Measuring and Reducing Embodied Carbon in Rwanda’s Built Environment
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 and Arup.

The project is funded by the Royal Academy of Engineering’s Africa Catalyst Sustainable Infrastructure programme.

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Version 1, June 2022

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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).

![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 prepopingulating 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. Five 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

<table>
<thead>
<tr>
<th>Materials in a 6x8m single storey building</th>
<th>Quantity</th>
<th>Cradle to gate (A1-3) embodied carbon factor</th>
<th>Cradle to gate (A1-3) embodied carbon (Percentage of total embodied carbon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete C25/30 with 15% pozzolana</td>
<td>22m³</td>
<td>278.6 kgCO₂e/m³</td>
<td>6130 kgCO₂e (32%)</td>
</tr>
<tr>
<td>Steel reinforcement</td>
<td>2200kg</td>
<td>1.99 kgCO₂e/kg</td>
<td>4380 kgCO₂e (23%)</td>
</tr>
<tr>
<td>100mm thick brick wall, 12mm mortar joints</td>
<td>70m²</td>
<td>43.2 kgCO₂e/m²</td>
<td>3025 kgCO₂e (16%)</td>
</tr>
<tr>
<td>12mm thick ceramic tiles, 20mm mortar bed</td>
<td>50m²</td>
<td>22.3 kgCO₂e/m²</td>
<td>1115 kgCO₂e (6%)</td>
</tr>
<tr>
<td>Steel framed window with single glazing</td>
<td>10m²</td>
<td>55.3 kgCO₂e/m²</td>
<td>555 kgCO₂e (3%)</td>
</tr>
<tr>
<td>Steel roof sheet with battens, waterproofing</td>
<td>50m²</td>
<td>46.8 kgCO₂e/m²</td>
<td>2340 kgCO₂e (12%)</td>
</tr>
<tr>
<td>Acoustic ceiling tiles</td>
<td>50m²</td>
<td>11.0 kgCO₂e/m²</td>
<td>550 kgCO₂e (3%)</td>
</tr>
<tr>
<td>RHS 120x80x6 (18.2kg/m) rafters at 2m c/c</td>
<td>550kg</td>
<td>1.55 kgCO₂e/kg</td>
<td>855 kgCO₂e (5%)</td>
</tr>
<tr>
<td>Total cradle to gate embodied carbon of the building</td>
<td></td>
<td></td>
<td>189.45 kgCO₂e</td>
</tr>
<tr>
<td>Cradle to gate embodied carbon per gross floor area (6x8m)</td>
<td></td>
<td></td>
<td>395 kgCO₂e/m²</td>
</tr>
</tbody>
</table>

*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].

![Chart showing energy and emissions distribution](image)

*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.
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.

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.

![Diagram of embodied carbon calculation]

**Example Calculations**

<table>
<thead>
<tr>
<th>Material</th>
<th>CO₂e kg/kg Material</th>
<th>Embodied CO₂e</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 kg steel</td>
<td>0.43 kg CO₂e/kg steel</td>
<td>43 kg CO₂e</td>
</tr>
<tr>
<td>50 kg glass</td>
<td>1.064 kg CO₂e/kg glass</td>
<td>53.2 kg CO₂e</td>
</tr>
</tbody>
</table>

*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.
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.

<table>
<thead>
<tr>
<th></th>
<th>Structure only (kgCO₂e/m²)</th>
<th>Structure, enclosure and interior walls (kgCO₂e/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advised maximum</td>
<td>400</td>
<td>600</td>
</tr>
<tr>
<td>Advised target</td>
<td>200</td>
<td>300</td>
</tr>
</tbody>
</table>

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.
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.

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.](image-url)
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 Skat’s Rowlock bond [15]. *Figure 12* below shows the embodied carbon to practical completion for various wall types. The wall thicknesses have been normalised.
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.
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.

**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 EPDs

**Manufacturers**

- Develop carbon reduction targets, with timelines set to achieve net zero embodied carbon by 2050
- Develop new low carbon products
- All manufacturers have declared their entire standard product portfolios via EPDs
- All forms of energy are from renewable or low carbon sources and excess emissions are mitigated

**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.

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, we advise that you should 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$^3$ 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 14 and classified according to EN 15978 in Figure 15.

![Figure 14: Typical stages of a building’s life cycle](image-url)
Figure 15 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 (kgCO₂e).

The recommended embodied carbon calculation shall include A1-5, B4 and C4-4, 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 16. The external area should be attributed to the buildings proportionally to their gross floor area (GFA).
The reported building elements with examples are provided in Table 3. 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. Building services have not been included in the assessment because there is a lack of Environmental Product Declarations (EPDs) for the possible equipment. 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].

<table>
<thead>
<tr>
<th>Building elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substructure e.g. foundations, basement walls, slab on grade</td>
</tr>
<tr>
<td>Structural frame e.g. beams, columns, structural walls, suspended slabs, decks, trusses, purlins</td>
</tr>
<tr>
<td>Roof finishes e.g. tiles, roof sheeting</td>
</tr>
<tr>
<td>Stairs and ramps</td>
</tr>
<tr>
<td>Non-structure walls e.g. non-structural walls</td>
</tr>
<tr>
<td>Windows and doors</td>
</tr>
<tr>
<td>Internal walls and partitions</td>
</tr>
<tr>
<td>Wall finishes e.g. plaster, paint, tiles, cladding</td>
</tr>
<tr>
<td>Floor finishes e.g. screed, tiles, carpet</td>
</tr>
<tr>
<td>Ceiling finishes e.g. acoustic tiles, plasterboard</td>
</tr>
<tr>
<td>External works e.g. hardscape, pavement, parking surfaces, external retaining walls, culverts, drains</td>
</tr>
</tbody>
</table>

*Table 3: 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 kgCO₂e for the whole building (kgCO₂e) and by gross floor area (GFA) (kgCO₂e/m²). 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 CO₂ 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 4** provides recommended reinforcement estimates to be used unless otherwise known.
<table>
<thead>
<tr>
<th>Concrete element</th>
<th>Reinforcement estimate (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>100</td>
</tr>
<tr>
<td>Slabs</td>
<td>100</td>
</tr>
<tr>
<td>Foundations</td>
<td>100</td>
</tr>
<tr>
<td>Columns</td>
<td>400</td>
</tr>
<tr>
<td>Beams</td>
<td>220</td>
</tr>
<tr>
<td>Walls</td>
<td>110</td>
</tr>
<tr>
<td>Stairs</td>
<td>135</td>
</tr>
</tbody>
</table>

*Table 4: 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 5* presents some transport emission factors estimated using UK data for transport emissions [19]. It is expected that the values provided in the table 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.
<table>
<thead>
<tr>
<th>Manufacturing region and distance assumption</th>
<th>Distance by road (km)</th>
<th>Transport emission factor for road (gCO2e/km.kg)</th>
<th>Distance by sea (km)</th>
<th>Transport emission factor for sea (gCO2e/km.kg)</th>
<th>Effective transport emission factor (kgCO2e/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locally manufactured</td>
<td>50</td>
<td></td>
<td>0</td>
<td></td>
<td>0.011</td>
</tr>
<tr>
<td>Nationally manufactured (Average distance from Kigali to Huye, Musanze)</td>
<td>125</td>
<td></td>
<td>0</td>
<td></td>
<td>0.027</td>
</tr>
<tr>
<td>Regionally manufactured (Average distance from Kigali to Nairobi, Dar Es Salam, Kampala)</td>
<td>1,100</td>
<td>0.213</td>
<td>0</td>
<td>0.013</td>
<td>0.234</td>
</tr>
<tr>
<td>Globally manufactured (Approximate distance from Kigali to Mombassa or Dar Es Salam by road and from either of those ports to a Chinese port)</td>
<td>1,400</td>
<td></td>
<td>10,000</td>
<td></td>
<td>0.430</td>
</tr>
</tbody>
</table>

Table 5: 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 19.94 kgCO2e/m² for tropical countries by One Click LCA.
Table 6 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.

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

Table 6: Material and product waste rates

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 3.4 kgCO₂e/m² 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 7 can be used.

<table>
<thead>
<tr>
<th>End of life</th>
<th>Carbon emissions (kgCO₂e/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reuse/recycling on site</td>
<td>0</td>
</tr>
<tr>
<td>Reuse/recycling/landfill</td>
<td>0.005 (assuming 50km travel by road)</td>
</tr>
</tbody>
</table>

Table 7: 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 0.013 kgCO₂e/kg of inorganic waste and 2.15 kgCO₂e/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

<table>
<thead>
<tr>
<th>Life Cycle Stages</th>
<th>kgCO₂e/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material production (A1-3)</td>
<td>640</td>
</tr>
<tr>
<td>Material biogenic storage (A1-3)</td>
<td>-2</td>
</tr>
<tr>
<td>Transportation (A4)</td>
<td>74</td>
</tr>
<tr>
<td>Construction (A5)</td>
<td>93</td>
</tr>
<tr>
<td>In Use (B)</td>
<td>109</td>
</tr>
<tr>
<td>End of Life (C)</td>
<td>68</td>
</tr>
</tbody>
</table>
**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

<table>
<thead>
<tr>
<th>Life Cycle Stages</th>
<th>kgCO₂e/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material production (A1-3)</td>
<td>272</td>
</tr>
<tr>
<td>Material biogenic storage (A1-3)</td>
<td>-148</td>
</tr>
<tr>
<td>Transportation (A4)</td>
<td>50</td>
</tr>
<tr>
<td>Construction (A5)</td>
<td>65</td>
</tr>
<tr>
<td>In Use (B)</td>
<td>85</td>
</tr>
<tr>
<td>End of Life (C)</td>
<td>242</td>
</tr>
</tbody>
</table>
**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

<table>
<thead>
<tr>
<th>Life Cycle Stages</th>
<th>kgCO₂e/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material production (A1-3)</td>
<td>269</td>
</tr>
<tr>
<td>Material biogenic storage (A1-3)</td>
<td>-21</td>
</tr>
<tr>
<td>Transportation (A4)</td>
<td>27</td>
</tr>
<tr>
<td>Construction (A5)</td>
<td>55</td>
</tr>
<tr>
<td>In Use (B)</td>
<td>46</td>
</tr>
<tr>
<td>End of Life (C)</td>
<td>67</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Life Cycle Stages</th>
<th>kgCO₂e/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material production (A1-3)</td>
<td>1092</td>
</tr>
<tr>
<td>Material biogenic storage (A1-3)</td>
<td>0</td>
</tr>
<tr>
<td>Transportation (A4)</td>
<td>71</td>
</tr>
<tr>
<td>Construction (A5)</td>
<td>157</td>
</tr>
<tr>
<td>In Use (B)</td>
<td>193</td>
</tr>
<tr>
<td>End of Life (C)</td>
<td>87</td>
</tr>
</tbody>
</table>
## Appendix D: Embodied carbon reduction strategies

<table>
<thead>
<tr>
<th>Group elements</th>
<th>Use less material</th>
<th>Use less embodied carbon intensive materials</th>
<th>Durability, adaptability and disassembly</th>
</tr>
</thead>
</table>
| 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 | • 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. |
wherever possible.

<table>
<thead>
<tr>
<th>Superstructure</th>
<th>Envelope</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Preserve and re-use existing structures wherever possible.</td>
<td>- Avoid brittle facades, such as glass, so seismic drift limits do not govern the structural design</td>
</tr>
<tr>
<td>- Review and reduce loading requirements wherever possible.</td>
<td>- Minimise glazing beyond what is needed for good building performance</td>
</tr>
<tr>
<td>- If using steel, use castellated beams or trusses to reduce material volume and weight and allow services to run through.</td>
<td>- Use durable materials to reduce the number of times the envelope needs to be replaced. Good</td>
</tr>
<tr>
<td>- If using concrete, consider forms that minimise material use, such as coffered slabs.</td>
<td>- Separate structural elements from elements that will change or move in the future, such as envelopes or interior walls.</td>
</tr>
<tr>
<td></td>
<td>- 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</td>
</tr>
<tr>
<td></td>
<td>- Avoid composite materials which may be hard to deconstruct in the future.</td>
</tr>
<tr>
<td></td>
<td>- Design connections to be visible and reversible such as bolts and screws rather than welds or glue.</td>
</tr>
<tr>
<td></td>
<td>- Consider low embodied carbon materials such as timber, stone and earth</td>
</tr>
<tr>
<td></td>
<td>- If using steel, prioritise high recycled content and shorter transport distances to site.</td>
</tr>
<tr>
<td></td>
<td>- Consider hybrid structures that optimise the performance of each material.</td>
</tr>
<tr>
<td></td>
<td>- Use 56-day strength concrete, if the construction schedule allows, and a high cement replacement mix.</td>
</tr>
<tr>
<td></td>
<td>- All timber should be from regulated and responsible sources.</td>
</tr>
</tbody>
</table>
- 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.
- Insulation choices should be assessed as part of a whole life carbon study alongside the operational carbon 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 | Use earth bricks for non-structural walls instead of fired brick or concrete blocks. | The use of natural materials like | Attach finishes assuming they will be removed in 10 years. | Avoid the use of glues and adhesives that will make |
under layers of materials such as plasterboard.
- Design to use the full dimensions of off-the-shelf materials to avoid waste by reducing offcuts.
- Linoleum, water-based eco paints, cork, bamboo and timber.
- Recycled products use no raw materials and are increasingly available.
- Separation at end of life difficult
- Durable materials will last longer, and require fewer replacement cycles over a building’s lifespan.

<table>
<thead>
<tr>
<th>Building services</th>
<th>Passive design and natural systems will reduce equipment and provide resilience</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Use simple, straight ducting routes to reduce duct material</td>
</tr>
<tr>
<td></td>
<td>Avoid refrigerants where possible and use chilled water instead.</td>
</tr>
<tr>
<td></td>
<td>Consider the potential impacts of future climate change and how best to avoid the need for extensive retrofit.</td>
</tr>
<tr>
<td></td>
<td>Provide easy access for regular inspections and maintenance.</td>
</tr>
<tr>
<td></td>
<td>Use systems that are appropriate for the context so they can be maintained locally</td>
</tr>
<tr>
<td></td>
<td>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.</td>
</tr>
</tbody>
</table>
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 8 provides some examples of existing project requirements and how these can be achieved while also reducing embodied carbon.

<table>
<thead>
<tr>
<th>Project aims</th>
<th>Embodied carbon reduction strategies that also achieve the project requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Award winning building</td>
<td>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.</td>
</tr>
<tr>
<td>Meet client or funder’s sustainability goals</td>
<td>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.</td>
</tr>
<tr>
<td>Low costs</td>
<td>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.</td>
</tr>
<tr>
<td>Low maintenance</td>
<td>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.</td>
</tr>
<tr>
<td>Quick construction</td>
<td>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.</td>
</tr>
<tr>
<td>User wellbeing</td>
<td>Using natural materials, which are low in embodied carbon, can provide better indoor air quality and biophilic effects.</td>
</tr>
<tr>
<td>Future adaptability</td>
<td>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.</td>
</tr>
<tr>
<td>Invest locally e.g. Made in Rwanda</td>
<td>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.</td>
</tr>
</tbody>
</table>

*Table 8: Achieving project requirements with embodied carbon reductions*

The LETI Embodied Carbon Primer [9] contains helpful tips on how designers can talk to clients about embodied carbon.
References


