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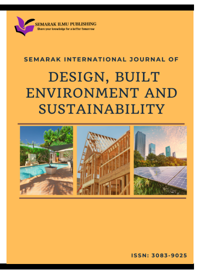

The Life Cycle Environmental Assessment of a Sustainable Building Design using A BIM Model

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ABSTRACT

The building sector faces pressing environmental challenges, making it essential to adopt tools that reduce resource use and limit environmental impacts. Life Cycle Assessment (LCA) has become one of the most widely used methods for evaluating the environmental performance of buildings and is central to achieving sustainability in construction. This dissertation develops an analytical framework for embedding LCA within routine design practices through Building Information Modelling (BIM) based approaches, with particular attention to integrating BIM and LCA as well as interpreting LCA outcomes within building design contexts.BIM, understood as a virtual 3D model linked to a database of building components, offers strong potential when combined with LCA. Existing research highlights that their integration not only simplifies data collection but also creates a mutually reinforcing relationship where BIM informs environmental assessment and LCA enhances design decision-making. This study undertakes a methodological exploration of BIM–LCA integration, focusing on how BIM can streamline data input, improve the reliability of outputs, and optimize results during environmental evaluation.The findings confirm the practicality of developing methods that use BIM models to structure building data for assessing environmental and energy impacts through LCA. This includes the application of templates and plug-ins within BIM software. Results further demonstrate that embedding LCA within BIM facilitates the generation of multiple design alternatives, ensures accurate and transparent data processing, and enables robust comparisons of design solutions against defined environmental benchmarks. Importantly, the study shows that design choices are influenced by how LCA results are interpreted, underscoring the value of applying LCA concepts early in the design process.

Keywords:
BIM, LCA; global warming; green house gas; carbon dioxide; end of life

1. Introduction

The concept of sustainability in construction has gained global momentum, driven by the urgent need to address social, economic, and environmental concerns associated with the built environment. Reports by Du Plessis [1] have drawn attention to the multifaceted impacts of the construction sector. The industry significantly influences environmental quality through extensive

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off-site, on-site, and operational activities, utilizing vast quantities of raw materials, energy, and water. According to Soust-Verdaguer *et al.*, [2], the construction sector globally consumes 32% of total resources, 40% of energy, and 12% of fresh water, reflecting its critical role in resource efficiency. Rock *et al.*, [3] emphasizes the considerable environmental burdens associated with both the construction and maintenance phases of buildings. The European Commission’s 'Roadmap to a Resource Efficient Europe' [4] underlines that better building practices could significantly reduce resource use and environmental impacts, cutting 42% of final energy consumption, 35% of greenhouse gas emissions, and up to 30% of water consumption. Since humans spend more than 90% of their lives indoors, the performance and sustainability of buildings directly impact quality of life and environmental resilience. A regenerative built environment is essential in shaping a sustainable future.

In the United Nations report released in 2019, Africa, with a population of over 1.2 billion, is expected to double by 2050. Rapid urbanization and economic growth present environmental risks, as highlighted by Rodriguez Fiscal *et al.*, [5]. Environmental challenges such as air pollution, chemical toxicity, and water scarcity are already severe, for instance, air pollution causes over a million deaths annually on the continent [6]. Many African economies rely on extractive industries and agriculture, including oil (Nigeria, Angola), metals (South Africa, Ghana), and crops like coffee and cocoa (Ethiopia, Ghana), which adds strain to ecosystems [7]. Despite the evident need, Life Cycle Assessment (LCA) has yet to gain substantial ground in Africa [5]. LCA provides a framework for evaluating environmental impacts at each stage of a product's life from raw material extraction to manufacturing, use, and disposal [7]. However, LCA research in Africa is limited and fragmented.

Huijbregts *et al.*, [8] note the scarcity of localized life cycle inventory (LCI) data, lack of peer-reviewed studies, and over-reliance on commercial data sources. A holistic and peer-reviewed LCA framework is necessary for informed policy-making and environmental regulation on the continent.

In Nigeria, efforts to regulate building energy performance are still developing [9]. The 2006 National Building Code did not include provisions for energy efficiency, although ongoing efforts aim to integrate energy codes, the focus remains on operational energy. At the same time, housing demand is rapidly increasing because of ongoing urban expansion. The housing deficit, estimated at 12–14 million units in 2007, rose to about 17 million by 2012 [10]. Bridging this gap will require large volumes of building materials and considerable energy, especially embodied energy, energy consumed in the extraction, processing, transportation, and assembly of materials [10]. Unlike in colder, industrialized regions where operational energy dominates, Nigeria’s tropical climate and limited energy supply mean embodied energy has a greater environmental impact. Low-income housing scenarios show that focusing on embodied energy can significantly reduce carbon emissions. Data remains insufficient to guide policy or practice. Conducting robust LCA studies of Nigerian housing stock could offer invaluable insights for improving energy efficiency at the material and process levels [11].

Building Life Cycle Assessment (LCA) is a valuable tool for evaluating a building's environmental impact from raw material extraction to demolition. While it promotes sustainable design, full-scale LCA remains complex, especially in regions like Africa with limited data and standardization [5]. LCA is often applied too late in the design process to guide decisions effectively [12]. Integrating LCA during early design changes are easier and cheaper [13]. Building Information Modelling (BIM) supports this by enabling accurate material data and analysis [14]. Tools like Tally and Athena link BIM models directly to LCA, streamlining assessments [15]. However, challenges such as poor interoperability, limited local datasets, and skill gaps hinder adoption. To improve sustainability outcomes in rapidly urbanizing countries like Nigeria, investment in BIM-LCA integration, regional databases, and professional training is urgently needed.

2. Literature Review

2.1 Emissions Contribution of The Construction Sector

Carbon dioxide (CO_2) remains the most significant anthropogenic greenhouse gas, responsible for altering atmospheric composition, increasing global temperatures, and exerting lasting ecological and health impacts, with an atmospheric lifetime ranging from 100 to 200 years [16]. While water vapor is the most abundant natural greenhouse gas, CO_2 serves as the standard reference due to its dominance from fossil fuel combustion and its far-reaching climatic effects. Other gases such as methane (CH_4), nitrous oxide (N_2O), and ozone (O_3) also contribute to warming, but their differing global warming potentials (GWP) necessitate conversion into a unified metric, carbon dioxide equivalent (CO_2e), for accurate comparison [16].

The construction sector is a major contributor to these emissions. The European Environment Agency (EEA) reported in 2021 that buildings alone accounted for approximately 35% of the EU's energy-related emissions, originating from material production, transport, on-site energy use, and end-of-life disposal [4]. Despite advances in insulation, glazing, heat pump technologies, and renewable integration, reductions remain insufficient to achieve the EU's "Fit for 55" target of a 55% emissions cut by 2030 [17]. Beyond operational energy, embodied carbon from extraction, processing, construction, and demolition contributes around 10% of global emissions [17]. The report Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future 2019, by the International Resources Panel-UNEP suggest material cycle interventions could reduce embodied emissions in residential buildings by up to 80% across G7 nations and China, though trade-offs persist: measures such as enhanced insulation lower operational energy but increase reliance on resource-intensive materials, shifting the carbon load to production. A balanced strategy combining energy performance improvements with material efficiency is therefore essential to mitigate both embodied and operational impacts [17].

2.2 Circular Buildings

Circular buildings, derived from Circular Economy (CE) principles, seek to minimize resource use, emissions, and waste by adopting closed-loop systems that prioritize reuse, recycling, and extended material lifecycles [18]. Two central strategies define this model: slowing resource loops through repair, refurbishment, and life-extension of materials, and closing loops by recycling materials back into production cycles [18]. In practice, construction can achieve these goals through modularity, standardization, lightweight design, non-raw or low-impact materials, and mechanical bonding for ease of reuse. At end-of-life, design for disassembly and material separation are critical to achieving recycling efficiency [19].

Nonetheless, implementation faces notable barriers, Van Stijn *et al.*, [19] highlight limitations including technological immaturity, underperformance of circular materials in terms of energy efficiency, water and gas safety, and a tendency for many designs to mirror conventional business-as-usual practices. Additional challenges include aesthetic concerns such as visible wear, hazards in reclaimed materials (e.g., chemicals in salvaged wood), reduced structural performance due to material degradation, and prohibitive costs undermining economic feasibility. These constraints illustrate why, despite its potential, circular construction remains in early stages of widespread adoption [19].

2.3 Standards and Frameworks
2.3.1 EN 15804 +A1/+A2 – products in the building sector

EN 15804 is the principal framework for Environmental Product Declarations (EPDs) in the construction industry, providing a harmonized structure to ensure transparency and comparability of environmental data. Originally introduced as EN 15804 +A1, the standard was revised into EN 15804 +A2 to tighten life cycle requirements, refine functional units, and broaden environmental impact indicators, thereby enhancing its role in Life Cycle Assessment (LCA) [20].

A key difference lies in the categorization of impacts: while EN 15804 +A1 offered a general framework, the +A2 version introduced a more detailed and extended breakdown, rendering +A1 data non-convertible and necessitating updates [20]. Among its indicators, climate change expressed through Global Warming Potential (GWP) in CO_2 equivalents is most critical, as it measures greenhouse gas contributions to global warming. In EN 15804 +A2, GWP is subdivided into three categories based on emission source, while many platforms incorporate a fourth indicator - total GWP - those accounts for embodied carbon across life cycle stages A1–A3. This revision positions EN 15804 +A2 as the prevailing framework for robust and sector-specific environmental reporting [20].

2.4 Green/Sustainable Buildings

Green and sustainable buildings are assessed through established frameworks such as BREEAM and LEED, which benchmark environmental and ecological performance [21]. According to RICS (2009), sustainable buildings should maximize value for owners, occupants, and society while minimizing resource consumption and environmental impacts, including biodiversity effects. Berardi [22] similarly argues that green buildings must balance environmental responsibility with fitness for functional use.

Cole [23] distinguishes between green and sustainable assessments, noting that while green evaluations focus on local environmental features against conventional baselines, sustainable assessments are measured against broader international goals encompassing environmental, economic, and social dimensions. However, some scholars caution that true sustainability may be unattainable, citing limitations in current standards [24]. Despite these debates, the terms “green” and “sustainable” are often used interchangeably to describe buildings meeting third-party certification systems such as LEED or BREEAM, which remain the most widely recognized measures of sustainable performance [24].

3. Methodology

This study focuses on integrating Life Cycle Assessment (LCA) into Building Information Modelling (BIM) to evaluate the environmental performance of a typical residential building design.

The methodological framework adopted as shown in Figure 1 below, is structured to manage building data and LCA results from the perspective of the design team. It emphasizes identifying the most appropriate design phase to conduct LCA, where its influence on decision-making is most effective. To evaluate how material choices impact environmental performance, three design options were developed for comparative life cycle assessment, as shown in Table 1. While the structural framework comprising reinforced concrete foundations, columns, and slabs remained constant across all options, variations were introduced in walling, roofing, and door or window systems, these quantities were expressed in terms of volume (m^3), area (m^2), kg, or number of units, depending on the nature of the material or component as shown in Table 2. To evaluate the environmental impacts of material selection and design decisions, three options were developed for comparative life cycle assessment as shown in Table 3

The case study is a three-story residential apartment building with a total floor area of 722 m², located in Lagos, Nigeria as shown in Figure 2-4 below. The BIM model includes all primary building components such as partition walls, slabs, columns, beams, foundations, parapet walls, roof, and openings. All modelled elements were considered within the scope of the LCA.

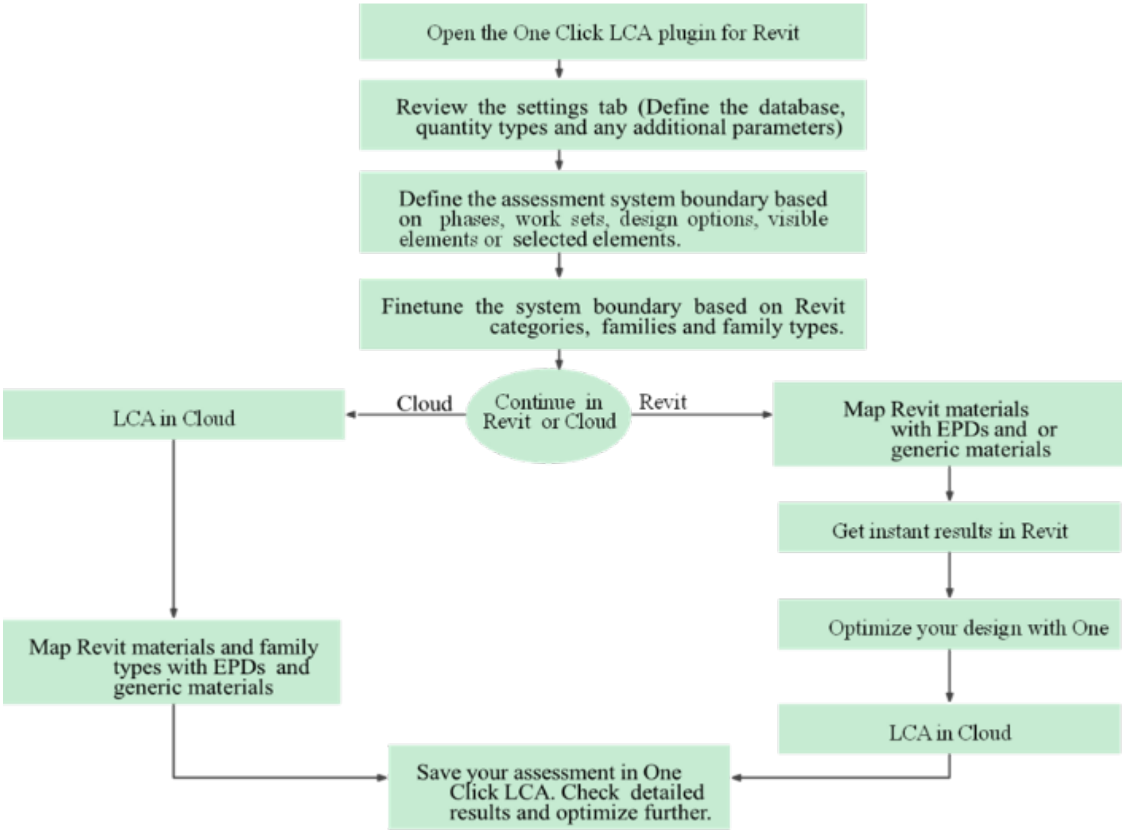


Fig. 1. Research flowchart

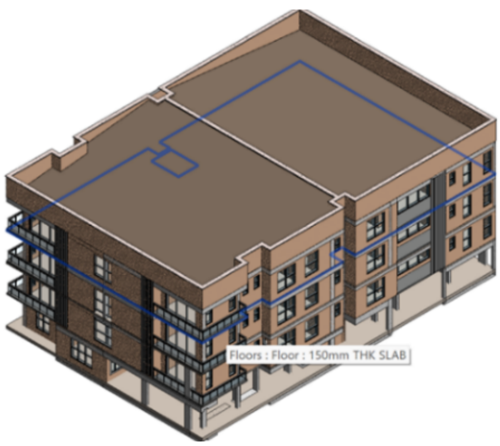


Fig. 2. 3D Architectural model of the structure

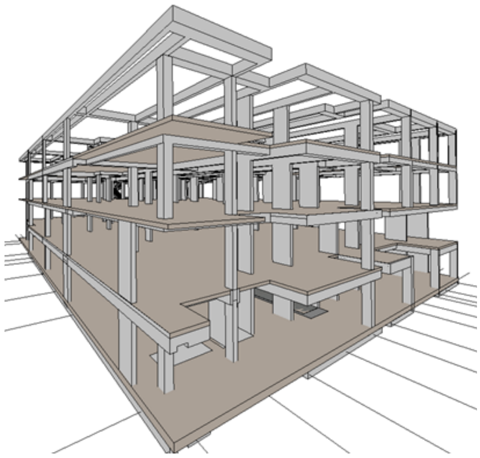


Fig. 3. 3D Structural frame model of the structure

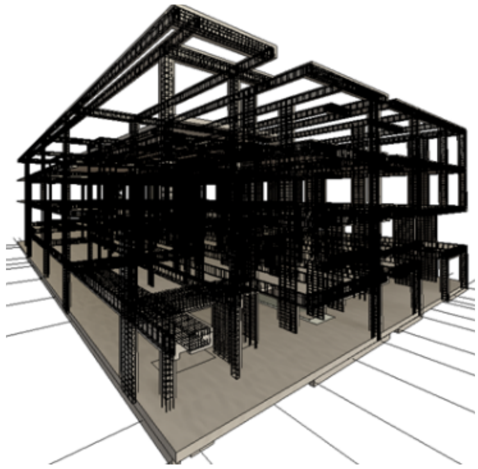


Fig. 4. 3D Reinforcement model of the structure

The BIM model was developed using Autodesk Revit 2024, following a structured modelling workflow that reflects common residential construction practices. Project base levels and structural grids were established to guide the placement of vertical and horizontal load-bearing elements.

The structural frame was created using reinforced concrete columns and beams, assigned with appropriate material properties (C20/25 ready-mix concrete). Concrete floor slabs of 300 mm and 150 mm thickness were modelled at ground and upper floors, respectively. Reinforcement details were incorporated using Revit's structural rebar tools, with slabs, beams, and columns all reinforced to match standard construction practice. Walls were modelled using custom wall types, with external walls consisting of 225 mm hollow concrete blocks and internal walls using either 225 mm or 150 mm blocks. A pitched roof system with clay (terracotta) tiles was added, followed by customized windows and doors placed according to architectural drawings.

After completing the architectural and structural modelling, the model was reviewed in 2D and 3D to ensure accuracy. Each element was verified for correct material assignment, dimensioning, and placement, ensuring consistency for accurate data extraction and reliable LCA analysis using the One Click LCA platform.

Table 1
Data Sources

	Primary data source	Secondary data source
A1 – A3 (Raw material, extraction, processing & manufacturing	Construction drawings, BOQ, Engineers	Verified environmental product declarations (EPDs), OneClick LCA database
A4 (Transport to site)	Project – specific transport data, if available	Regional transport scenarios within OneClick LCA, reflecting typical routes and modes
A5 (Construction & Installation process)	On-site estimated utility consumption	Default values from OneClick LCA for conservative estimates
B1 – B5 (Use phase, material replacement)	Manufacture data, project service-life	Standard service life metrics for materials, verified against project conditions
C1 – C4 (End of life)	Demolition reports (if available)	Default waste scenarios in line with EN 15804 +A1/A2 requirements

Table 2
Material inventory of the structure

	CATEGORY	*TYPE*	*QUANTITY*	*UNIT*	*UNIT (PCS)*	*TRANSPORT DIST. (km)*
WALL	Exterior Walls	Hollow Blocks (450x225x225)	3668.76	m^2	285	30
	Exterior Walls	CEB Blocks				
	Interior Walls	Hollow Blocks (450x150x150)	9581.12	m^2	915	30
	Interior Walls	CEB Blocks				40
DOOR	Doors	Interior Door 750mm	11.7	m^2	12	30
	Doors	Interior Door 750mm (Panel)	126.88	m^2	79	
	Doors	Interior Door 750mm (Frame)	125.35	m^2	79	
	Doors	Interior Door 750mm (Architrave)	65.65	m^2	79	
	Doors	Interior Door 900mm	384.71	m^2	86	
	Doors	Interior Door 1200mm	5.28	m^2	1	
WINDOW	Windows	OP1200	0.14	m^3	3	30
	Windows	OP1800	0.21	m^3	4	
	Windows	OP2200	0.13	m^3	2	
	Windows	OP2500	0.45	m^3	8	
	Curtain Wall Mullions	50 x 150mm	10.65	m^3	1735	
	Curtain Panels	Glazed	371.69	m^2	526	
ROOF	Roofs	ROOF	677.11	m^2	2	30

Table 2 (*Continued*)

STAIRS	**Stairs**	**190mm max riser 250mm going**	**1.87**	**m^3**	**3**	**60**
	Stairs	190mm max riser 250mm going	1.87	m^3	3	
	Top Rails	Elliptical - 40x30mm	0.47	m^3	15	30
	Railings	Glass Panel - Bottom Fill	0.26	m^3	15	
SLAB	Floors	150mm THK SLAB	4199.14	m^2	6	60
BEAM	Structural Framing	B1- 450 x 230mm	65.04	m^3	241	60
	Structural Framing	B10- 450 x 250mm	27.18	m^3	61	
	Structural Framing	B11- 600 x 450mm	1.83	m^3	2	
	Structural Framing	B2- 600 x 230mm	38.50	m^3	105	
	Structural Framing	B4- 600 x 1000mm	3.88	m^3	2	
	Structural Framing	B4- 600 x 750mm	1.14	m^3	1	
	Structural Framing	B7- 600 x 300mm	4.82	m^3	8	
	Structural Framing	B7- 600 x 600mm	8.98	m^3	10	
	Structural Framing	B8- 230 x 600mm	0.7	m^3	2	
	Structural Framing	F.B1 - 450x230mm	3.29	m^3	37	
	Structural Framing	F.B2 - 600x230mm	14.94	m^3	58	
COLUMN	Structural Columns	C1	40.87	m^3	120	60
	Structural Columns	C2	26.16	m^3	58	
	Structural Columns	C3	6.94	m^3	41	
	Structural Columns	C4	4.05	m^3	18	
	Structural Columns	C5	1.48	m^3	3	
	Structural Columns	C6	3.96	m^3	7	
FDN (Slab)	Structural Foundation	Foundation Slab 300mm THK	216.5202832	m^3	1	60
REBAR	Structural Rebar	H10	5200	kg		30
	Structural Rebar	H12	5600	kg		
	Structural Rebar	H16	7500	kg		
GROSS FLOOR AREA		710	m^2			

Table 3
Summary of material specifications for the three options

Building Element	Option 1	Option 2	Option 3
Foundation	C20/25 concrete	C20/25 concrete	C20/25 concrete
External walls	225mm Hollow concrete blocks	225mm Hollow concrete blocks	Compressed Earth blocks
Internal Walls	225mm Hollow concrete blocks	150mm Hollow concrete block	Compressed Earth blocks
Columns	C20/25 concrete	C20/25 concrete	C20/25 concrete
Beams	C20/25 concrete	C20/25 concrete	C20/25 concrete
Staircase	C20/25 concrete	C20/25 concrete	C20/25 concrete
Reinforcement	Ɵ 10, 12, 16	Ɵ 10, 12, 16	Ɵ 10, 12, 16
Floors	C20/25 concrete	C20/25 concrete	C20/25 concrete
Windows	Aluminium framed window	Aluminium framed window	Timber framed window
Doors	Aluminium door system	Aluminium door system	Timber door system
Roof	Roofing Tiles - Clay	Roofing Tiles - Clay	Roofing Tiles - Clay

3.1 Exporting the Revit Model to One Click LCA

After completing the BIM model in Autodesk Revit, the relevant building elements and their material quantities were exported to the One Click LCA platform to facilitate environmental impact analysis as shown in Figure 5 and Figure 6. This was achieved through the One Click LCA Revit plugin, which establishes a direct link between Revit and the LCA tool. Once installed, the plugin appeared in the Revit toolbar and scanned the model to automatically categorize elements such as walls, floors, roofs, foundations, windows, and doors forming the core of the life cycle inventory.

A selective export process was then carried out, focusing on high-impact components like reinforced concrete (used in slabs, beams, and columns), hollow concrete blocks (for wall construction), and glazing systems (from windows and doors), while excluding some non-structural items such as fixtures and furniture. Before exporting, the model was thoroughly reviewed to ensure accurate material assignments and that Revit's volume, area, and mass computations were properly enabled, as these parameters are critical for reliable take-offs. The export process generated a structured dataset containing essential material and dimensional data, which was then uploaded to the One Click LCA cloud platform for further environmental assessment.

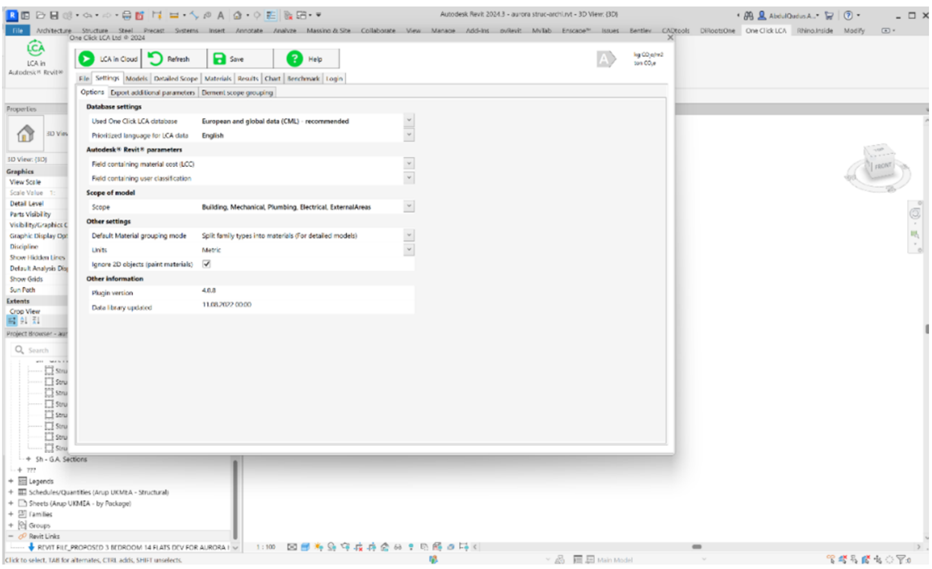


Fig. 5. OneClick LCA plugin in Revit – options tab

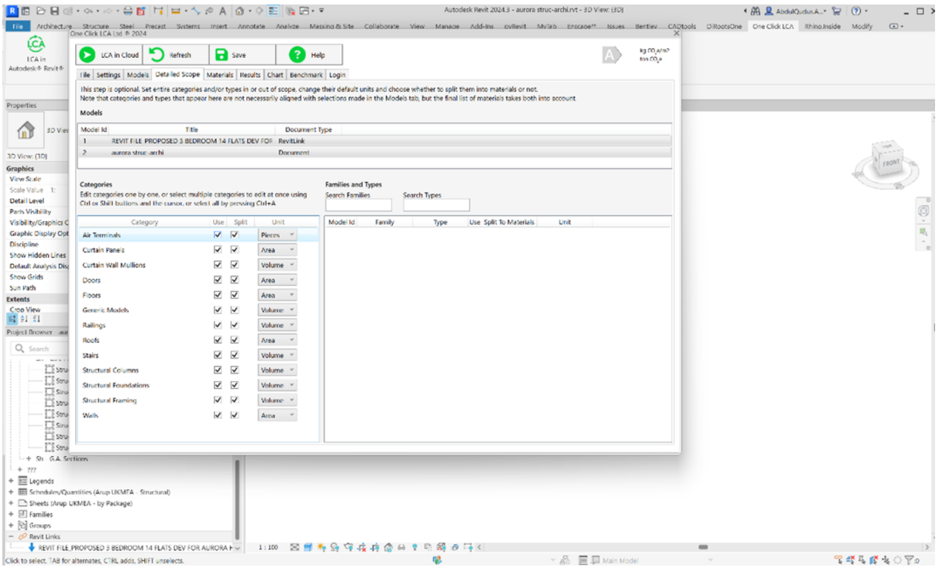


Fig. 6. OneClick LCA plugin in Revit – data and scope tab

3.2 Material Mapping in One Click LCA

The material mapping process in One Click LCA involved assigning verified Environmental Product Declarations (EPDs) to each material from the Revit model to ensure accurate environmental impact data as shown in Figure 7 and Figure 8 below. After importing the model, elements were automatically grouped (e.g., walls, floors, roofs) with quantities expressed in volume, area, mass, or units (Table 4). Each material was matched to a suitable environmental profile from One Click LCA's EPD library and databases like Ecoinvent, based on technical similarity and lifecycle coverage. Where possible, metadata such as transport distances, service life, and recycled content were added using typical Nigerian values. A final review ensured all materials were properly assigned, forming a solid basis for the next stage LCA parameter definition and impact analysis.

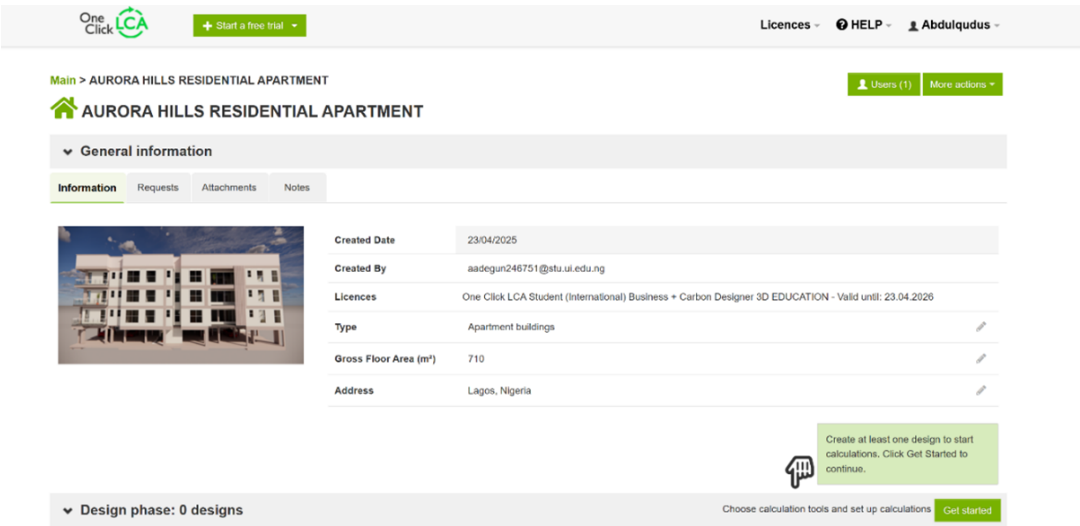
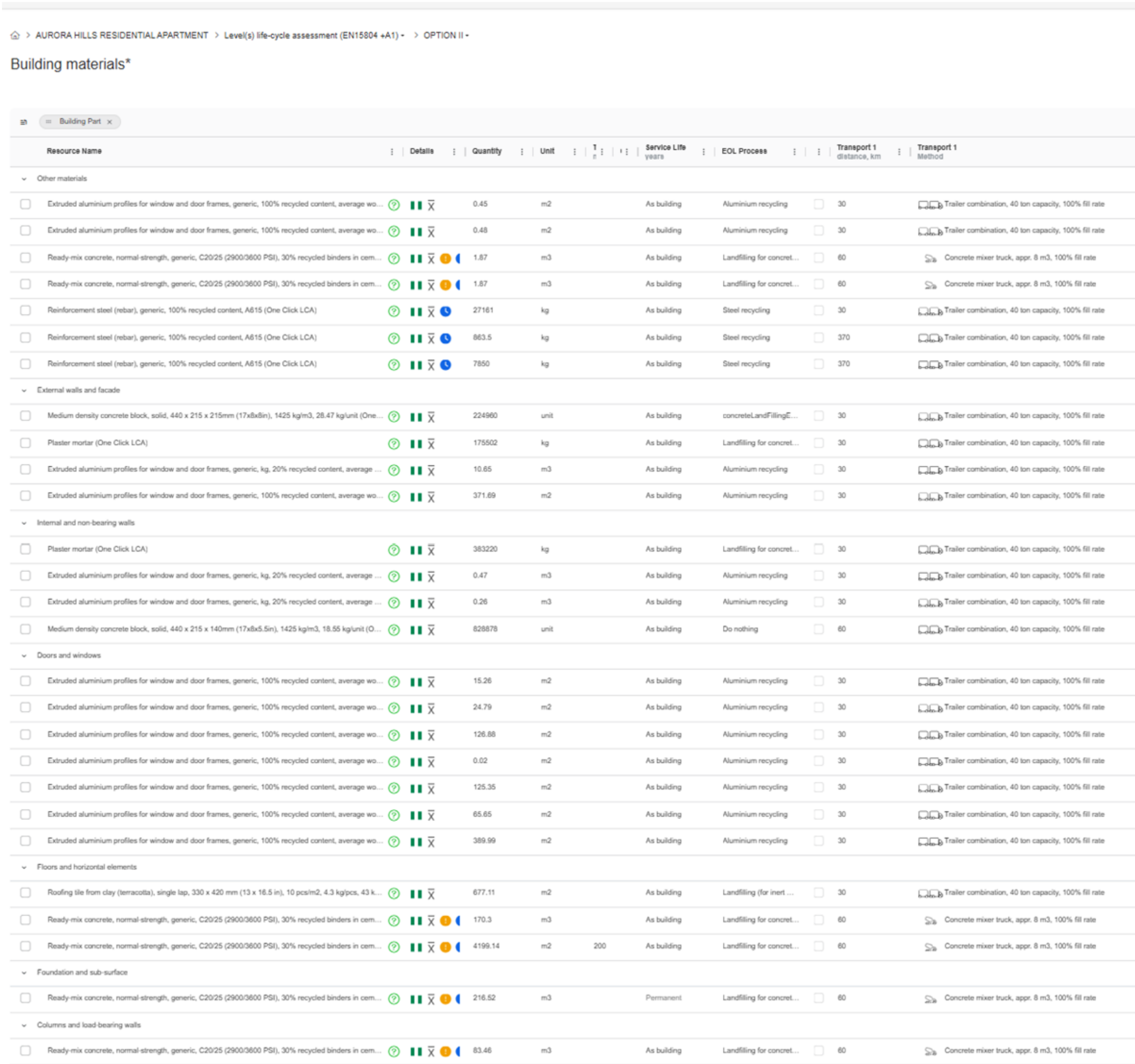


Fig. 7. OneClick LCA online platform – information tab


AURORA HILLS RESIDENTIAL APARTMENT > Level(s) life-cycle assessment (EN15804 +A1) > OPTION II

Building materials*

Building Part

Resource Name	Quantity	Unit		Service Life years	EOL Process	Transport 1 distance, km	Transport 1 Method
Other materials							
Extruded aluminium profiles for window and door frames, generic, 100% recycled content, average wo...	0.45	m2		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, 100% recycled content, average wo...	0.48	m2		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Ready-mix concrete, normal-strength, generic, C20/25 (2900/3600 PSI), 30% recycled binders in cem...	1.87	m3		As building	Landfilling for concret...	60	Concrete mixer truck, appr. 8 m3, 100% fill rate
Ready-mix concrete, normal-strength, generic, C20/25 (2900/3600 PSI), 30% recycled binders in cem...	1.87	m3		As building	Landfilling for concret...	60	Concrete mixer truck, appr. 8 m3, 100% fill rate
Reinforcement steel (rebar), generic, 100% recycled content, A615 (One Click LCA)	27161	kg		As building	Steel recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Reinforcement steel (rebar), generic, 100% recycled content, A615 (One Click LCA)	863.5	kg		As building	Steel recycling	370	Trailer combination, 40 ton capacity, 100% fill rate
Reinforcement steel (rebar), generic, 100% recycled content, A615 (One Click LCA)	7850	kg		As building	Steel recycling	370	Trailer combination, 40 ton capacity, 100% fill rate
External walls and facade							
Medium density concrete block, solid, 440 x 215 x 215mm (17x8x8in), 1425 kg/m3, 28.47 kg/unit (One...	224960	unit		As building	concreteLandFillingE...	30	Trailer combination, 40 ton capacity, 100% fill rate
Plaster mortar (One Click LCA)	175502	kg		As building	Landfilling for concret...	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, kg, 20% recycled content, average ...	10.65	m3		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, 100% recycled content, average wo...	371.69	m2		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Internal and non-bearing walls							
Plaster mortar (One Click LCA)	383220	kg		As building	Landfilling for concret...	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, kg, 20% recycled content, average ...	0.47	m3		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, kg, 20% recycled content, average ...	0.26	m3		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Medium density concrete block, solid, 440 x 215 x 140mm (17x8x5.5in), 1425 kg/m3, 18.55 kg/unit (O...	828878	unit		As building	Do nothing	60	Trailer combination, 40 ton capacity, 100% fill rate
Doors and windows							
Extruded aluminium profiles for window and door frames, generic, 100% recycled content, average wo...	15.26	m2		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, 100% recycled content, average wo...	24.79	m2		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, 100% recycled content, average wo...	126.88	m2		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, 100% recycled content, average wo...	0.02	m2		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, 100% recycled content, average wo...	125.35	m2		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, 100% recycled content, average wo...	65.65	m2		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Extruded aluminium profiles for window and door frames, generic, 100% recycled content, average wo...	389.99	m2		As building	Aluminium recycling	30	Trailer combination, 40 ton capacity, 100% fill rate
Floors and horizontal elements							
Roofing tile from clay (terracotta), single lap, 330 x 420 mm (13 x 16.5 in), 10 pcs/m2, 4.3 kg/pcs, 43 k...	677.11	m2		As building	Landfilling (for inert ...	30	Trailer combination, 40 ton capacity, 100% fill rate
Ready-mix concrete, normal-strength, generic, C20/25 (2900/3600 PSI), 30% recycled binders in cem...	170.3	m3		As building	Landfilling for concret...	60	Concrete mixer truck, appr. 8 m3, 100% fill rate
Ready-mix concrete, normal-strength, generic, C20/25 (2900/3600 PSI), 30% recycled binders in cem...	4199.14	m2	200	As building	Landfilling for concret...	60	Concrete mixer truck, appr. 8 m3, 100% fill rate
Foundation and sub-surface							
Ready-mix concrete, normal-strength, generic, C20/25 (2900/3600 PSI), 30% recycled binders in cem...	216.52	m3		Permanent	Landfilling for concret...	60	Concrete mixer truck, appr. 8 m3, 100% fill rate
Columns and load-bearing walls							
Ready-mix concrete, normal-strength, generic, C20/25 (2900/3600 PSI), 30% recycled binders in cem...	83.46	m3		As building	Landfilling for concret...	60	Concrete mixer truck, appr. 8 m3, 100% fill rate

Fig. 8. OneClick LCA online platform – building materials

3.3 Life Cycle Assessment Setup and Scope Definition

The assessment framework followed in this study was based on the principles and structure outlined in the EN 15978 standard, titled "Sustainability of Construction Works, Assessment of Environmental Performance of Buildings - Calculation Method" as shown in Figure 9. Project-specific settings were configured in the One Click LCA platform to contextualize the assessment, including specifying Nigeria as the project location, setting a 25-year reference study period, and inputting the building's gross floor area to normalize results (e.g., kg CO_2e/m^2 GFA). Transport distances and approximate waste generation rates for key materials like concrete and blocks were also entered, with default values used conservatively where local data was unavailable.

The analysis focused on Global Warming Potential (GWP) as the primary impact indicator, while also reviewing secondary metrics like Acidification and Resource Depletion. Results were presented as both total and normalized values, supporting the identification of high-impact materials and guiding strategies to reduce the building's embodied carbon footprint.

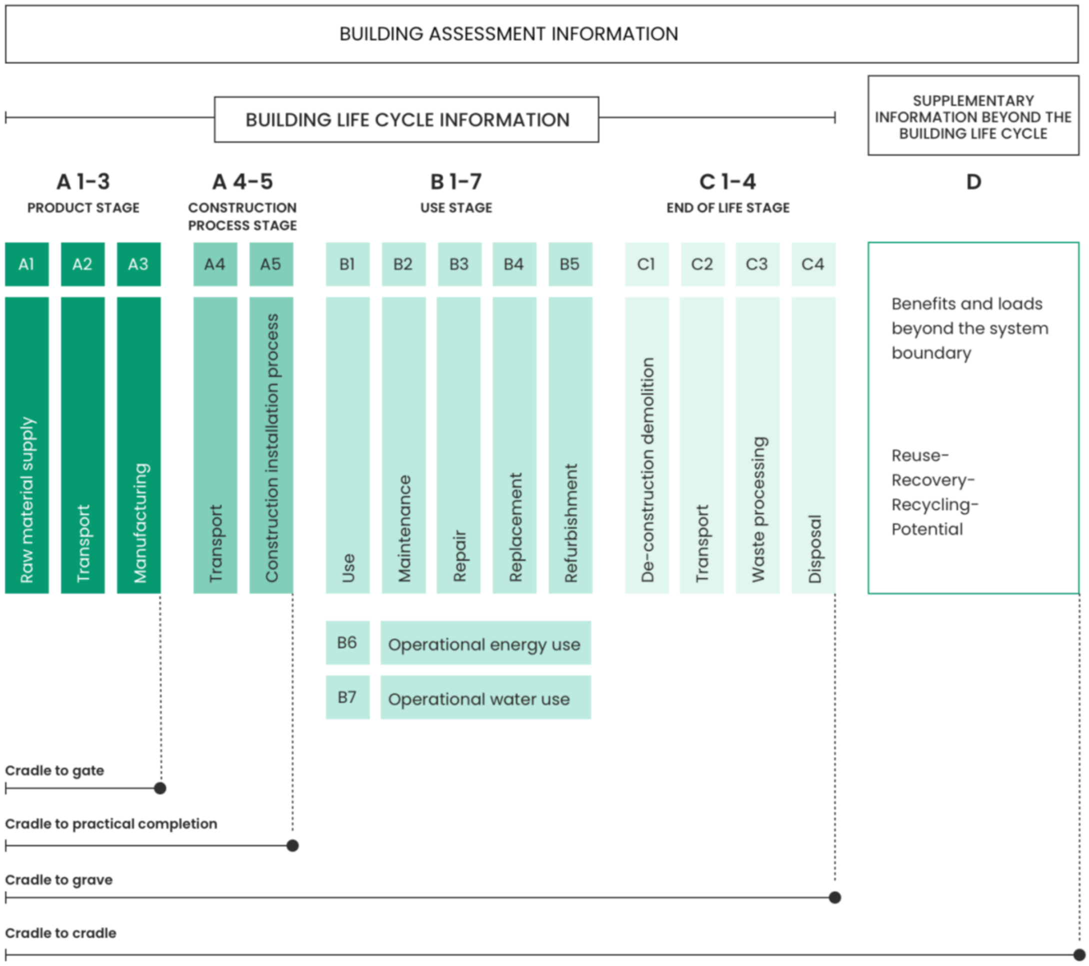


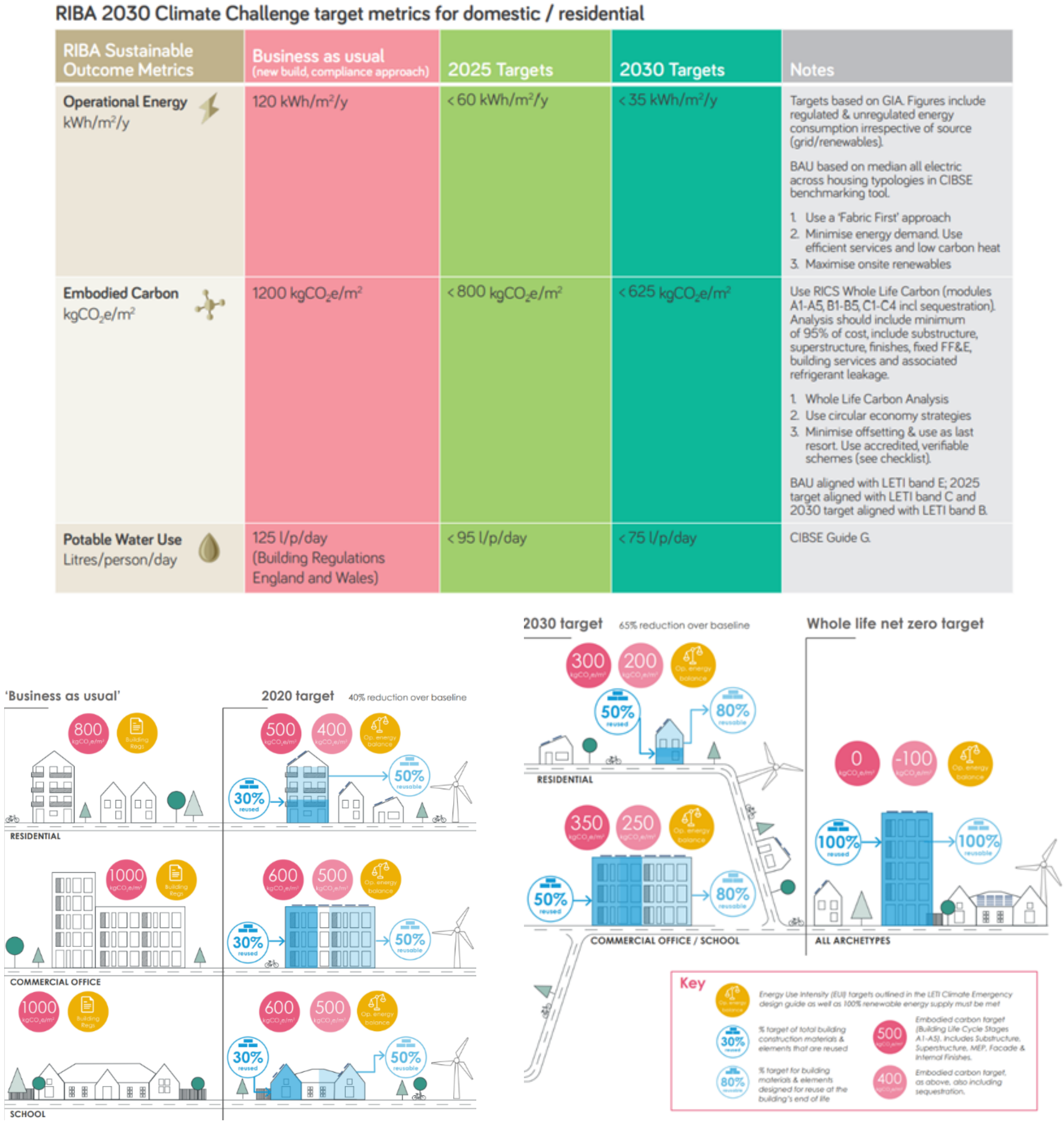
Fig. 9. Building life cycle stages

3.4 Embodied Carbon Target Metrics for Residential Buildings

To support decarbonization, key built environment bodies like RIBA, LETI, and IStructE have set benchmark targets for embodied carbon in residential buildings as shown in Table 4 below, serving as design-stage performance indicators to reduce upfront emissions from materials and construction as shown in Figure 10.

Table 4
Summary of material specifications for the three options

Organization	Scope	Metric Unit	Target Level	Target Value (kgCO$_2$e/m^2)
RIBA (2021)	A1–A5	GFA	2020 Target	≤ 1200
			2025 Target	≤ 800
			2030 Target	≤ 625
LETI (2020)	A1–A5	GIA	Business As Usual	~800–1000
			Current Best Practice	~500–600
			LETI Target (2020s)	≤ 300
			LETI Stretch Target	≤ 250
IStructE (2023)	A1–A5	GIA (Structure Only)	Typical Practice	200–300
			Good Practice	≤ 200
			Best Practice	≤ 100



RIBA 2030 Climate Challenge target metrics for domestic / residential

RIBA Sustainable Outcome Metrics	Business as usual (new build, compliance approach)	2025 Targets	2030 Targets	Notes
Operational Energy $kWh/m^2/y$	120 $kWh/m^2/y$	< 60 $kWh/m^2/y$	< 35 $kWh/m^2/y$	Targets based on GIA. Figures include regulated & unregulated energy consumption irrespective of source (grid/renewables). BAU based on median all electric across housing typologies in CIBSE benchmarking tool. 1. Use a 'Fabric First' approach 2. Minimise energy demand. Use efficient services and low carbon heat 3. Maximise onsite renewables
Embodied Carbon $kgCO_2e/m^2$	1200 $kgCO_2e/m^2$	< 800 $kgCO_2e/m^2$	< 625 $kgCO_2e/m^2$	Use RICS Whole Life Carbon (modules A1-A5, B1-B5, C1-C4 incl sequestration). Analysis should include minimum of 95% of cost, include substructure, superstructure, finishes, fixed FF&E, building services and associated refrigerant leakage. 1. Whole Life Carbon Analysis 2. Use circular economy strategies 3. Minimise offsetting & use as last resort. Use accredited, verifiable schemes (see checklist). BAU aligned with LETI band E; 2025 target aligned with LETI band C and 2030 target aligned with LETI band B.
Potable Water Use Litres/person/day	125 l/p/day (Building Regulations England and Wales)	< 95 l/p/day	< 75 l/p/day	CIBSE Guide G.

Fig. 10. Building life cycle stages

4. Results

This chapter presents the Life Cycle Assessment results of AURORA HILLS residential apartment in Lagos, Nigeria, a three-story building with a total floor area of 722 m². The assessment quantified environmental impacts, including Global warming potential, Acidification, Eutrophication, Ozone depletion, Photochemical ozone creation, and Fossil resource depletion, focusing on embodied carbon (GWP in kg CO_2e/m^2) across the life cycle stages defined by EN 15978. The results for all three design options (I, II, and III), along with their comparison, are presented as shown in Figure 11-14, and Table 5-8 below.

4.1 Option I

Fig. 11. OPTION I: (a) Most contributing materials, (b) Bubble chart life-cycle resources, (c) Result by Life cycle stage, (d) Sankey Diagram (e) Life Cycle Overview of Global Warming (f) Embodied Carbon Benchmark

Table 5
Option I – Summary of assessment

Aspect	Result
Embodied Carbon	1133 kg CO_2e/m^2
Main contributors	Concrete, mortar, masonry blocks
Highest impact stage	A1 – A3 (Product stage) – 88.7% of total emissions
Construction stage (A5)	6.3%
Transport (A4)	2.4%
End-of-Life (C2 – C4)	<3%
Benchmark Targets	Exceeds RIBA (500), LETI (625) benchmarks.

4.2 Option II

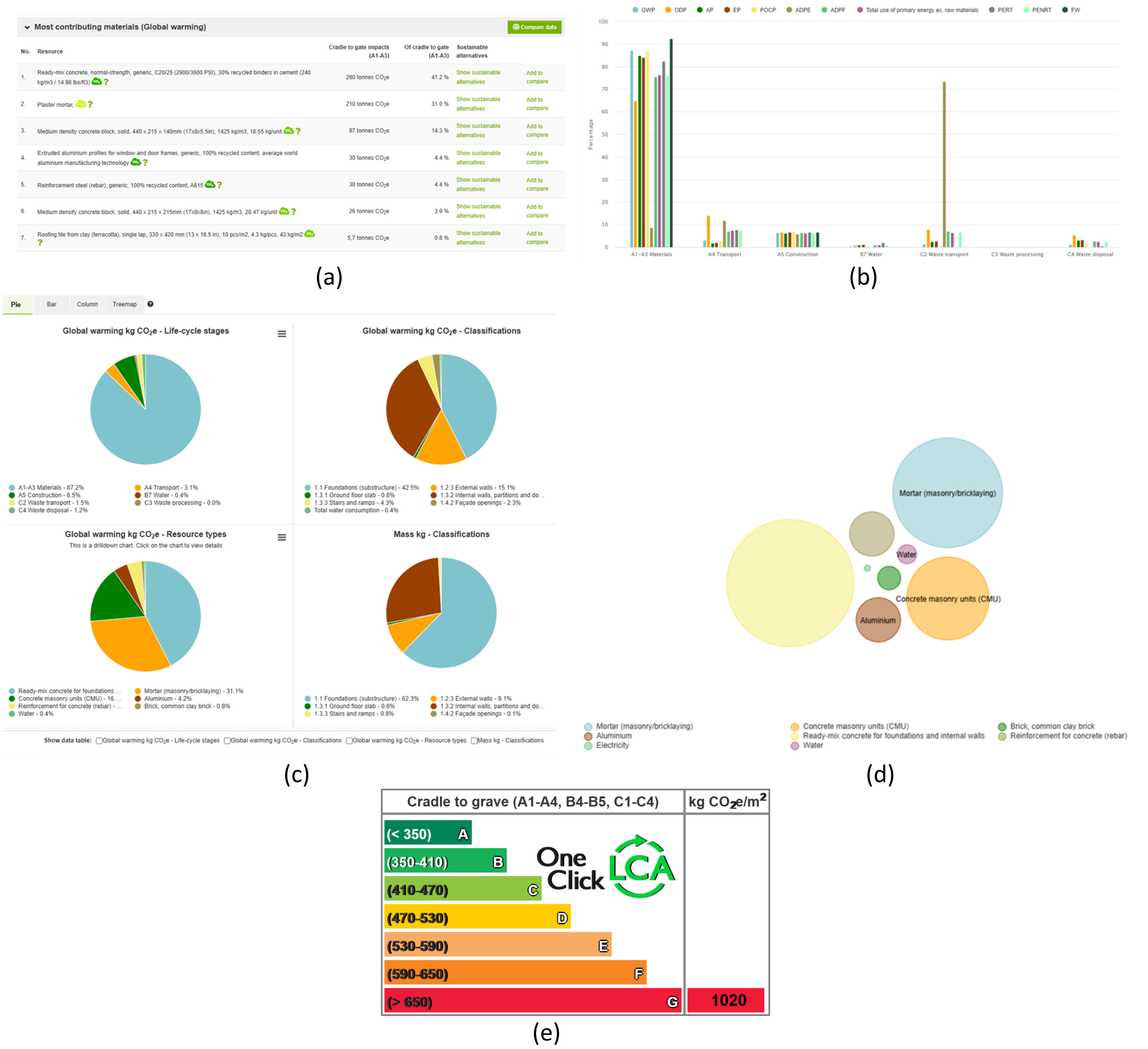


Fig. 12. OPTION II. (a) Most contributing materials, (b) Result by Life cycle stage, (c) Life Cycle Overview of Global Warming, (d) Bubble chart life-cycle resources, (e) Embodied Carbon Benchmark

Table 6
Option II – Summary of assessment

Aspect	Result
Embodied Carbon (A1 – C)	1020 kg CO_2e/m^2
Main contributors	Concrete, Plaster, Masonry blocks
Highest impact stage	A1 – A3 (Product stage) – 87.2% of total emissions
Construction stage (A5)	6.5%
Transport (A4)	3.1%
End-of-Life (C2 – C4)	2.7%
Benchmark Targets	Exceeds RIBA (500), LETI (625) benchmarks

4.3 Option III

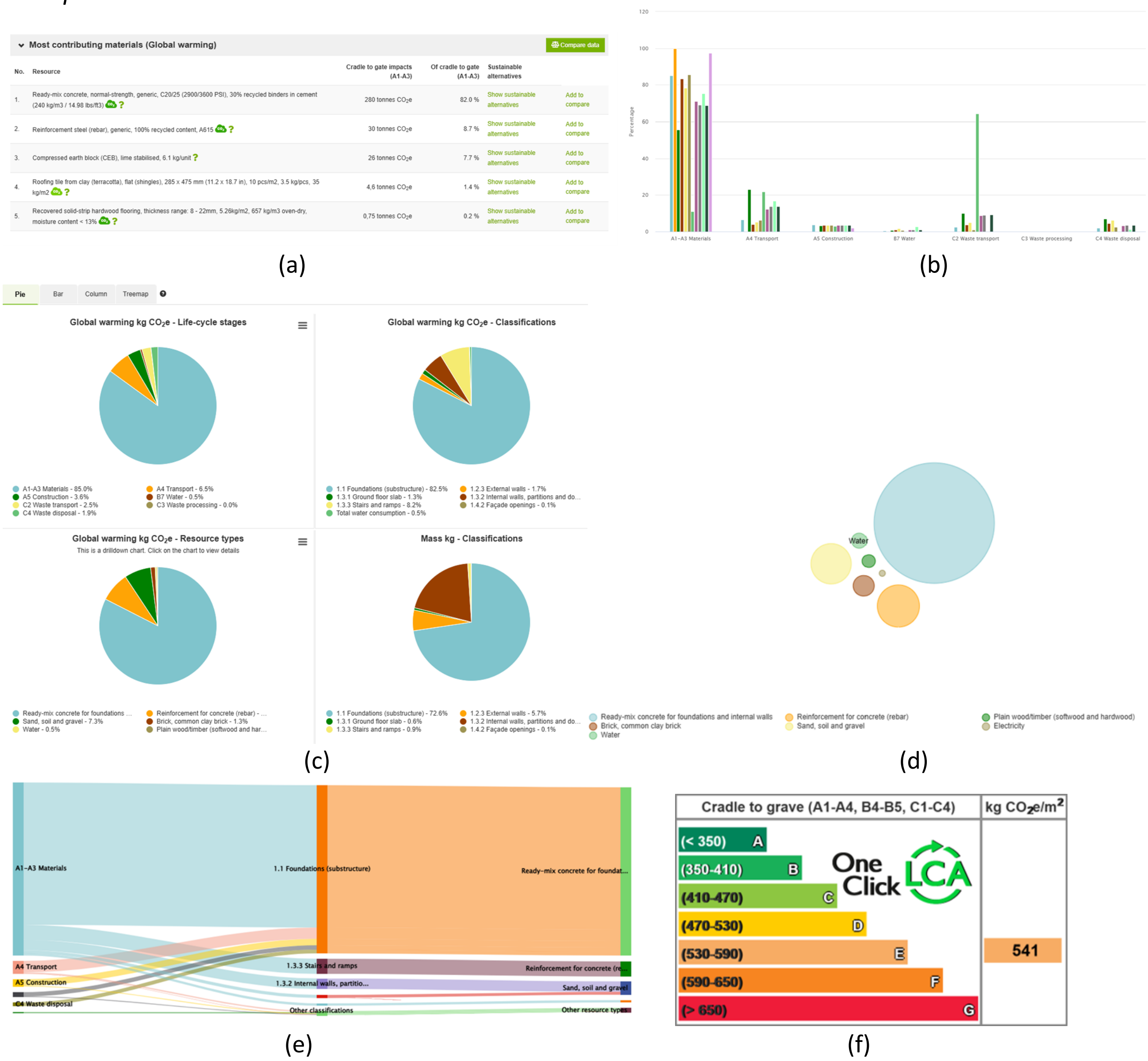


Fig. 13. OPTION III: (a) Most contributing materials, (b) Result by Life cycle stage, (c) Life Cycle Overview of Global Warming, (d) Bubble chart life-cycle resources, € Sankey Diagram, (f) Embodied Carbon Benchmark

Table 7
Option III – Summary of Assessment

Aspect	Result
Embodied Carbon (A1 – C)	541 kg CO_2e/m^2
Main contributors	Concrete
Highest impact stage	A1 – A3 (Product stage) – 85% of total emissions
Construction stage (A5)	3.6%
Transport (A4)	6.5%
End-of-Life (C2 – C4)	4.4%
Benchmark Targets	Aligns with RIBA (500), LETI (625) benchmarks

4.4 Comparing Options I, II and III

Fig. 14. (a) LCA Design Phases, (b) Life Cycle Assessment - All impact categories, (c) Life Cycle Assessment – Compare Elements, (d) Life Cycle Assessment - Elements and Life Cycle Stages

Table 8
Comparative table summary for option I, II, III

Category	Option I	Option II	Option III
Embodied Carbon ($kgCo_2e/m^2$)	1133	1020	541
Main contributors	Ready-mix concrete, mortar, masonry blocks	Ready-mix concrete, Plaster, Masonry blocks	Ready-mix concrete
Highest impact stage	A1 – A3 (Product stage) – 88.7% of total emissions	A1 – A3 (Product stage) – 87.2% of total emissions	A1 – A3 (Product stage) – 85% of total emissions
Construction stage (A5)	6.3%	6.5%	3.6%
Transport (A4)	2.4%	3.1%	6.5%
End-of-Life (C2 – C4)	<3%	2.7%	4.4%
Benchmark Targets	Exceeds RIBA (500), LETI (625) benchmarks	Exceeds RIBA (500), LETI (625) benchmarks	Aligns with RIBA (500), LETI (625) benchmarks

5. Conclusions

This study conducted a Life Cycle Environmental Assessment (LCA) of a Building Information Modelling (BIM)-based residential apartment design, with the aim of minimizing embodied carbon emissions throughout the building's life cycle. The methodology involved architectural and structural modelling using Autodesk Revit and environmental analysis using One Click LCA, in accordance with EN 15804, EN 15978, and BREEAM standards.

Three design options were developed and compared. The findings can be summarized as follows:

1. The product stage (A1-A3) consistently contributed the highest share of embodied carbon in all three design options.
2. Option I had the highest total embodied carbon at 1133 kgCo2e/m2, primarily due to the extensive use of concrete masonry unit, mortar and ready-mix concrete.
3. Option II reduced emissions to 1020 kgCo2e/m2, reflecting limited material improvements but still failing to meet sustainability benchmarks.
4. Option III, which incorporated compressed earth blocks and concrete with recycled binders, achieved the lowest environmental impact (541 $kgCO_2e/m^2$), representing a 52% reduction compared to Option I.
5. Despite lower circularity (87.2%), Option III outperformed the others in overall sustainability, demonstrating that material efficiency and low-carbon design are more critical than recyclability alone.
6. Across all environmental impact categories, option III showed the best performance, including lower acidification, eutrophication, and resource depletion.
7. All options exceeded the 'RIBA 2030' target (625 kgCO2e/m2) and 'LETI goal' (500 kgCO2e/m2), except option III, which falls within these benchmarks.
8. The use of BIM-LCA tools (Revit + OneClick LCA) proved highly effective for assessing and comparing environmental performance at the early design stage.

In conclusion, the study demonstrates that BIM-LCA integration is both feasible and valuable for guiding sustainable building design. Standardized guidance for interpreting LCA outcomes is essential to support designers in making informed, low-impact design choices at the early stages of development.

References

[1] Du Plessis, Chrisna. "A strategic framework for sustainable construction in developing countries." *Construction management and economics* 25, no. 1 (2007): 67-76. https://doi.org/10.1080/01446190600601313.

[2] Soust-Verdaguer, Bernardette, Carmen Llatas, and Antonio García-Martínez. "Critical review of bim-based LCA method to buildings." *Energy and Buildings* 136 (2017): 110-120. https://doi.org/10.1016/j.enbuild.2016.12.009

[3] Röck, Martin, Marcella Ruschi Mendes Saade, Maria Balouktsi, Freja Nygaard Rasmussen, Harpa Birgisdottir, Rolf Frischknecht, Guillaume Habert, Thomas Lützkendorf, and Alexander Passer. "Embodied GHG emissions of buildings–The hidden challenge for effective climate change mitigation." *Applied energy* 258 (2020): 114107. https://doi.org/10.1016/j.apenergy.2019.114107.

[4] European Commission. 2011. Roadmap to a Resource Efficient Europe. COM(2011) 571 final. Brussels: European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0571.

[5] Fiscal, Paulina Rodríguez, Rallou Taratori, Marie Abigail Pacho, Christos S. Ioakimidis, and Sesil Koutra. "A strategic and smart environmental assessment of rapid urbanization in Beijing." *Energies* 14, no. 16 (2021): 5138. https://doi.org/10.3390/en14165138.

[6] Fisher, Samantha, David C. Bellinger, Maureen L. Cropper, Pushpam Kumar, Agnes Binagwaho, Juliette Biao Koudenoukpo, Yongjoon Park, Gabriella Taghian, and Philip J. Landrigan. "Air pollution and development in Africa: impacts on health, the economy, and human capital." *The Lancet Planetary Health* 5, no. 10 (2021): e681-e688. https://doi.org/10.1016/S2542-5196(21)00201-1

[7] Karkour, Selim, Yuki Ichisugi, Amila Abeynayaka, and Norihiro Itsubo. "External-cost estimation of electricity generation in G20 countries: Case study using a global life-cycle impact-assessment method." *Sustainability* 12, no. 5 (2020): 2002. https://doi.org/10.3390/su12052002.

[8] Huijbregts, Mark AJ, Zoran JN Steinmann, Pieter MF Elshout, Gea Stam, Francesca Verones, Marisa Vieira, Michiel Zijp, Anne Hollander, and Rosalie Van Zelm. "ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level." *The international journal of life cycle assessment* 22, no. 2 (2017): 138-147.https://doi.org/10.1007/s11367-016-1246-y.

[9] Abdulkareem, Mahmood, and Sura Al-Maiyah. "Improving the Thermal Environment of Abuja's Affordable Housing Through Passive Design Solutions." *Sustainability* 17, no. 18 (2025): 8435. https://doi.org/10.3390/su17188435.

[10] Ezema, I. C., A. O. Olotuah, and O. I. Fagbenle. "Estimating embodied energy in residential buildings in a Nigerian context." *International Journal of Applied Engineering Research* 10, no. 24 (2015): 44140-44149.

[11] Hu, Ming. "A Building life-cycle embodied performance index—The relationship between embodied energy, embodied carbon and environmental impact." *Energies* 13, no. 8 (2020): 1905. https://doi.org/10.3390/en13081905.

[12] Roberts, Matthew, Stephen Allen, and David Coley. "Life cycle assessment in the building design process–A systematic literature review." *Building and Environment* 185 (2020): 107274. https://doi.org/10.1016/j.buildenv.2020.107274.

[13] Zimmermann, R. Kjaer, Kai Kanafani, F. Nygaard Rasmussen, and Harpa Birgisdottir. "Early design stage building LCA using the LCAbyg tool: comparing cases for early stage and detailed LCA approaches." In *IOP conference series: earth and environmental science*, vol. 323, no. 1, p. 012118. IOP Publishing, 2019. DOI: 10.1088/1755-1315/323/1/012118.

[14] Zanni, Maria Angeliki, Robby Soetanto, and Kirti Ruikar. "Towards a BIM-enabled sustainable building design process: roles, responsibilities, and requirements." *Architectural engineering and design management* 13, no. 2 (2017): 101-129. https://doi.org/10.1080/17452007.2016.1213153.

[15] Alecrim, Ismael, J. P. Carvalho, L. Bragança, and Ricardo Mateus. "Using BIM for assessing buildings life cycle impacts." In *IOP Conference Series: Earth and Environmental Science*, vol. 503, no. 1, p. 012005. IOP Publishing, 2020. https://doi.org/10.1088/1755-1315/503/1/012005.

[16] Archer, David, and Victor Brovkin. "The millennial atmospheric lifetime of anthropogenic CO2." *Climatic Change* 90, no. 3 (2008): 283-297. https://doi.org/10.1007/s10584-008-9413-1.

[17] Brożyna, Jacek, Wadim Strielkowski, and Aleš Zpěvák. "Evaluating the chances of implementing the "Fit for 55" green transition package in the V4 countries." *Energies* 16, no. 6 (2023): 2764. https://doi.org/10.3390/en16062764.

[18] Santos, Paulo, Génesis Camila Cervantes, Alicia Zaragoza-Benzal, Aimee Byrne, Ferhat Karaca, Daniel Ferrández, Adriana Salles, and Luís Bragança. "Circular material usage strategies and principles in buildings: a review." *Buildings* 14, no. 1 (2024): 281. https://doi.org/10.3390/buildings14010281.

[19] Van Stijn, A., B. Wouterszoon Jansen, V. Gruis, and G. A. Van Bortel. "Towards implementation of circular building components: A longitudinal study on the stakeholder choices in the development of 8 circular building components." *Journal of Cleaner Production* 420 (2023): 138287. https://doi.org/10.1016/j.jclepro.2023.138287.

[20] Moshood, Taofeeq Durojaye, James Olabode Bamidele Rotimi, and Funmilayo Ebun Rotimi. "Combating Greenwashing of Construction Products in New Zealand and Australia: A Critical Analysis of Environmental Product Declarations." *Sustainability* 16, no. 22 (2024): 9671. https://doi.org/10.3390/su16229671.
[21] Ellison, L., and M. Brown. 2011. "Sustainability Reporting in Construction and Real-Estate." Sustainability 3 (5): 1042–59. https://doi.org/10.3390/su3051042.
[22] Berardi, Umberto. "Sustainability assessment in the construction sector: rating systems and rated buildings." *Sustainable development* 20, no. 6 (2012): 411-424. https://doi.org/10.1002/sd.532.
[23] Cole, Raymond J. "Building environmental assessment methods: clarifying intentions." *Building Research & Information* 27, no. 4-5 (1999): 230-246. https://doi.org/10.1080/096132199369354.
[24] Goodland, Robert, and Herman Daly. "Environmental sustainability: universal and non-negotiable." *Ecological applications* 6, no. 4 (1996): 1002-1017. https://doi.org/10.2307/2269583.