advanced optimisation techniques in design. For years optimisation algorithms have been used to acquire the best performing designs, with respect to different metrics, whilst still complying with standards and regulations. A common example is a minimisation of material used, for which topology optimisation algorithms are well suited.

One of the main limitations on the widespread adoption of optimisation in the construction industries lies in the conditions on the construction site. As optimised designs often approach the boundaries of what is possible or allowed, they are more vulnerable to construction errors. Additionally, the scale on which the geometry can be optimised is limited by the often manual process employed on the construction site.

By use of additive manufacturing in construction some of the main limitations on use of design optimisation can be removed, enabling the design and construction of further optimised, more environmentally friendly buildings and infrastructure.

Project

The 4TU.Bouw Lighthouse project on "Optimising 3D concrete printing" aims to make the first steps towards an environment in which geometries can be optimised whilst taking the properties and limitations of a 3D concrete printer and the resulting material properties into account. These additive manufacturing specific features are key to ensuring the optimised geometry can indeed be printed and that the resulting artifact behaves as expected. Once again, as optimised geometries are often on the limit of the materials potential, the correctly modelled behaviour is even more important in optimisation than in conventional design techniques.



Printer Properties

Whilst additive manufacturing has an increased geometrical freedom in comparison with many conventional construction techniques, there still are boundaries to what can and cannot be printed. In the "Optimising 3D concrete printing" project the following aspects are identified and considered:

- Vertical cantilevering angle between layers
  Without the use of a support material the layers can only cantilever a few degrees, both in the printing direction, as well as perpendicular to that direction.
- Printing direction
  In this project, the printing direction is kept constant. Layers are printed next to each other and on top of each other.
- Nozzle width and layer height
  The nozzle width and the layer height can be chosen at the start of the optimisation.

As the actual values of these parameters are printer- and/or material specific, they are kept as free variables in the optimisation environment where possible.

Material properties

The printing process has influence on the material properties of the resulting concrete artefact. From the concrete mix, which has to be compliant with the printer, to the depositing method, speed and direction a lot of printer specific parameters influence the material properties. In the "Optimising 3D concrete printing" project the following aspects are explored and tested:

- (An)Orthotropic behaviour
  The tests performed on the bulk material indicate that the mixture behaves in an orthotropic manner. This constant behaviour is incorporated in the optimisation.
- Non-linear behaviour of the mixture;
  Concrete-like materials do not behave elastic under loading. The cracked properties of the concrete are used in the optimisation.

Optimisation

Based on the material- and printer properties found, a custom topology algorithm has been developed. The topology optimisation algorithm strives to save material by iteratively filter the densities of the elements to obtain a structure that is as stiff as possible for a predefined fraction of the initial volume. By checking, during the iterations, that the geometry is printable and taking into account the material properties of the printed concrete during analysis, a structurally optimised, printable geometry is generated.

Results

The "Optimising 3D concrete printing" project has advanced the insight in the properties of both concrete 3D printers and the resulting 3D printed artifacts. Additionally, it has resulted in the first optimisation environment in which these capabilities and limitations are taken into account, enabling the use of additive manufacturing for the realisation of structurally sound, optimised concrete structures. As a proof of concept a topological optimised, concrete, printable floor slab is generated using the optimisation environment, and consequently 3D printed.

Delft University of Technology
BEMNext lab
dr.ir. Jeroen Coenders,
Maarten Mathot, Pascal Martens

Eindhoven University of Technology
dr.ir. Freek Bos, Rob Wolfs MSc.

White Lioness technologies
ir. Anke Rolvink,
Puck Middelkoop MSc.,
dr.ir. Jeroen Coenders,
Maarten Mathot

POLYARCH

POLYARCH

The challenge of the future is to minimize the energy consumption of buildings while maintaining an optimal comfort level in the interior. Controlling the energy streams into and out of the building and daylight management play an important role. Polymer technologies and especially responsive liquid crystal networks can improve the daylight management capabilities of building envelopes by making it adaptive on the Nano scale. A similar technology as used in this project is widely applied in LCD screens today but the integration into building technology poses many challenges.

In order to explore the possibilities of transferring polymer technologies into the field of building technology, an interdisciplinary research team has been established, covering the scientific areas of facades design and building physics on one side and chemical engineering on the other.

In a first step the PolyArch project focuses on applying reflective coatings on glass as a means of sun shading. Experiments and simulation show that adaptive coatings can have a clear energetic advantage when compared to current fixed metallic coatings. The project outlines the need for further research on technology development, colouration light perception studies, energy savings potential and other high potential applications.

The Building Envelope as a Potential Field of Application

Building envelopes need to deal with many, sometimes conflicting functions: Generally, a maximum of natural lighting is desired to reduce the need for energy for artificial lighting which in today's buildings accounts for approximately 30% of the total electricity demand. But daylight also contains a lot of energy that is sometimes unwanted and needs to be controlled.

For example, we need to block sun radiation in summer to prevent overheating, whereas in winter this incoming energy is desired to reduce the need for heating energy.

There are several traditional strategies to control daylight such as metallic coatings, exterior and interior sunshades. Existing daylight management strategies are rather inefficient or they involve considerable constructive effort, high investment costs and high maintenance and cleaning expenditures. On top of that the architectural impact of additional external or internal functional layers is big and they often do not comply with the designer's vision.

In this first approach, the project focuses on daylight management, but responsive polymer coatings also show a great potential for other building related applications such as responsive surfaces to control heat absorption/emission, responsive insulation and colour change of architectural surfaces.

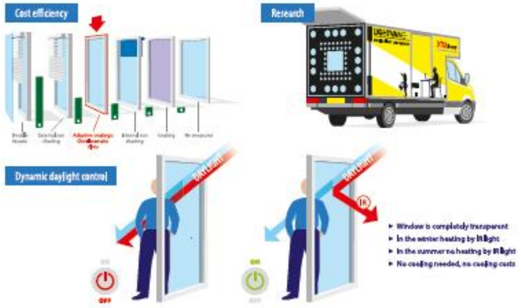
New Polymer Coating Technologies

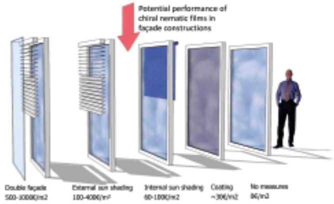
Our collaborating party, the Department of Functional Organic Materials and Devices at the TU/e is a leader in developing new responsive coatings. These materials are able to switch physical properties such as colour, reflectance and heat transfer. For instance, so called 'responsive liquid crystal networks' may adapt the degree of reflection. The position of the reflection band in the electromagnetic spectrum can be dynamically shifted in response to temperature or light. Reflection can be shifted in the near infrared part of the spectrum, thus controlling heat flux without affecting transparency in the visible part of the spectrum. When applied on a glass window this film determines whether the heating part of sun light is being transmitted or reflected, thus offering a new and unique method to manage daylight in.

Potential Energetic Performance and Lighting Quality

Due to the high intensity of sunlight in the wavelength range just outside the visible region, it is worthwhile to explore whether reflectivity of the switchable NIR coating in this range can be improved. A simulation study was carried out with idealized dynamic reflection properties in the range between 700 and 800 nm, to evaluate what the effect of such an improvement would be. The simulation results showed that for a south facing office zone in the climate of Madrid, an additional 15% of cooling energy reduction is possible compared to the existing window prototype.

The analysis of the samples' transmittances in the visible wavelength region has revealed that there is no negative impact on the interior illumination by daylight. At the same time, their spectral transmittance does not impact the quality of the light entering a building. Still it needs more research into perception studies because the film is light angle dependent which means that the colour disturbance could occur at different angles of sight.





Conclusion and Outlook

Up to now, the focus of the PolyArch project lies in applying reflective coatings on glass as a means of sun shading. A core feature of this technology is that the effect can be turned on and off. One can imagine a mirror that would switch to a transparent state. The switching determines if the sun radiation is transmitted into the room or reflected (in summer).

First samples have been created, measured and simulated for a coating in the infrared light spectrum, just outside the visible light. The human eye would thus not see the switching effect. It shows that the technology would reduce the cooling needs for south facing offices by about 15% as compared to existing static coatings. Theoretically the reflection could even be extended into the visible light range, displaying a sun-glass effect to prevent discomfort by glare and delivering a higher energetic effect.

Since the coating is responsive, this technology will potentially deliver a much better performance than current static metallic coatings.

Polymer coatings can be applied by embedding them into prefabricated insulated glass units. That means it can relatively easy be adopted into established design and building processes without the need for additional constructive effort for external sun shading devices. We can expect a high acceptance by decision-making parties.

But other applications need to be researched as well, such as opaque building envelopes that change colour according to architectural desires or absorbing and reflecting surfaces. 3TU.Bouw funding enabled a proof of concept for applying polymer technologies to the field of building construction and justifies the need for research into coloration light perception studies, energy savings potential, application possibilities and of course the development of switchable polymer coatings.

Delft University of Technology
ir. Eric van den Ham, dr. Truus Hordijk, Dr.-Ing. Tillmann Klein

Eindhoven University of Technology
prof.dr.ir. Jan Hensen,
prof.Dr.-Ing. Habil. Alexander Rosemann
prof.dr. Albert Schenning,
dr. Michael Debije

PD LAB

PD LAB

While architects and engineers work already entirely digitally to create our build environment, contractors and craftsmen on the building site still rely mostly on printed paper plans. This practice bears the risk of failure costs. With a growing demand for more sustainable and affordable housing it seems to be about time to start the digital revolution in this sector as well. With the help of computer controlled machines such as a CNC router we are able to fabricate building components based directly on the design of the architects. The digitally created files are sent to a router that cuts components out of wooden or natural fiberboards with high accuracy and speed. While all details that form a system of pre-engineered solutions will form a database of building blocks, costs will be lowered and quality increased. Within the Product Development Lab project the file to factory approach is investigated in form of the first fully digitally produced house as a demonstrator on the campus of the Faculty of Architecture. The project is embedded in the graduation education program, and offers a unique environment to explore the possibilities but also restrains of this approach.

Current Building Practice and Potential

Every building is unique, while most of the problems during erection seem to continue to repeat themselves. It is up to the craftsmen to solve problems on the fly. Some of the related costs are named failure costs. In the Netherlands, these failure costs in the building industry are an estimated 10,6% of its total turnover, resulting in annual costs of over 5 billion euro.

Imagine a building assembled from a well thought through kit of parts, like a kitchen from Ikea; with an infinite number of options available, the system used allows freedom to design within its system boundaries. Installations like light, water and gas or the placement of different third parties appliances are already taking into account and based on a highly industrialized production chain, meaning that the costs remain low and the task on site can be done with less effort.

File to Factory – Digital Fabrication – CNC Milling

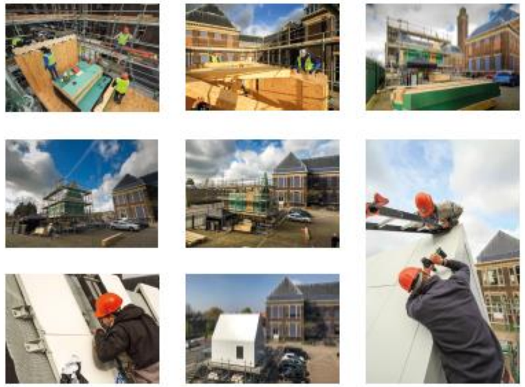
Such mass-customization in design combined with the benefits of industrial production could become possible with digital fabrication. Emerging digitally driven construction processes like 3D printing and CNC milling create a direct link between digital and physical. This so-called file-to-factory process has the potential to bridge the gap between designing and making, as digital design information is directly used in construction to drive computer controlled machinery. While most of the productions in the automotive, marine and aerospace industries are already digitally designed and digitally produced with highly advanced fully automated production technologies, the quality of our buildings often still relies on the sharpness of the pencil point on the building site. Automation is the solution to our demands for individualism, comfort and human being. It allows for products with high precision, quality and at an affordable price.

Project Goals

Therefore, in this PD Lab project we do not use expensive technologies to make even more expensive architecture, but use the potential of these technologies to create high quality, low energy consumption affordable buildings that respond to our demanding challenge towards an energy neutral future. We would like to increase the quality of the building process and the building itself. The question is how this method or process can contribute to an economic and ecological advantage for the building sector. With this lighthouse project a platform will be developed to explore the applications of building sector related product development – the PD Lab.

Building System

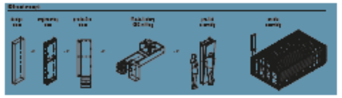
Currently CNC milling already has great potential to create fully digitally produced building structures with integrated friction-fit connections, as shown in professor Larry Sass's (MIT) CNC house at MOMA and the open-source Wikihouse project. Pieter Stoutjesdijk developed this principle further with ECOnnect in Delft, using 600mm wide demountable integrated building components and making optimal use of the third axis on a CNC router to create 2.5D connections. Boards from agricultural waste and wood serve as the main building materials, therefore the structures roughly store their own weight in carbon emissions. Through the file-to-factory process, the components have the potential to be mass customized globally before being produced locally. The precision of the digital production process allows for fast and easy assembly and disassembly through integrated connections and airtight construction details. While the use of standardized building components accepts the reuse of the components like Lego blocks, the building itself allows a high amount of flexibility over time. Due to the use of environmental friendly materials the blocks themselves can be easily disassembled after its lifetime and fed back into the ecological cycle.



Conclusion

We take a pragmatic approach to architecture from an understanding of manufacturing and an appreciation of the way things go together. Up to now we have already concluded that the engineering part of such a system demands a high collaboration within all joining disciplines, communication on a digital platform or one common 3D model seems to be essential to allow the integration of all components. Scale tests and mock-ups to test fit and assembling orders become more and more essential; also as a base for discussion. In addition to the technological challenges a design methodology was set up as well to validate and judge requirements and demands. First iterations already showed that details and components will look differently if the requirements are set up differently.

The role of product design changes from delivering systems prior to the actual design and building process towards an integrated product building solutions. Here, the PD Lab itself is a case study and serves as a platform to explore new methods in product design. The project is supported by teaching activities at TUD.



Delft University of Technology
Dr.-Ing. Marcel Bilow,
Dr.–Ing. Tillmann Klein,
ir. Pieter Stoutjesdijk

Eindhoven University of Technology
prof.dr.ir. Jos Lichtenberg

ECOnnect

Fabrication Factory

Festool Group GmbH & Co

Guardian Glass

Isovlas Oisterwijk BV

Meested Hout & Plaat bv

Reynobond Alcoa Architectural Products

Poly-Ned

Rojo Steigers

Rollecate bv

The New Makers

FACADE LEASING

FACADE LEASING

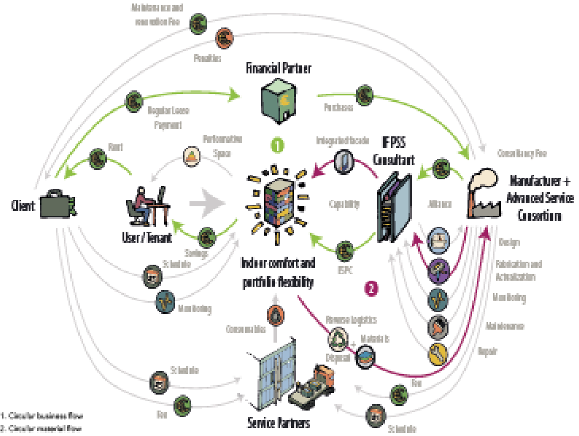
Façade Leasing explores a systemic transition in the construction industry, from a business structure based on the supply of products, to one based on the delivery of ongoing performance services. This could facilitate the introduction of circular economic strategies into the construction process.

Circular Economy

The principle of circular economic development is to preserve components and materials within closed loops of either biological or technical nutrients, maximizing the conserved value for any particular component. Parts should not simply be recycled, as this results in the loss of embodied energy and value, but instead reused or re-manufactured to extend their potential service lives.

Circular Business Model

A circular business model based on multifunctional façades as performance delivering tools could increase the rate and depth of building renovations, accelerate the market uptake of new building technologies, and optimize the reuse and recycling of components and materials within the construction industry. Innovation in building envelope and service technologies, and real estate development and management strategies, come together to turn this concept into a practical reality.



1. Circular business flow
2. Circular material flow

Delft University of Technology
ir. Juan Azcarate-Aguerre,
dr.ir. Tillmann Klein,
dr.ir. Alexandra den Heijer

ClimateKIC

AluEco I VMRG

Alcoa I Kawneer

Aldowa

Alkondor

DeHaan Westerhoff

Kindow

MHZ

Panelen Holland

Real Capital Systems

Renson

Scheuten

Schuurman Elektrokem Solutions

Somfy

Tros

VML Technologies

Symposium “High Performance Building Envelopes”

▫ The Dutch government aims for a **climate-neutral built environment in 2050**. Renovation of the existing building stock is essential in realizing this ambition as the market needs to prepare for delivering 200,000 high performance renovations per year. This requires, among others the development of affordable renovation solutions, enabling the transition toward a fully sustainable energy supply and a fast renovation process.

▫ Adapting the building envelope is an important element for this transition. This implies improving the **thermal performance of the envelop** (lower energy losses through better insulation, better windows, etc.) as well **actively utilizing the envelop for the production of renewable energy**.

▫ Various smart solutions for the building envelope were developed in the last couple of year and the key question is: **how can we scale up these projects** to contribute **to delivering 200,000 high performance renovations per year**?

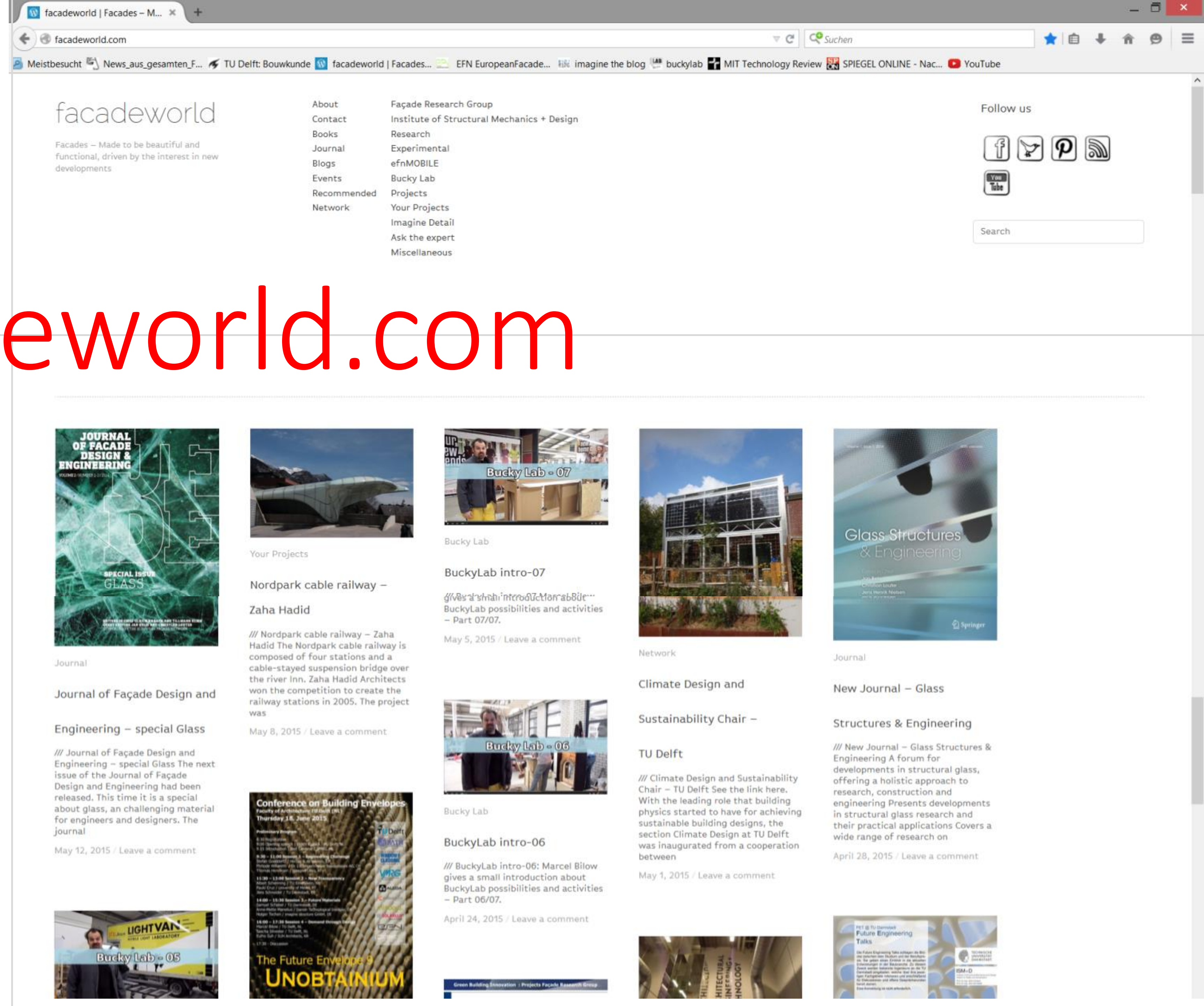
▫ At this symposium we will discuss:
o What are promising concepts and developments?
o What is needed to scale up these concepts?
o Which innovations are needed to reduce costs?
o How can robotisation and digitization contribute to development of affordable renovation?
o What process innovation do we need in the construction chain?

Symposium “High Performance Building Envelopes”

New Technologies
New Materials
Energy collection / Energy storage
Innovation processes

Adaptation of the technologies: who wins what?

www.facadeworld.com



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

The Next Big Thing