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Optimising Sustainability through digital tools: Energy and Carbon Comparative Analysis of Brick, Concrete and Wood Frame construction envelopes in Coimbra Residences

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Abstract. Global warming, driven by greenhouse gas emissions, threatens to exceed the 2°C threshold set by the United Nations Convention on Climate Change. The construction sector contributes to 37% of global emissions, largely due to embodied carbon from materials. This study evaluates the environmental impact and energy performance of three construction assemblies for a single-family house in Coimbra, Portugal: traditional ceramic brick, aggregate concrete blocks, and wood frame. A BIM-based method integrating lifecycle stages (A1–A3, B4, B6) was applied to analyse embodied and operational carbon. The energy simulations, conducted using LadyBug and HoneyBee in the Grasshopper environment, revealed that the wood frame assembly achieved the best performance, reducing the annual thermal load by nearly 2000 kWh compared to concrete assemblies. Embodied carbon emissions were significantly lower for wood frames (76.99 $kgCO_2e/m^2$) than ceramic brick (478.0 $kgCO_2e/m^2$) or concrete blocks (461.4 $kgCO_2e/m^2$), highlighting the carbon sequestration benefits of timber. Despite better operational performance, concrete options exhibited higher long-term emissions due to poor thermal efficiency. By integrating energy simulations into lifecycle analysis, designers can prioritize solutions that achieve a balance between thermal performance, occupant comfort, and environmental impact, ultimately supporting the global goal of carbon neutrality, while considering a holistic approach. While wood frame assemblies offer a sustainable alternative, broader strategies, such as integrating circular economy principles and enhancing public awareness, are vital for systemic change. Limitations, including early design-phase data and incomplete lifecycle stages, highlight the need for further research to refine sustainable building practices in Portugal and beyond.

Keywords: Energy Efficiency; Embodied Carbon; Building Digital Simulations.

1 Introduction

1.1 The role of buildings in addressing the Climate Crisis

The global climate crisis has become a pressing issue, with rising temperatures and escalating greenhouse gas (GHG) emissions demanding urgent attention. Between 2013 and 2023, the global mean temperature rose by approximately 1.19°C to 1.22°C above pre-industrial levels, making it the warmest decade on record. Projections indicate that without significant mitigation efforts, global temperatures could increase by 3.3°C to 5.7°C by the end of the century, far surpassing the 2°C threshold established by the United Nations Framework Convention on Climate Change (UNFCCC) underscores the necessity of immediate and transformative action across all sectors contributing to GHG emissions. [1] [2].

The building and construction industry is a critical focus area, accounting for approximately 37% of global emissions. These emissions arise not only from operational activities, such as heating, cooling, and lighting but also from the embodied carbon in construction materials like steel, aluminium, and cement. While historically, operational carbon been the primary target for mitigation—leading to advancements in energy efficiency—the embodied carbon of materials has received comparatively less attention. This is despite the fact that, as operational emissions are projected to decrease from 75% to 50% of the sector's total emissions in the coming decades, the relative importance of embodied emissions is expected to grow. [3].

1.2 Shifting Perspective to a Life Cycle Approach

To effectively reduce the environmental impact of buildings, a full lifecycle perspective is essential. This involves considering not just operational emissions but also the embodied impacts of design, material production, construction, and eventual demolition. Lifecycle assessment (LCA), standardized internationally in EN 15978, provides a robust framework for quantifying the environmental performance of buildings from "cradle to grave”. However, systemic challenges persist. Environmental impacts from construction are often attributed to the industrial sector rather than the buildings sector, creating a fragmented understanding of the full impact. Additionally, public awareness of these issues remains limited, as evidenced by surveys indicating widespread ignorance of building materials and sustainability programs specific regions of countries like Portugal. [4].

1.3 The Portuguese Context

In Portugal, heating and cooling represent most of the energy needed for a building to operate. According to literature [5], 88% of energy is obtained from the Portuguese national grid, with only a small portion coming from self-generation. Moreover, energy poverty and housing shortages present further challenges, approximately 826 families in Coimbra faced severe housing deficits, prompting government initiatives to expand housing stock. However, the focus on traditional construction materials like concrete and cement bricks risks perpetuating high energy and carbon costs [6].

1.4 Research Scope and Objectives

This study examines the environmental performance of alternative construction materials and assemblies for a single-family home in Coimbra, Portugal. Specifically, it evaluates the trade-offs between energy efficiency, operational and embodied carbon emissions for three construction assemblies: traditional ceramic brick, concrete blocks, and wood frame. By integrating BIM-based energy simulations and lifecycle assessments, this research aims to identify strategies for reducing the energy loads and carbon footprint of housing, in the context of energy poverty and sustainability in Portugal's non-metropolitan regions.

This investigation not only contributes to ongoing efforts to decarbonize the built environment but also emphasizes the need for comprehensive, lifecycle-informed decision-making in construction, aligning with global climate goals and national sustainability priorities.

2 Methodology

This study proposes a BIM-based method to assess building energy performance and GWP, considering the A1-A3 (production stage), B4 (replacement), and B6 (operational energy use) building lifecycle stages, as defined in EN 15978. The method is applied to evaluate the tradeoffs of operational and embodied carbon in different material assemblies for the building envelope of a single-family house in Coimbra (Portugal) during early design.

The single-family reeling is a three-bedroom house with just one floor and a small annex, with a total floor area of 251.5 m^2. It has a flat, non-accessible roof and an exterior wooden deck. The building has large windows, which are around 2.20 meters high. These allow a good view of the garden and offer the building a lot of interior light.

The architectural BIM model was modelled in Autodesk Revit to generate technical drawings with a low Level of Development (LOD) and without detailed material specifications. The model was classified using the Uniclass classification system to streamline simulations and minimise modelling errors that

could lead to inaccurate bills of quantities (BoQ) and GWP calculations, e.g., incorrect category assignments.

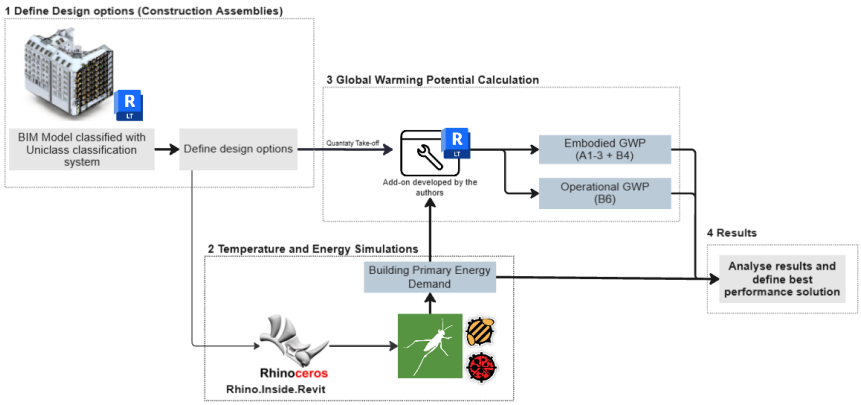


Fig. 1. Visual representation of the study's methodology.

Fig.1 outlines the proposed method, divided into four main stages. The first stage involves *defining construction assemblies for the building envelope*, where three construction systems are established: a traditional ceramic brick system, a concrete and an aggregate concrete block system and a lightweight wall system with a self-supporting timber structure, as detailed in Section 2.1. The second stage includes conducting *temperature and energy simulations to calculate the building energy demand with the different construction assemblies* using the LadyBug and HoneyBee plug-ins within the Grasshopper ecosystem. The building geometry is exported from Revit to Rhino via the Rhino Inside Revit plug-in, as described in Section 2.2. In the third stage, *the calculation of Global Warming Potential (GWP)* using the BIM-based method proposed by Parece (2024). This method is designed for early design stages and low LOD BIM models classified with the Uniclass classification system, as further explained in Section 2.3. Finally, the results are analysed, and the construction solution with the best performance is selected.

2.1 Construction Assemblies

Three different construction assemblies are considered for this study: a traditional assembly comprised of a double wall using two layers of ceramic brick and one layer of insulation; one assembly consisting of a single wall using one layer of cement bricks and a layer of insulation and drywall; and one wood frame assembly comprising of two OBS panels and a middle layer of insulation. The layers of these wall and roof assemblies and data used for the energy simulations can be seen in Tables 1 to 5. All walls have the same overall thickness, between 0.36 and 0.37 m, and the same insulation thickness, 0.08m, for adequate comparison. This study considers two types of flat, non-accessible roofs: a roof with a concrete slab,

insulation, separation layer and a layer of pebbles and a wood frame roof with wooden slabs, insulation and OSB panels. The insulation thickness remains the same on both roofs. Only one type of floor is considered, which is a concrete slab. Due to the type of land variations, the floors are adiabatic, so no energy losses are regarded through the floor.

Table 1. Traditional Ceramic Brick Wall (Uniclass Code: Ss_25_13_50. Op1) data for simulations.

Material Layer	Thickness (m)	Density (kg/m^3)	Mass (Kg/m^2)	Percentage of mass (%)	Thermal Conductivity [W/(m.K)]	Specific Heat Capacity (J/kg-K)
			Interior			
Plaster	0.02	800	30	12%	0.07	840
Ceramic Brick	0.15	1800	116.4	47%	0.70	800
Insulation (Rock wool)	0.08	80	6.4	3%	0.047	1030
Ceramic Brick	0.09	1800	63.45	26%	0.07	800
Render	0.02	-	30	12%	-	-
			Exterior			
Total	0.36	_	246.25	100%		

Table 2. Aggregate concrete block wall (Uniclass Code: Ss_25_13_50. Op2) data for simulations.

Material Layer	Thickness (m)	Density (kg/m^3)	Mass (Kg/m^2)	Percentage of mass (%)	Thermal Conductivity [W/(m.K)]	Specific Heat Capacity (J/kg-K)
			Interior			
Drywall	0.065	700	8.78	3%	0.19	837
Hollow concrete blocks	0.22	1000	222	80%	0.96	1000
Insulation (Rock wool)	0.08	80	6.4	3%	0.047	1030
Render	0.02	_	30	14%	-	-
			Exterior			
Total	0.365	_	214.7	100%		

Table 3. Wood frame wall (Uniclass Code: Ss_25_11_90.Op3) data for simulations.

Material Layer	Thickness (m)	Density (kg/m^3)	Mass (Kg/m^2)	Percentage of mass (%)	Thermal Conductivity [W/(m.K)]	Specific Heat Capacity (J/kg-K)
			Interior			

	6					
Drywall	0.065	700	8.78	6%	0.19	837
OSB panel	0.018	640	11.52	8%	0.13	1552
Insulation (cellulose fiber)	0.08	40	3.2	2%	0.04	2100
Wooden Slats (Pine)	0.11	750	72	54%	0.075	1300
OSB panel	0.018	640	11.52	8%	0.13	1552
Render	0.02	_	30	22%	-	-
			Exterior			
Total	0.356	_	137	100%		

Table 4. Concrete flat roof (Uniclass Code: Ss_30_10_30_70) data for simulations.

Material Layer	Thickness (m)	Density (kg/m^3)	Mass (Kg/m^2)	Percentage of mass (%)	Thermal Conductivity [W/(m.K)]	Specific Heat Capacity (J/kg-K)
			Interior			
ReinforcedConcrete slab (rebar 4.2%)	0.20	2505	517.1	85.4	1.00	900
Insulation (Rock wool)	0.08	80	6.4	1.1	0.047	1030
Separation layer (polypropylene)	0.02	900	18	3.0	0.20	1400
Pebbles	0.05	1650	82.5	13.6	-	-
			Exterior			
Total	0.35	_	605.9	100		

Table 5. Wood frame flat roof (Uniclass Code: Ss_30_10_30_85) data for simulations.

Material Layer	Thickness (m)	Density (kg/m^3)	Mass (Kg/m^2)	Percentage of mass (%)	Thermal Conductivity [W/(m.K)]	Specific Heat Capacity (J/kg-K)
			Interior			
Drywall	0.065	700	8.78	13%	0.19	837
OSB panel	0.018	640	11.52	17%	0.13	1552
Insulation (cellulose fiber)	0.08	40	3.2	5%	0.04	2100
Wooden	0.11	750	27	40%	0.075	1300

Slats (Pine)						
OSB panel	0.018	640	11.52	17%	0.13	1552
Galvanised Roof Sheet	0.007	7850	6.22	9%	50	448
			Exterior			
Total	0.31		68.22	100%		

Table 6. Concrete Floor (Uniclass Code: Ss_30_12) data for simulations.

Material Layer	Thickness (m)	Density (kg/m^3)	Mass (Kg/m^2)	Percentage of mass (%)	Thermal Conductivity [W/(m.K)]	Specific Heat Capacity (J/kg-K)
			Interior			
Tile Finish	0.01	2000	20	2.7	1.2	1000
Reinforced Concrete Slab	0.15	2505	387.55	52.9	1.0	900
Thermal Insulation (XPS)	0.08	35	2.8	0.4	0.033	1500
Waterproof Membrane	0.002	900	1.8	0.2	0.69	1600
Gravel Base	0.20	1600	320	43.7	-	-
			Exterior			
Total	0.442	-	732.15	100		

2.2 Temperature and Energy Simulations

Grasshopper, a node-based algorithmic editor plug-in that works with the Rhinoceros 3D software, is a sophisticated and popular tool for parametric modelling. It has become a popular platform for architectural exploration: it is frequently updated, has a sizable online community for support, supports a wide range of plug-ins that expand its functionality, and enables structural, dynamic and environmental simulations to validate designs. Additionally, Grasshopper connects with other tools, allowing for real-time connections with Ecotec, Photoshop, Excel, and Revit [7]. It also facilitates hardware integration via a number of plug-ins. For this research, Rhinoceros 3D and Grasshopper are chosen as the software tools to carry out the interior temperature and energy study and evaluate the expected performance results.

The main tools utilized in this study were LadyBug and HoneyBee, two plug-ins for environmental, thermal, and energy analysis that are supported by Grasshopper's ecosystem. They are chosen because of their shown ability to carry out energy simulations in the early phases of architectural designs, offering trustworthy and useful information for computer analysis [8]. Using EnergyPlus software, LadyBug allows users to import, view, and analyze meteorological data from files from the U.S. Department of Energy. These weather files are essential for carrying out precise simulations and producing trustworthy findings since they cover a wide range of worldwide regions and contain substantial climatic data spanning several years [9]. The Rhinoceros 3D model can be filled with materials, building occupancy schedules, and energy loads using HoneyBee, which enhances this feature. Then, depending on the user's inputs and desired results, HoneyBee can perform energy, daylight, temperature, and humidity simulations.

The parameters for each visual programming node needed for the simulations are provided in further detail. Domingos (2022) [10] previously developed the Grasshopper script used in this research.

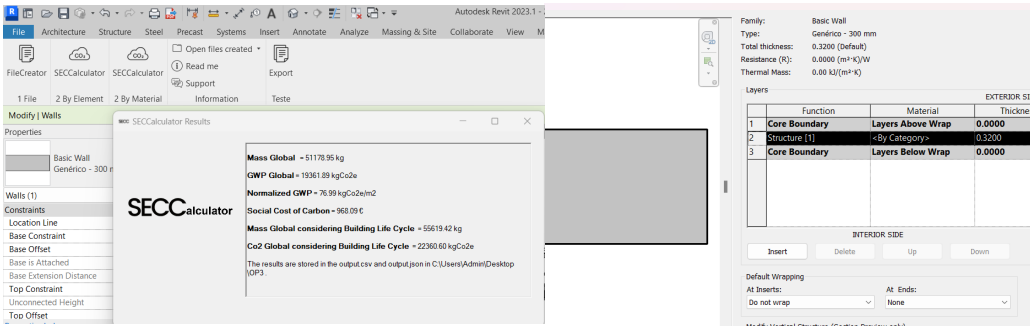
To conduct accurate energy performance simulations, Grasshopper requires the input of the material layers that make up the wall. This information is retrieved from the tables presented in the previous section. For all assemblies, the same type of glass is considered for the window elements, it’s a double glass with a u-value of 1.5 and a solar heat gain coefficient of 0.3. These are general performance values for double glasses. The used mechanical ventilation rate is the same as typical residential levels and is adjusted to the minimum comfort requirements for six people, set at 0.0001 $m^3/s\text{-}m^2$ and 0.0014 m^3/s per person, totaling 0.0083 m^3/s. The rate of outside air infiltration is also defined, the used value is 0.0003, which is a value for a general building. The shelter floor surfaces are considered adiabatic, so energy transfer through the ground is not considered, as this could depend on many uncontrollable variables. Lastly, the lightning density per area is also indicated, with a value of 3 W/m^2, common for efficient LED lightbulbs, and an equipment load per area of 2 W/m^2, which is enough for a laptop or two in a determined zone.

2.3 Embodied and Operational Carbon Calculations

The BIM-based method proposed by Parece (2024) was used to calculate the Global Warming Potential (GWP) across the A1-A3, B4, and B6 stages of the building lifecycle for each construction assembly [11]. This method is an add-on for Autodesk Revit (Fig. 2a).

The Uniclass code establishes a dynamic connection between specifications and environmental data of materials and products stored in an external database and the BIM objects.

The case study is in the early design phase, and the BIM model has a low LOD with no material information (Fig. 2b). Therefore, product and material information is stored in an external database. The material details for each building system are in *Tables 1-6 (refer to section 2.1, Construction Assemblies)*. The material quantities for each BIM object are determined by cross-referencing the relative material quantity from the database with the BIM object absolute quantities (e.g., m, m², unit) using the SECClasS code as illustrated in Fig.3. This method allows a quick simulation of material and design options without re-



modeling.

Fig. 2. a- Add-on for Autodesk Revit; b – BIM object without material information from the Case study model.

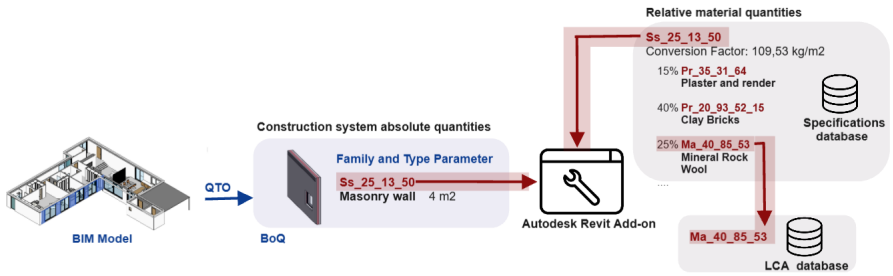


Fig. 3. Representation of the Quantity take-off (QtO) method using the Uniclass classification system. The absolute quantities of BIM objects are extracted from the model, and the relative of materials from the database, based on

After conducting the energy simulations, we calculated the total annual thermal load and multiplied it by Portugal's estimated Electricity Emission Factor, which is 0.262 tCO2 eq./MWh. This calculation was done to evaluate the greenhouse gas emissions during the operational phase [5]. With the growing emphasis on renewable energy production, it is expected the annual greenhouse gas emissions from building energy consumption to decrease over time. According to the International Energy Agency (IEA), the global greenhouse gas intensity of energy production fell by an average of 2.0% from 2014 to 2018

[12]. Consequently, we simulated scenarios in which the energy grid's emissions factor either remained stable or decreased by an average of 2%.

3 Results and Discussion

3.1 Temperature and Energy Simulations

Two types of energy simulations were conducted: the first, to assess the free-floating indoor temperature of the building if no conditioning systems (heating or cooling) were considered, and the second, to calculate the amount of energy required to keep the building comfortable, with a temperature between 18 (for winter), minimum, and 26 (for summer), maximum. The simulations were conducted for a whole year, from January 1st to December 31st. The results of the simulations are presented below.

Table 7. Results of the energy simulations.

Envelope Construction Assembly	Min. free-floating temperature (Cº)	Max. free-floating temperature (Cº)	Avg. free-floating temperature (Cº)	Cooling energy required (kWh)	Heating energy required (kWh)	Total thermal load (kWh)	Total thermal load (kWh/m2)
Option 1 Traditional Ceramic Brick Wall + Concrete flat roof + Concrete Floor	9.17	38.62	22.11	2189.69	5495.02	7684.70	30.56 kWh/m²
Option 2 Aggregate concrete block wall + Concrete flat roof + Concrete Floor	8.01	41.15	22.20	2567.13	5813.93	8381.05	33.32 kWh/m²
Option 3 Wood frame wall + Wood frame flat roof + Concrete	10.05	37.86	22.37	1884.34	4501.56	6385.92	25.39 kWh/m²

Taking into account the results from both simulations, it's possible to conclude that the wood frame construction assembly performed better, followed by the traditional ceramic brick construction and, last, the fully concrete-built assembly. Reductions in the total thermal load, of almost 2000 kWh less per year, were obtained between the best-performing assembly (wood) and the worst (concrete).

Differences are also evident in the free-floating temperature of the building if no conditioning is considered. However, the minimum and maximum temperatures are not within the comfortable temperature range for humans, ranging between 8 and 10 ºC for the winter and 37 to 41 ºC in the summer. Lack of thermal comfort within homes is a common issue in Portugal, as stated in the Portal of Sustainable Construction (PCS) enquiries [13]. Portugal is also the fourth country in Europe in the worst energy poverty situation, as Eurostat concluded [14]. The region of Coimbra, being in the interior of Portugal and not on the coastline (such as the capital city of Lisbon or the metropolitan area of Porto), has harsher climate conditions, with more extreme winters and summers. This likely justifies the more uncomfortable colder and warmer free-floating temperatures. Regardless, the wood frame construction assembly provided a more comfortable temperature in winter (warmer) and summer (colder). It's worth noting, however, that the average temperature amongst the construction assemblies remained similar, at around 22 ºC.

3.2 Embodied Carbon Calculations

The three construction assemblies evaluated for the case study envelope are detailed in Table 8, with lifecycle assessment (LCA) data sourced from the University of Bath's Inventory of Carbon and Energy (ICE).

Option 1, which consists of a traditional ceramic brick wall, a concrete flat roof, and a concrete floor, exhibits the highest embodied carbon emissions during the construction phase (A1-3) at 478.0 kg CO_2e/m^2. This is followed by Option 2, featuring an aggregate concrete block wall, a concrete flat roof, and a concrete floor, which has emissions of 461.4 kg CO_2e/m^2. Option 3, with a wooden frame wall, a wooden frame flat roof, and a concrete floor, shows significantly lower emissions at just 76.99 kg CO_2e/m^2. When considering the additional B4 stage, the emission trends remain consistent.

The annual operational GWP (B6) emissions are highest for Option 2 at 8 $kgCO_2e/m^2$, followed by Option 1 at 8.73 $kgCO_2e/m^2$, and are lowest for Option 3 at 6.65 $kgCO_2e/m2$.

Table 8. Results of option 1 for building envelope by classification code.

Envelope Construction Assembly	Mass (A1-3) (t)	GWP (A1-3) (tCO_2e)	Mass (A1-3 +B4) (t)	GWP (A1-3 +B4) (tCO_2e)	Mass (A1-3) (kg/m^2)	GWP (A1-3) ($kgCO_2e/m^2$)	GWP (B6 annual) (tCO_2e)	GWP (B6 annual) ($kgCO_2e/m^2$)
Option 1 Traditional Ceramic Brick Wall + Concrete flat roof + Concrete Floor	219.9	120.2	373.8	174.7	874.2	478.0	2.01	8.00
Option 2 Aggregate concrete block wall + Concrete flat roof + Concrete Floor	214.6	116.0	242.6	170.8	853.3	461.4	2.20	8.73
Option 3 Wood frame wall + Wood frame flat roof + Concrete Floor	51.18	19.36	55.62	22.36	203.49	76.99	1.67	6.64

The most significant factors in each option underscore the important role of reinforced concrete in the overall mass and GWP for Options 1 and 2 (see Tables 9 and 10, Fig 4 and 5). Specifically, the roof systems are major contributors to the environmental impact. In contrast, Option 3, which incorporates timber for the wall and roof systems, demonstrates a considerably lower environmental impact. In this case, the floor and deck structure systems are the primary contributors (refer to Table 11 and Fig 6). The negative GWP values for the timber wall systems in Option 3 indicate a positive effect of carbon sequestration, positioning it as a more sustainable choice in terms of embodied carbon.

Table 9. Results of option 1 for building envelope by classification code.

Uniclass_ Code	Uniclass_Title	Mass (A1-3) (t)	GWP (tCO_2e)	Mass (A1-3 +B4) (t)	GWP (tCO_2e)	Mass (A1-3) (kg/m^2)	GWP (A1-3) ($kgCO_2e/m^2$)
Ss_30_10_30_70.O	Reinforced concrete roof sys-	152.3	80.0	179.1	131.8	605.7	318.1

p1	tems						
Ss_30_12.Op1	Floor and deck structure systems	22.6	27.3	22.6	27.3	89.9	108.4
Ss_25_30_95	Window systems	1.4	2.2	2.7	4.4	5.5	8.8
Ss_30_10_30_70.Op2	Masonry wall systems	43.4	10.4	43.4	10.4	172.4	41.4
Ss_25_30_20_25	Door set systems	0.2	0.3	0.4	0.7	0.8	1.4
Total		219.9	120.2	248.2	174.6	874.2	478.0

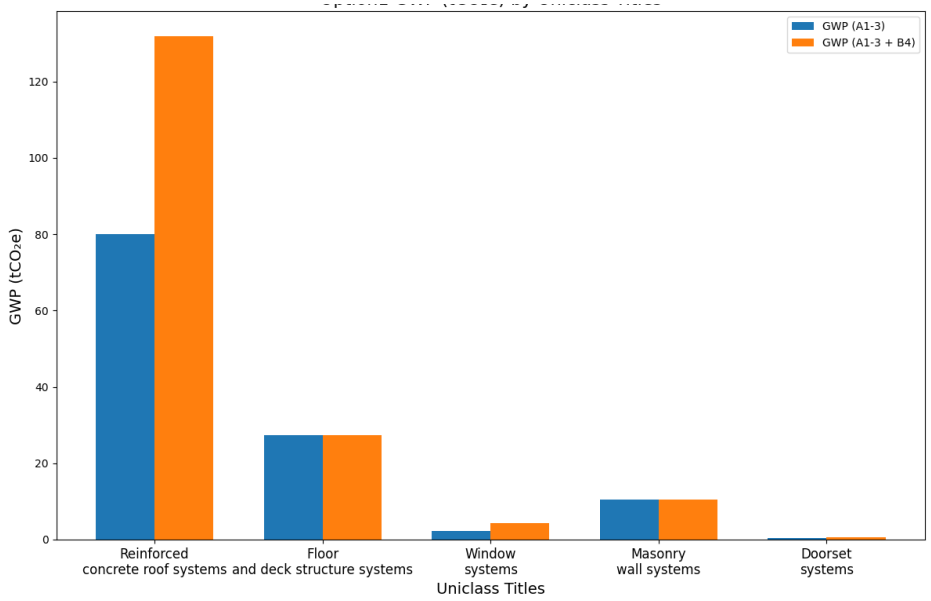


Fig 4. Results of option 1 for building envelope by classification code.

Table 10. Results of option 2 for building envelope by classification code.

Uniclass_ Code	**Uniclass_Title**	**Mass (A1-3) (t)**	**GWP (tCO_2e)**	**Mass (A1-3 +B4) (t)**	**GWP (tCO_2e)**	**Mass (kg/m^2)**	**GWP ($kgCO_2e/m^2$)**
Ss_30_10_30_70.Op1	Reinforced concrete roof systems	152.3	80.0	179.1	131.8	605.7	318.1
Ss_30_12.	Floor and deck	22.6	27.3	22.6	27.3	89.9	108.4

Op1	structure systems						
Ss_25_30_95	Window systems	1.7	2.7	3.3	5.4	6.6	10.7
Ss_30_10_30_70.Op2	Masonry wall systems	37.8	5.7	37.2	5.6	150.3	22.8
Ss_25_30_20_25	Door set systems	0.2	0.3	0.4	0.7	0.8	1.4
Total		214.6	116.0	242.6	170.8	853.3	461.4

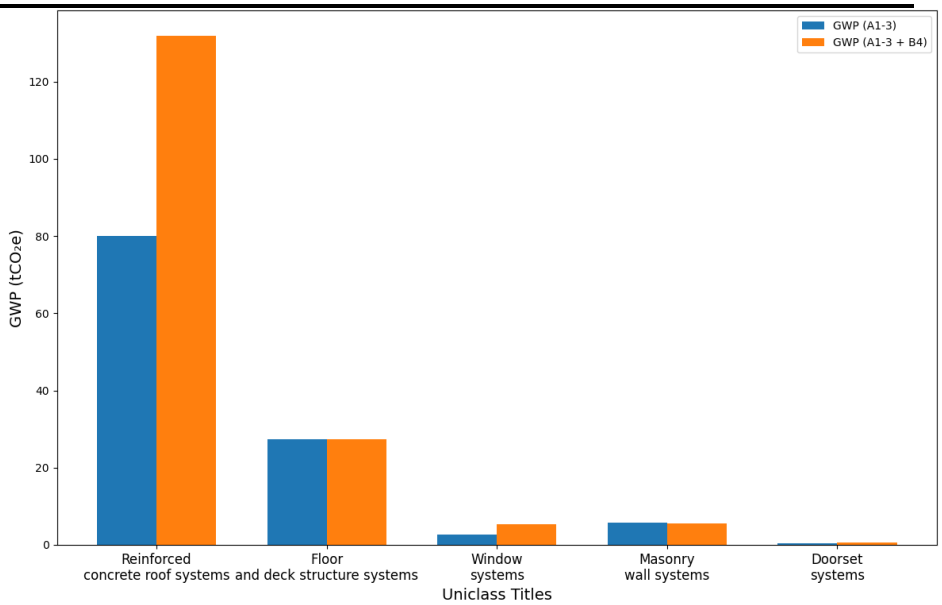


Fig 5. Results of option 2 for building envelope by classification code.

Table 11. Results of option 3 for building envelopes by classification code.

Uniclass_Code	**Uniclass_Title**	**Mass (A1-3) (t)**	**GWP (tCO_2e)**	**Mass (A1-3 +B4) (t)**	**GWP (tCO_2e)**	**Mass (kg/m^2)**	**GWP ($kgCO_2e/m^2$)**
Ss_30_10_30_70. Op1	Reinforced concrete roof systems	2.57	-0.03	5.15	-0.06	10.23	-0.11
Ss_30_12. Op1	Floor and deck structure systems	22.62	27.27	22.62	27.27	89.92	108.43
Ss_25_30_95	Window systems	1.67	2.69	3.34	5.38	6.65	10.69

Ss_30_10_30_70. Op2	Timber wall systems	24.12	-10.91	24.12	-10.91	95.91	-43.36
Ss_25_30_20_25	Door set systems	0.20	0.34	0.39	0.68	0.78	1.35
Total		51.18	19.36	55.62	22.36	203.49	76.99

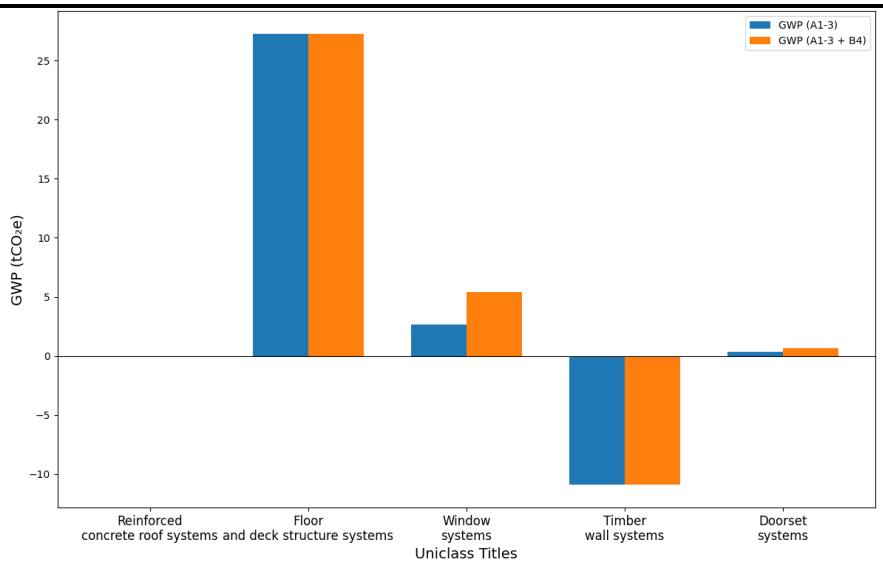


Fig 6. Results of option 3 for building envelope by classification code.

Figure 7 illustrates the building's GWP emissions over the years, simulating two scenarios: one where the emission factor of the Portuguese electricity grid remains stable, and another with an annual reduction of 2%. The notable 'carbon spike' observed during the construction year (i.e., year 3) results from the emissions associated with the production of building materials and the construction process itself. While these embodied emissions are concentrated in the initial phase, operational greenhouse gas (GHG) emissions occur annually throughout the building's lifecycle.

It is important to note that Option 1 has higher GWP emissions during the construction phase (A1-3) compared to Option 2. Option 2 exhibits lower emissions over the years due to its inferior thermal performance, resulting in higher operational emissions. This underscores the importance of considering both initial embodied emissions and long-term operational emissions when evaluating the overall environmental impact of construction assem-

blies.

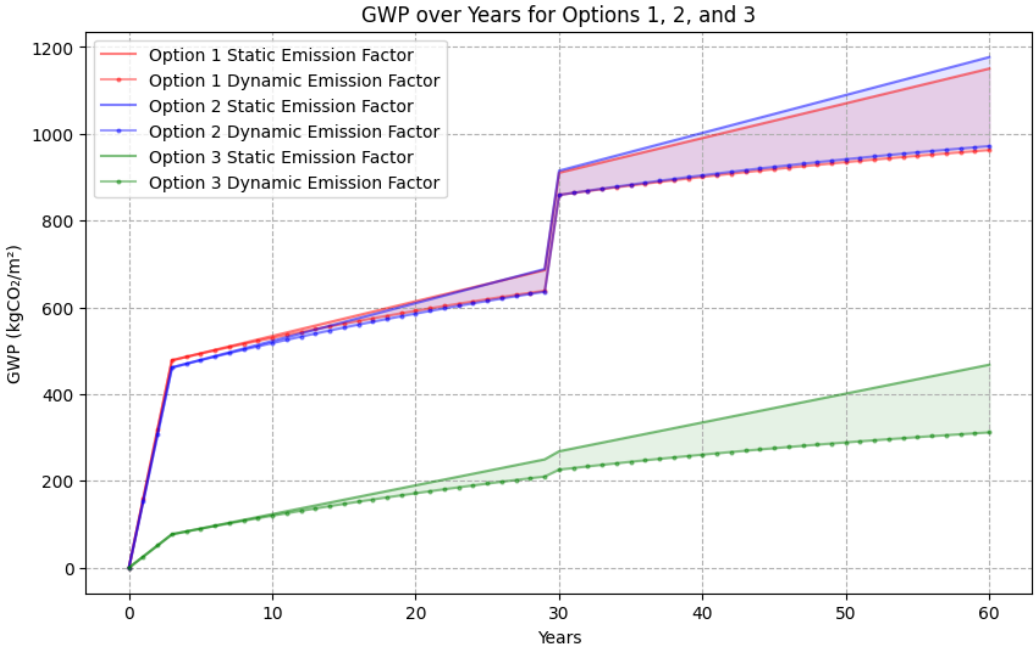


Fig 7. The estimated GWP emissions for options 1, 2, and 3 of the building over the years. Projections for future reductions in emission intensity (hatched areas) are based on a yearly improvement of 2%.

4 Conclusion

This study presented a BIM-based method for evaluating building energy performance and global warming potential (GWP) across multiple lifecycle stages, as defined in EN 15978. The methodology was applied to assess trade-offs between operational and embodied carbon for different construction assemblies in the building envelope of a single-family house in Coimbra, Portugal, during the early design phase.

Results from temperature and energy simulations demonstrated that the wood frame construction assembly outperformed traditional ceramic brick and concrete block options in energy efficiency, reducing the total annual thermal load and operational GWP emissions. This, coupled with its significantly lower embodied GWP due to carbon sequestration properties, identified the wood frame assembly as the most sustainable choice. The findings underscore the importance of integrating energy simulations and holistic lifecycle assessments in construction to make environmentally informed decisions, balancing operation-

al and embodied carbon impacts. Notably, while the aggregate concrete block assembly exhibited lower emissions during construction, its poor thermal performance resulted in higher long-term emissions, reinforcing the need to evaluate lifecycle trade-offs comprehensively.

Despite its contributions, the study has limitations. Conducted during the early design phase, it relied on estimated material quantities, potentially affecting accuracy. Additionally, lifecycle assessment data may not fully align with the Portuguese context, and only select lifecycle stages were considered, leaving some environmental impacts unaddressed. Future research should refine data precision, expand lifecycle scope, and incorporate localized datasets to enhance the relevance and robustness of sustainable construction strategies.

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