# 5 Slabs

## In-depth study and additions to Stahlbeton II

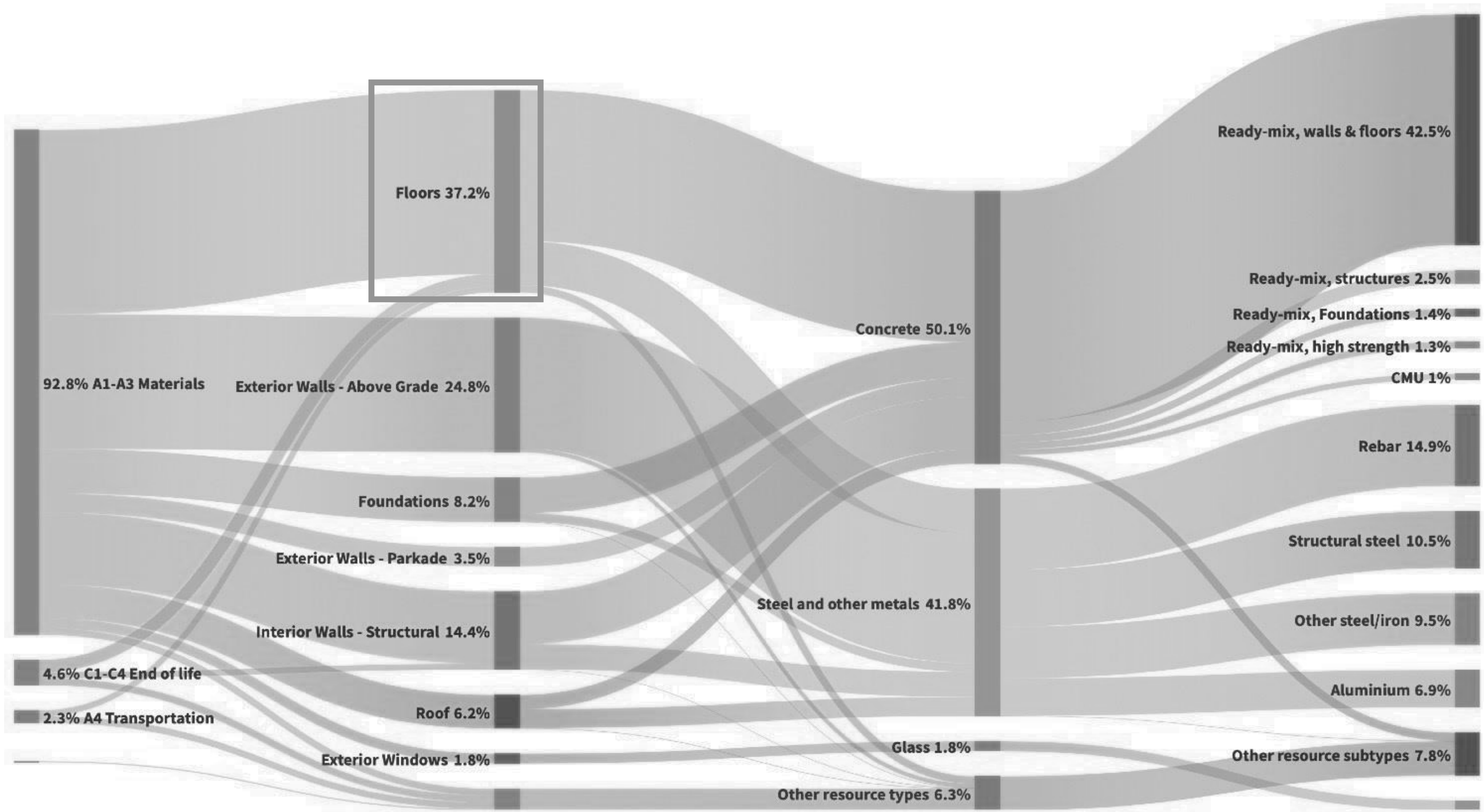
## 5.9 Sustainability

# Learning objectives

Within this chapter, the students are able to:

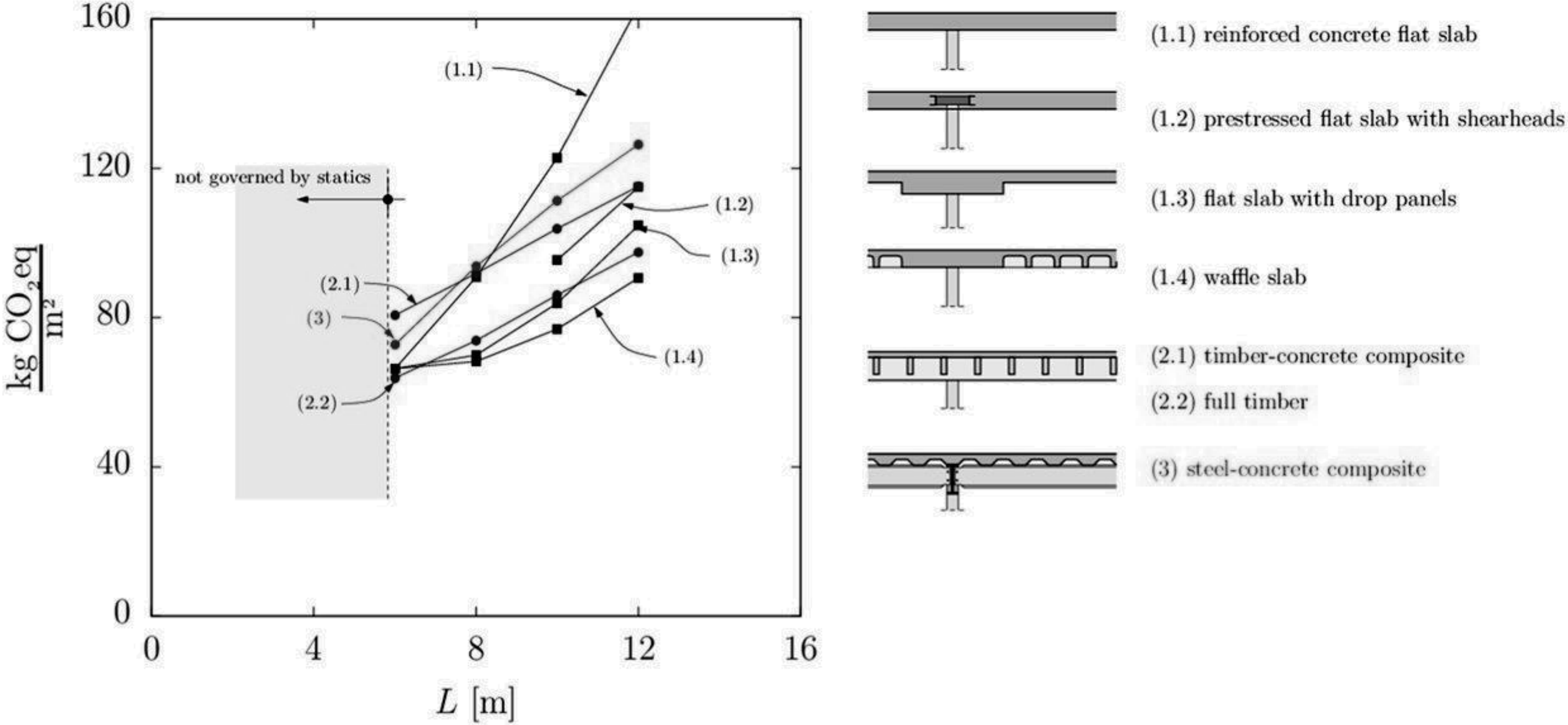
- select different types of concrete slabs and assess their environmental impact as well as structural efficiency:
  - recognise the importance of the engineer in the decision-making and minimising the environmental impact of a structure
  - identify the potential and limitations of various concrete slab types.

# Environmental impact of slabs



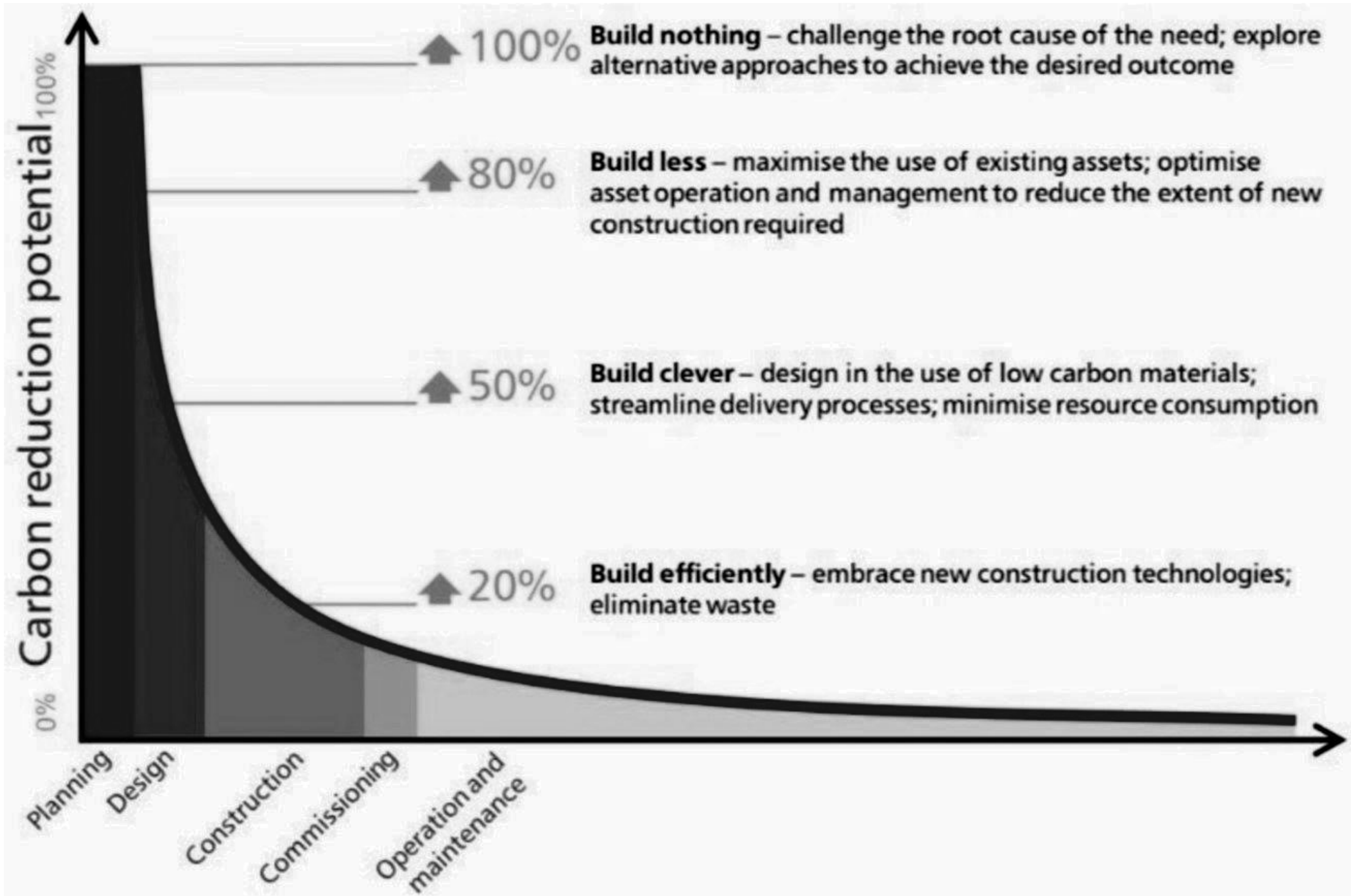

Anthony Pak - Embodied Carbon: Key Considerations for Key Materials, 2020

# Environmental impact of slabs




Regúlez et al. 2022

# Environmental impact of slabs

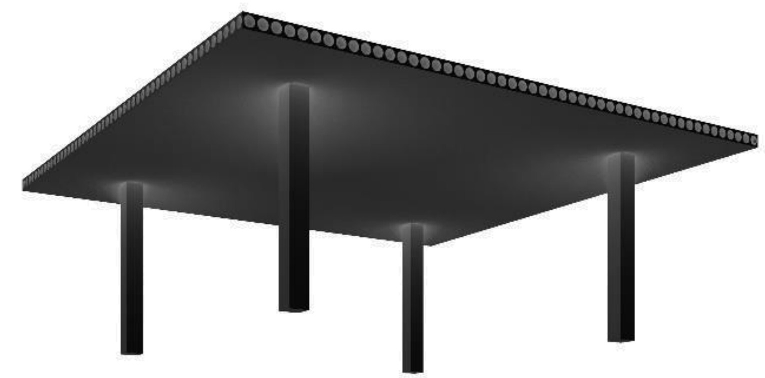


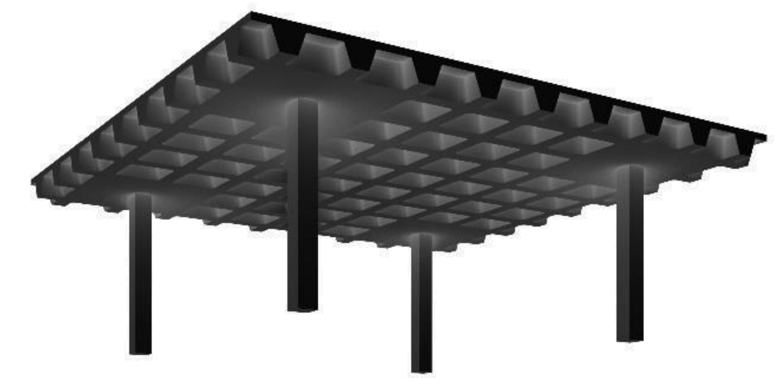

Negle et al. 2022

# Concrete slab types


Flat slab
Post-tensioned flat slab


Mushroom slab


Voided flat slab


Waffle slab

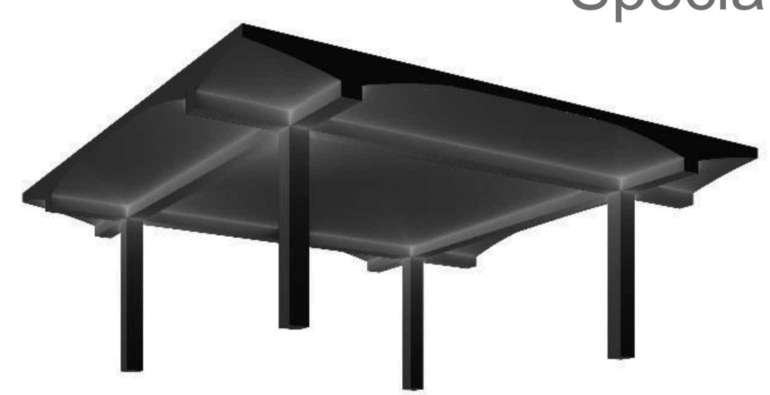
Onsite

Pre-fabrication


Hollow core slab (with topping)

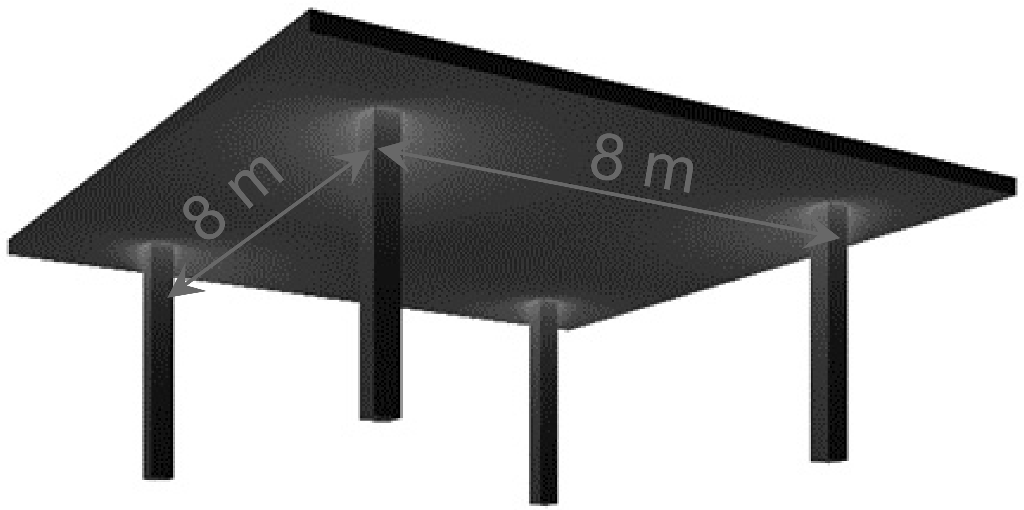

Ribbed slab (with topping)

Special


Vaulted slab

… and many more

# Case study: Concrete slab systems

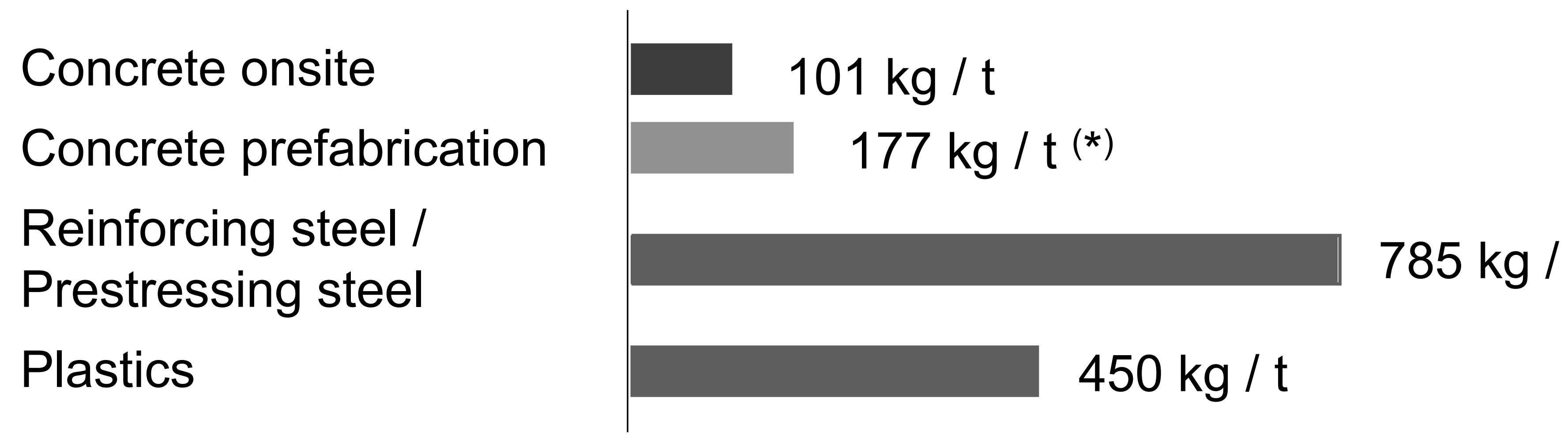



Floor slab with 8 m inter-column span

Load combination: self-weight, additional load (2kN/m$^2$), live load (2kN/m$^2$)

Impact of design on Global Warming Potential GWP ($CO_2$-eq.)?

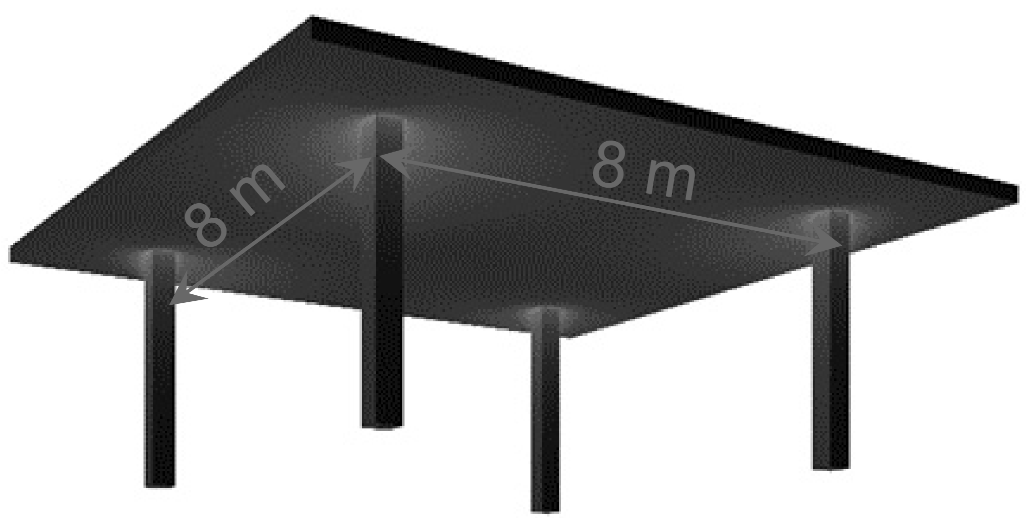
Assumptions for $CO_2$-eq of used materials:




(*) including reinforcement in prefab element

KBOB – Ökobilanzdaten im Baubereich, V4.0, 2023

# Case study: Concrete slab systems

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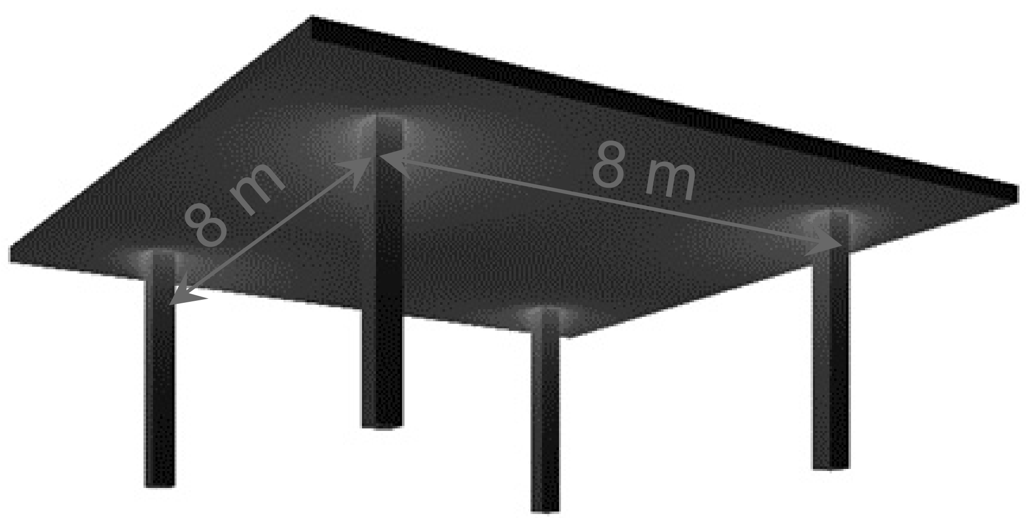
# Case study: Concrete slab systems




The following results are only valid for the assumptions made and cannot directly be generalised to other conditions. Results can change especially for

- different inter-column spans
- edge regions
- non-regular floor layouts
- in case of openings

Often requirements independent of the direct structural design case, such as of fire safety, sound insulation, thermal insulation, limit the optimisation of the dimensions. The GWP of the formwork (different for each case presented here) and costs are not considered.

# Flat slabs

Classic way of constructing in-situ concrete slabs

Dimensions are often defined by building systems, sound insulation etc.

**Advantages**

- Easy and simple construction
- Easy to dimension
- Redundancy and high flexibility
- Integration of building systems

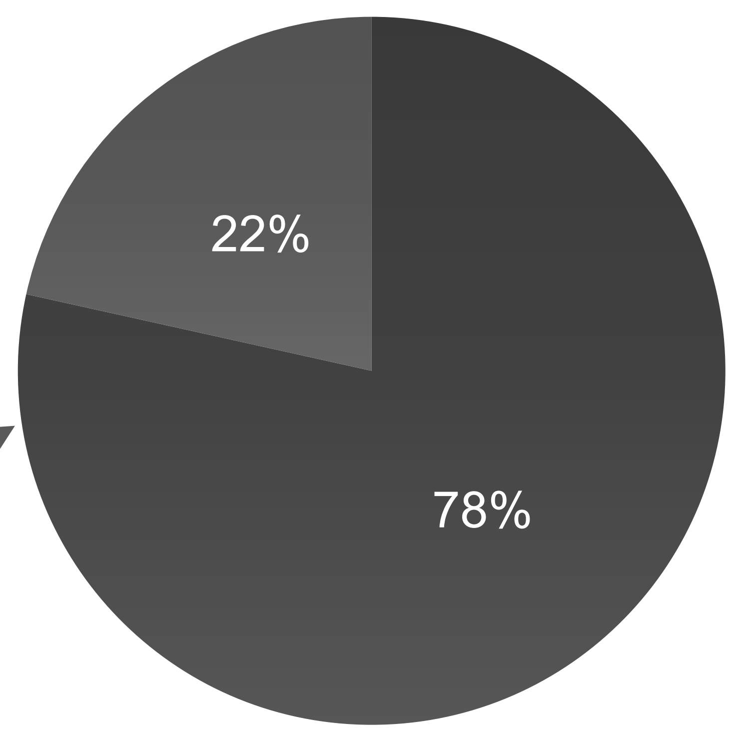
**Limitations**

- Very high material usage
- High self-weight
- Deflections and punching often governing

**Not optimised flat slab**

*h* = 26 cm

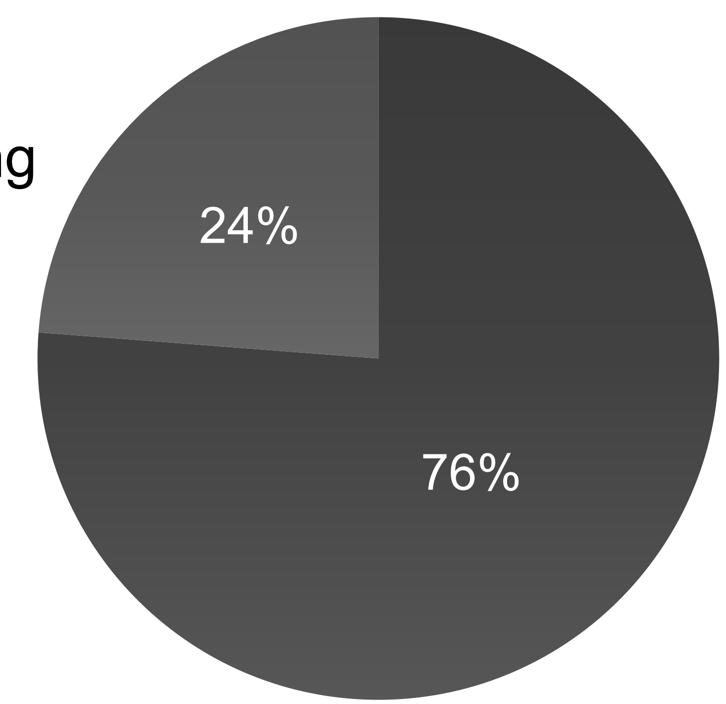
77 kg/m$^2$ $CO_2$-eq.




**Optimised flat slab**

*h* = 23 cm, deflections governing

70 kg/m$^2$ $CO_2$-eq.
-10 %




Concrete
Reinforcement
Prefab concrete
Plastics

# Prestressed flat slab

Classic way of constructing in-situ concrete slabs

Dimensions are often defined by fire safety & punching

**Advantages**

- Easy and simple construction
- Medium effort for dimensioning
- Redundancy and some flexibility
- Substantially less material usage

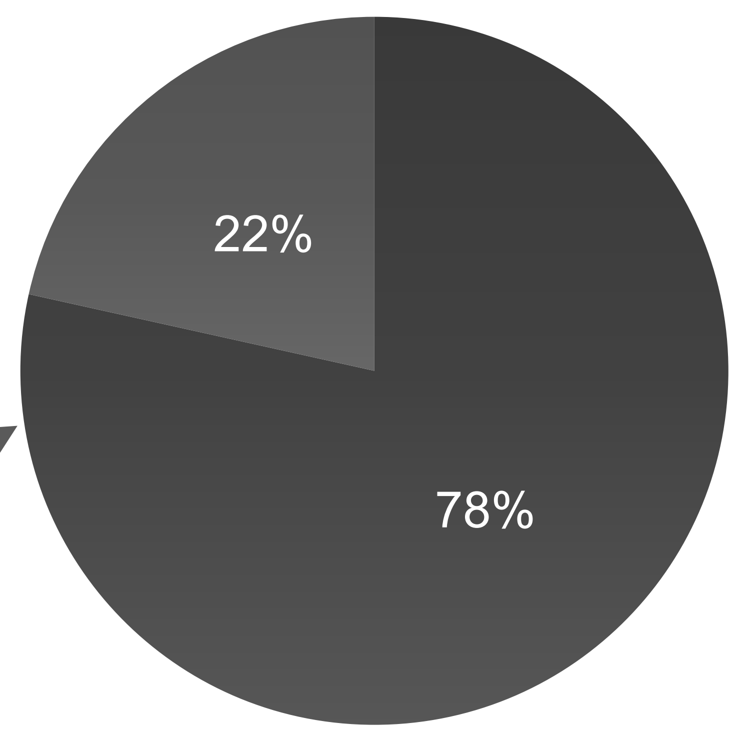
**Limitations**

- Fire safety & punching often governing
- Integration of building systems only partly possible

**Not optimised flat slab**

*h* = 26 cm

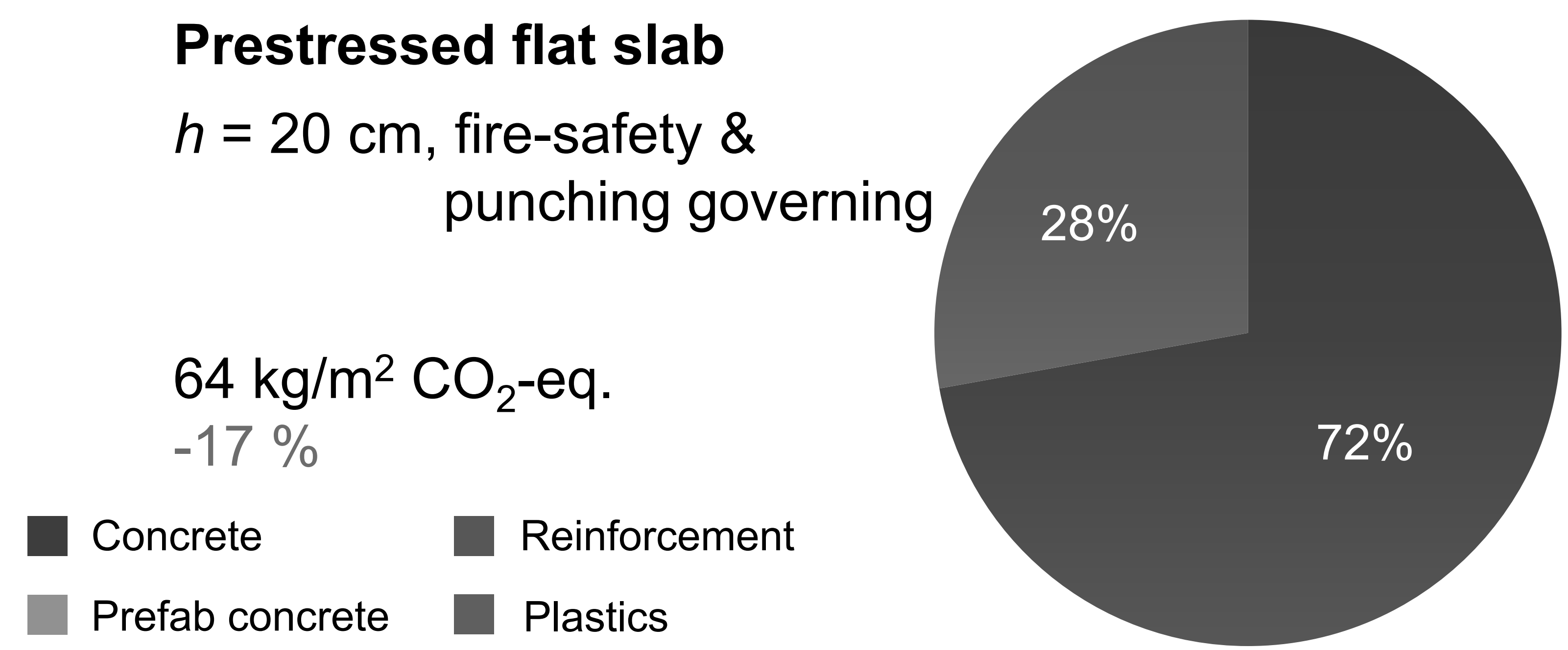
77 kg/m² $CO_2$-eq.




**Prestressed flat slab**

*h* = 20 cm, fire-safety & punching governing

64 kg/m² $CO_2$-eq.
-17 %



# Mushroom slab

Particularly suitable for high punching loads

Reduced slab thickness in the fields but increased concrete volume at supports

**Advantages**

- Substantial material savings
- Much lighter structure (leaner foundation)
- Redundancy
- Very efficient regarding punching

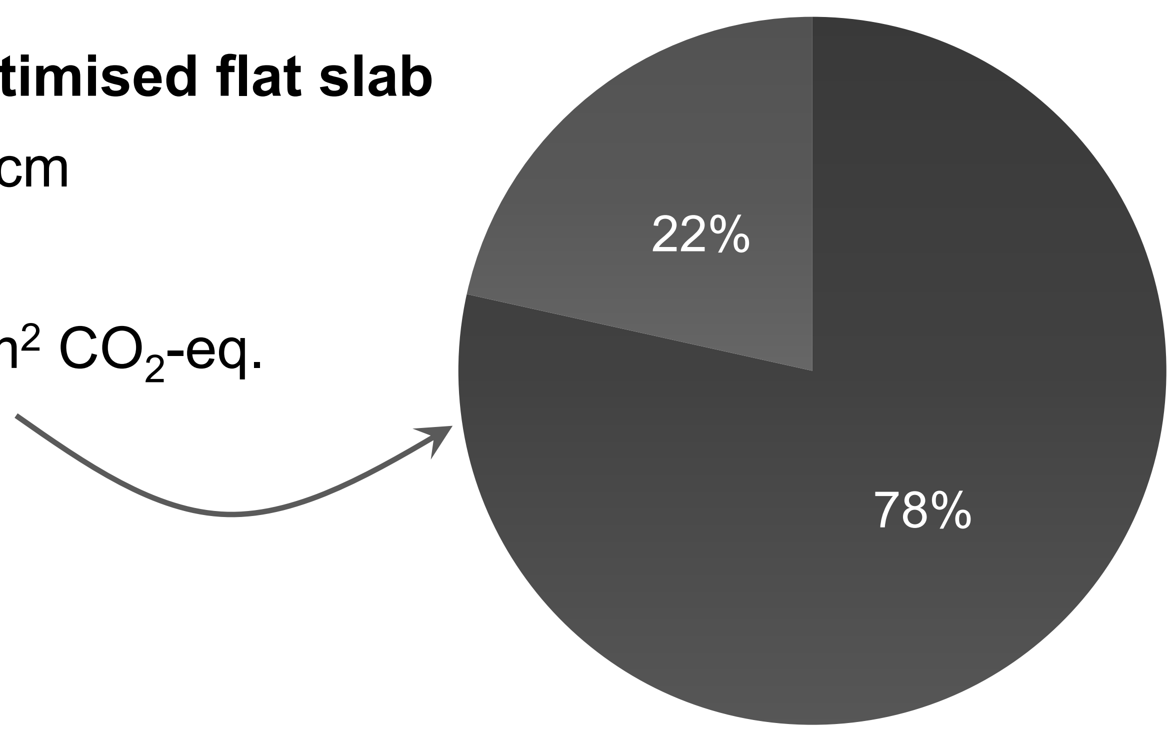
**Limitations**

- Formwork more tedious
- Discussible aesthetics
- Deflections often governing
- Integration of building systems only partly possible

**Not optimised flat slab**

*h* = 26 cm

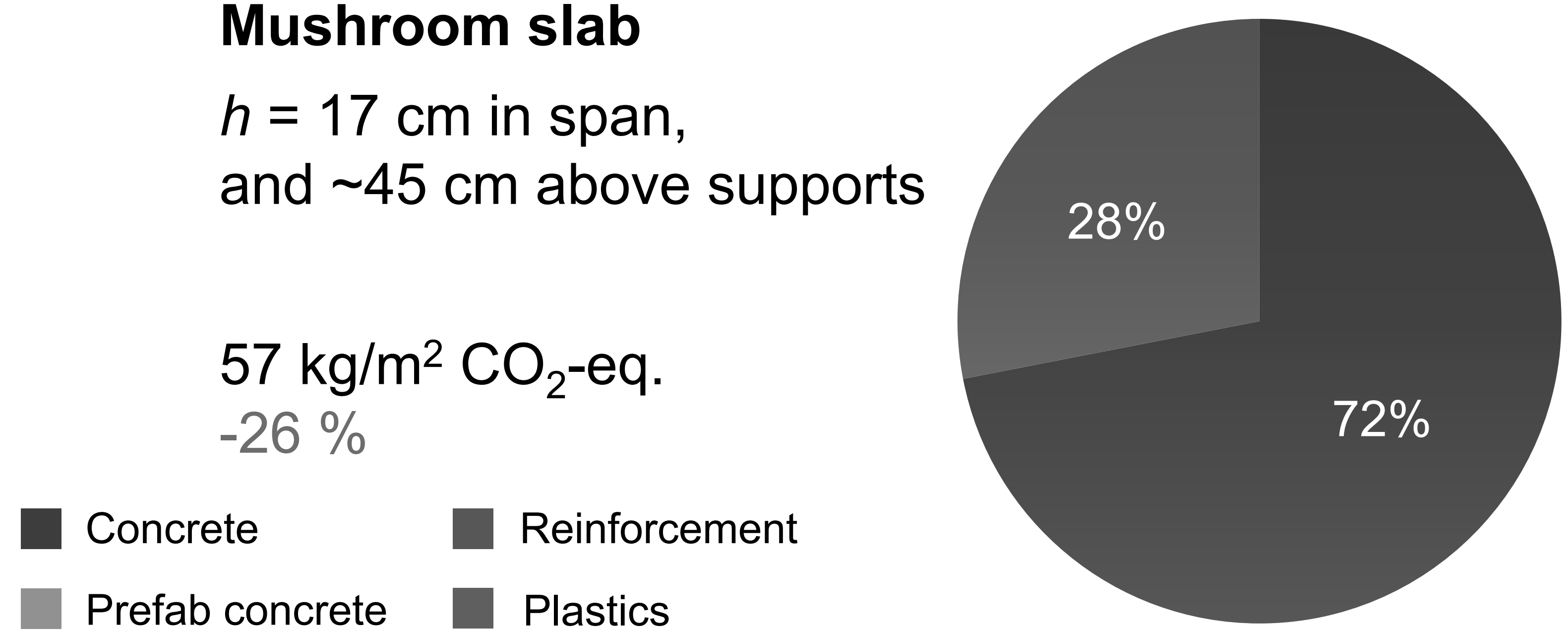
77 kg/m² $CO_2$-eq.



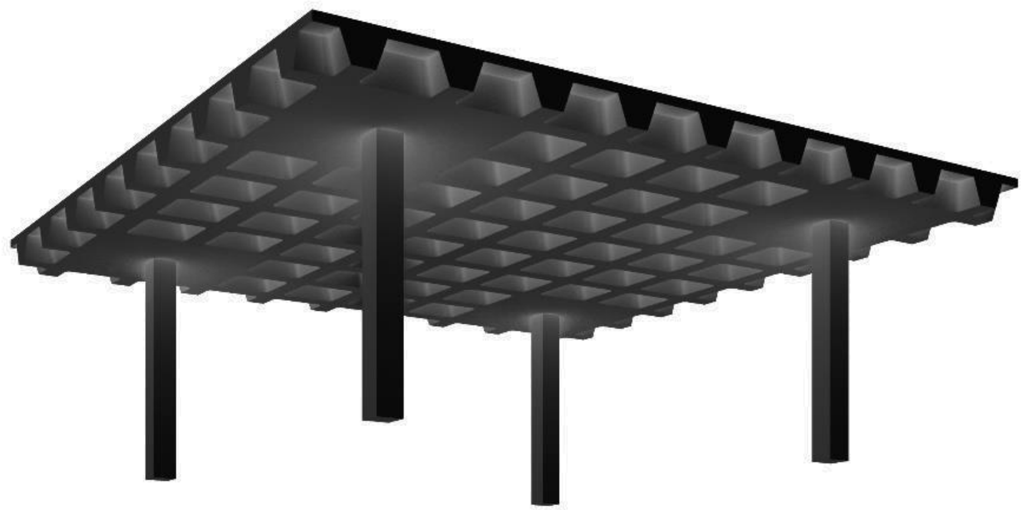

**Mushroom slab**

*h* = 17 cm in span,
and ~45 cm above supports

57 kg/m² $CO_2$-eq.
-26 %



# Waffle slab



Very efficient floor system

Increases storey height (decreases number of stories for given total height)

**Advantages**

- Substantial material savings
- Much lighter structure (leaner foundation)
- Redundancy and high flexibility

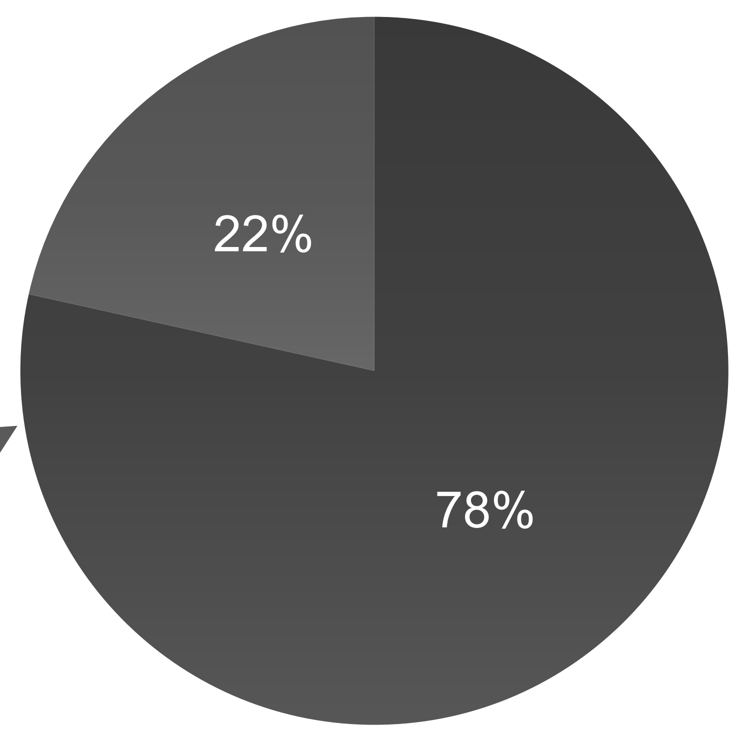
**Limitations**

- Increased storey height (especially with intermediate ceiling)
- No flat soffit
- No integration of building systems
- Very tedious formwork

**Not optimised flat slab**

*h* = 26 cm

77 kg/m² $CO_2$-eq.

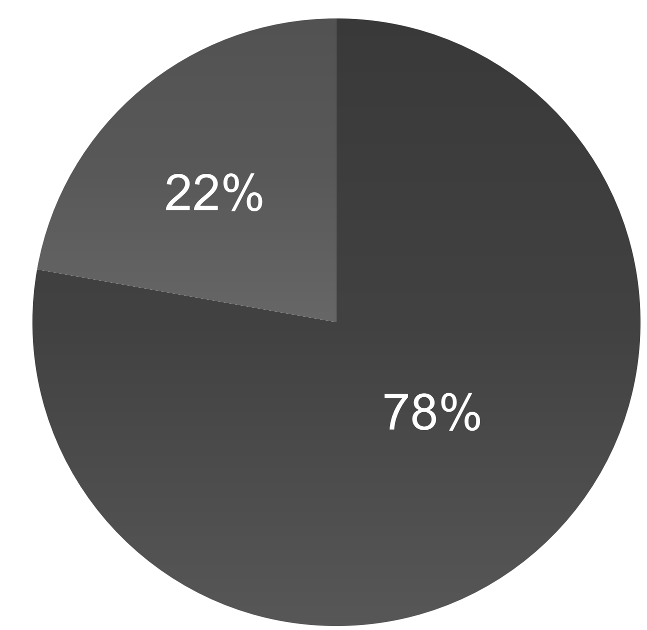



**Waffle slab**

$h_{tot}$ = 35 cm, $h_{slab}$ = 10 cm

57 kg/m² $CO_2$-eq.
-26 %

Concrete
Reinforcement
Prefab concrete
Plastics



# Voided slab

No influence on bending resistance but significant influence on shear resistance
→ do not place voids in areas of high shear forces

online dimensioning tools of the producers available

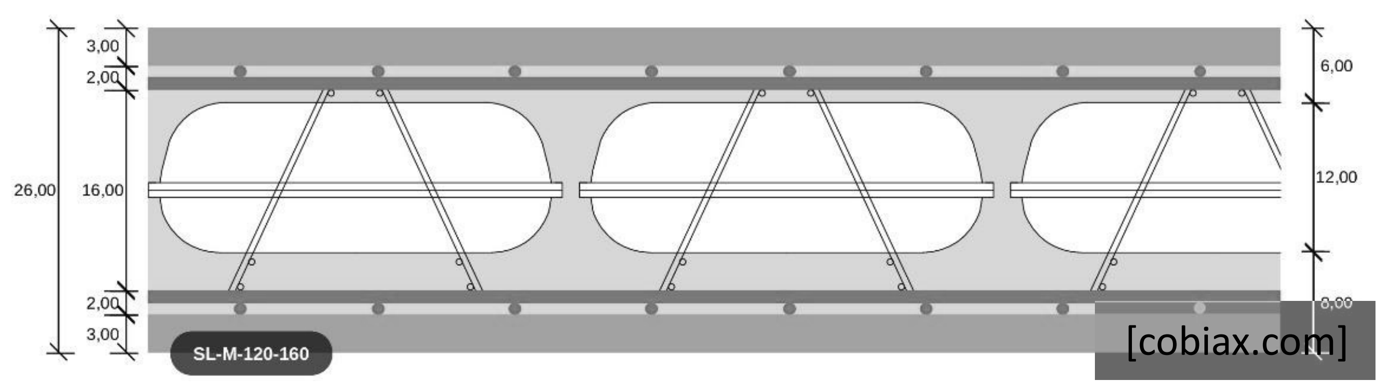
**Advantages**

- Substantial material savings
- Flat surfaces
- Much lighter structure (leaner foundation)

**Limitations**

- Less flexibility
- Challenging construction (e.g. buoyancy)
- Issues regarding recycling
- No integration of building systems

[unidome.de]




[cobiax.com]

25% concrete volume reduction
voided areas compared to full s

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**Not optimised flat slab**

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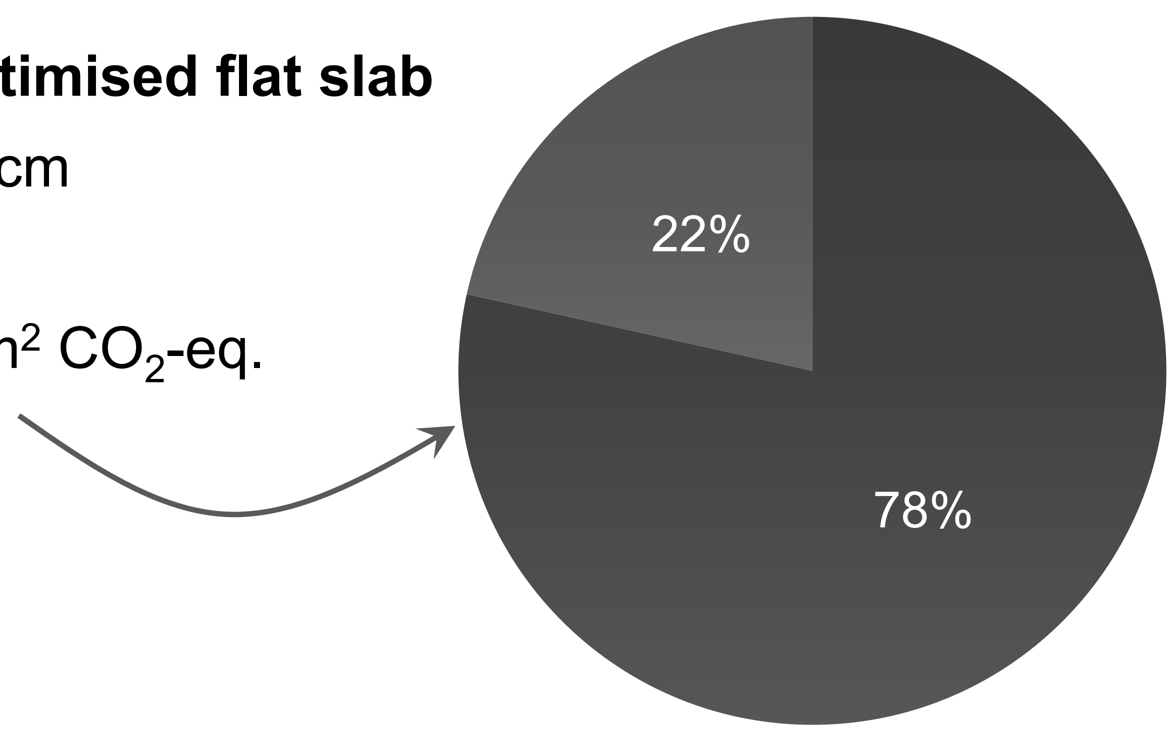
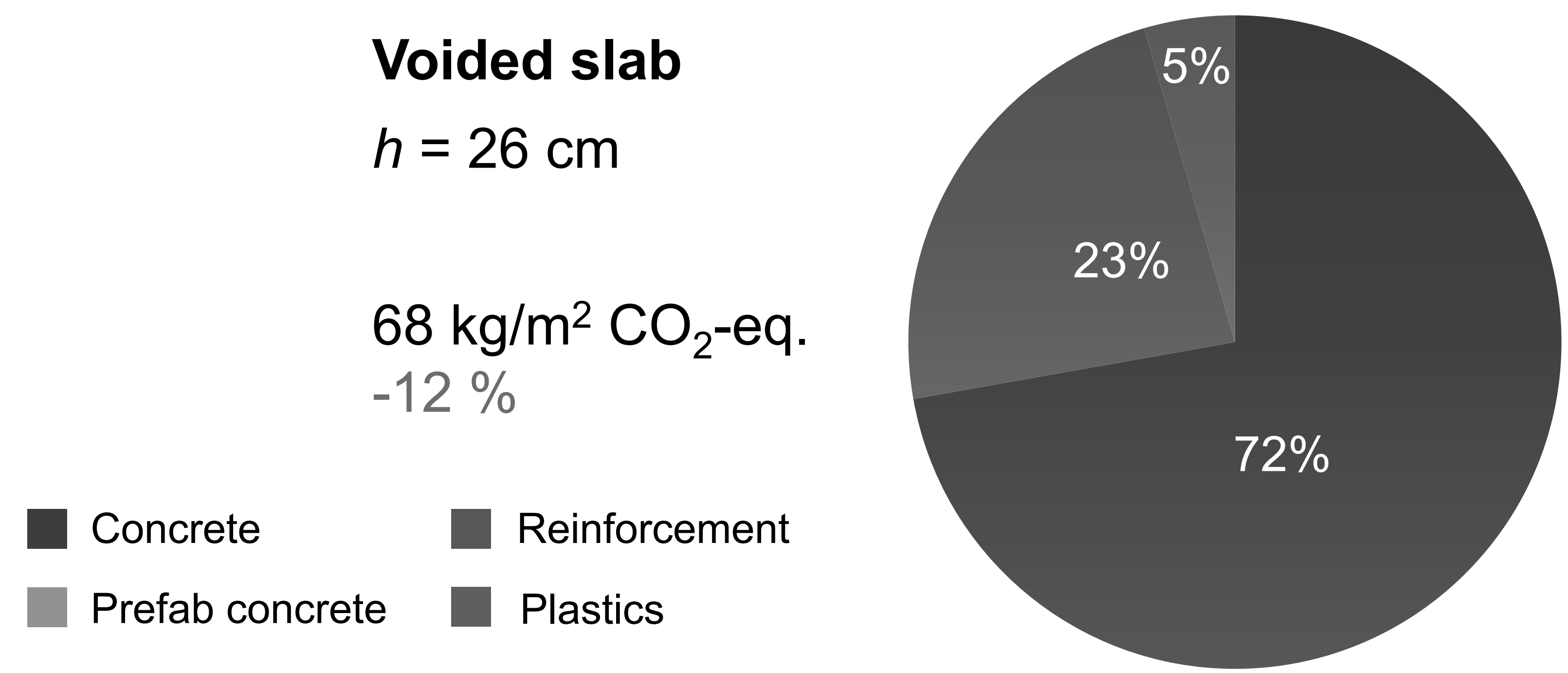



**Voided slab**

$h$ = 26 cm

68 kg/m² $CO_2$-eq.
-12 %



# Hollow core slab

Prestressed beams

According to fabricator documentation

**Advantages**

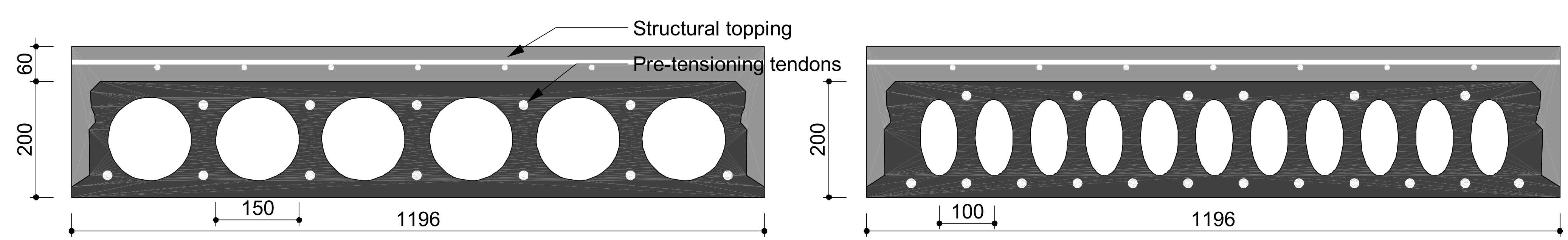
- Efficient production, i.e. extrusion
- Large material savings
- Scaffold-free construction
- Building systems partly integrable

**Limitations**

- Uni-directional load-bearing
- Topping required (in most cases)
- Limited customisation
- Typically higher cement contents in prefabricated elements


Reduction of self-weight compared to 26 cm full slab with 8 x 8 m span:

- ~ 50% (no topping)
- ~ 30% (60 mm structural topping)



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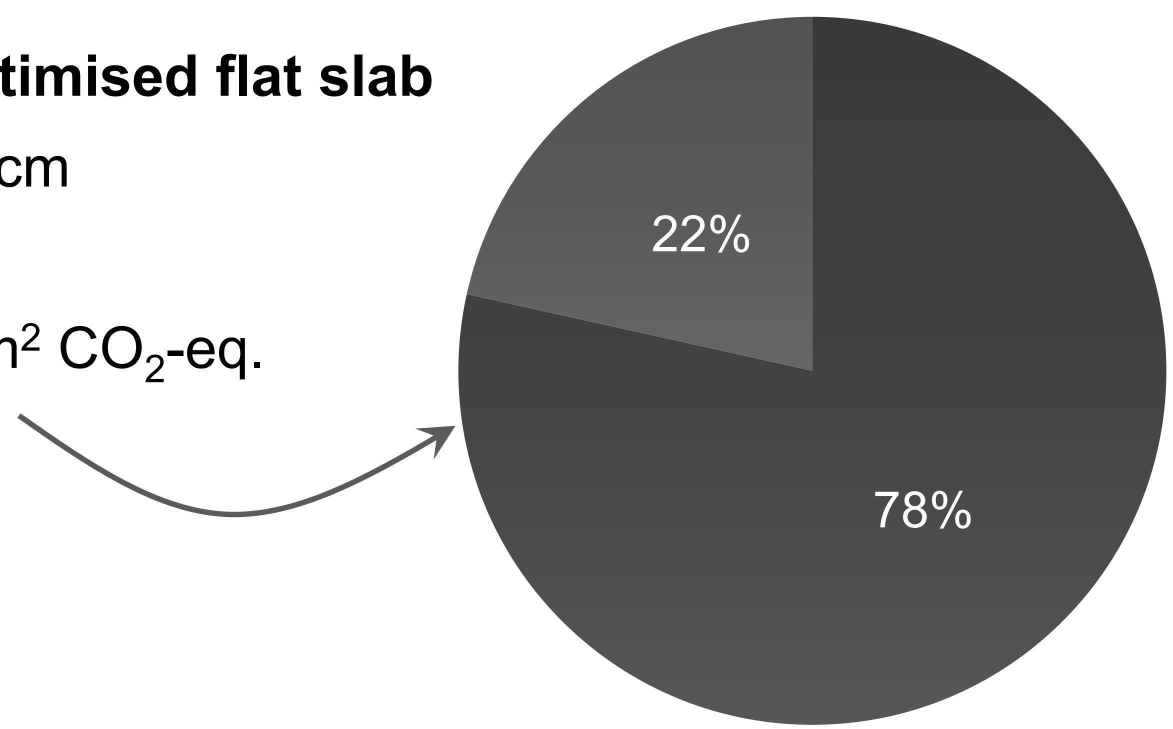
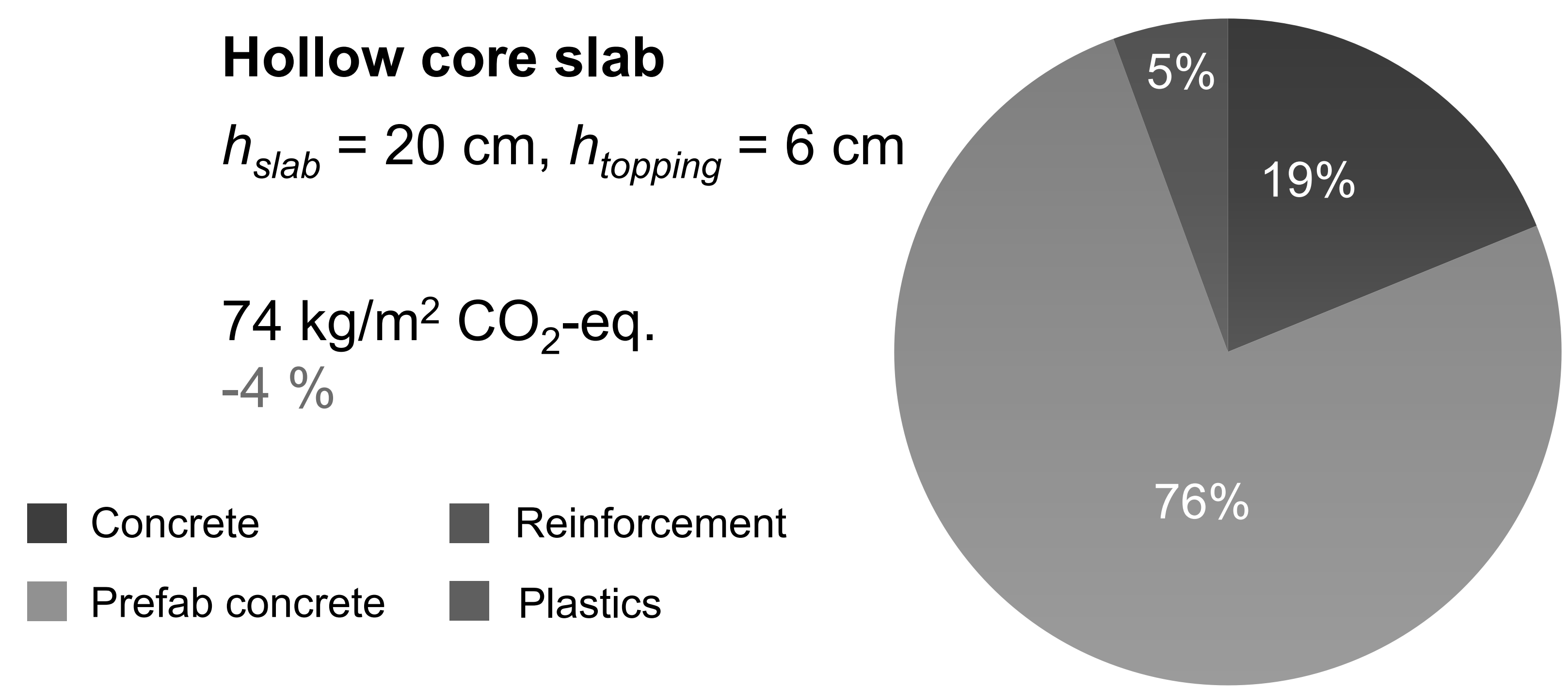



**Hollow core slab**

$h_{slab}$ = 20 cm, $h_{topping}$ = 6 cm

74 kg/m² $CO_2$-eq.
-4 %



# Ribbed slab with TT-beams

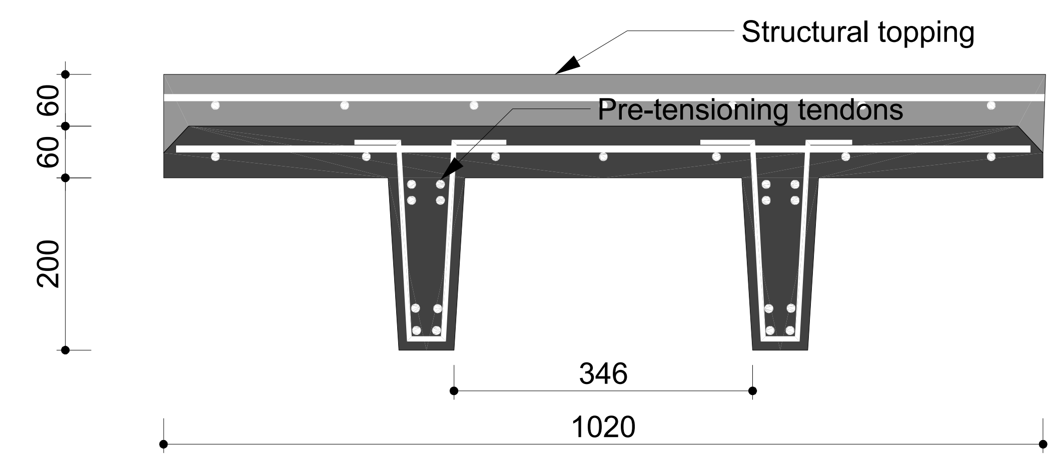
(Prestressed) beams

According to fabricator documentation

**Advantages**
- Efficient production
- Large material savings, especially for large spans
- Scaffold-free construction

**Limitations**
- Uni-directional load transfer
- Limited customisation
- No flat soffit
- Increased storey height
- No integration of building systems


Reduction of self-weight compared to 26 cm full slab with 8 x 8 m span:
~ 40% (60 mm structural topping)



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- Increased storey height
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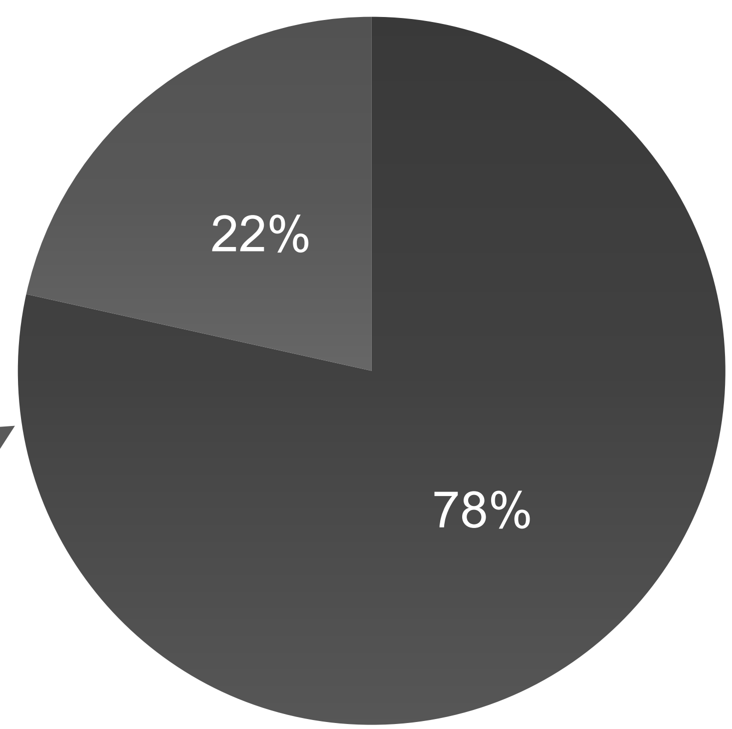
**Not optimised flat slab**

$h$ = 26 cm

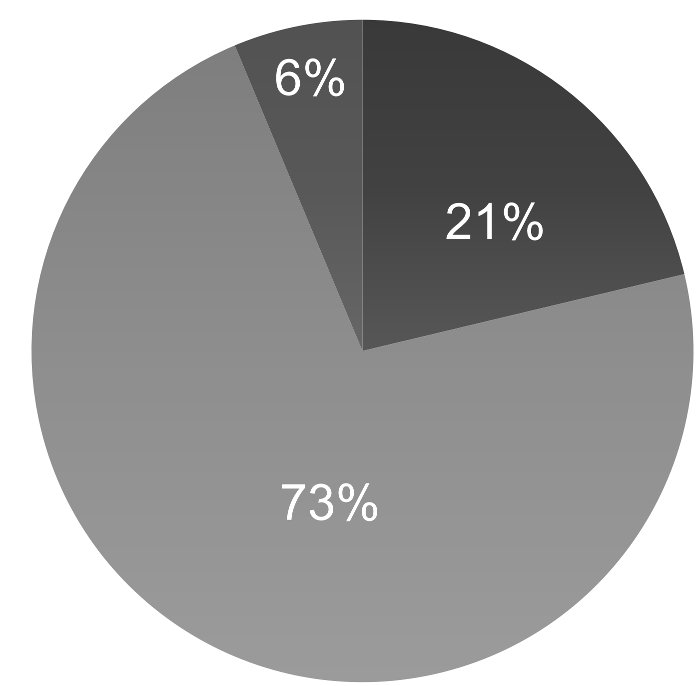
77 kg/m$^2$ $CO_2$-eq.



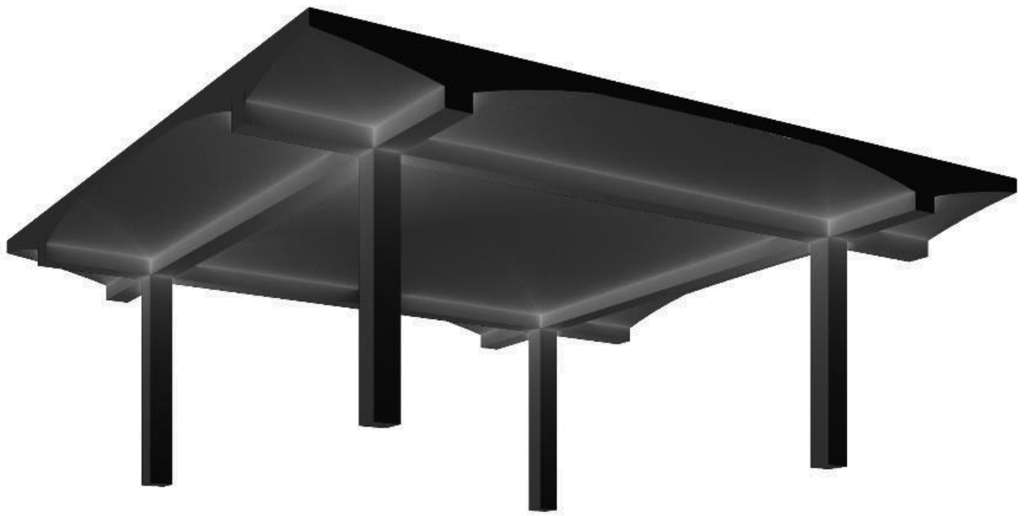

**Ribbed slab**

$h_{tot}$ = 32 cm, $h_{slab}$ = 12 cm

65 kg/m$^2$ $CO_2$-eq.
-16 %



# Vaulted slab



Shell design

Large thrust forces need to be considered

**Advantages**

- Efficient load transfer
- Substantial material savings

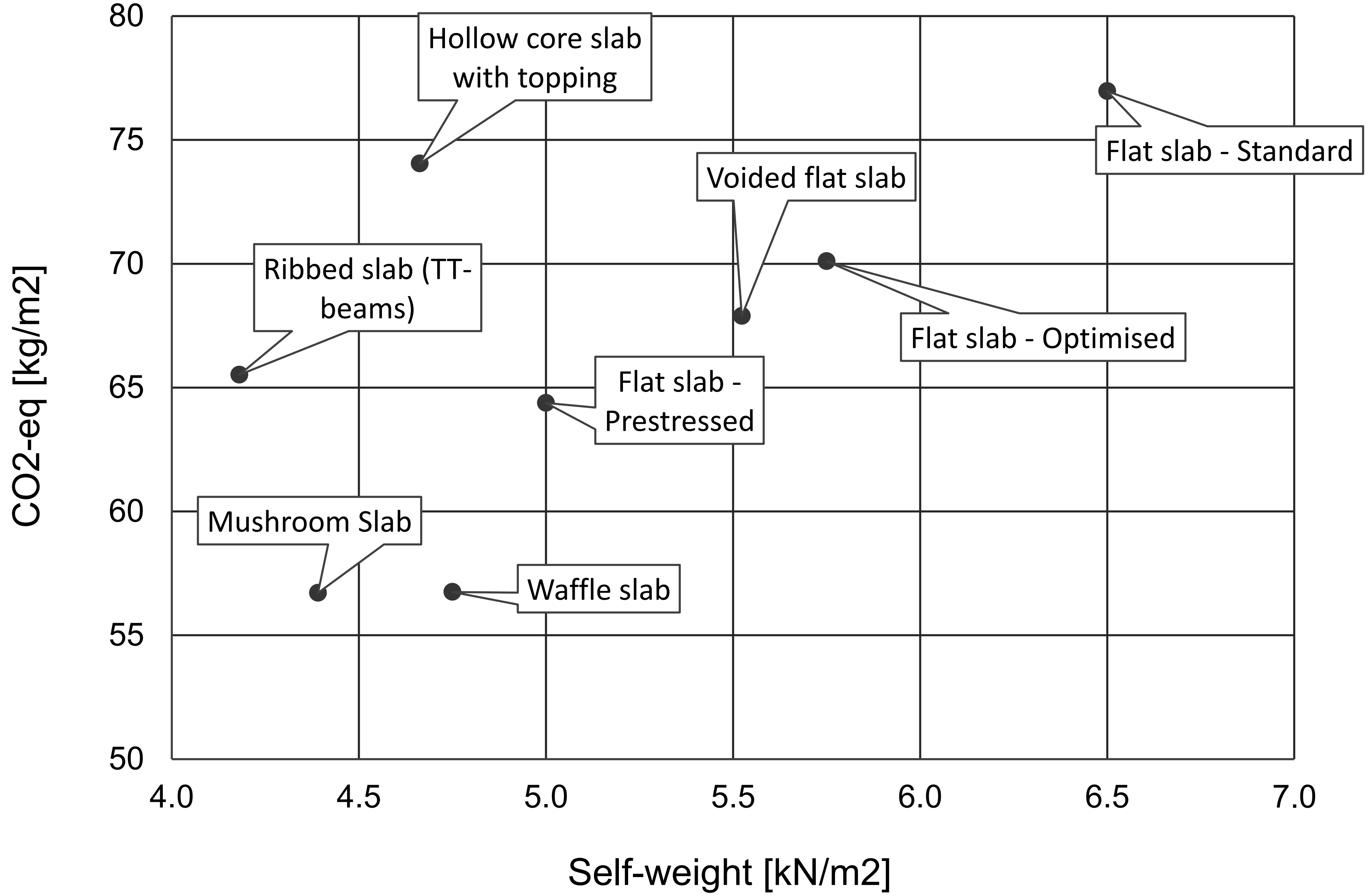
**Limitations**

- Restricted floor plan
- Complex formwork required
- No flat soffit
- Typically requires large structural height

[Vaulted AG]

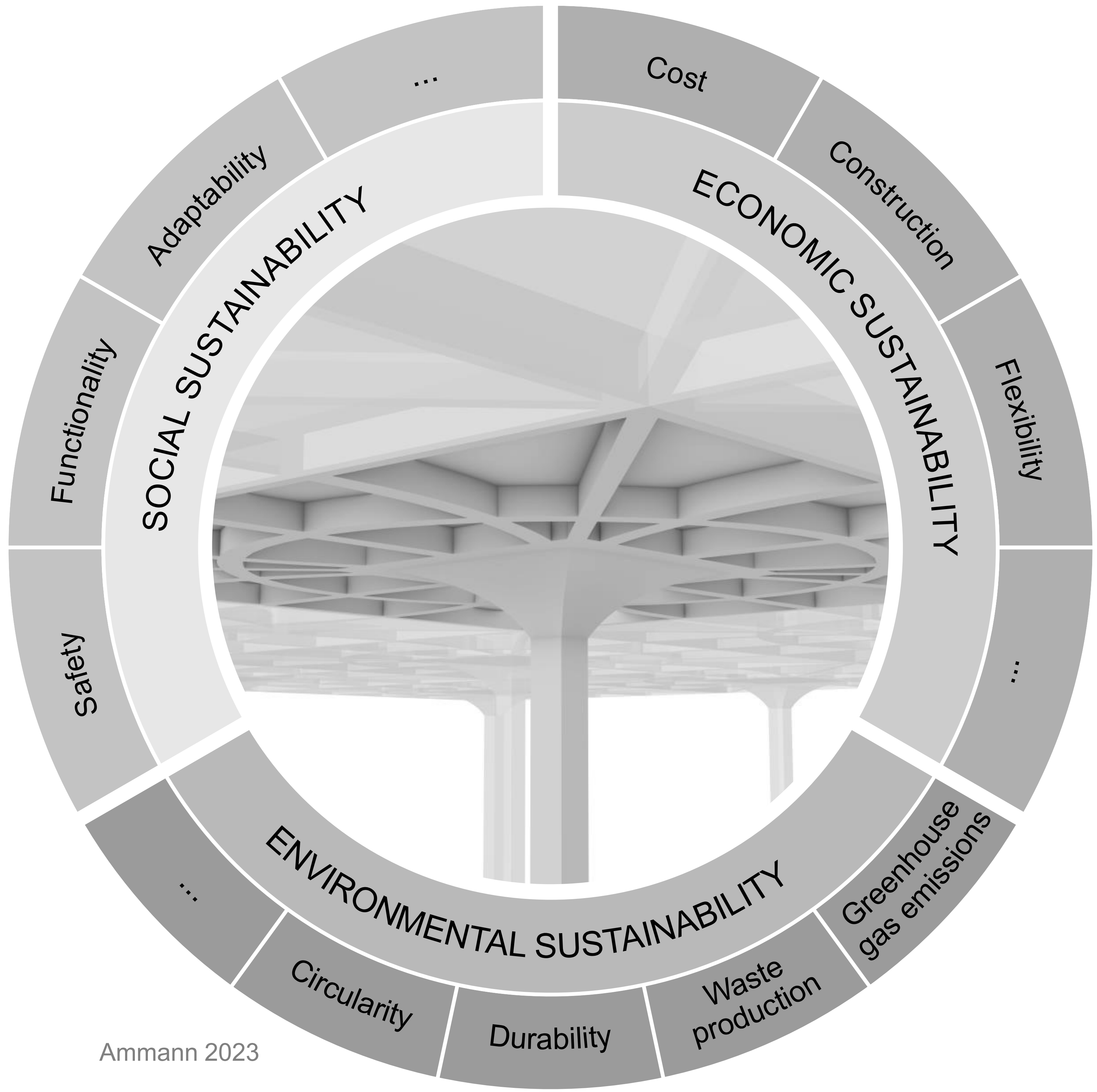
[University of Cambridge]

# Overview slab systems




Only valid for the given boundary conditions, cannot be directly generalised.

# Holistic approach




Ammann 2023