When Digital Fabrication provides Environmental Benefits:

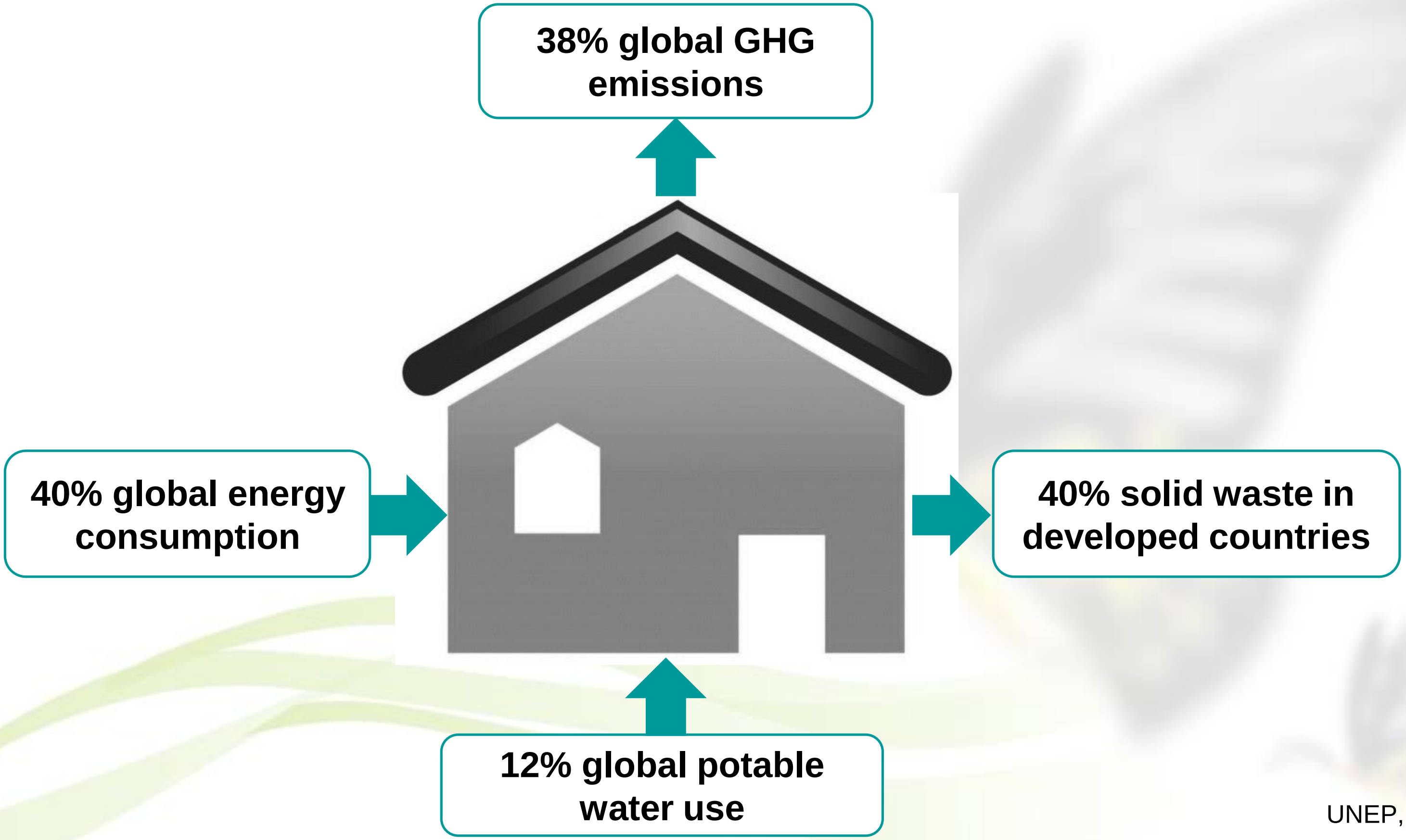
Study of Complex Structures

Isolda Agustí Juan, Prof. Dr. Guillaume Habert

Chair of Sustainable Construction, ETH Zürich
NCCR Digital Fabrication

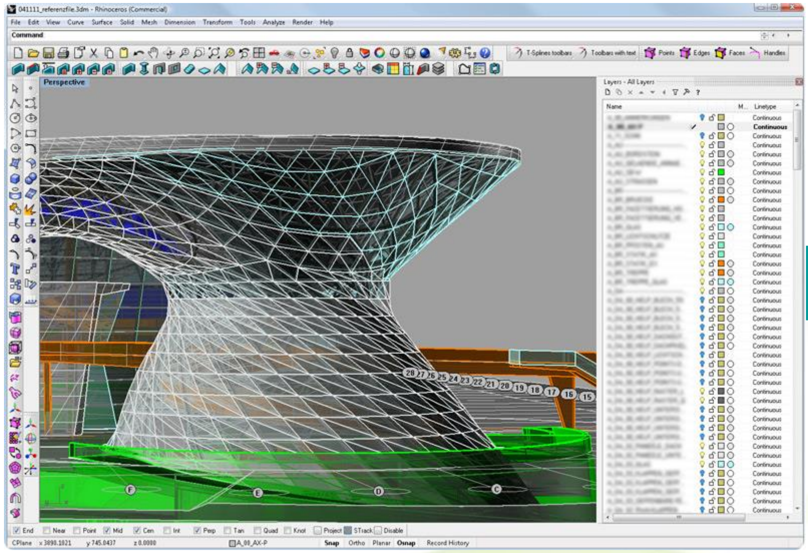
World Sustainable Built Environment Conference
5-7 June 2017, Hong Kong

The construction sector
need of sustainability improvement

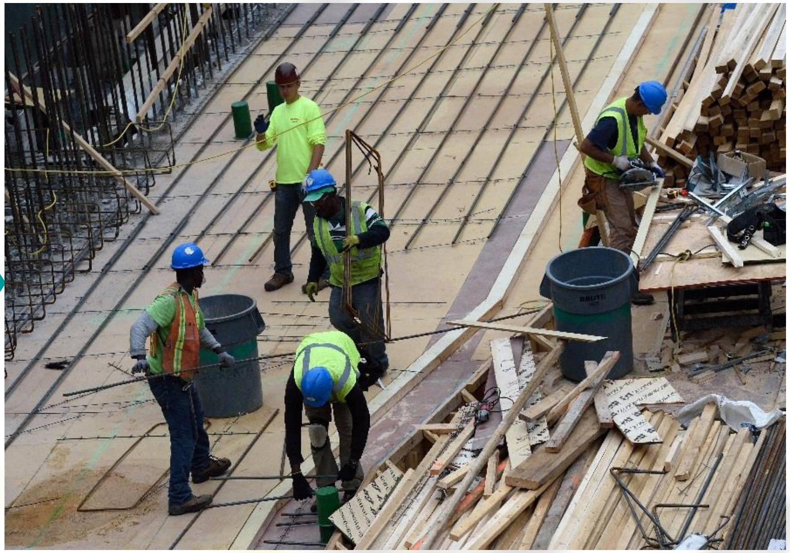


UNEP, 2012

The construction sector
traditional and fragmented industry



CAAD software: increase of complexity in architecture



Traditional construction: labour intensive and resource consuming

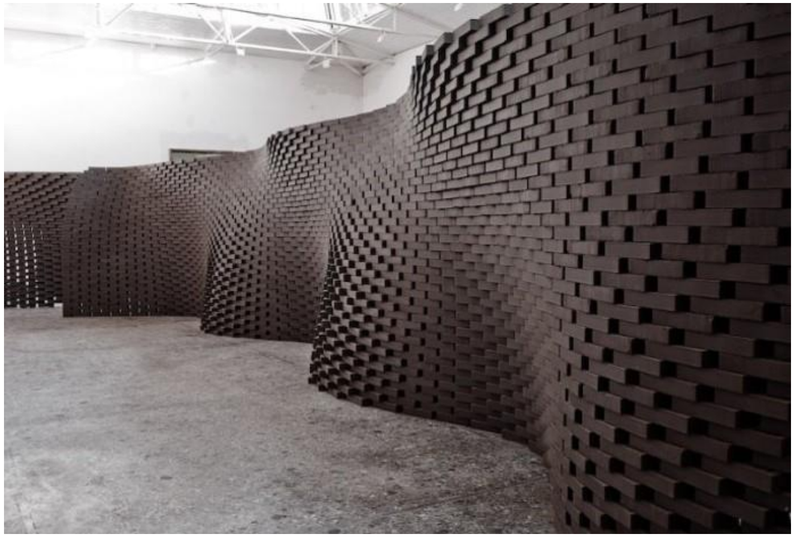
Digital Fabrication
computational design + robotic fabrication

Modern Architecture

Victoria and Albert Museum extension proposal, England, 1996

Digital media are drawing tools, no influence in the design process

Digital Fabrication

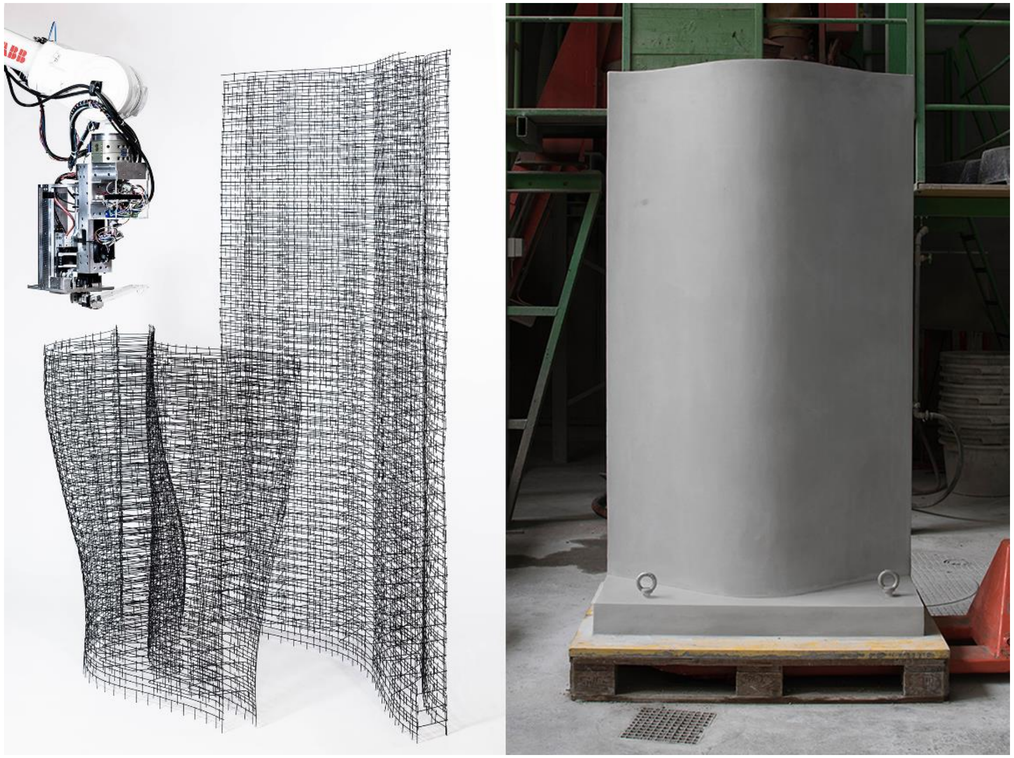


Gramazio & Kohler, Swiss Pavilion, Venice Biennale, 2008

Digital media are part of the design process, influence the final geometry

Case study: Mesh Mould

- Novel construction system for concrete structures
- Robotically fabricated steel mesh
- Combination of formwork and reinforcement
- High architectural complexity



Mesh Mould, Gramazio Kohler Research, ETH Zürich

Case study: Mesh Mould

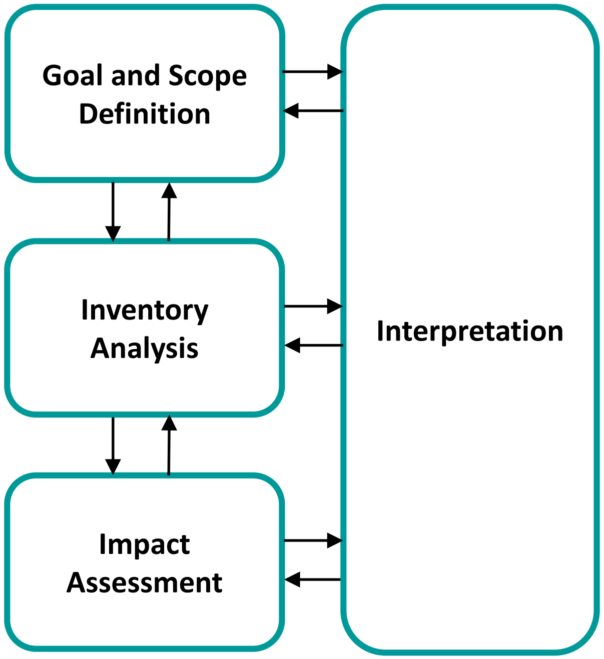
Mesh Mould

ETH zürich

National Centre of Competence in Research Digital Fabrication

Is Mesh Mould sustainable?
Evaluation method

- Life Cycle Assessment (LCA) framework
- Evaluation of Mesh Mould wall.
- Comparison with conventional concrete wall with the same complexity and structural capacity.
- Comparison approaches
  - complexity level
  - structural optimization
- ***Goal:*** understand when Mesh Mould process brings environmental benefits compared to conventional construction.



Life Cycle Assessment, ISO 14040-44:2006

LCA of Mesh Mould wall

Functional unit

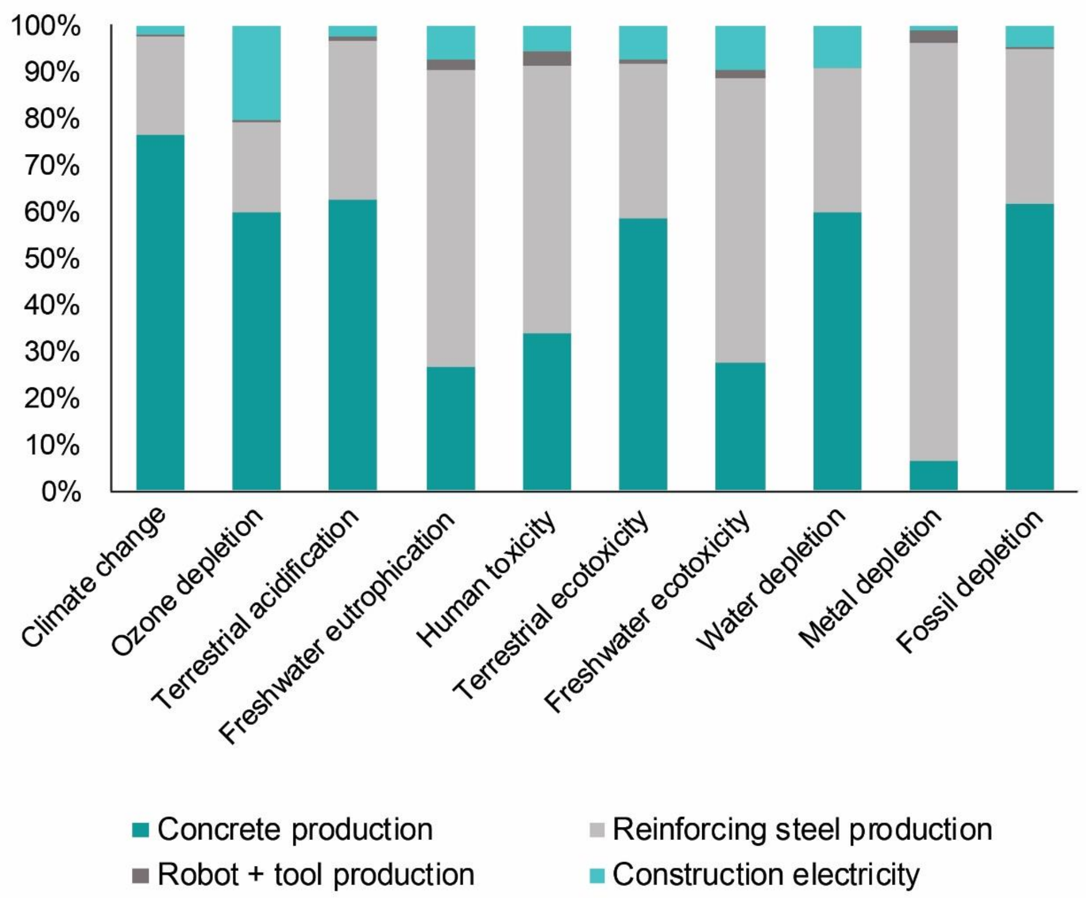
- 1 m^2 Mesh Mould wall

System boundaries

- production + construction

Life cycle inventory

- Concrete: HPC, V = 0.2 m^3
- Steel: B500A, r = 0.7%
- Construction time: 10 h
- Energy: 17 kWh



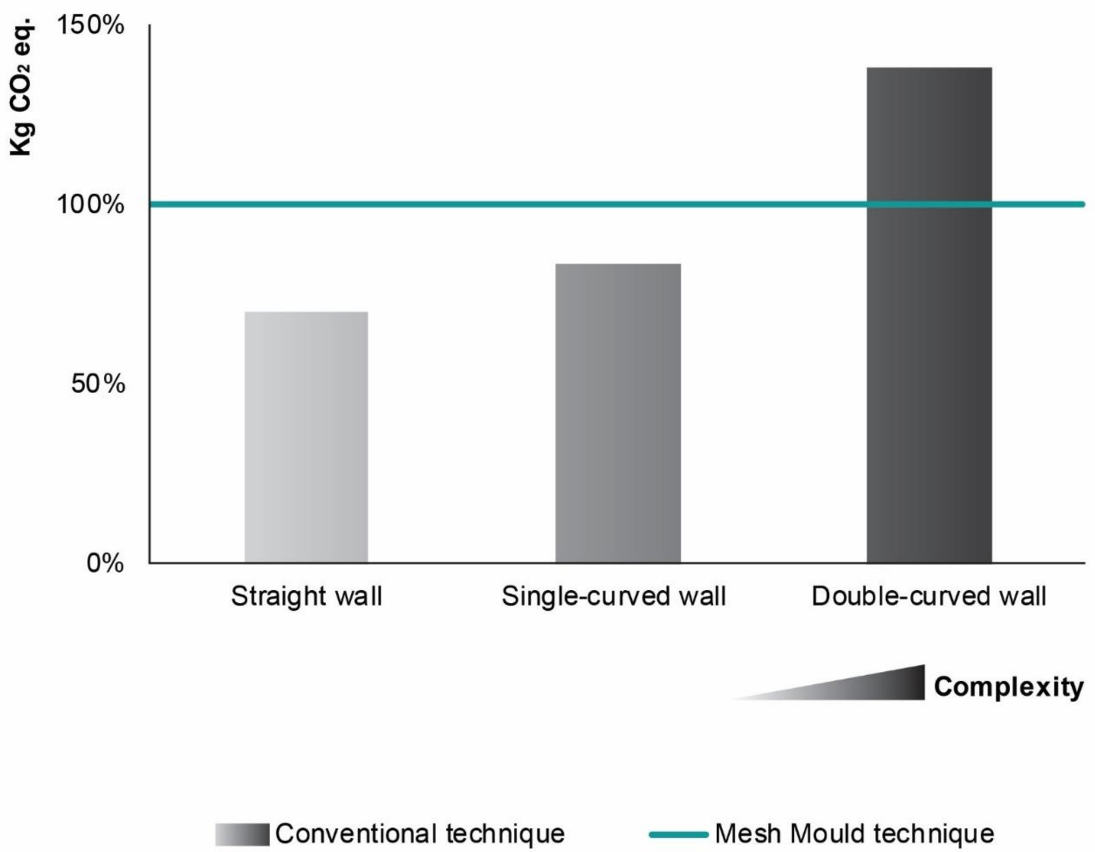
LCA comparison: complexity

Conventional wall

- ***Straight wall***: plywood formwork
- ***Curved wall:*** plywood formwork
- ***Double-curved wall***: polystyrene formwork

Mesh Mould wall

- Adaptable to different complexity levels
- ***No conventional formwork***



LCA comparison: optimization

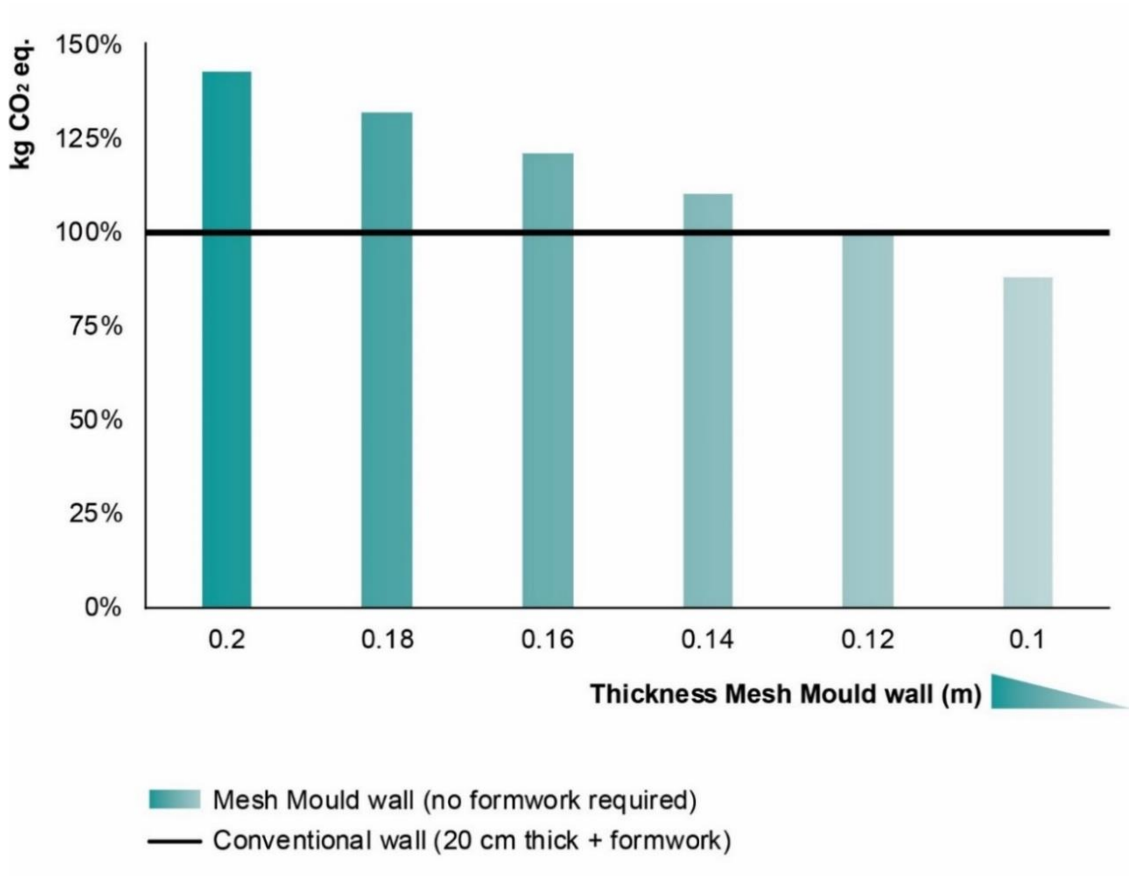
Conventional wall

- ***Concrete:*** 30 MPa
- ***Thickness:*** 0.2 m (standard)

Mesh Mould wall

- ***Concrete:*** 60 Mpa
- ***Thickness***: until 0,1 m without decreasing structural capacity compared to conventional wall

CO_2 break-even point: 0.12 m



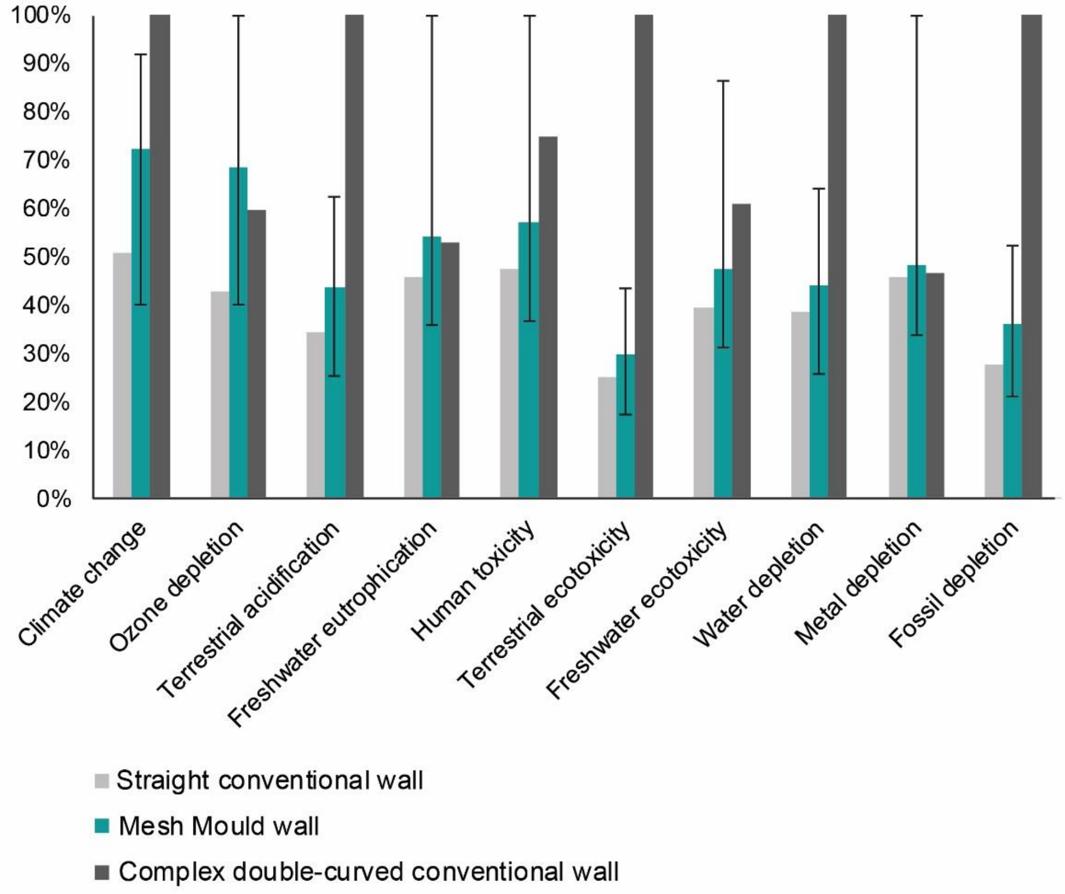
Synthesis

Mesh Mould wall

- ***Best*****:** t =0.1 m, r =0.5%
- ***Reference:*** t =0.2 m, r =0.7%
- ***Worst:*** t =0.2 m, r =1.5%

Conventional wall

- ***Straight:*** t =0.2 m, r = 0.7%, wooden formwork reused
- ***Complex:*** t = 0.2 m, r = 0.7%, EPS formwork not reused



Conclusion

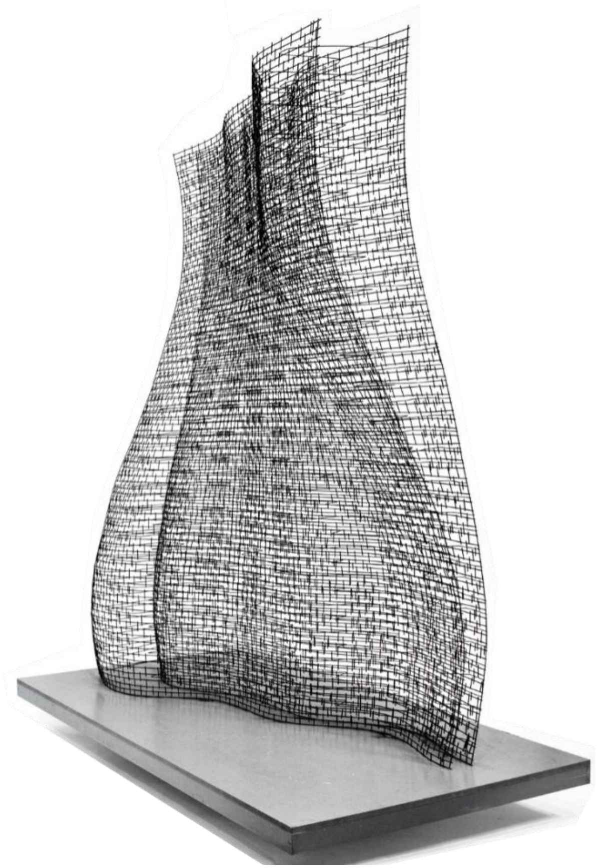
- The environmental impact of digital fabrication is negligible compared to the impact of materials production.
- The Mesh Mould technique allows an efficient construction of **complex structures** without using conventional formworks.
- Contrarily to conventional techniques, the impact of the Mesh Mould process does not change with an increase of **complexity** in the architectural form.
- Digital fabrication is more environmentally performant than conventional construction for **complex geometries**.

Interest of complexity

- Digital fabrication techniques facilitate the production of complex structures.

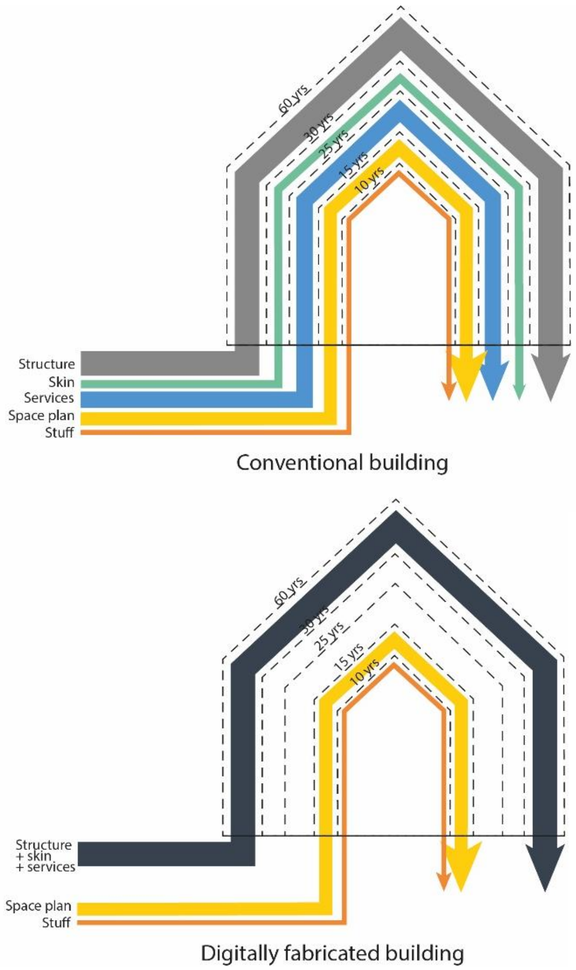
- When is complexity environmentally relevant?

- In a complex geometry, the form can provide a function (i.e. acoustic performance):
  - The initial function of the building element is provided similar amount of material (+/- 20%).
  - But the additional function avoids the use of other material.



Interest of complexity

- Functional hybridization: reduction of material and assembly time.
- Environmentally relevant in building elements and functions with high impact.
- Problem: increase of environmental impacts due to service life variability, maintenance issues, etc.
- Functional hybridization requires design flexibility.



Questions?

Isolda Agustí Juan
agusti@ibi.baug.ethz.ch

Thank you

Agustí-Juan, I., Müller, F., Hack, N., Wangler, T., Habert, G., 2017. Potential benefits of digital fabrication for complex structures: Environmental assessment of a robotically fabricated concrete wall. Journal of Cleaner Production 154, 330-340