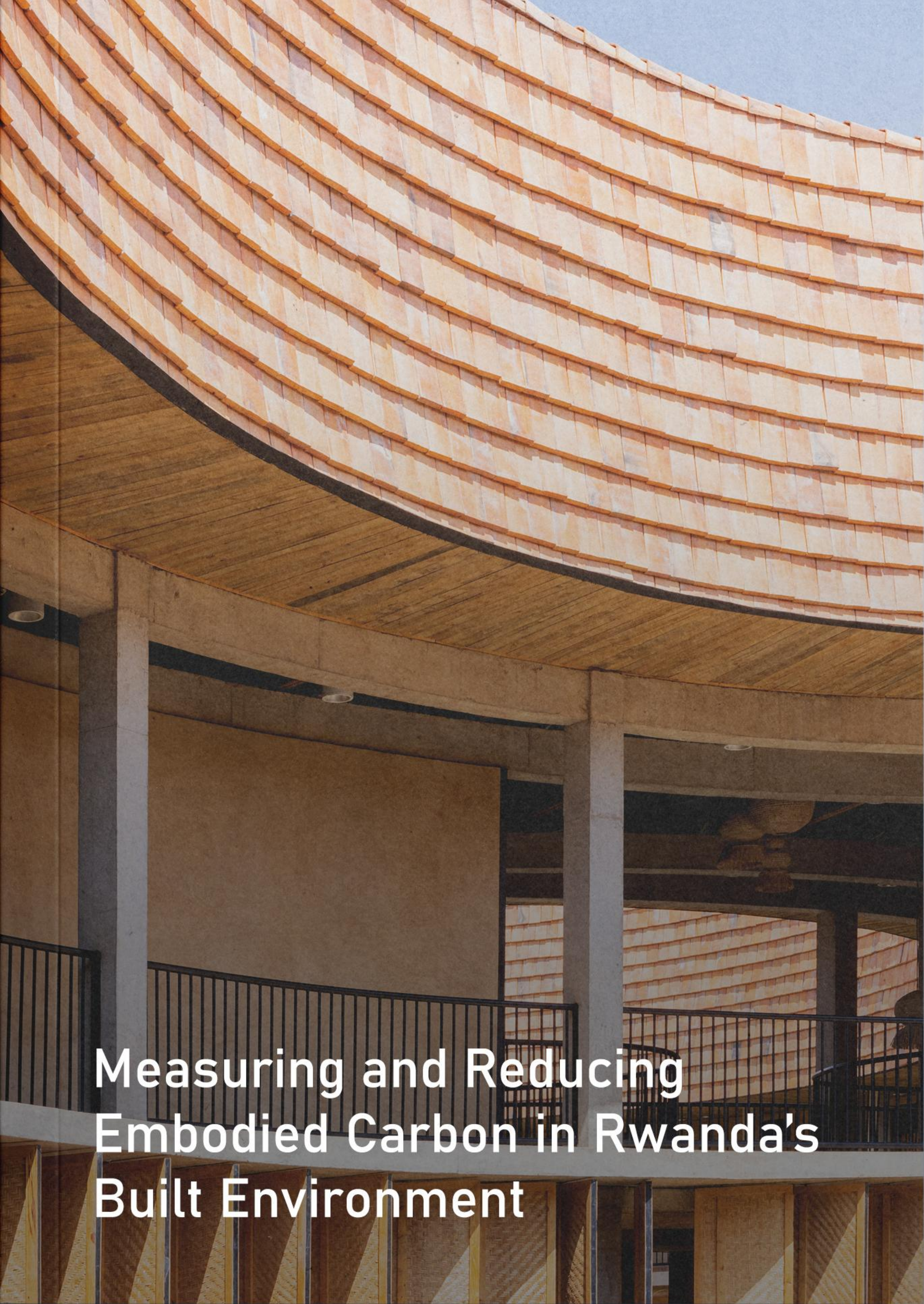

Measuring and Reducing Embodied Carbon in Rwanda's Built Environment

Measuring and Reducing Embodied Carbon in Rwanda’s Built Environment

MASS.

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This document is an output from the research project *A Toolkit for Built Environment Practitioners to Measure and Reduce Embodied Carbon in Rwanda;* a collaboration between MASS Design Group, The University of Rwanda, Feilden Clegg Bradley Studios and Arup.

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Royal Academy
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Executive Summary

Building construction accounts for approximately 10% of global greenhouse gas emissions, which contribute directly to climate change. Embodied carbon is the sum of the greenhouse gas emissions associated with the manufacturing, transportation, construction, deconstruction, and waste processing of new and replacement products throughout a building's lifetime (Figure 1).

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Figure 1: Embodied and operational carbon by life cycle stage [1]

Calculating embodied carbon is straightforward: the quantity of each material is multiplied by appropriate factors that represent their climate change impact. The embodied carbon of multiple materials can be summed together to estimate the embodied carbon of a whole building or part of it. This calculation can be performed for different design iterations, which can be compared against each other.
Table 1 , below, is a simple example of a cradle-to-gate embodied carbon calculation. The Rwanda Embodied Carbon Calculator (RwECC) simplifies embodied carbon assessments by prepopulating appropriate data for materials and assemblies across their entire life cycle.

This report explains how to measure embodied carbon, and provides explanations of ways to reduce it. Six key opportunities were identified to reduce embodied carbon in buildings, each of which are presented more fully in this document and are summarised below:

1. Optimise – create compact, highly utilised, and structurally efficient buildings
2. Fired brick – ensure durability and material-efficient use of fired brick, and explore alternative materials
3. Concrete – reduce concrete consumption and impact of concrete through cement replacements
4. Landscape – use salvaged and recycled materials, and generally prefer softscape to hardscape
5. Finishes – minimise finishes, and prioritise natural and durable options when required
6. Cooling – minimise the use of refrigerants by utilising passive cooling strategies, and specify low GWP refrigerants when they are required

Materials in a 6x8m single storey building	Quantity	Cradle to gate (A1-3) embodied carbon factor	Cradle to gate (A1-3) embodied carbon (Percentage of total embodied carbon)
Concrete C25/30 with 15% pozzolana	22m^3	278.6 kgCO$_2$e/m^3	6130 kgCO$_2$e (32%)
Steel reinforcement	2200kg	1.99 kgCO$_2$e/kg	4380 kgCO$_2$e (23%)
100mm thick brick wall, 12mm mortar joints	70m^2	43.2 kgCO$_2$e/m^2	3025 kgCO$_2$e (16%)
12mm thick ceramic tiles, 20mm mortar bed	50m^2	22.3 kgCO$_2$e/m^2	1115 kgCO$_2$e (6%)
Steel framed window with single glazing	10m^2	55.3 kgCO$_2$e/m^2	555 kgCO$_2$e (3%)
Steel roof sheet with battens, waterproofing	50m^2	46.8 kgCO$_2$e/m^2	2340 kgCO$_2$e (12%)
Acoustic ceiling tiles	50m^2	11.0 kgCO$_2$e/m^2	550 kgCO$_2$e (3%)
RHS 120x80x6 (18.2kg/m) rafters at 2m c/c	550kg	1.55 kgCO$_2$e/kg	855 kgCO$_2$e (5%)
Total cradle to gate embodied carbon of the building			18945 kgCO$_2$e
Cradle to gate embodied carbon per gross floor area (6x8m)			**395 kgCO$_2$e/m^2**

Table 1: Example cradle-to-gate embodied carbon calculation for 6x8m single storey building (values have been rounded)

Introduction

This guide seeks to concisely explain how to incorporate embodied carbon assessments and reduction practices into building and infrastructure design and construction. It is intended to offer insight for many different readers including developers, investors, policy makers, manufacturers, and researchers. However, those closest to the design and construction process should reference this guide regularly until embodied carbon reduction becomes standard practice.

This guide brings together global best practices and local knowledge to provide contextually appropriate solutions.

Motivation

There is a direct link between carbon emissions and global temperature increase (Figure 2). The concentration of Greenhouse Gas Emissions (GHG) has been steadily rising, and mean global temperatures along with it since the Industrial Revolution, as a result of human activity (primarily the burning of fossil fuels and changes in land use).

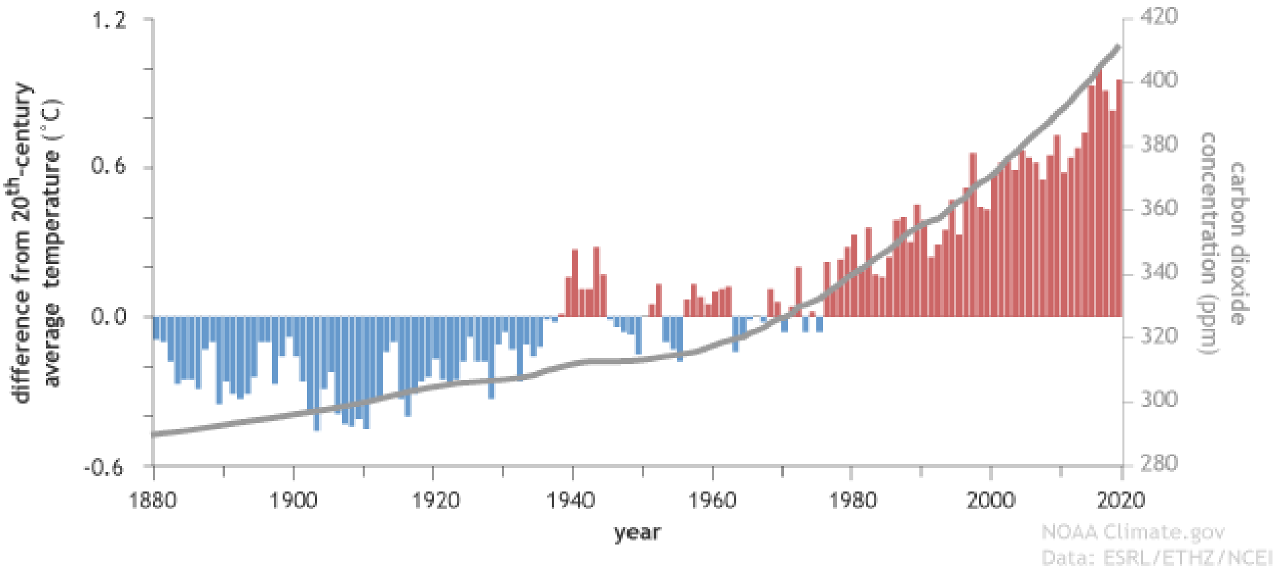


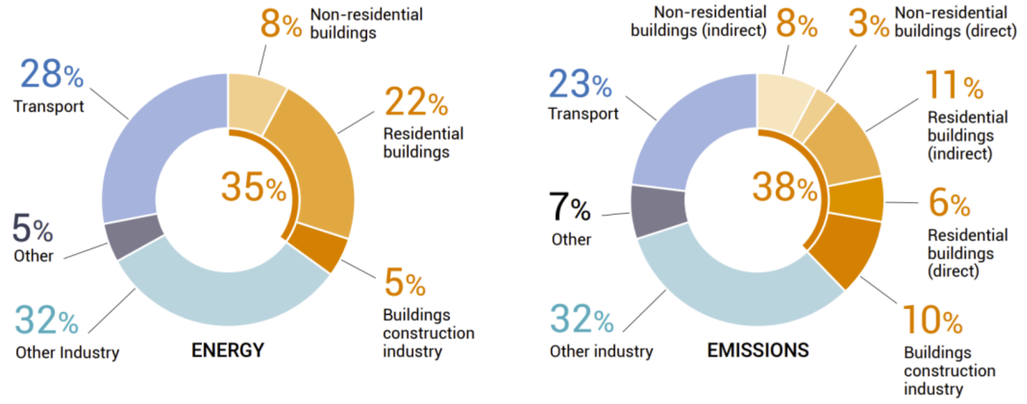
Figure 2: Atmospheric carbon dioxide and earth's surface temperature (1880-2019) [2]

In 2015 at COP 21 in Paris, several countries, including Rwanda, reached a landmark agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future.

To limit global warming to 1.5 degrees above pre-industrial temperatures, there are three key targets to meet [3]:

1. Greenhouse gas emissions must peak well before 2030
2. Greenhouse gas emissions must have reduced by approximately half from 2017 levels by 2030
3. Achieve carbon neutrality by 2050

The building and construction sector remain a critical element in the race to keep carbon emissions below dangerous levels for our planet. Buildings consume 35% of energy produced and are responsible for 38% (Figure 3) of global carbon emissions [4], making it the largest contributing sector to climate change. The sum of GHG emissions in 2050 from a building built now are expected to be 50% operational emissions and 50% embodied emissions [5].



Notes: Buildings construction industry is the portion (estimated) of overall industry devoted to manufacturing building construction materials such as steel, cement and glass. Indirect emissions are emissions from power generation for electricity and commercial heat.
Sources: (IEA 2020d; IEA 2020b). All rights reserved. Adapted from "IEA World Energy Statistics and Balances" and "Energy Technology Perspectives".

Figure 3: Global share of buildings and construction final energy and emissions [4]

We're already seeing the impacts of climate change in Rwanda: changing weather patterns (Figure 4) and drought have resulted in crop failure, while intense rainfall has caused flooding and landslides.

Figure 4: Flooding in Kigali (left) and clearing a landslide caused by heavy rain (right)

Rwanda was one of the first countries to submit their Nationally Determined Contributions, aiming to reduce their 2030 expected carbon emissions by 38% (Figure 5). While Rwanda's contribution to Climate Change is very small [2], it is committed to reducing greenhouse gas emissions and leading developing nations in Climate Positive solutions.

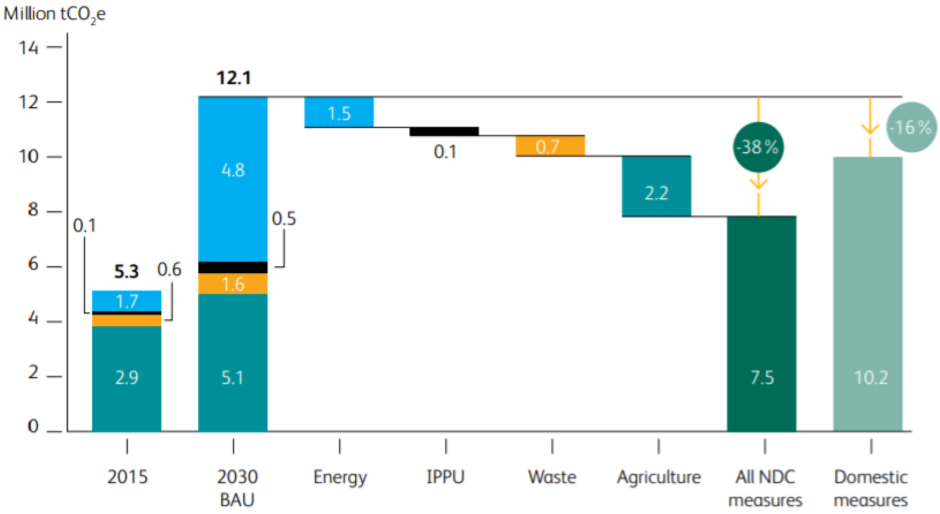


Figure 5: Rwanda's Nationally Determined Contributions to reduce business as usual emissions [6]

By 2032, Rwanda is expected to need approximately 2 million additional homes due to a population increase of 3.2 million people, all while household sizes decrease [2]. In addition to new homes, new commercial buildings and associated infrastructure will also be required. The continued development of Rwanda will bring many benefits, but needs to be well considered to minimise the potential climate change impact.

Assessments

Embodied carbon is the sum of the greenhouse gas emissions associated with the manufacturing, transportation, construction, deconstruction, and waste processing of new and replacement products across a building's lifetime (Figure 1).

Calculating embodied carbon is straightforward: the quantity of each material is multiplied by appropriate factors that represent their climate change impact. The embodied carbon of multiple materials can be summed together to estimate the embodied carbon for either a part of, or a whole, building (Figure 6). This calculation can be performed for different design iterations, which can be compared against each other.

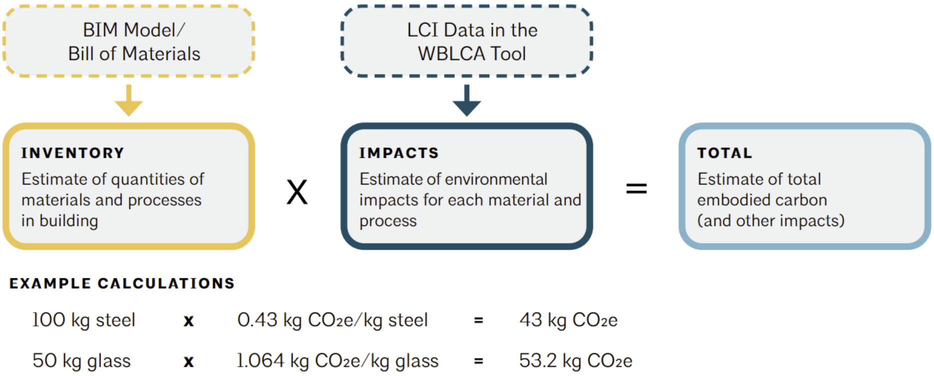


Figure 6: Calculation process for embodied carbon [7]

When performing calculations, it is important to balance speed, completeness, and accuracy so as to inform the design process. While embodied carbon by element and by life cycle stage can vary enormously between projects, a typical approximation can be seen in Figure 7. The embodied carbon impacts from material extraction to practical completion is known as the upfront embodied carbon. Embodied carbon calculations should include, as a minimum, the upfront embodied carbon for the superstructure and substructure. The Rwanda Embodied Carbon Calculator (RwECC) provided with this guide assesses all life cycle stages.

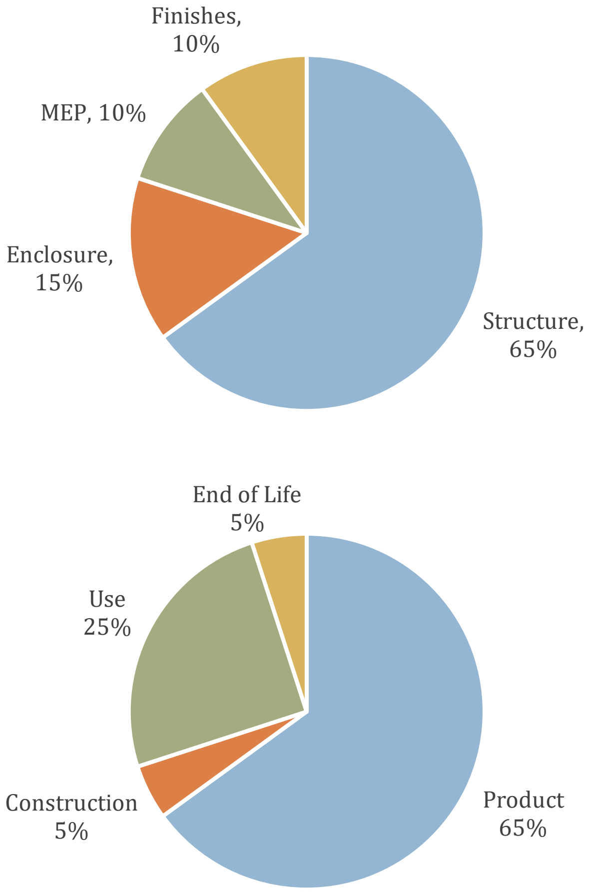


Figure 7: Example breakdown of embodied carbon by element and by life cycle stage

Appendix C contains four case studies of buildings in Rwanda, assessed using the RwECC. It is helpful to become familiar with the range of numbers that can be expected.

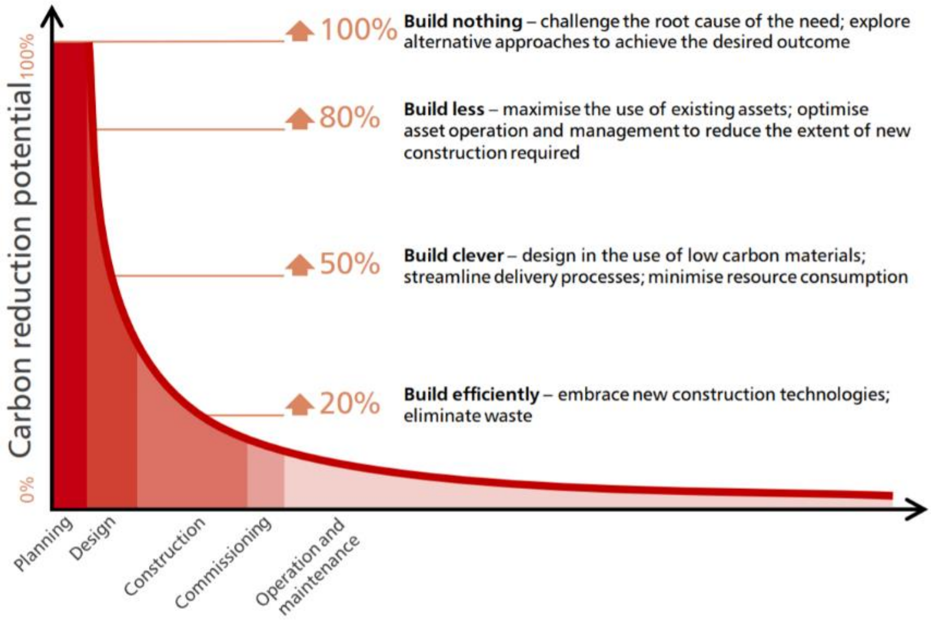
Table 2 presents an advised maximum and target for upfront embodied carbon emissions. These are based on the author's experience. The maximum may be enforced and the target may be incentivised through mechanisms such as building permit fee or processing time reductions.

	Structure only (kgCO$_2$e/m^2)	Structure, enclosure and interior walls (kgCO$_2$e/m^2)
Advised maximum	400	600
Advised target	200	300

Table 2: Recommended maximised and incentivised upfront embodied carbon emissions

Reduction Strategies

The greatest carbon reduction potential can be achieved at the start of a project, as shown in Figure 8, when major programme and design decisions can still be made.



Build nothing – challenge the root cause of the need; explore alternative approaches to achieve the desired outcome

Build less – maximise the use of existing assets; optimise asset operation and management to reduce the extent of new construction required

Build clever – design in the use of low carbon materials; streamline delivery processes; minimise resource consumption

Build efficiently – embrace new construction technologies; eliminate waste

Figure 8: Embodied carbon reduction potential over the life of a project [8]

Understanding the relative proportion of embodied carbon by building part (substructure, roof, finishes etc.), through whole building assessments, helps to identify where the highest embodied carbon reduction potential is, and therefore where most effort should be spent. This is shown in the indicative building assessment in Figure 9.

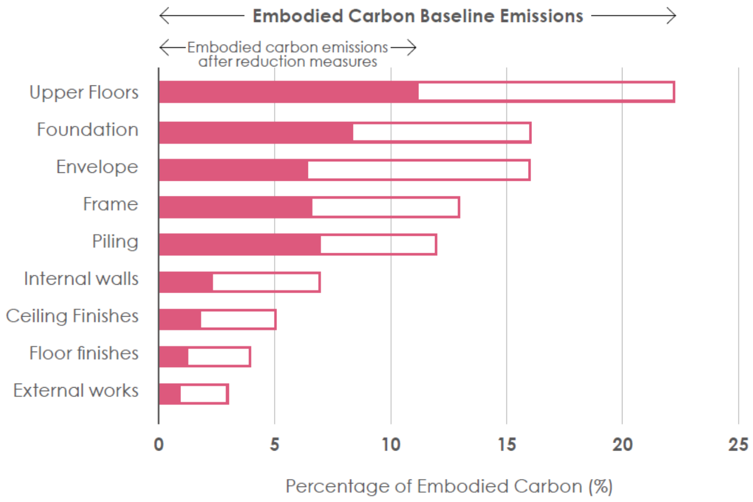


Figure 9: Approximate embodied carbon breakdown by building category and reduction potential [9]

While the planning stage of a project offers the greatest opportunity for carbon reduction, built environment professionals, who are the primary audience of this guide, are more typically engaged at the start of the design process. Because of this, the top five embodied carbon reduction opportunities featured in this guide have been developed with this in mind. These opportunities were uncovered through a multi-disciplinary workshop. More opportunities can be found in Appendix D.

1. *Optimise* At the beginning of design big decisions can be made that will greatly impact the embodied carbon of the building.
    a. Decide on size and massing that maximises usable space while minimising roof, envelope, and substructure footprint. This is similar to a building's Form Factor which is the ratio between envelope area and internal volume. Figure 10 shows an example study that was performed at schematic design that demonstrates how embodied carbon varies with the number of above ground floors.
    b. A building should be designed to provide as many programmes that support as many people in as small an area as possible. This could include designing for a high number of people per floor area and designing spaces that serve multiple uses at different times. For example, a classroom that can become a community room in the evening potentially reduces the number of buildings required.
    c. Optimise structural spans for embodied carbon. Figure 11 shows an example study that was performed at schematic design to determine that a 5x5m structural grid had the lowest embodied carbon. This type of analysis can be performed for different construction types using rules of thumb sizes.

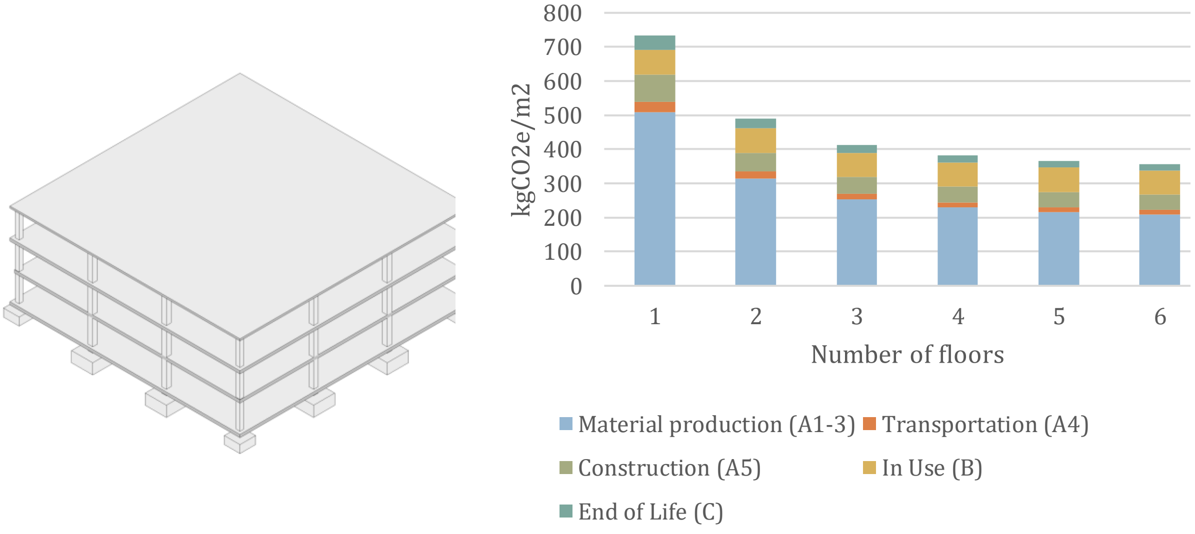


Figure 10: Example of how embodied carbon varies with number of above ground floors. The assessment model includes the envelope and finishes as well as the concrete frame shown above.

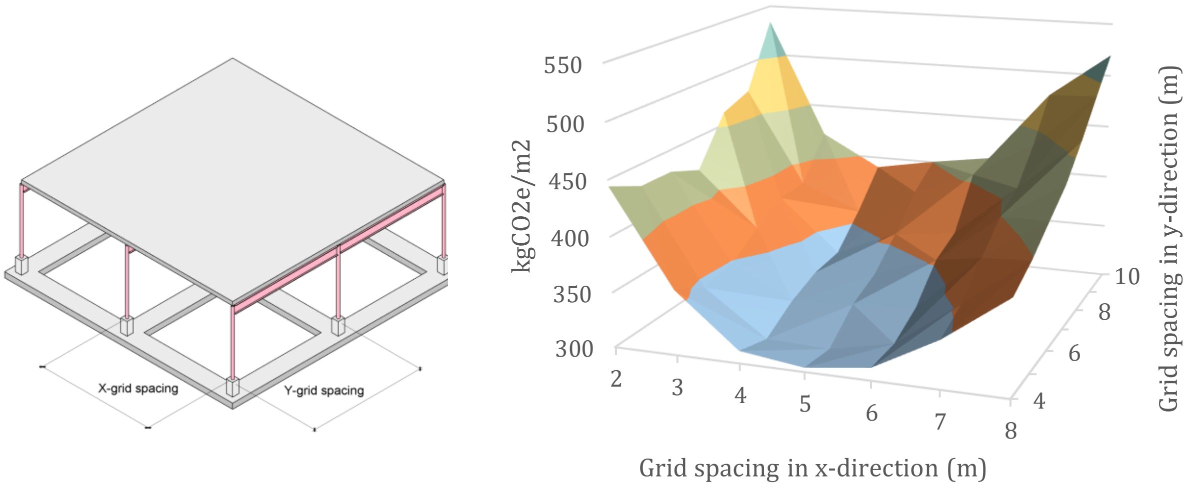


Figure 11: Example of how the cradle to gate embodied carbon of a steel structure with concrete deck and foundations varies with structural grid spacing. A 5x5m grid was found to have the lowest embodied carbon

2. *Fired brick* Fired bricks use a combustible fuel to bake clay at high temperatures into a strong and durable material. The fuel type used in the firing process is responsible for the majority of the GWP [12]. Traditional, informally made bricks are typically inefficiently fired with wood from unsustainable sources, leading to deforestation and a higher energy consumption than formally fired bricks using modern practices [13]. Some manufactures, such as Ruliba, use agricultural waste products to fire their clay, significantly reducing their embodied carbon emissions. Well-constructed and detailed adobe or compressed stabilised earth block (CSEB) walls are suitable low

embodied carbon alternatives to brick, because they do not require firing. CSEB typically contain a small percentage of cement, which accounts for their higher embodied carbon compared to adobe. When using fired brick, it is best to use modern firing methods, because these are more durable than traditional informally fired bricks [14]. Material efficient construction methods should also be utilised, such as the Rowlock bond as demonstrated in the Swiss Cube [15]. Figure 12 below shows the embodied carbon to practical completion for various wall types. The wall thicknesses have been normalised.

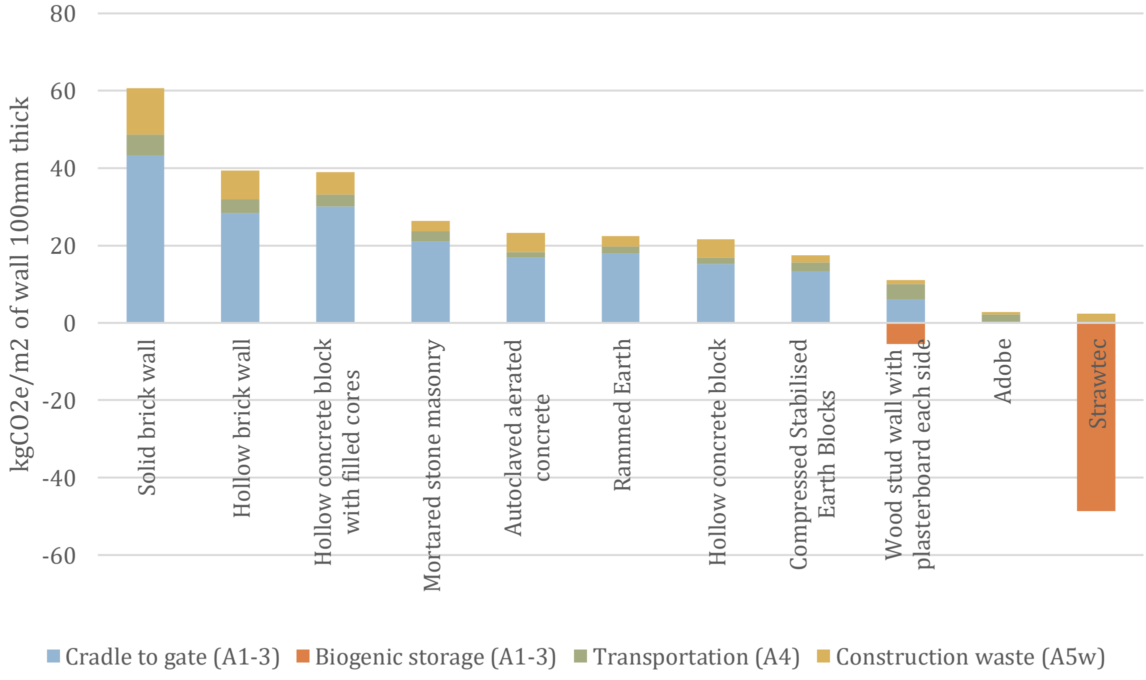


Figure 12: Embodied carbon to practical completion for various wall types

3. *Concrete* – Concrete is the biggest contributor to embodied carbon in Rwanda (Refer to Case Studies), so even small changes to reduce its impact can have significant effects. This high embodied carbon is primarily due to the cement, the most carbon intensive material within concrete. The impact of concrete can be minimised by:
   a. Replacing concrete elements with stone, such as using stone foundations and retaining walls.
   b. Use concrete efficiently by avoiding transfer structures, optimising structural spans, analysing slabs that are 10mm thinner than typical e.g. 190mm rather than 200mm, and using efficient structural systems such as waffle slabs and buttressed retaining walls.
   c. Use high percentages of cement replacement, such as pozzolana. Figure 13 shows how cement replacement and concrete strength effect embodied carbon.
   d. Build high quality concrete so the structure will endure.

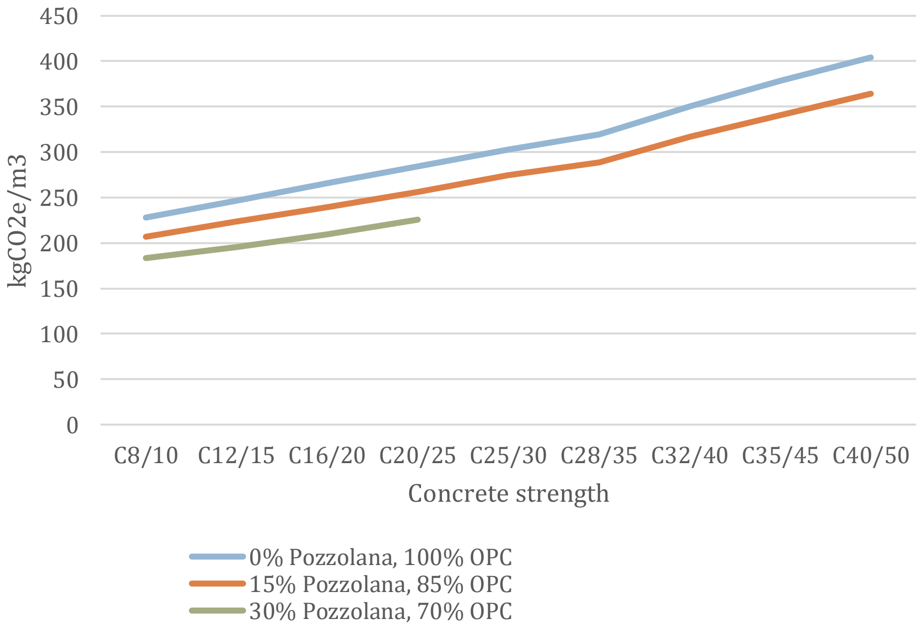


Figure 13: Cradle to gate embodied carbon for different concrete strengths and percentages of cement replacement

4. *Landscape* - The landscape surrounding a building can contribute significantly to the embodied carbon of the project. Elements such as retaining walls, hardscaping and infrastructure are typically high in embodied carbon.
    a. Use salvaged material from deconstructed buildings in the landscape such as brick and broken up concrete. This reduces the need for new material to be produced in its place.
    b. Minimise hardscape and replace it with vegetated areas or use permeable pavers that allow vehicles to drive over but approximately 40% less material. These options also reduce rainwater runoff and reduce the localised temperature, creating a more pleasant environment.
    c. Arrange the site to avoid large concrete retaining walls where possible. Instead, prefer to use natural or engineered slopes, or small stone retaining walls.

5. *Finishes* – Materials such as concrete and brick can be left unfinished if care is taken during construction, removing the need for any additional finishes. Natural materials such as sustainably sourced wood have an extremely low impact, and excellent acoustic properties. Durable materials such as terrazzo and tiles are very durable but have a high initial impact so should be used selectively.
6. *Cooling* – The GWP impact of cooling systems comes predominantly from refrigerant leakage (Figure 14) and somewhat from the embodied carbon of the cooling equipment themselves.

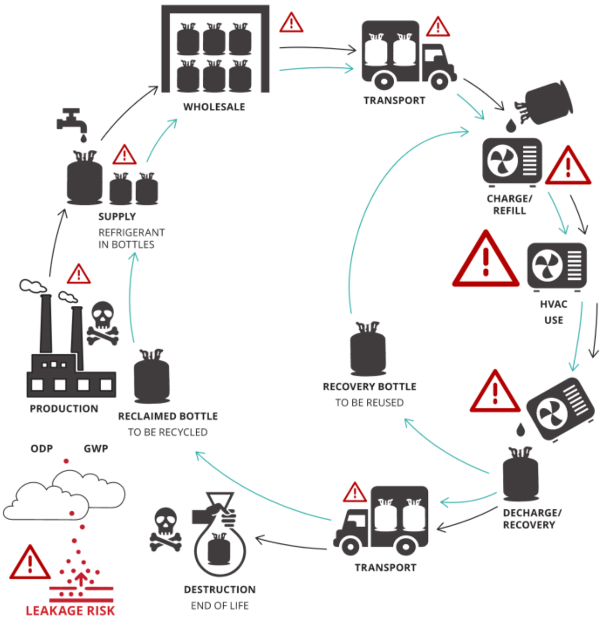


Figure 14: Refrigerant lifecycle and environmental impacts. Warning symbols indicate leakage risk. [10]

The impact of cooling systems can be minimised by:

a. Reducing the need for cooling by utilizing passive strategies will reduce refrigerant charge, equipment quantity, and even operational energy consumption, ultimately reducing whole life carbon emissions.
b. Use the recommended GWP limit or absolute GWP limit, as set by Rwanda's National Cooling Strategy [11], for refrigerants. (Table 3).
c. Use cooling systems with less refrigerant and with less leakage risk. In general, packaged centralized systems, such as chillers, are better than distributed systems, such as VRF systems.

A study was performed on an actual project that shows the change in embodied carbon when the conditioned area is varied and the refrigerent type is changed between R410a (GWP of 2088 kgCO2e/kg) and R32 (GWP of 677 kgCO2e/kg).

Product Class	Global Warming Potential Absolute Limit [11] (kgCO2e/kg)	Global Warming Potential Recommended Limit (kgCO2e/kg)
Self-Contained Systems	150	5
Split System	750	5

Table 3: GWP limits for refrigerant [11]

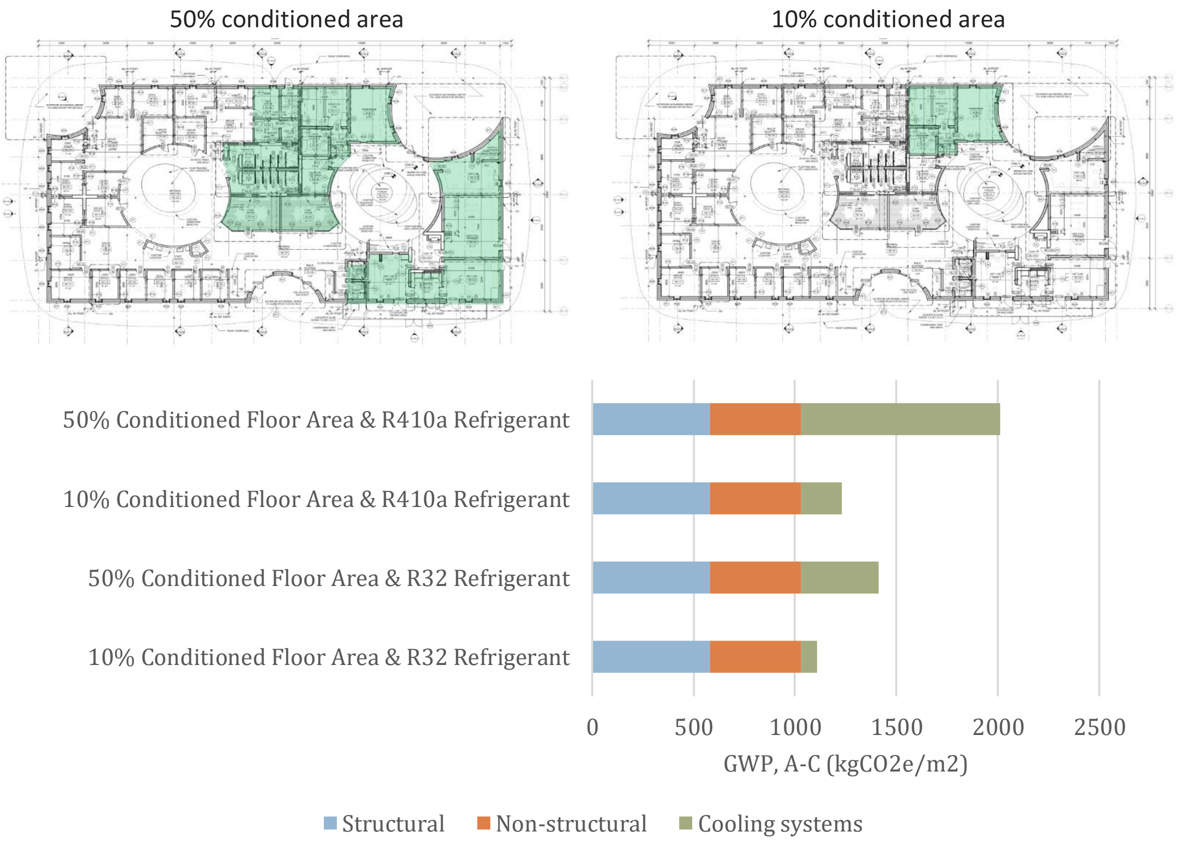


Figure 15: Example of cooling system embodied carbon as conditioned area and refrigerant type is varied. The reduction values are for the cooling system only and from the first scenario.

Process

To make real embodied carbon reductions that remain in the project throughout, embodied carbon design thinking needs to be embedded in the design approach. A suitable analogy is how a team works together to construct a building within the client's budget. Through experience, designers have an intuitive understanding of the cost of different systems and materials, which allows them to make quick decisions, while also considering many other factors. A cost estimator is able to produce a cost estimate to varying degrees of accuracy depending on the project stage, which can tell the design team if they are within budget or need to make changes. A similar process should be undertaken for embodied carbon, but the major differences are that currently embodied carbon is not well understood by all parties and there are no immediate implications of exceeding a carbon budget.

It is a common misconception that reducing embodied carbon makes the building more expensive. Embodied carbon reductions can be achieved using typical construction techniques by reducing material quantities and using lower embodied carbon intensive materials. Appendix E contains helpful approaches that can be used to align existing project aims, such as cost and schedule, with embodied carbon reduction.

The tasks at each design stage are broadly presented below. Emphasis should be put on the start of the project so it is set up to succeed.

Pre-design – Goal Setting

1. The client and lead consultant should set the embodied carbon objectives for the project. If the project team is new to embodied carbon, then it may be sufficient to report embodied carbon at the end of each design stage. More ambitious teams may decide to set a target.
2. Select a team to perform whole building embodied carbon assessments. This is best placed to be the architects or cost estimator, unless another discipline is more familiar.
3. If applicable, site selection and programme requirements should be evaluated with regards to embodied carbon.

Schematic Design – Strategy & Integration

4. Charrette with the design team methods of achieving the embodied carbon budget, considering: building and material reuse, space utilisation, massing and structural grids, and materials and technical specifications.
5. Use rules of thumb guidance or quick numerical assessments to evaluate design options for embodied carbon.

Detailed Design and Construction Documentation – Monitor & Review

6. Perform whole building embodied carbon assessments to identify carbon hotspots and provide reduction recommendations to remain within the carbon budget.
7. Evaluate any proposed design changes with regards to embodied carbon.

Enabling mechanisms

Built environment professionals can make decisions that reduce embodied carbon, though these decisions may be constrained by laws, standards, skills, supply chains, and other competing priorities. To make any changes, many groups of people need to be working towards the same goal. The following sections include recommended actions to be taken by different groups of people to achieve significant embodied carbon reduction. The actions are informed by the World Green Building Council [7] and made relevant to Rwanda. A common action between all these groups is engagement and advocacy.

Clients, developers, investors

- Public commitment to reducing embodied carbon in buildings
- Developers only build, and investors only finance, new projects that will demonstrate embodied carbon reduction and eventually demonstrate net zero embodied carbon.

Policy makers

Recommended for: Ministry of Infrastructure (MINIFRA), Rwanda Transport Development Agency (RTDA), Rwanda Housing Authority, One Stop Centre, City of Kigali (CoK) and the Secondary Cities,

- All levels of government develop a strategy to achieve net-zero embodied carbon
- Government to implement embodied carbon targets for buildings and infrastructure
- Incorporate embodied carbon reductions into NDCs

Professional institutes, researchers and NGOs

Recommended for: Rwanda Institute of Architects (RIA), Institution of Engineers Rwanda (IER), Rwanda Green Building Organization (RWGBO), Commonwealth Association of Architects (CAA), University of Rwanda, Global Green Growth Institute (GGGI)

- Implement standardised embodied carbon calculation methods
- Design tools and guidance to reduce embodied carbon
- Contribute to establishment of databases and set benchmarks
- Include embodied carbon reduction as a requirement in green building certificates.
- Provide continuing education for professional members
- Provide initial education for students on embodied carbon reduction
- Assist manufacturers in following Product Category Rules to create Environmental Product Declarations (EPDs)

Manufacturers

- Develop carbon reduction targets, with timelines set to achieve net zero embodied carbon by 2050
- Develop new low carbon products
- All forms of energy are from renewable or low carbon sources and excess emissions are mitigated
- All manufacturers have declared their entire standard product portfolios via EPDs. For further discussion regarding EPDs please refer to Appendix J: Environmental Product Declaration

Built Environment Professionals

Recommended for: Architects, Engineers, Cost Estimators, Builders

- Integrate low embodied carbon design into the design process
- Publicly share life cycle assessments and lessons learnt
- All design companies require projects to be net zero
- Supply chain data and construction site emission data collected and reported
- Buildings built for deconstruction and reuse
- As-built BIM models maintained through building life

Appendix A: Terminology and Acronyms

This section presents terminology and acronyms commonly used in industry, and thus aligns with the terminology used throughout this guide.

Building element: A major physical part of a building that fulfills a specific function, or functions, irrespective of its design, specification or construction, e.g. floors, frame, external walls.

Carbon factor: Normally measured in kgCO2e per unit of product e.g. kgCO2e/kg or kgCO2e/m2

kgCO2e: Carbon dioxide equivalent emissions, or 'carbon' for short, the contribute to climate change. This can also be referred to as 'global warming potential' (GWP) or 'Greenhouse Gases' (GHG)

Environmental Product Declaration (EPD): An independently verified and registered document that communicates transparent and comparable information about the life cycle environmental impact of products. For further discussion regarding EPDs please refer to Appendix J: Environmental Product Declaration

Embodied carbon (kgCO2e): Carbon emissions associated with the following:

- extraction and manufacturing of materials and products
- in-use maintenance and replacement
- end of life demolition, disassembly, and disposal
- including transportation relating to all three

Cradle to gate: The life cycle stages A1-3 from EN 15978; extraction and manufacturing of materials and products.

Cradle to site: The life cycle stages A1-4 from EN 15978; extraction and manufacturing of materials and products, and transportation to the construction site.

Cradle to practical completion: The life cycle stages A1-5 from EN 15978; extraction and manufacturing of materials and products, transportation to the construction site, and construction including waste and energy consumption.

Embodied carbon over the life cycle (kgCO2e): Carbon dioxide equivalent emissions associated with Modules A1–A5, B1–B5 and C1–C4.

Net zero carbon: When the amount of carbon emissions associated with a building's embodied and operational impacts over the life of the building, including its disposal, are zero or negative. Since offsetting carbon emissions must only be a last resort, and given that there are no negative emissions options, it is advised to view the carbon target as an absolute one: zero carbon means zero emissions.

Operational carbon (kgCO2e): The carbon dioxide associated with the in-use operation of the building, Modules B6 and B7. This usually includes carbon emissions associated with heating, hot water, cooling, ventilation and lighting systems, as well as those associated with cooking, equipment and lifts, i.e. both regulated and unregulated energy uses.

Whole life carbon (kgCO2e): Carbon emissions associated with Stages A–C and D, with Stage D reported separately. This may also be referred to as ‘cradle to cradle’.

Climate positive: An activity that goes beyond net zero by achieving an overall reduction in greenhouse gas in the atmosphere. Also referred to as carbon negative.

Greenhouse Gas Emissions (GHG): Refer to kgCO2e

Appendix B: Calculating embodied carbon

The Rwanda Embodied Carbon Calculator (RwECC) that is provided along with this document uses the methodology stated in this section. It is recommended that users new to embodied carbon start by assessing a project, with a completed design, using the RwECC. The calculator simplifies the assessment because it is populated with data appropriate to typical construction in Rwanda and material quantities are entered in a convenient format e.g. m^2 of wall or m^3 of concrete. The calculator can be used for reporting and evaluating design options.

The case studies in Appendix C have been assessed using the RwECC.

Scope

Life cycle stages

A Life Cycle Assessment analyses the environmental impacts, such as climate change, throughout a product's life cycle from raw material through production, use and end of life [10]. The life cycle stages are illustrated in Figure 16 and classified according to EN 15978 in Figure 17.

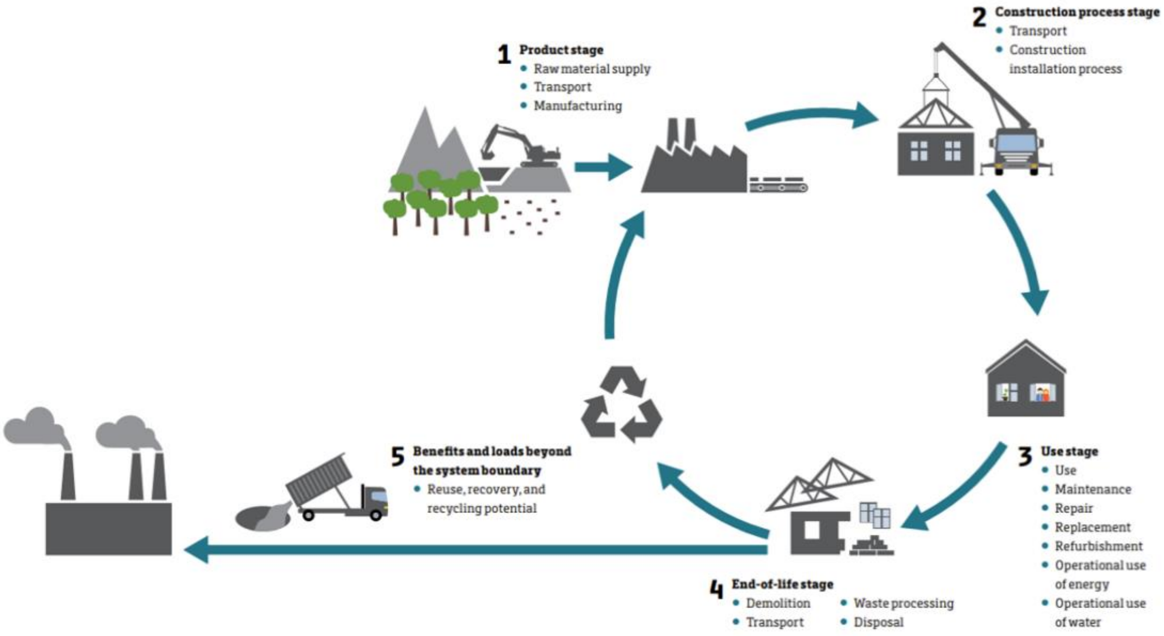


Figure 16: Typical stages of a building's life cycle [13]

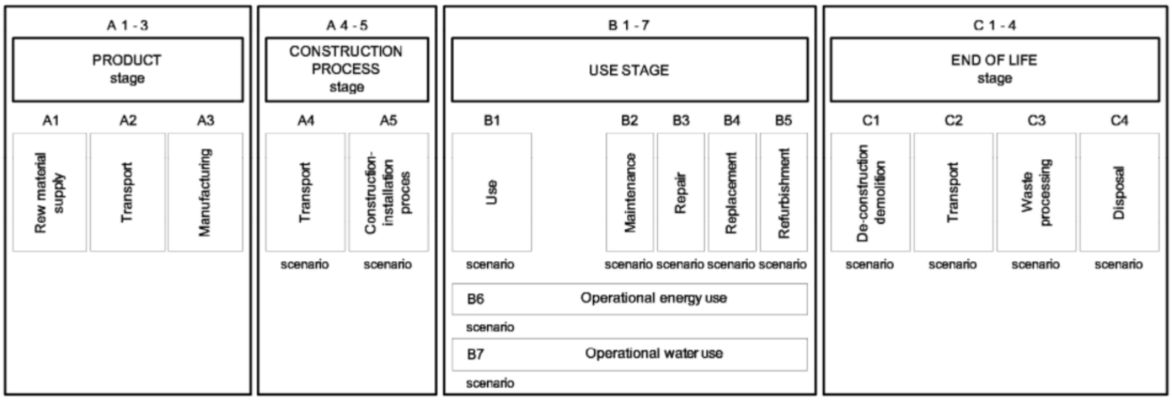


Figure 17: Life cycle stages according to EN 15978 [12]

Embodied carbon assessments consider the environmental impact of climate change associated with all life cycle stages except B6 and B7 (Figure 6). Operational carbon assessments consider the impact of climate change associated only with the B6 and B7 life cycle stages. Climate change impact is measured in carbon dioxide equivalent emissions (kgCO_2e).

The recommended embodied carbon calculation shall include A1-5, B4 and C1-4, however stages A1-3 should be assessed as a minimum. The RwECC includes results for all life cycle stages separately.

The EN 15978 life cycle stages are referred to often throughout this document and in the ReECC. In the RwEEC, the biogenic storage aspect of A1-3, is referred to as A1-3_seq and the emissions associated with construction waste is referred to as A5w.

Building elements

It’s recommended to include as many building elements as possible in the assessment, however the substructure and superstructure are the minimum that should be included in the assessment.

Everything within the grounds associated with the building should ideally be included. An example is shown in red in Figure 18. The external area should be attributed to the buildings proportionally to their gross floor area (GFA).

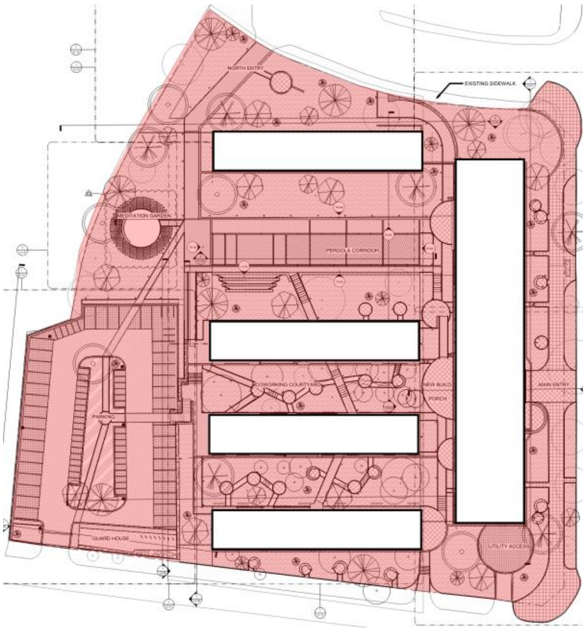


Figure 18: Diagram showing the surrounding area in red to be included in the assessment

The reported building elements with examples are provided in Table 4. Reporting embodied carbon against these building elements can help identify where the 'carbon hotspots' are within a building, such as in the case studies in Appendix C. Literature indicates that anywhere from 2% to 25% of the cradle to practical completion (A1-5 life cycle stages) can be attributed to building services [13]. In version 2 of the RwECC cooling systems have been included.

Building elements
Substructure e.g. foundations, basement walls, slab on grade
Structural frame e.g. beams, columns, structural walls, suspended slabs, decks, trusses, purlins
Roof finishes e.g. tiles, roof sheeting
Stairs and ramps
Non-structure walls e.g. non-structural walls
Windows and doors
Internal walls and partitions
Wall finishes e.g. plaster, paint, tiles, cladding
Floor finishes e.g. screed, tiles, carpet
Ceiling finishes e.g. acoustic tiles, plasterboard
External works e.g. hardscape, pavement, parking surfaces, external retaining walls, culverts, drains
Cooling systems e.g. mechanical equipment related to cooling the building space and its corresponding refrigerant

Table 4: Building categories embodied carbon should be reported under

Reporting

Embodied carbon assessments should be performed as part of the design process and results should also be reported. Reporting to a database is required to enable analysis across a large number of projects, so research can be performed to develop benchmarks that can be used to inform embodied carbon targets for future legislation and improve industry understanding of embodied carbon in the built environment.

When the RwECC is used to perform an assessment, the spreadsheet should be sent to jkitchin@mass-group.org. No information is needed that can identify the building so if privacy is a concern, please anonymise the information. All data will be provided upon request.

Verification

All members of an organisation should be encouraged to perform and report embodied carbon assessments, however they should be verified by an experienced assessor.

Reference unit

Embodied carbon assessments, as well as other types of building assessments, are typically reported in $kgCO_2e$ for the whole building ($kgCO_2e$) and by gross floor area (GFA) ($kgCO_2e/m^2$). This allows buildings of different sizes to be compared to each other, however this does not identify how functional the building is. Therefore, it is helpful to provide a description of the building uses and expected number of occupants.

Building use

In accordance with the Rwanda Building code version 2019 [14], the assessment shall identify the building use from the following. If the building has less than 60% of the floor area devoted to a single use then it should be classified as mixed use.

- Assembly: gatherings, civic, religious, social, recreational
- Business (commercial): Office, professional or service transaction
- Educational: Schools
- Factory and industrial: Manufacturing, fabrication, packaging
- Institutional: Assisted living, hospitals, prisons
- Mercantile: Display and sale of merchandise
- Residential: Housing, Apartments, Hotel
- Storage: Non or low-hazardous storage (parking garages)
- Memorial
- Mixed use
- Miscellaneous: other functions

Biogenic Carbon Storage

Biomass, like trees, remove CO_2 from the atmosphere as they grow and store it as carbon; this is known as sequestration. It is temporarily stored in the biomass until it is released at the end of life, often through burning or decomposition. Keeping CO2 stored for as long as possible in biomass products in buildings is one way of reduce the short term Global Warming Potential (GWP) of our build environment, however the harvested biomass must be regrown. When reporting biogenic storage it should be reported separately but may be included if life cycle stages A-C are aggregated.

Refer to Timber and Carbon Sequestration [15] by the IStructE for more information.

Data

Ideally data used in embodied carbon assessments should be geographically, temporally, and technologically relevant however there is limited data in East Africa so this is not possible at present. A lack of ideal data should not be a barrier to us measuring and reducing embodied carbon, therefore this section of the guide provides data which can be used. This also has the benefit of ensuring local organisations are using the same input values which allows them to be more easily reviewed and compared. Alternative values can be used but they must be well justified.

Materials and Products

Most of the material and product data used is generic, and not product specific, because there is no regionally available data available at present. The lack of specific data should not be a barrier to these assessments and the recommended data for materials and products is provided in RwECC. The data has been selected to be as appropriate as possible to typical construction in Rwanda.

The main sources for A1-3 life cycle stage emissions:

- Inventory of Carbon and Energy v3 Database [16]
- One Click LCA’s Environmental Product Declarations (EPDs) database - specifically selecting the median value from all the relevant EPDs
- Carbon Leadership Forum’s 2021 Material Baselines [17]
- Embodied Carbon in Construction Calculator (EC3) median values for materials
- Embodied Energy of Various Materials and Technologies by Auroville Earth Institute [18]

Product specific data is provided in Environmental Product Declarations (EPDs). It is not recommended to rely on product specific data during the design stage unless the actual manufacturer is known with certainty.

Steel reinforcement in concrete is a high impact material which is sometimes wrapped up in the concrete line item of Bill of Quantities (BOQs), therefore sometimes the quantity of reinforcement sometimes needs to be estimated if it is not known accurately.
Table 5 provides recommended reinforcement estimates to be used unless otherwise known.

Concrete element	Reinforcement estimate (kg/m^3)
General	100
Slabs	100
Foundations	100
Columns	400
Beams	220
Walls	110
Stairs	135

Table 5: Concrete reinforcement estimates

Transport

This section refers to module A4 which is related to the transportation of materials or products from the factory gate to the construction site. Module A4 is likely to account for a small percentage of embodied carbon over the life cycle of a building project. If heavy materials, such as stone, are procured from far away, then the associated embodied carbon will be high. Transport distances should be estimated based on project-specific scenarios. Ask your suppliers for manufacturing locations.

Table 6 presents some transport emission factors estimated using UK data for transport emissions [19]. It is expected that the values provided are lower than they would be in Rwanda, however no local emissions data exists and transportation generally makes up a small portion of whole life embodied carbon emissions so it is acceptable to use this information.

Manufacturing region and distance assumption	Distance by road (km)	Transport emission factor for road (gCO2e/ km.kg)	Distance by sea (km)	Transport emission factor for sea (gCO2e/ km.kg)	Effective transport emission factor (kgCO2e/kg)
Locally manufactured	50	0.213	0	0.013	0.011
Nationally manufactured (Average distance from Kigali to Huye, Musanze)	125		0		0.027
Regionally manufactured (Average distance from Kigali to Nairobi, Dar Es Salam, Kampala)	1,100		0		0.234
Globally manufactured (Approximate distance from Kigali to Mombassa or Dar Es Salam by road and from either of those ports to a Chinese port)	1,400		10,000		0.430

Table 6: Transportation emissions by manufacturing location

Construction

This refers to carbon emissions associated with module A5. The emissions from this stage predominantly occur from energy consumption and construction waste.

The emissions associated with energy consumption from site vehicles, machinery and offices has been estimated as 19.94kgCO_2e/m^2 for tropical countries by One Click LCA.

Table 7 contains waste rates from the WRAP Net Waste Tool [20] should be used unless more accurate information is known. These are used for estimating emissions due to waste, referred to as A5w in the RwECC. A study on waste rates in Rwanda was performed and the outcomes can be found in Appendix G: Results from construction waste survey.

Material/Product	Waste Rate
In-situ concrete, mortar, screed	5%
Concrete precast	1%
Steel reinforcement	5%
Concrete blocks and bricks	20%
Stone	10%
Timber cut off site	1%
Timber cut on site	10%
Glass	5%
Plasterboard	22.5%

Table 7: Material and product waste rates

In Use

The impacts of use or application of an installed product is captured in module B1. Typically these impacts are due to chemical leakage from building products. Spray foam, for instance, is installed with blowing agents that may continue to off gas throughout the life of the building. Refrigerant leakage is a major source of greenhouse gases and is discussed more fully in

Appendix F: Embodied carbon impacts of cooling systems.

Service life

The product and material service life heavily influences the emissions associated with the B4, replacement, stage. The shorter the service life, the more often it is replaced during a building’s life. Therefore, it is beneficial to promote durable materials and materials that, if broken, can be replaced in isolation, such as a tile. Products often don’t last as long as manufacturers suggest they can due to low quality construction, incorrect detailing, changes in fashion or changes in space needs. It is recommended that the envelope, finishes, doors and windows have a service life of 30 years, and all other products have a service life equal to the building life.

The service life of a typical building is to be 60 years unless an alternative is well justified.

End of life

This refers to carbon emissions associated with module C1 - C4. This is likely to account for a small percentage of embodied carbon over the life cycle, unless biogenic based products are used.

In the absence of more accurate information, an average rate for C1 (demolition and deconstruction) of 3.4kgCO$_2$e/m^2 GIA from the RICS [21] can be assumed.

Transportation of materials away from site at End of life (C2) is calculated in exactly the same way as A4 transportation emissions, but the waste processing or disposal facilities are likely to be local to the site, so the transportation distances are likely to be shorter. Default assumptions in Table 8 can be used.

End of life	Carbon emissions (kgCO$_2$e/kg)
Reuse/recycling on site	0
Reuse/recycling/landfill	0.005 (assuming 50km travel by road)

Table 8: End of life transportation emissions

Carbon factors for waste processing for reuse, recovery or recycling (C3) and disposal (C4) are often grouped together. The default factor for combined C3 and C4 modules is 0.013kgCO$_2$e/kg of inorganic waste and 2.15 kgCO$_2$e/kg for organic waste [21].

Appendix C: Case studies

These buildings were assessed using the RwECC and are provided here as an example of useful embodied carbon data that can be reported.

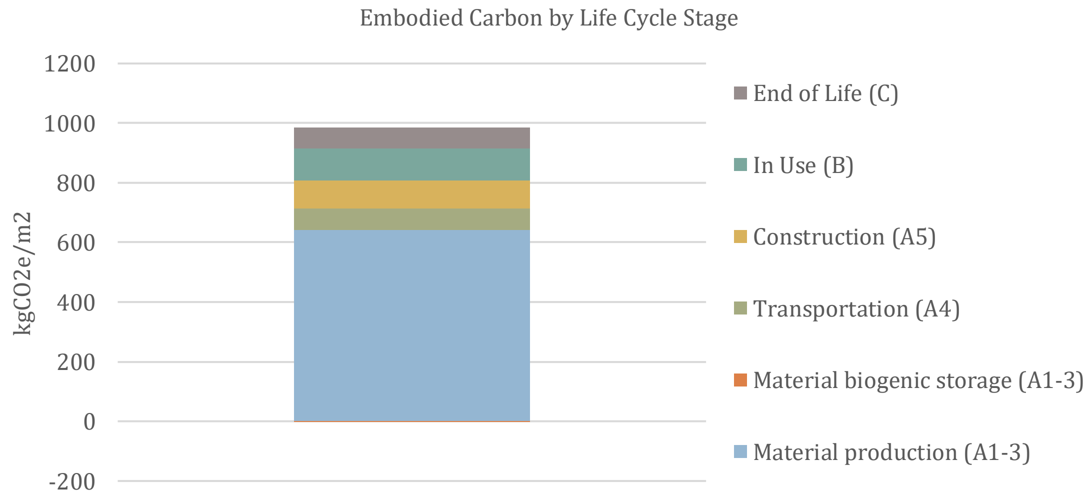
The School of Architecture and Built Environment

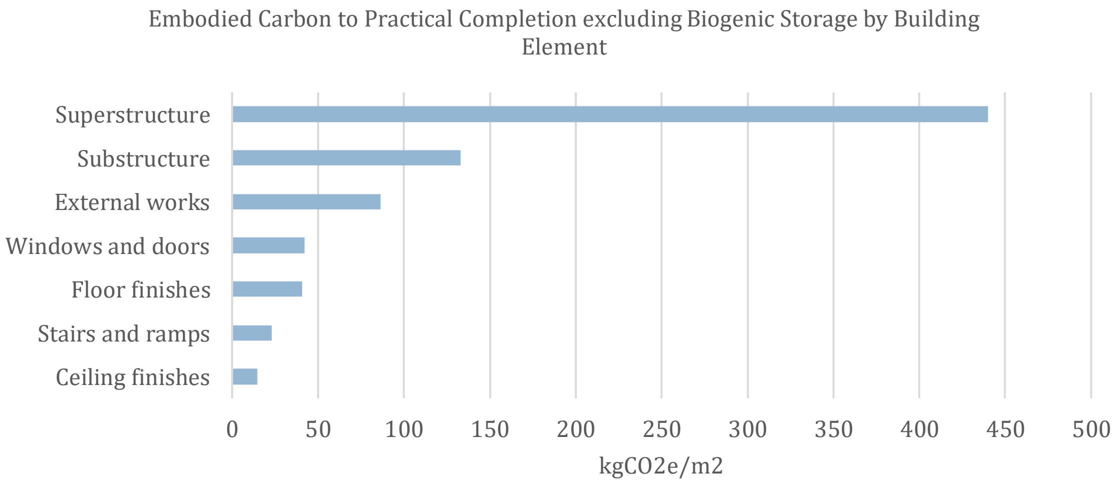
Designed by Patrick Schweitzer & Associés, The School of Architecture and Built Environment was built in 2017 and is located in the University of Rwanda's College of Science and Technology campus in Nyarugenge District.

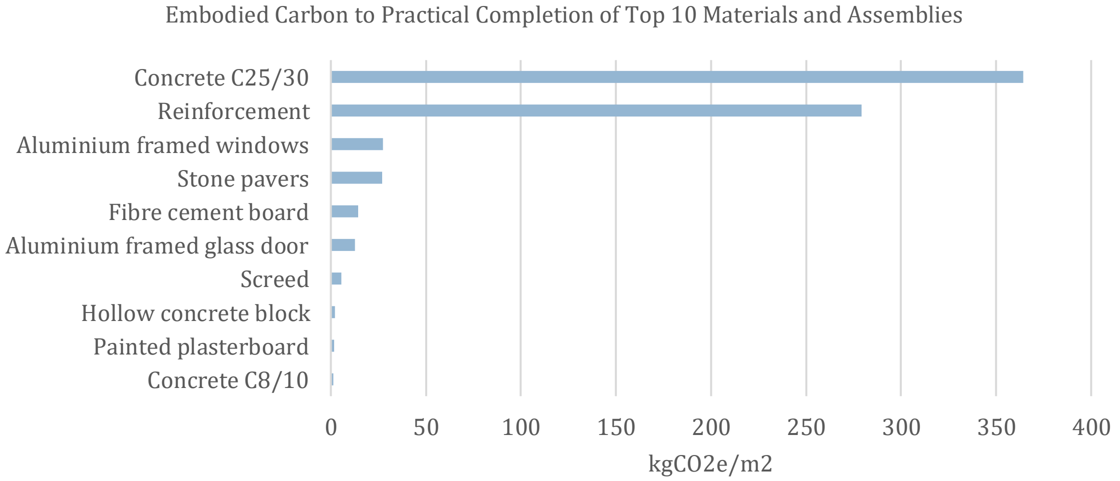
The building has several structures from one to two stories. Its main function is as an educational space. The primary construction material is reinforced concrete, which accounts for 87% of the upfront embodied carbon emissions (life cycle stage A).

Photo credit: Jules Toulet

Life Cycle Stages	$kgCO_2e/m^2$
Material production (A1-3)	640
Material biogenic storage (A1-3)	-2
Transportation (A4)	74
Construction (A5)	93
In Use (B)	109
End of Life (C)	68


Embodied Carbon by Life Cycle Stage
kgCO2e/m2
1200
1000
800
600
400
200
0
-200
End of Life (C)
In Use (B)
Construction (A5)
Transportation (A4)
Material biogenic storage (A1-3)
Material production (A1-3)


Embodied Carbon to Practical Completion excluding Biogenic Storage by Building Element
Superstructure
Substructure
External works
Windows and doors
Floor finishes
Stairs and ramps
Ceiling finishes
0
50
100
150
200
250
300
350
400
450
500
kgCO2e/m2


Embodied Carbon to Practical Completion of Top 10 Materials and Assemblies
Concrete C25/30
Reinforcement
Aluminium framed windows
Stone pavers
Fibre cement board
Aluminium framed glass door
Screed
Hollow concrete block
Painted plasterboard
Concrete C8/10
0
50
100
150
200
250
300
350
400
kgCO2e/m2

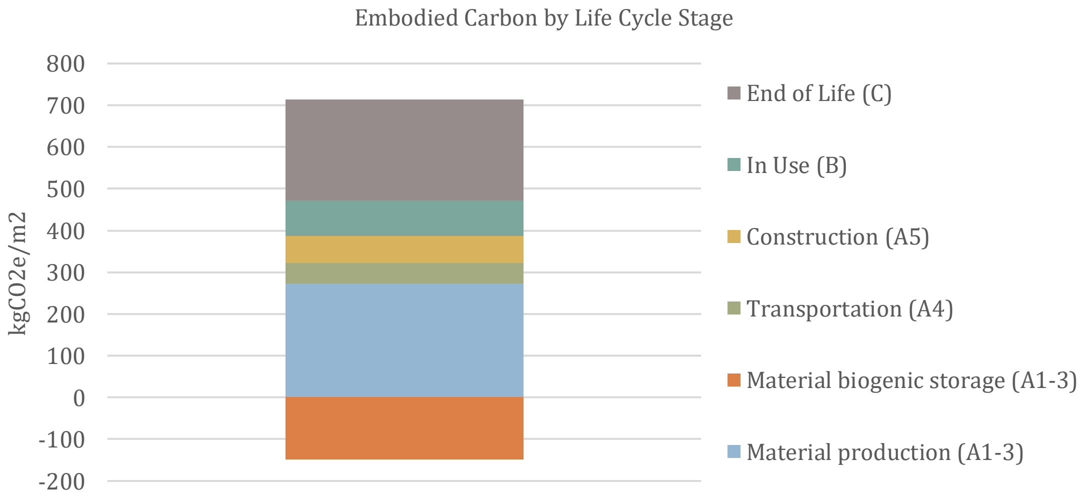
Rwanda Institute for Conservation Agriculture, Year 2 and 3 Housing

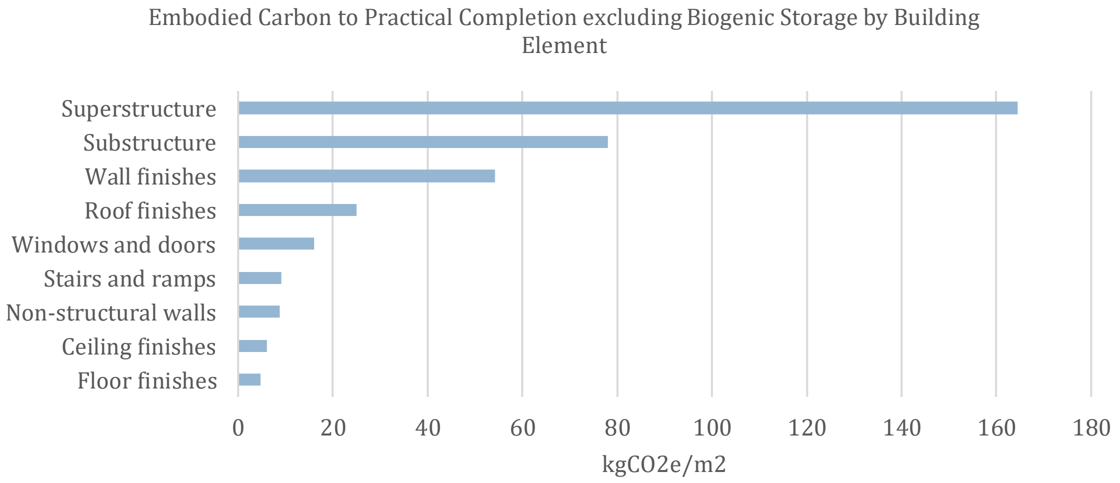
The Rwanda Institute for Conservation Agriculture campus is located in Bugesera. It was conceived and funded by the Howard G. Buffett Foundation, supported by the Government of Rwanda, and designed by MASS Design Group. The Year 2 and 3 Housing is a residential building for students at the campus and was completed in 2021.

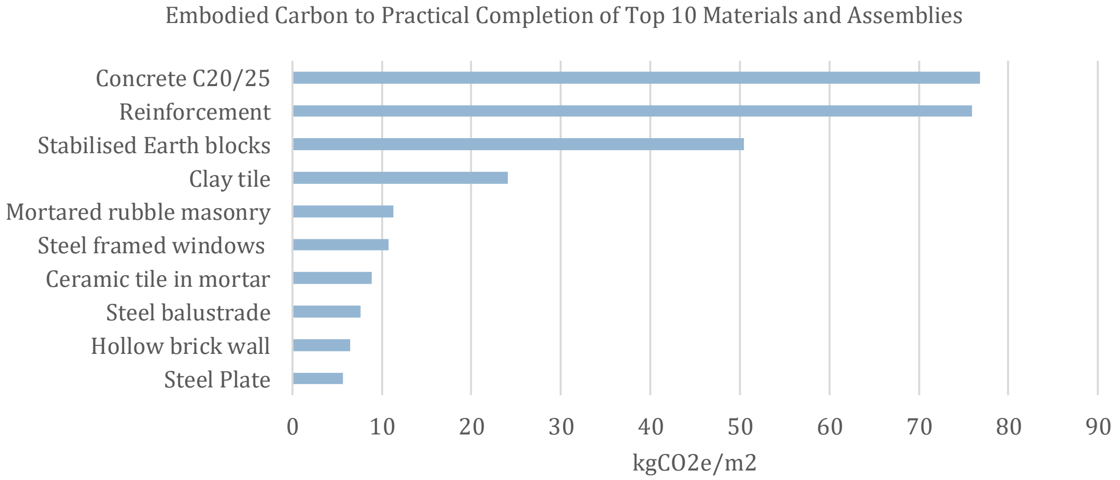
The building is two stories. The main structural materials are stone masonry foundation, compressed earth walls, timber roof structure and concrete slabs. The finishes are minimal but the primary ones are made from earth plaster, clay tiles, and wood. The End of Life (C) contribution to emissions is higher than often seen due to the wood releasing the biogenic stored emissions.

Photo credit: Iwan Baan

Life Cycle Stages	$kgCO_2e/m^2$
Material production (A1-3)	272
Material biogenic storage (A1-3)	-148
Transportation (A4)	50
Construction (A5)	65
In Use (B)	85
End of Life (C)	242


Embodied Carbon by Life Cycle Stage
kgCO2e/m2
800
700
600
500
400
300
200
100
0
-100
-200
End of Life (C)
In Use (B)
Construction (A5)
Transportation (A4)
Material biogenic storage (A1-3)
Material production (A1-3)


Embodied Carbon to Practical Completion excluding Biogenic Storage by Building Element
Superstructure
Substructure
Wall finishes
Roof finishes
Windows and doors
Stairs and ramps
Non-structural walls
Ceiling finishes
Floor finishes
0
20
40
60
80
100
120
140
160
180
kgCO2e/m2


Embodied Carbon to Practical Completion of Top 10 Materials and Assemblies
Concrete C20/25
Reinforcement
Stabilised Earth blocks
Clay tile
Mortared rubble masonry
Steel framed windows
Ceramic tile in mortar
Steel balustrade
Hollow brick wall
Steel Plate
0
10
20
30
40
50
60
70
80
90
kgCO2e/m2

Rwanda Cricket Stadium

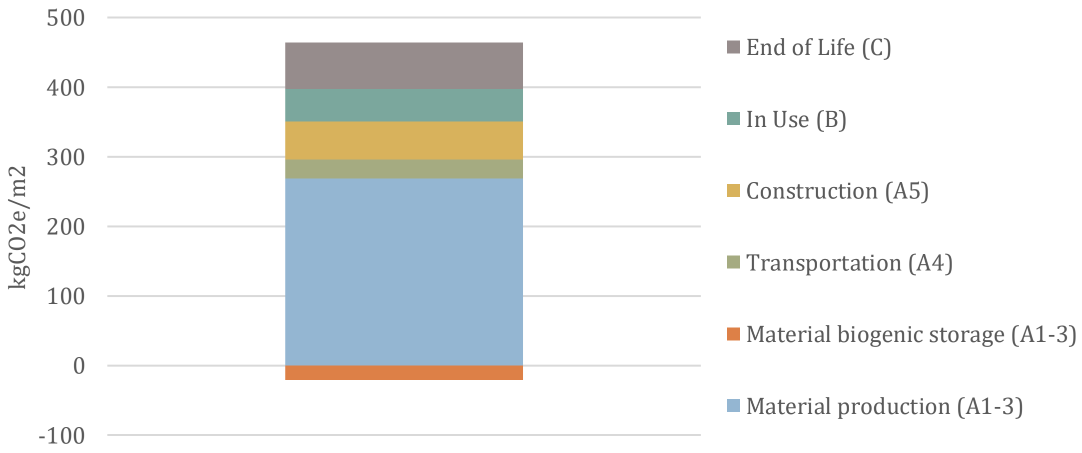
Rwanda Cricket Stadium, completed in 2017, is located in Gahanga. The project was designed by Light Earth Designs and built using local labour and materials avoiding imports, lowering carbon, and building skills and economies.

The vaulted structure spans up to 16m and is built from site compressed stabilised soil tiles mortared together in layers with geogrid reinforcing to provide seismic protection. The sheltered structures under the vaults are built from masonry and concrete, and primarily serve as changing rooms and a restaurant.

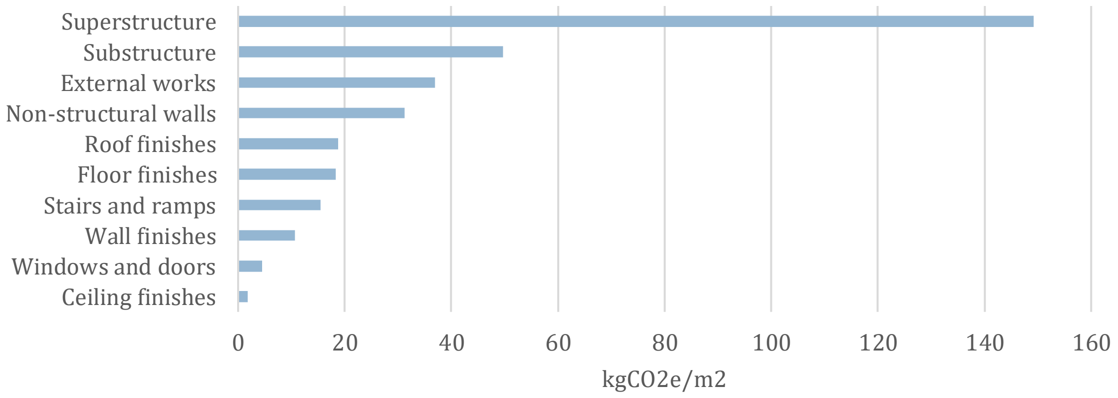
Photo credit: Light Earth Designs

Life Cycle Stages	$kgCO_2e/m^2$
Material production (A1-3)	269
Material biogenic storage (A1-3)	-21
Transportation (A4)	27
Construction (A5)	55
In Use (B)	46
End of Life (C)	67

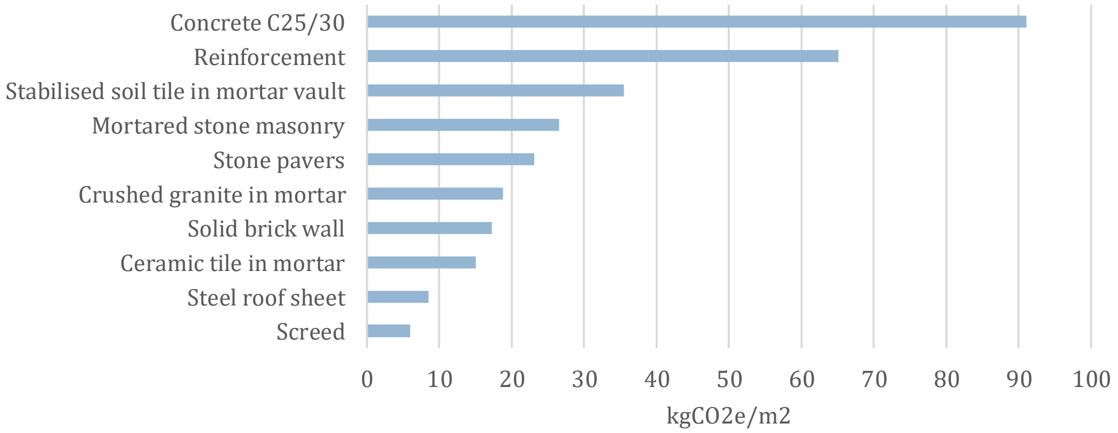
Embodied Carbon by Life Cycle Stage



Embodied Carbon to Practical Completion excluding Biogenic Storage by Building Element



Embodied Carbon to Practical Completion of Top 10 Materials and Assemblies



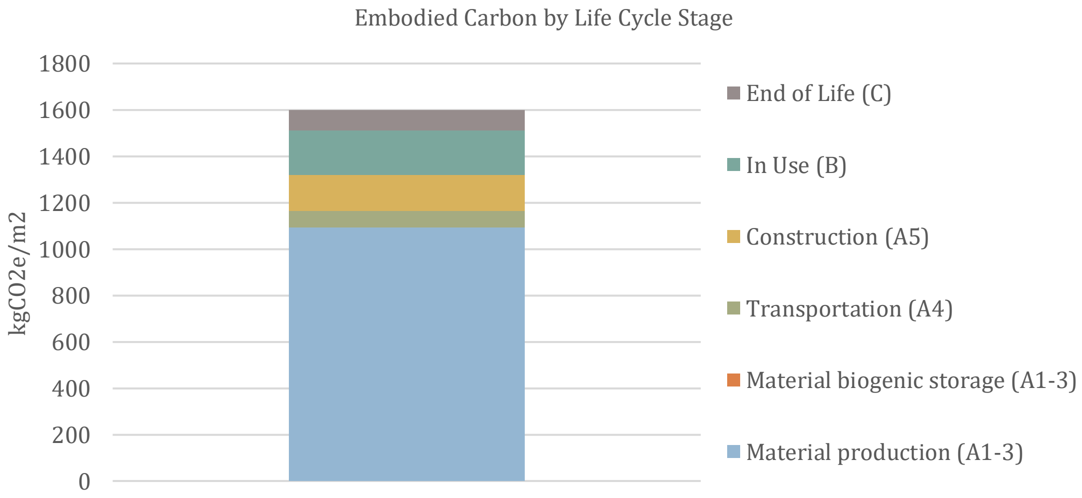
The School of Mining and Geology

The School of Mining and Geology is under construction and is expected to be completed in 2022. It is located in the University of Rwanda's College of Science and Technology campus in Nyarugenge District, adjacent to the School of Architecture and the Built Environment. This project was designed by Korean firm SAMOO and local firm GMK.

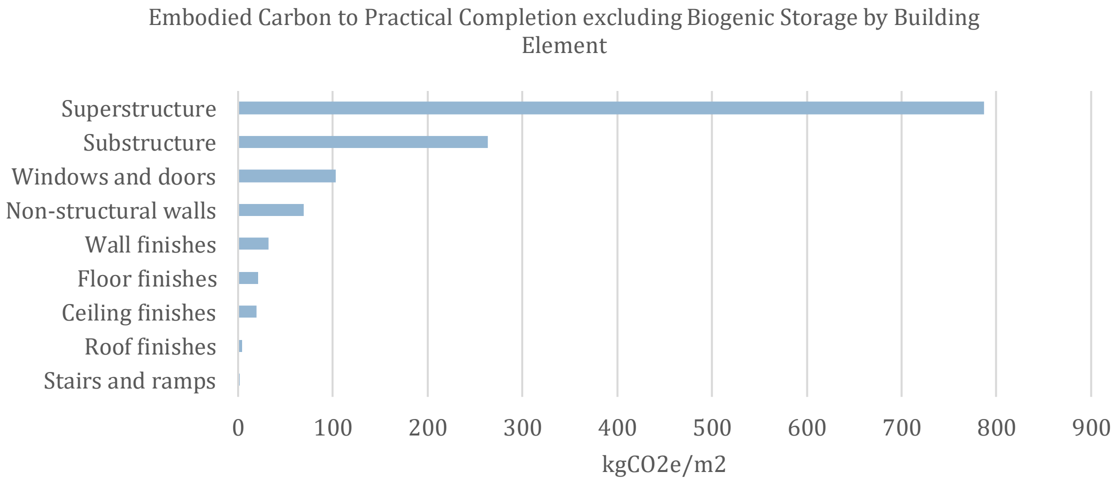
The building structure is made from reinforced concrete with two floors above ground. The building contains offices, lecture rooms and a museum.

Photo credit: Alex Ndibwami

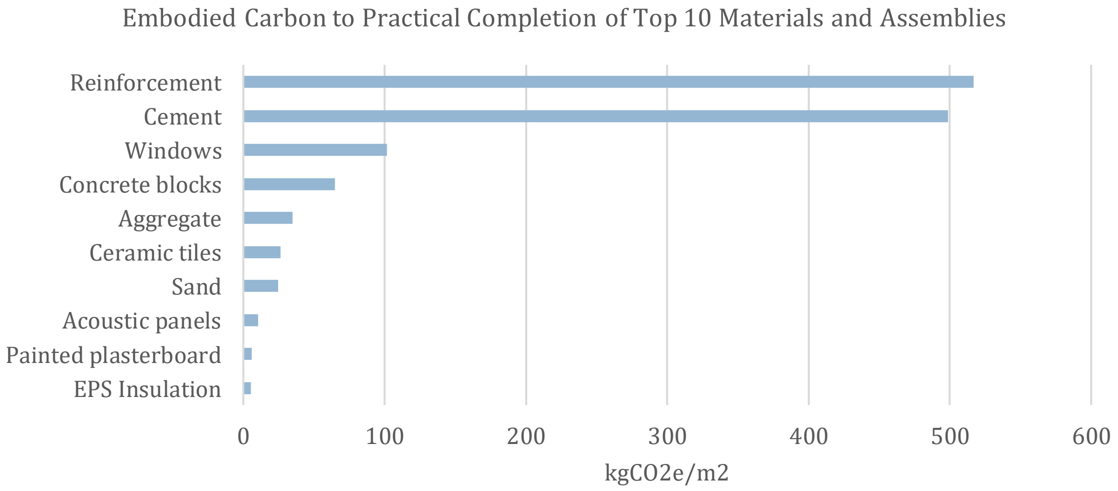
Life Cycle Stages	$kgCO_2e/m^2$
Material production (A1-3)	1092
Material biogenic storage (A1-3)	0
Transportation (A4)	71
Construction (A5)	157
In Use (B)	193
End of Life (C)	87



Embodied Carbon by Life Cycle Stage



Embodied Carbon to Practical Completion excluding Biogenic Storage by Building Element



Embodied Carbon to Practical Completion of Top 10 Materials and Assemblies

Swiss Cube

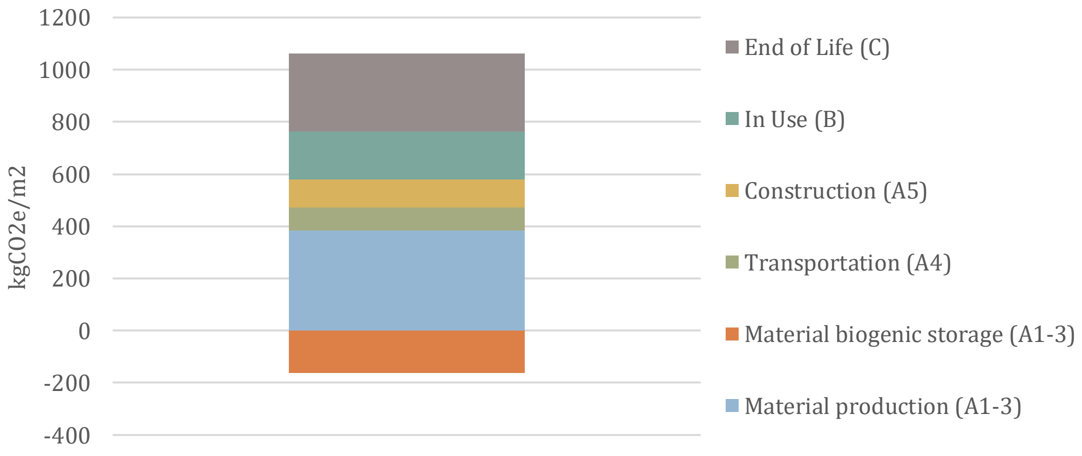
The Swiss Cube, as commonly named in Rwanda, is located at the Kigali International Trade Fair grounds. Its architectural concept is characterized by an optimized design, built with locally produced, quality materials. The Cube is a modular system designed to be flexible, scalable and interchangeable, to reinterpret Rwandan vernacular architecture and adapt to the needs of a more sustainable urbanisation process. The Swiss Cube demonstrates the potential of the local construction industry to deliver quality urban affordable and greener housing solutions. The building structure is made from reinforced Row lock bond masonry with two floors and was designed by SKAT Consulting Rwanda through the PROECCO program, sponsored by the Swiss Development and Cooperation Agency (SDC).

The impact of this innovative approach generated interest in both private and public sector, leading to the construction of over 5,000 dwelling units in both private and public housing projects.

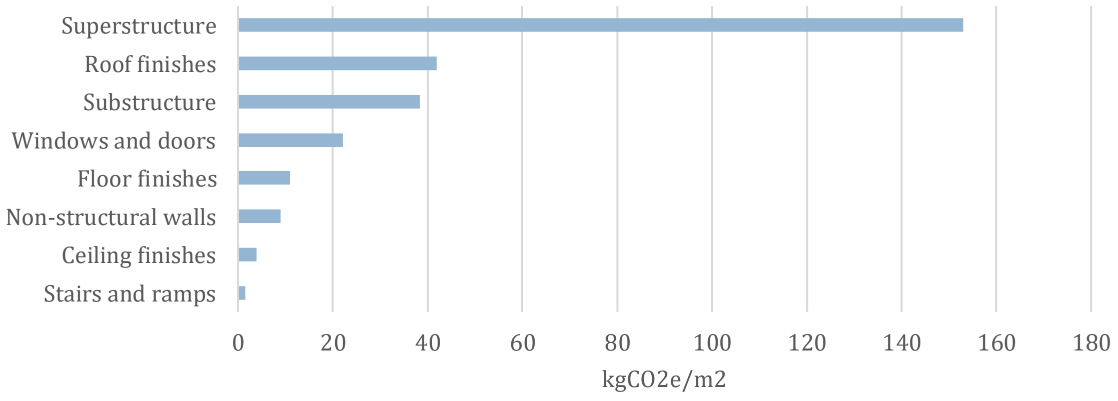
Photo credit: SKAT Consulting Rwanda

Life Cycle Stages	kgCO$_2$e/m^2
Material production (A1-3)	383
Material biogenic storage (A1-3)	-163
Transportation (A4)	90
Construction (A5)	108
In Use (B)	184
End of Life (C)	297

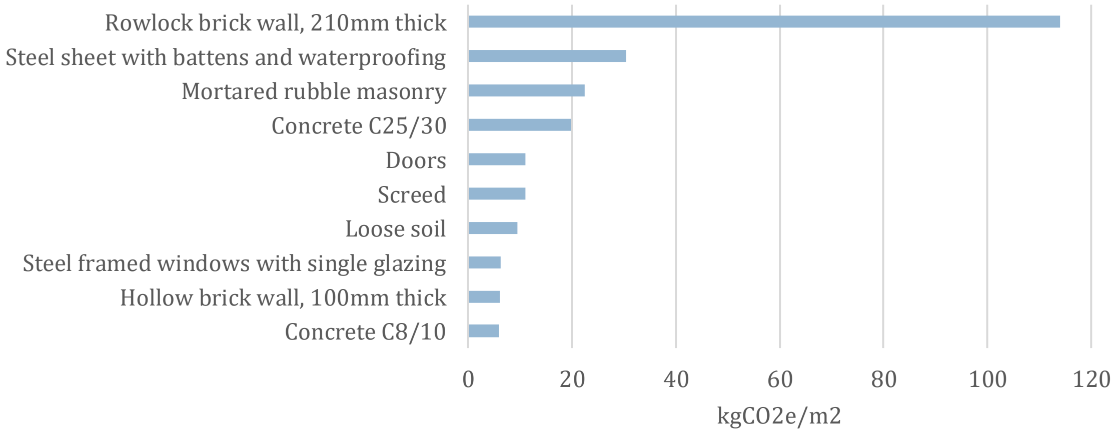
Embodied Carbon by Life Cycle Stage



Embodied Carbon to Practical Completion excluding Biogenic Storage by Building Element



Embodied Carbon to Practical Completion of Top 10 Materials and Assemblies

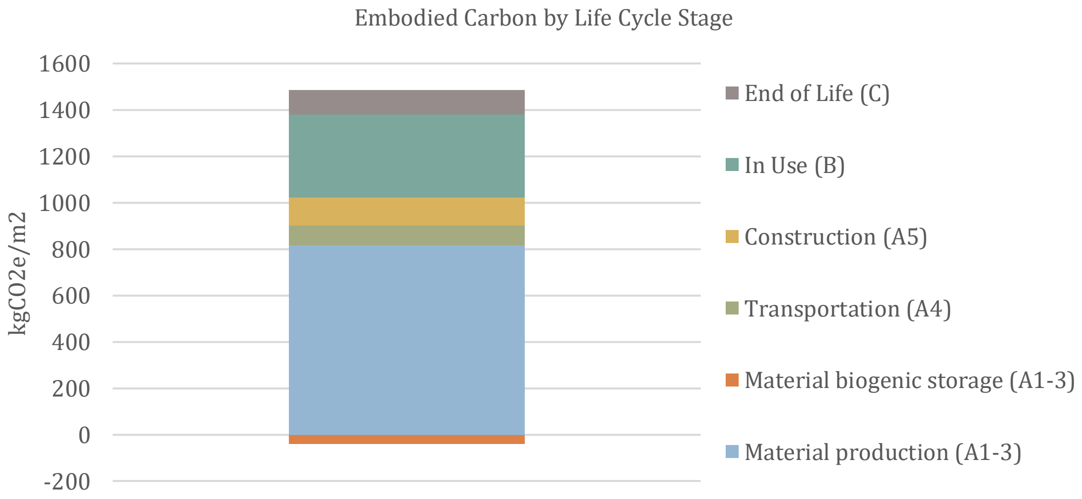


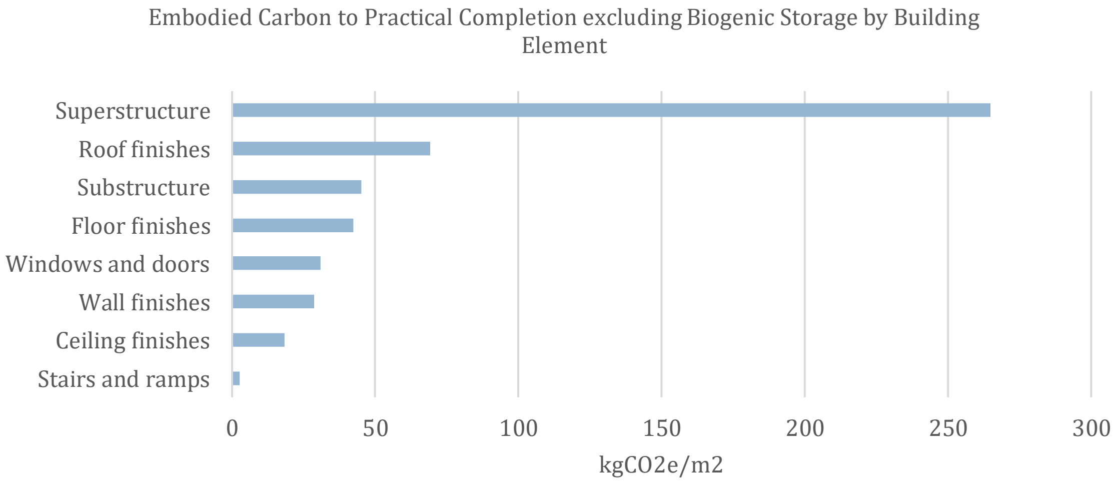
Bwiza Riverside Homes

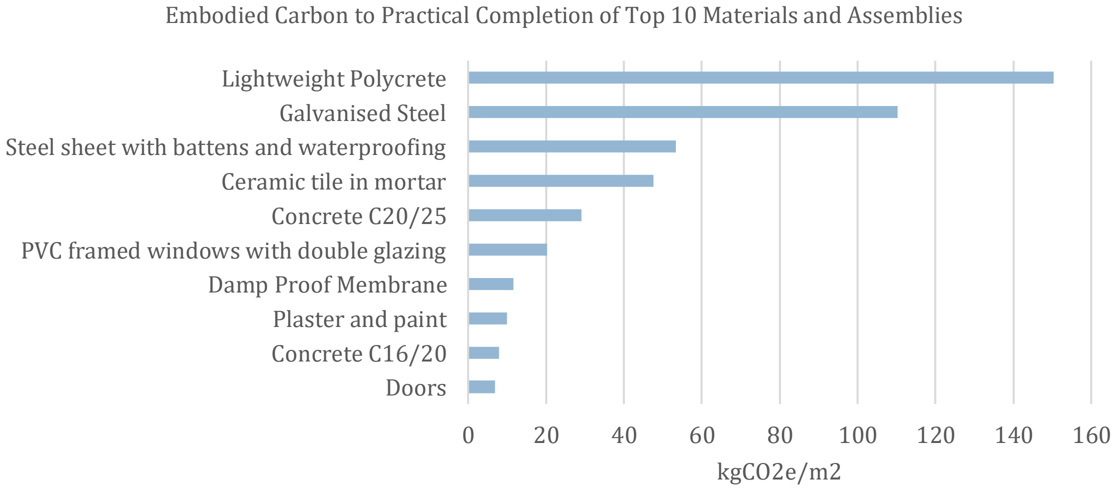
Bwiza Riverside Homes is the first Edge Advance Certified Housing Project completed in Rwanda in 2023. It is located in Karama, Norvege in Nyarugenge District of Kigali. The housing development was designed to redefine the housing sector by introducing a construction method that reduces the volume and weight of materials by 80%. The aim is to reduce resource extraction, construction waste and embodied carbon. Bwiza Riverside Homes land development and urbanization improvement impacts by reusing the excavated soft soils and reinforcing it with geo-textile obtained from recycled plastics. The Sponge City principal manages water with less material. Underground drainage, storage, detention and retention are incorporated into permeable roads, footpaths, and green grass parking, thus controlling the runoff storm water and flood mitigation.

Photo credit: Charis UAS, Bwiza Riverside Homes

Life Cycle Stages	$kgCO_2e/m^2$
Material production (A1-3)	816
Material biogenic storage (A1-3)	-39
Transportation (A4)	88
Construction (A5)	120
In Use (B)	360
End of Life (C)	102


Embodied Carbon by Life Cycle Stage


Embodied Carbon to Practical Completion excluding Biogenic Storage by Building Element


Embodied Carbon to Practical Completion of Top 10 Materials and Assemblies

Vision City Row House

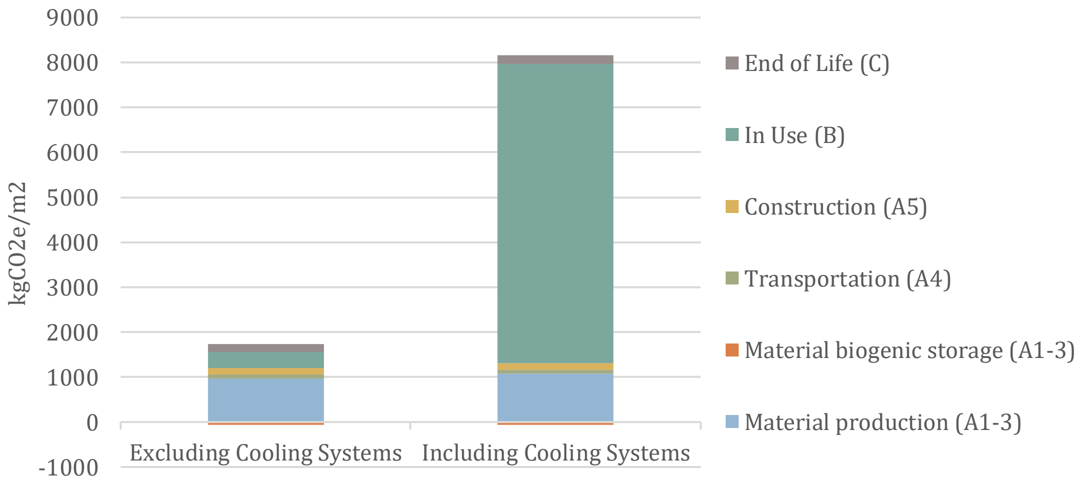
Vision City Phase 1 is a large-scale urban development project in Kigali, Rwanda developed by Ultimate Developers Ltd (UDL) which was completed in 2017.

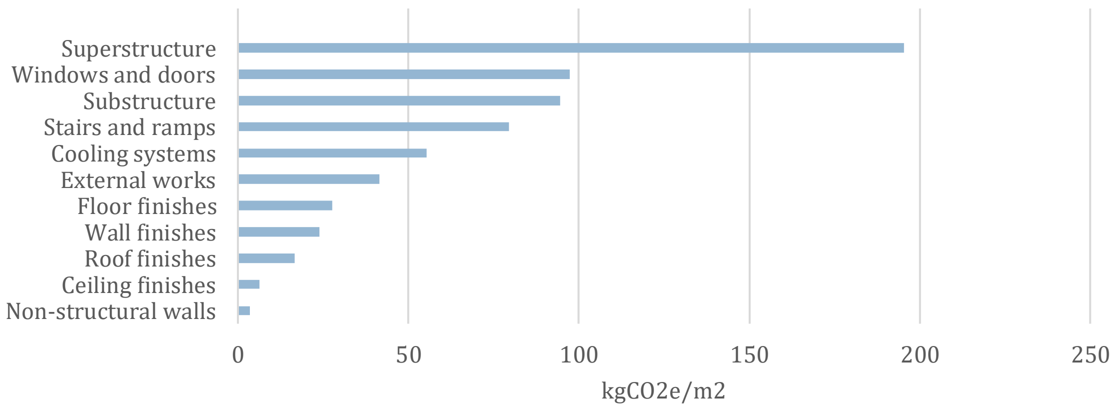
The primary objective of Vision City is to address the increasing demand for housing and infrastructure in Kigali while promoting sustainable development practices. The project aims to create a well-planned, integrated, and modern urban environment with a design that incorporates green building practices, energy-efficient infrastructure, and the integration of green spaces to enhance the overall environmental performance of the development.

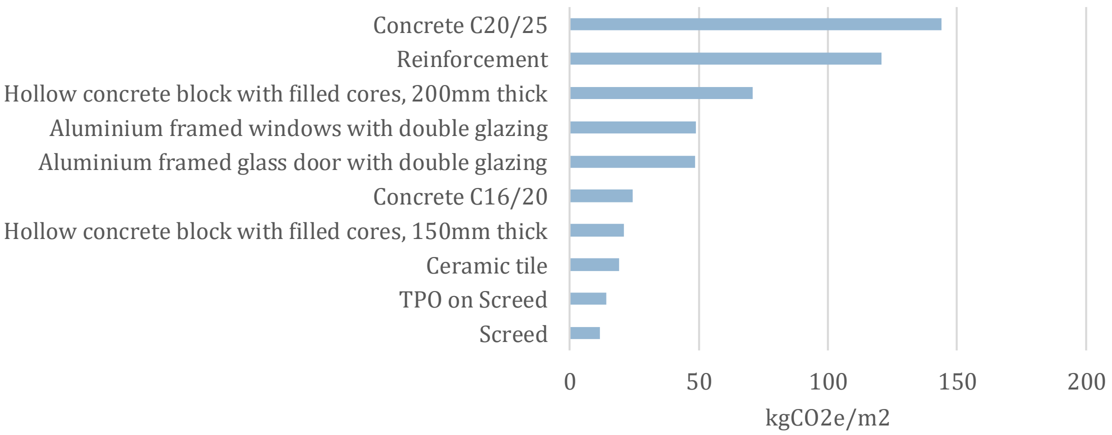
Vision City Phase 1 is made up of various typologies including 2, 3 and 4-bedroom apartments; 4 and 5-bedroom luxury villas; 3 bedroom townhouses; and 3 and 4-bedroom semi-detached houses.

Photo credit: Ultimate Developers Ltd

Life Cycle Stages	Excluding Cooling Systems $kgCO_2e/m^2$	Including Cooling Systems $kgCO_2e/m^2$
Material production (A1-3)	969	1080
Material biogenic storage (A1-3)	-57	-57
Transportation (A4)	90	90
Construction (A5)	133	133
In Use (B)	369	6668
End of Life (C)	182	182


Embodied Carbon by Life Cycle Stage


Embodied Carbon to Practical Completion excluding Biogenic Storage by Building Element


Embodied Carbon to Practical Completion of Top 10 Materials and Assemblies

Appendix D: Embodied carbon reduction strategies

Group elements	Use less material	Use less embodied carbon intensive materials	Durability, adaptability and disassembly
Substructure	● Optimise the amount of reinforcement in underground concrete elements, often foundation elements working in compression need little or no reinforcement. ● Use geotechnical surveys to optimise design. ● Reduce the amount and height of retained soil, to reduce retaining wall and foundation sizes. ● Reduce the building weight where possible, to reduce foundation sizes. ● Use excavated earth and recycled aggregate for ground work. ● Reuse existing substructures wherever possible.	● Use stone masonry instead of concrete foundations or retaining walls. ● Use ground improvement techniques. ● Use alternative retaining wall designs to cantilever or gravity walls ● Design to use reusable formwork to reduce waste. ● Use 56-day strength concrete, if the construction schedule allows, and a high cement replacement mix.	
Superstructure	● Preserve and re-use existing structures wherever possible. ● Review and reduce loading	● Consider low embodied carbon materials such as timber, stone and earth	● Separate structural elements from elements that will change or move in the future, such as envelopes or

	requirements wherever possible. ● If using steel, use castellated beams or trusses to reduce material volume and weight and allow services to run through. ● If using concrete, consider forms that minimise material use, such as ● coffered slabs.	● If using steel, prioritise high recycled content and shorter transport distances to site. ● Consider hybrid structures that optimise the performance of each material. ● Use 56-day strength concrete, if the construction schedule allows, and a high cement replacement mix. ● All timber should be from regulated and responsible sources.	interior walls. ● Consider slight changes in spans, loads and structural grids that allow for alternative uses, e.g. designing roofs to be solar ready or using a regular 6m span throughout ● Avoid composite materials which may be hard to deconstruct in the future. ● Design connections to be visible and reversible such as bolts and screws rather than welds or glue.
Envelope	● Avoid brittle facades, such as glass, so seismic drift limits do not govern the structural design ● Design lighter facades that allow larger deflections at slab edges ● Where appropriate, design for repetition and off-site manufacture, to reduce waste during manufacturing and construction.	● Minimise glazing beyond what is needed for good building performance ● Insulation choices should be assessed as part of a whole life carbon study alongside the operational carbon	● Use durable materials to reduce the number of times the envelope needs to be replaced. Good detailing and quality construction are also important in durability. ● Design fixings that can easily be disassembled for adaptation, maintenance or replacement. ● Consider panelised construction for easier disassembly, ensuring one part of the envelope can be replaced in isolation.

			● For brick facades, using lime mortar over cement mortar enables the bricks to be reclaimed and reused following disassembly. ● Using regular sized windows and doors allow them to be more easily used in future buildings.
Interiors	● Use the exposed surface of superstructure and ● exposed MEP systems as the final finish rather than concealing these under layers of materials such as plasterboard. ● Design to use the full dimensions of off-the-shelf materials to avoid waste by reducing offcuts.	● Use earth bricks for non-structural walls instead of fired brick or concrete blocks. ● The use of natural materials like linoleum, water based eco paints, cork, bamboo and timber. ● Recycled products use no raw materials and are increasingly available.	● Attach finishes assuming they will be removed in 10 years. ● Avoid the use of glues and adhesives that will make separation at end of life difficult ● Durable materials will last longer, and require fewer replacement cycles over a building’s lifespan.
Building services	● Passive design and natural systems will reduce equipment sizes, reduce refrigerant quantity and provide resilience ● Use simple, straight ducting routes to reduce duct material	● Avoid refrigerants where possible ● Use low GWP refrigerants where required	● Consider the potential impacts of future climate change and how best to avoid the need for extensive retrofit. ● Provide easy access for regular inspections and maintenance. ● Use systems that are appropriate for the context so they can be

			maintained locally ● Building services components should also be demountable and easy to disassemble in order to operate well for a longer period, and be recycled or reused at their end-of-life.
External works	● Use softscape rather than hardscape ● Use open cell permeable pavers rather than solid pavers and use 40% less concrete ● Design considerately of the topography to limit concrete retaining walls ● Specify different hardscape thicknesses according to the loading (pedestrian / traffic). ● Consider reducing waste from site by crushing materials on site for use as aggregate or a subbase for the new development.	● Build retaining walls from stone, sandbags and hollow blocks ● Use alternative retaining wall designs to cantilever or gravity walls ● Use salvaged materials in the landscape. ● For timber decking, make sure the wood is certified and sustainably sourced. ● Use nearby natural stone instead of concrete slabs.	● The use of an open area above a basement should be considered for future uses. ● Use mortar beds that are permeable so that slabs can be removed without damage.

Appendix E: Embedding low embodied carbon design into a project

Embodied carbon assessments or reductions are not currently required by the Rwanda Building Code [14]. Therefore, since climate change and the impacts of embodied carbon are externalities to the project, it can be challenging to set and meet embodied carbon targets when there are other project demands. Table 9 provides some examples of existing project requirements and how these can be achieved while also reducing embodied carbon.

Project aims	Embodied carbon reduction strategies that also achieve the project requirements
Award winning building	Building sustainability and therefore embodied carbon is becoming a serious criteria for award winning buildings. For instance, the RIBA and AIA awards must meet certain sustainability requirements and their designers must have signed the corresponding 2030 pledges.
Meet client or funder's sustainability goals	Sustainability goals can be broad; however any project that can be shown to have a lower climate change impact will often help client's and funder's meet their sustainability goals.
Low costs	One of the main strategies to reduce embodied carbon is to reduce material quantities, which often leads to lower costs, especially in locations like Rwanda where materials are more expensive than labour.
Low maintenance	Maintenance is a concern for all building users and owners. Reducing finishes to expose more robust structural materials and using more durable materials will reduce maintenance requirements and embodied carbon.
Quick construction	Using repeating elements and fastening them together is a quick method of construction and allows them to be disassembled, which means they can be more easily reused in the future, reducing embodied carbon.
User wellbeing	Using natural materials, which are low in embodied carbon, can provide better indoor air quality and biophilic effects.
Future adaptability	Providing spaces that can be adapted to the client's needs in the future is a sensible design strategy and it also leads to lower embodied carbon because the building will need less modification when it is adapted.
Invest locally e.g. Made in Rwanda	Buying materials locally reduces transport distances and associated emissions. Transportation emissions are only one form of emission so the emissions from the product manufacture must also be taken into account.

Table 9: Achieving project requirements with embodied carbon reductions

Appendix F: Embodied carbon impacts of cooling systems

The GWP impact of cooling systems comes predominantly from refrigerant leakage and somewhat from the embodied carbon of the cooling systems themselves. Refrigerant management was identified by Project Drawdown as the most effective method of reducing Green House Gas (GHG) emissions within the built environment [22].

Refrigerants are phase change materials that absorb and release thermal energy and are used in space cooling and conditioning. In 1987, the Montreal Protocol was signed by every UN member nation, banning CFCs and HCFCs, the most common refrigerants of the time, to protect our ozone layer. They were replaced by hydrofluorocarbons (HFCs), another type of Flourinated GHG that has a high Global Warming Potential (GWP). In 2016, the Kigali amendment to the Montreal Protocol set a strict time line to phase out HFCs; first in high-income countries and then in low-income countries by 2030, in order to reduce the GWP impact from refrigerants. The new refrigerants that are on the market are Hydrofluoro-olefins (HFOs) and natural/hydrocarbon options, such as water, CO2, and ammonia.

The major issue associated with the use of refrigerant is leakage, resulting in release of refrigerant into the atmosphere. Refrigerants are classified by ASHRAE - Standard 34 and assigned an 'R' number, determined by the molecular structure, which is how you will see them presented in this report and the RwECC. Figure 19 shows the GWP of common and historic refrigerants. The GWP of refrigerants can be thousands of times higher than CO_2

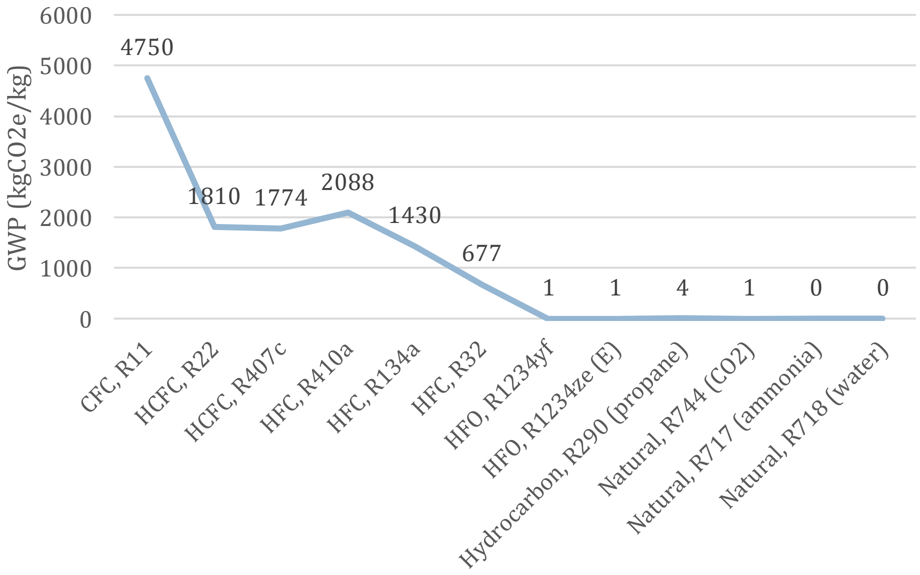


Figure 19 GWP of refrigerants [24]

The method laid out in TM65 [24] is used to measure the embodied carbon impact of building services, including refrigerants. When the GWP impact of refrigerants commonly quoted is from the B1, Use, phase because the A1-3, production, phase impacts are typically much smaller. In case of R410a the impacts from Production and Use are:

- Production (modules A1-3): 10.12 kgCO2e/kg [25]
- Use (module B1): 2088 kgCO2/kg [24]

Leakage can occur during any stage of the life cycle (Figure 14) however they are greatest during the Use phase. With excellent refrigerant management the leakage rates could be as low as 1% annually, however they have been identified as high as 200% annually in some cases. The RwECC uses a leakage rate of 9% annually based on TM65LA [26]. Leakage risk is lower for sealed packaged systems, such as chillers, than it is for systems that have piped refrigerant such as VRF systems.

Refrigerant is contained within the cooling equipment and within pipework. The quantity of refrigerant is called the charge. The change can vary enormously depending on the system type, for instance, distributed systems such as VRF have a large charge because the refrigerant is piped throughout the building, where as a packaged individual system has less charge. Wherever possible the charge should be calculated by the engineer, however the RwECC estimates charge using a study from Hoare Lea [27]:

- Distributed = 79 g/m^2
- Individual or packaged = 17 g/m^2

The design and as-built refrigerant charges were compared for a single project with a VRF system in Rwanda (Table 10). The as-built refrigerant charge was provided by the contractor and is 1.5x greater than the estimated design value. In both the design and as-built cases the refrigerant charge is greater than the estimated of 79 g/m^2. This identifies that there is significant variation between projects.

	Conditioned area (m2)	Cooling power (kW)	Refrigerant in pipes (kg)	Refrigerant in equipment (kg)	Total refrigerant (kg)	Refrigerant charge (g/m2)
Design	118	33.3	5.6	6.3	11.9	100
As-built	118	33.3	-	-	18	153

Table 10: Comparison between designed and as-built refrigerant change for a project with a VRF system

Refer to the discussion within the Reduction Strategies section for methods of reducing the impact of cooling systems.

Appendix G: Results from construction waste survey

For many construction materials and products, the carbon footprint is often not provided for the expected waste generated during their construction. This is primarily because construction waste generation is outside of the product manufacturer's control, however it is then down to the life cycle assessment performer to determine an appropriate waste rate. This is made challenging due to the lack of accurate data collection of waste rates and waste streams. Waste streams refer to what happens to the waste, such as: salvage, recycling, and disposal in landfill. Waste rates have a significant impact on a building's embodied carbon footprint. Compare, for instance, two building sites, one where 20% of the bricks are broken and one where only 5% of the bricks are broken. The embodied carbon of the bricks on the second site will be over 10% less than the bricks on the first site.

This study aims to investigate the variability of waste rates across construction sites in Rwanda and the likely waste streams for different types of products. At present the RwEC tool uses waste rates from the WRAP Net Waste Tool. These rates were generated through surveys, questionnaires and interviews with Contractors in the UK. A similar approach has been taken in this study which attempts to understand the waste rates and streams for building materials in Rwanda.

Three recently completed or ongoing construction projects were identified for this study. The projects broadly fall into small, medium and large categories based on physical size and cost. The information from this study will not replace the data used in the RwEC tool because the sample size is too limited to be considered statistically significant. The results of the study are intended to highlight areas of interest for further study and potential improvements that could be made with regards to construction waste.

The study collects the following information:

- Site Location
- key contributors to waste
- Size of project
- Waste %
- Rationale behind waste calculation
- Typical waste stream
- Anecdotal information about material waste

In all instances waste is defined as “debris generated during the construction that needs to be taken off site by the contractor”. This definition is discussed in Waste Streams.

Discussion

Waste Data Measurement

The major challenge in conducting any sort of study into waste management on construction sites is the lack of data that is being collected. Most information received were estimates from experienced site personnel. This challenge is not unique to the construction sites assessed as part of this study.

Waste Rates by Materials

Waste rates vary significantly between contractor and materials (Figure 20). Product cost, fragility, handling and storage all influence waste rates. Ceramic sanitary items are damaged easily, however they are costly since they are imported and great care is taken to ensure they are not damaged. Storage conditions have a notable impact on the waste rate of materials like sand. If the storage area lacks proper paving, sand can be lost and dispersed into the ground which contributes to waste. Similarly, rain may wash away sand that is not protected.

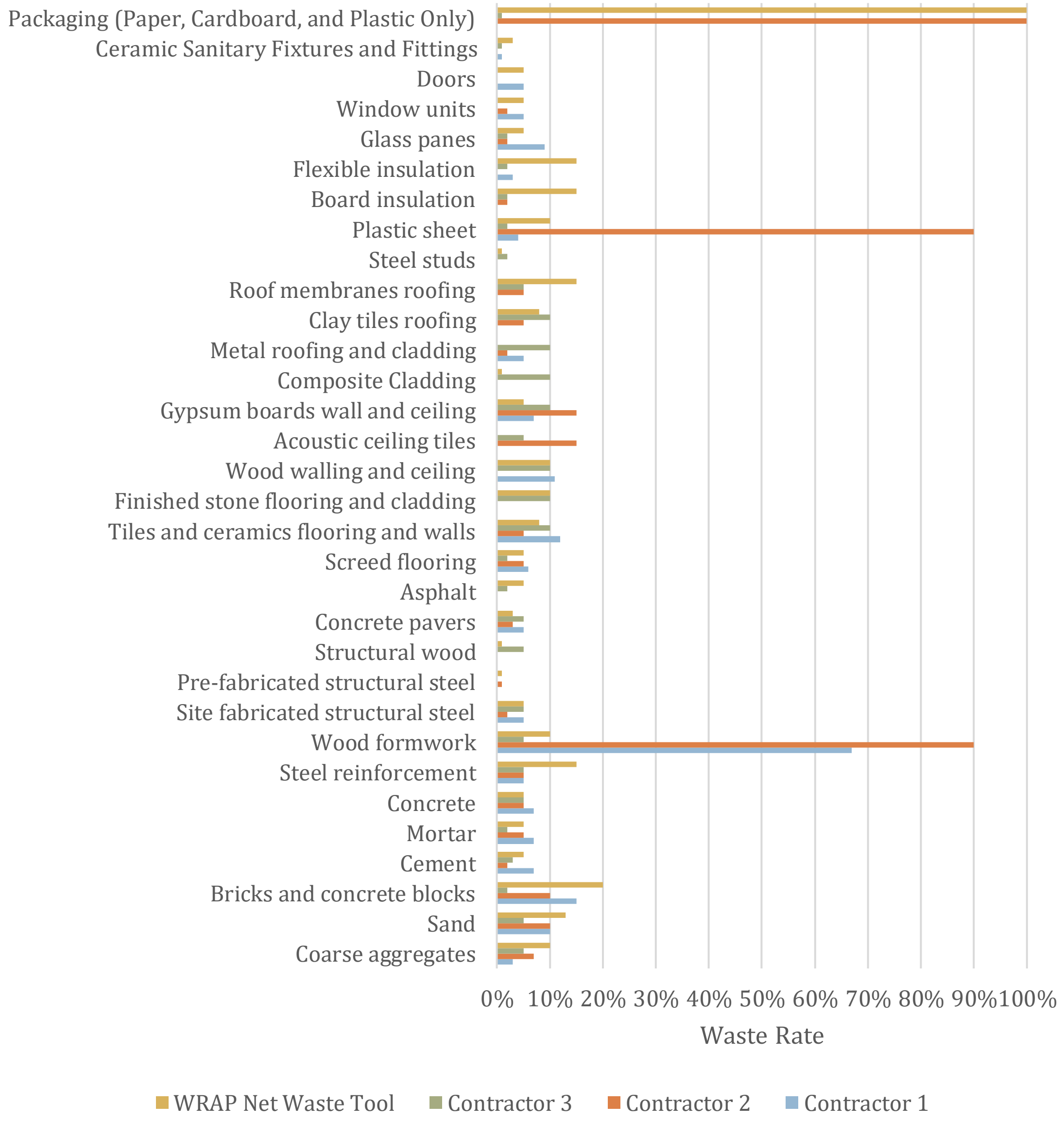


Figure 20: Waste rate comparison by material

Waste Streams

There are very limited formal recycling facilities that process construction waste in Rwanda. Anything that is defined as waste by the contractors is transported to landfill sites. Construction materials that are recycled on site, such as broken bricks for hardcore, are not included in these values. It should be noted that there are regulations on construction waste in Rwanda and it is enforced for larger projects, however this is only to ensure waste is sent to landfill, rather than disposing of it informally.

Even without formal recycling facilities, there is a level of informal recycling and reuse that occurs. It was identified that construction sites that adequately separate their waste and advertise its availability can attract people that would collect the waste. If this was the case the contractors did not identify it as waste. Contractor Nr. 3 separates waste into the categories identified in Table 11. Contractor Nr. 3 is the largest and had the most organised waste management of the three contractors. Their success in reducing waste rates can be seen in materials such as Wood Formwork, where at the end of a project they are able to sell it.

Segregated materials and products	**Potential waste stream**
Steel, aluminum, wood	Reasonable demand. Commonly metal is informally recycled and wood is used as fuel.
Ceramic tiles	Reasonable demand. Commonly used in mosaics.
Hardcore, rubble, concrete blocks, brick etc.	Low demand.
Vegetation	Very low demand.

Table 11: Waste segregated categories and potential waste streams beyond landfill as provided by the contractor on the Large Construction Site.

Unfortunately, this informal waste diversion from landfill is not guaranteed. It is also expected to differ between locations, with projects in larger cities able to utilise this more effectively.

Appendix H: Results from product service life survey

It is common to assume a building service life of 60 years, and within this period it is expected that certain systems, such as the envelope and finishes, will need to be replaced. The service life of these systems has a significant impact on the whole life embodied carbon of a building because every time a building system is replaced it assumes that the products are remanufactured and installed anew into the building.

Similarly, building components will be maintained and repaired throughout their lifespan which will also contribute to the embodied carbon footprint of the building, albeit less that wholesale replacement.

The RwEC assumes that the envelope, finishes, doors and windows have a service life of 30 years, and all other products have a service life equal to the building life. This means they are expected to be replaced once in the life of the building. This is a longer service life than some sources would suggest, however reducing the service life would mean the products are replaced at least twice in the life time of the building, giving more importance to the future replacement stage of a life cycle assessment, even though this is uncertain, and detracting from the production and construction stages of an LCA which are more certain and have a significant impact on climate change due to the time value of carbon.

It is understood that the service life of products can vary due to many factors, including environmental conditions. Therefore, this short study intended to discover how the expected service of products through discussions with facility managers of buildings in Kigali.

Discussion

Limitations

A major challenge to performing this study in Rwanda was that the more modern buildings that have a need for facilities managers have only been in existence for approximately 15 years. Therefore, it is not possible to collect data on product service life because this data does not exist but it suggests there is an opportunity to collect this data in the future. The discussion points primarily relate to maintenance and repair of products, rather than the complete replacement.

Lifespan due to workmanship

It is assumed that prior to building occupation, building quality is inspected and approved, however regardless of use defects can appear. These are often attributed to initial workmanship which is difficult to disprove.

Anecdotally the labour determines the frequency the replacement or repair. For instance, the HVAC systems are prone to leaks and in one building, the maintenance company identified that they repaired the system once and had no further issue leading them to the conclusion that it was the initial instalment that was at fault.

Lifespan due to product quality

Product quality goes a long way to affecting the product throughout its lifespan, and this is critical to components subjected to more wear and tear.

Detailing of the project such as waterproofing can inform the repair frequency, for instance at Silverback mall they relatively have to repair the paints due to mold issue on the walls which was not the case at Kigali heights

Lifespan due to building use

Both buildings we looked at are used for mixed commercial use, the silverback mall has a gym at the upper floor which often replaces partition walls and tiles on an almost 6 months basis.

Doors operated in high traffic areas, such as restaurants, will often require repair or replacement when compared to doors in areas of lesser traffic.

Bathrooms that were used by university students found themselves replacing the sanitary fixtures and tiles more often than the same space in the building that was used by university staff.

Appendix I: Embodied Carbon and Circularity CPD Series

A series of one hour long Continuous Professional Development sessions have been organised which are arranged into a curriculum applicable for all Built Environment Professionals (Table 12).

Title	**Primary Learning Objective**
Environmental challenges within the built environment	Understand how material and energy consumption are leading to global and local environmental impacts
How do you Measure Embodied Carbon?	Analyse embodied carbon using the RwECC and understand carbon hotspots within projects.
How do you Reduce Embodied Carbon?	Discover strategies for reducing embodied carbon in projects.
How do you Improve Circularity?	Discover methods for increasing circularity of buildings.
How do you Reduce Construction Waste?	Discover methods for reducing construction waste in the built environment.
How do you Improve Building Product Service Life?	Discover approaches for improving durability of building systems.

Table 12: Future proposed Continuing Professional Development sessions

Appendix J: Environmental Product Declaration

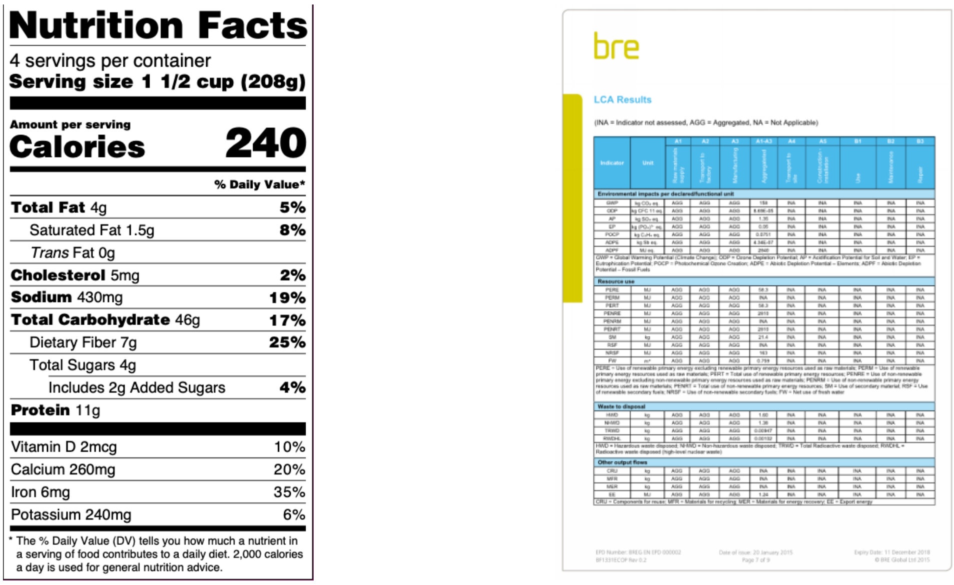
What is an Environmental Product Declaration?

An Environmental Product Declaration, or EPD, is a document which transparently communicates the environmental performance or impact of any product or material over its lifetime.

Every EPD provides the product’s carbon footprint – called the Global Warming Potential (GWP). In addition to carbon, the EPD contains environmental impacts to air, soil and water bodies. EPDs are often referred to as nutrition labels for products (Figure 21).

They are used by:

- Architects, engineers and designers to understand the impacts of their choices.
- Manufacturers to optimise the impact of their products and market their carbon transparency.



Nutrition Facts

4 servings per container

Serving size 1 1/2 cup (208g)

Amount per serving

Calories 240

	% Daily Value*
Total Fat 4g	**5%**
Saturated Fat 1.5g	**8%**
Trans Fat 0g	
Cholesterol 5mg	**2%**
Sodium 430mg	**19%**
Total Carbohydrate 46g	**17%**
Dietary Fiber 7g	**25%**
Total Sugars 4g	
Includes 2g Added Sugars	**4%**
Protein 11g	
Vitamin D 2mcg	10%
Calcium 260mg	20%
Iron 6mg	35%
Potassium 240mg	6%

* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

bre

LCA Results

(INA = Indicator not assessed, AGG = Aggregated, NA = Not Applicable)

Figure 21: EPDs are often referred to as nutrition labels for products

Why are Environmental Product Declarations important?

They help you meet your client’s needs

1. Help your clients to gain accreditation for green building certifications and access ESG restricted funding
2. Help your clients to choose low carbon products.

You need to stand out in a crowded marketplace

1. An EPD demonstrates commitment to sustainability. Once you have your EPD it can play an important role in your marketing to attract more clients and investors.
2. An EPD benchmarks your performance which allows you to showcase areas where your product excels.

You need to prepare your product for a carbon-focused market

1. Visualise your manufacturing process and supply chains. An LCA allows you to see a comprehensive inventory of all the components and substances used in your product, which can highlight production costs.
2. Future-proofing your product development. New rules and market forces are pushing us to a low-carbon future. BlackRock, responsible for $9trillion of assets, has said that the time has come to transition to net zero and put transparency at the heart of this.

How to get EPDs done efficiently and reliably?

Any member of this project team will gladly support your organisation to develop an EPD by facilitating a connection with specialist consultants.

Step 1. Collect data. Including raw material, resource consumption and waste data for your product.

Step 2. Conduct a life-cycle assessment.

Step 3. Prepare background report for EPD. The background report is a vital accompaniment to your public EPD.

Step 4. 3rd party verification. This ensures accuracy, reliability and ensures that the EPD conforms to the requirements of the relevant Product Category Rules.

Step 5. Publication. Once your EPD has been verified by an independent third party, it is ready to be put into the public domain via publication.

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