DFAB and Challenges of Smart Dynamic Casting

Presentation

Author(s):
Gramazio Kohler Research; Flatt, Robert; NCCR Digital Fabrication; Lloret-Fritschi, Ena

Publication date:
2020-10-02

Permanent link:
https://doi.org/10.3929/ethz-b-000388171

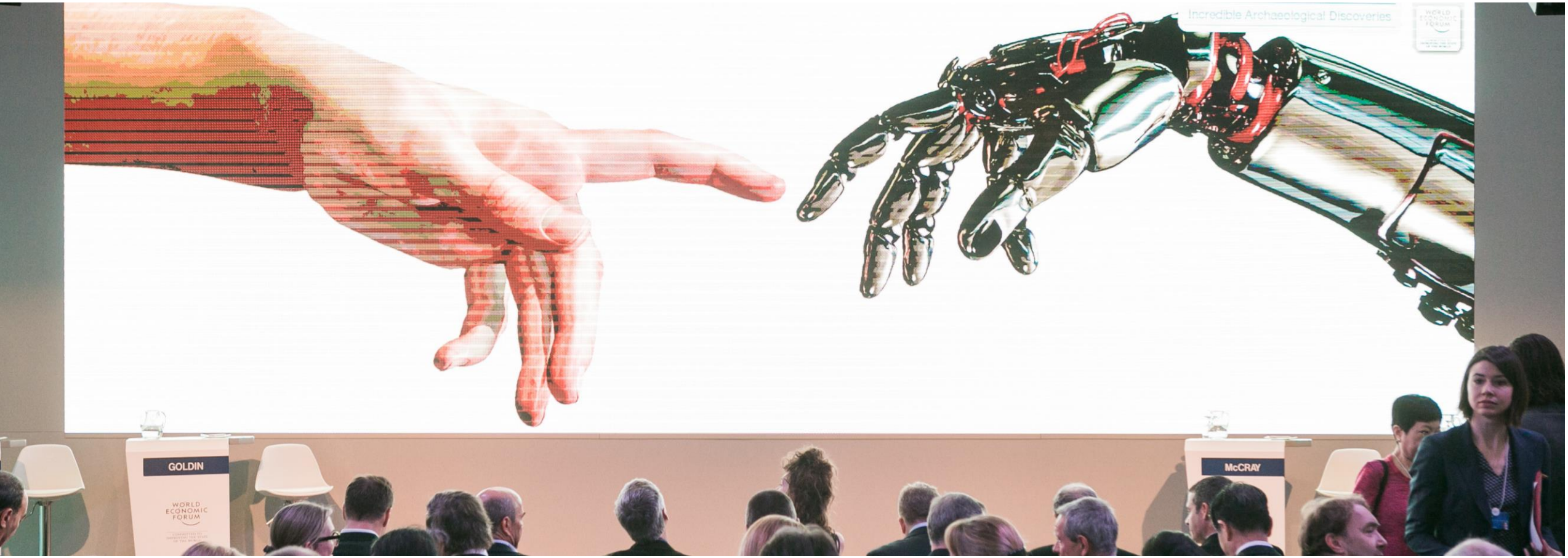
National Centre of Competence
in Research
Digital Fabrication

DFAB and Challenges of Smart Dynamic Casting

Gramazio Kohler Research, Chair of Architecture and Digital Fabrication, ETH Zurich
Prof. Robert Flatt, Institute for Building Materials, ETH Zurich
NCCR Digital Fabrication, ETH Zurich

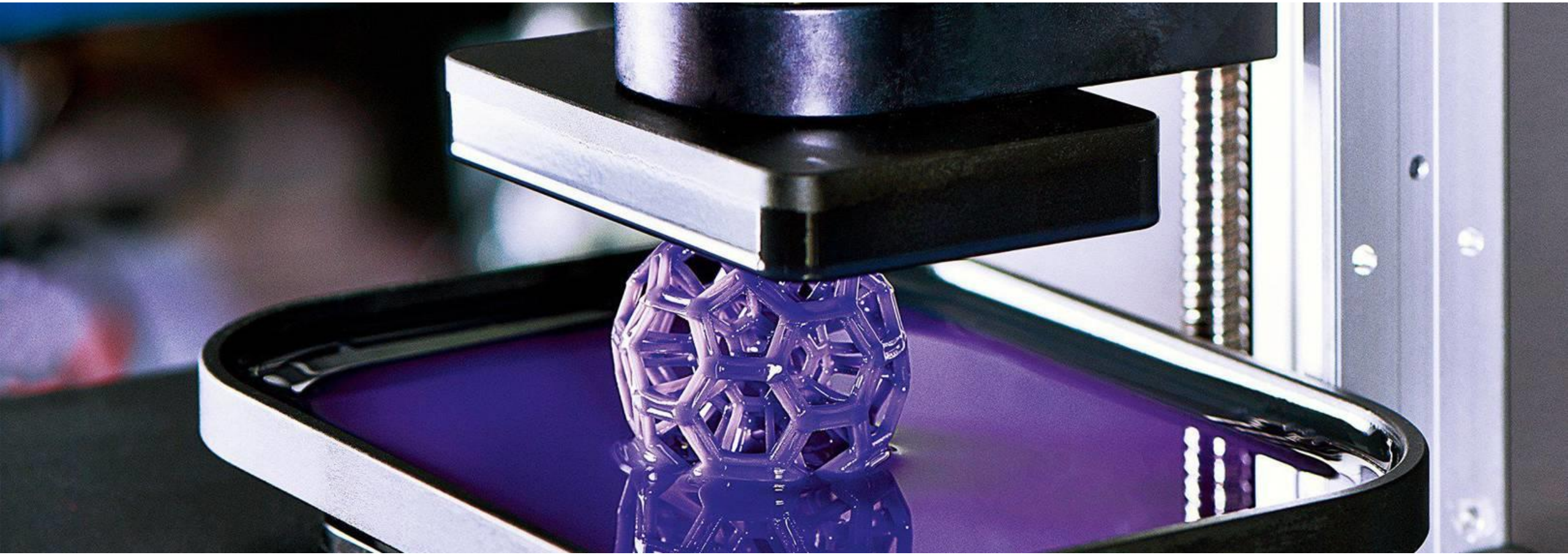
Speaker: Ena Lloret-Fritschi

The World Is Changing



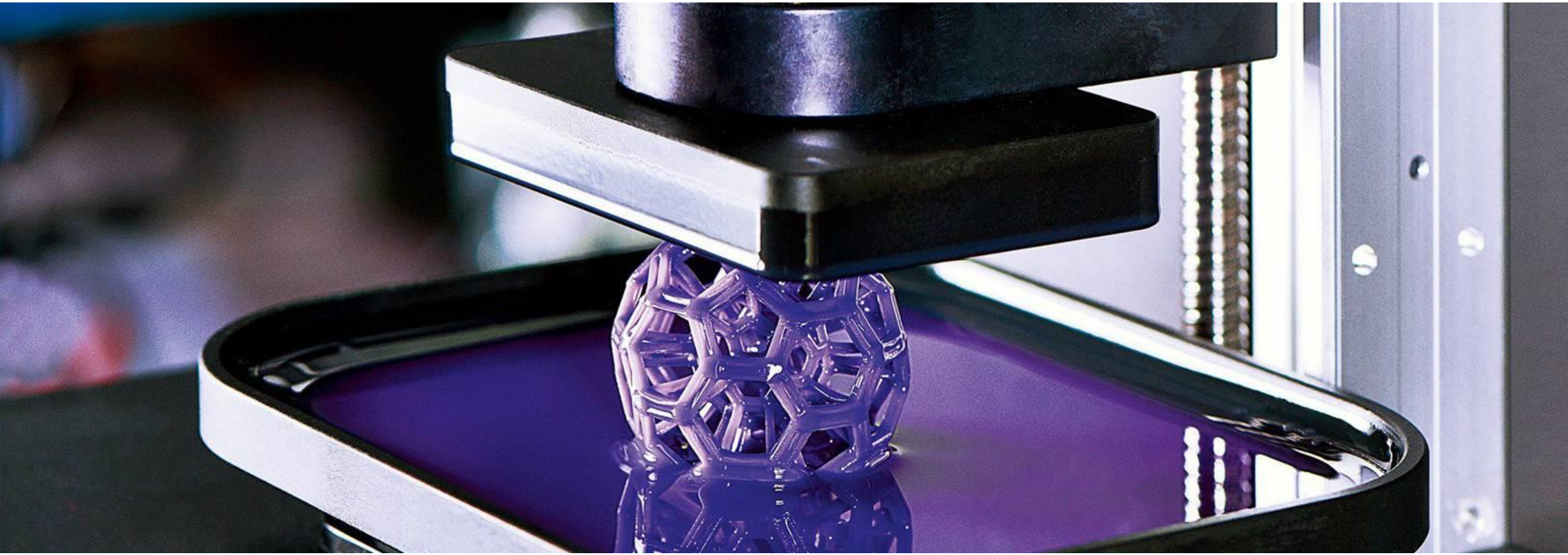
World Economic Forum 2016: ***Mastering the Fourth Industrial Revolution***

The way we produce is changing



100 x schnellerer 3D Druck mit Carbon UV3D Drucker (Foto: Spencer Lowell)

The way we produce is changing



100 x schnellerer 3D Druck mit Carbon UV3D Drucker (Foto: Spencer Lowell)

Will the way we build buildings also change?

Foto: Hilti

Will you control this change?

(Foto: Jules Spinatsch)

Programmed Wall, Gramazio Kohler Research, ETH Zürich, 2006

Programmed Wall, Gramazio Kohler Research, ETH Zürich, 2006

```
// Filename: Dfab_Rotate_2.mel
// Author: Silvan Oesterle
// Purpose: generate a modified "Maerkischer Verband" mit Stossfugenabstand

proc brickWall (int $x, int $z, float $stoneW, int $stoneH, float $vertGap, int $horizGap, float $spacing) {

    float $stoneD = ($stoneW / 2) - ($vertGap / 2);
    float $spacing;
    float $rotateMod;
    float $moveValue;
    float $rotateMax = 37.0;

    for ($i = 0; $i < $z; $i++) { // vertical loop

        for ($j = 0; $j < $x; $j++) { // horizontal loop

            $moveValue = $stoneD + $spacing;
            $rotateMod =  sin ((($j * $i)) * 3.1415927 / 120.0);
            print $rotateMod + "\n";

            if ($i%2 == 0) { // modulo um gerade und ungerade lagen zu unterscheiden

                if ($j == 0) { // erzeugt am anfang jeder lage einen weiteren stein und verschiebt ihn
                    polyCube -w $stoneW -h $stoneH -d $stoneD -ax 0 0 1;
                    rotate -r -ws 0 0 90;
                    move -r (-((0.25*$moveValue)+($moveValue*$j))) 0 (($horizGap+$stoneH)*$i);
                }
                polyCube -w $stoneW -h $stoneH -d $stoneD -ax 0 0 1;
                rotate -r -ws 0 0 90;
                move -r ((0.5 * $moveValue) + ($moveValue * $j)) 0 (($horizGap + $stoneH) * $i);
                rotate -r 0 0 ($rotateMax * $rotateMod);

            } else {
                polyCube -w $stoneW -h $stoneH -d $stoneD -ax 0 0 1;
                rotate -r -ws 0 0 90;
                move -r ($moveValue * $j) 0 (($horizGap + $stoneH) * $i);
                rotate -r 0 0 ($rotateMax * $rotateMod);
            }
        }
        $rotateMax-=0.32;
    }
}
```

Programmed Wall, Gramazio Kohler Research, ETH Zürich, 2006

NCCR Investigators in Phase 2

Fabio Gramazio
Architecture and
Digital Fabrication
ETH Zurich

Matthias Kohler
Architecture and
Digital Fabrication
ETH Zurich

NCCR Investigators in Phase 2

Philippe Block
Architecture and Structures
ETH Zurich

Robert Flatt
Building Materials
ETH Zurich

Margarita Chli
Vision for Robotics
ETH Zurich

Stelian Coros
Computational Robotics
ETH Zurich

Benjamin Dillenburger
Digital Building Tech.
ETH Zurich

Fabio Gramazio
Architecture and Digital Fabrication
ETH Zurich

Marco Hutter
Robotic Systems
ETH Zurich

Walter Kaufmann
Structural Engineering
ETH Zurich

Matthias Kohler
Architecture and Digital Fabrication
ETH Zurich

Mark Pauly
Computer Graphics and Geometry
EPFL

Christophe Girot
Landscape Architecture
ETH Zurich

Joseph Schwartz
Structural Design
ETH Zurich

Kristina Shea
Engineering, Design and Computing
ETH Zurich

Roland Siegwart
Autonomous Systems
ETH Zurich

Yves Weinand
Timber Construction
EPFL

Eleni Chatzi
Structural Mechanics
ETH Zurich

Arno Schlüter
Architecture and Building Systems
ETH Zurich

Corentin Fivet
Structural Xploration
EPFL

Gudela Grote
Work and Organ. Psychology
ETH Zurich

Guillaume Habert
Sustainable Construction
ETH Zurich

Daniel Hall
Innovative and Industr. Construction
ETH Zurich

Agathe Koller-Hodac
Mechatronics and Automation
HSR

Andreas Luible
Façade and Metal Construction
HSLU

Roy Smith
Automatic Control
ETH Zurich

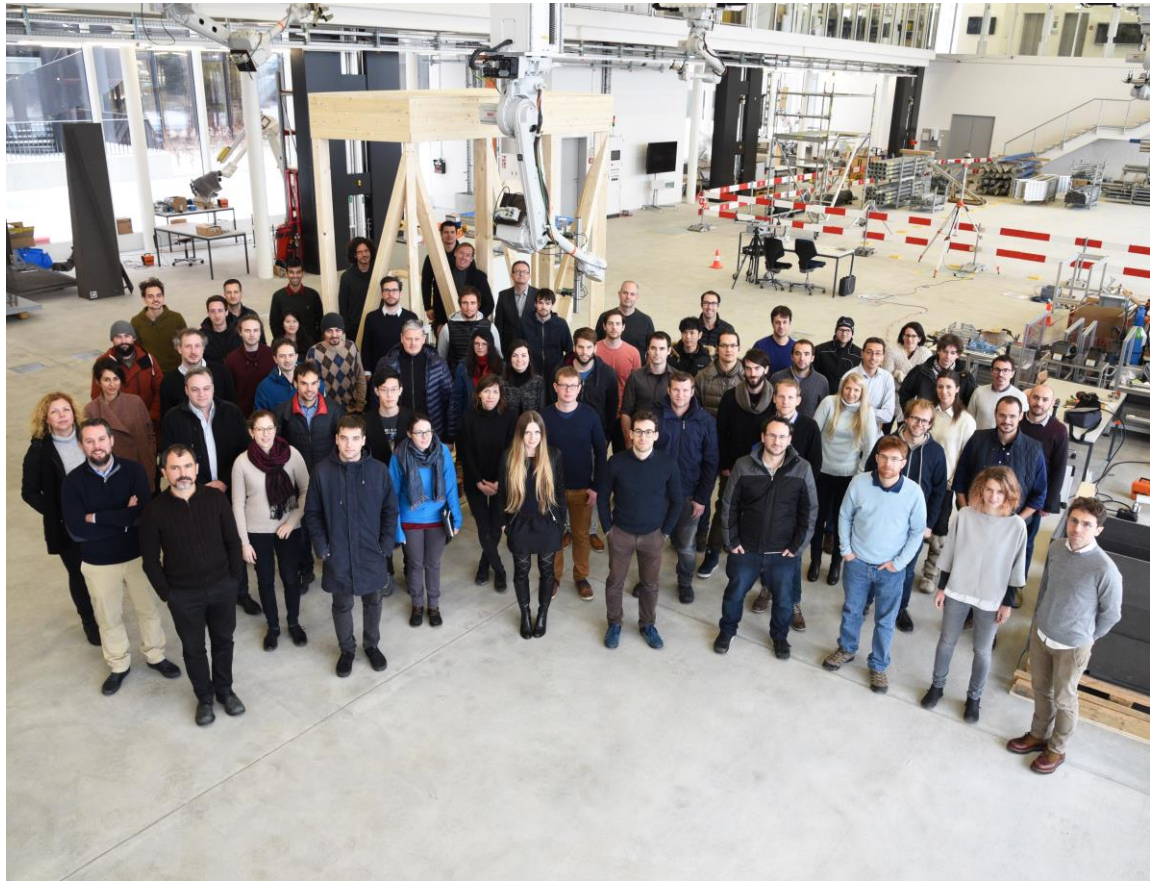
Olga Sorkine-Hornung
Interactive Geometry
ETH Zurich

Melanie Zeilinger
Dynamic and Systems Control
ETH Zurich

Andrea Frangi
Timber Structures
ETH Zurich

Andreas Wieser
Geosensors and Engineering Geodesy
ETH Zurich

Facts and Figures



Group image of NCCR Digital Fabrication, 2016

Switzerland‘s initiative to lead the development and integration of digital technologies within architecture

Date of initiation: June 2014

Home institution: ETH Zurich

Partner institutions: EPF Lausanne, Empa, Bern University of Applied Sciences

Funding period 1: 2014 – 2018 (CHF 13.4 Mio SNSF)

Funding period 2: 2018 – 2022 (CHF 14.4 Mio SNSF)

Researchers:

- 47 Postdoc + PhD + researchers
- 28 Principal Investigators
- 12 Technicians and management personnel
- Over 50 associated researchers + scientific assistants

Total: Over 150 people network

Robotic Fabrication Laboratory, Arch_Tec_Lab, ITA, ETH Zürich

Robotic Fabrication Laboratory, Arch_Tec_Lab, ITA, ETH Zürich

Robotic Fabrication Laboratory, Arch_Tec_Lab, ITA, ETH Zürich

Rolex Learning Center, SANAA, EPFL Lausanne, 2010

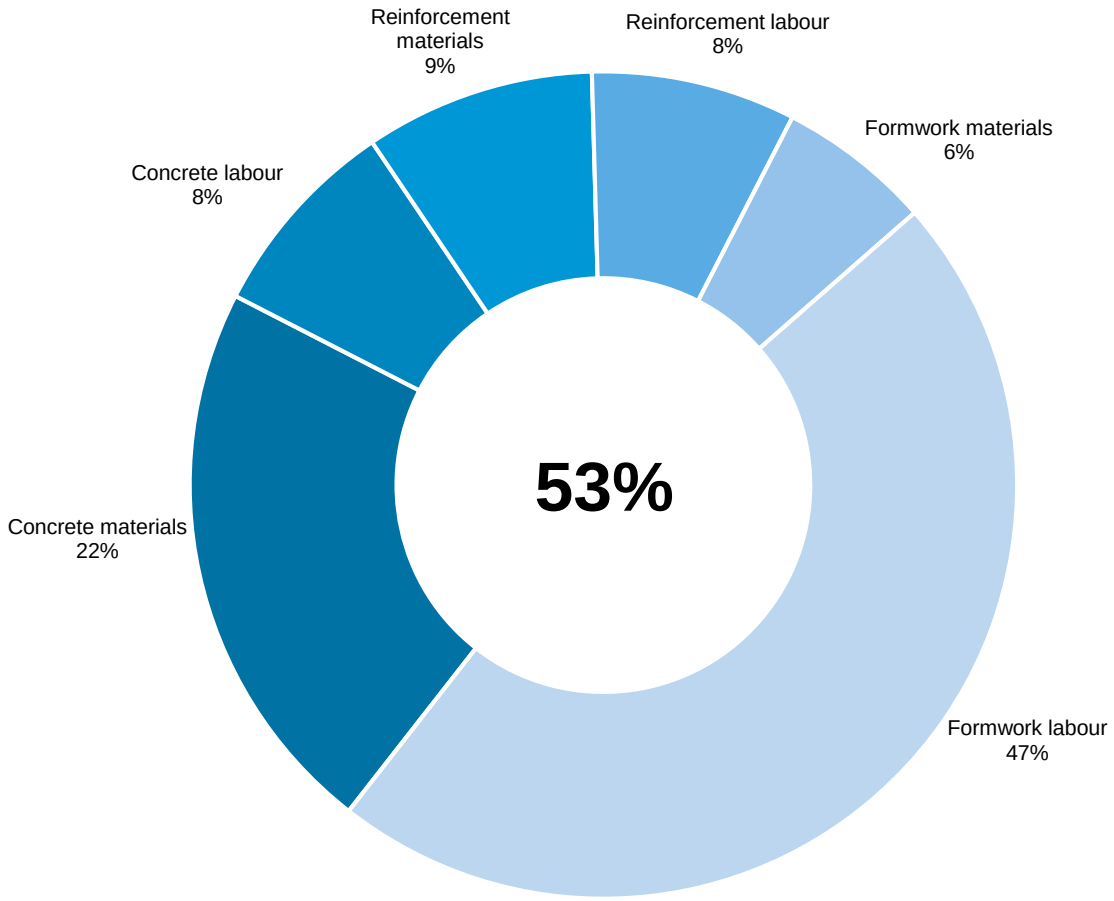
Rolex Learning Center, SANAA, EPFL Lausanne, 2010

Conventional Non Standard Formwork

Formwork of EPFL Rolex Learning Centers

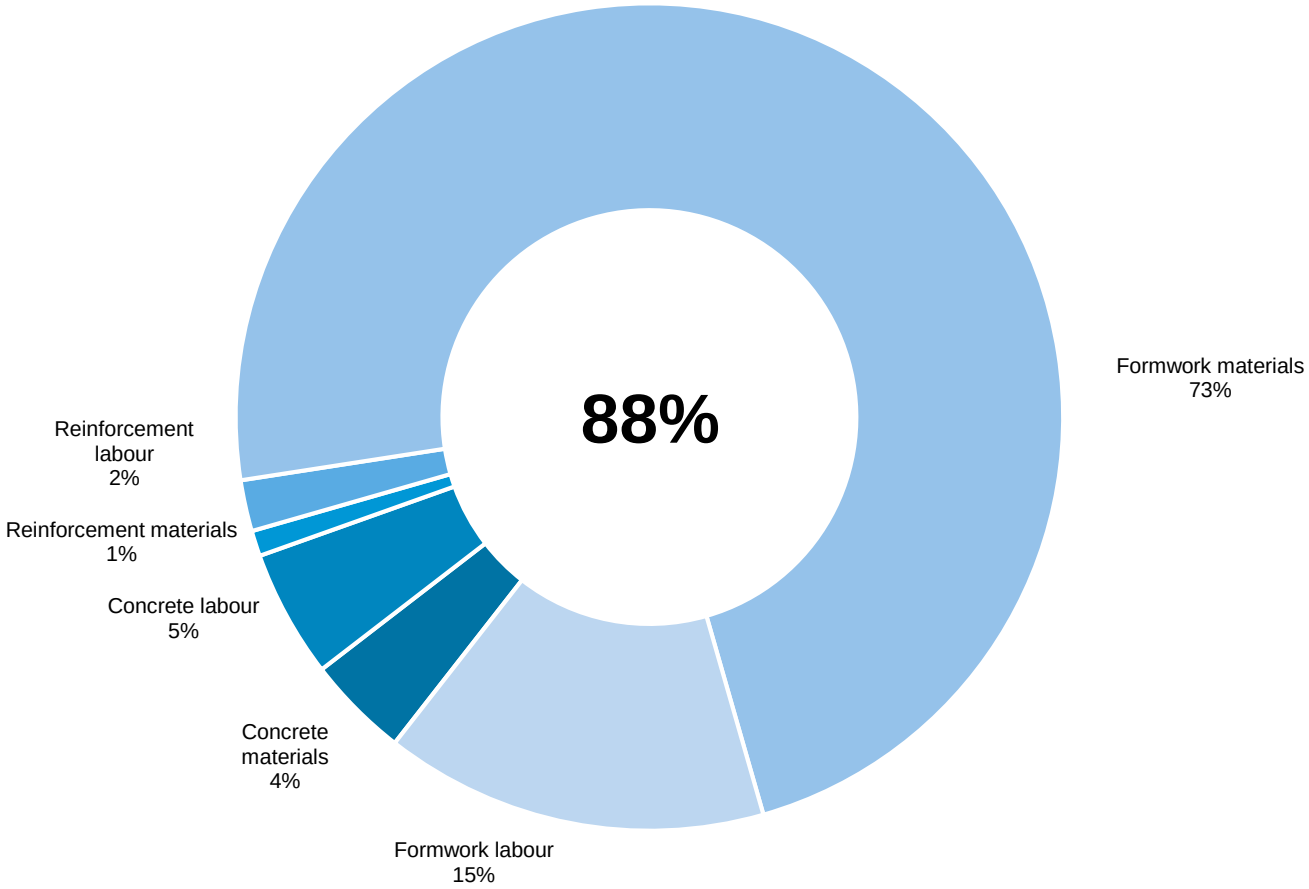
Gramazio Kohler Research
ETH Zurich

Standard formwork: Cost distribution



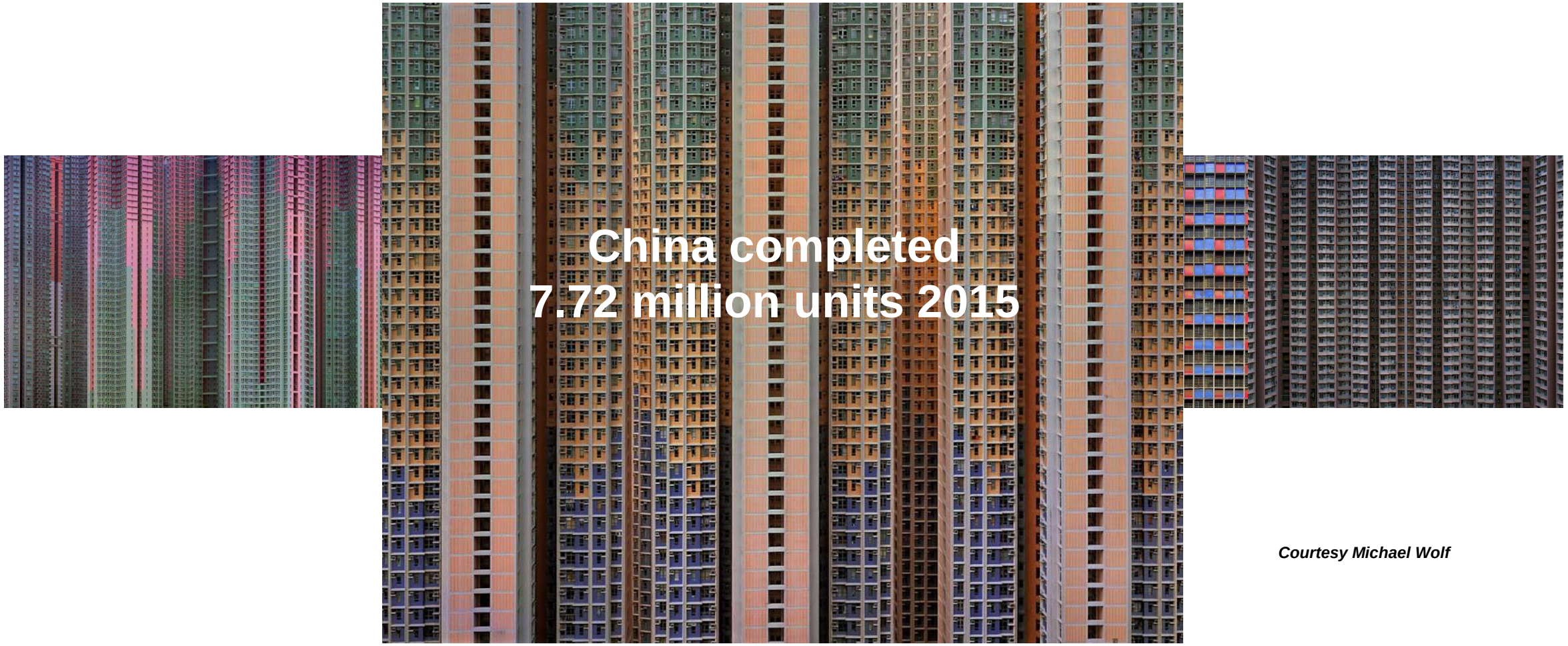
H. Robert, Structure Magazine, April 2007

Non-Standard formwork: Cost distribution



H. Robert, Structure Magazine, April 2007

Standard Architecture

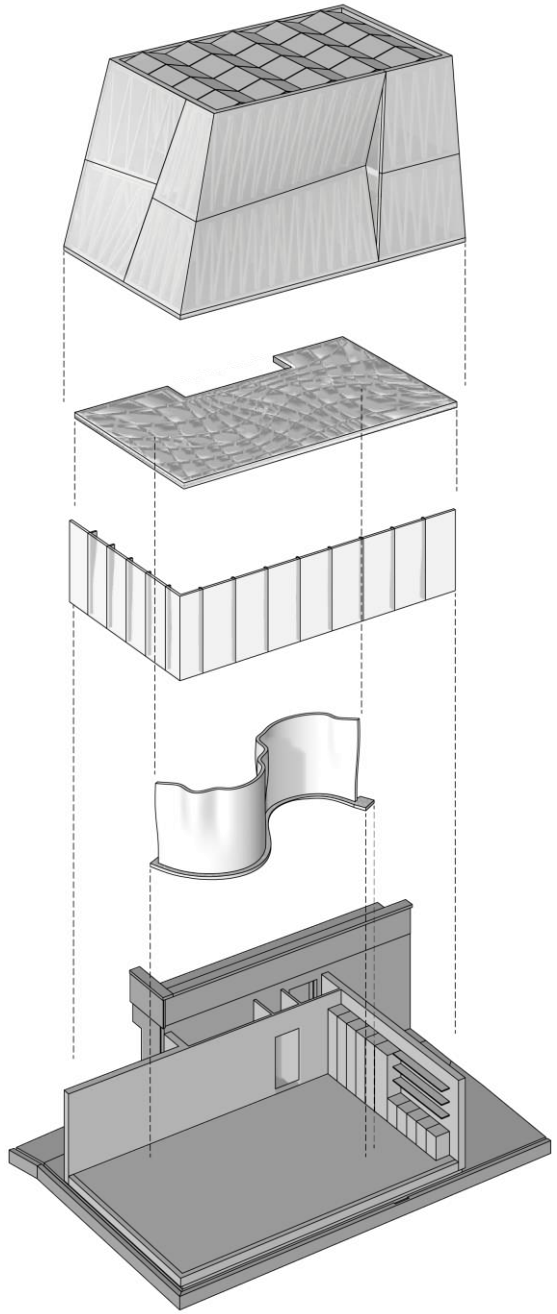


Courtesy Michael Wolf

DFAB HOUSE

Digital Fabrication and Living

DFAB HOUSE



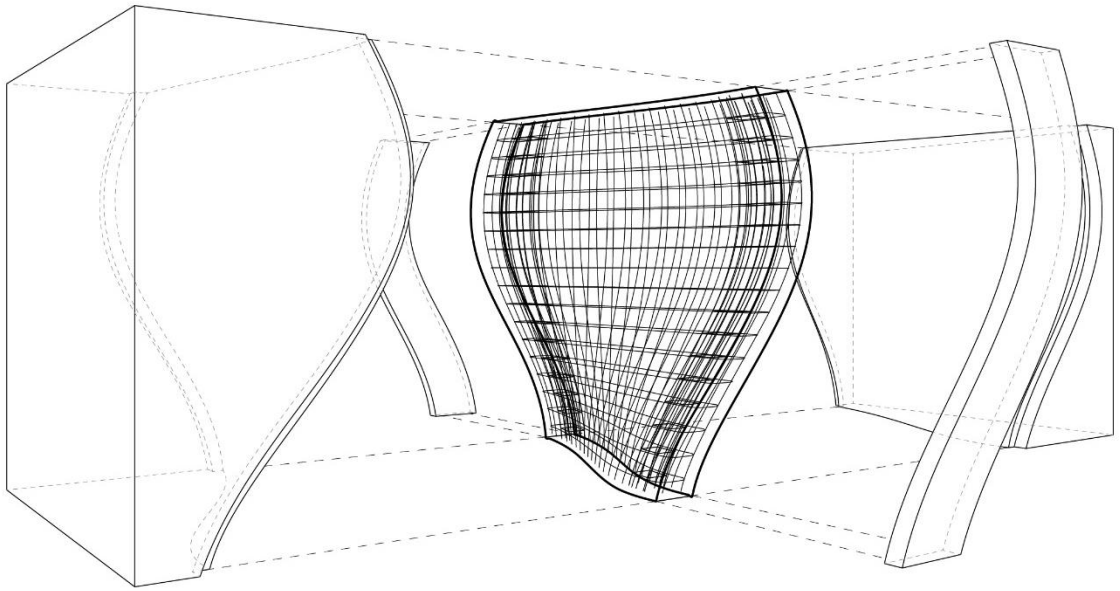
Spatial Timber Assemblies
Translucent Façade (Aero Gel)

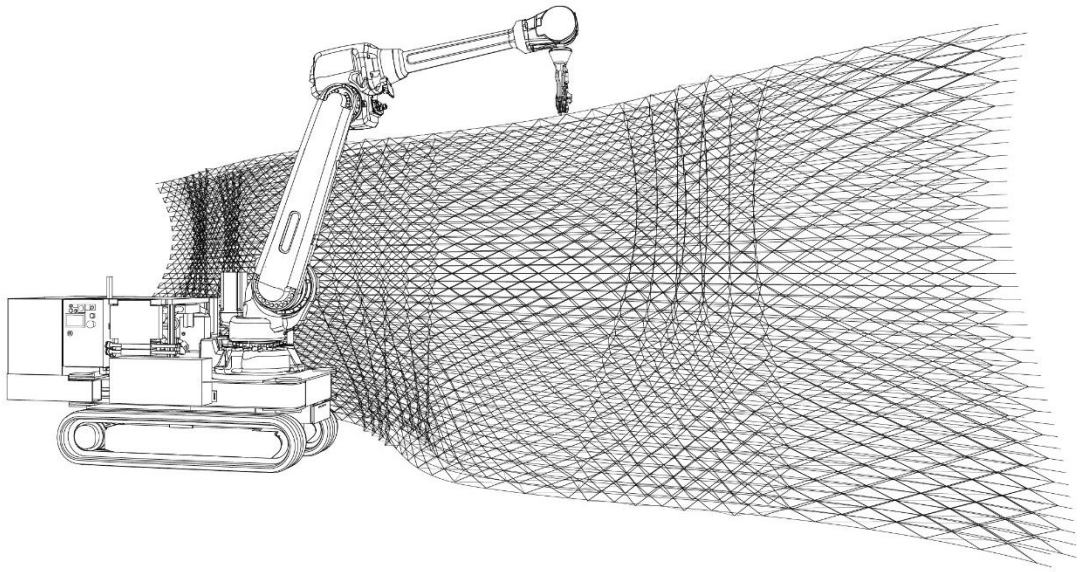
Smart Slab

Smart Dynamic Casting

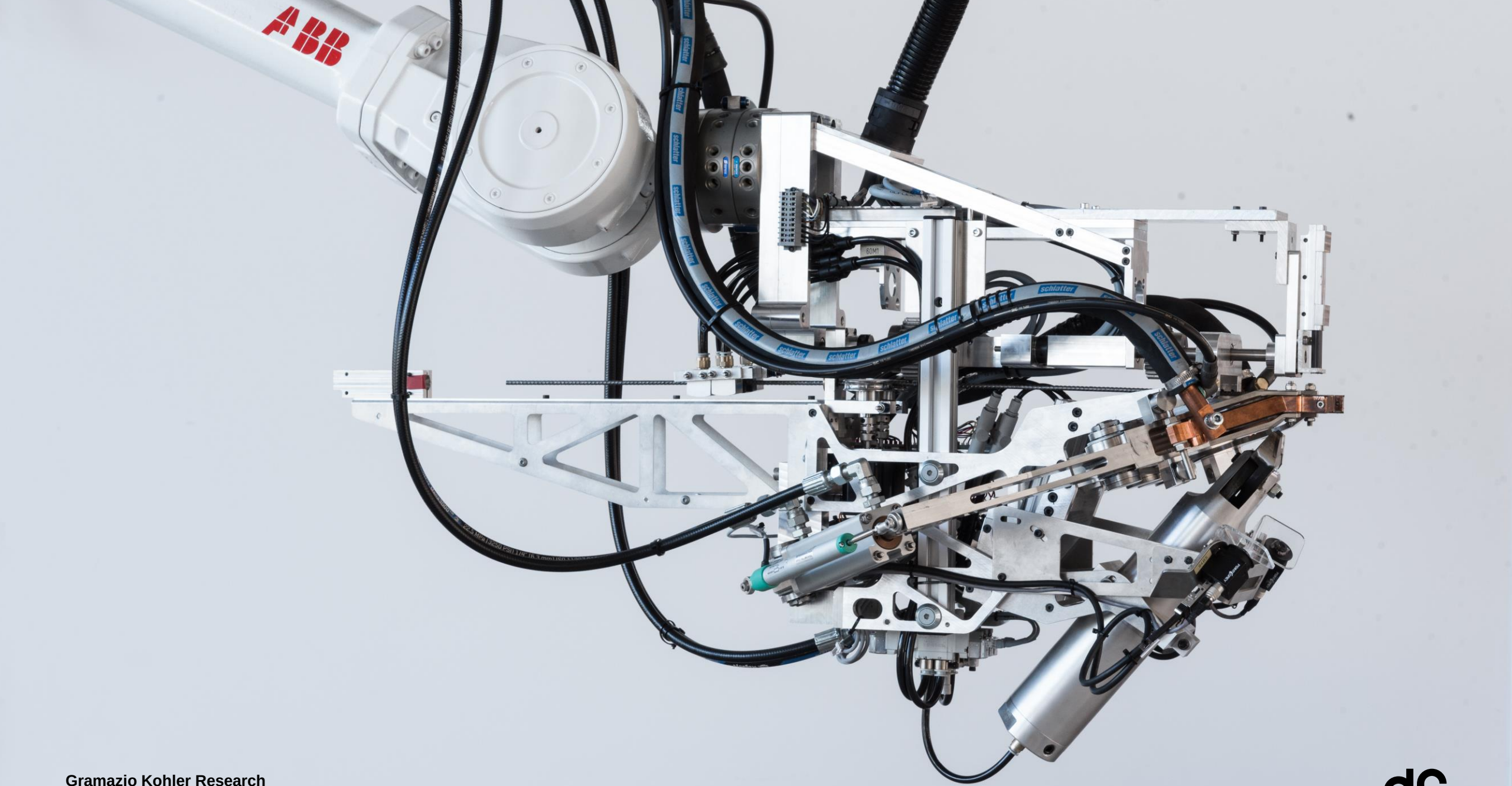
Mesh Mould
In Situ Fabricator

In situ Fabricator (IF) & Mesh Mould

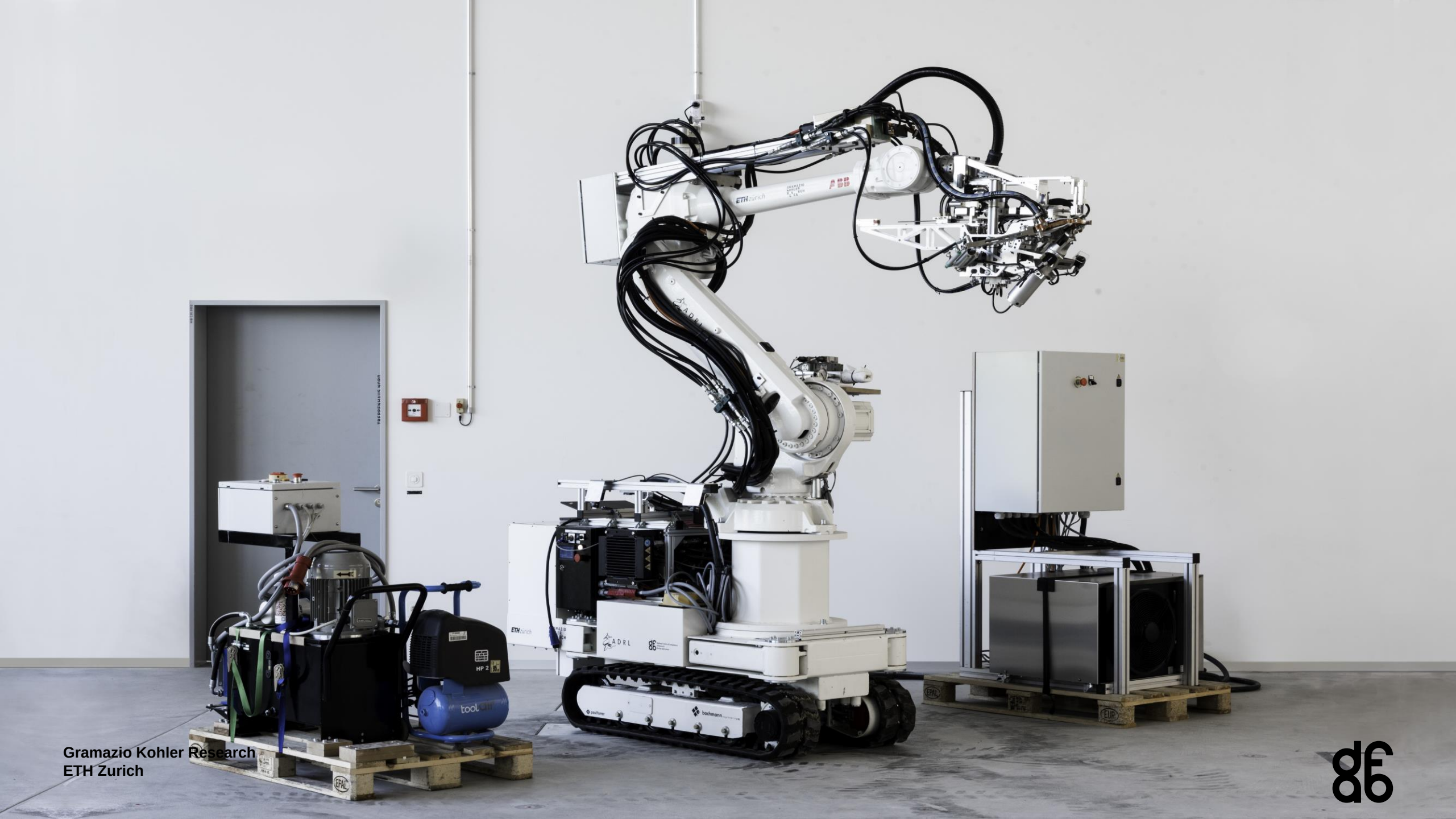




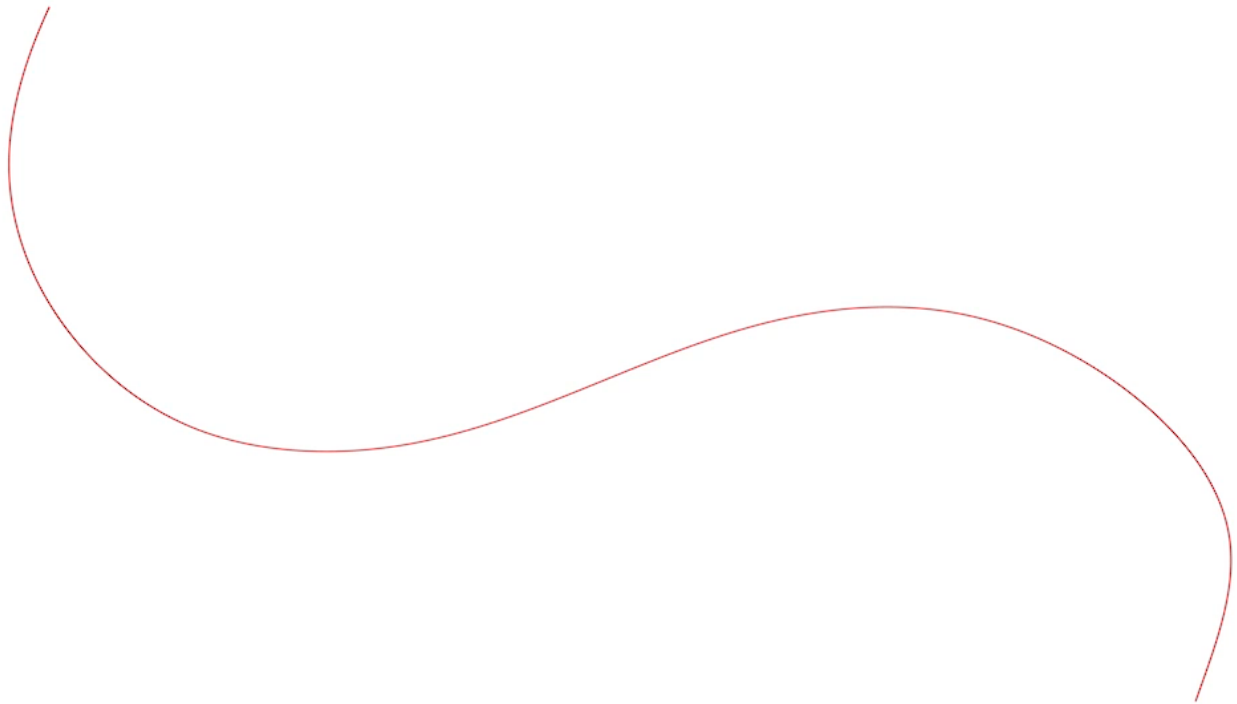
Left: Conventional fabrication method, Right: Innovative fabrication process
Gramazio Kohler Research, ETH Zurich



Gramazio Kohler Research
ETH Zurich

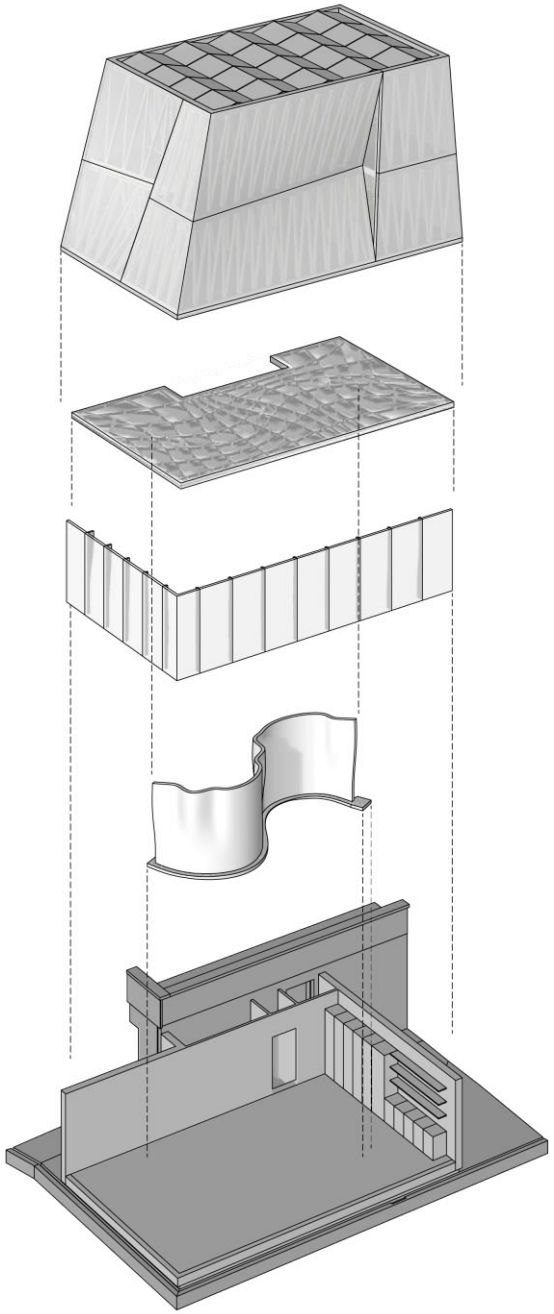


Gramazio Kohler Research
ETH Zurich



Gramazio Kohler Research / Institute for Building Materials
ETH Zurich

DFAB HOUSE



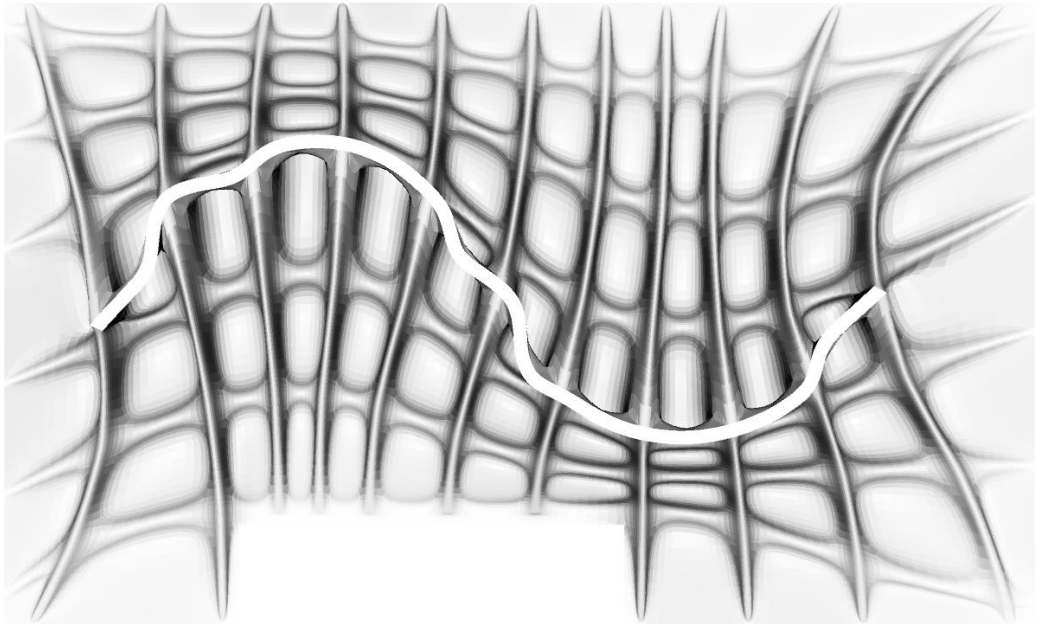
Spatial Timber Assemblies
Translucent Façade (Aero Gel)

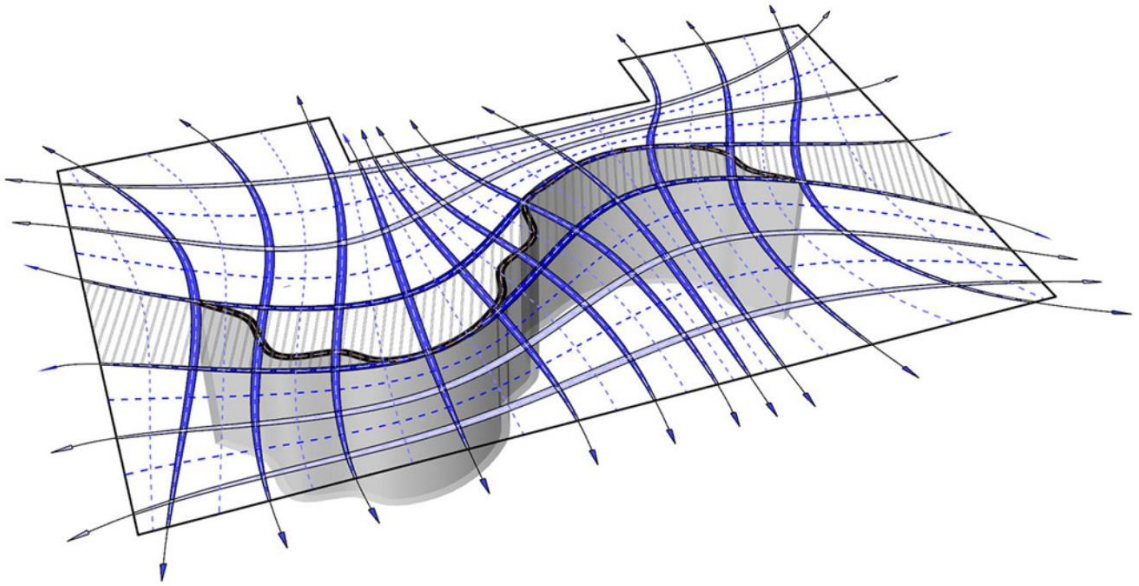
Smart Slab

Smart Dynamic Casting

Mesh Mould
In Situ Fabricator

Bespoke Design





Large-Scale 3D-Sand Printing

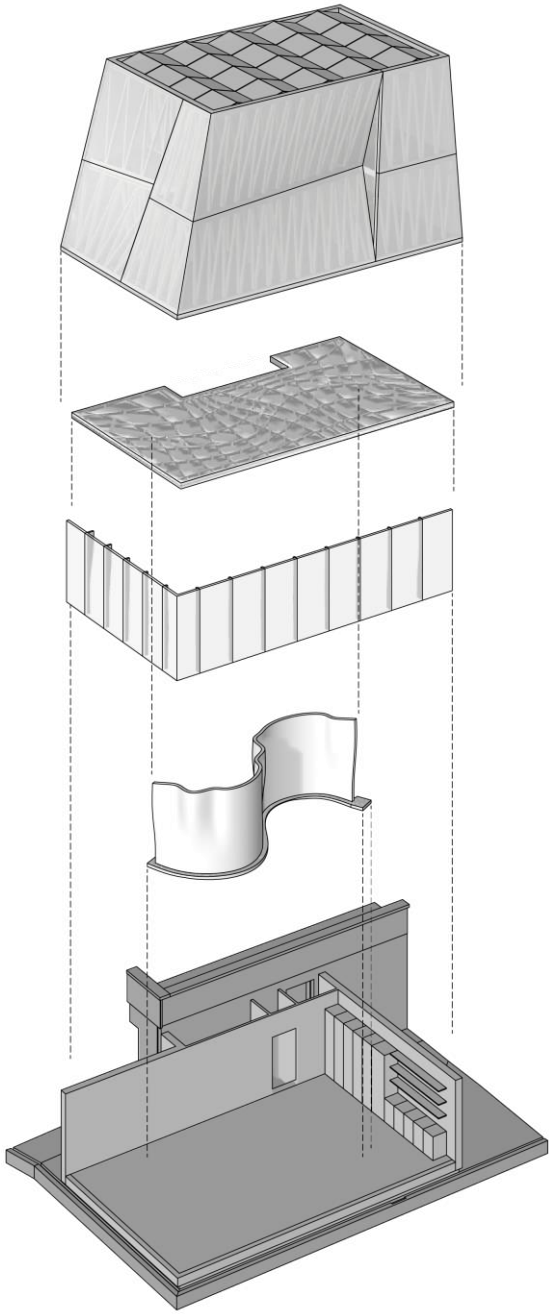
Voxeljet, 2018

Abb. (nächste 5 Folien): NFS Digitale Fabrikation / digital building technologies, Prof. Benjamin Dillenburger, ETH Zürich, 2018

Installation of Smart Slab Elements


70 % Material Reduction

DFAB HOUSE

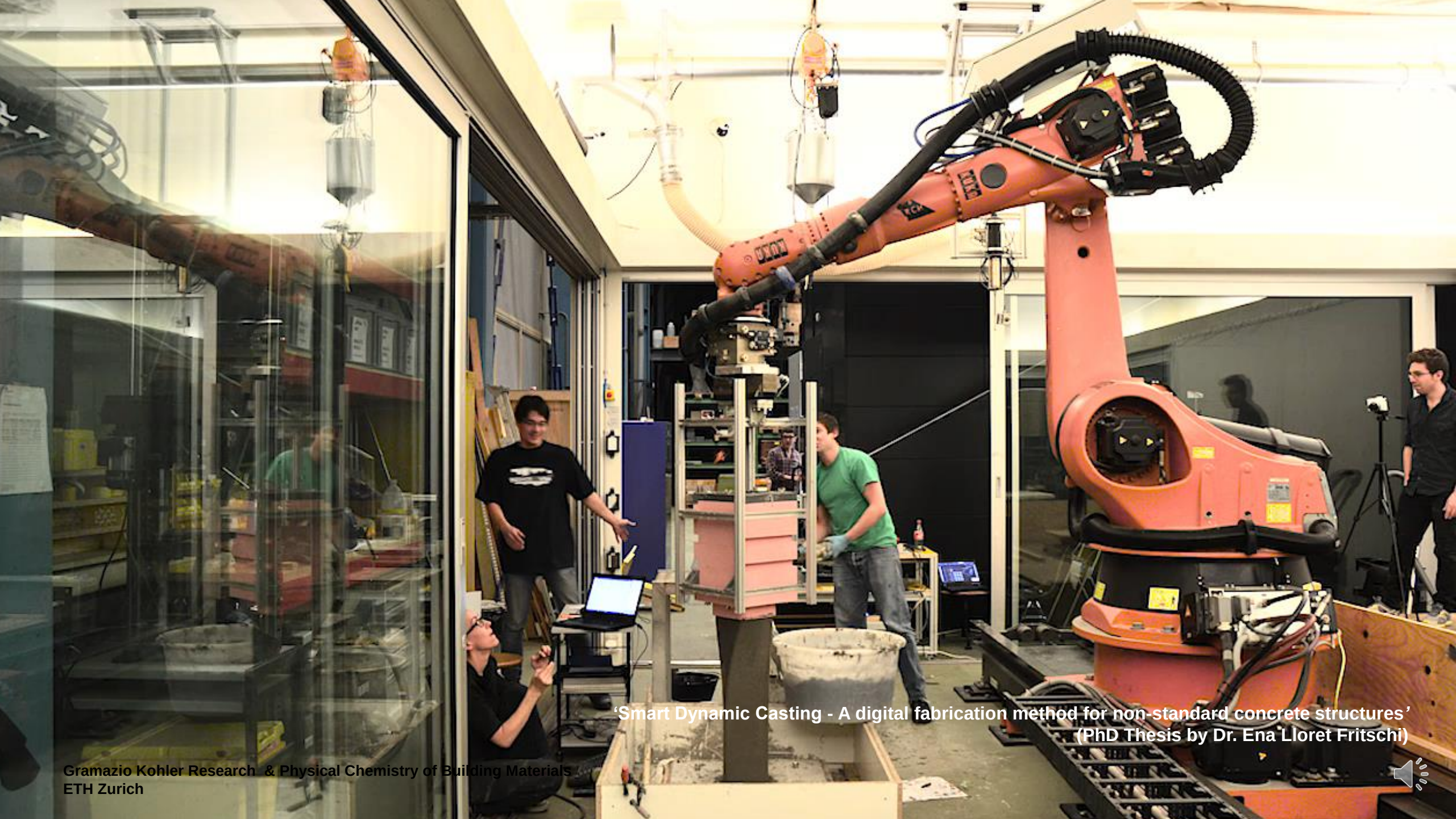


Spatial Timber Assemblies
Translucent Façade (Aero Gel)

Smart Slab

Smart Dynamic Casting

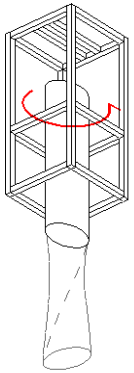
Mesh Mould
In Situ Fabricator



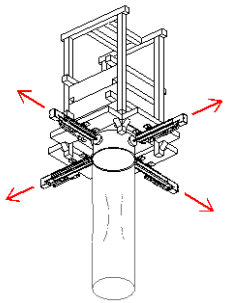
‘Smart Dynamic Casting - A digital fabrication method for non-standard concrete structures’
(PhD Thesis by Dr. Ena Lloret Fritschi)

Gramazio Kohler Research & Physical Chemistry of Building Materials
ETH Zurich

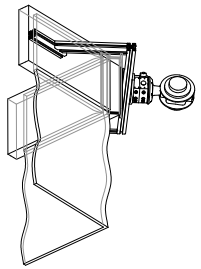
Introduction Formwork types



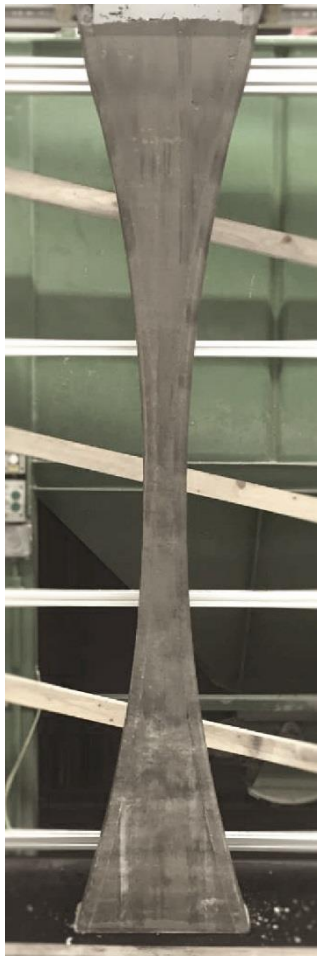
A

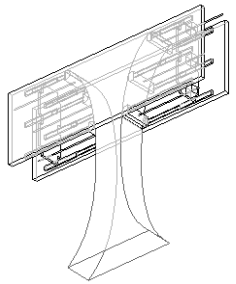


B



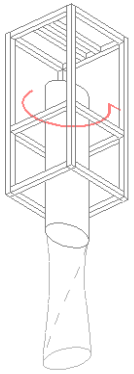
C



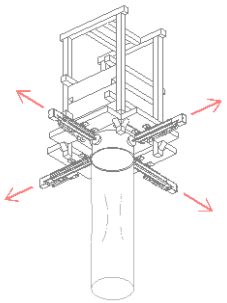


D

Introduction Formwork types



A



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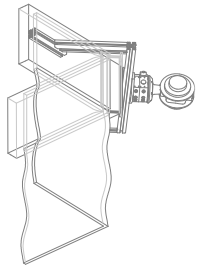

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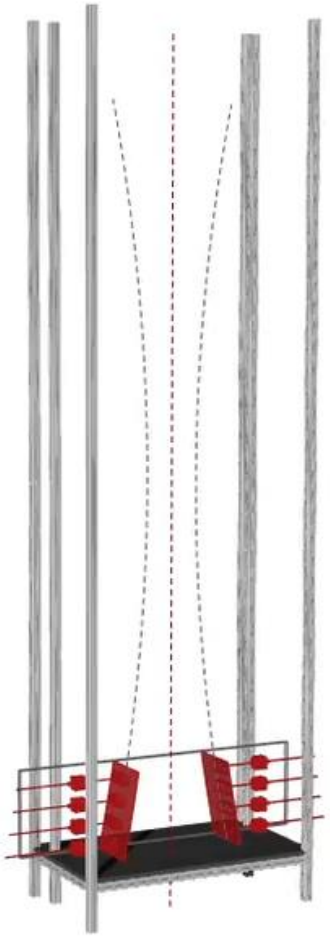
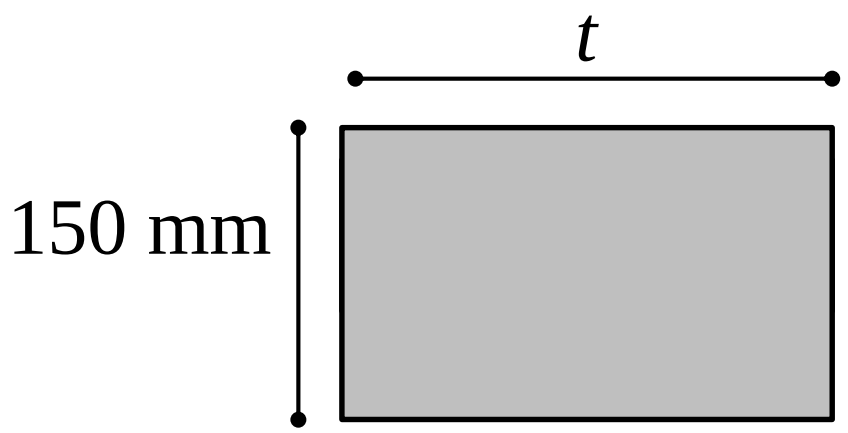
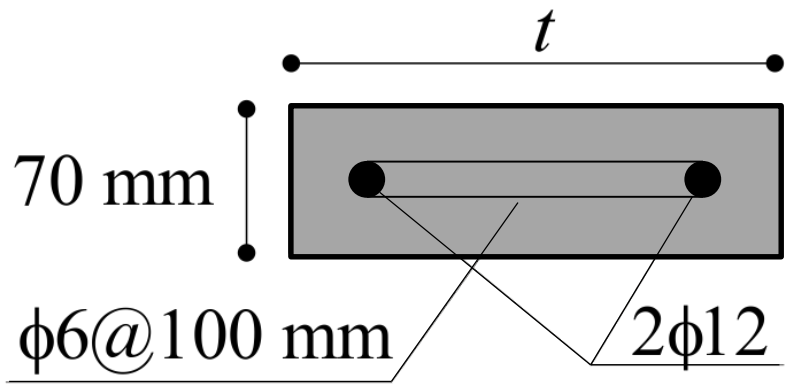


D

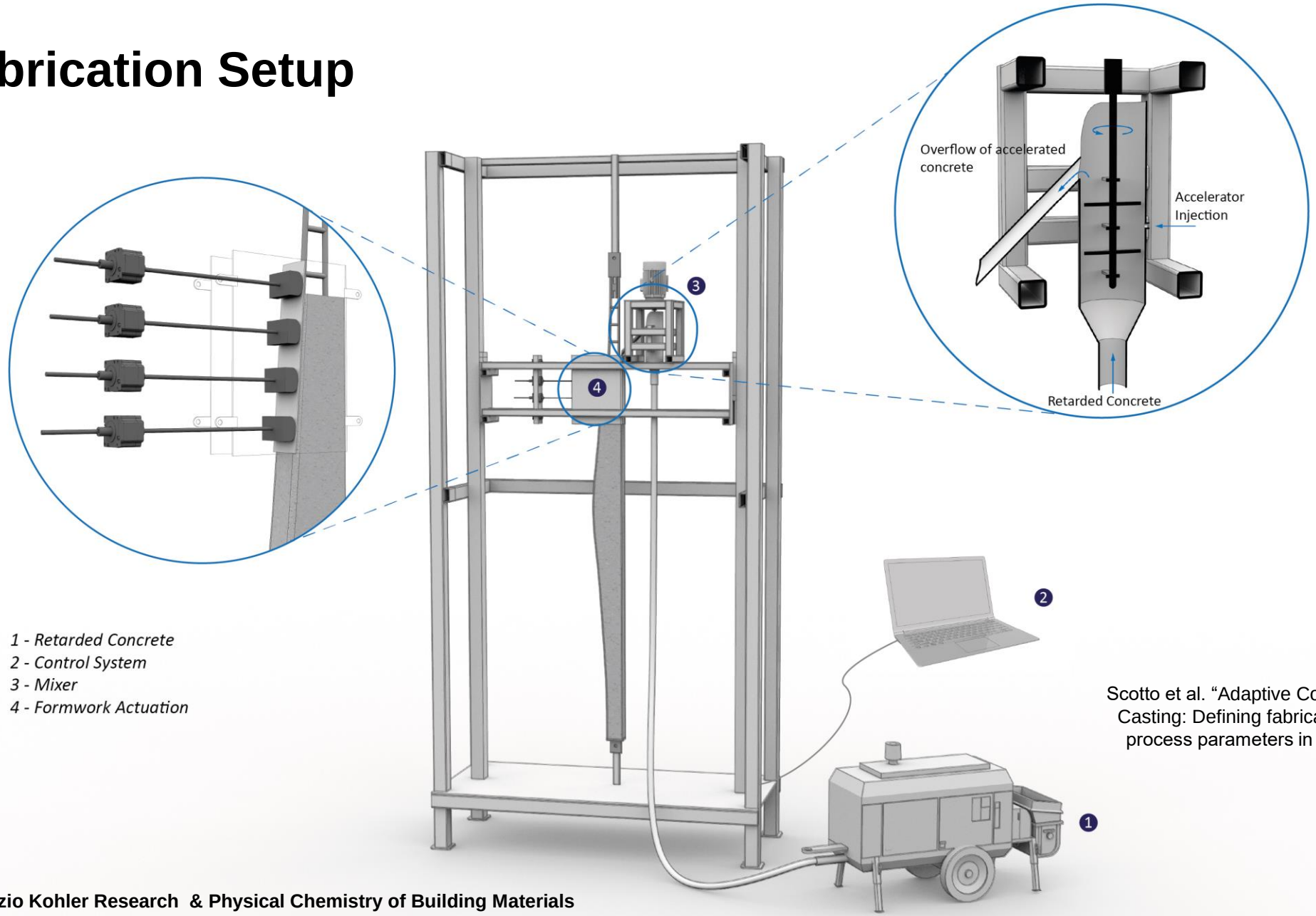
DFAB House design challenge



DFAB House design challenge



Fabrication Setup

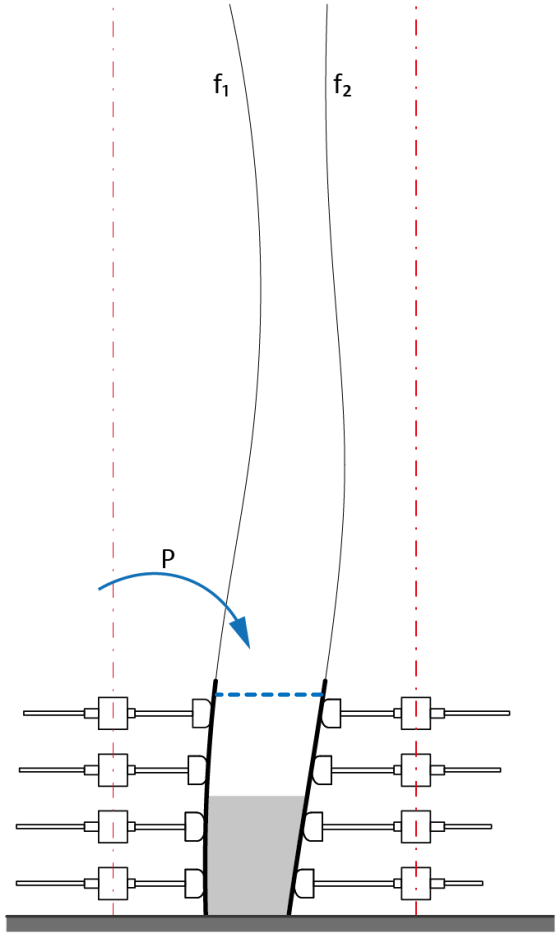


1 - Retarded Concrete
2 - Control System
3 - Mixer
4 - Formwork Actuation

Scotto et al. “Adaptive Control System for Smart Dynamic Casting: Defining fabrication-informed design tools and process parameters in Digital Fabrication processes”

Gramazio Kohler Research & Physical Chemistry of Building Materials
ETH Zurich

Fabrication Parameters



1 Fill concrete into formwork with pumping rate P;

2 Move formwork vertically with speed V. Update horizontal position of actuators (H) along the fabrication path f;

3 Repeat process to the end of fabrication path;

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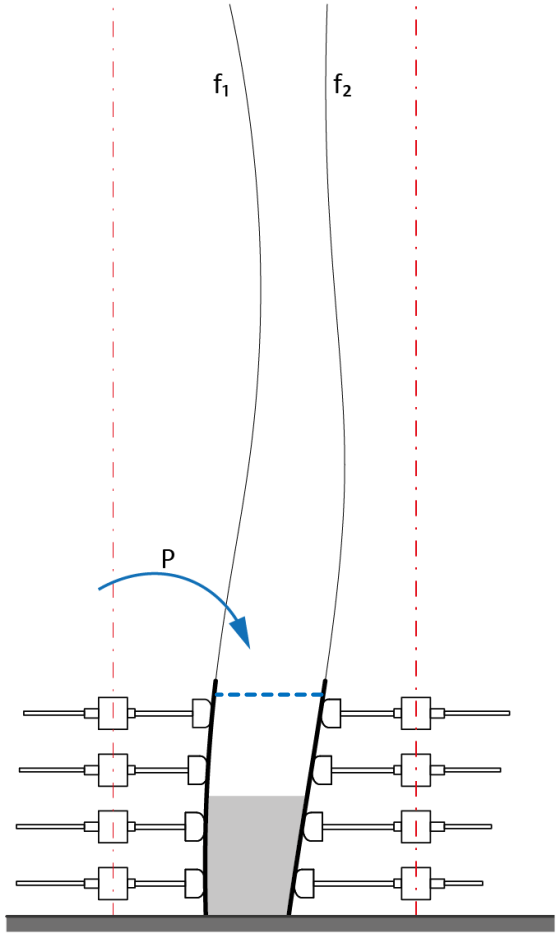
ETH Zurich

Fabrication Parameters



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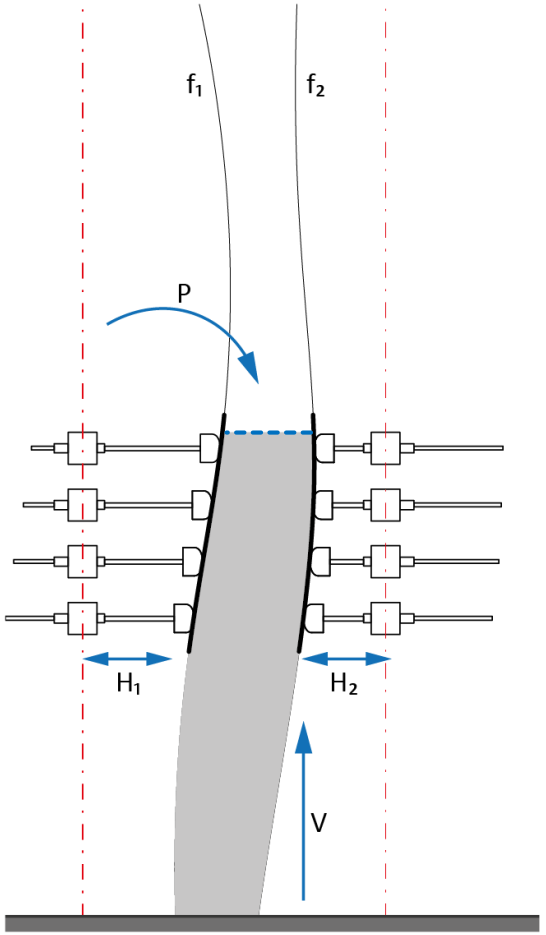

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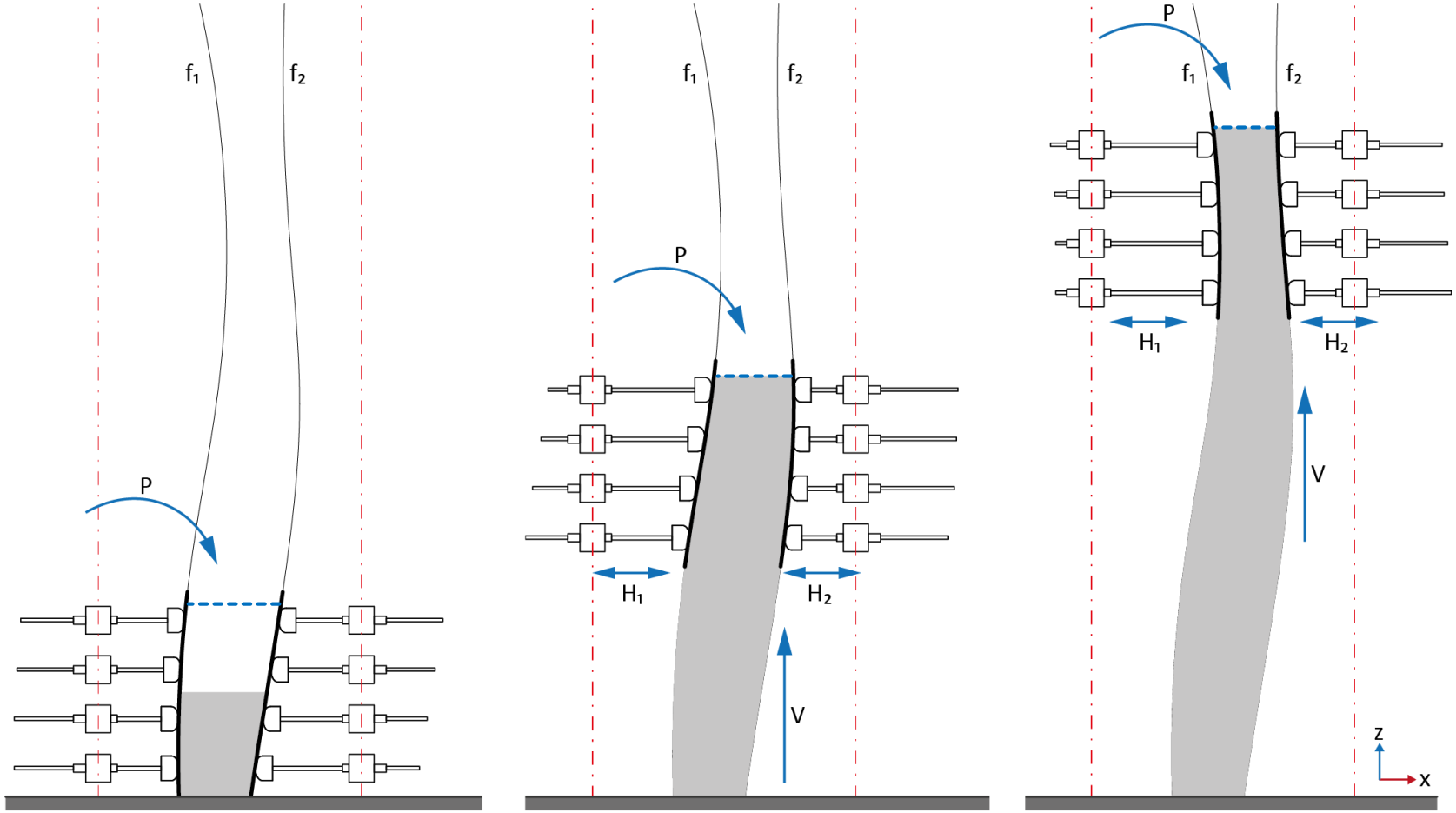
ETH Zurich

Fabrication Parameters



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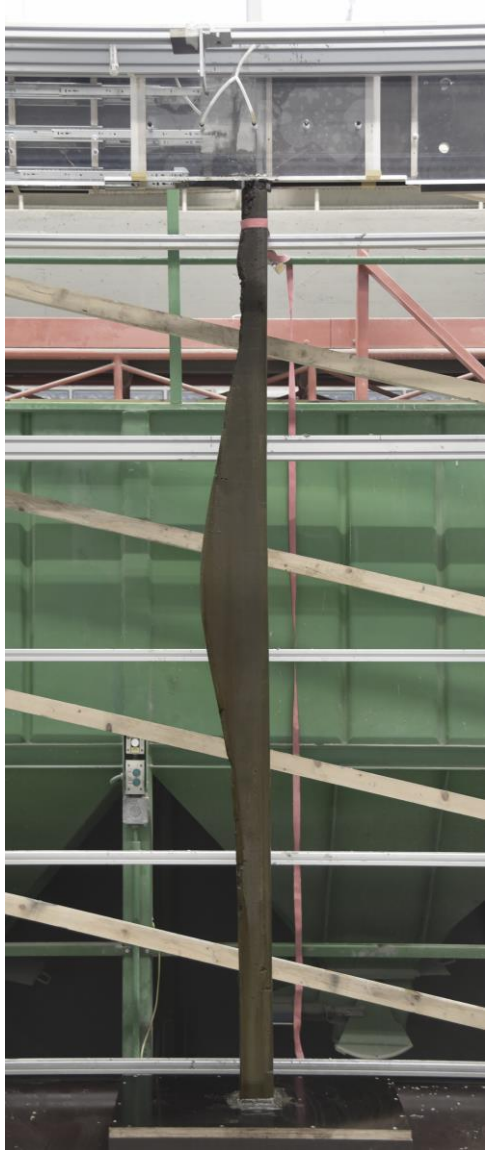
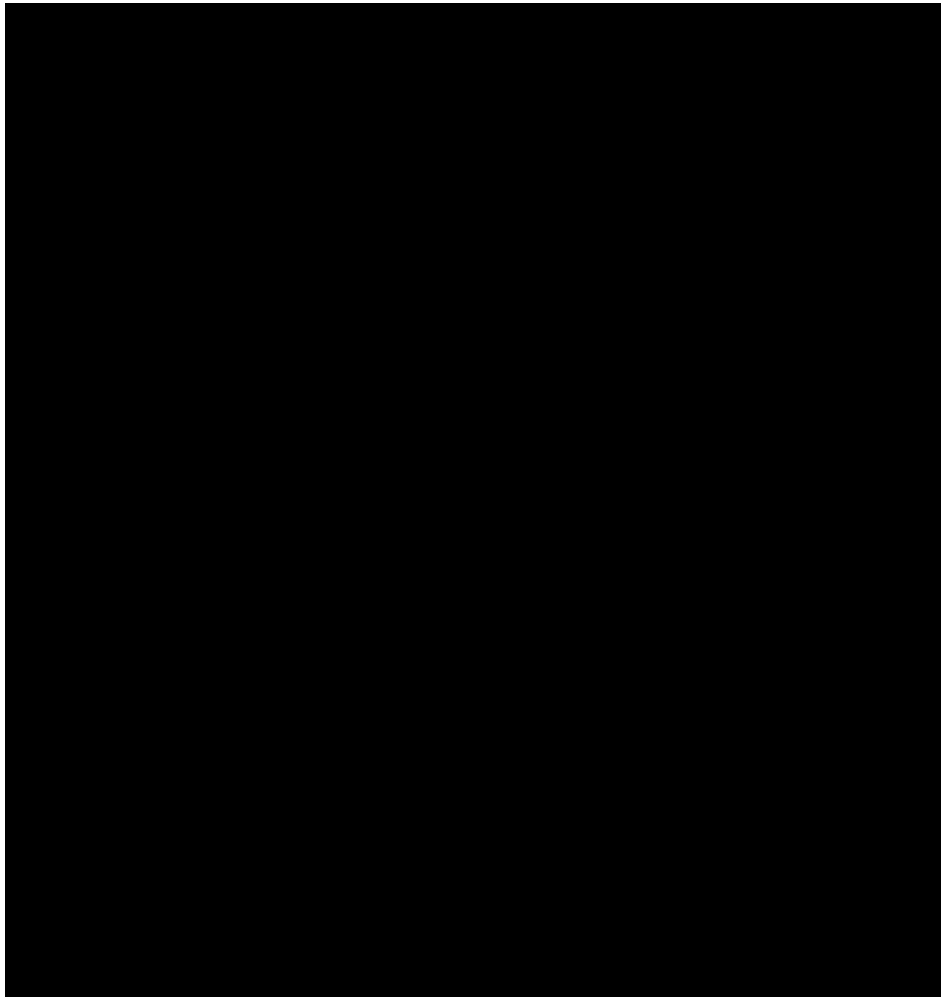
Fabrication





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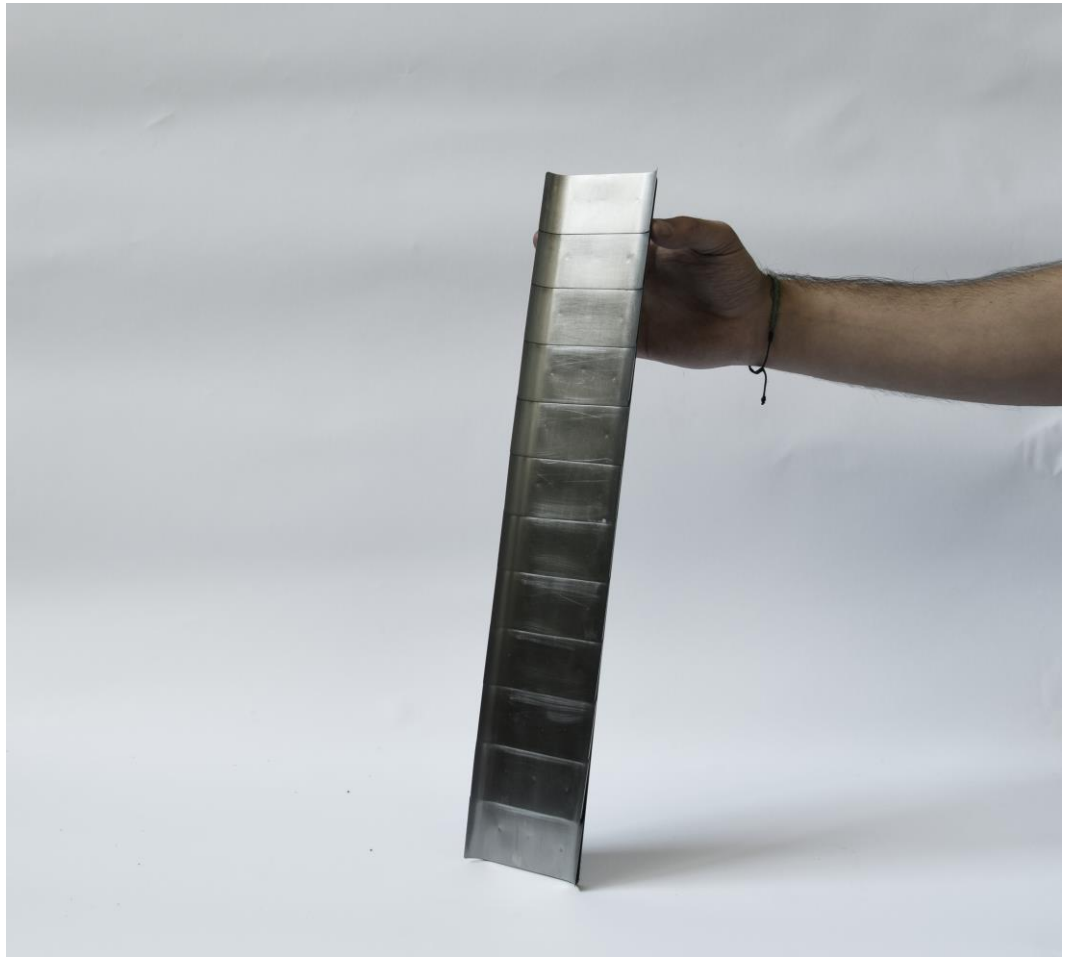
ETH Zurich

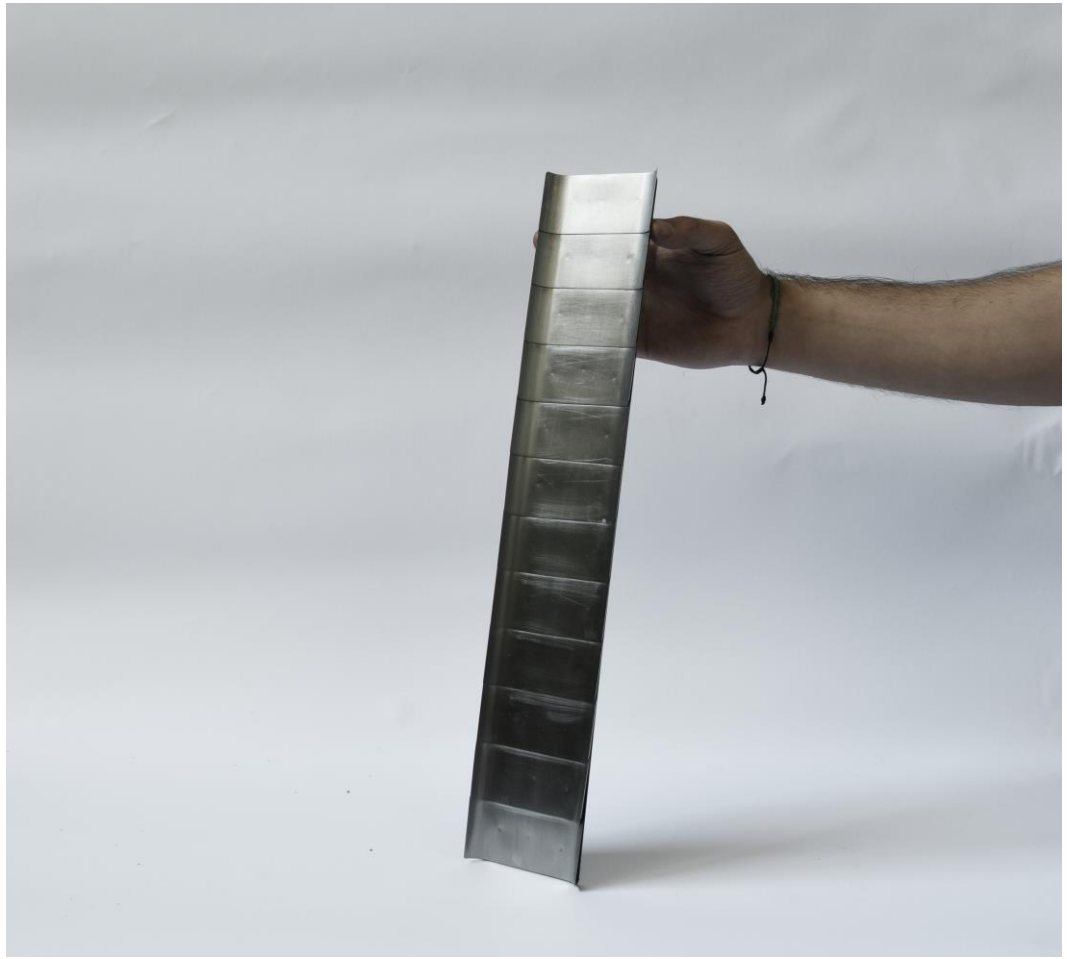
Formwork

Formwork – Shell

Formwork – Shaping Strip



Formwork – Shaping Strip



Formwork - Actuators

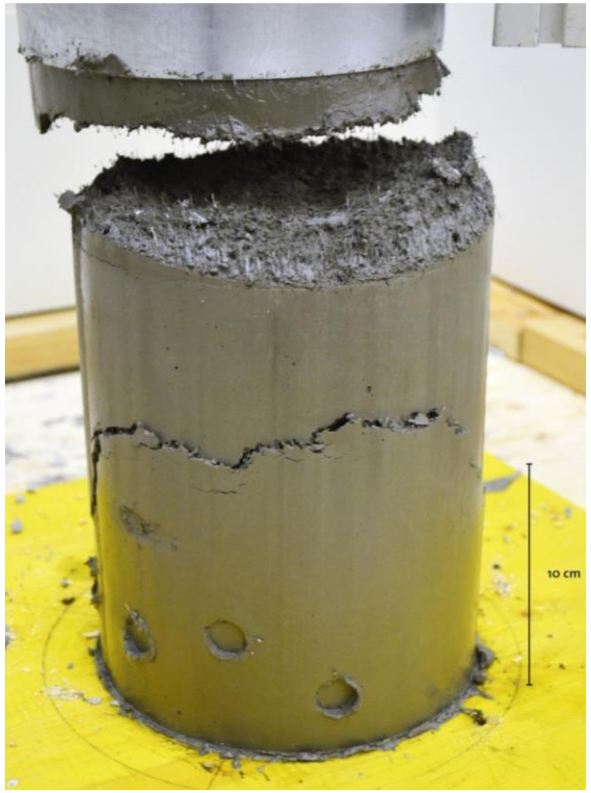
Image by Flavio Pinton – Rich Media Producer – Zühlke Group

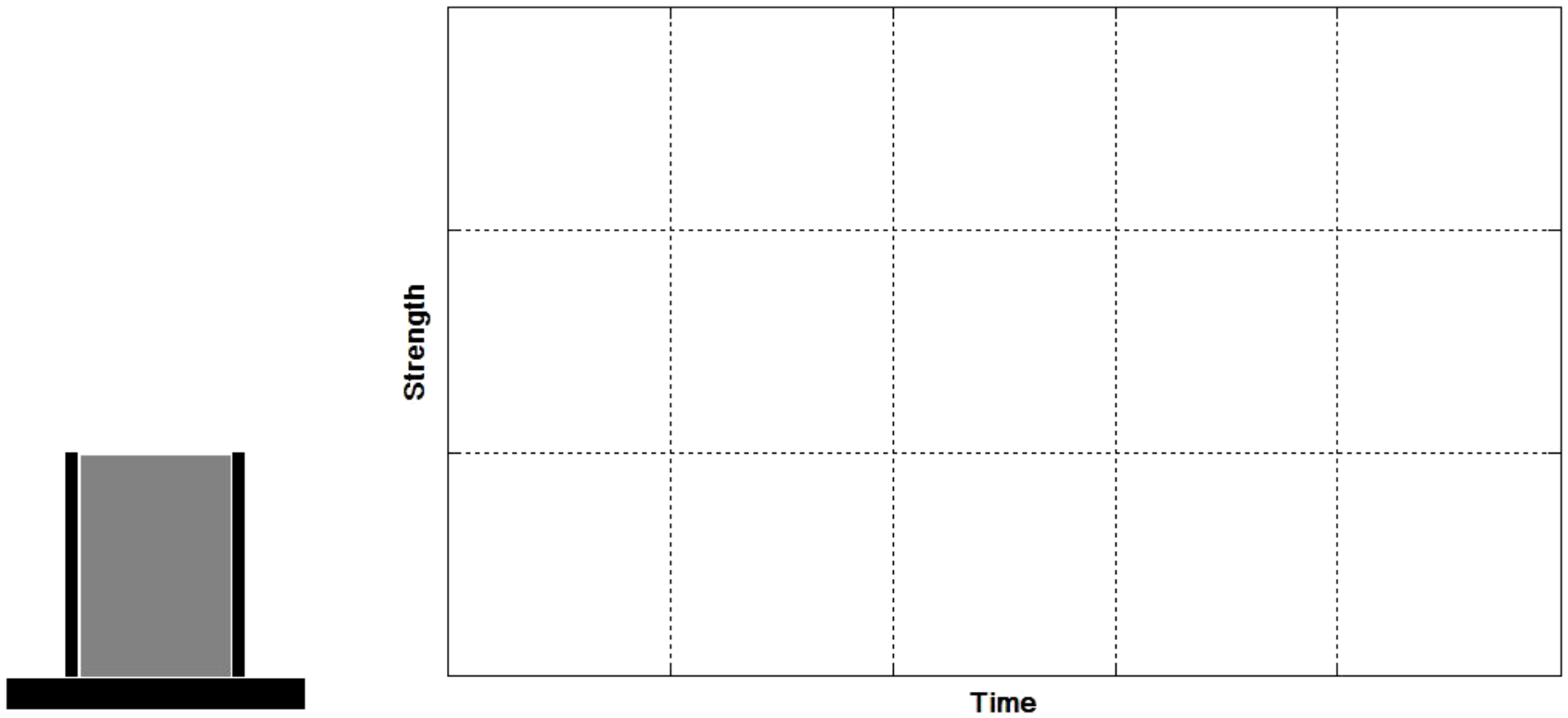
Material Mix

Material properties

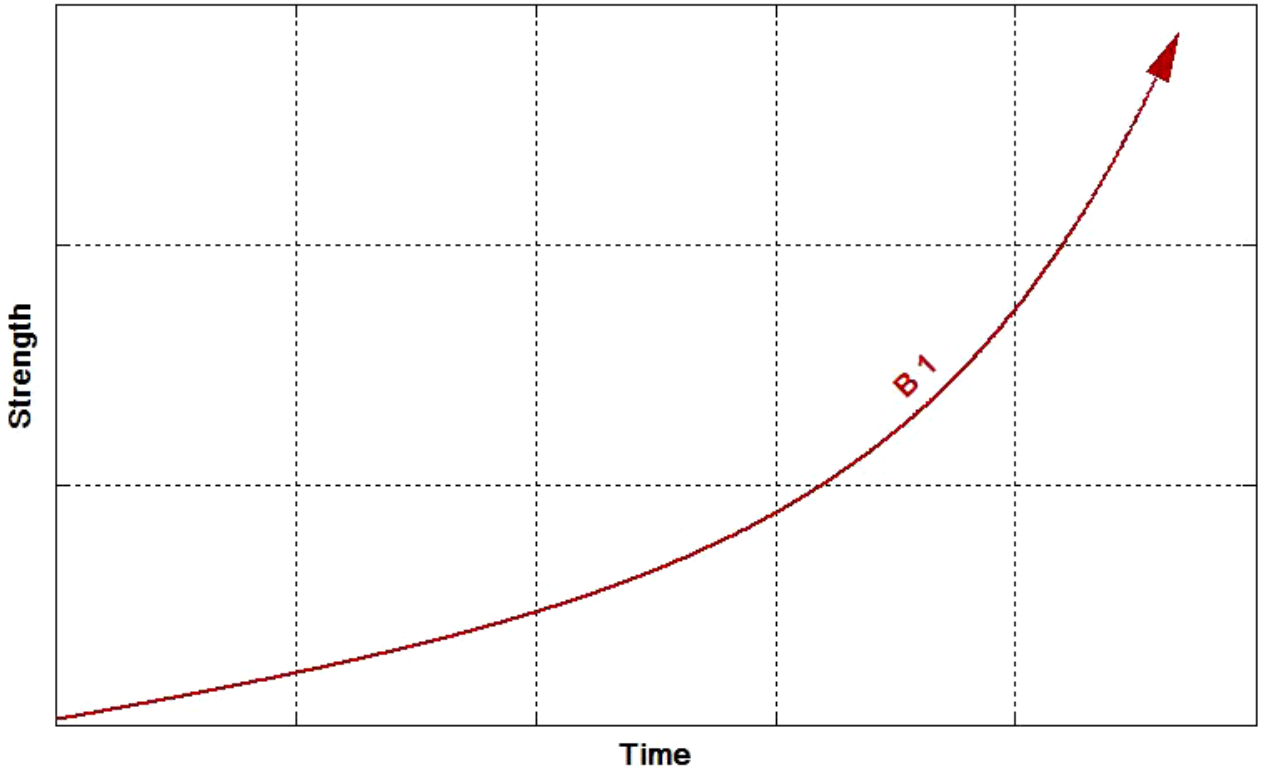
Too soft

Too hard





Lloret et al. "Smart Dynamic Casting: A robotic fabrication system for complex structures", In conference proceedings, of 1st Concrete Innovation Conference, (Oslo, Norway, 2014)



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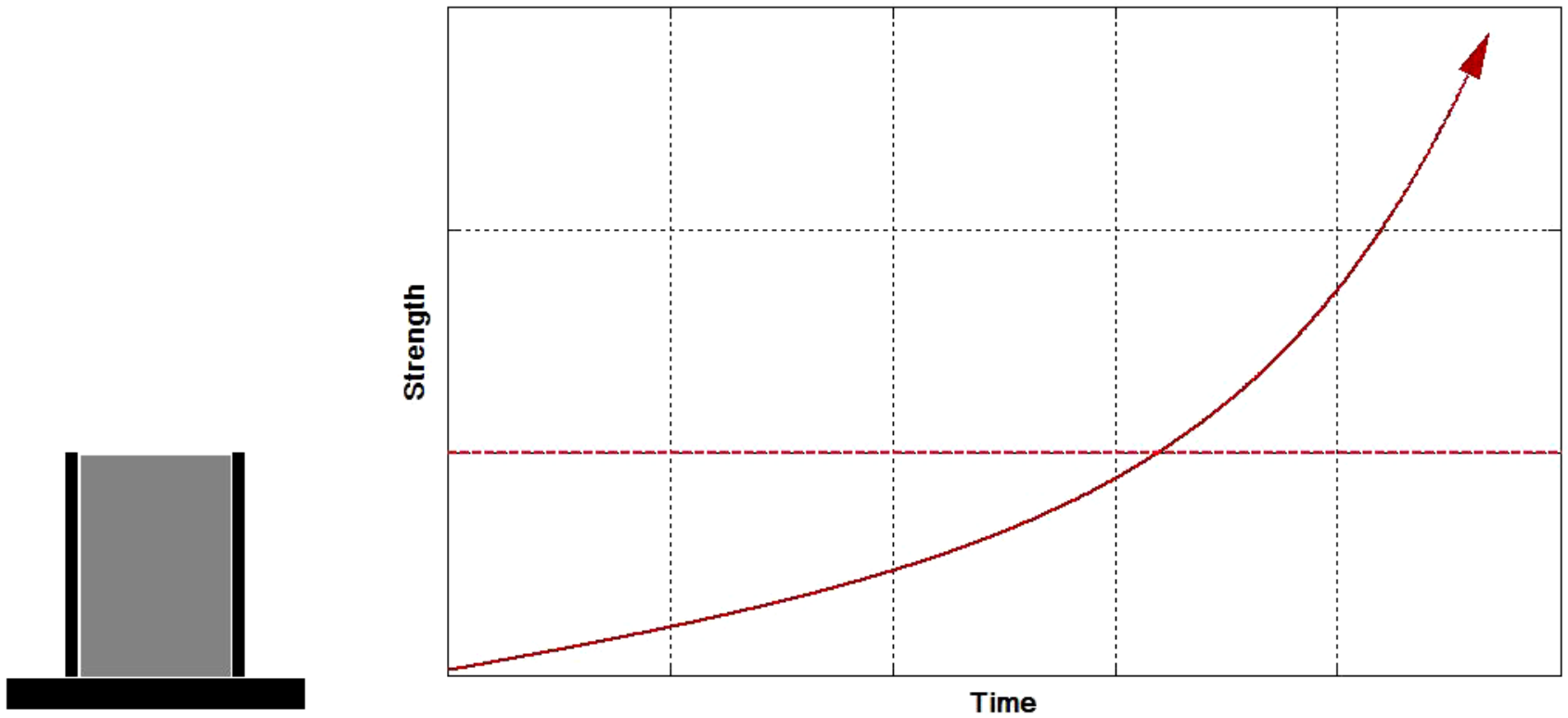

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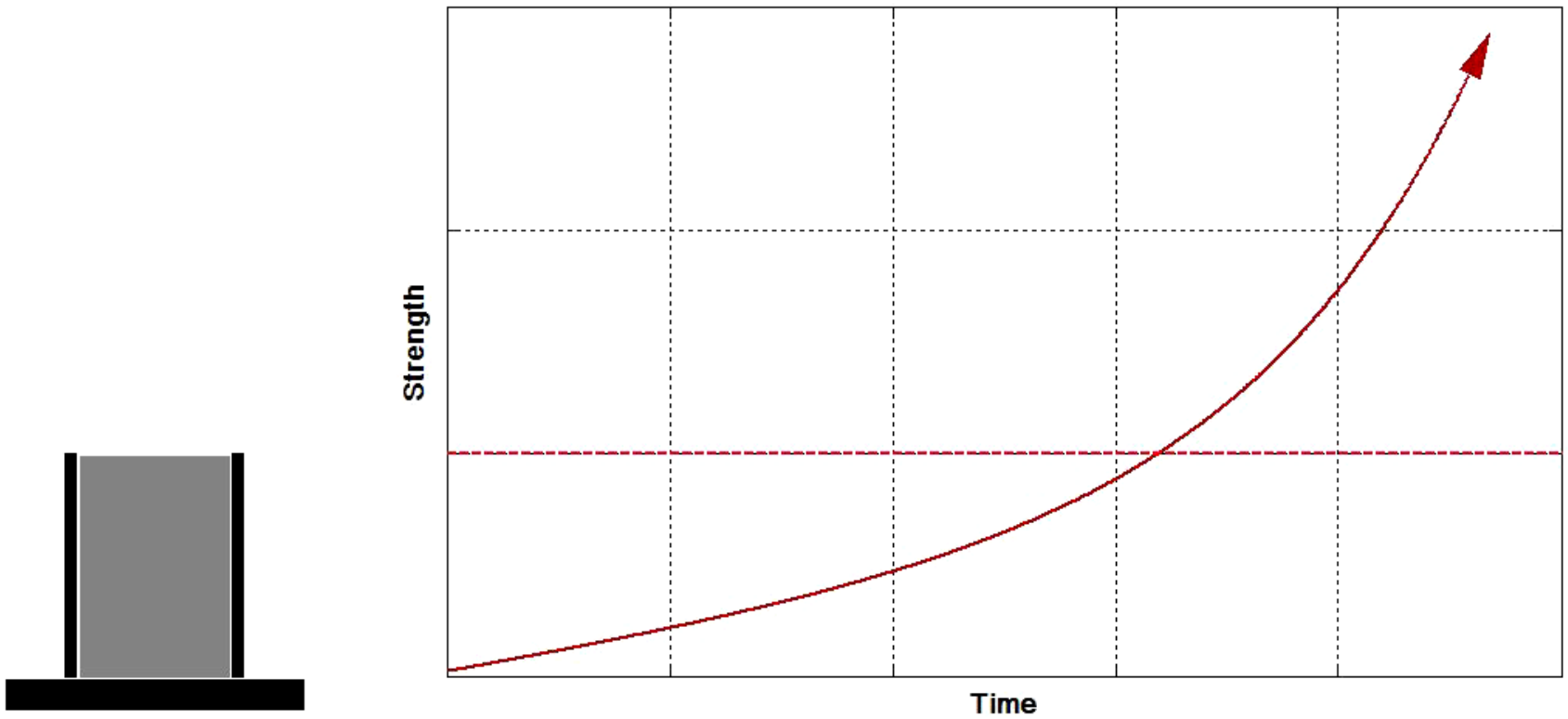

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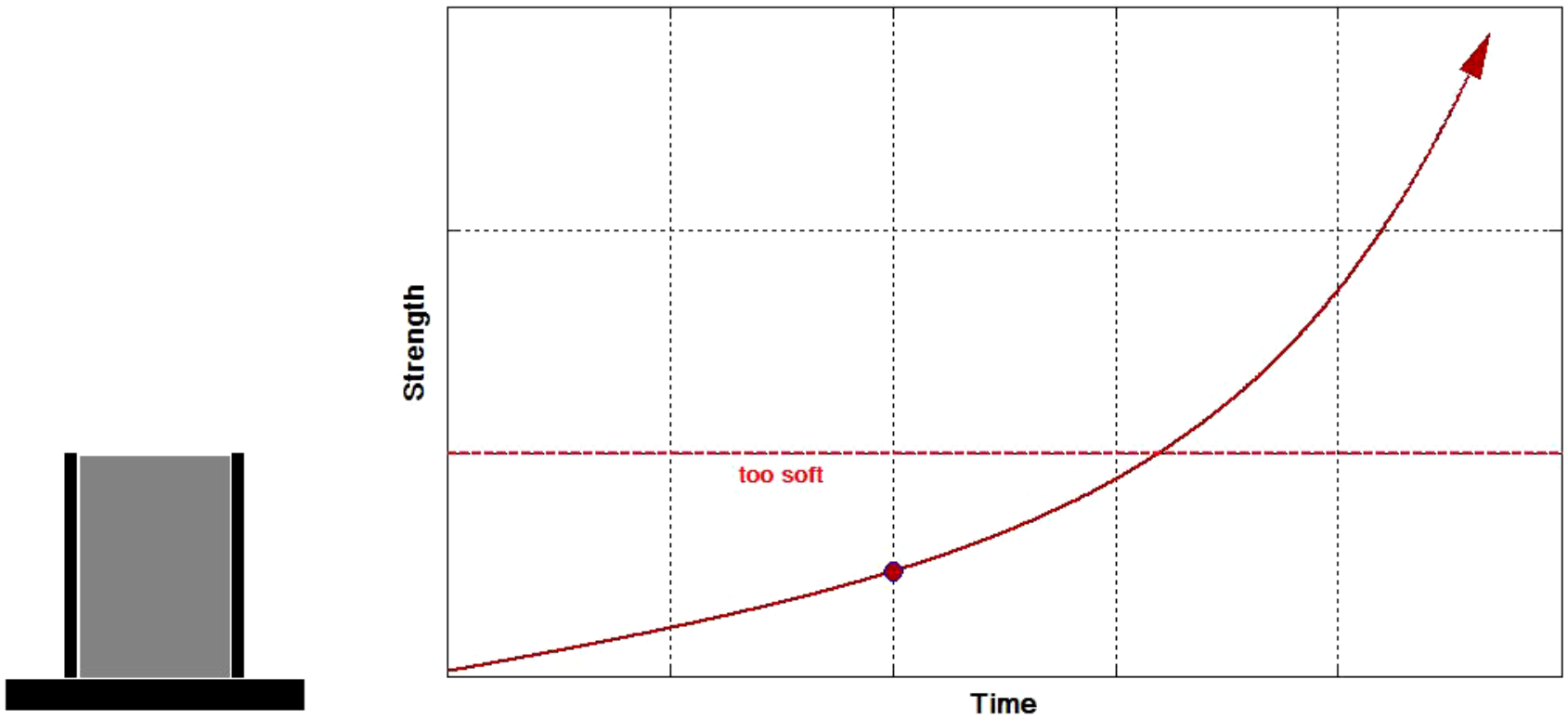

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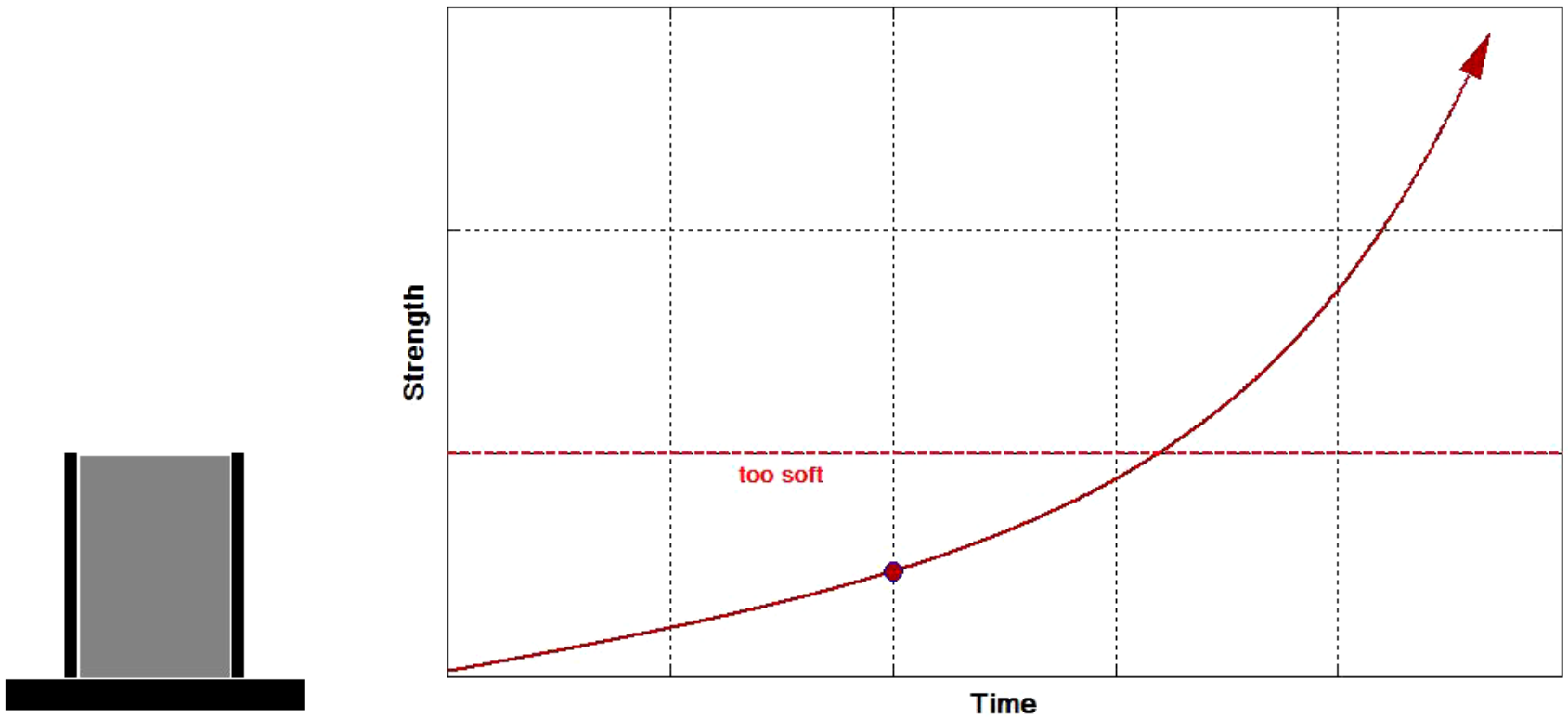

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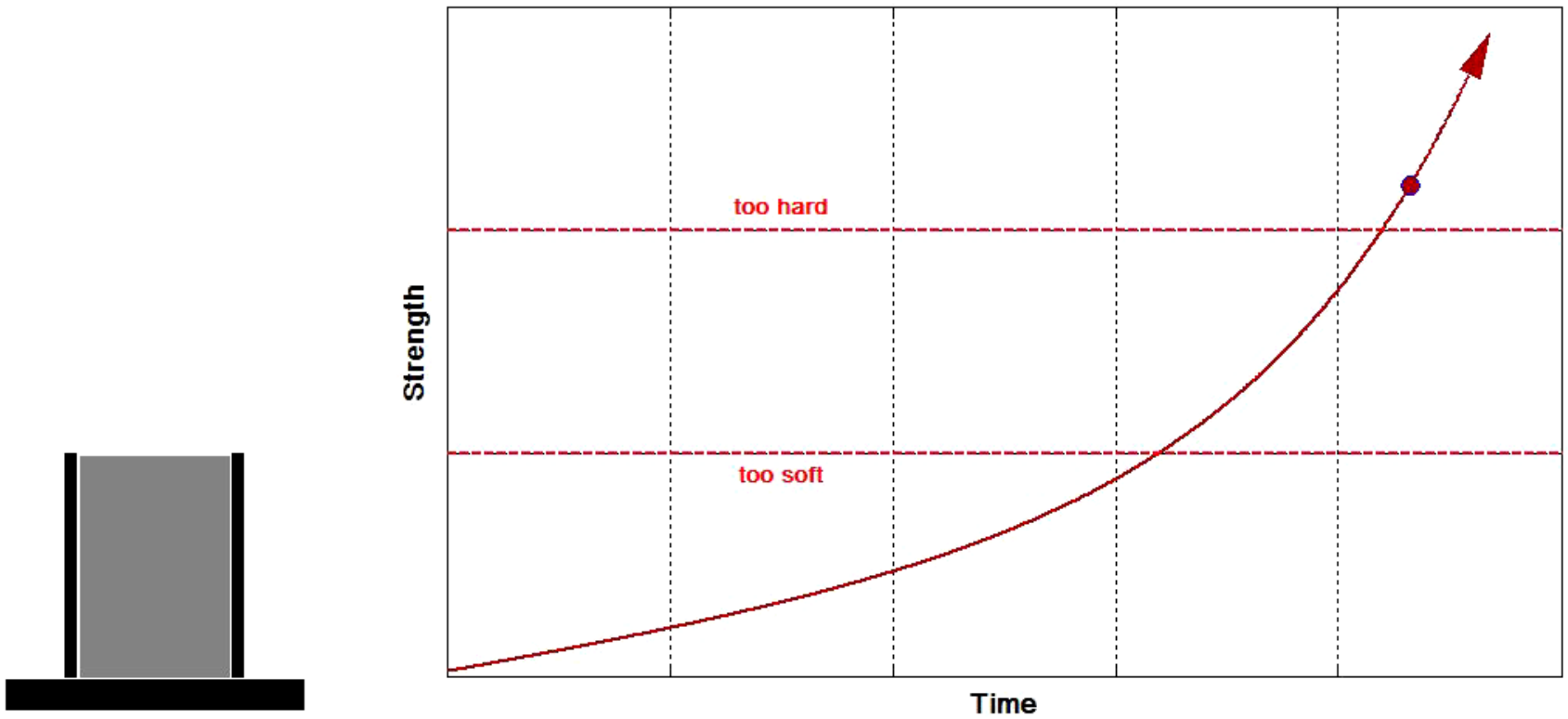

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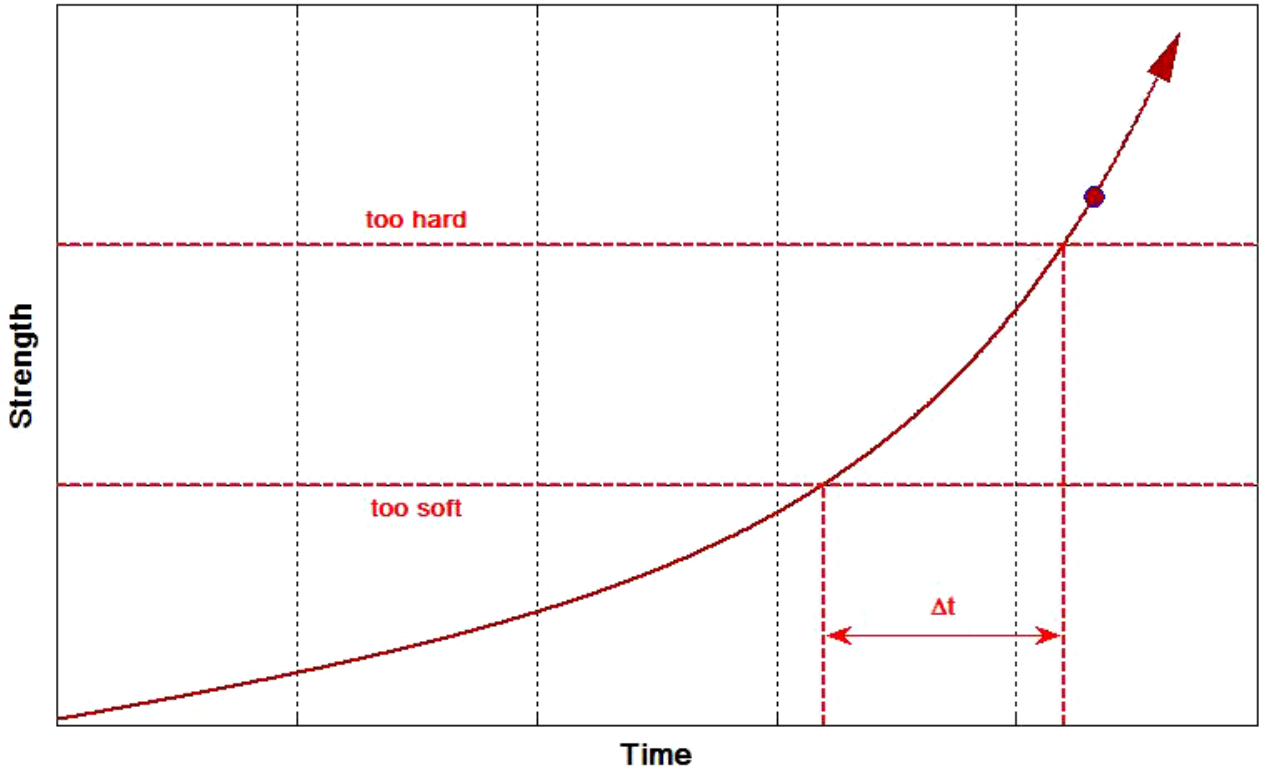

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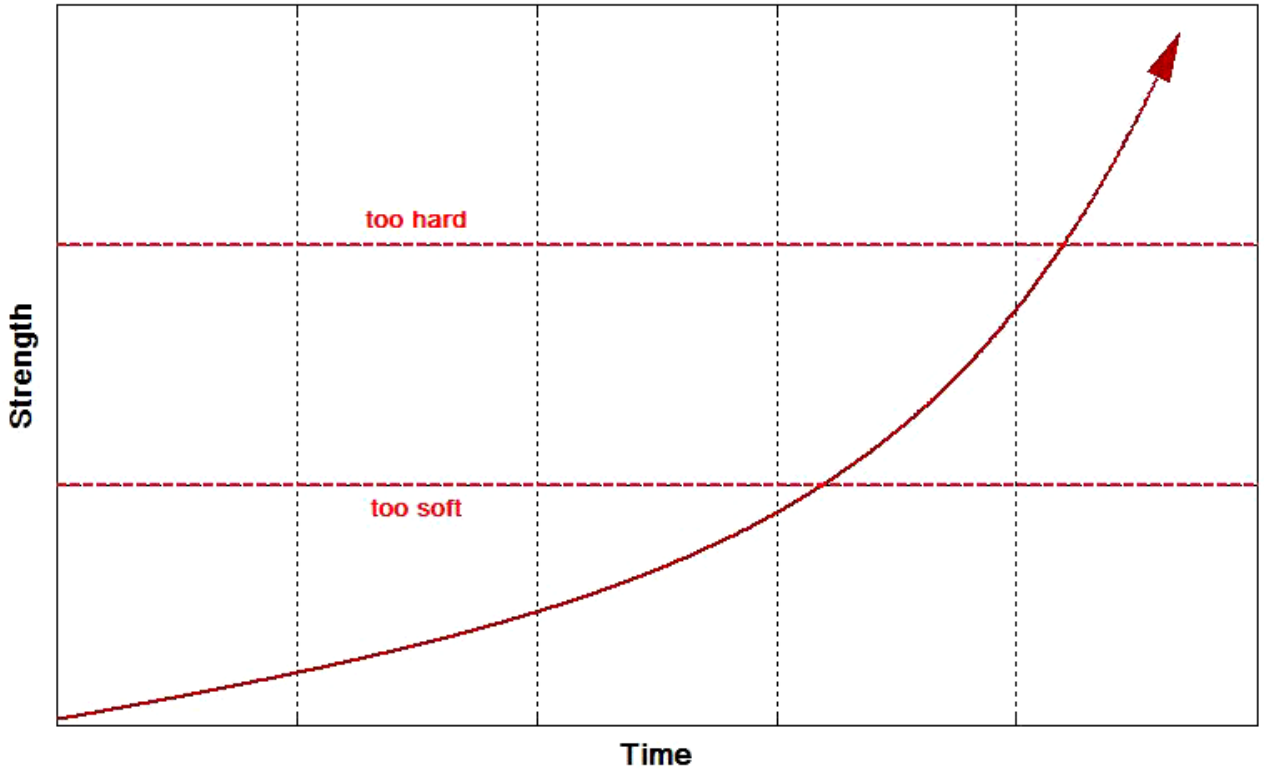

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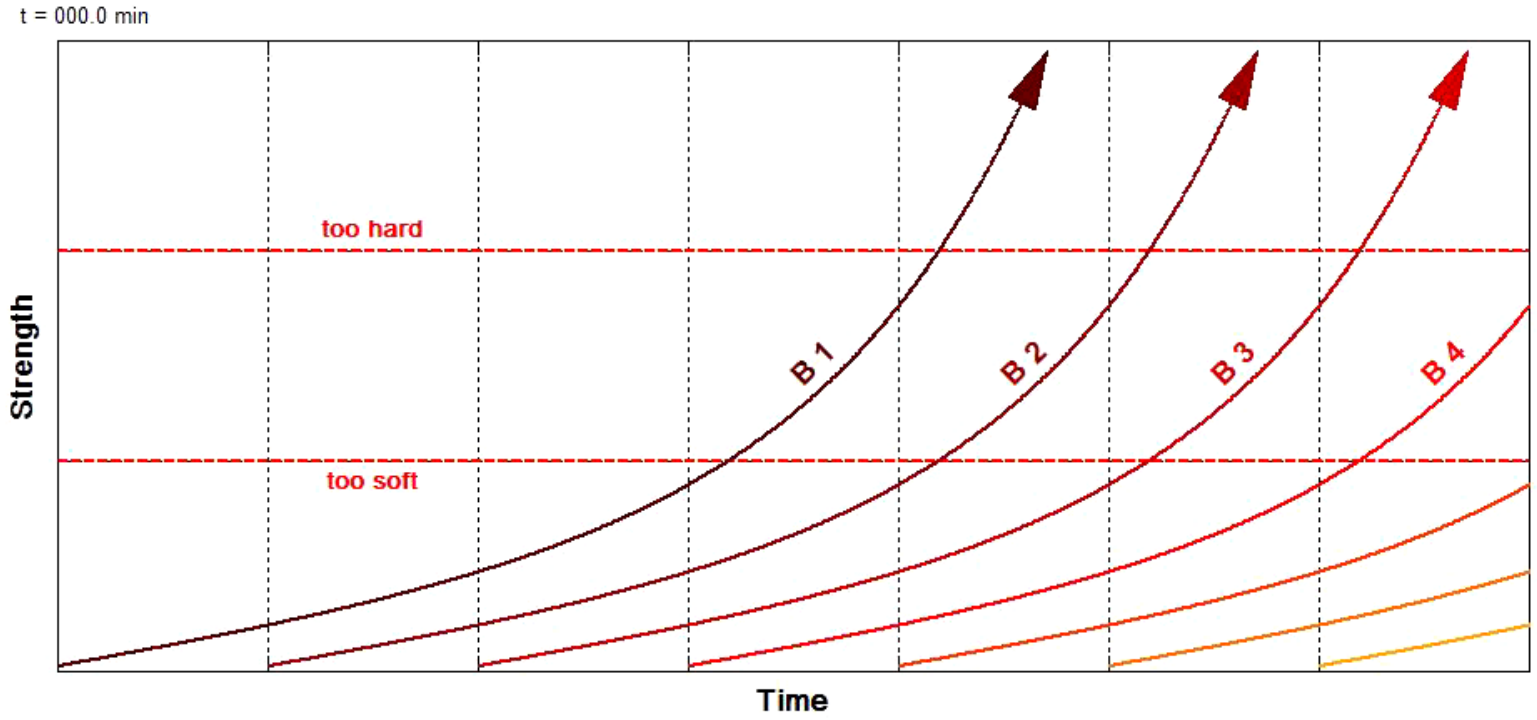

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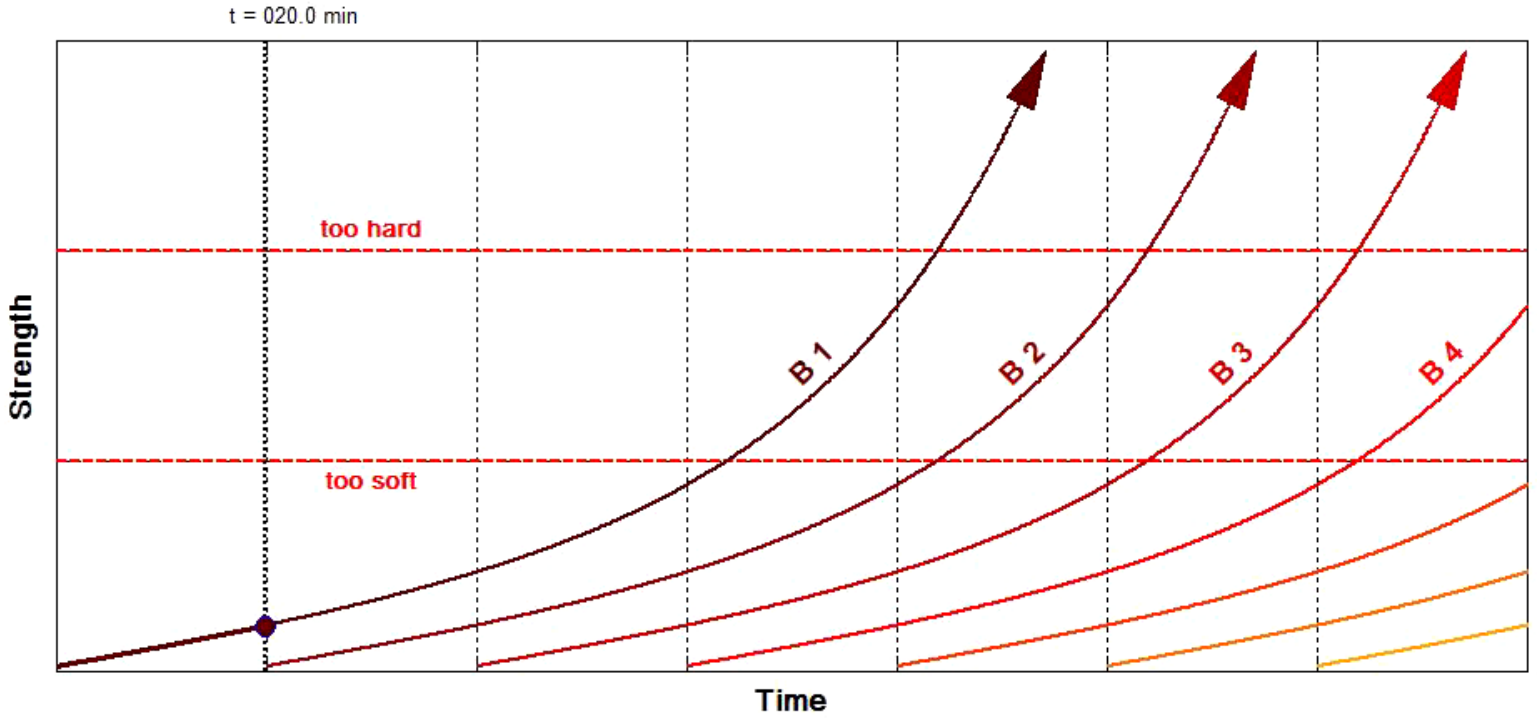

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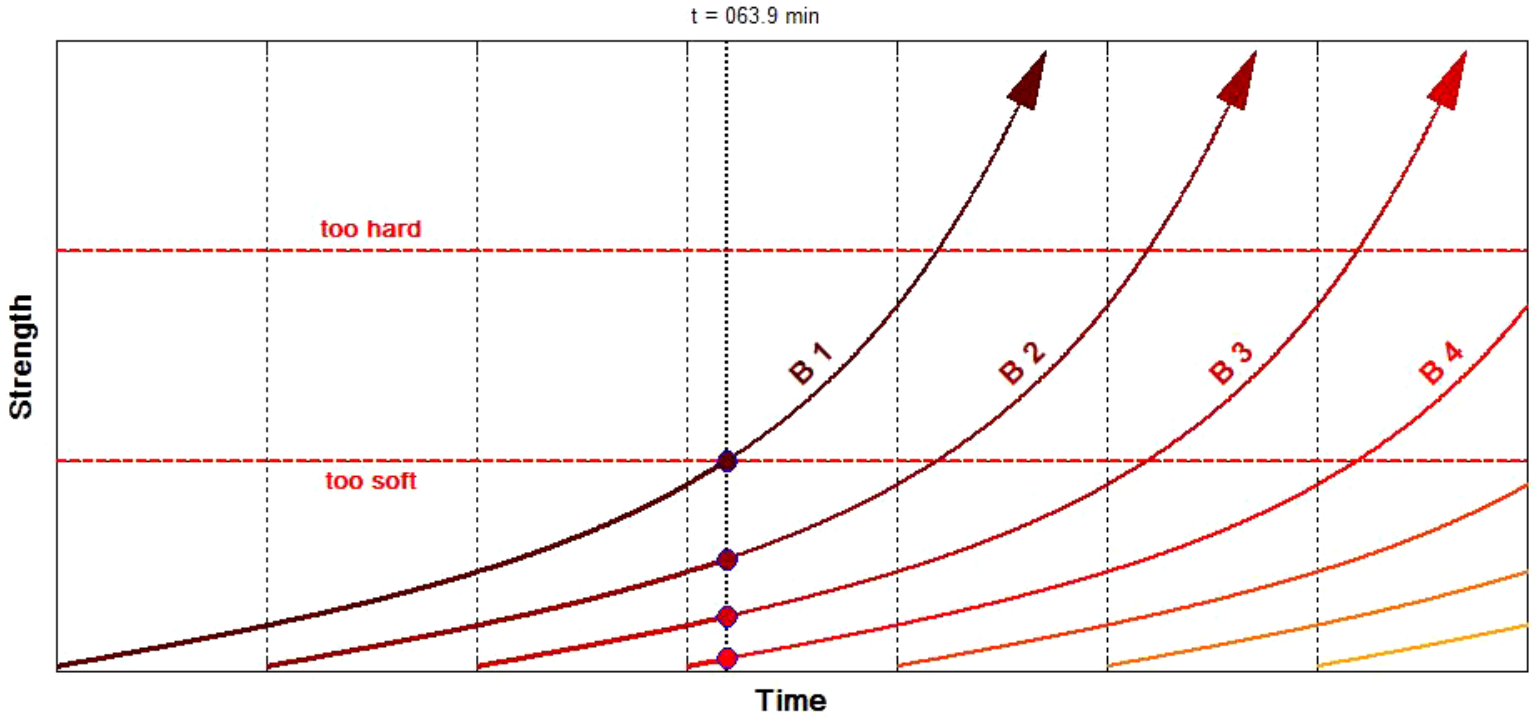

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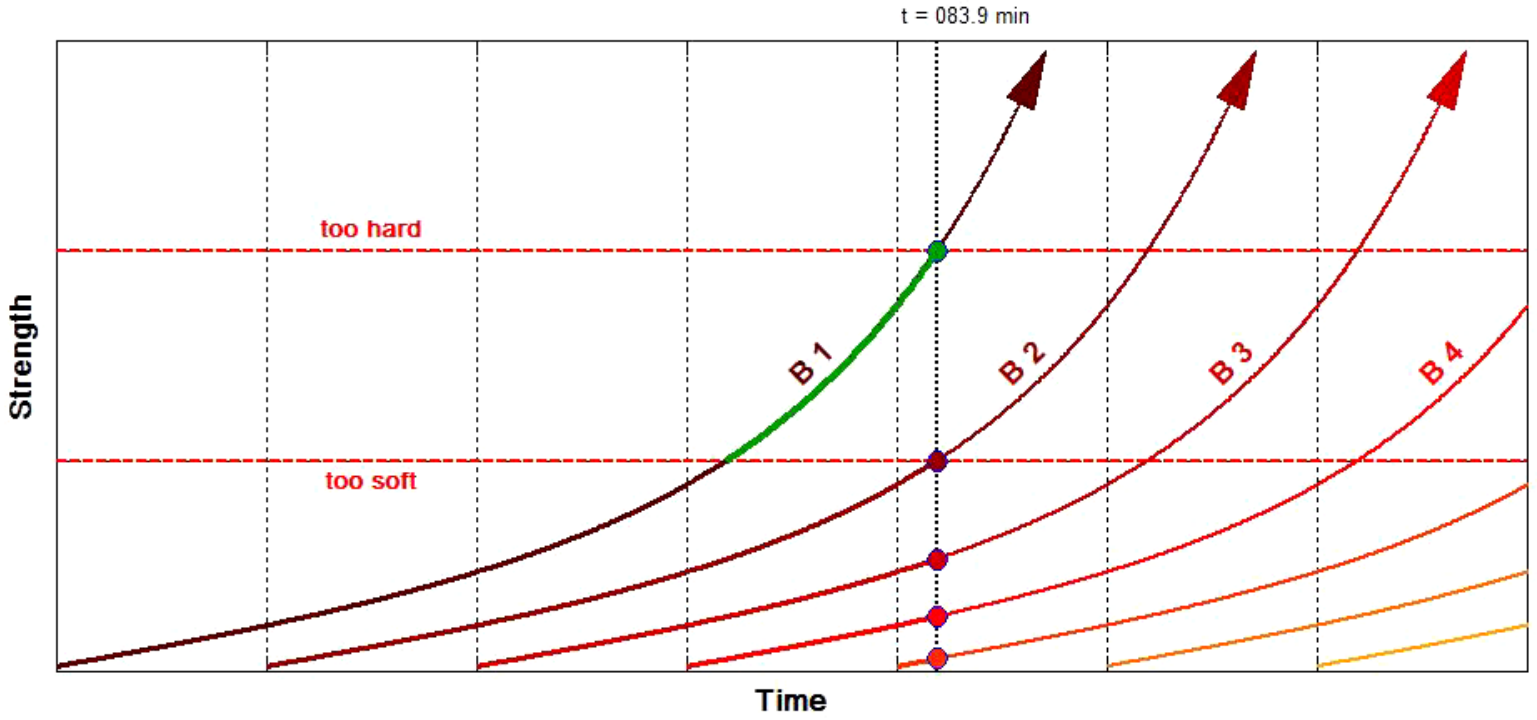

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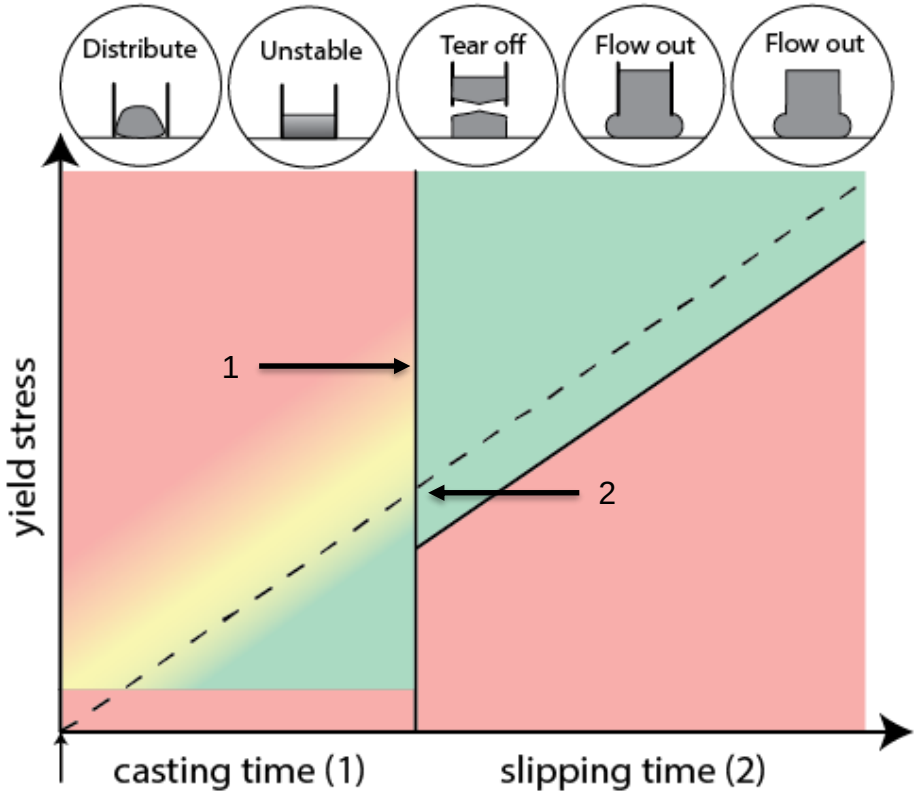
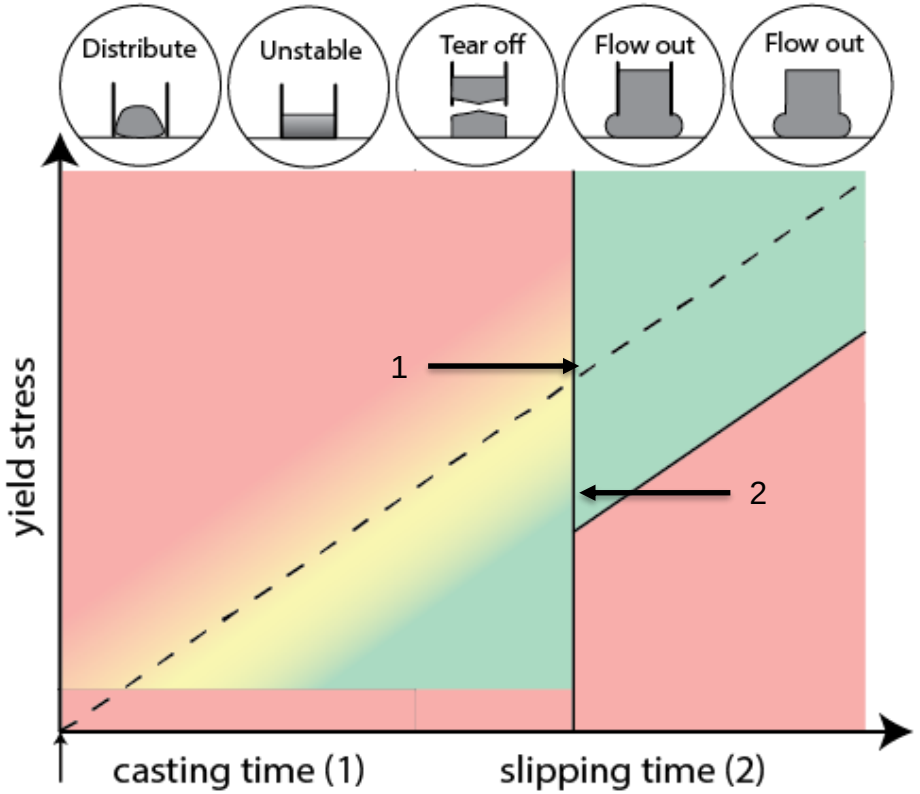
Material Mix – Processing and Activation



L. Reiter et al 'The role of early age structural build-up in digital fabrication with concrete', 2018

Material Mix – Processing and Activation



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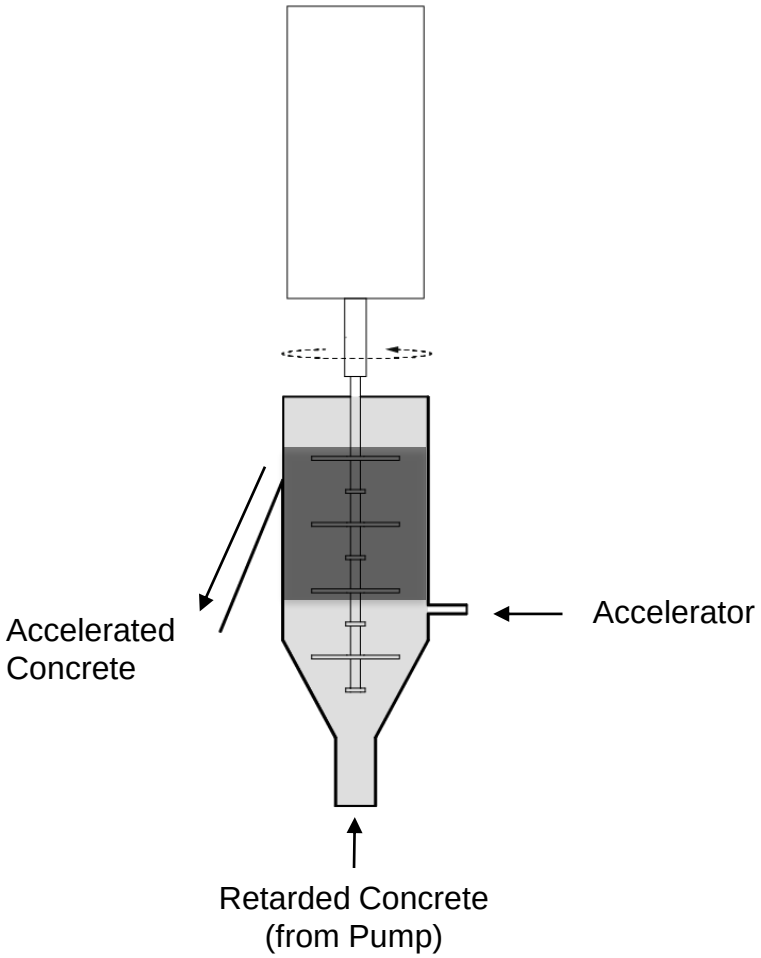
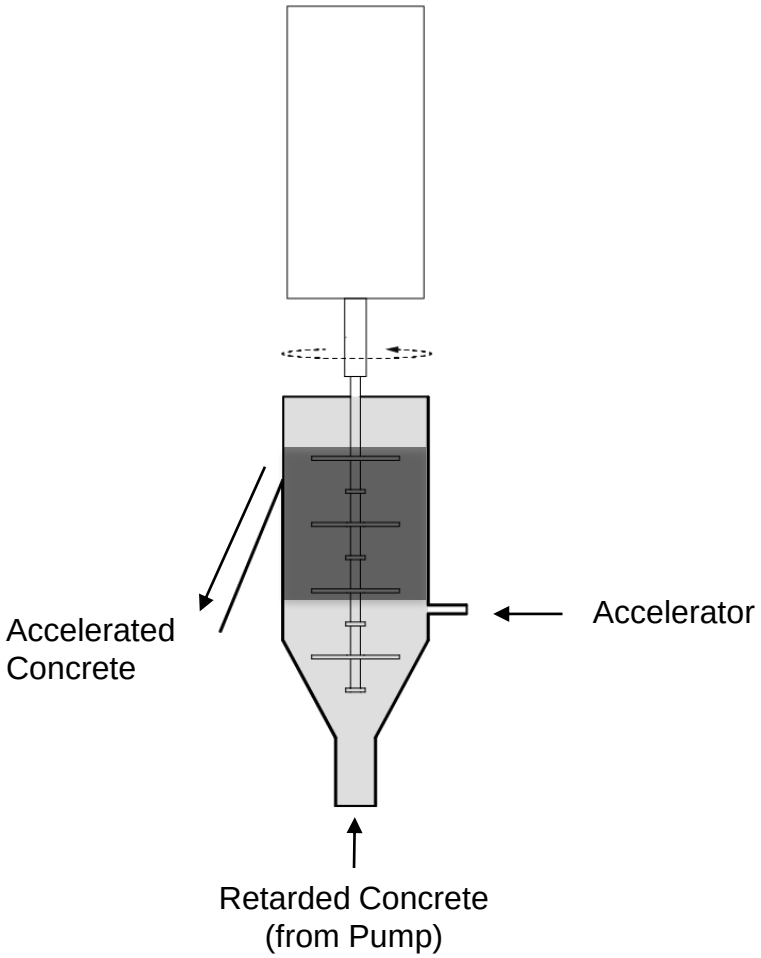
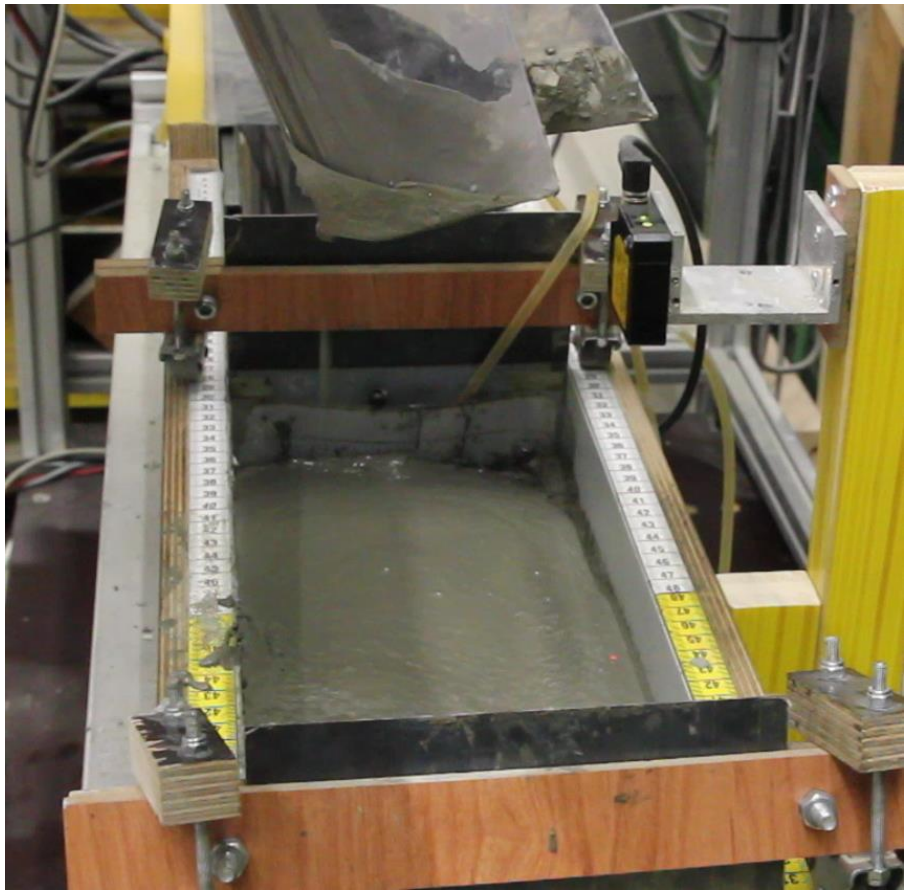
Controlled casting



Controlled casting





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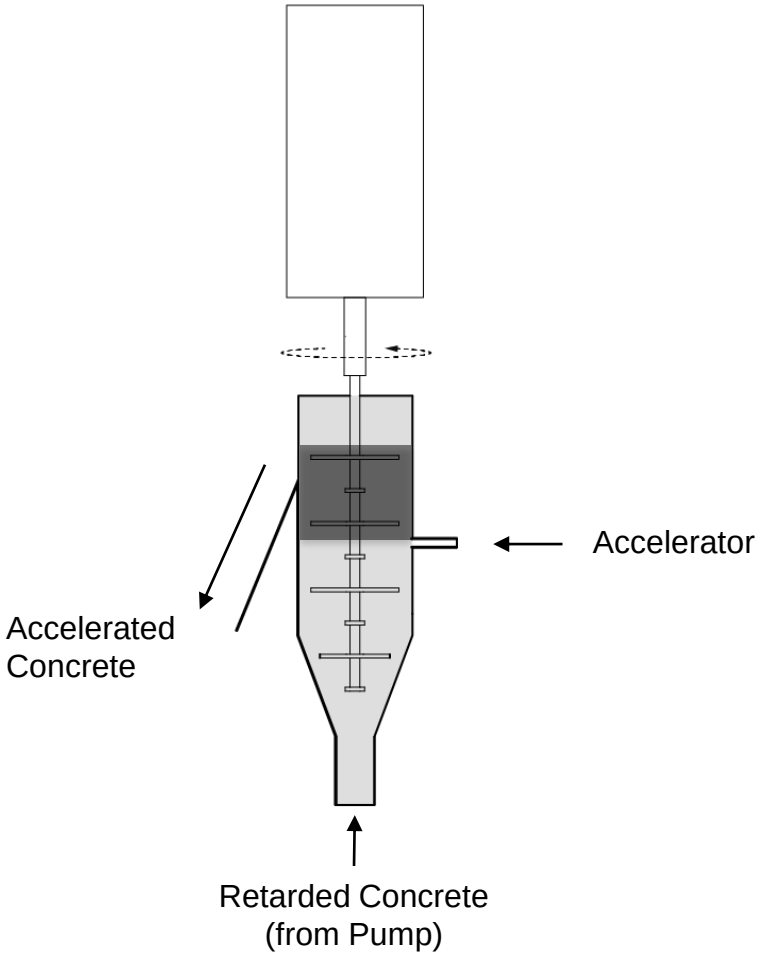
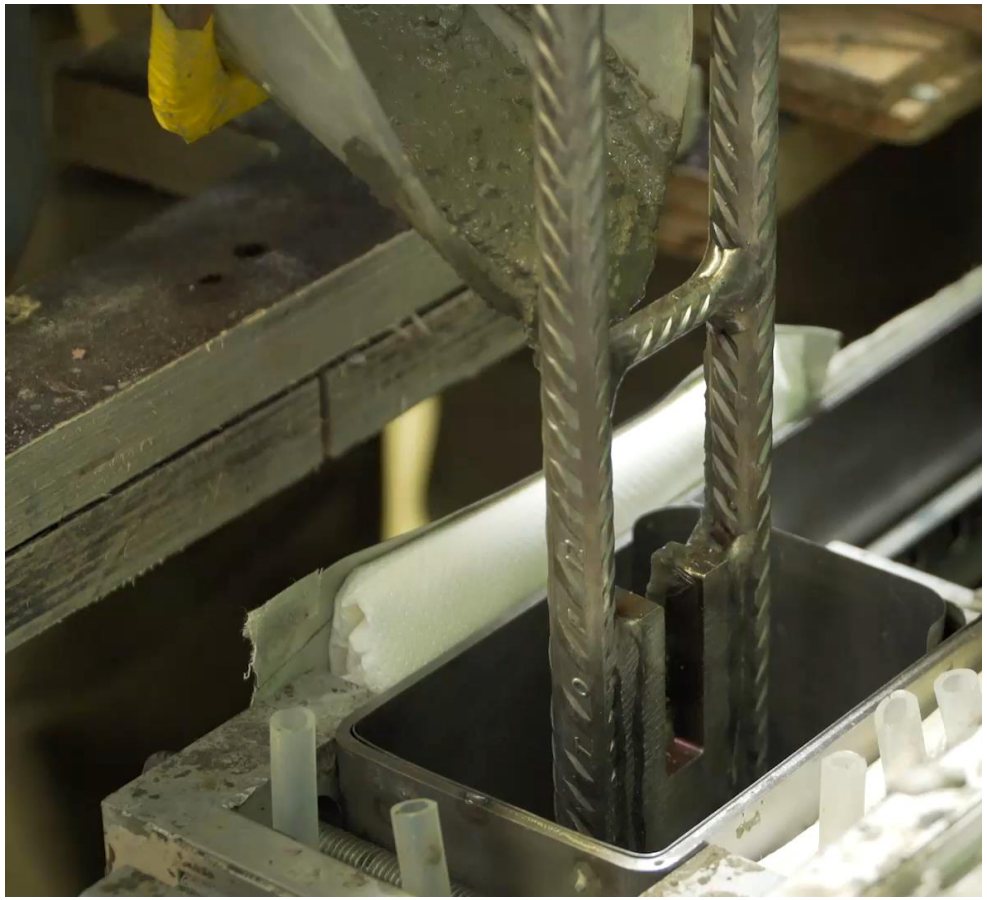
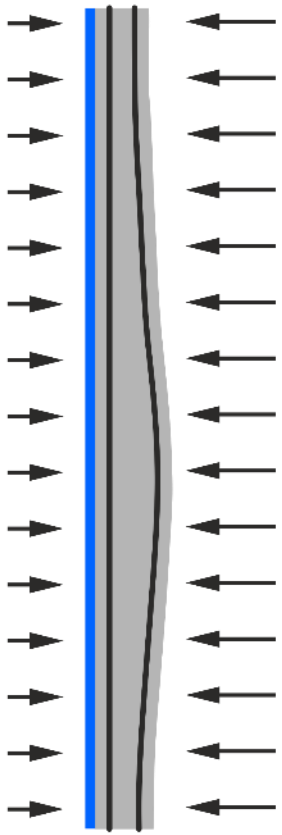




Reinforcement

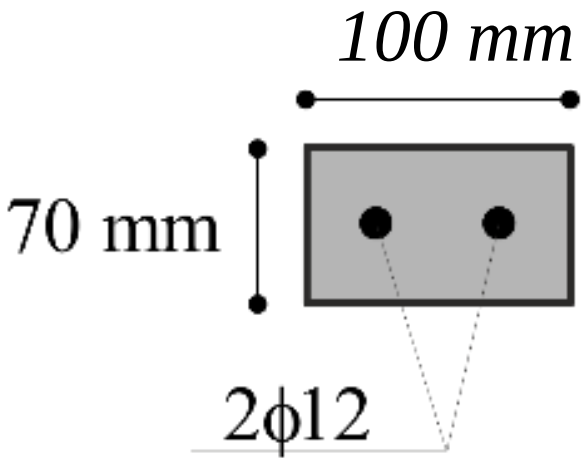
Wind loads & structural requirements



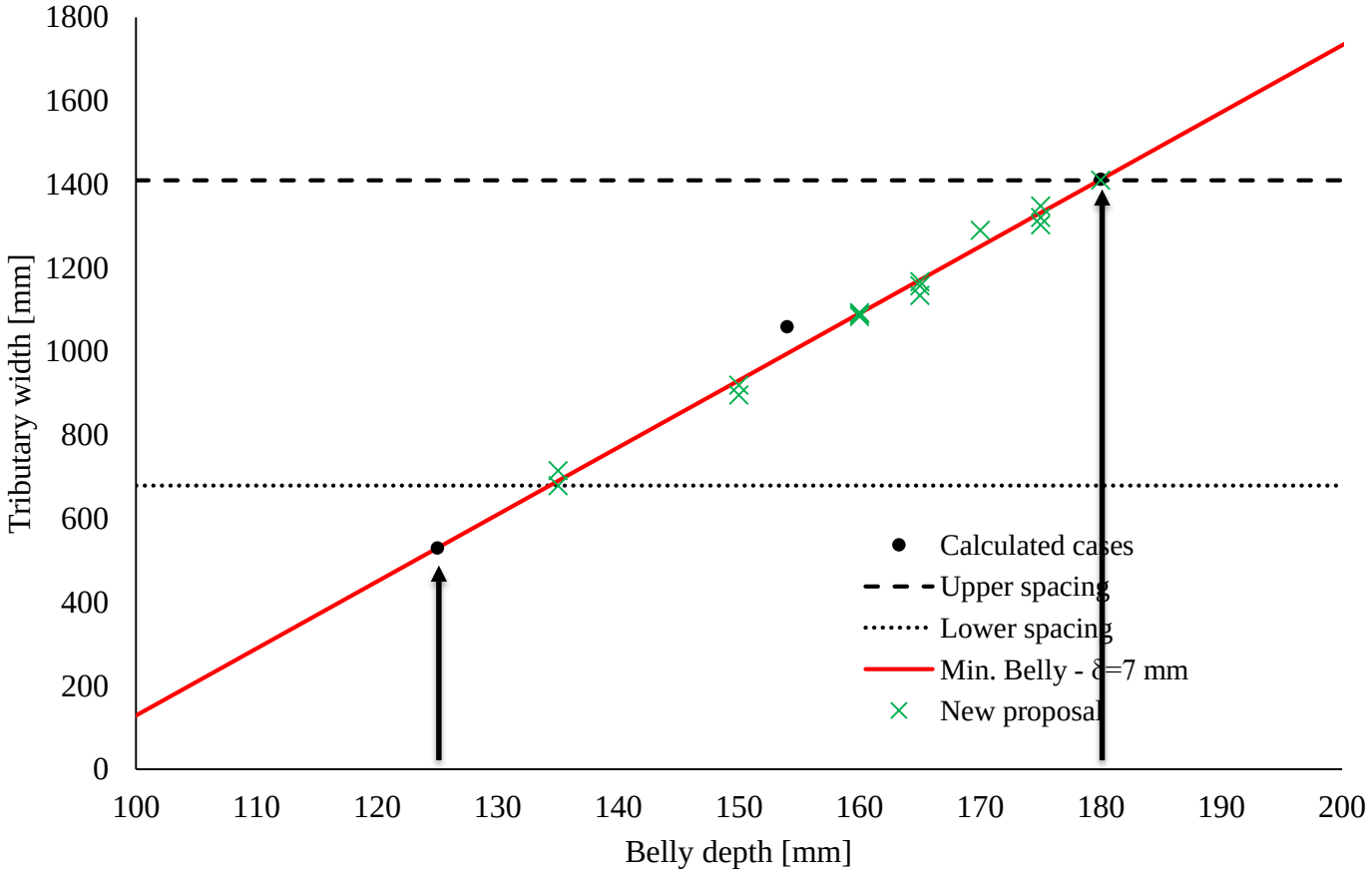
Bending verification

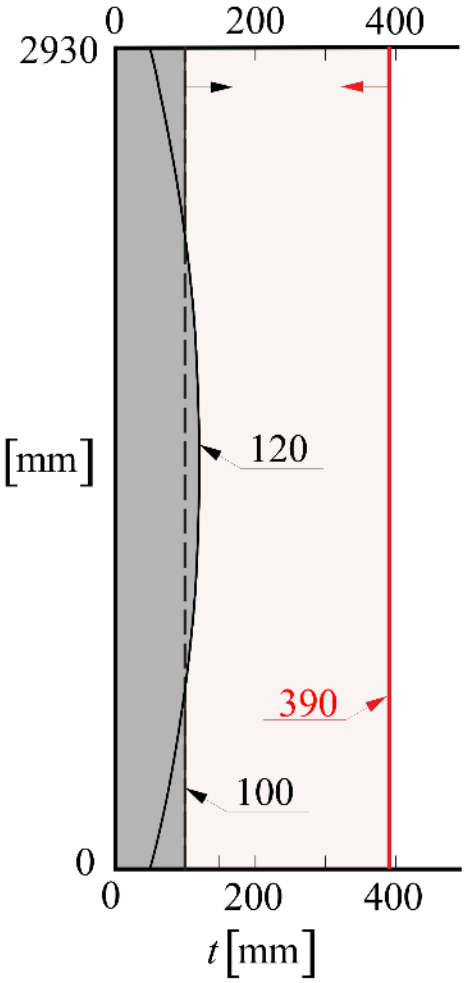
Shear verification

Ductility after cracking



Reinforcement – Structural Design





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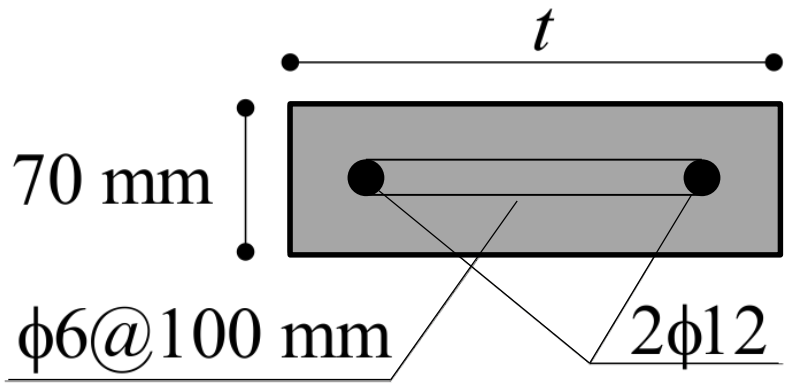

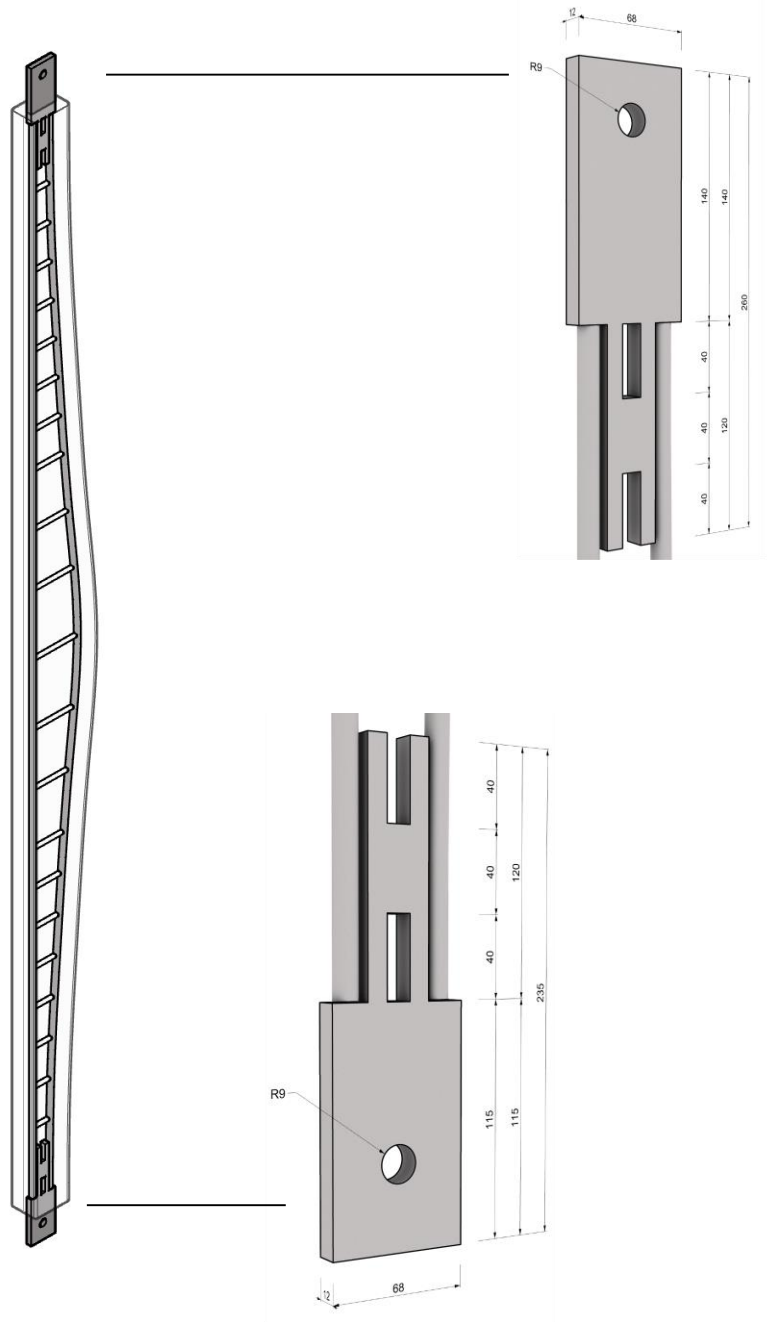

Bild: Roman Keller

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Bild: Roman Keller

Bild: Roman Keller

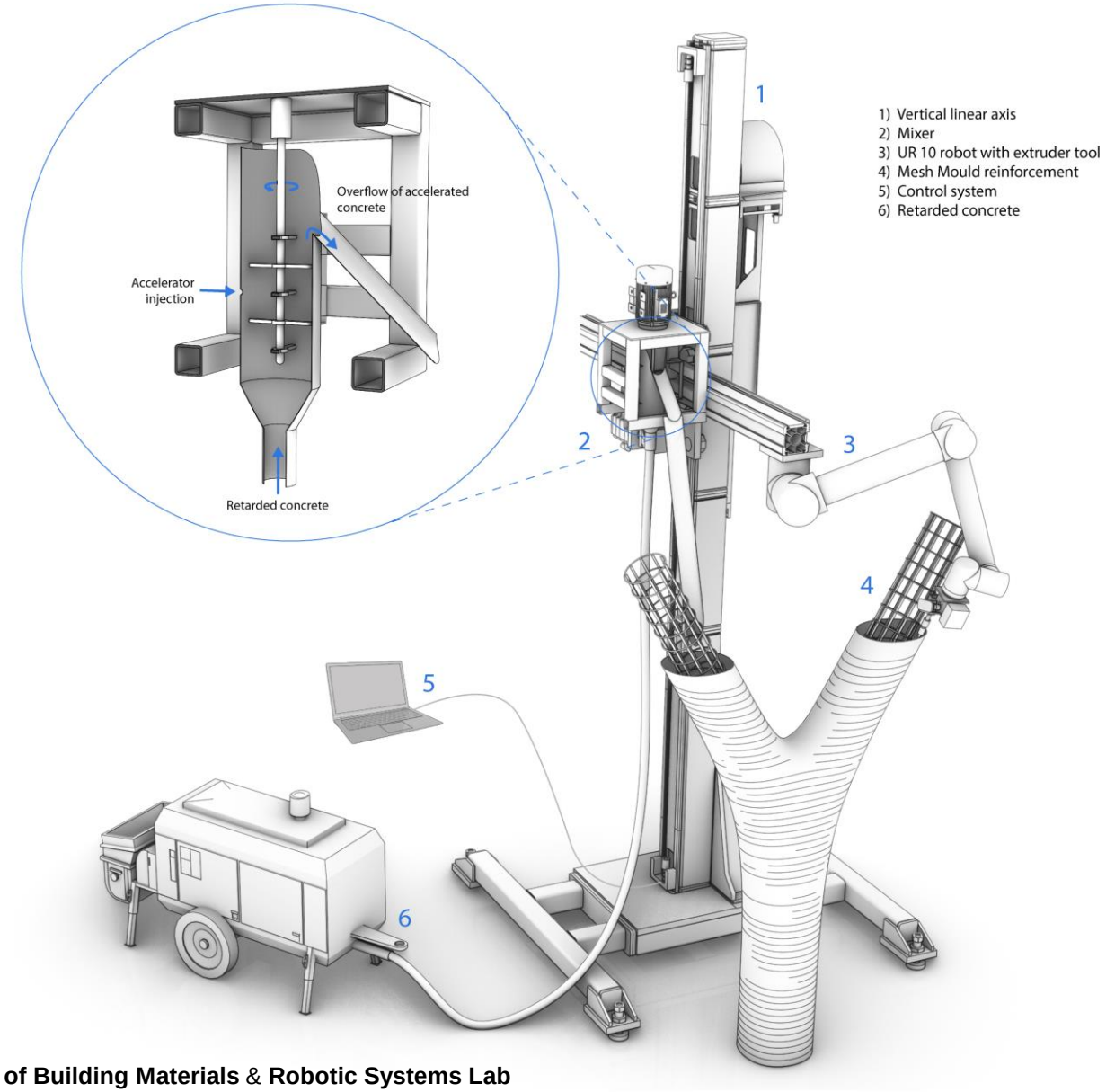
Eggshell

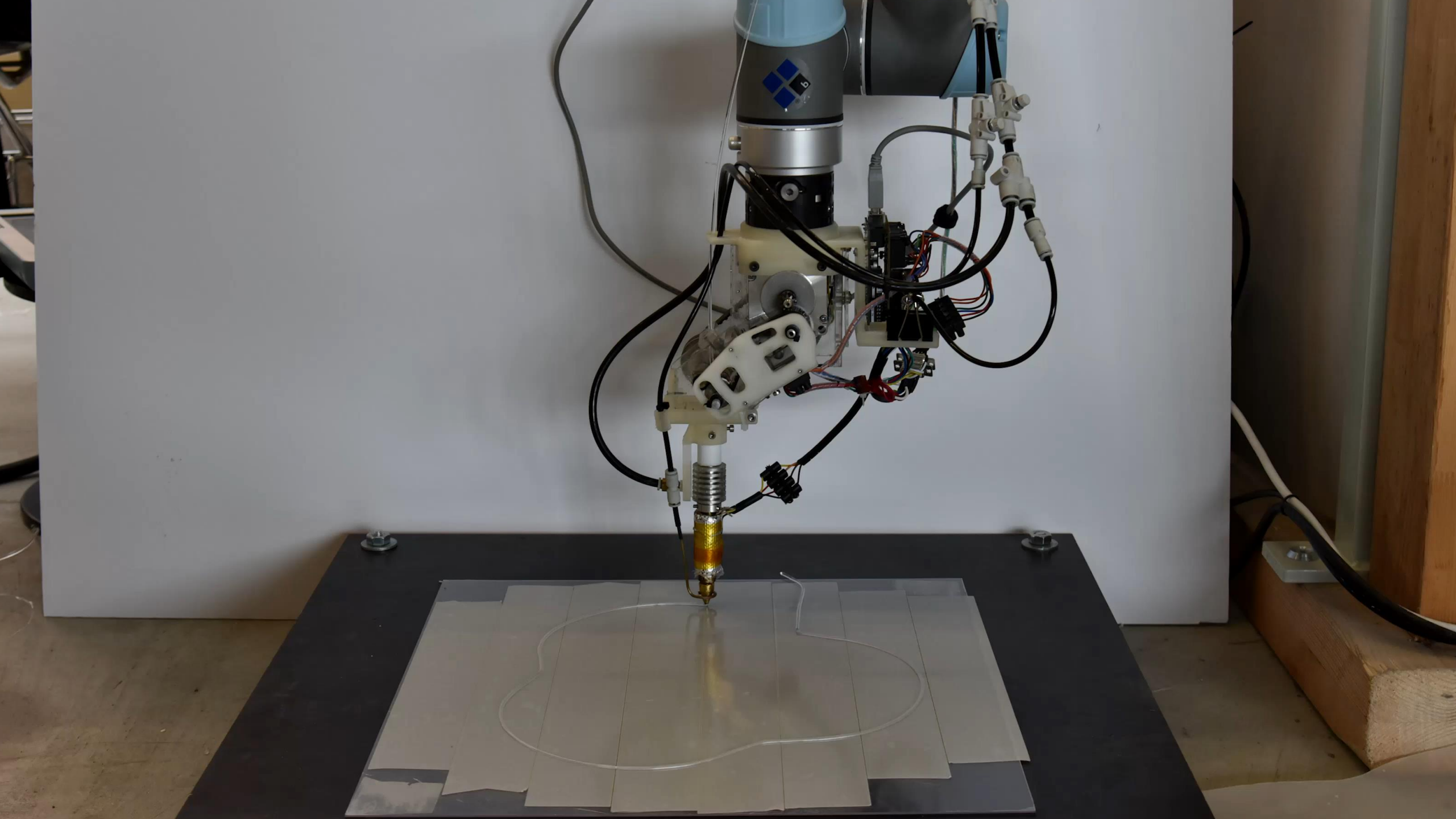
Research Project 2016-2022

In cooperation with: Physical Chemistry of Building Materials group (Prof. Dr. Robert J. Flatt)

Collaborators: Joris Burger (PhD), Dr. Ena Lloret-Fritschi, Fabio Scotto, Nizar Taha, Bruno Pinto Aranda, Dr. Thibault Demoulin, Dr. Sara Mantellato, Andi Reusser, Michael Lyrenmann, Philippe Fleischmann

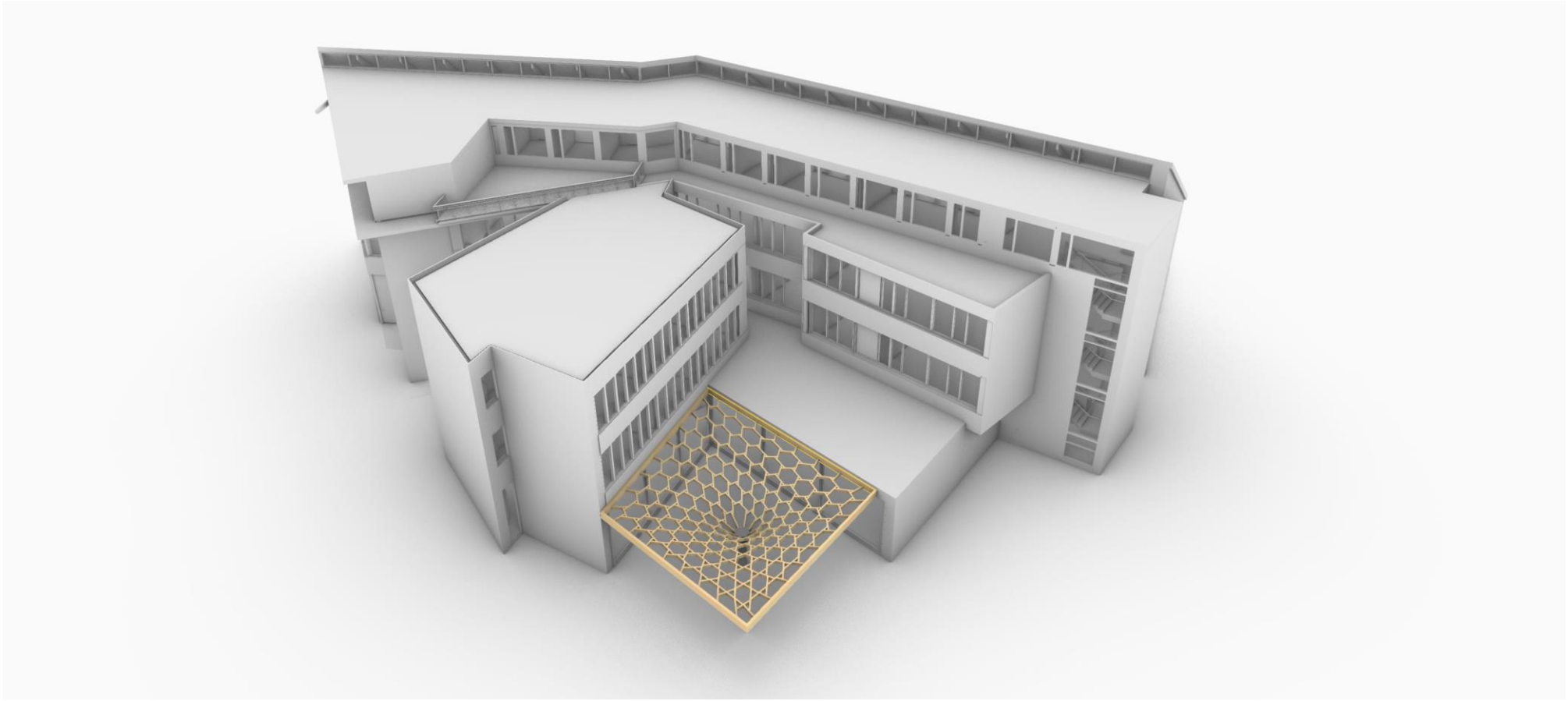
Concept


Overflow of accelerated concrete
Accelerator injection
Retarded concrete
1
2
3
4
5
6
1) Vertical linear axis
2) Mixer
3) UR 10 robot with extruder tool
4) Mesh Mould reinforcement
5) Control system
6) Retarded concrete



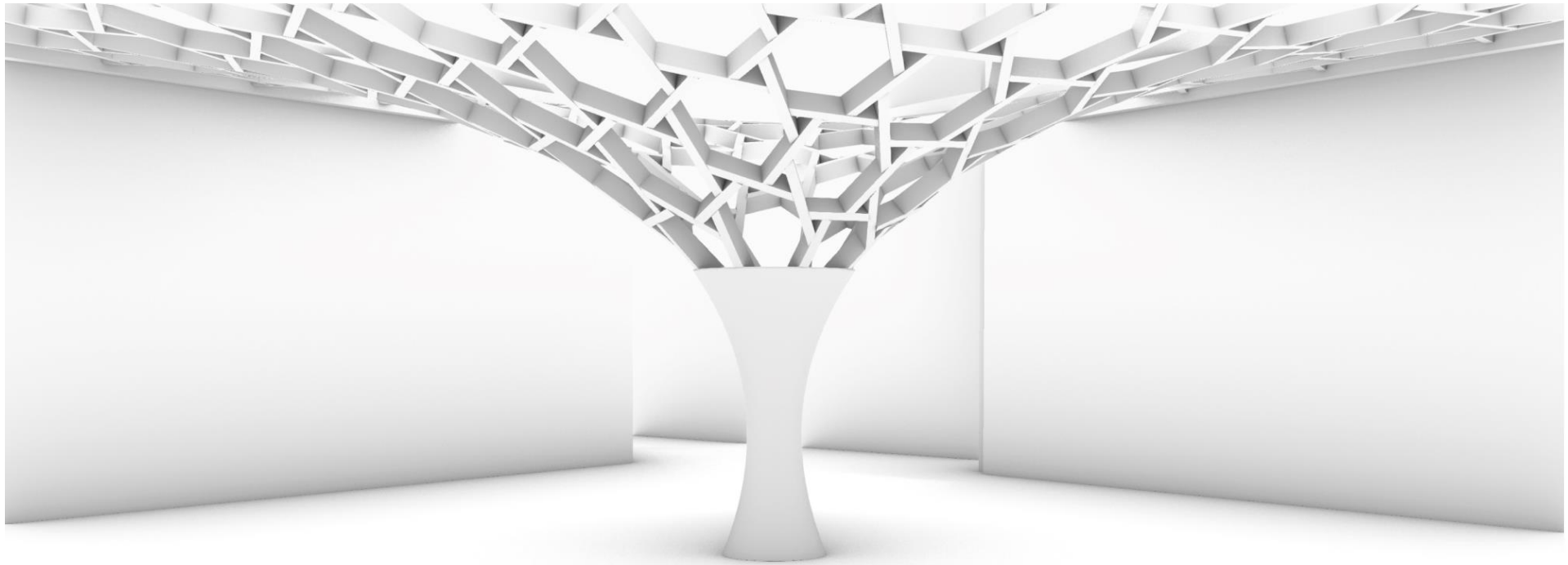
Scale-up

Basler & Hofmann case study



Phase II: Scale-up

Starting point



Reinforcement

Gramazio Kohler Research
ETH Zurich


Nutzlast max.
00 kg/m²
B 65.2

Conclusions

- Hydration control (set-on-demand) is key in digital casting to:
- Re-think formwork for concrete
- Open up new design space (standard elements will rarely pay off)
- Interlink design with fabrication and fabrication limits
- Material aware fabrication
- Added value, functionality or integration will pay off
- New horizon for design tools informed by material and new construction methods

***Imprimer le Monde*, Centre Pompidou, 2017**

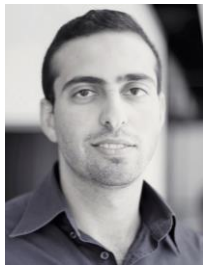
Acknowledgements

Gramazio Kohler Research (Prof. Fabio Gramazio & Matthias kohler)


Ena Lloret-Fritschi


Fabio Scotto


Joris Burger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Collaborators

Physical Chemistry of Building Materials:
Prof. Dr. Robert J. Flatt (PI)

Heinz Richner
Andreas Reusser
Dr. Sara Mantellato
Dr. Thibault Demoulin
PhD Lex Reiter
Dr. Tim Wangler
Dr. Nicolas Roussel
Lukas Fuhrimann
Pierre Brasay

Gramazio Kohler Research:
Prof. Fabio Gramazio (PI)
Prof. Matthias Kohler (PI)

Dr. Ena Lloret-Fritschi
PhD Anna Szabo
Fabio Scotto

Concrete Structures and Bridge Design
Prof. Walter Kaufmann
Dr. Jaime Mata-Falcon

Institute of Geodesy and Photogrammetry:
Prof. Dr. Andreas Wieser
Hasret Gümgüncü

Department of Architecture
Prof. Dr. Joseph Schwartz

Zühlke Engineering AG:
Markus Foellmi
Hans Flückiger

Pemat AG:
Peter Mattle
Benjamin Buschor

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DARCH Departement Architektur
Institute of Technology in Architecture Faculty of Architecture / ETH Zurich
IfB Institut für Baustoffe Institute for Building Materials
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Thanks for your attention