Modeling Lisbon using integrated benchmarks of operational energy and embodied carbon

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Research Motivations

Evaluating the total carbon footprint of the current Portuguese building stock is a fundamental part of guiding policy for carbon reduction strategies and informing decision-making on building retrofit and future building design. Cities such as Lisbon must reduce *both* operational energy use and embodied carbon from materials' production and construction to achieve carbon neutrality by 2050.

So far, previous work on urban building energy modeling (UBEM) has successfully established building archetype templates for operational energy estimation [1]. In contrast, reliable benchmarks for embodied carbon quantification at the urban scale are still lacking. This is mainly because estimating the embodied carbon of a building's structural system without accurate datasets can lead to large uncertainties as the structure contributes about 50% of a building's embodied carbon [2].

Objective

This collaborative research aims to establish new benchmarks of operational energy use and embodied carbon in the current building stock of Lisbon by using more accurate structural model archetypes.
The long-term impact of this work is to build a fully integrated operational/embodied building stock model for all of Portugal.

Methodology

Using a large dataset of 5000+ building massing models in the C-Tech area in Lisbon, we create five building archetypes across chosen construction periods. We then quantify this building stock's operational energy and embodied carbon using a simulation tool called the Urban Modeling Interface (UMI). This study assumes a simplification of the structural system model using a constant normalized structural material quantity for the operational energy and embodied carbon analysis.

DATA COLLECTION

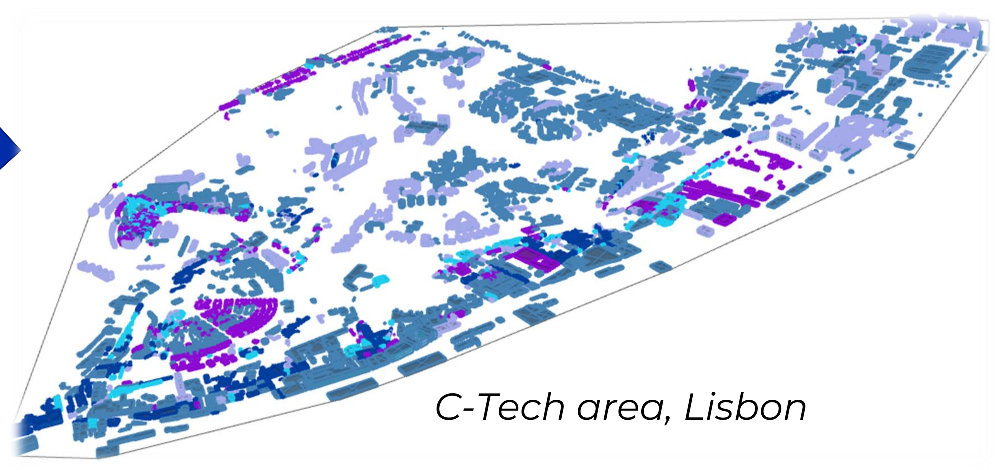
- Collect historical data on the building stock of the C-Tech area.
- Divide buildings into 5 groups based on construction periods.

BUILDING TEMPLATE CREATION

- Create building templates for operational energy and embodied carbon based on similarities in the buildings' typologies.

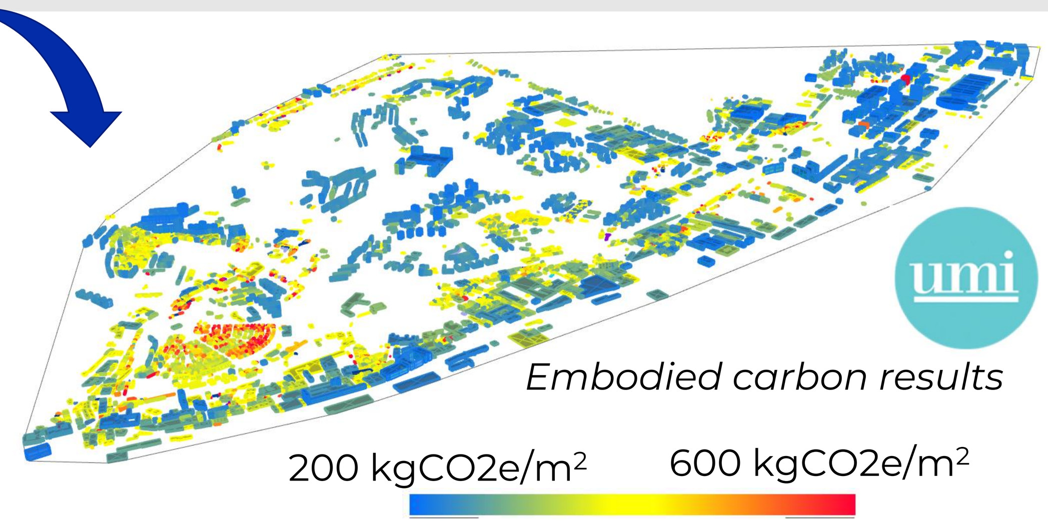
URBAN MODELING SIMULATION

- Assign suitable building templates to each archetype.
- Estimate operational energy use (EUI) and embodied carbon (EC).



C-Tech area, Lisbon

- Archetype Pre-1919 – 458 buildings
- Archetype 1919-1945 – 419 buildings
- Archetype 1946-1960 – 819 buildings
- Archetype 1961-1980 – 2264 buildings
- Archetype 1981-2011 – 1233 buildings



Embodied carbon results

Preliminary results

Table 1: Summary of operational energy and embodied carbon results for each archetype.

Archetypes	Pre-1919	1919-1945	1946-1960	1961-1980	1981-2011
Description	- Thick stone masonry façade - Timber floors - Timber or brick partitions	-Thick stone masonry façade - Thin reinforced concrete slab - Brick partitions	- Double stone-brick façade - Reinforced concrete slab - Double-brick partitions	- Reinforced concrete façade, structural walls, and slab - Double-brick partitions	- Insulated reinforced concrete façade, and slab - Double-brick partitions
EUI (kWh/m²)	75	77	72	76	69
EC ($kgCO_2e/m^2$)	361	370	394	264	263

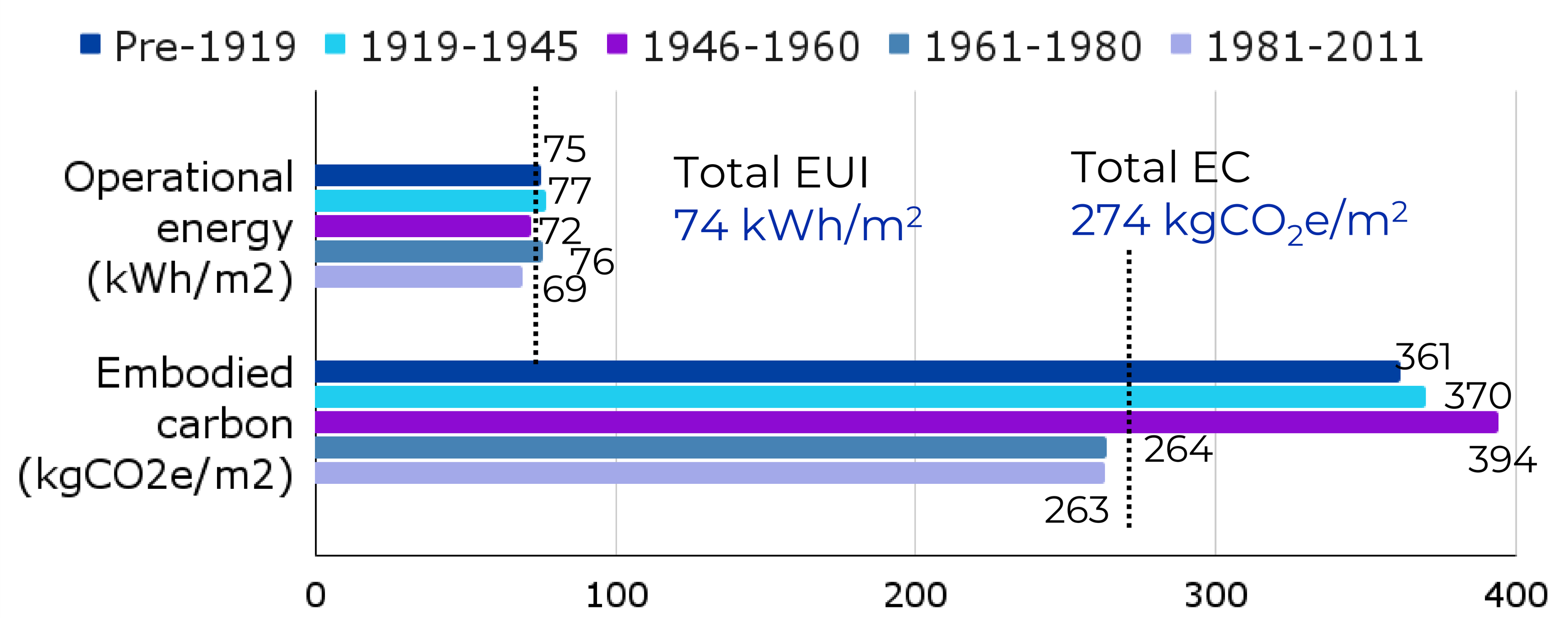


Fig. 1: Comparison against total operational energy and embodied carbon.

- All 5 archetypes show little variations in EUI, with the lowest operational energy use reported for the archetype 1981-2011 (with insulation).
- Small changes in EC appear between archetypes except for the significant drop after 1961 due to the prevalence of reinforced concrete in structural systems.
- Preliminary results do not yet provide clear benchmarks and highlight the importance of improving the accuracy of the structural system model.

Future work

- Create a robust library of building templates with detailed data on structural systems' materials and typologies.
- Apply a trained machine learning model focused on the prediction of the structural system's embodied carbon.

References:
[1] C. C. Davila, "Building Archetype Calibration for Effective Urban Building Energy Modeling," Massachusetts Institute of Technology, 2017.
[2] K. Simonen, B. X. Rodriguez, and C. De Wolf, "Benchmarking the Embodied Carbon of Buildings," Technol. Archit. Des., vol. 1, no. 2, pp. 208–218, 2017.

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