When Digital Fabrication provides Environmental Benefits:
Study of Complex Structures

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The construction sector need of sustainability improvement

- 12% global potable water use
- 40% global energy consumption
- 38% global GHG emissions
- 40% solid waste in developed countries

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

![Image](image1.jpg)
Victoria and Albert Museum extension proposal, England, 1996

Digital Fabrication

![Image](image2.jpg)
Gramazio & Kohler, Swiss Pavilion, Venice Biennale, 2008

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

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
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 m² Mesh Mould wall

System boundaries
• production + construction

Life cycle inventory
• Concrete: HPC, V = 0.2 m³
• 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

**CO₂ break-even point**: 0.12 m
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?


Thank you