Module 5
Building Materials & Systems
Circular Economy in Construction

MODULAR BUILDINGS
To equip the learner with the relevant knowledge required to understand the impact of material and systems selection and installation for circular buildings.
1. Explain the **impact that material and system selection** can have on the building and operational carbon emissions
2. Understand the importance of providing a circular building taking into consideration the **occupant’s health and wellbeing**, and the building life in the future.
3. Outline **challenges in maintaining the value of materials and products in the economy** for as long as possible, reducing resource use and preventing waste on site.
4. Outline the **use of construction techniques that promote the durability of buildings** and the resilience of the materials
5. Outline the **use of construction techniques that promote the adaptability of buildings**
Topic 1 – Circular materials and systems in buildings

Topic 2 – Circular construction techniques
1. Circular materials and systems in buildings
Circular economy principles in materials and buildings

How do we apply Circular economy principles in materials and buildings?

It is a process that involves long-term thinking and a whole life-cycle approach in order to optimise performance, value and longevity of a building project.

- Circular economy can be applied across the entire building lifecycle from design, construction, and operation through to disassembly and re-purposing or reuse.

- It addresses
  - resource efficiency, ensuring properties are designed for longevity
  - efficiency and flexibility in the use of space.
When reusing a product or a building, you are also **saving on embodied carbon**.

- This is the carbon dioxide emitted during the manufacture, transport and construction of new building materials, together with end of life emissions.

*Image source: IGBC*
A building consists of a number of elements, such as

- the **structure and fit-out** (materials in core, shell, internal partitions, fit-out),
- its **systems** (equipment, HVAC, water and waste) and
- its **occupants** (people).

There is also **ground works** required to construct a building, such as foundations, parking spaces, outdoor areas, etc., all of which require a significant amount of energy and resources.

**Question:** How can we better design in order to use fewer resources?
Materials

In a traditional building cycle, virgin, raw materials are extracted, used and thrown away after demolition.

But not anymore.

- **Clients** are increasingly viewing material procurement and waste as a high risk to their businesses.
- **Product manufacturers** are also shifting to a circular economy model, placing production (based on recycled or renewable resources), repair, reuse and recycling at the heart of a cyclical process.
- **The building industry is shifting** from ‘product’ to ‘service’ by leasing, maintaining, repairing and reselling products.
Zero waste = Maximise resources!

Construction Waste

- In Ireland it is estimated in [a report from 2019](#) by the Irish Concrete Federation that the current demand for construction aggregates in Ireland is **twice the average demand in the EU**.

- An estimated 400 tonnes of aggregate is required for a typical Irish home. 4.75 million tonnes of **construction and demolition waste** were produced in Ireland in 2019 with over 80% comprising of soil and stones.

- Whilst no comparable figures exist for Ireland, in the UK the construction industry accounts for approximately **60% of materials used**.

- Therefore, there is huge **opportunity in the construction industry** to re-think the input to output process and **to implement circular economy principles to reduce waste and increase materials reuse**.
A goal of circular economy is to develop a supportive system that enables the building industry to reuse surplus materials (from demolition or construction waste) in other projects.

This process has a potential cost saving and embodied carbon reduction.

A material banking platform can be used so that materials can continue to be in use after their first cycle of life.
Further reading - examples of CE

Read about how to reuse glass from one building project to another one, [here](#) for the **Building Glass into Circular Economy How-to guide**!

learn about the reuse of steel tubes while ensuring traceability through a pipe numbering system, read [here](#).

learn about the **Materials Passports Platform prototype** for materials banking [here](#).

the **Oisín House** case study, a five-storey 1970’s office block in Dublin City centre (read [here](#)), shows that processed concrete arising on site from demolition can be used for other purposes.

Further reading - examples of CE

Energy Efficiency for Construction: Building Materials and Systems

[Insert Organisation Logo Here](#) for illustrative purposes only. Delete this stage from final production.

Technological University of the Shannon: Midlands Midwest

For illustrative purposes only. Delete this stage from final production.

Liam Ó hAilpin

Liam Ó hAilpin
Existing buildings

- Buildings are currently under-utilised. According to the GeoView Commercial Vacancy Report in Ireland it is estimated that 13.3% of all commercial property is vacant varying from 18% in Sligo to 10% in Meath.

- Efficient use of existing stock avoids the need for new resources and reduces the embodied carbon of the built environment.

- This circularity may have environmental, economic and social impacts via the regeneration of existing urban areas, the reduction of construction noise, traffic and pollution, and the saving of raw resources.
Renovation is Circular

RENOVATING & REFURBISHING USES FAR LESS MATERIAL
We already spend about 90% of our time inside buildings. This statistic must encourage us to ensure we design **sustainable buildings with healthy indoor environments**, operate them efficiently and ensure they last for a long time.

*Image source: Harvard School of Public Health*
2. Circular construction techniques
Circular construction aims to close building material loops by **reusing, sharing, leasing, repairing, refurbishing, upcycling or recycling** rather than continuing the traditional take-make-consume-dispose process.

It involves **considering how to maximise the lifespan and reusability of entire buildings or materials at the very start of the design process**.

Many techniques, tools and approaches related to circular construction have been developed and tested around Europe.
On-site, prefabrication and modular

**ON-SITE CONSTRUCTION**
- Structure built on site
- Longer construction time
- Creates more mixed waste
- Uses more material

**PREFAB + ASSEMBLY**
- Elements made in factory and assembled on site.
- Shorter site time
- Less site wastage.
- Saves material in case of concrete.

**MODULAR BUILDINGS**
- Large building blocks made in factory and lifted on place
- Short site time
- Material efficiency varies
- Can be moveable
ON-SITE CONSTRUCTION
Wood: stick frame
Material efficient, may need weather protection.

Concrete: cast-in-place
uses lot of concrete, may need heat. No reuse later.

Stone/brick/rammed earth
on site built structures, typically for low-rise

PREFAB + ASSEMBLY
Wood: clt / lvl / elements
may use more material, fast to build

Concrete: prefabricated
uses less concrete, initial curing in the factory

Steel: steel frame factory made structure, with enclosure assembled

Light weight ext. Walls factory made structure, and a lighter enclosure

MODULAR BUILDINGS
Modular wood buildings
low carbon footprint, but may damage easier if moved

3d printed buildings
other 3d printed buildings

Modular steel buildings
factory made structure, with enclosure assembled
Most construction methods allow for deconstruction, if **designed for disassembly**.

**UN-DOABLE CONNECTIONS**

**NO NAILS, NO CHEMICALS**

**CONNECTION DESIGN**

Design for Disassembly
Salvage and Deconstruct

Materials can then be salvaged and deconstructed for reuse (partial or full)

FOR REUSE ELSEWHERE

FOR REUSE ON SITE
Construction materials: carbon emissions

Embodied carbon breakdown by material type for key building types

- Commercial: 41% Concrete (all types), 27% Steel (all types), 13% Other metals, 8% Insulation, 5% Gypsum, cement and mortar, 3% Doors, windows and glass, 3% Other materials
- Industry: 45% Concrete (all types), 39% Steel (all types), 5% Other metals, 3% Insulation, 3% Gypsum, cement and mortar, 1% Doors, windows and glass, 1% Other materials
- Education: 42% Concrete (all types), 30% Steel (all types), 1% Other metals, 5% Insulation, 3% Gypsum, cement and mortar, 4% Doors, windows and glass, 4% Other materials
- Office: 43% Concrete (all types), 28% Steel (all types), 5% Other metals, 3% Insulation, 5% Gypsum, cement and mortar, 3% Doors, windows and glass, 3% Other materials
- Residential: 45% Concrete (all types), 22% Steel (all types), 4% Other metals, 5% Insulation, 3% Gypsum, cement and mortar, 3% Doors, windows and glass, 3% Other materials

[https://www.oneclicklca.com/eu-embodied-carbon-benchmarks/](https://www.oneclicklca.com/eu-embodied-carbon-benchmarks/)
Construction material types

- MINERAL-BASED
- METAL-BASED
- CHEMICAL-BASED
- BIO-BASED
- + COMPOSITES & ASSEMBLIES
Main construction product value chains

**Primary Manufacturing**
- **Extraction**
  - Aggregates
  - Limestone
  - Gypsum
  - Clay
- **Raw Materials**
  - Non-metal minerals
    - Aggregates
    - Limestone
    - Gypsum
    - Clay
  - Metals
    - Iron ore
    - Bauxite
  - Wood
    - Logging
    - Sawn wood
  - Chemicals
    - Oil / Natural gas
    - Biochemicals
- **Product Manufacturing**
  - Semi-finished
    - Asphalt
    - Ready-mix
    - Steel traders
    - Aluminiun extrusion
    - Wood boards
  - Final Products
    - Precast
    - Gypsum products
    - Fabricators
    - Aluminium products
    - Plastic extrusion
    - Advanced chemicals
    - Building chemicals
- **Systems Manufacturing**
  - Sub-systems
    - Wall systems
    - Cross-lam / lvl
    - Building elements
  - Systems
    - Metal systems
    - Wood systems
    - Plastic systems

= product sold to projects
Material processing

Mineral-based construction materials from the least processed to heavily thermally processed and their carbon impact

LOW PROCESSING

HEAVILY THERMALLY PROCESSED

- Slaked Lime
- Cement
- Glass
- Concrete
- Mineral Wool
- Fired Bricks
- Asphalt
- Gypsum Products
- Natural Stone
- Alternative Binders: Slags, Ashes
- Rammed Earth
- Sun-Dried Bricks
- Crushed Concrete

Energy Efficiency for Construction: Building Materials and Systems

Co-funded by the Erasmus+ Programme of the European Union
# Environmental impacts of materials

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Mineral-based</th>
<th>Metal-based</th>
<th>Chemical-based</th>
<th>Bio-based</th>
<th>Composites / assemblies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>Easily extracted, typically local material</td>
<td>Energy intensive to extract, often imported</td>
<td>Oil-, natural gas- or bio-based chemicals. Upstream emissions</td>
<td>Wood or plant fibre, or wool or fungi. Stores bio-based carbon.</td>
<td>Any mix or combination of the previous</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>Thermal &amp; chemical carbon impacts for limestone, gypsum</td>
<td>Very energy intensive primary manufacturing, also process emissions</td>
<td>Mostly in precursor manufacturing, less in final manufacturing</td>
<td>Often relatively low impact even if treated</td>
<td>Limited for assemblies, often higher for composites</td>
</tr>
<tr>
<td>Transport</td>
<td>Often local but very massive materials</td>
<td>Commodities – trans-ported long distances</td>
<td>Depending on material – limited</td>
<td>Can be also very long – light materials</td>
<td>Depends on product mass and value</td>
</tr>
<tr>
<td>Use</td>
<td>Lasts very long. May carbonate in use. Has thermal mass.</td>
<td>Lasts very long.</td>
<td>Lifetime depends on application(s) and exposure(s)</td>
<td>Often is treated (but it is a choice), increases maintenance</td>
<td>Depends on product</td>
</tr>
<tr>
<td>End of life</td>
<td>If deconstructible, can be reused, or alternatively crushed</td>
<td>Easy to disassemble, recycles, forever, commercially salvaged</td>
<td>Currently, landfilled or incinerated but more and more raw material recycling</td>
<td>Currently, often incinerated/landfilled, but could be salvaged for new applications</td>
<td>Hard to recover for composites but assemblies can be used as they are</td>
</tr>
</tbody>
</table>
➢ **New construction methods** that avoid the use of concrete, which constitutes the largest component of CDW, have a high impact on the reduction of waste.

➢ The **off-site manufacturing** of 3-D modules, like roofs, block work or external insulation, the substitution of concrete frames with timber or steel, pre-cast or composite panels have a waste reduction potential of up to 90%

➢ The resource-efficient use of concrete and the possibility to **deconstruct it and reuse it**, besides from being economical and reducing costs, is also important because of concrete production’s environmental impact.
➢ The production of concrete depends on the extraction of sand and gravel, which has negative environmental impacts as it destabilises riverbeds, putting farming land at higher risk of flooding and leaving coastal communities more vulnerable to storm damage.

➢ With sand becoming scarcer and more expensive, illegal sand extraction is taking place, destroying ecosystems. Up to 10% of sand in concrete can be replaced by plastic, without affecting the structural integrity of the material.
Cement is made by heating crushed limestone in a kiln to 1400 °C (2500 °F) to create clinker.
Cement climate impacts arise due to the calcination process and process fuel use.

**TYPICAL IMPACT**

In EU, around 700 kg co2e / ton, of which more than one half due to calcination in the process. Varies by region and supplier

**LOWER CARBON OPTIONS**

Alternative binders: blast furnace slag & other geopolymers, fly ash, rice husk ash and other pozzolans & gypsum and range of innovative technologies*

*https://gccassociation.org/cement-and-concrete-innovation/alternative-binders/
The cement industry is extremely sensitive to climate change regulations and taxes.
Ready mix concrete is made by mixing cement, water, aggregates & admixtures. Curing happens in formwork on site.
Ready mix concrete climate impact is mostly due to cement it’s using

**TYPICAL IMPACT**

Depending on strength class, ca 200-500 kg CO2e / m³ (or 100 kg per ton). Varies by region & exposure class.

**LOWER CARBON OPTIONS**

Substitute cement with alternative binders, longer curing time (e.g. 90 or 60d instead of 28d)
Precast concrete is made by preparing reinforcement with connections in a mould. Concrete is then poured in a factory for curing.
Precast environmental impact is mostly due to cement and rebar, and possible insulation.

**TYPICAL IMPACT**

Depends completely on the function of the product in question, as strength and amount of reinforcement is based on function.

**LOWER CARBON OPTIONS**

Substitute cement with alternative binders, use hollow core products, consider bubbledeck, or other element design strategies.
Concrete blocks are massive, having both high material use and high structural load. They are laid either with mortar or reinforcement, or use both.

**SOLID BLOCKS**
- High load bearing ability & CO2 impact

**HOLLOW BLOCKWORK**
- Much lighter, hence lower impacts, also very limited load bearing ability

**ALTERNATIVE MATERIALS**
- Leca blocks, cinderblocks, autoclaved aerated concrete - lighter but limited load bearing
Not even 1% of the world’s concrete buildings are deconstructed at end of life...

**HIGH CARBON MATERIALS**

- **CEMENT**
  - 4 gigatons ~8% of global GHGs

- **STEEL**
  - 3 gigatons ~6% of global GHGs

**DURABLE PRECAST PRODUCTS**

**HIGH CARBON WASTE**
Steel is made by Electric Arc Furnace & Basic Oxygen Furnace processes at 1800/1600°C, with preliminary iron reduction to remove oxygen from ore.
Steel and aluminium

Steel manufacturing impacts are driven by fossil fuels & energy use in primary steel making

TYPICAL IMPACT

Steel carbon footprint is directly proportional to the recycled content, but also heavily influenced by manufacturing energy mix and process energy efficiency (and feedstocks)

LOWER CARBON OPTIONS

Most important at global/policy level is to favour low carbon primary steel (as scrap only covers 25% of global demand), but for project results the recycling rates make a big difference too
Aluminium is made by chemically & thermally processing bauxite to alumina which is then electrolyzed at temperature of 950°C.
Typical impacts for primary aluminium

Average impacts for primary aluminium ingot

<table>
<thead>
<tr>
<th></th>
<th>kg CO₂e per kg aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average primary aluminium from China</td>
<td>20</td>
</tr>
<tr>
<td>Average primary aluminium used globally</td>
<td>16.7</td>
</tr>
<tr>
<td>Carbon Trust limit for low-carbon aluminium</td>
<td>8</td>
</tr>
<tr>
<td>Typical low-carbon aluminium</td>
<td>6.67</td>
</tr>
</tbody>
</table>
Range of aluminium impacts is vast, when recycling rates are considered.

Benchmark for Aluminium, 333 products, KG - CO2 CML

The benchmark data does not consider local compensation. Results after compensation may vary.

Select threshold: Cut off 10%

To narrow down visualised ranges, click names of undesirable quintiles to remove them from the graph.

Very high • High • Average • Low • Very low

Your material: Anodised aluminium coil and sheets, for wall cladding – 10.0 kg

CO2 CML

Building Materials and Systems

Neighbouring countries

All

One Click LCA

Co-funded by the Erasmus+ Programme of the European Union
Steel and aluminium

Metals are extremely recyclable, but focus should still to be on reuse as product and favouring low-carbon primary production

STEEL SCRAP COVERS 25 % OF GLOBAL DEMAND

ALUMINIUM SCRAP COVERS 30 % OF GLOBAL DEMAND
Wood and Wood-based products

**DO’s**

- Consider material efficiency
- Consider end of life utilisability
- Consider impact of chemicals and additional protective layers timber structures would require
- Consider mass reduction timber allows to achieve for structures and foundations

**DON’Ts**

- Use illegally logged timber or timber from unsustainable forestry
- Let timber get landfilled at end of life (this causes huge methane emissions)
- Use unnecessary treatment or painting if not functionally required
- Don’t think carbon storage is permanent unless you secure reuse
TYPICAL IMPACT

Sawn timber has naturally lower impacts than clt, glulam or lvl

LOWER CARBON CLT

Manufacturers also have some differences between products, but be wary of their accounting methods.
There’s a vast range of types of insulation

https://www.ecopassivehouses.com/insulation-materials/
**DO’s**

- Avoid spray foam and foam insulation with unspecified blowing agents (esp. Outside eu/eea)
- Prefer recoverable insulation (avoid chemical bonds with moisture barrier)
- Consider low-carbon or carbon-storing insulation materials
- Consider impact of insulation layer thickness on total structural materials demand (if walls become 100mm thicker, what does it mean)

**DON’Ts**

- Allow for use of spray foam and use of unspecific foam insulation materials
- Reduce insulation to grow energy use without considering life-cycle impact
- Forget to recycle clean insulation waste for built on site projects
Gypsum

Gypsum is recovered both from nature and from the flue gas of coal-fired power plants and used in several types of construction products

**GYPSUM BOARDS**
Installed with steel or wood studs, do ensure adaptable installation

**FINISHING PLASTER**
For levelling non load bearing surfaces

**FLOORING SCREED**
Alternative to cement flooring screeds
Float glass is made from silica sand in an integrated process in temperature of up to 1600°C. Once made, it lasts for a very long time.
Bricks have a climate impact themselves, and they are laid using a cement-based mortar.

**FIRED BRICKS**
Fired clay. Impact mostly from the fuel.

**AIR-DRIED BRICKS**
Not load bearing (unless cementious)

**RECLAIMED BRICKS**
Separated from the mortar already

**WALL SECTIONS**
Sections from walls come with mortar.
Assessment

QUIZ!
Thank You