

# Re-Thinking Formwork for Concrete Structures

Prof. Dr. Ena Lloret-Fritschi

Swiss Re // Concrete Solutions for Sustainable Construction // 5<sup>th</sup> October 2022



ETH zürich

DARCH

Departement Architektur



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E EA

IfB

Institut für Baustoffe  
Institute for Building Materials



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## What does it mean to build with less?



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Lecture Hall Zoological Institute University Freiburg  
Hans Dieter Hecker (1968)



014 Tower, Riser Uamato, 2012



Bosjes Chapes Steyn Studio, 2018



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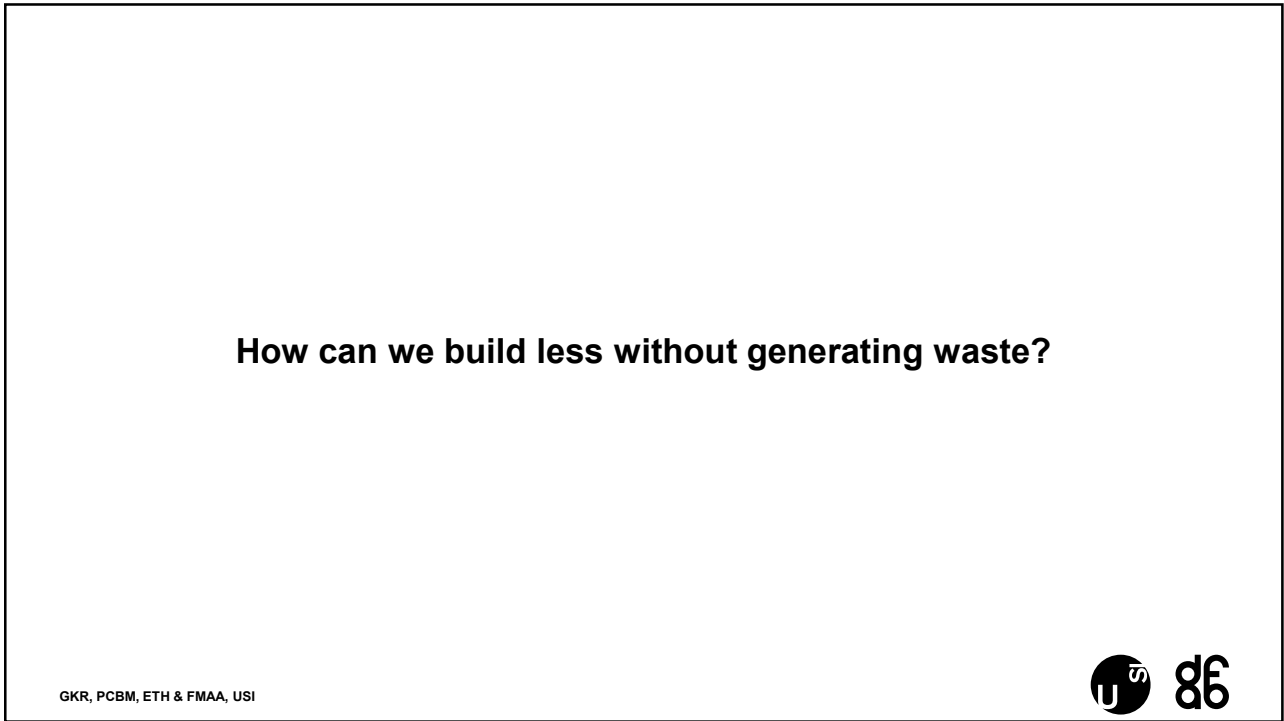


# 36% of waste came from the construction industry in EU 2016

*Waste generation by economic activities and households, EU-20*

GKR, PCBM, ETH & FMAA, USI

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**How can we build less without generating waste?**

GKR, PCBM, ETH & FMAA, USI



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3D Concrete Printing

Digital Casting Systems (DCS)

Stay in place formwork

Counter Pressure Formwork

SDC, 2012

X-Tree, 2018

Contour Crafting, Prof. Koshnevic, 2004

Counter Pressure Formwork, DBT, ETHZ, 2018

AI Build  
<https://www.ai-build.com/contact.html>

Eggshell, GKR, 2018

AeroCrete, GKR 2018

MeshMould, GKR, ETHZ, 2018

GKR, PCBM, ETH & FMAA, USI

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3D Concrete Printing

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Contour Crafting, Prof. Koshnevic, 2004

Counter Pressure Formwork, DBT, ETHZ, 2018

AI Build  
<https://www.ai-build.com/contact.html>

Thin formwork, GKR, 2018

AeroCrete, GKR 2018

MeshMould, GKR, ETHZ, 2018

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## Material Control & Processing

Too Soft



Too Hard



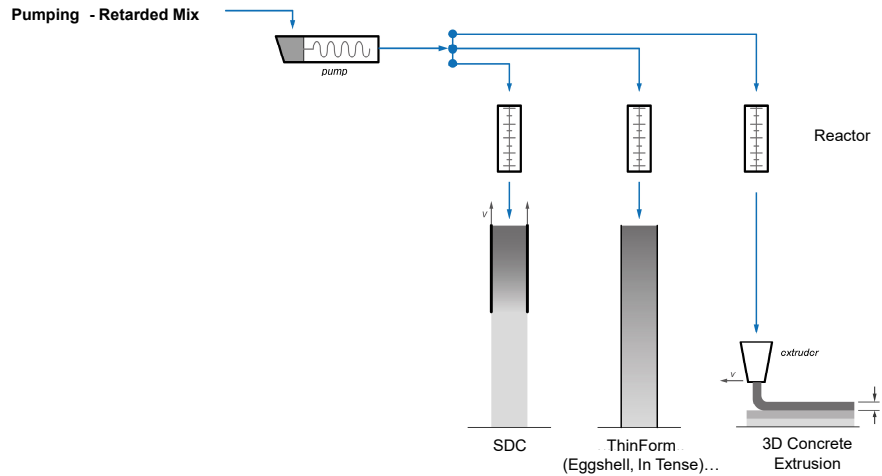
*Robotic slipforming for non-standard structures*  
Lloret-Fritschi, 2016

GKR, PCBM, ETH & FMAA, USI



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## Digital Casting Systems Set-On-Demand Processing



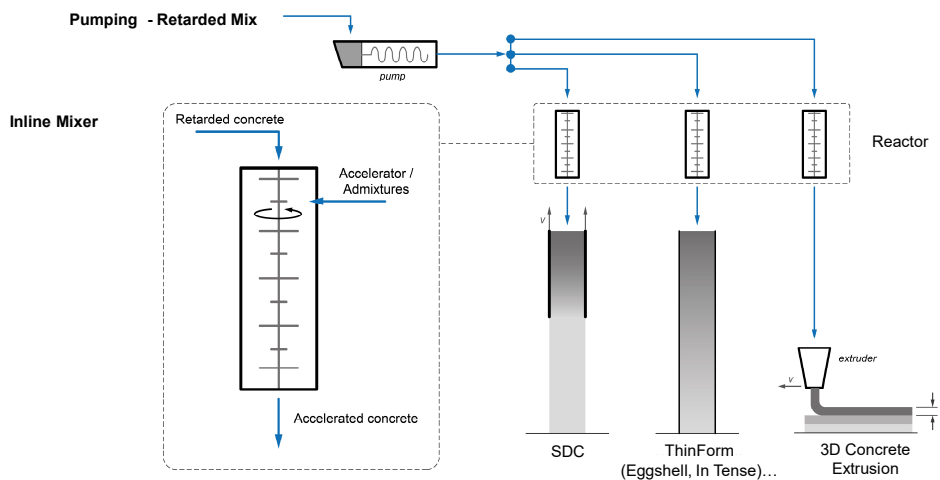
From Smart Dynamic Casting to a growing family of Digital Casting Systems,  
Lloret et al, Cement and Concrete Research, Vol 138, 2020

GKR, PCBM, ETH & FMAA, USI



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## Digital Casting Systems Set-On-Demand Processing



From Smart Dynamic Casting to a growing family of Digital Casting Systems,  
Lloret et al, Cement and Concrete Research, Vol 138, 2020

GKR, PCBM, ETH & FMAA, USI



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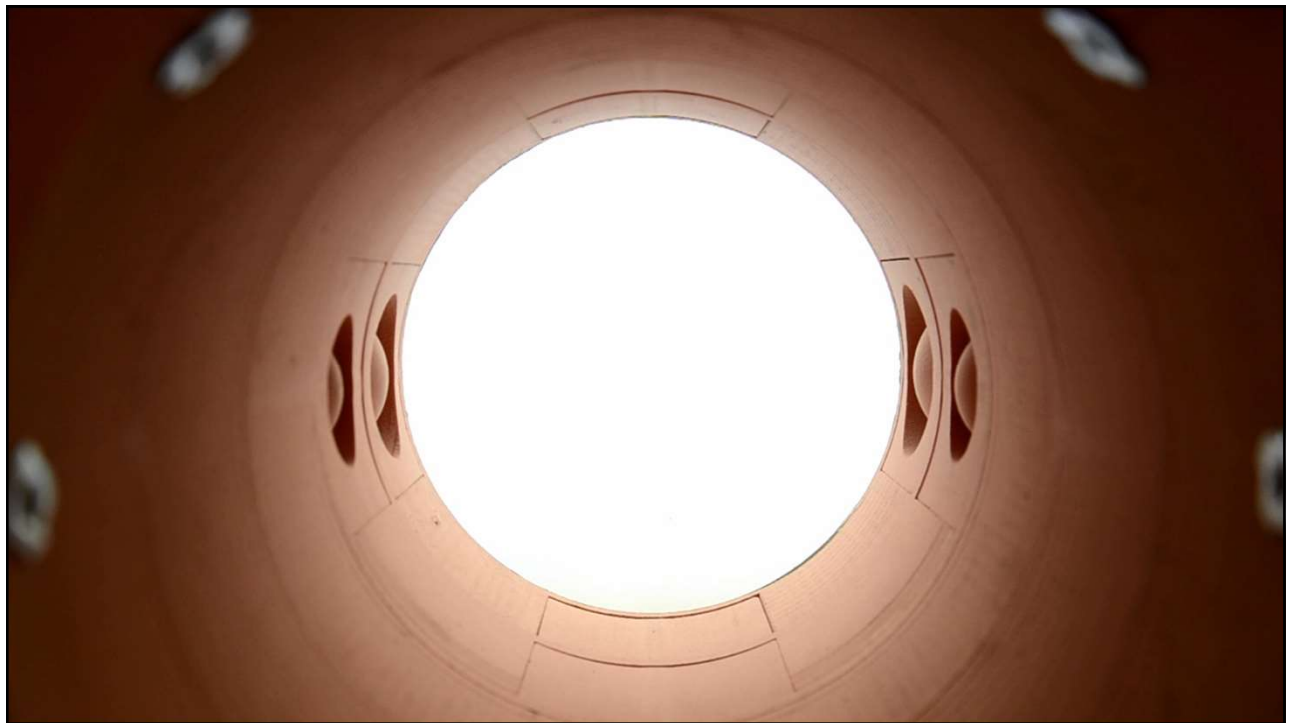
## Rigid Formwork



GKR, PCBM, ETH & FMAA, USI

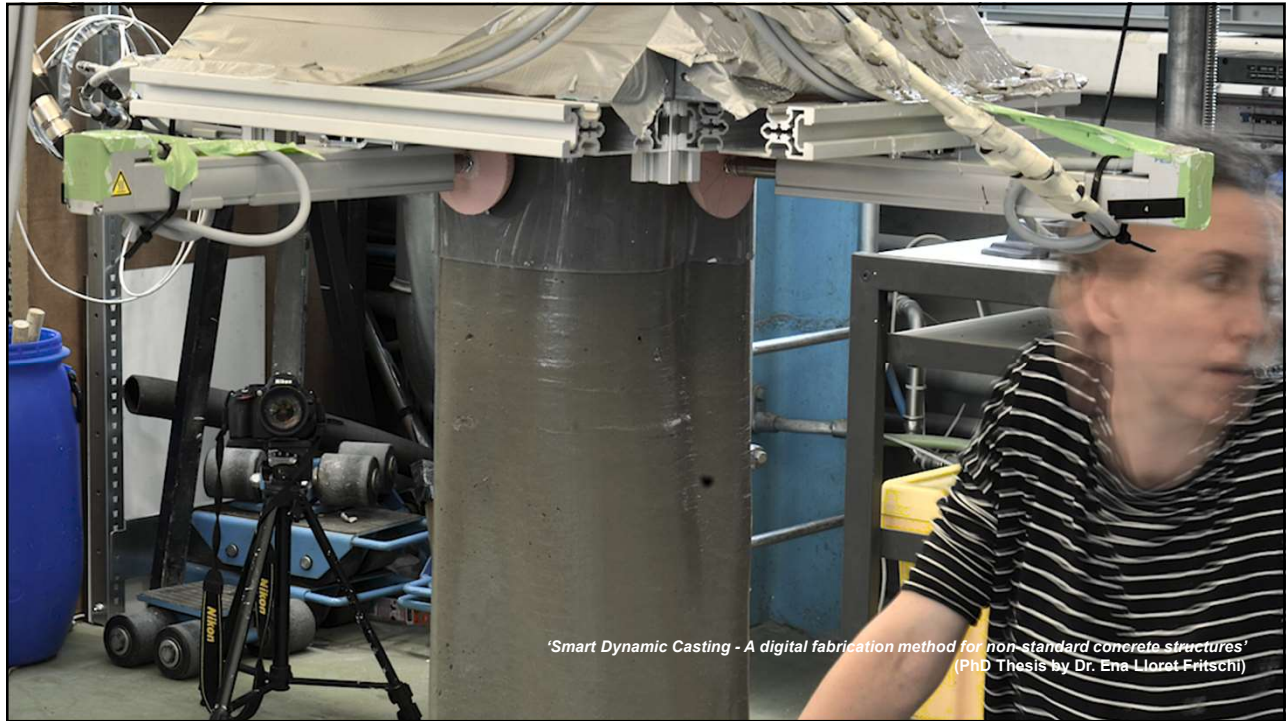


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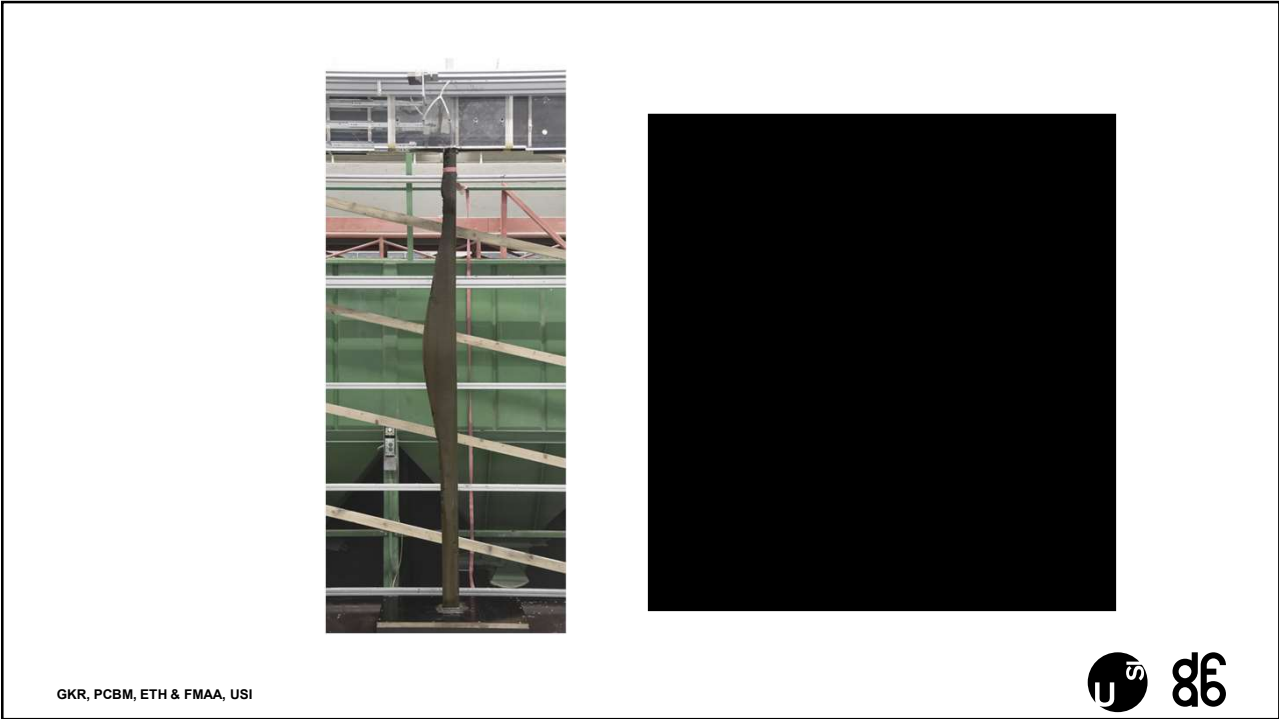
*'Smart Dynamic Casting - A digital fabrication method for non-standard concrete structures'*  
(PhD Thesis by Dr. Ena Lloret-Fritsch)

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# DFAB HOUSE

GKR, PCBM, ETH & FMAA, USI

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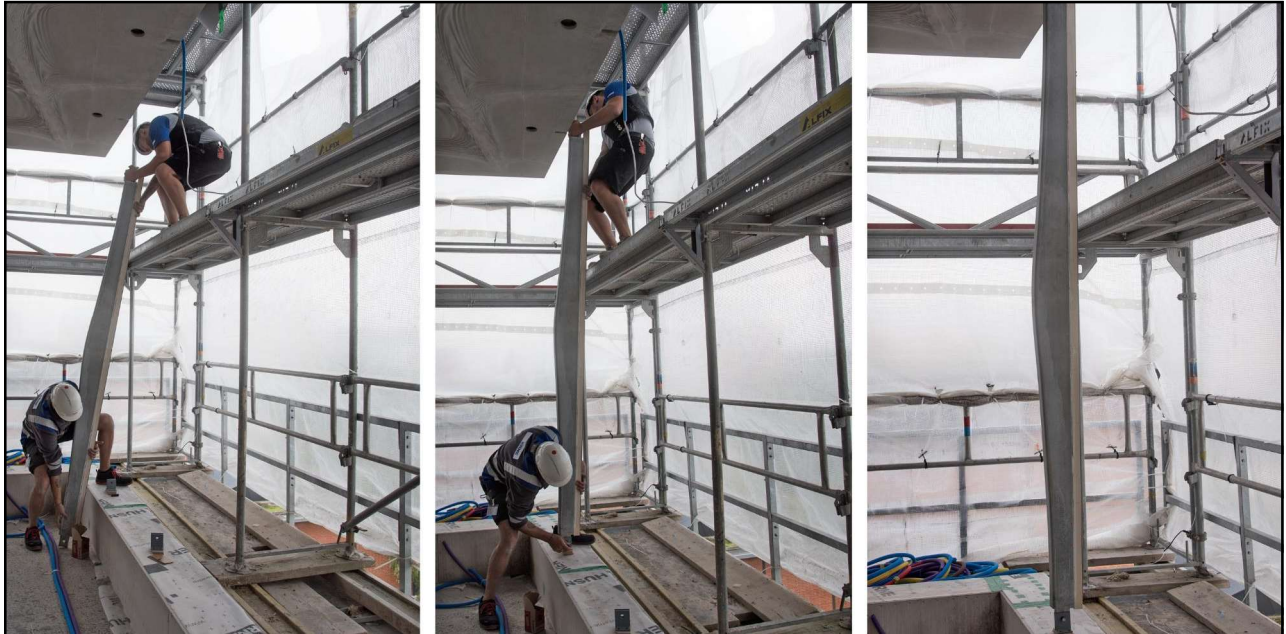


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Bild: Roman Keller

30% less material



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# Future Tree

**Research & Construction Project 2017-2019**

**Gramazio Kohler Research, Architecture & Digital Fabrication, ETH Zurich**

**Team:** Dr. Aleksandra Anna Apolinarska, Dr. Ena Lloret-Fritschi, Joris Burger, Nizar Taha, Fabio Scotto

**In cooperation with:** Physical Chemistry of Building Materials group (ETH Zurich, Prof. Dr. Robert J. Flatt, Dr. Thibault Demoulin, Bruno Pinto Aranda)

**Selected experts:** Basler & Hofmann AG, ERNE AG Holzbau, SJB Kempter Fitze AG, Concrete Structures & Bridge Design (ETH Zurich, Prof. Walter Kaufmann, Dr. Jaimé Mata-Falcon)

**Selected contractors:** ERNE AG Holzbau (Fabrication timber structure)

**Client:** Basler & Hofmann AG

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KÖHLER  
RESEARCH  
ETH ZÜRICH**

**ETH zürich**

**Basler & Hofmann**

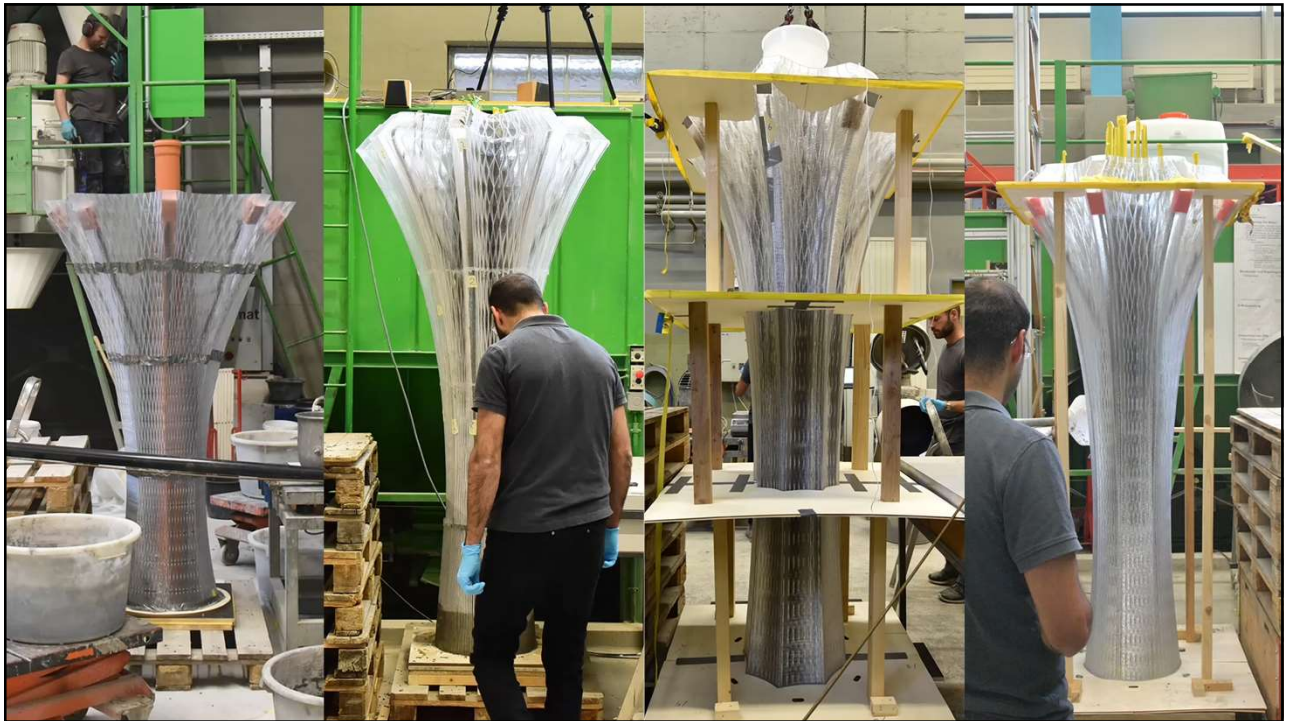
**ERNE**  
wir bauen vorwärts

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## Prototypes



#1



#2



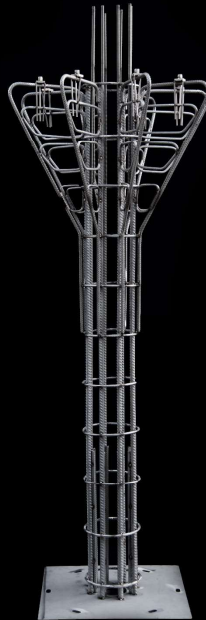
#3



#4

Gramazio Kohler Research / Physical Chemistry of Building Materials  
ETH Zurich

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Gramazio Kohler Research / Physical Chemistry of Building Materials  
ETH Zurich



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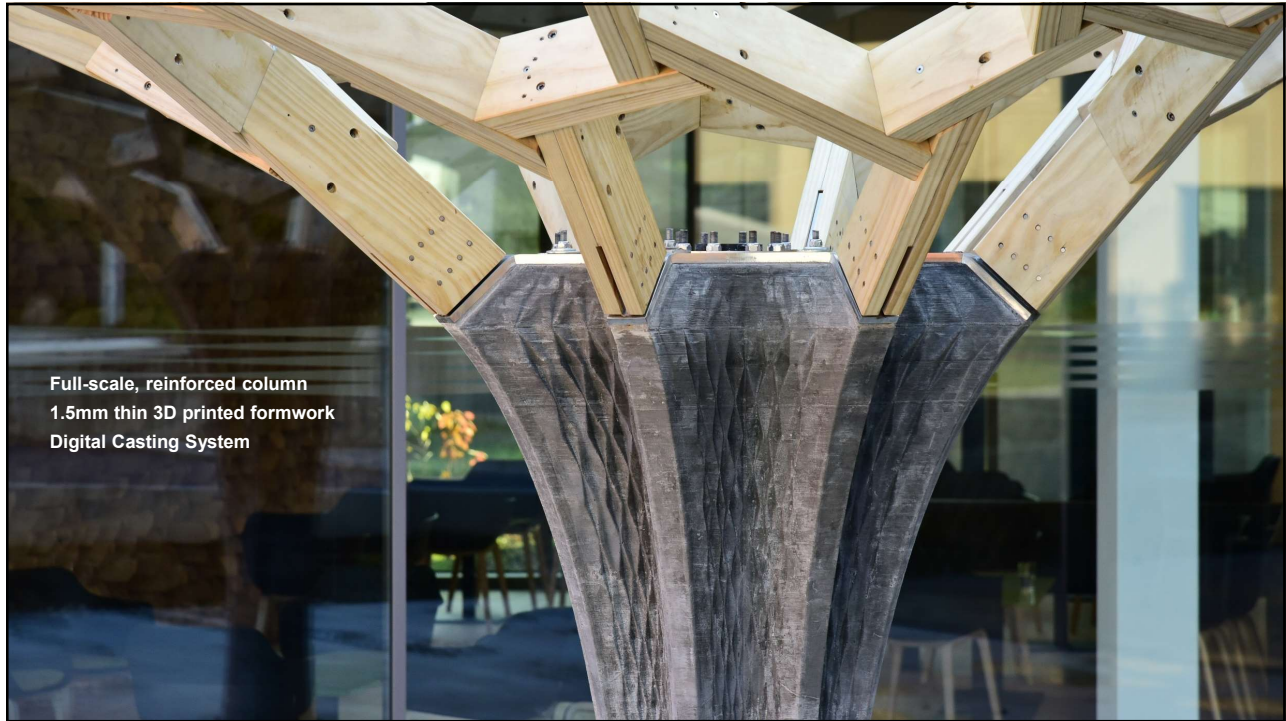


Gramazio Kohler Research & Physical Chemistry of Building Materials, ETH Zurich



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Full-scale, reinforced column  
1.5mm thin 3D printed formwork  
Digital Casting System

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# RIBB3D

## Optimised ribbed slabs with 3D printed formwork

Research Project 2021

**Concrete Structures and Bridge Design (Prof. Dr. Walter Kaufmann)**

**Gramazio Kohler Research (Prof. Fabio Gramazio, Prof. Matthias Kohler)**

**Team:** Dr. Tobias Huber, Joris Burger, Dr. Jaime Mata Falcón, Dr. Ena Lloret-Fritschi, Ping-Hsun Tsai

**Support:** Structural Lab, Robotic Fabrication Laboratory, Concrete Lab (ETH Zurich)

**Sponsors:** SACAC AG, Debrunner Acifer Bewehrungen

**Funding:** ETH Foundation, Siemens, Geberit

**ETH** zürich

**i|b|k**

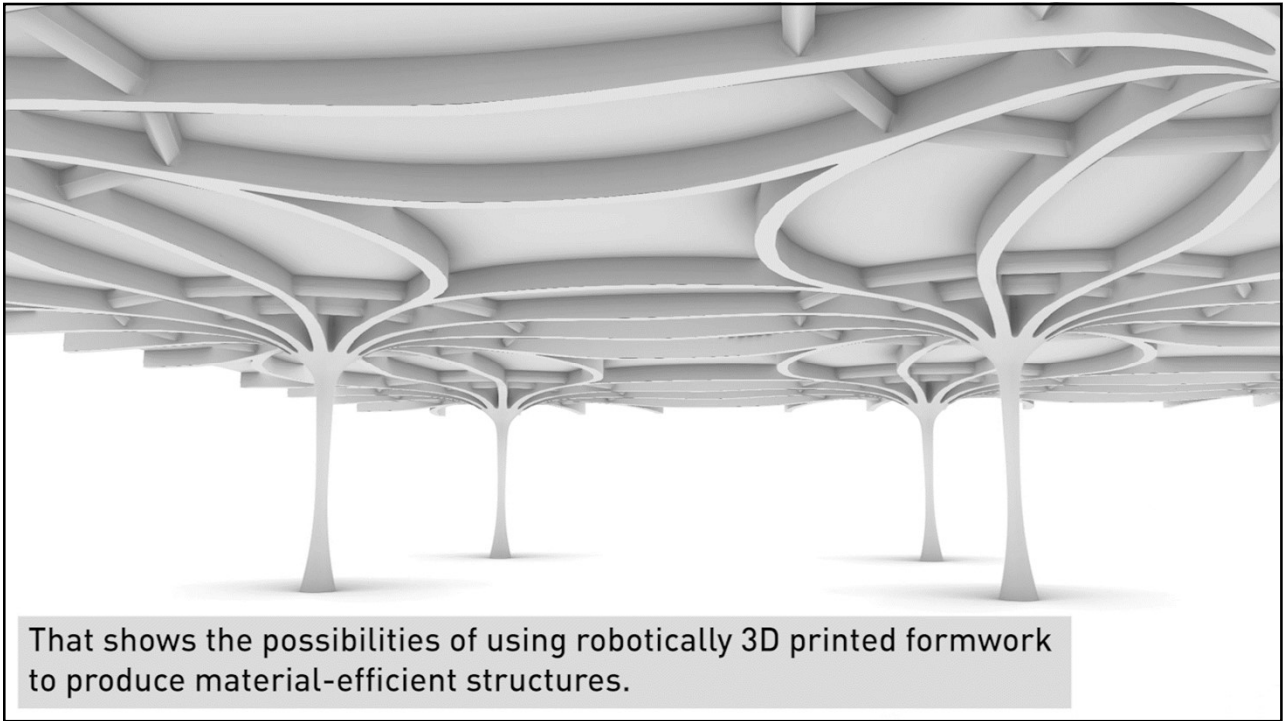
**DBAUG**

**GRAMAZIO  
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RESEARCH**

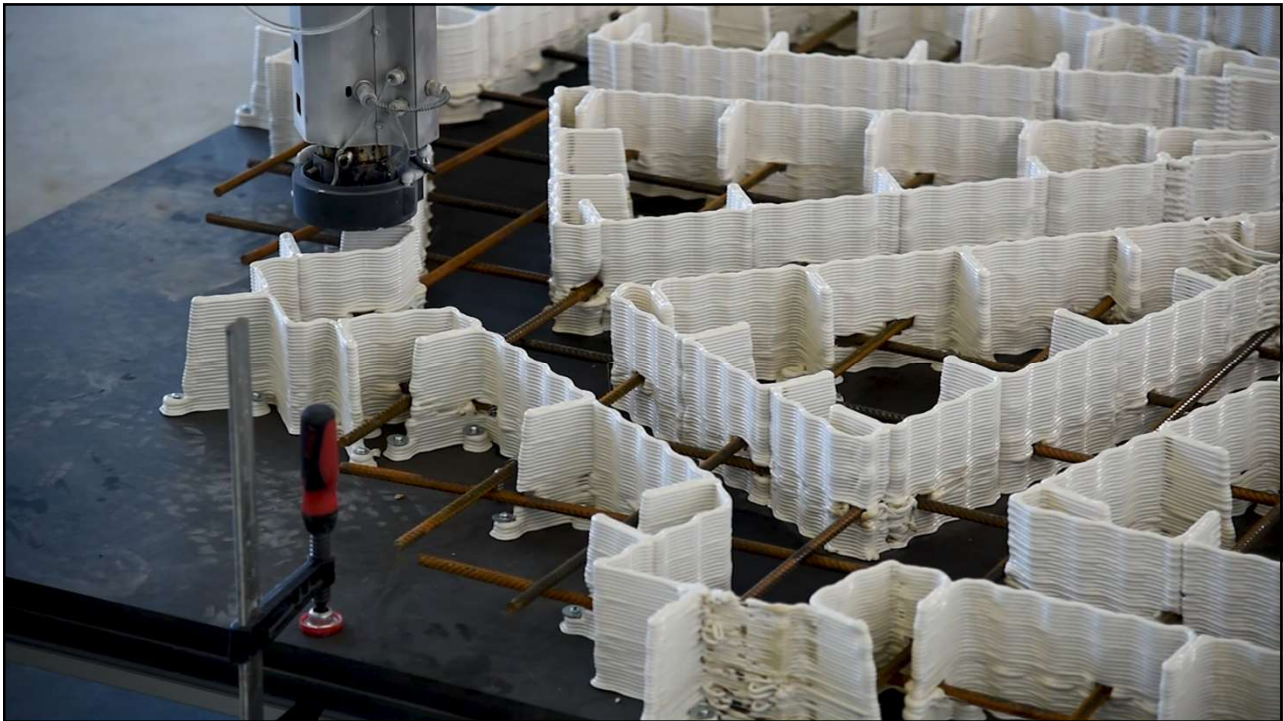
**gk**

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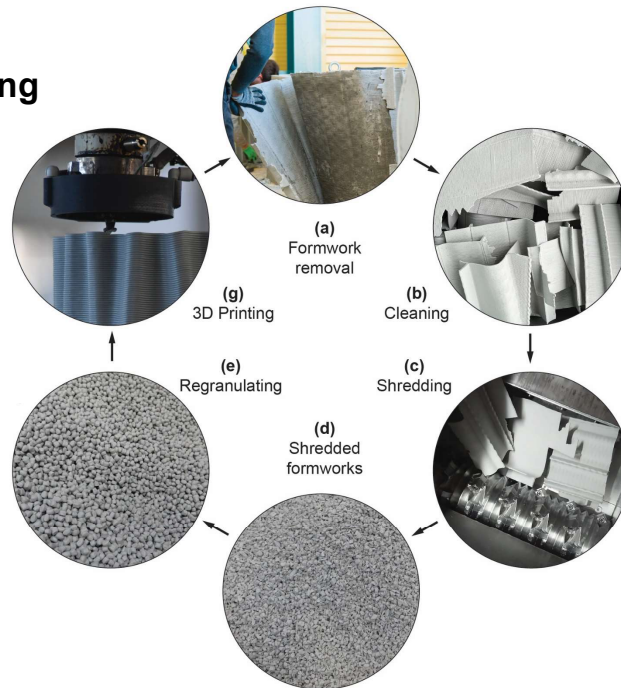
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## Material Recycling



Gramazio Kohler Research  
ETH Zurich

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# Eggshell Pavilion

Research, Teaching, and Construction Project, 2022

Gramazio Kohler Research, Architecture & Digital Fabrication, ETH Zurich

**Tutors:** Joris Burger (research), Petrus Aejmelaeus-Lindström (teaching), Guillaume Jami, Seyma Gürel Saydam

**Students:** Vasileios Aloutsanidis, El Mehdi Belyasmine, Ananya Kango, Che Wei Lin, Wenjun Liu, Erika Marthins, Nikolaos Maslarinos, Gabriele Mattei, Andrea Victoria Mendoza, Chris Norcross, Muslima Rafikova, Joaquin Tobar Martinez, Katarina Toumpektsi, Jingwen Wang, Ming Yang Wang, Vincent Wörndl, Hanbing Zhao

**In cooperation with:** Dr. Filip Niketic (Nicolas Fehlmann Ingénieurs Conseils SA), Seyma Gürel Saydam (Physical Chemistry of Building Materials, ETH Zurich - Prof. Dr. Robert J. Flatt)

**Selected Experts :** Marc Akermann (IWK Institut für Werkstofftechnik und Kunststoffverarbeitung - Prof. Daniel Schwendemann), Theo Bürgin (Bürgin Creations)

**Support:** Philippe Fleischmann, Michael Lyrenmann (Robotic Fabrication Laboratory, ETH Zurich), Andreas Reusser (Physical Chemistry of Building Materials, ETH Zurich)

**Sponsors:** ABB, Debrunner Acifer Bewehrungen, Holcim, Krinner, MÜLLER-STEINAG ELEMENT AG, NFIC, SACAC AG, Welti Furrer

ETH zürich

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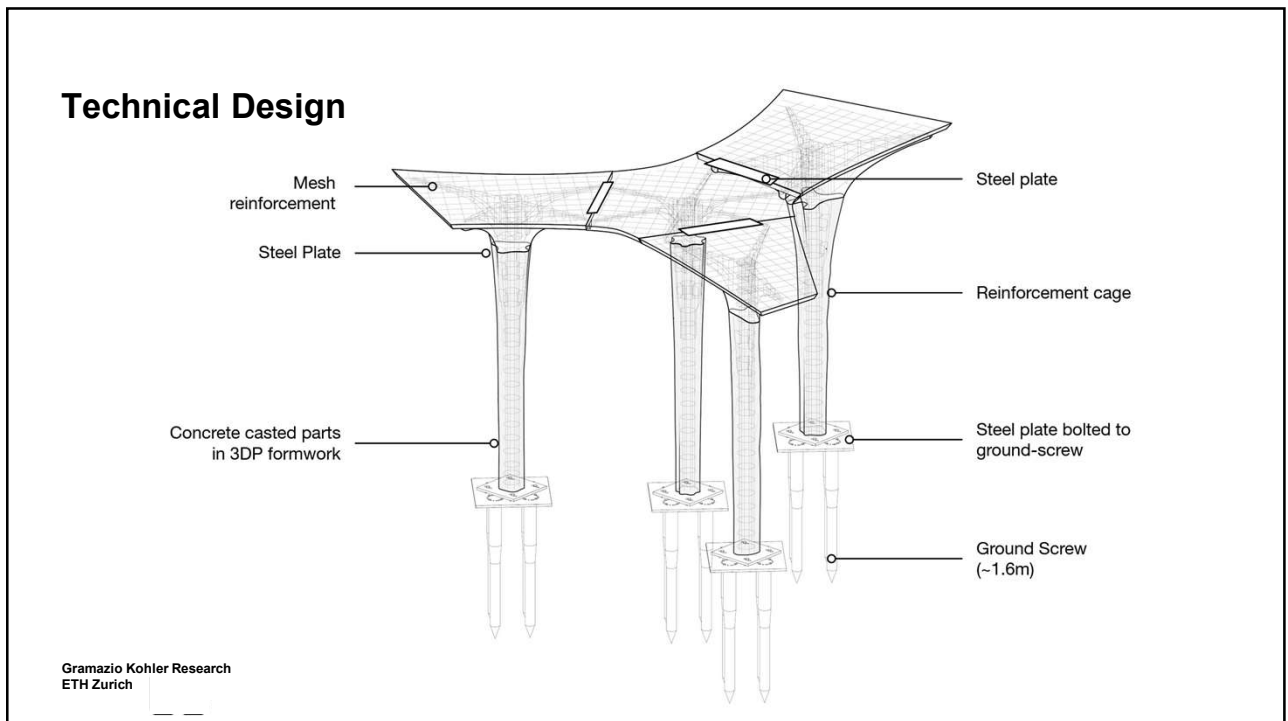
IfB IZF

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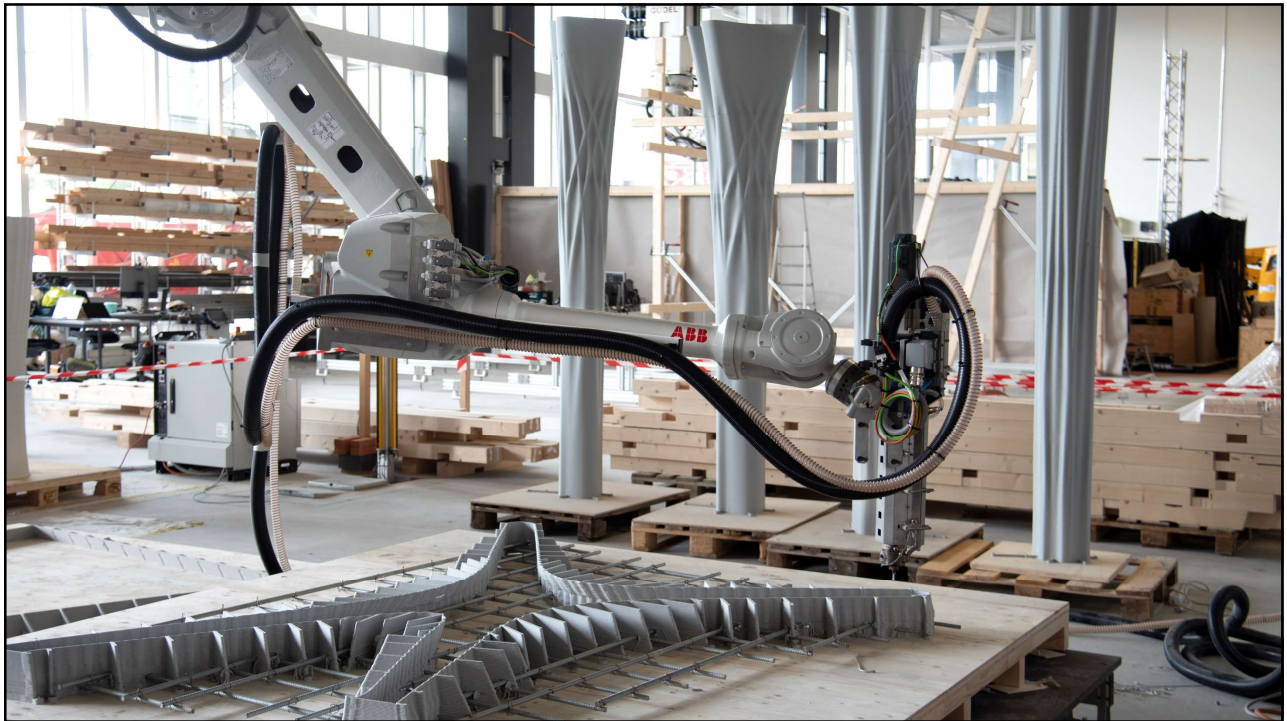
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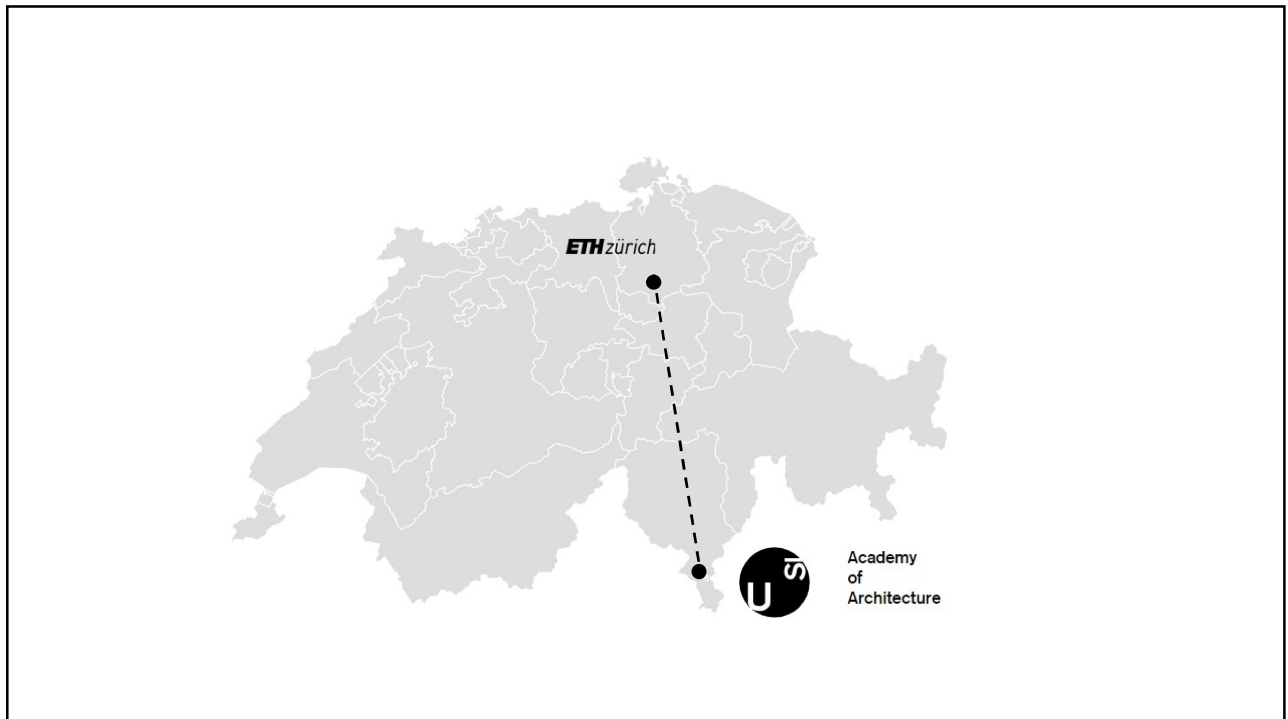


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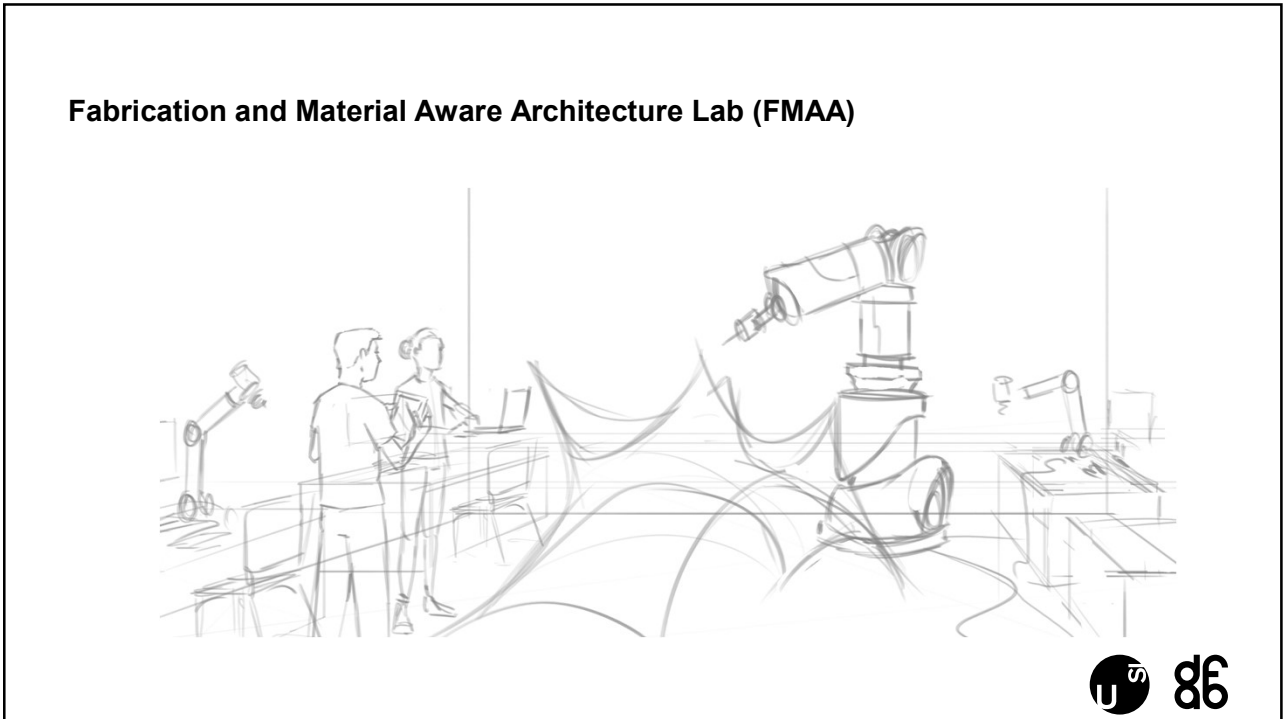
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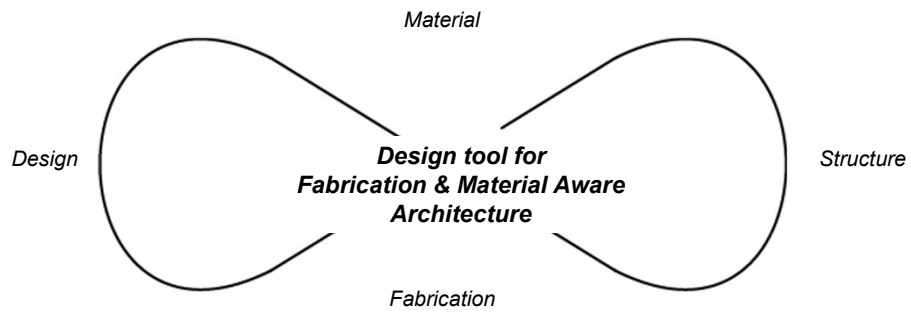


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## Fabrication and Material Aware Architecture Lab (FMAA)



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## Fabrication and Material Aware Architecture Lab (FMAA)

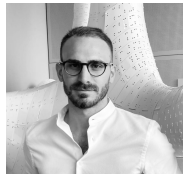
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Prof. Dr. Ena Lloret-Fritschi



Post. Doc. Selen Ercan-Jenny



Dr. Candidate Fabio Amicarelli



Dr. Candidate Sacha Cutajar



Research Assistant Fen Chan

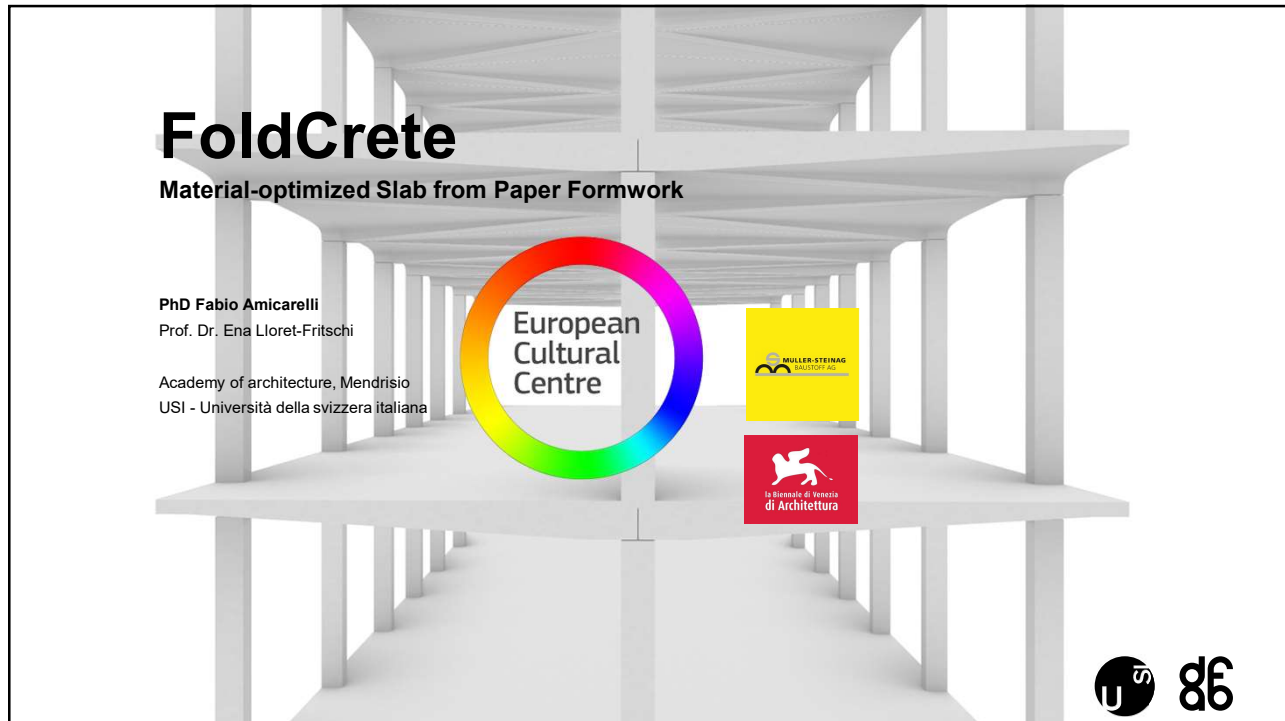


Research Assistant Wei Ting Chen

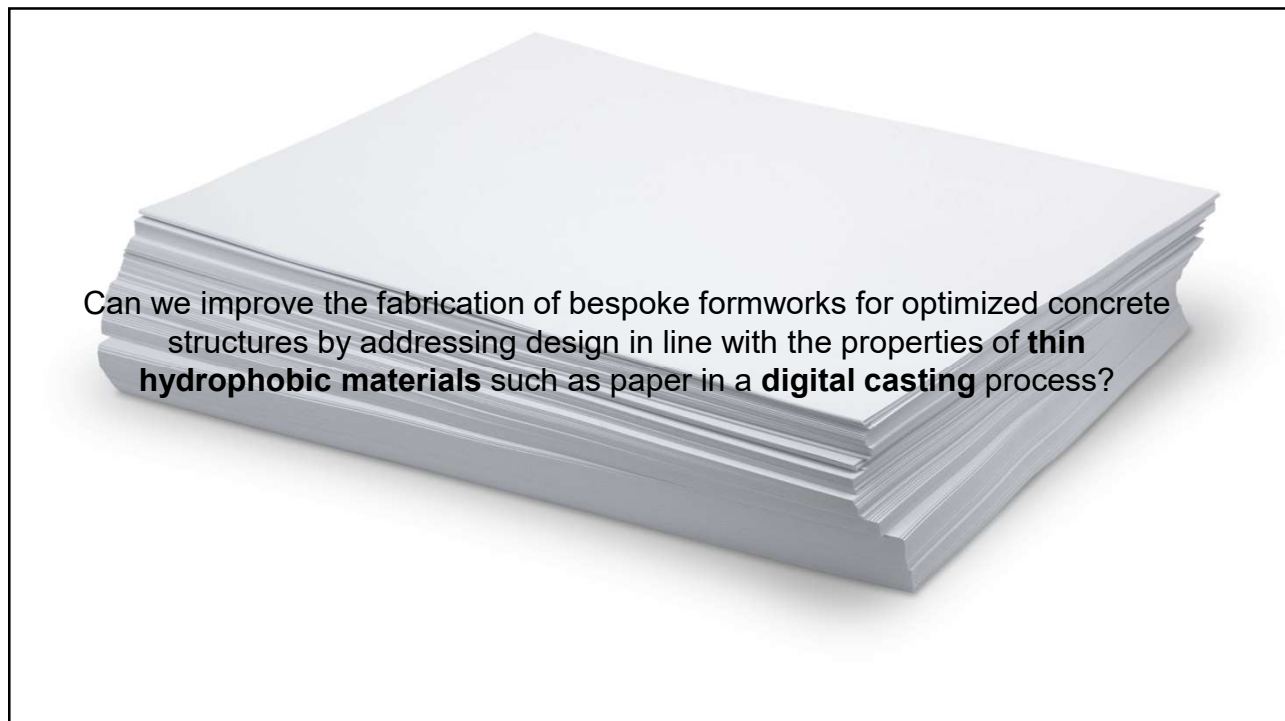


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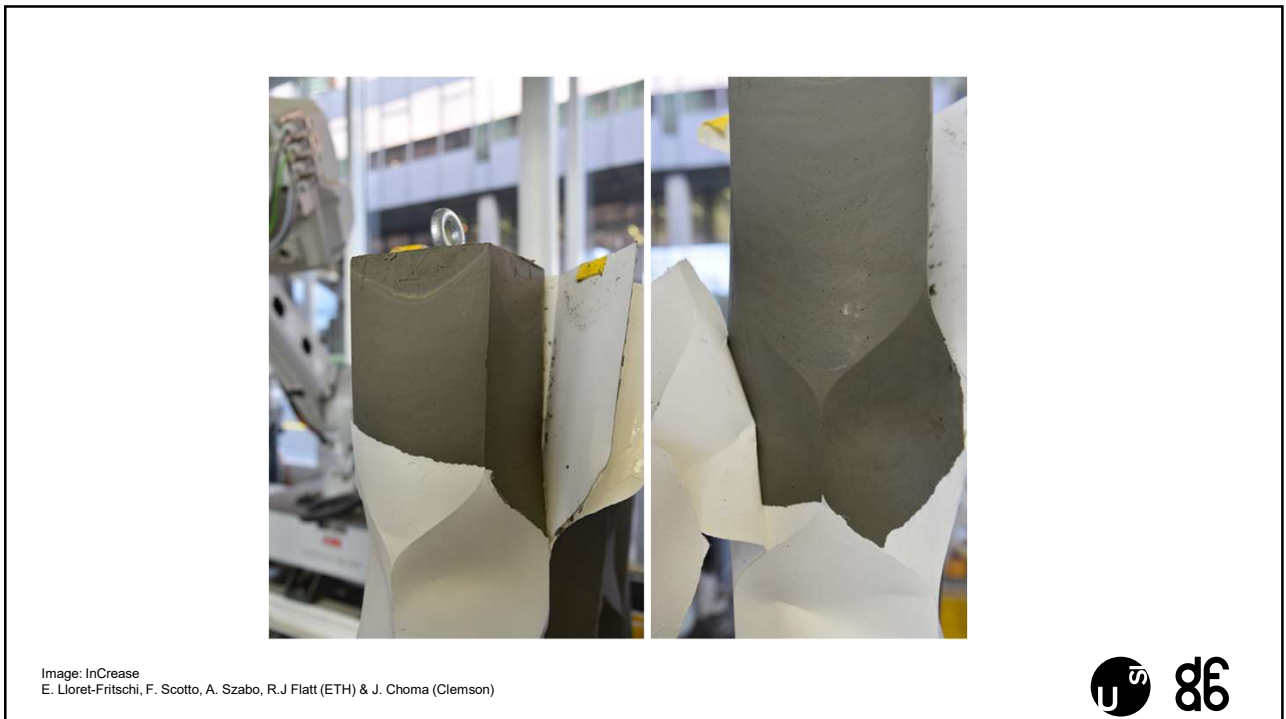
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Image: InCrease  
E. Lloret-Fritschi, F. Scotto, A. Szabo, R.J Flatt (ETH) & J. Choma (Clemson)



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Image: InCrease  
E. Lloret-Fritschi, F. Scotto, A. Szabo, R.J Flatt (ETH) & J. Choma (Clemson)



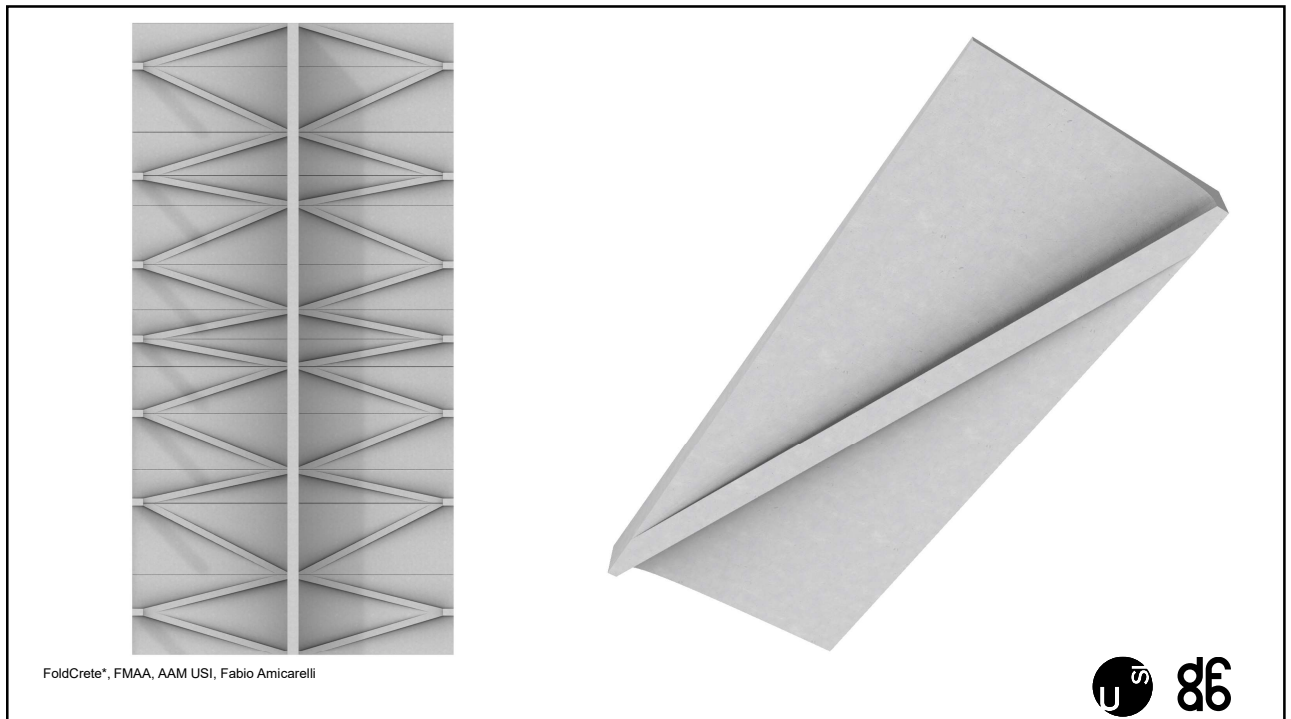
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DATA  
FMAA, AAM USI Data, AAM USI; 2022

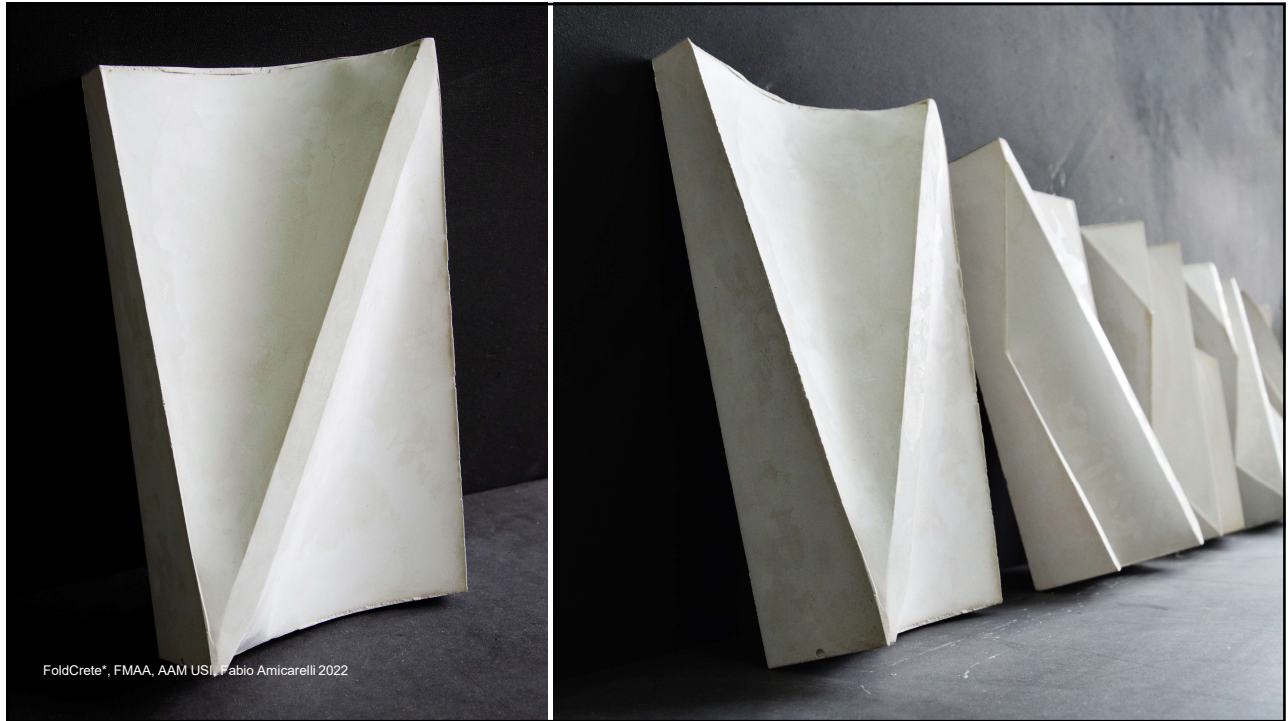
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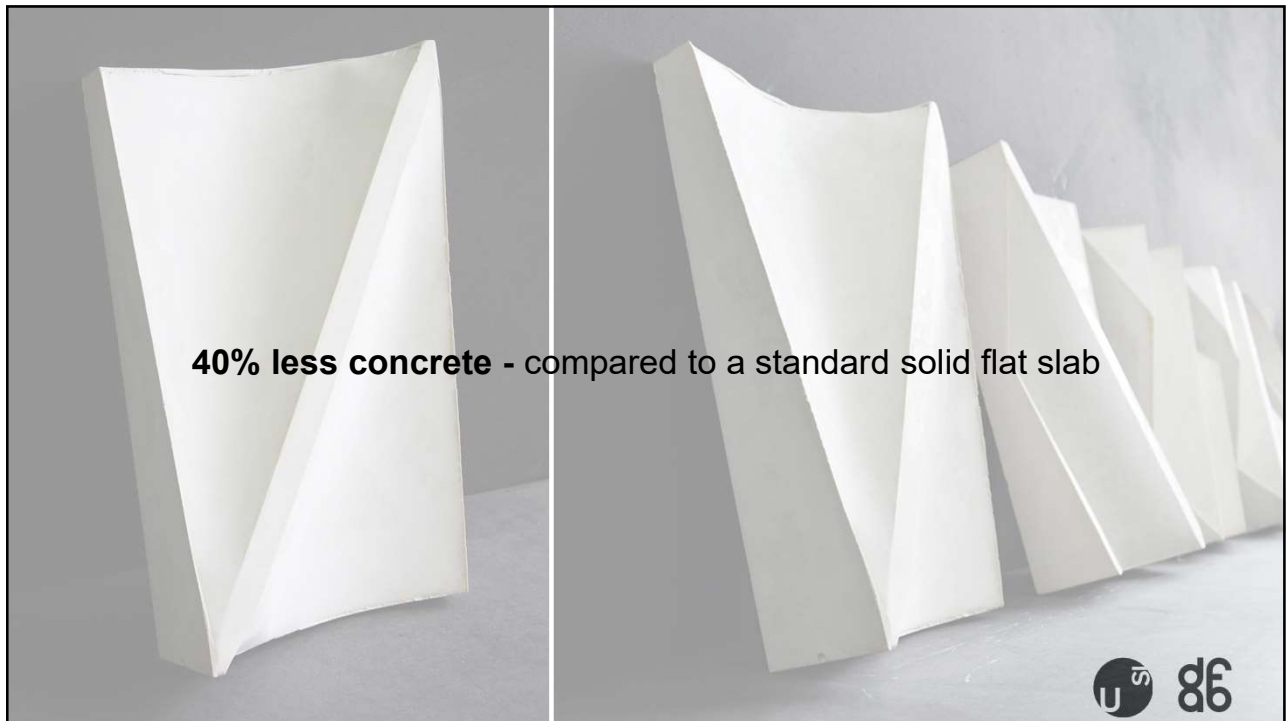
FoldCrete\*, FMAA, AAM USI, Fabio Amicarelli



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## Architectural Application

**Digital Casting Systems**  
w. standard and ultra-thin formworks



Digital Casting Systems, PCBM, GKR, ETH & FMAA, USI



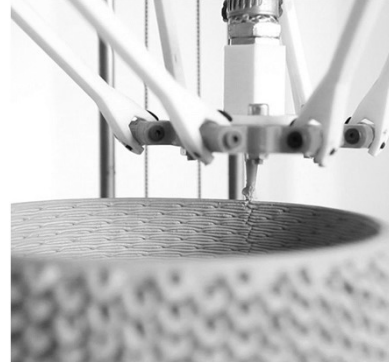
**Stay-in-place formworks**



AeroCrete, GKR, 2018



**Printed formworks**  
(clay, earth, polymer)



Earth-to-Earth



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## Thanks for Your Attention

**Prof. Dr. Ena Lloret Fritschi**

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