**Inaugural Symposium: The Role of Higher Education Institutes and Life Cycle Assessment in Achieving Sustainable Futures**

Imperial Network of Excellence in Sustainability through Life Cycle Approaches

# The impact of lifespan assumptions in LCA: Comparing the replacement of building parts versus building layers—A housing case study

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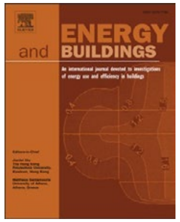


# The impact of lifespan assumptions in LCA: Comparing the replacement of building parts versus building layers—A housing case study

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A R T I C L E I N F O

*Keywords:*
Building Layers
Building Parts
Replacement
Industrialised Construction
EU Level(s) Framework
Life cycle thinking
Housing

A B S T R A C T

The circular economy transition of the built environment is of high priority in the EU, a challenge even more pressing in the housing sector. Conceptualising buildings as ensembles of standardised and prefabricated products, which can be separated into both defined building parts or layers is an accepted circular design approach facilitating future replacement and reuse. Life Cycle Assessment (LCA) is a tool for achieving circularity by informing design choices based on predefined lifespans. However, there is conflicting top-down guidance about whether to assume individual lifespans for constituent components or to group these into building layers when carrying out whole building LCAs. This study reviews the latest guidance on building layers and parts according to the European Level(s) framework, ISO 20887 standard for Design for Disassembly and Adaptability, and the Shearing Layers concept. An energy efficient housing case study was used to compare organisation of the Life Cycle Inventory into separate lifespans for components and layers aligned to Shearing Layers, with lifespans defined by Level(s) Indicator 2.1. The study focussed on Module B4 replacements over a 100-year period. The findings reveal that assuming the replacement of building components as opposed to layers results in greater carbon emissions. In both cases, emissions were approximately double the amount of upfront carbon to produce the initial building. These findings demonstrate the importance of lifespan assumptions in LCA, which should be further developed. The study provides an LCA template for practitioners to organise the building inventory and apply lifespan assumptions, improving rationale behind design decisions.

## 1. Introduction

Approximately half of the planet's natural resources are utilised for the built environment [79], making the construction industry both the recognising the need to reduce greenhouse gas emissions from both operational activities and resource consumption [66,73]. This has resulted in a greater reliance on Life Cycle Assessment (LCA), which is increasingly required and regulated in Europe [38,72]. LCA is also more

# Presentation Outline



## Applying key circular architectural design theories to LCA

# 1. Introduction

# The construction sector - climate impacts

## *The facts*


**40%**

**energy-related $CO_2$ emissions**

# The construction sector - climate impacts

*The facts*

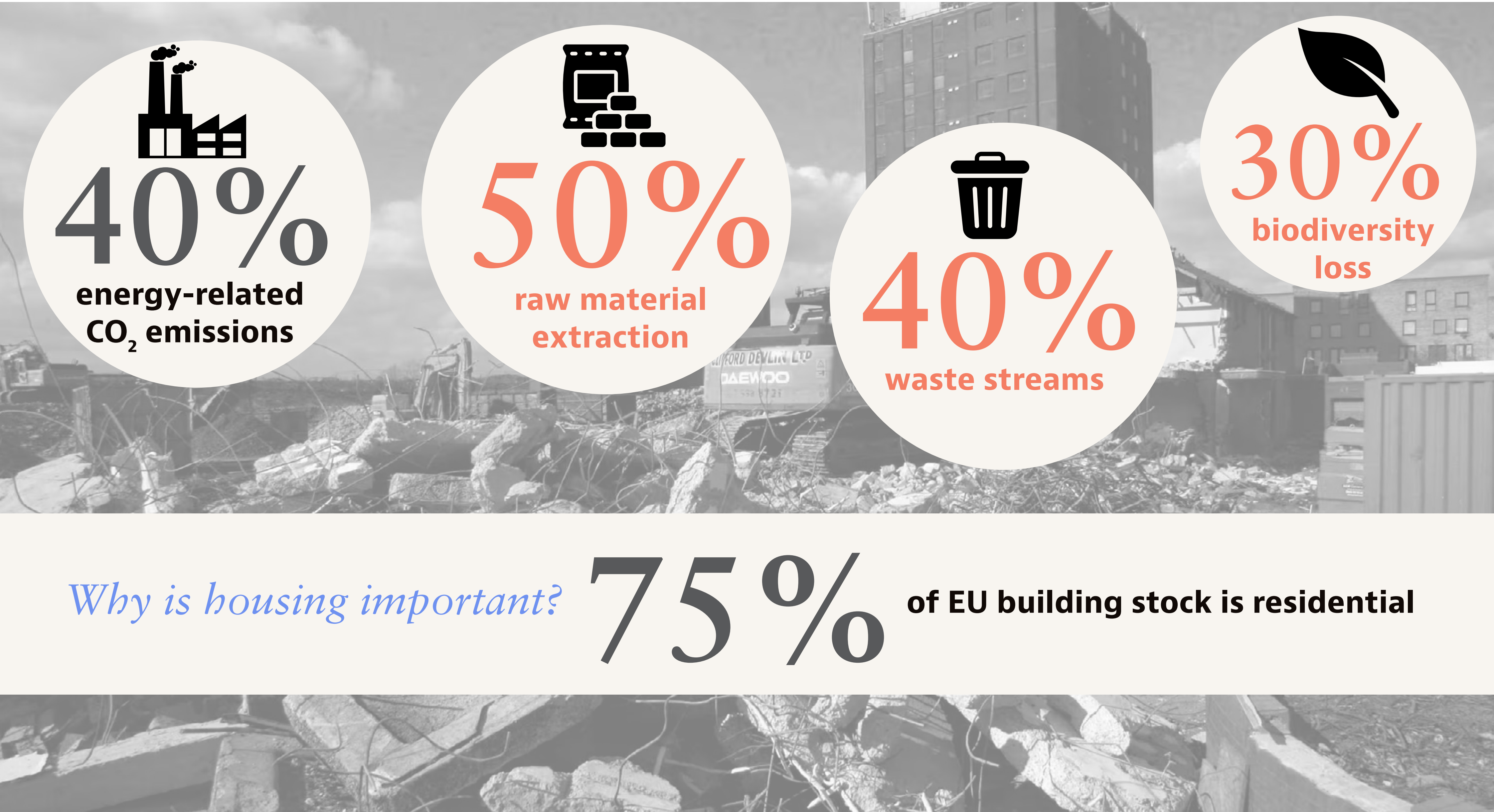
# The construction sector - climate impacts

*The facts*


*Why is housing important?*

# The construction sector - climate impacts

*The facts*



**40%** energy-related $CO_2$ emissions

**50%** raw material extraction

**40%** waste streams

**30%** biodiversity loss

*Why is housing important?* **75%** of EU building stock is residential


**Demolition work in preparation for the Olympic Park, London in 2007.**
Photograph: Matt Cardy/Getty Images

# Industrialised Construction
## *'Modular' approach supporting the Circular Economy transition*

**Daiwa House Modular Europe's off-site factory & built housing in Wales, UK.**

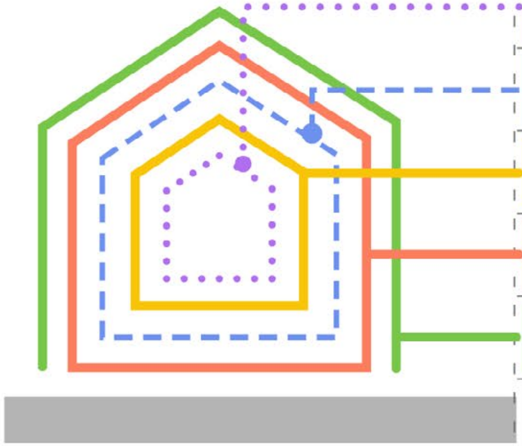
# Current guidelines

## *Lifespan assumptions - EU Level(s) indicator 2.1*

| Thematic areas | Macro-objectives | Indicators | | | |
|---|---|---|---|---|---|
| Resource use and environmental performance | 1. Greenhouse gas emissions along a building's life cycle | 1.1 Use stage energy performance (kWh/ m2/year) | 1.2 Life cycle Global warming potential (CO2 eq./m2/year) | | |
| | 2. Resource efficient and circular material life cycles | 2.1 Bill of quantities, materials and lifespans | 2.2 Construction and demolition waste | 2.3 Design for adaptability and renovation | 2.4 Design for deconstruction |
| | 3. Efficient use of water resources | 3.1 Use stage water consumption (m3/ occupant/year) | | | |
| Health and comfort | 4. Healthy and comfortable spaces | 4.1 Indoor air quality | 4.2 Time out of thermal comfort range | 4.3 Lighting | 4.4 Acoustics |
| Cost, value and risk | 5. Adaption and resilience to climate change | 5.1 Protection of occupier health and thermal comfort | 5.2 Increased risk of extreme weather | 5.3 Sustainable drainage | |
| | 6. Optimised life cycle cost and value | 6.1 Life cycle costs (€/m²/year) | 6.2 Value creation and risk factors | | |

# Current guidelines

## *Contradictory layering approaches for practitioners*

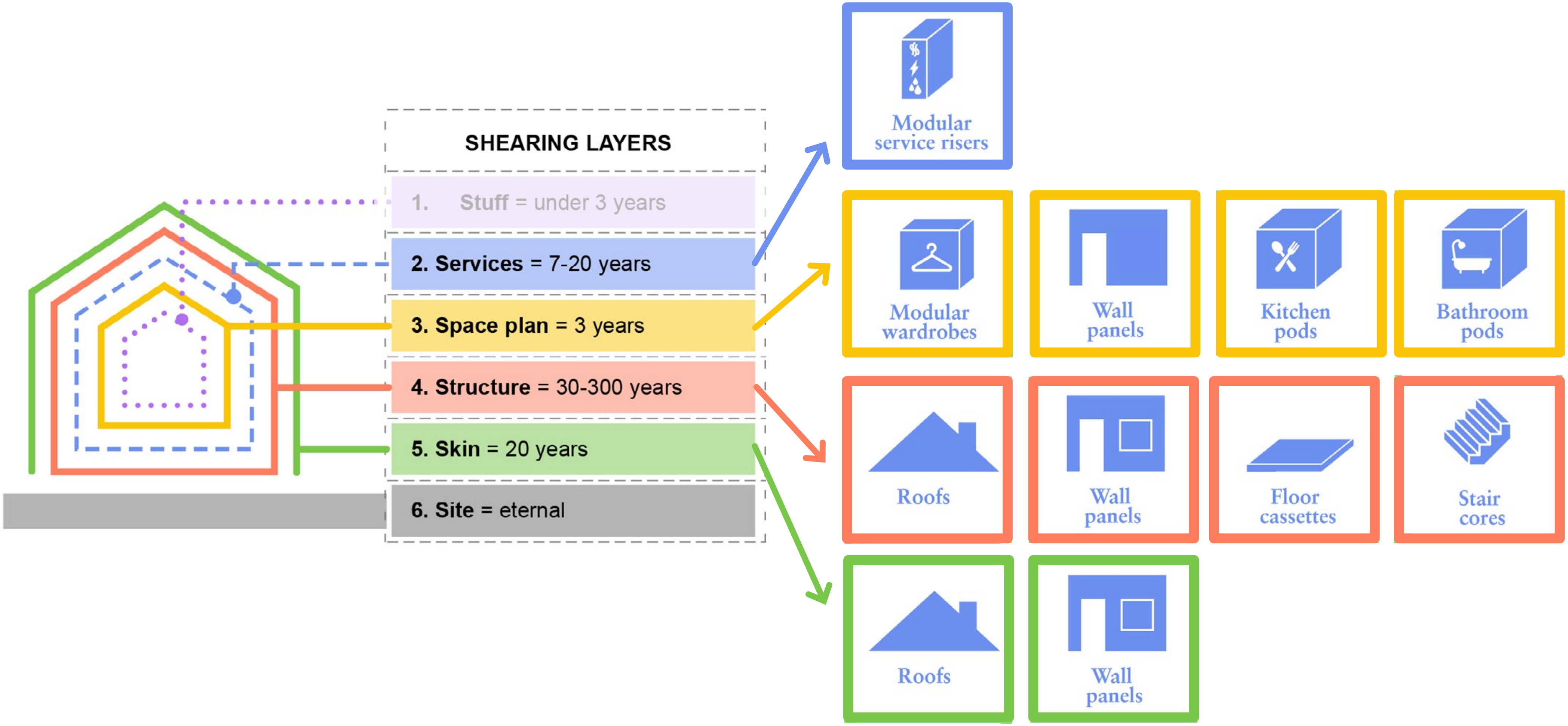


| SHEARING LAYERS | LEVEL(S) 'TIER 1' LAYERS | ISO 20887 DfD/A LAYERS |
|---|---|---|
| 1. **Stuff** = under 3 years | | |
| 2. **Services** = 7-20 years | 1. **Core** = 10-30 years | 1. **Mechanical & Electrical Services** = 15 years |
| 3. **Space plan** = 3 years | | 2. **Fit-out** = 5 years |
| 4. **Structure** = 30-300 years | 2. **Shell** = 10-60 years | |
| 5. **Skin** = 20 years | | 3. **Shell and Core** = 50-100 years |
| 6. **Site** = eternal | 3. **External Works*** = 25-30 years | |

*Includes utilities equipment and connections

# Current guidelines

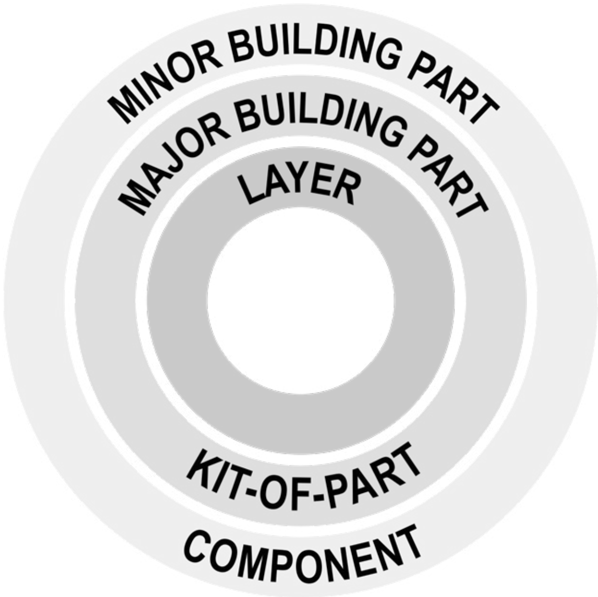
*Contradictory layering approaches for practitioners*



# Industrialised Construction

## *Defining 'Components' and 'Kit-of-Parts'*

**Kit-of-Parts**, or major building parts, create building systems that may **form enclosed spaces**. Examples include **external wall panels, façade systems, bathroom pods, and internal wall systems** (with doors).




Kit-of-Parts are composed of **components** , or minor building parts, such as **doors and windows** within wall panels, **partition walling, and fitted wardrobes.**

# Aims of the study

The purpose of this LCA study is to **compare the impact on GWP results of replacements during the use phase**, based on two prominent circular architectural design approaches outlined in relevant grey and academic literature: **assuming individual lifespans for minor building parts (components)** versus grouped average lifespans **for building layers.**

**This study considers:**

- **Defined building parts and layers** consistent with an **industrialised approach**.
- **Recurring embodied carbon** due to replacements.
- **A 100-year lifespan**, appropriate for housing and promoting longevity.
- **Application of Brand's Shearing Layers**, with inclusion of the building services layer.
- **Visual presentation of LCA results** to aid practitioners in **carbon hot-spotting** to inform sustainable design decisions.

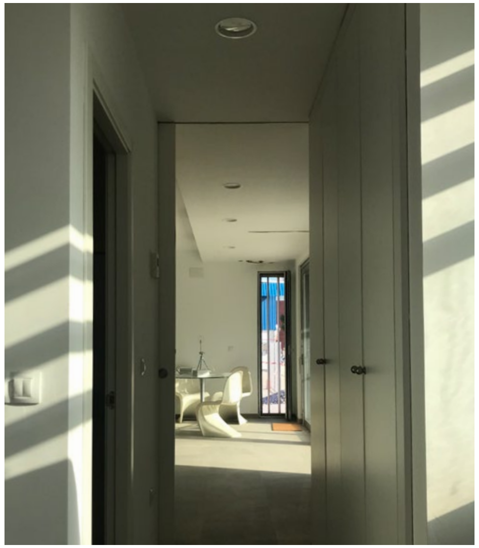
# 2. Methodology

# The case study house

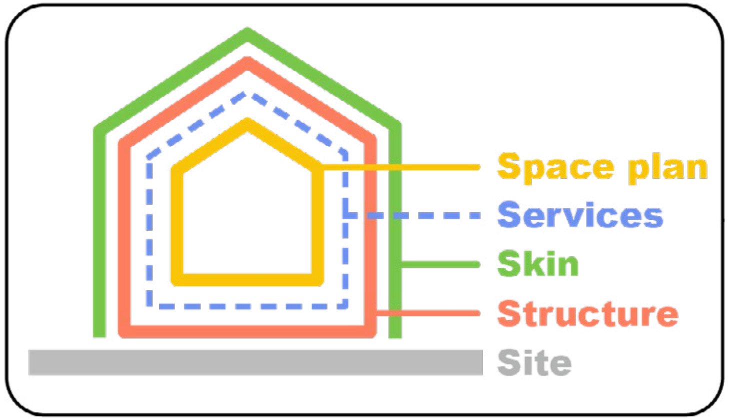
## *A highly energy-efficient house built using industrialised construction*

### Edificación Eco-Eficiente

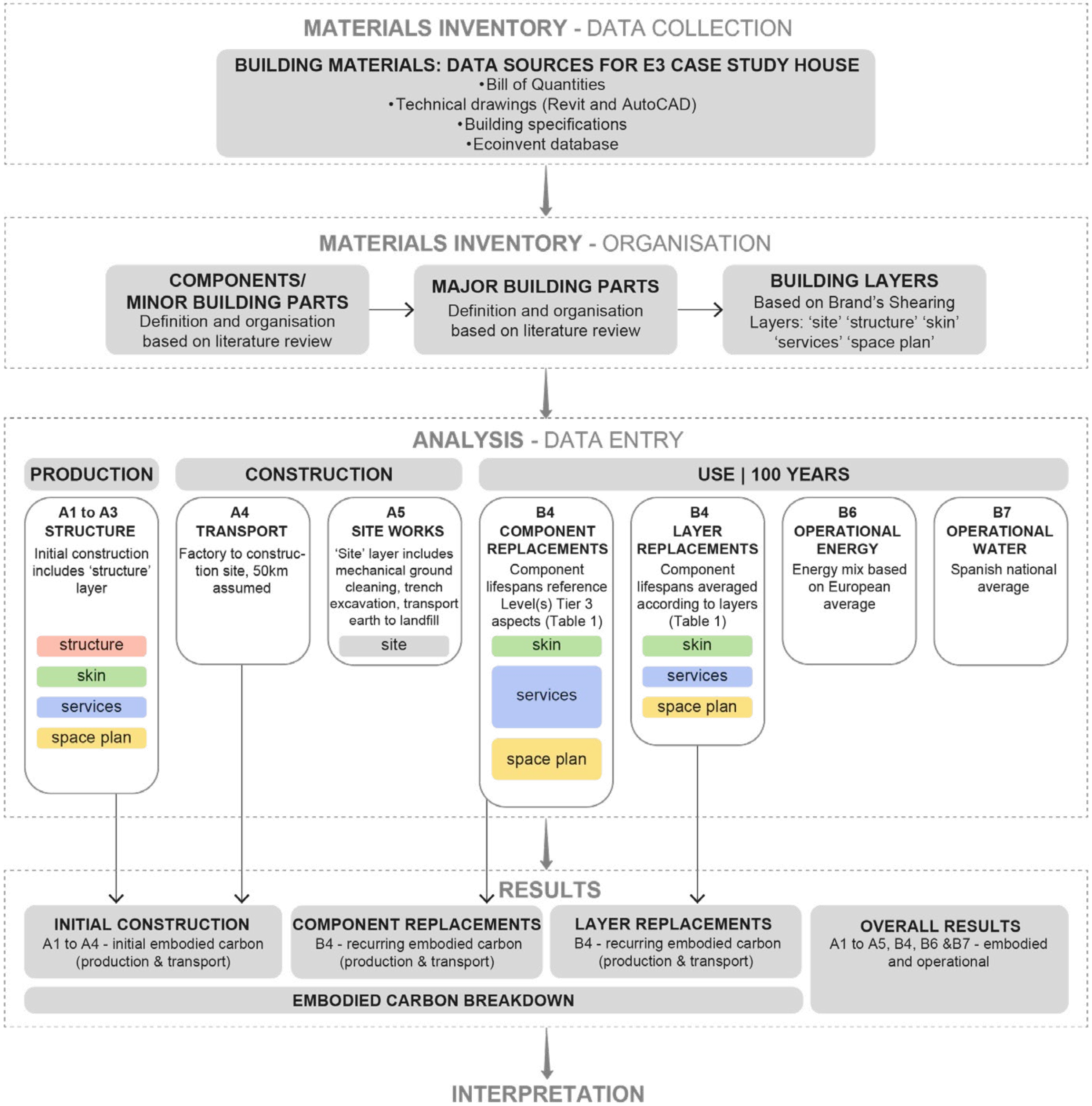
**Location:** UPV campus. Valencia, Spain
**Built:** 2011. Prefabricated and assembled within 19 days on-site
**Architect:** Ignacio Guillén Guillamón
**Construction:** Steel frame & ventilated facade
**Energy strategy:** Passive design & on-site electricity generation (Class A energy rating)



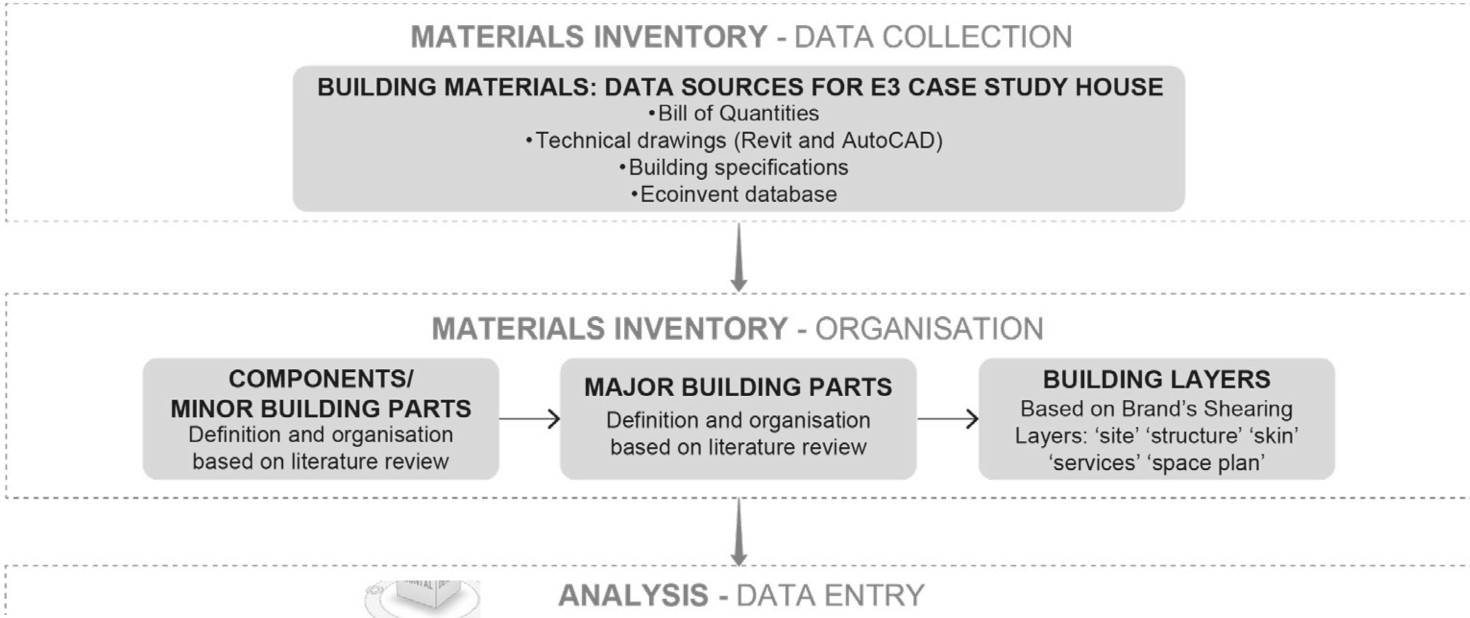
# Methodology




Five of Stewart Brand's six 'Shearing Layers of Change' applied to the case study house



# Methodology



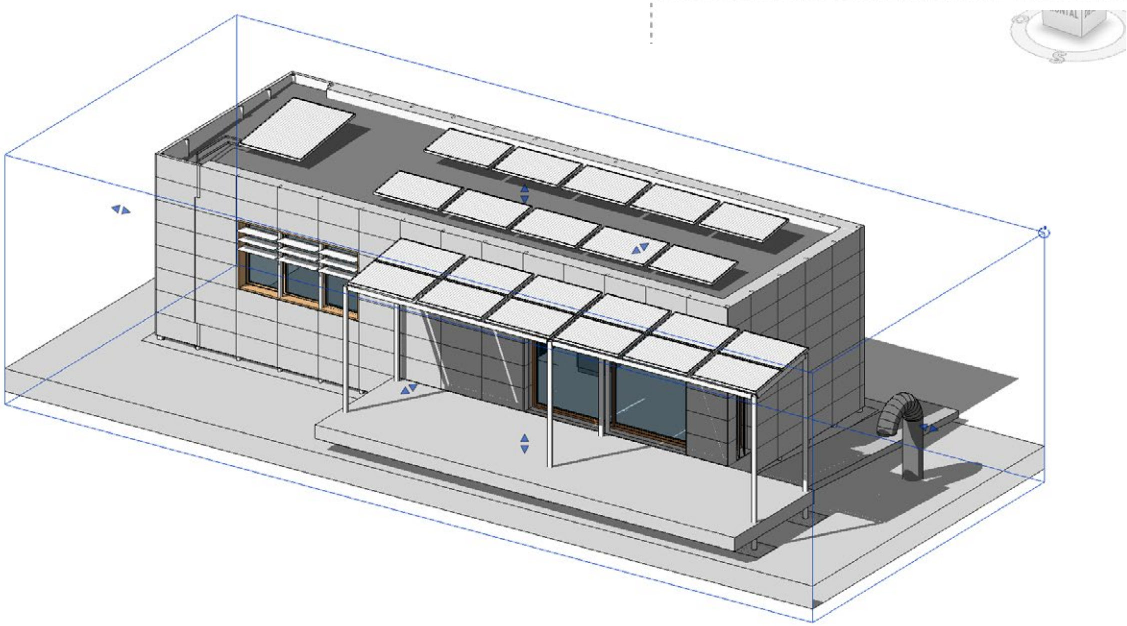



**Image show the Revit BIM model for the Edificación Eco-Eficiente house**
Model used in conjunction with CAD drawings, specifications and BoQ for the lifecycle inventory - material types and quantities

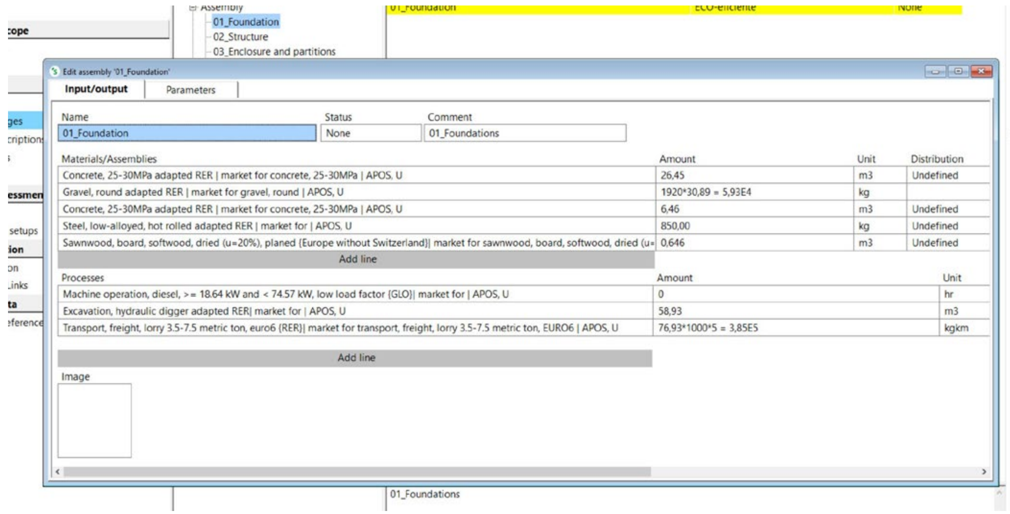
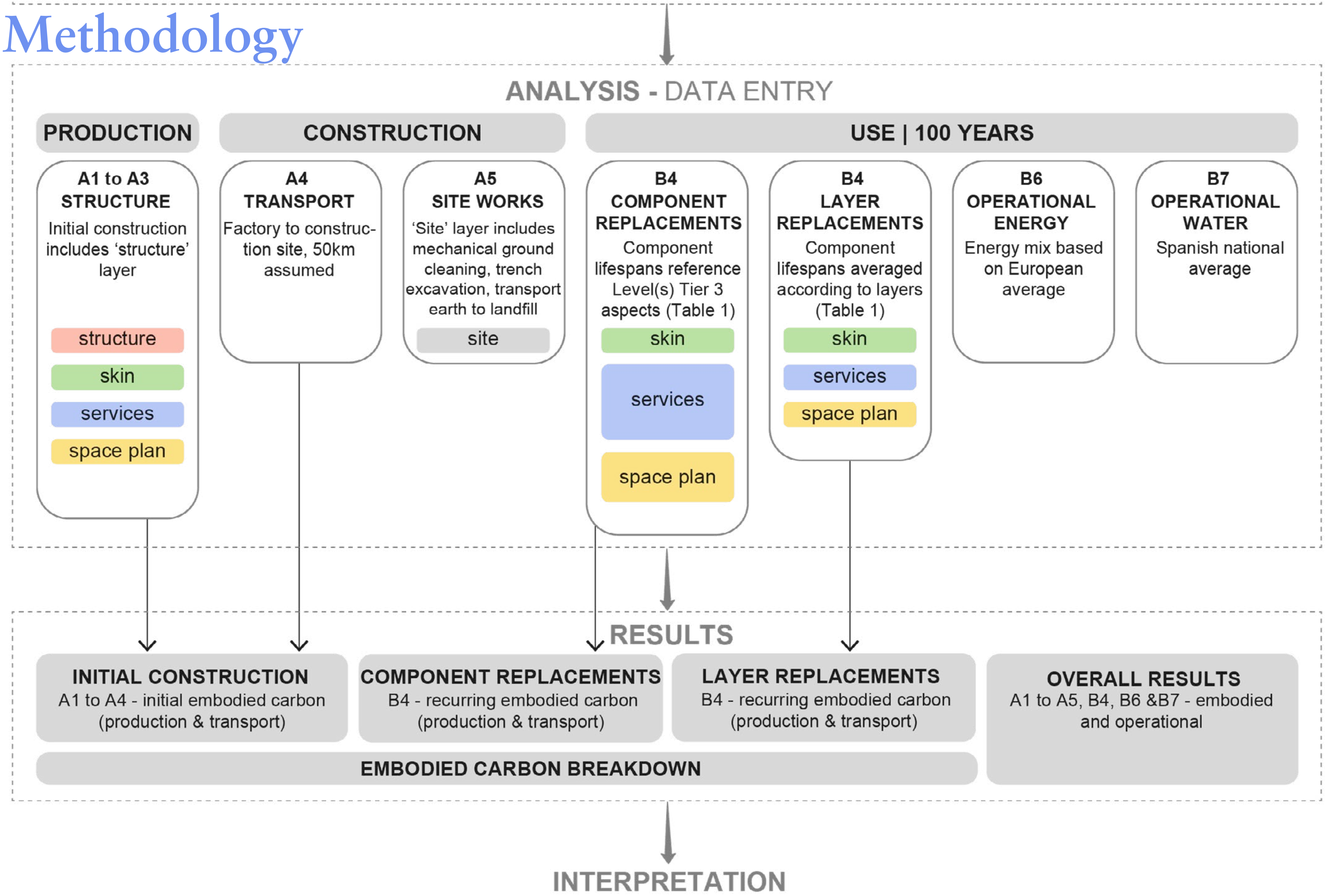
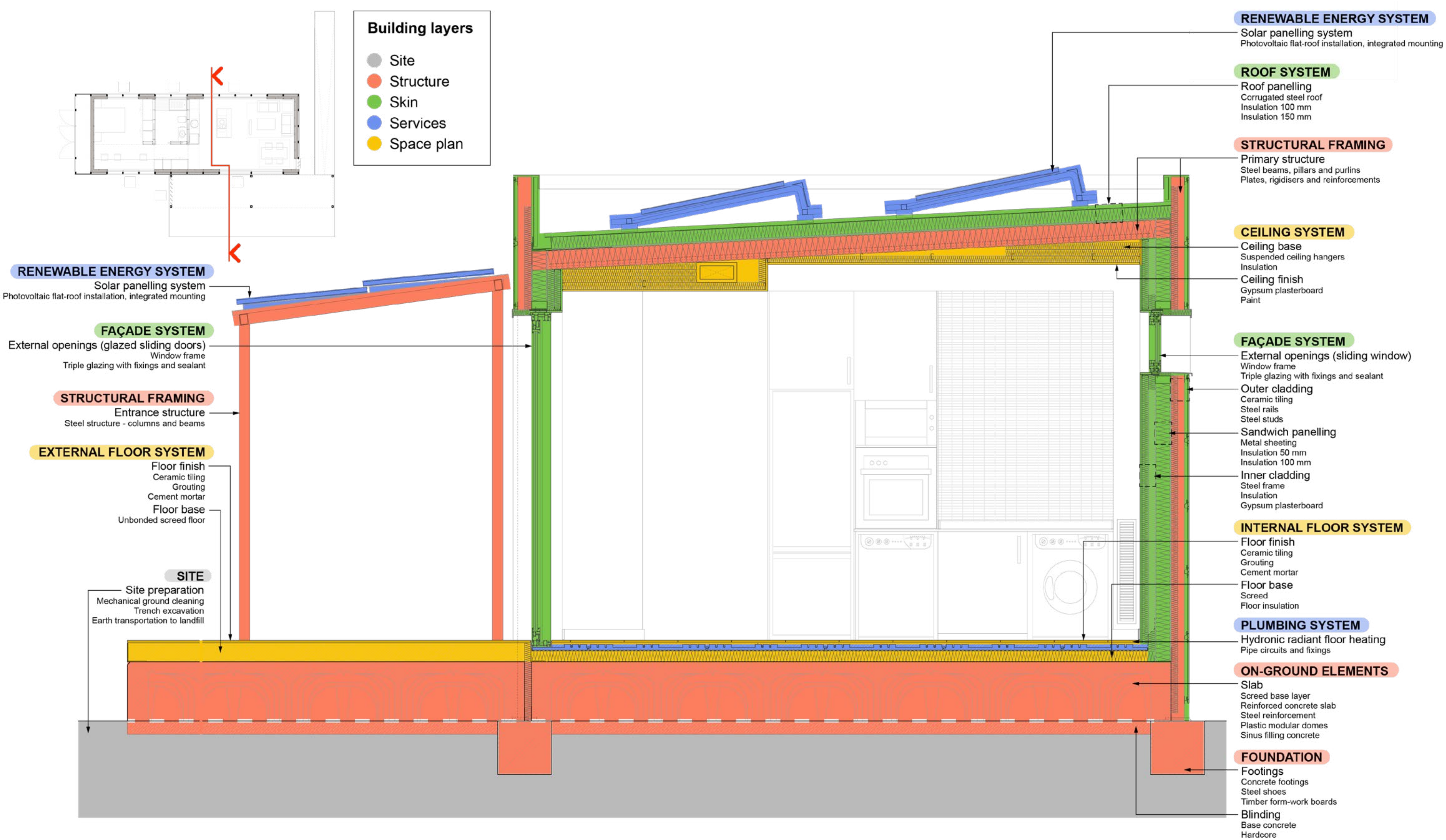


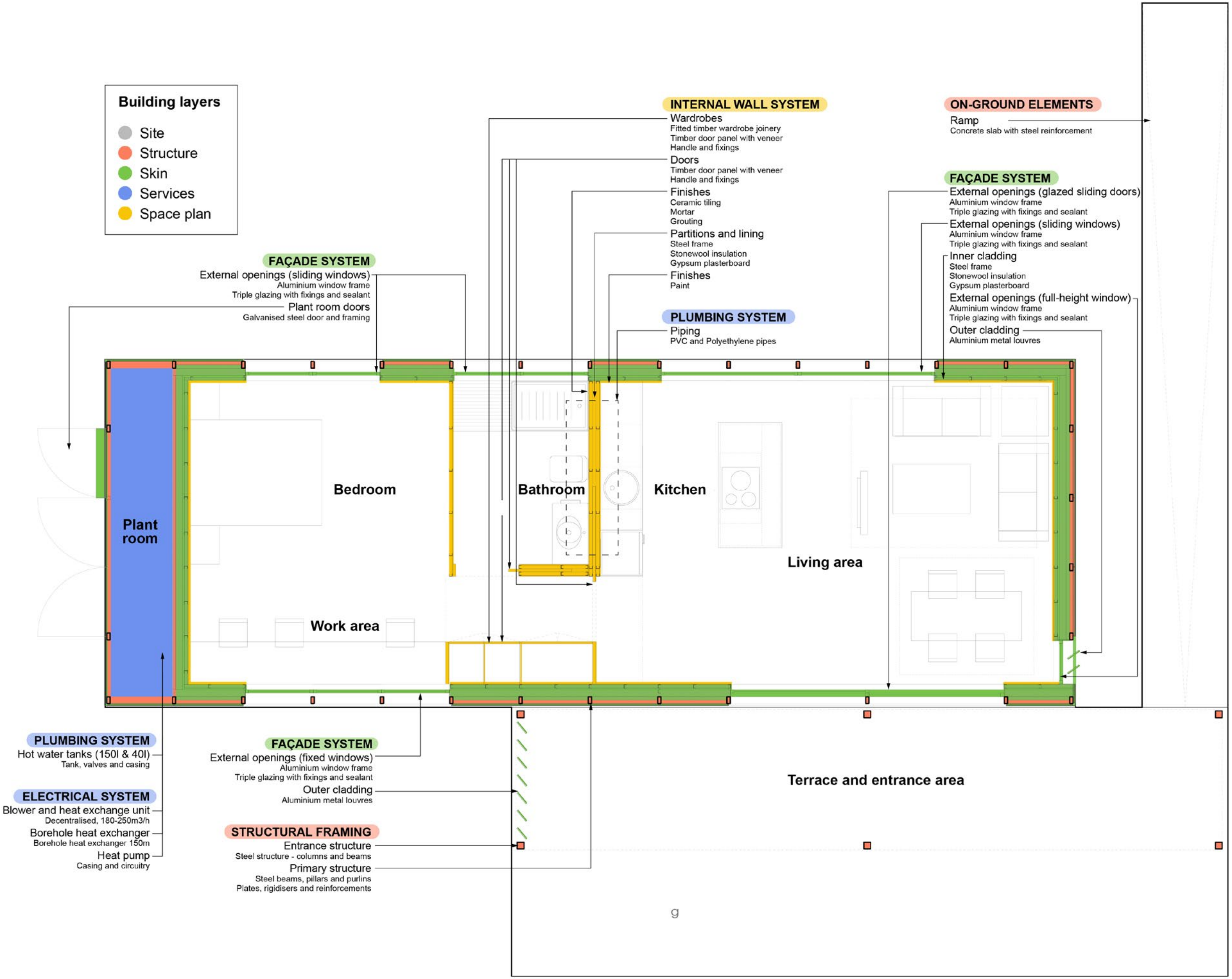

**Image shows data entry within Simapro software**
The study utilises the Ecoinvent database

# Methodology





Building layers
Site
Structure
Skin
Services
Space plan
RENEWABLE ENERGY SYSTEM
Solar panelling system
Photovoltaic flat-roof installation, integrated mounting
FAÇADE SYSTEM
External openings (glazed sliding doors)
Window frame
Triple glazing with fixings and sealant
STRUCTURAL FRAMING
Entrance structure
Steel structure - columns and beams
EXTERNAL FLOOR SYSTEM
Floor finish
Ceramic tiling
Grouting
Cement mortar
Floor base
Unbonded screed floor
SITE
Site preparation
Mechanical ground cleaning
Trench excavation
Earth transportation to landfill
RENEWABLE ENERGY SYSTEM
Solar panelling system
Photovoltaic flat-roof installation, integrated mounting
ROOF SYSTEM
Roof panelling
Corrugated steel roof
Insulation 100 mm
Insulation 150 mm
STRUCTURAL FRAMING
Primary structure
Steel beams, pillars and purlins
Plates, rigidisers and reinforcements
CEILING SYSTEM
Ceiling base
Suspended ceiling hangers
Insulation
Ceiling finish
Gypsum plasterboard
Paint
FAÇADE SYSTEM
External openings (sliding window)
Window frame
Triple glazing with fixings and sealant
Outer cladding
Ceramic tiling
Steel rails
Steel studs
Sandwich panelling
Metal sheeting
Insulation 50 mm
Insulation 100 mm
Inner cladding
Steel frame
Insulation
Gypsum plasterboard
INTERNAL FLOOR SYSTEM
Floor finish
Ceramic tiling
Grouting
Cement mortar
Floor base
Screed
Floor insulation
PLUMBING SYSTEM
Hydronic radiant floor heating
Pipe circuits and fixings
ON-GROUND ELEMENTS
Slab
Screed base layer
Reinforced concrete slab
Steel reinforcement
Plastic modular domes
Sinus filling concrete
FOUNDATION
Footings
Concrete footings
Steel shoes
Timber form-work boards
Blinding
Base concrete
Hardcore



Building layers
Site
Structure
Skin
Services
Space plan
INTERNAL WALL SYSTEM
Wardrobes
Fitted timber wardrobe joinery
Timber door panel with veneer
Handle and fixings
Doors
Timber door panel with veneer
Handle and fixings
Finishes
Ceramic tiling
Mortar
Grouting
Partitions and lining
Steel frame
Stonewool insulation
Gypsum plasterboard
Finishes
Paint
PLUMBING SYSTEM
Piping
PVC and Polyethylene pipes
ON-GROUND ELEMENTS
Ramp
Concrete slab with steel reinforcement
FAÇADE SYSTEM
External openings (glazed sliding doors)
Aluminium window frame
Triple glazing with fixings and sealant
External openings (sliding windows)
Aluminium window frame
Triple glazing with fixings and sealant
Inner cladding
Steel frame
Stonewool insulation
Gypsum plasterboard
External openings (full-height window)
Aluminium window frame
Triple glazing with fixings and sealant
Outer cladding
Aluminium metal louvres
FAÇADE SYSTEM
External openings (sliding windows)
Aluminium window frame
Triple glazing with fixings and sealant
Plant room doors
Galvanised steel door and framing
Plant room
Bedroom
Bathroom
Kitchen
Living area
Work area
Terrace and entrance area
PLUMBING SYSTEM
Hot water tanks (150l & 40l)
Tank, valves and casing
ELECTRICAL SYSTEM
Blower and heat exchange unit
Decentralised, 180-250m3/h
Borehole heat exchanger
Borehole heat exchanger 150m
Heat pump
Casing and circuitry
FAÇADE SYSTEM
External openings (fixed windows)
Aluminium window frame
Triple glazing with fixings and sealant
Outer cladding
Aluminium metal louvres
STRUCTURAL FRAMING
Entrance structure
Steel structure - columns and beams
Primary structure
Steel beams, pillars and purlins
Plates, rigidisers and reinforcements

# Case study inventory

**Table 1**
Case study inventory organised into building layers, major and minor building parts.

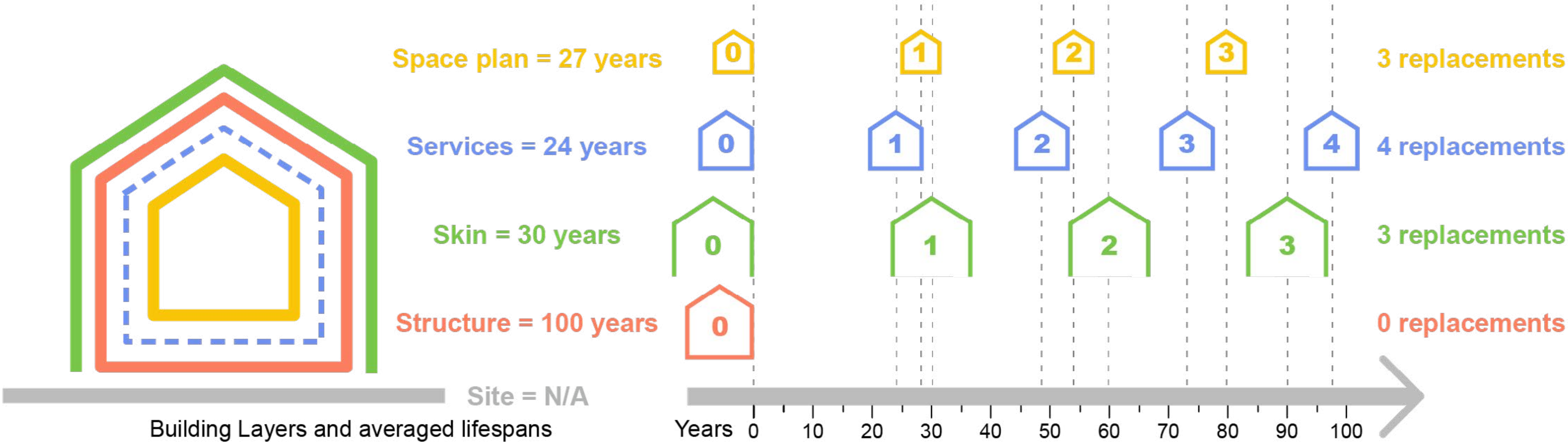
| Building layer | Average lifespan (years) | Average replace-ments | Major building part | Minor building part | Lifespan (years) | Replace-ments | Referenced Level(s) 'Tier 3 Aspect' Indicator 2.1 |
|---|---|---|---|---|---|---|---|
| Structure | 100 | 0 | Foundation | Slab on grade | 100 | 0 | Frame (beams, columns and slabs) *Structural building parts assumed 100-year lifespan rather than 60 years as per Level(s) Indicator 2.1 |
| | | | | Footings | 100 | 0 | |
| | | | On-ground elements | Ramp | 100 | 0 | |
| | | | | Slab | 100 | 0 | |
| | | | Structural framing | Primary structure | 100 | 0 | |
| | | | | Entrance structure | 100 | 0 | |
| Skin | 30 | 3 | Façade system | Outer cladding | 30 | 3 | External wall systems, cladding and shading devices |
| | | | | Sandwich panelling | 30 | 3 | |
| | | | | Inner cladding | 30 | 3 | |
| | | | | External openings | 30 | 3 | Façade openings (including windows and external doors) |
| | | | Roof system | Roof panelling | 30 | 3 | Weatherproofing |
| Services | 24 | 4 | Renewable energy system | Photovoltaic panelling system | 15 | 6 | Electricity generation |
| | | | | Solar collector system | 15 | 6 | |
| | | | Electrical system | Blower & heat exchange unit | 30 | 3 | Electricity distribution |
| | | | | Borehole heat exchanger | 30 | 3 | |
| | | | | Heat pump | 20 | 4 | Heating plant and distribution |
| | | | Plumbing systems | Underfloor heating | 30 | 3 | Radiators |
| | | | | Hot water tanks | 25 | 3 | Cold water distributionHot water distribution |
| | | | | Pipes | 25 | 3 | |
| Space Plan | 27 | 3 | Internal wall systems | Partitions and lining | 30 | 3 | Internal walls, partitions and doors |
| | | | | Finishes | 20 | 4 | Wall and ceiling finishes |
| | | | | Doors & wardrobes | 30 | 3 | Internal walls, partitions and doors/Cupboards, wardrobes and worktops |
| | | | External floor system | Floor base | 30 | 3 | Ground floor slab |
| | | | | Floor finish | 25 | 3 | Paving and other hard surfacing |
| | | | Internal floor system | Floor base | 30 | 3 | Ground floor slab |
| | | | | Floor finish | 30 | 3 | Floor finishes, coverings and coatings |
| | | | Ceiling system | Ceiling base | 30 | 3 | Internal walls, partitions and doors |
| | | | | Ceiling finish | 20 | 4 | Wall and ceiling coatings |

# Layers & lifespan assumptions

*Defining the number of replacements within 100 years*

**average lifespan = rounded((x1 + x2 + x3 +...+ xn)/n)**

Values for building layer lifespans were calculated by averaging using the mean: sum of all **component lifespans (x)** divided by the **total number of building parts within the layer (n)** rounded to the nearest whole number.

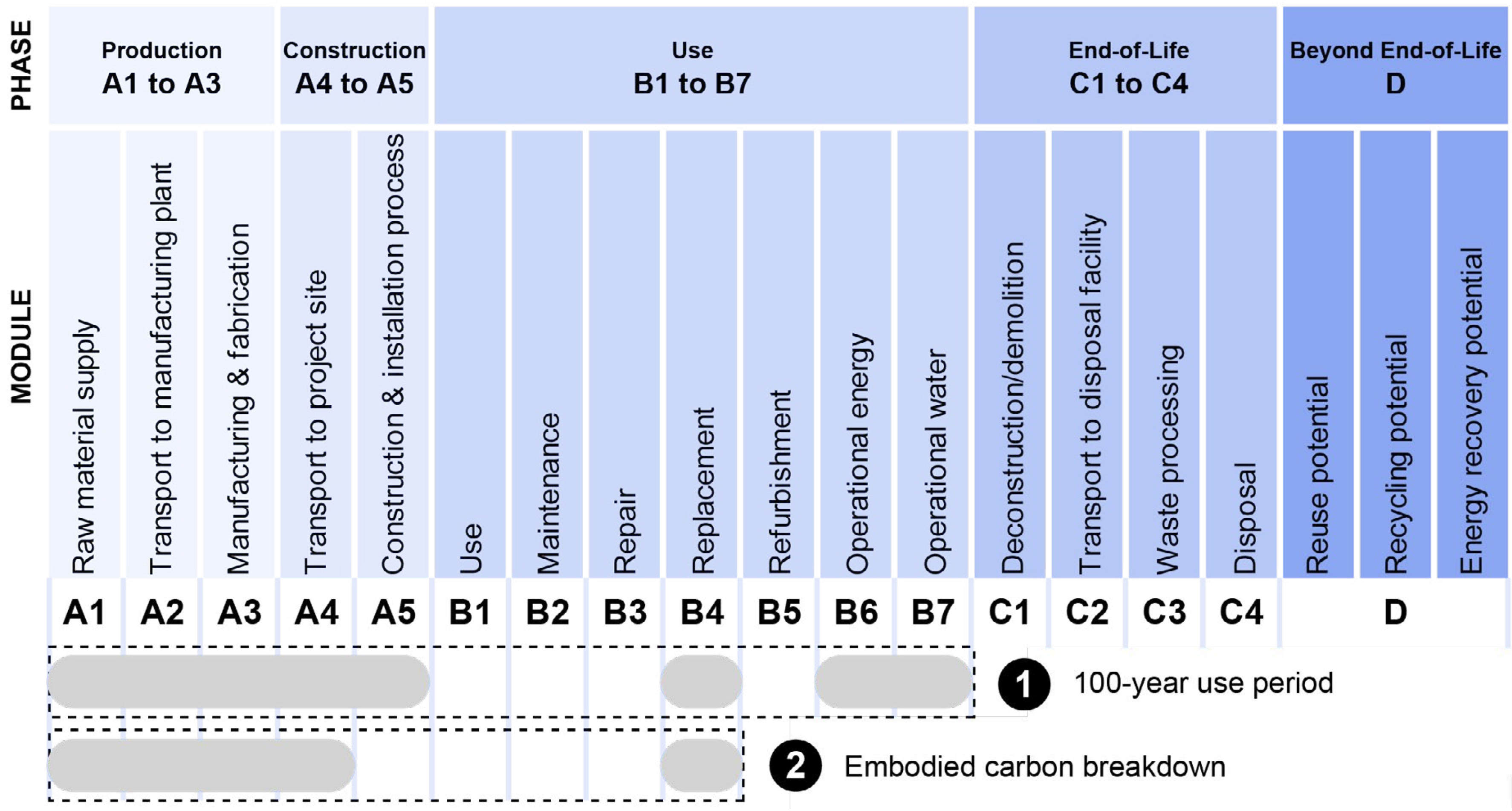


# Case study inventory

**Table 1**
Case study inventory organised into building layers, major and minor building parts.

| **Building layer** | **Average lifespan (years)** | **Average replace-ments** | **Major building part** | **Minor building part** | **Lifespan (years)** | **Replace-ments** | **Referenced Level(s) 'Tier 3 Aspect' Indicator 2.1** |
|---|---|---|---|---|---|---|---|
| Structure | 100 | 0 | Foundation | Slab on grade | 100 | 0 | Frame (beams, columns and slabs) |
| | | | | Footings | 100 | 0 | *Structural building parts assumed 100-year lifespan rather than 60 years as per Level(s) Indicator 2.1 |
| | | | On-ground elements | Ramp | 100 | 0 | |
| | | | | Slab | 100 | 0 | |
| | | | Structural framing | Primary structure | 100 | 0 | |
| | | | | Entrance structure | 100 | 0 | |
| Skin | 30 | 3 | Façade system | Outer cladding | 30 | 3 | External wall systems, cladding and shading devices |
| | | | | Sandwich panelling | 30 | 3 | |
| | | | | Inner cladding | 30 | 3 | |
| | | | | External openings | 30 | 3 | Façade openings (including windows and external doors) |
| | | | Roof system | Roof panelling | 30 | 3 | Weatherproofing |
| Services | 24 | 4 | Renewable energy system | Photovoltaic panelling system | 15 | 6 | Electricity generation |
| | | | | Solar collector system | 15 | 6 | |
| | | | Electrical system | Blower & heat exchange unit | 30 | 3 | Electricity distribution |
| | | | | Borehole heat exchanger | 30 | 3 | |
| | | | | Heat pump | 20 | 4 | Heating plant and distribution |
| | | | Plumbing systems | Underfloor heating | 30 | 3 | Radiators |
| | | | | Hot water tanks | 25 | 3 | Cold water distributionHot water distribution |
| | | | | Pipes | 25 | 3 | |
| Space Plan | 27 | 3 | Internal wall systems | Partitions and lining | 30 | 3 | Internal walls, partitions and doors |
| | | | | Finishes | 20 | 4 | Wall and ceiling finishes |
| | | | | Doors & wardrobes | 30 | 3 | Internal walls, partitions and doors/Cupboards, wardrobes and worktops |
| | | | External floor system | Floor base | 30 | 3 | Ground floor slab |
| | | | | Floor finish | 25 | 3 | Paving and other hard surfacing |
| | | | Internal floor system | Floor base | 30 | 3 | Ground floor slab |
| | | | | Floor finish | 30 | 3 | Floor finishes, coverings and coatings |
| | | | Ceiling system | Ceiling base | 30 | 3 | Internal walls, partitions and doors |
| | | | | Ceiling finish | 20 | 4 | Wall and ceiling coatings |

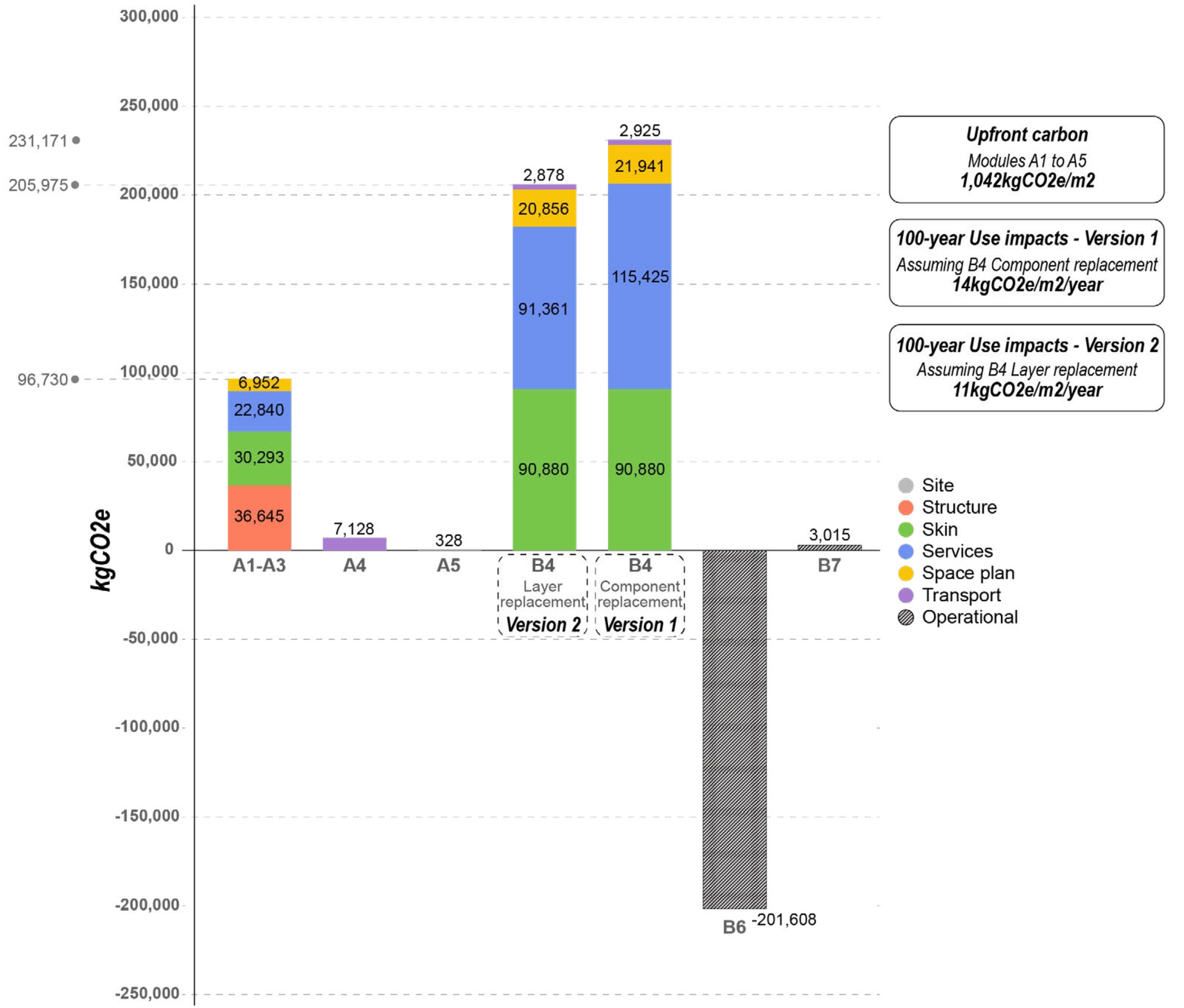
# LCA modules included in the study



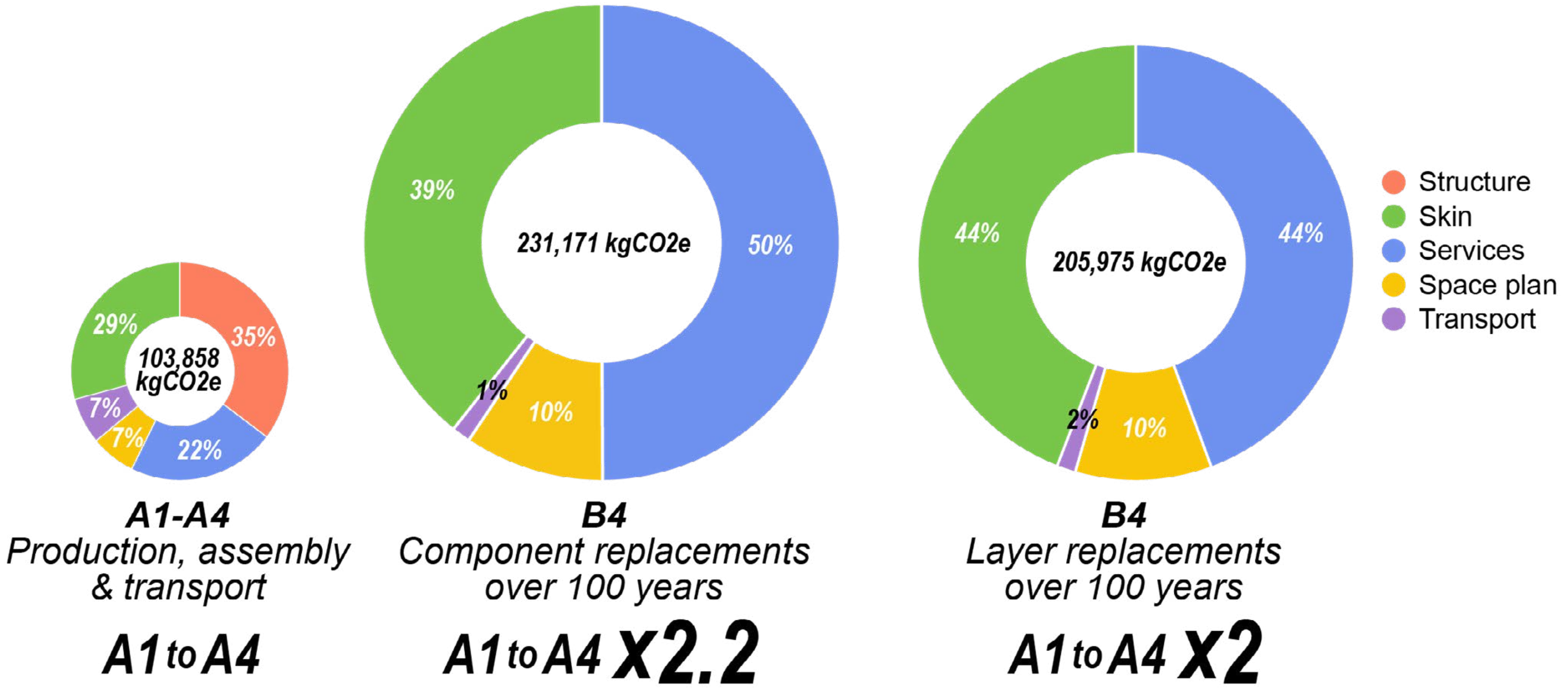

**EN 15978** Sustainability of Construction Works.
Assessment of Environmental Performance of Buildings. Calculation Method.

# 3. Interpretation of Results

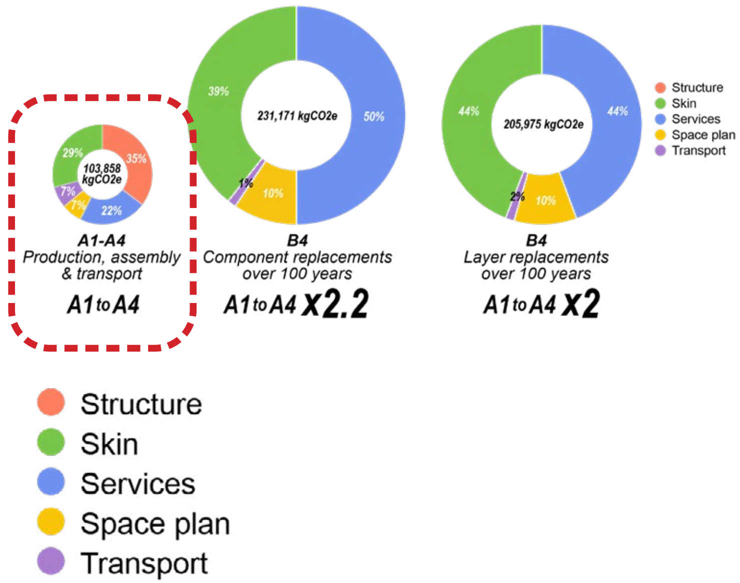
# Carbon dioxide emissions during a 100-year use period

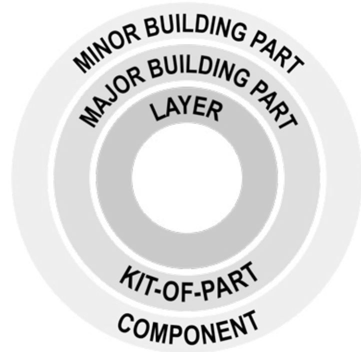


# Embodied carbon breakdown by layer

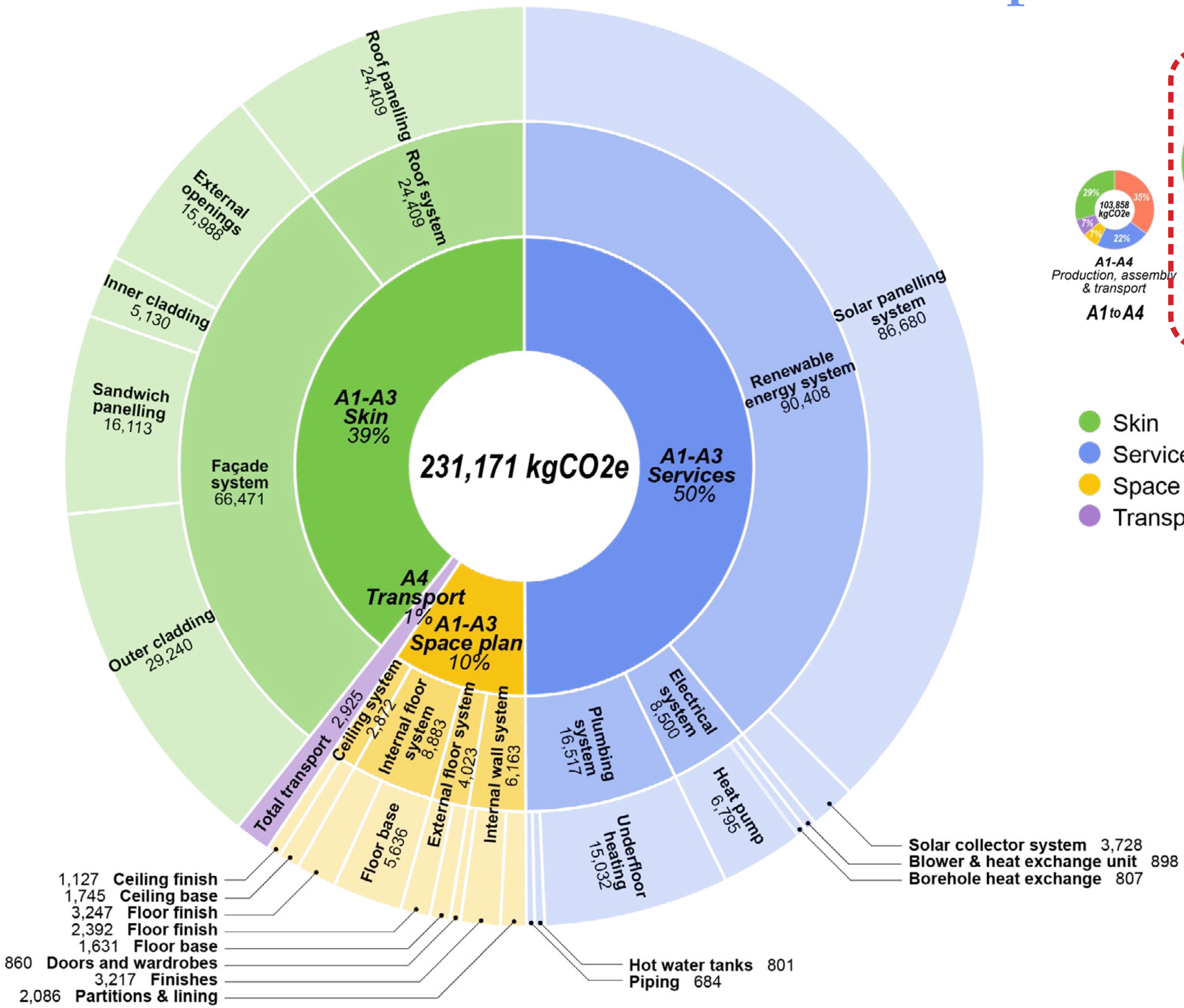


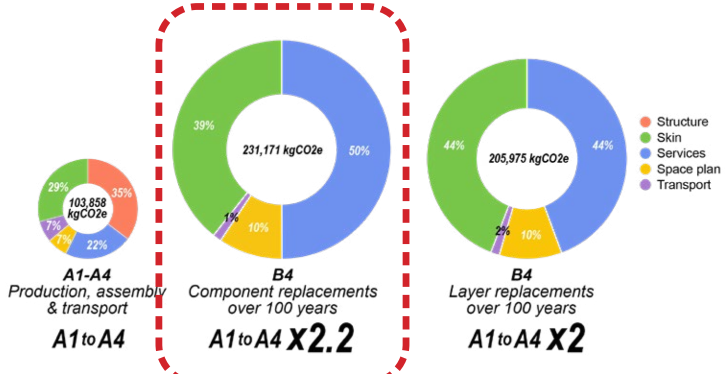
# A1–A4 embodied carbon breakdown

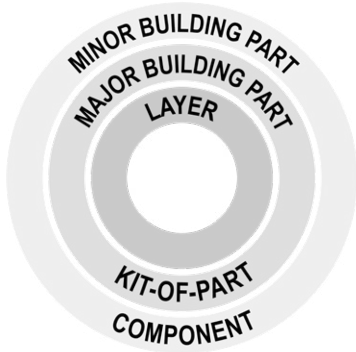



# B4 embodied carbon breakdown - component lifespans

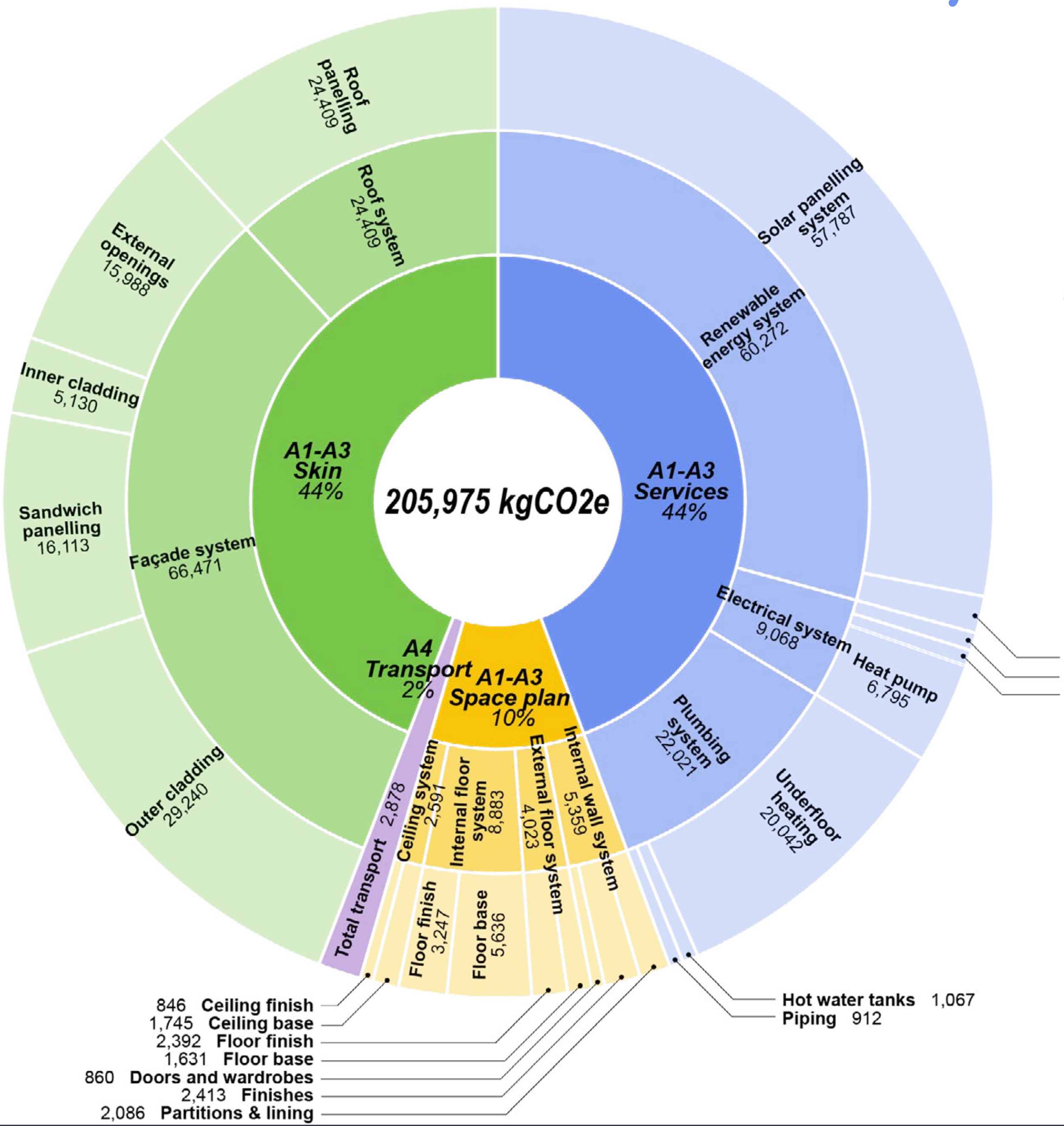


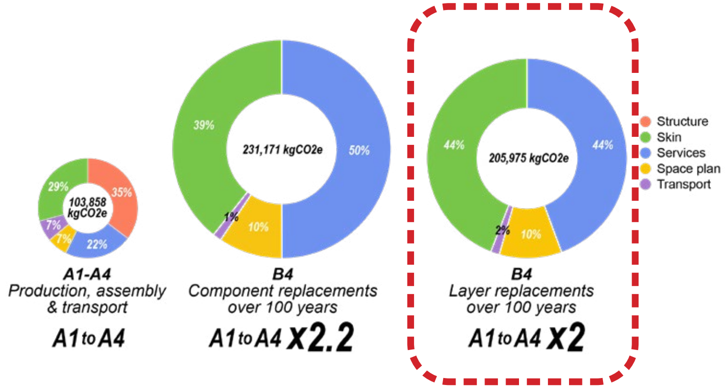



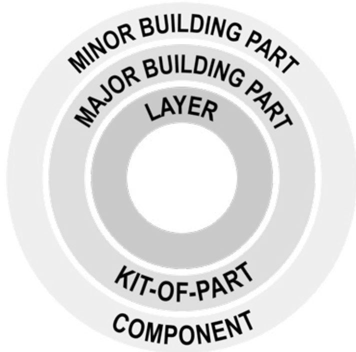

Skin
Services
Space plan
Transport



# B4 embodied carbon breakdown - layer lifespans



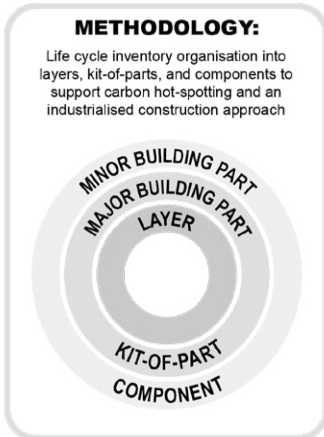
# 4. Conclusions

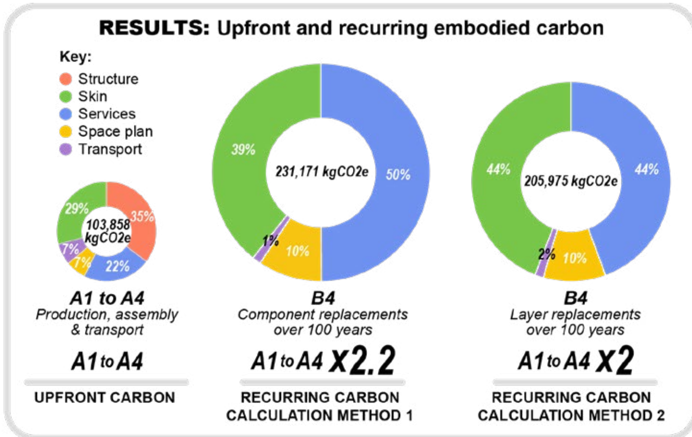
# Conclusions

**Applying the circular principle building layers to the replacement of building parts has an impact on LCA results quantifying $CO_2$ emissions, producing different results compared to managing individual component lifespans.**

## *Highlights*

- LCA study investigating the **impact of circular design principles** in industrialised housing.
- **Two calculations compare** replacement of building layers versus components.
- Replacement of building **components results in greater carbon emissions**.
- **Both methods** resulted in emissions approximately **double the upfront carbon**.
- The findings are useful for Life Cycle **Inventory definition** and **carbon hot-spotting**, which is particularly advantageous for the continuous improvement of industrialised building systems.



# 5. Reflections

# Implications for practice

it is crucial for practitioners to utilise **industrialised construction**, integrating **design for disassembly** to facilitate future maintenance, building adaptations, and End-of-Life reuse scenarios. This enhances **building circularity** and increases the likelihood of realising LCA calculations and assumptions.

- LCA replacement calculations should use a component approach
- Using layers is helpful to organise the LCI and aid carbon hot-spotting
- More accurate lifespan data needed from manufacturers
- Designers to incorporate measures to reduce embodied emissions during the use phase
- Greater LCA collaboration between designers and off-site contractors needed
- Simplified LCA methodologies needed for 'normal' architects
- Detailed up-to-date databases needed for LCA practitioners
- Regulating embodied carbon - LCA calculations should be included in the procurement process
- Policy measures needed to enhance reliability/standardisation for component lifespans

# Implications for academia & education

The construction industry is **risk-averse, resistant to change and slow to modernise**. It is crucial for architectural education to **integrate life cycle thinking** to embed sustainable design practices from the **planning and concept design stages**.

- ✓ Students increasingly familiar with the basics from information exposure in the media
- ✓ Need to incorporate LCA into architecture courses & educational programs
- ✓ Applied design projects for students to critically assess/contextualise impact of design decisions
- ✓ Introduce each life cycle stage in separate curriculum modules to go into greater depth
- ✓ Need to make students passionate about environmentally sustainable design
- ! "If we show LCA as something foreign to architectural practice, students will hate it"

# Thank you

# Questions?

read the full article published in Elsevier's Energy & Buildings

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## If you would like to know more, please contact me at annette.davis@salle.url.edu or visit the project website at re-dwell.eu

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