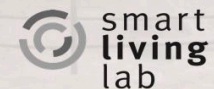
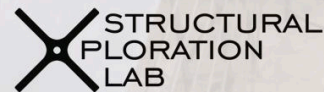




# Efficient use of materials in building design

Catherine De Wolf

Marie Skłodowska-Curie Postdoctoral Fellow  
Swiss Government Excellence Scholar





WHY

WHAT

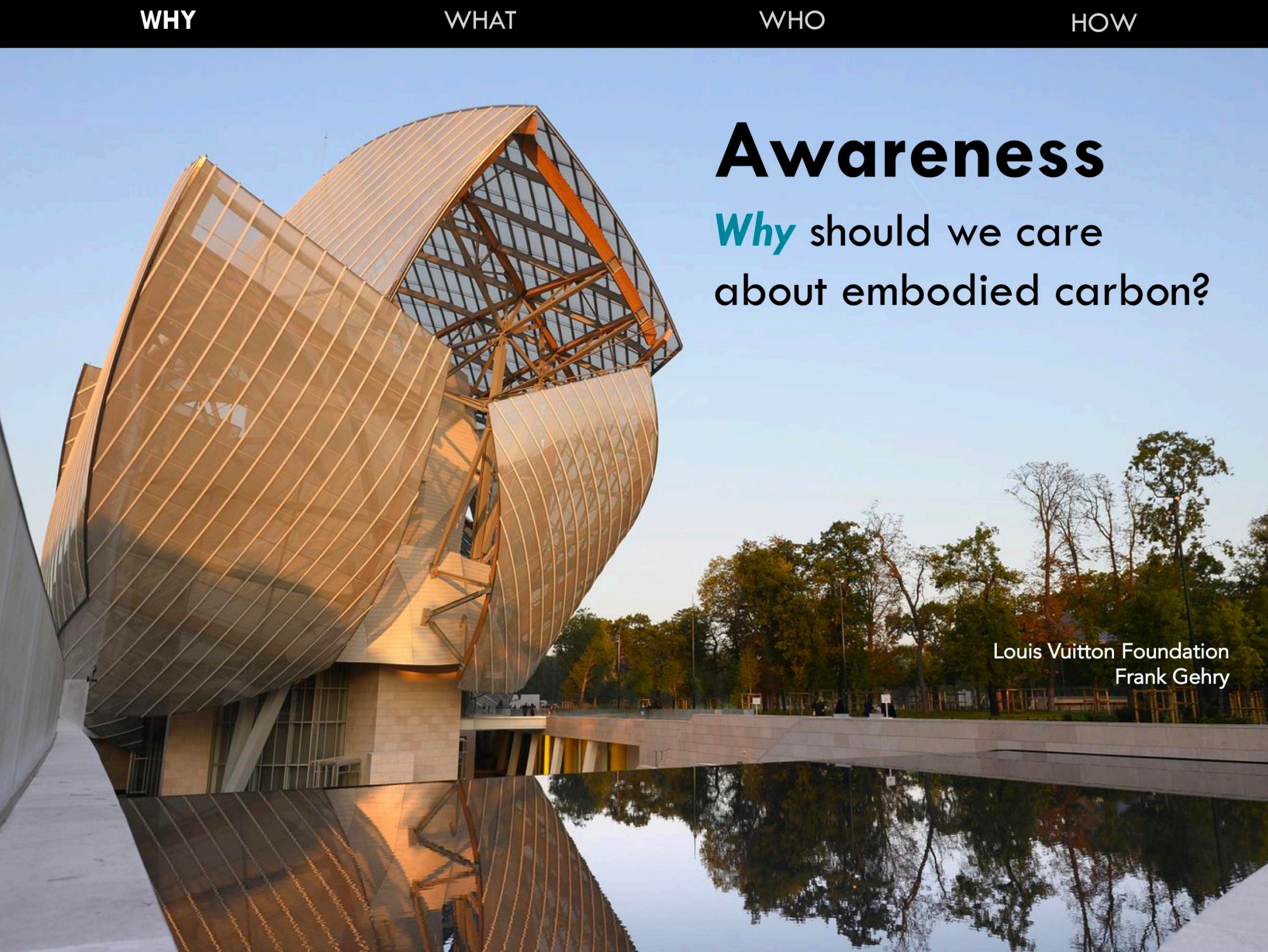
WHO

HOW

# Awareness

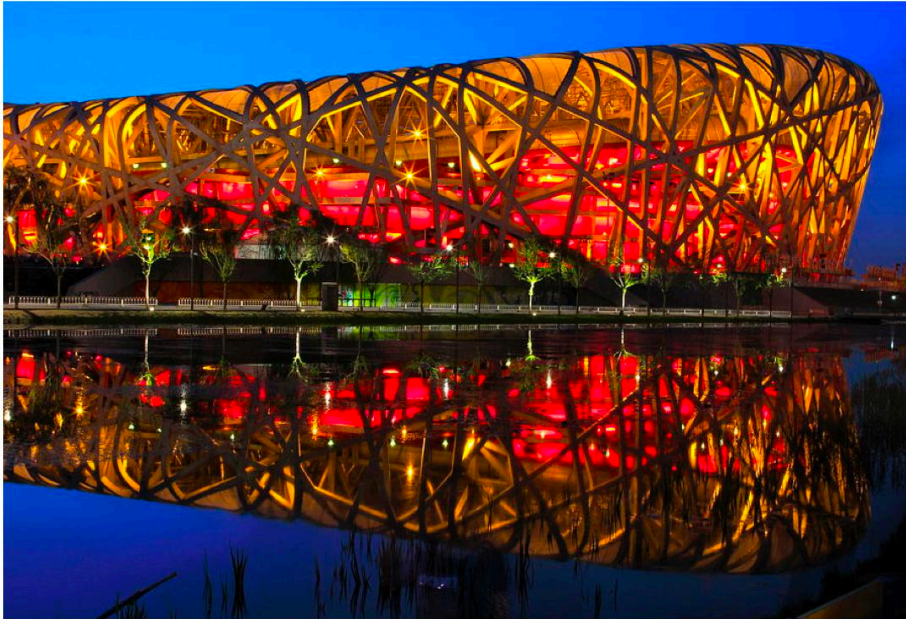
*Why* should we care  
about embodied carbon?

Louis Vuitton Foundation  
Frank Gehry





## Why Embodied Carbon?



Beijing Olympic Stadium, China  
Arup, 2008



London Olympic Stadium, United Kingdom  
Buro Happold, 2012

De Wolf C., Hogroian J., Ochsendorf J., "Comparing material quantities and embodied carbon in stadia," *Proceedings of the IASS, Brasilia, BR, September 17, 2014.*



## Why Embodied Carbon?



**Pantheon, Rome**  
Former roman temple, 119-128 AD



**Kingdome, Seattle**  
Naramore, Skilling & Praeger, 1976



## Why Embodied Carbon?



**Pantheon, Rome**  
Former roman temple, 119-128 AD



**Kingdome, Seattle**  
Naramore, Skilling & Praeger, 1976



# Benchmarks

*What* is the embodied carbon of building structures?



Knokke Footbridge  
Ney & Partners, Belgium

$$\sum_{i=1}^n \text{ECC}_i \times \text{SMQ}_i = \text{GWP}$$

$\sum_{i=1}^n$  Embodied Carbon Coefficients<sub>i</sub> × Structural Material Quantities<sub>i</sub> = Global Warming Potential

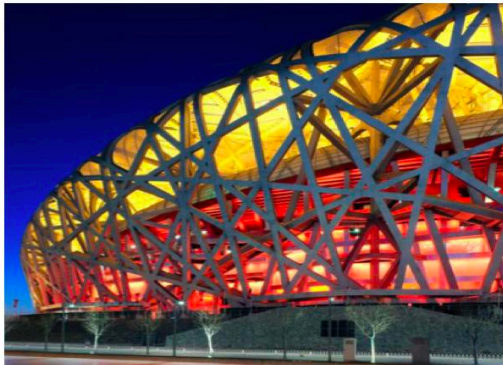
$[\text{kg}_{\text{CO}_2\text{e}}/\text{kg}_{\text{material}}]$   $[\text{kg}_{\text{material}}/\text{m}^2]$   $[\text{kg}_{\text{CO}_2\text{e}}/\text{m}^2]$



Database of embodied  
Quantity outputs

1. Create interactive interface
2. Collaborate with design firms
3. Collect data of >600 projects

ARUP



Thornton  
Tomasetti



Buro Happold



NEY  
+PARTNERS



SOM



Unit system

Metric



Sort by category

Program Category



Value on Y axis

Global Warming Potential (kg-CO<sub>2</sub>e/m<sup>2</sup>)

Filter by

None

[Draw graph](#)



Unit system

✓ Metric

Imperial

Sort by category

Value on Y axis

Global Warming Potential (kg-CO<sub>2</sub>e/m<sup>2</sup>)

Filter by

None

Draw graph



Unit system

Metric

Sort by category

Value on Y axis

Filter by

Draw graph

✓ Program Category

Program

-----  
Accredited Rating Scheme

Accredited Rating

-----  
Region

Country

-----  
Main Structural Material-----  
Number of stories

Number of Occupants

Floor Area (m<sup>2</sup>)-----  
Average clear span

Longest clear span



Unit system

Metric

Sort by category

Main Structural Material

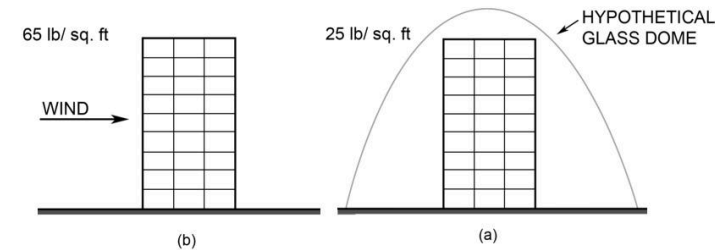
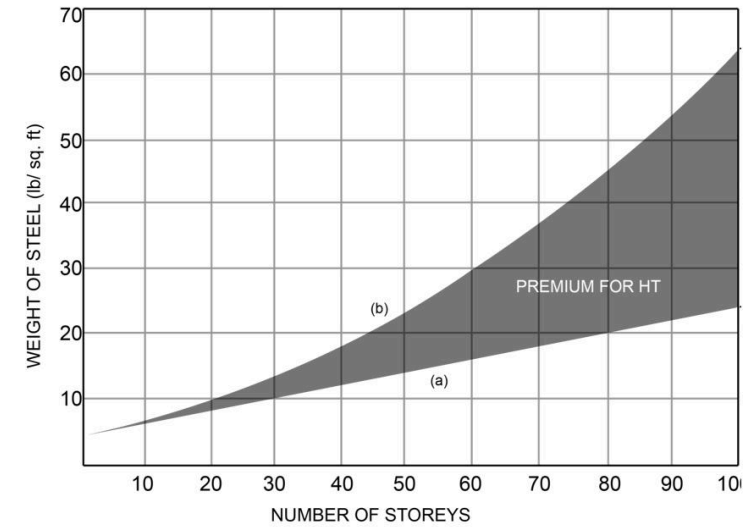
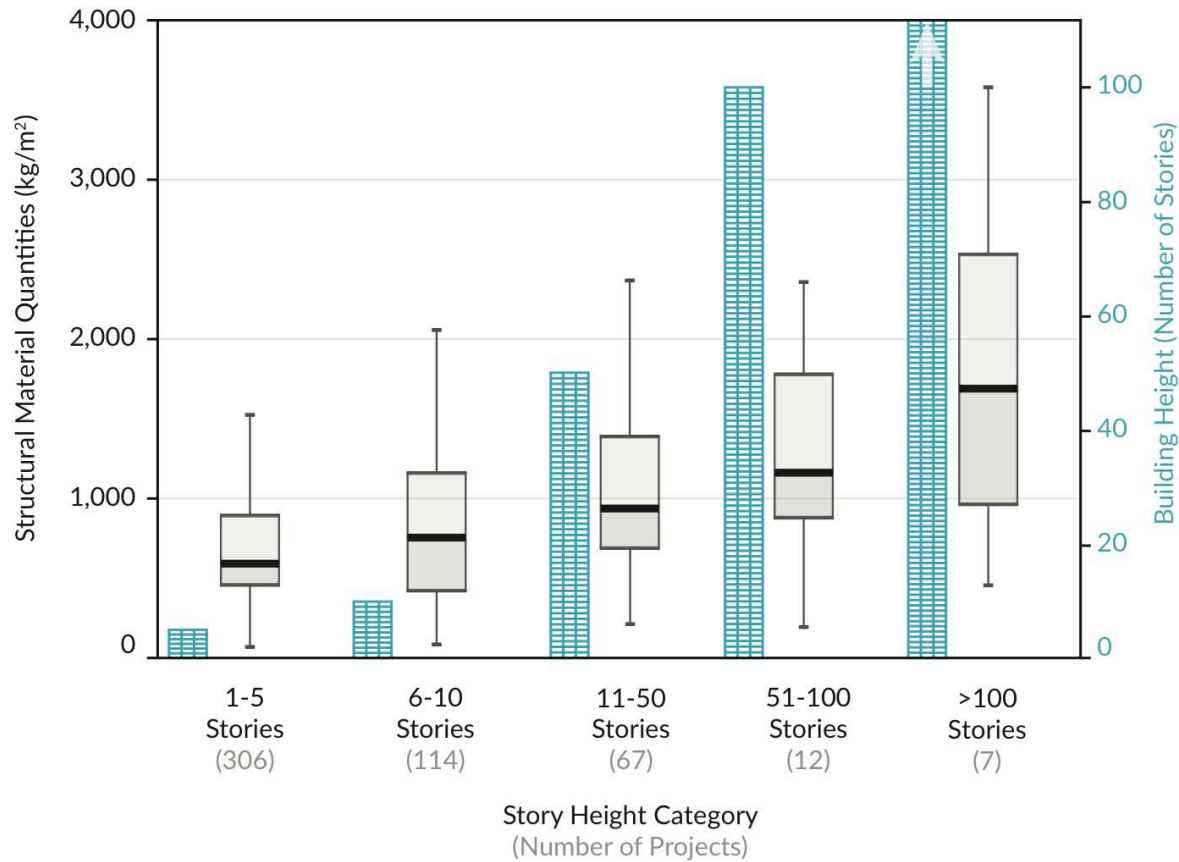
Value on Y axis

✓ Global Warming Potential (kg-CO<sub>2</sub>e/m<sup>2</sup>)Structural Material Quantity (kg/m<sup>2</sup>)

Filter by

Draw graph





Simonen K., Rodriguez B., **De Wolf C.**, "Benchmarking the Embodied Carbon of Buildings: Current Knowledge, Uncertainty and Applicability," TAD, 2017.

[Khan, 1981]



WHY

WHAT

WHO

HOW



# Industry

*Who* can lower the impact of building structures?



## Industry Strategies • Structural Engineers 2050 Commitment

- Leading to Zero Carbon Structures

Architects: operational

Engineers: embodied

AIA **2030** Commitment

SE **2050** Commitment

- Inspire structural engineers

Provide data to deQo

Meet reduction targets



STRUCTURAL  
ENGINEERING  
INSTITUTE

**Sustainability Committee**

*Advancing sustainability in the structural engineering community.*



**Thornton  
Tomasetti**

ARUP

WALTER  
P MOORE

MAGNUSSON  
KLEMENCIC  
ASSOCIATES

SIMPSON GUMPertz & HEGER

SOM

## Industry Strategies • Dissemination

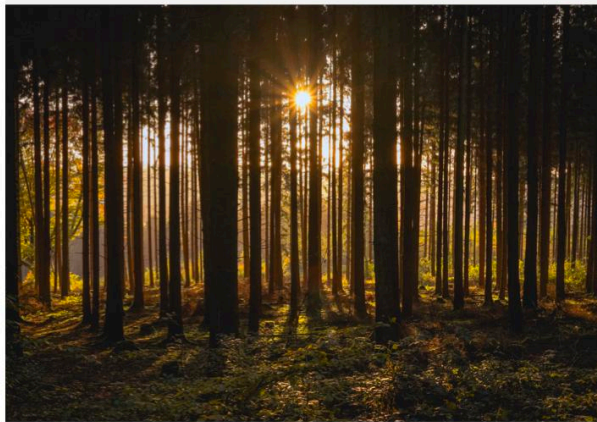
RICS professional statement



RICS professional standards and guidance, UK

**Whole life carbon  
assessment for the  
built environment**

1st edition, November, 2017



sturgis carbon profiling FAITHFUL+GOULD ARUP GREEN ALLIANCE COUNCIL  
sbp sustainable business partnership UNIVERSITY OF CAMBRIDGE LandSecurities LAING O'ROURKE

Francesco Pomponi · Catherine De Wolf  
Alice Moncaster *Editors*

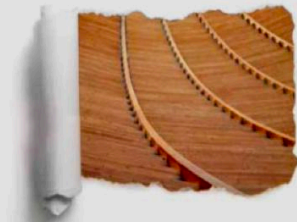
# Embodied Carbon in Buildings

Measurement, Management, and  
Mitigation

Springer

"TRULY, WHAT A FANTASTIC, TIMELY, IMPORTANT BOOK!"  
— PAUL HAWKEN, author of *Drawdown* and *Blessed Unrest*

# THE NEW CARBON ARCHITECTURE



BUILDING TO COOL  
THE CLIMATE

**BRUCE KING**



WHY

WHAT

WHO

HOW

# Design

*How* low can we go?



Mapungubwe Interpretation Centre  
Peter Rich, South Africa



## Low Carbon Design • Resource scarcity

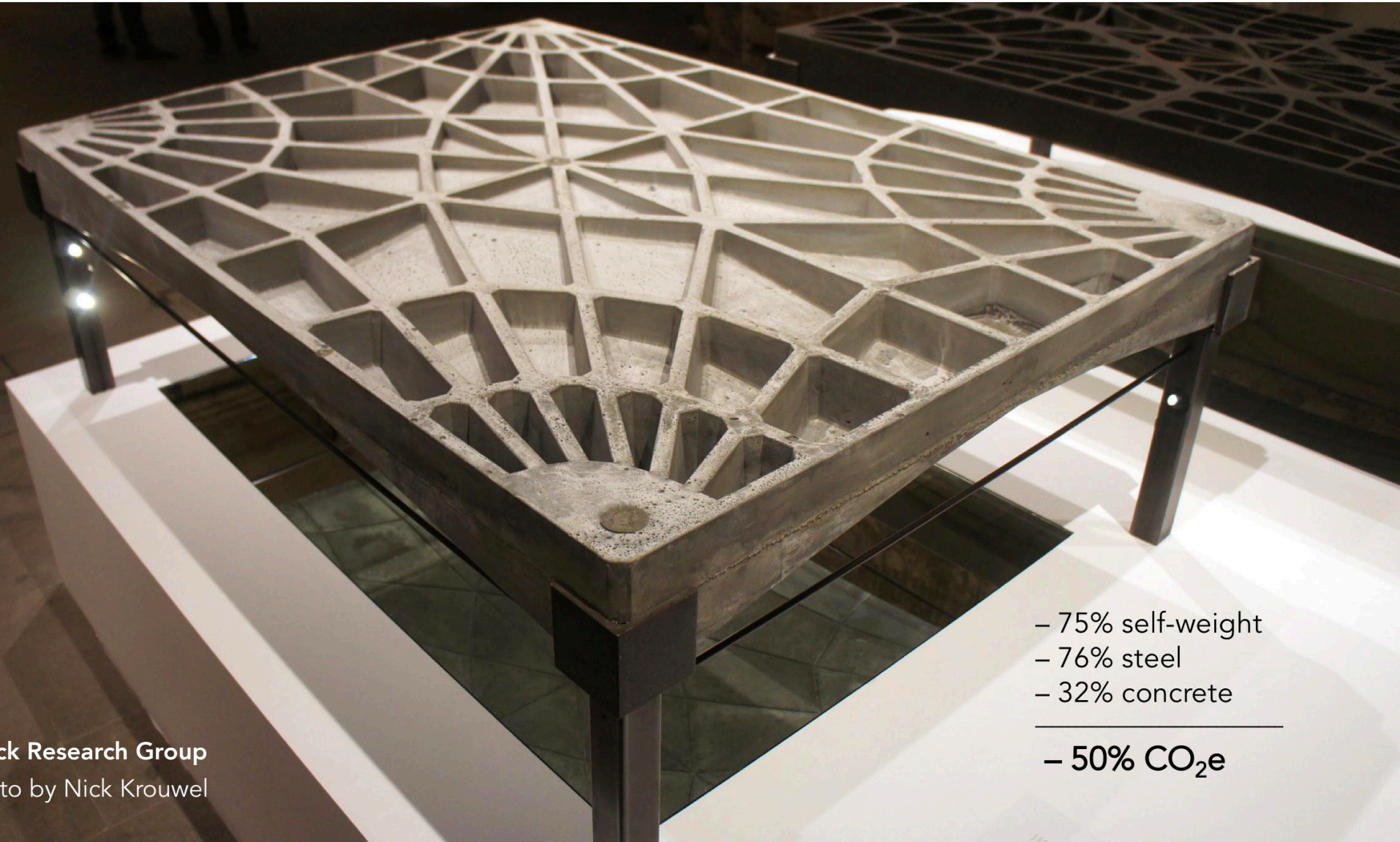


Ilima Primary School, Congo  
MASS Design Group, 2015



## Low Carbon Pathways • Rib-stiffened Funicular Floor

Liew A. et al. "Design, fabrication & testing of a prototype, thin-vaulted, unreinforced concrete floor," *Engineering Structures*, 2017  
Block P. et al. "Compressive assemblies: Bottom-up performance for a new form of construction," *AD Architectural Design*, 2017  
Agustí-Juan I., Habert G. "Env. design guidelines for digital fab.," *Journal of Cleaner Production*, 2017



- 75% self-weight
  - 76% steel
  - 32% concrete
- 
- 50% CO<sub>2</sub>e



## Reuse • Waste Materials



Circular economy principles  
Escuela Agustín García Padilla  
2017  
Venezuela

TRAZANDO  
ESPACIOS  
PÚBLICOS





## Reuse • Proof of Concept



**Ski Pavilion**

Corentin Fivet, Sofia Colabella, Jan Brütting, Claude-Alain Jacot, etc.



## Conclusions

$$\sum_{i=1}^n \text{ECC}_i \times \text{SMQ}_i = \text{GWP}$$

$\sum_{i=1}^n$  Embodied Carbon Coefficients<sub>i</sub> × Structural Material Quantities<sub>i</sub> = Global Warming Potential  
 $[\text{kg}_{\text{CO}_2\text{e}}/\text{kg}_{\text{material}}]$   $[\text{kg}_{\text{material}}/\text{m}^2]$   $[\text{kg}_{\text{CO}_2\text{e}}/\text{m}^2]$



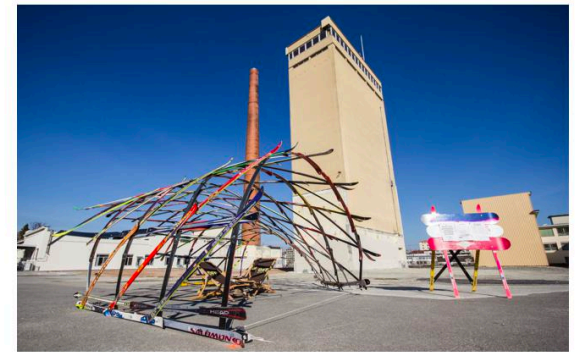
Low ECC

Low Carbon Materials



Low SMQ

Structural Efficiency



Low GWP

Reuse



The image shows the interior of the Bamboo Cathedral at night. The structure is a large, arched space made of numerous vertical bamboo poles that form a complex, lattice-like roof. The interior is illuminated with warm, yellow light, creating a glowing effect. In the foreground, several people are visible, some sitting on wooden benches and others standing. The perspective leads the eye towards a dark, arched opening at the far end of the structure, which appears to be the entrance or exit. The overall atmosphere is one of a unique, organic architectural space.

Questions?

Bamboo Cathedral  
Simon Velez, Colombia, 1999