Timber and Concrete Sustainability Study

December 2023

Introduction

When assessing the sustainability benefits and drawbacks of structural materials, understanding the impacts beyond "carbon" or "net zero" is vital if we are to properly address sustainability and resilience of the built environment. The risk of missing a benefit or doing unintended environmental harm is reduced when multiple sustainability aspects, such as biodiversity and social value, are considered alongside the more traditional carbon accounting.

This document looks at timber and concrete as structural materials within the context of the UK construction industry, exploring their benefits and drawbacks under the following five sustainability themes:

1. Biodiversity
2. Embodied carbon/net zero
3. Health and wellbeing
4. Social value
5. Circularity

The report is intended to be impartial, with a summary of relevant information and associated evidence or research presented for both timber and concrete to provide some context to wider sustainability issues. It is hoped that this will allow designers and clients to ask relevant questions of their projects and understand the materials in a more holistic way.

The study identifies that in the context of the above, neither material is without its drawbacks. This highlights the importance of closely assessing different materials on an individual building or use basis.

01

Biodiversity

Plummeting biodiversity is rapidly gaining attention as one of the most important crises of our time. Addressing it requires a different perspective to carbon, as biodiversity and ecosystems are complex, and metrics, best practice and legislation specific to the built environment are still in their infancy.

Globally the construction industry threatens nearly one third of the world's most endangered species and the UK is one of the most biodiversity depleted countries in the world [1]. The 2021 Environment Act requires most developments in England to deliver at least a 10% improvement to the biodiversity value of sites, from November 2023 [2]. Similar to the Paris Agreement for the climate, the UK has committed to the biodiversity targets of the Kunming-Montreal Framework to be achieved by 2030 [3]. As a result it is important that engineers understand the biodiversity impacts of their decisions and material choices.

Biodiversity

Material sourcing

Both timber and concrete start as naturally occurring resources and must be felled or quarried prior to manufacturing and use in construction. Timber is a renewable resource, while concrete and aggregates come from mineral deposits that have built up over millennia and are not renewable.

Timber

Timber used in construction is grown in natural forests or managed plantations. The average rotation cycle (the time it takes for a new tree to grow after harvest) in the UK is 35 years, in continental Europe and Scandinavia it is 70-75 years [4]. Almost all (94%) of sawn softwood used for building in the UK is imported from the EU [5].

FSC and PEFC are certification programmes accepted as proof for legal and sustainable timber procurement. Both are imperfect, and have been subject to criticism, including around checking compliance from supply chain members, transparency, and whether they do ultimately protect biodiversity and prevent habitat loss [6][7]. Currently over 90% of timber imported to the UK is PEFC or FSC certified [8].

Concrete

Concrete production requires extraction of limestone, sand and gravel from quarries. These are finite resources. In England alone there are over 2,000 quarries, covering 64,000 hectares (0.1% of the country's land area [9]) producing a wide range of minerals that include construction aggregates and building stone [10]. Sand and gravel are also dredged from the seabed around the UK to provide high quality aggregate. Dredging can negatively impact marine life by changing water and sedimentation flow [11].

Tree plantation

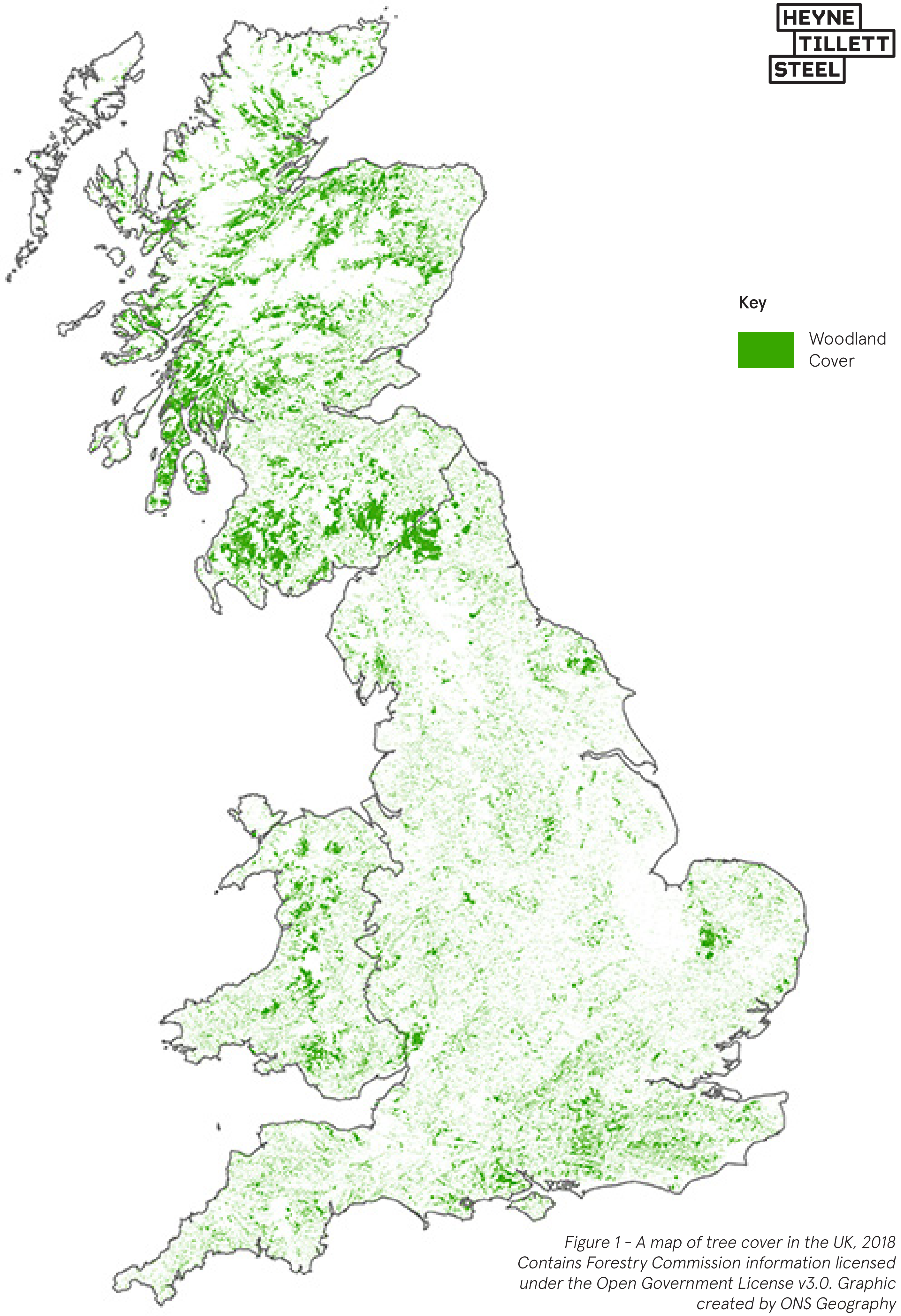

Figure 1 - A map of tree cover in the UK, 2018
Contains Forestry Commission information licensed under the Open Government License v3.0. Graphic created by ONS Geography

Biodiversity

Manufacturing and production impacts

Both timber and concrete production can have significant impacts on biodiversity. Timber monocultures do not support biodiversity but use land relatively efficiently. Harvesting timber from natural forests can lead to deforestation, a disaster for biodiversity. Quarries destroy habitats and restoration projects can take decades.

Timber

Biomass extraction is responsible for most of the biodiversity loss in the UK [12].

A low-rise timber building requires over 50 times the amount of forest land area compared to a quarry for concrete, for an equivalent building [13] *however, this claim is from the Global Cement and Concrete Association, and it might be misleading.* Nevertheless, there is a clear tension here: highly productive monoculture plantations lack biodiversity but use land efficiently, while harvesting timber from natural forests leads to deforestation and habitat degradation. Globally, timber for construction is linked to forest degradation.

Growing sustainable timber with biodiversity benefits requires well-managed, highly productive plantations of diverse native species. Diverse plantations grow more efficiently and store more carbon than monocultures, and native tree species provide better protection to biodiversity [14]. Despite their limitations, FSC and PEFC certify sustainably managed plantations. A Swedish study showed forest biodiversity has improved in the last 20 years [15], showing that forests can be sustainably managed to provide commercial timber and provide a biodiverse habitat.

At the end of its useful life, a small percentage of timber is sent to landfill. Landfills have harmful effects on biodiversity and any material that adds to the waste contributes to the environmental impact.

Concrete

The quarrying industry's main impact on biodiversity is during excavation. Quarries and mines cover 0.9% of the land area in England, but almost half are in sensitive landscapes such as AONBs and National Parks. Creating a quarry destroys habitats and the species they support [16][17].

Quarrying can have secondary effects such as noise, dust, pollution, waste and increase in traffic movements all of which can have negative impact on plants and animals [16]. There can also be other indirect damage to ground or surface water which affects surrounding habitats [16].

Around half of the UK's biodiversity is found in the seas [18]. Proper aggregate dredging methods can minimise the impact on geomorphology and ecology - the effects on flora, infauna, and the seabed are relatively well documented, but impacts on marine mammals are less well understood [19]. The British Marine Aggregate Producers Association (BMAPA) publishes figures annually to show the extent of dredging operations, however it does not comment on biodiversity gain [20].

Quarry restorations (with careful planning) can make a major contribution to biodiversity. Some quarries are better adapted for natural regeneration than others, such as gravel workings where open water will be left, compared to those where the ground is likely to remain bare or only sparsely vegetated. Recreational facilities are an alternative to natural restoration. Ripon City Wetlands is a wildlife haven created in a partnership between the aggregates industry and the Yorkshire Wildlife Trust. It was a working quarry until 2003 when it began transforming into a "living landscape" of wildlife habitats that are well managed and joined up [21]. This provided £1.4 million of biodiversity net-gain, but also provide £350,000 of recreational benefits [22].

Once concrete reaches the end of its life it is usually crushed and reused as aggregate. However, in 2018 the UK sent 5 million tonnes of construction and demolition waste to landfill having recovered or downcycled 63 million tonnes of construction waste [23]. Landfill sites require wild land to be cleared, they introduce rats and crows to local wildlife populations, pollute local streams and lakes and reduce the fertility of the soil, all of which have a negative impact on biodiversity [24].

Active quarry

Former quarry

02

Embodied Carbon / Net Zero

Embodied carbon is a measure of the greenhouse gases emitted to the atmosphere from the production of a material. It accounts for the raw materials being mined, manufactured, transported, and constructed on site, as well as maintenance, repairs, and eventual disposal/recycling at end of life. Embodied carbon is a useful measure because it can be directly quantified and used to objectively compare one material to another.

Embodied Carbon / Net-Zero

HEYNE TILLETT STEEL

Direct lifecycle carbon emissions

Direct lifecycle carbon emissions are from the manufacture, construction and use of the materials. Timber temporarily stores carbon and reduces emissions. Cement production emits high levels of carbon, which can only be partially offset by carbonation. The comparison is not that straightforward as concrete cannot simply be swapped for timber in all applications, particularly below-ground and highly stressed uses.

Timber

Embodied carbon emissions from timber come from felling and planting operations, transportation, and manufacturing raw timber into engineered products. One m^3 of sawn timber joists has about 175 kg embodied carbon. One m^3 of engineered timber, such as cross-laminated timber (CLT) or glue-laminated timber (glulam), has about 230-360 kg embodied carbon (both A1-5 for typical UK project).

However, timber also absorbs carbon dioxide from the atmosphere as it grows, storing it in its cellular structure, and releasing it back to the atmosphere when the timber rots or is burnt. About 750 kg of CO_2 is sequestered in every m^3 of timber. This carbon is known as "biogenic" or "sequestered" carbon. Using timber in long life products such as structural elements helps prevent sequestered carbon release back to the atmosphere for as long as possible.

Concrete

The embodied carbon of concrete is mainly due to cement manufacturing, up to 97% for a typical C32/40 mix. Making cement requires very high temperatures and lots of fuel. In addition, about half the carbon dioxide emissions are due to the chemical reactions occurring within the kiln - this means that current cement production is impossible to decarbonise.

One m^3 of reinforced concrete has about 600 kg embodied carbon (C32/40 with 0% GGBS, A1-5 for a typical UK project). The embodied carbon of concrete varies widely, depending on its strength and constituent ingredients.

Once the concrete has hardened, carbonation begins. Carbonation is a natural chemical reaction between the concrete and the surrounding air, resulting in CO_2 reabsorption. This process happens slowly throughout the lifetime of a building and varies based on multiple factors, such as are the area of exposed surface and the concrete porosity. Excessive carbonation of reinforced concrete results in reinforcement corrosion.

Carbonation cannot lead to net-zero concrete. Throughout the life of a building concrete can reabsorb between 7% and 24% of the CO_2 emitted during the manufacturing phase [25]. Carbonation continues in the demolition phase of a building, at a higher rate due to the increased surface area of crushed concrete, however, this crushed material is not usually left open to the air long enough to make a significant impact on the uptake of CO_2.

Upfront Embodied Carbon Comparison

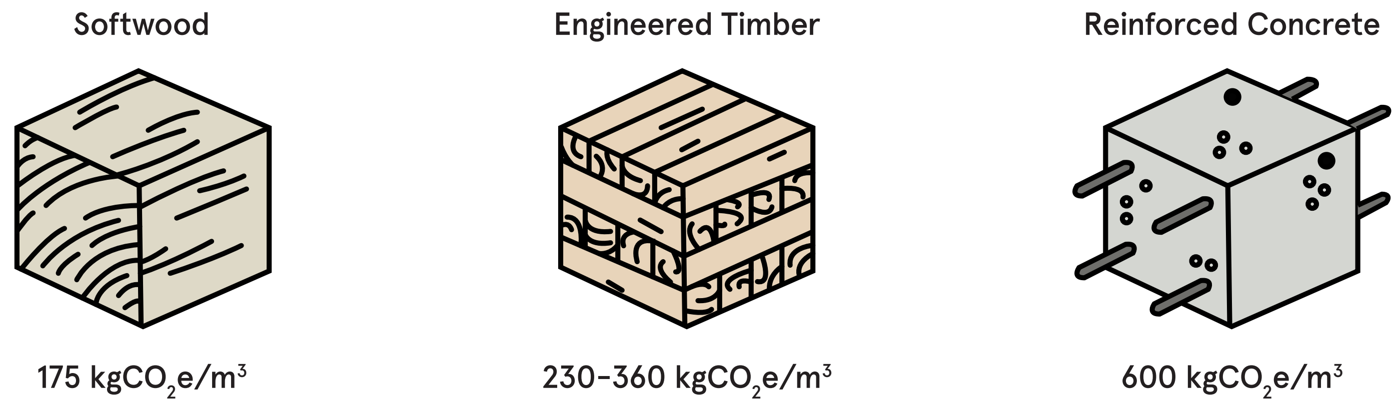

Figure 2 - Approximate embodied carbon for 1m³ of softwood, engineered timber and reinforced concrete, to illustrate the differences, A1-5 for a typical UK project. Note: this comparison does not tell the whole story, as different volumes of each material would be required to serve the same function. Adapted from drawing by Ciaran Malik.

Indirect carbon effects

The choice of material can indirectly affect the overall building's embodied carbon, for instance by locking in carbon through the life of the structure, and by reducing or displacing the need for higher-carbon materials.

Timber

Timber creates a carbon store in the built environment and can displace other carbon-intensive materials in construction.

- Mass timber can reduce construction phase (A1-5) emissions by 69% if substituting carbon intensive materials [26]. However, this number will vary by project, depending on the scale/geometry of the structure and its geographical location.
- Using timber from sustainably managed forests with certification (such as PEFC or FSC) in long-life products sequesters carbon and locks it into the built environment, freeing up space to plant more trees and absorb more carbon. This is a viable climate change mitigation measure [27]. If timber is not sustainably harvested, it does not have the benefit of any carbon sequestration [28]. But there are many remaining complexities with sequestration, particularly soil carbon storage disruption and what happens at the timber product's end of life.
- Cascading timber through multiple lives (for example a joist, chipped and made into an OSB panel, then made into animal bedding, then finally burnt for biomass) can store carbon for longer, and incineration for energy recovery can substitute fossil fuels [27].
- Mass timber is lighter than reinforced concrete, requiring less extensive foundations and making retrofitting of existing structures more feasible.

PEFC/03-01-01

Embodied Carbon / Net-Zero

Opportunities

Cement replacements such as ground granulated blast furnace slag (GGBS) and pulverised fuel ash (PFA) can be used to reduce concrete's embodied carbon, but their availability is limited. Other novel cements that do not rely on GGBS are being developed but are not yet at commercial scale.

Concrete

Since concrete's embodied carbon is almost entirely due to cement, replacing some cement with lower-carbon alternatives reduces embodied carbon. The main options currently used are GGBS (a co-product of the steelmaking industry) or PFA (a co-product of burning coal).

As these are industrial co-products their embodied carbon emissions are much lower, and their use also helps reduce waste, although their availability is finite. GGBS is commonly used in the UK at 50% replacement for certain structural elements. PFA is used less often, and it is a declining resource in the UK with few readily accessible stockpiles remaining. Cement replacements take longer to cure particularly in cold temperatures.

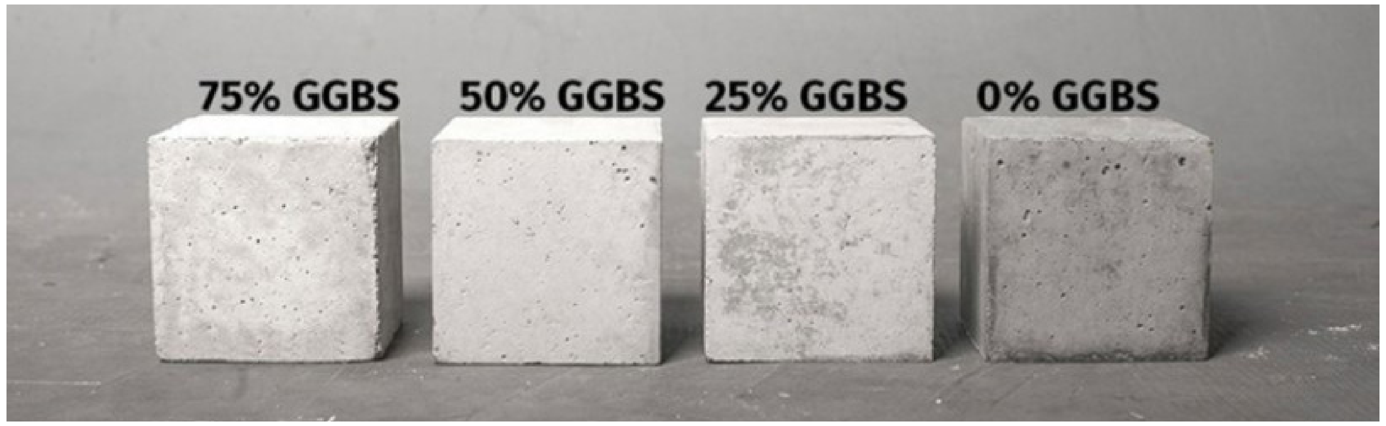

Figure 3 - Adding GGBS to concrete makes it lighter in colour

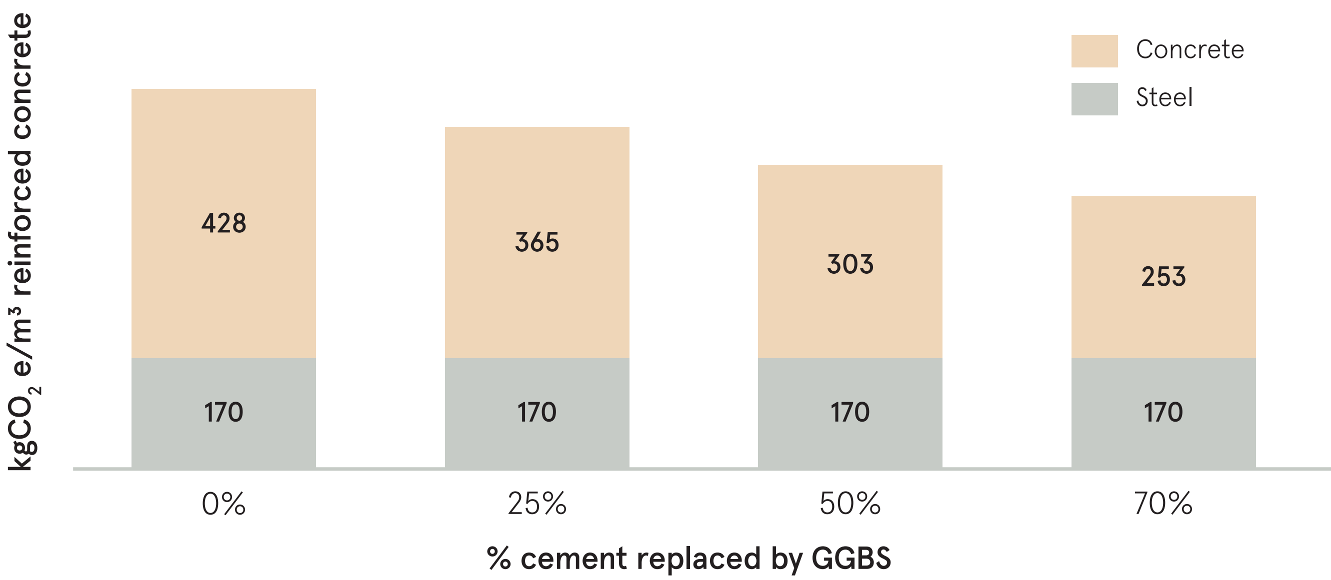

Figure 4 - The effect on embodied carbon of using GGBS as a cement replacement (typical C32/40 reinforced concrete)

Alkali-activated cementitious materials such as Cemfree, Earth Friendly Concrete and ECOPact Max AS go a step further and replace the cement entirely, replacing it with about 95% GGBS and a proprietary chemical activator. These have been trialled in the UK for specific cases and can achieve up to 80% less CO_2e than an equivalent cement mix. However, these cement-free concretes do not fall under current British construction standards so their use must be accompanied by testing, which is costly and time-consuming.

A recent publication by the IStructE on the efficient use of GGBS challenges the global benefit of replacing cement with too much GGBS. Globally there is only enough GGBS to meet about 10% of cement demand. It suggests that GGBS should continue to be used where required to improve concrete durability, but not in high proportions exclusively to reduce embodied carbon as this is unlikely to decrease global greenhouse gas emissions [29].

While the pace of research and development has accelerated in recent years, a viable cement alternative that does not rely on GGBS is not yet commercially available, let alone business as usual. Promising technologies should be supported but none exist at scale yet and neither does carbon capture, which the concrete industry is reliant on for its eventual decarbonisation.

There are many promising cement replacement technologies at differing levels of development. Some examples are below, however none of these is yet commercially available in the UK.

- Calcined clay-based cements such as LC3.
- Silica-based cements such as Seratech.
- Biocements, which use bacteria to achieve the reactions required to turn the ingredients into cement.

Seratech's carbon-neutral concrete Installation at the London Design Festival 2022

03

Health and Wellbeing

The health and wellbeing of a building's users, and site operatives during construction, is an important perspective to look at when determining overall sustainability. Spaces that are conducive to health, both physical and mental, are likely to be well-maintained and last longer.

Health and Wellbeing

User health and wellbeing

User health and wellbeing looks at the effect of materials on the indoor air quality, energy use, moisture and temperature regulation, as well as physical and mental effects on humans such as blood pressure and creativity on the users and occupiers of a building. It also considers exposure to potentially toxic materials.

A study on the impact of different structural materials on a building's operational energy (including concrete and mass timber) found that the choice of material has negligible influence on the energy needed to heat or cool a building. This implies that different thermal mass of materials used in the structure does not impact energy efficiency for multi-storey buildings. The size and shape of a building has is far more impactful on the energy used [30]. The exception to this is if concrete is detailed specifically for thermal mass benefits (see below).

Timber

Timber is a biological material and exposing it within buildings is a form of biophilic design, connecting occupants to nature with the associated benefits this brings [31] [32]. Exposed timber also offers specific health benefits, such as:

- Reduced stress and increased creativity, focus and productivity – used in workplaces and schools, timber increases rates of learning and concentration [33] [34].
- Lower blood pressure and heart rate – in healthcare environments, timber has been found to reduce recovery time and pain perception [31] [34].
- Improved indoor air quality and stable humidity – timber is a hygroscopic material and exchanges moisture with its surroundings to regulate indoor humidity [35].

Engineered timber can also contribute negatively to indoor environments. CLT, glulam, plywood and other engineered timber contains glues to bind the individual timber layers together. Studies on CLT have shown that formaldehyde-based glues do not meet the accepted volatile organic compound emission limits. Therefore, most CLT manufacturers have swapped to using polyurethane (PUR) glue [36]. The main downside of PUR glue is that it is a thermoplastic and is more affected by fire. To combat this, a new class of glues is being developed called HBX glues which are more resistant to high temperatures.

Concrete

Concrete's density offers thermal mass [37] which, when properly located and detailed, can balance indoor temperature fluctuations, reduce overheating and the need for air-conditioning, reducing energy use and cost – an additional benefit to affordability. The thermal mass must be located in an area where it can take up solar radiation during the day and release it at night, otherwise the effect is negligible. Concrete's density also provides good acoustic separation between dwellings [38].

Exposed concrete structure

Exposed timber structure

Health and Wellbeing

Health and wellbeing during construction

Health and wellbeing of site workers during construction is another facet of overall sustainability. This looks at reducing negative outcomes, both acute and long term, of exposure to construction materials and undertaking construction activities. Both timber and concrete present risks, but concrete is likely worse in terms of long-term effects. Timber also benefits from off-site manufacture, where adhesives and treatments are managed in a controlled environment.

Timber

- Contact with any wood preservatives, adhesives and other chemical treatments can be hazardous as they are often toxic.
- Inhaling wood dust can cause occupational asthma and lung cancer.
- Wood dust can cause eye irritation and damage.
- Skin contact with wood dust can cause skin irritation, ulceration and dermatitis.

Concrete

- Wet cement is highly alkaline. A serious burn or ulcer can rapidly develop if it is trapped against the skin.
- Cement can cause chemical burns to the eyes.
- Heavy and prolonged exposure to fine dust containing silica can cause lung cancer and other serious respiratory diseases from cutting, drilling, grinding and polishing concrete elements. Silica is the biggest risk to construction workers after asbestos, estimated to be responsible for the death of over 500 construction workers in 2005.
- The most common types of accidents associated with rebar are impalements and abrasions.

Refurbishment of a concrete structure by HTS

Beyond project boundaries

This section looks at how material choices can have effects beyond the workers and users of a specific building in an urban context.

Timber

- Timber buildings have an increasing role in making cities more sustainable and desirable places to live and work [39].
- Timber construction is typically quicker to construct on site than concrete, involves fewer vehicle movements in the local area, resulting in less noise and disruption to the local community.

Concrete

- With dense urban living, concrete can be designed to reduce noise from neighbours, overheating in summer and concerns about fire safety, thereby being a positive for individuals and society more generally [38].
- Durability over a construction lifetime reduces annualised embodied environmental impacts [37].
- Well-designed and constructed concrete structures are likelier to resist extreme weather and can (with appropriate considerations) resist earthquakes [37].

Refurbishment with timber of an existing structure

04

Social Value

Social value looks at the impacts of industry on the lives of humans in terms of jobs, livelihoods and quality of life. It is a key pillar of sustainability as it addresses the justness or fairness of transitions away from polluting industries and practices. The social impact of the concrete and timber industries is generally difficult to quantify but can be significant for both as their associated supply chains are broad and distributed, and the natural resources on which they draw have significant impacts on land use.

Social Value

Social value of the industry

The value to society of the concrete and timber industries is hard to quantify but there is socio-economic value in the provision of jobs.

Timber

Forests bring mental and physical health benefits to humans. Household surveys in Britain indicate 350 million recreational visits per year to forests and woodlands, with environmental and social benefits worth £1 billion annually [40]. However, these benefits are associated with natural forests, rather than plantations which are often used for production of commercial timber, in which public access is limited during harvesting [41].

One quantifiable aspect of social value is the number of jobs each industry provides. The UK timber industry employed approximately 33,000 people in 2021: 20,000 in forestry, 8,000 in sawmilling, and 5,000 in panel mills [42].

Concrete

The concrete industry is a labour-intensive industry which generates considerable employment opportunities. The industry relies on the supply of aggregates whose sector provides jobs for an estimated 88,000 people [43] [44]. Concrete materials are generally sourced locally creating jobs across the country [45].

Workers pouring concrete on site

Issues around material supply and demand

While both the timber and concrete are local industries in the UK (to varying degrees) the demand for certain products is met by importation. This can cause issues, associated to jobs moving abroad and the burden of transportation. In general, most timber used in construction is imported. GGBS, the main component of lower-carbon concrete, is also mainly imported. This may cause issues in the immediate future as demand for these lower-carbon products rises.

Timber

Despite 13% of its land being forested, the UK is the second-largest global importer of timber behind China [46]. Around 95% of sawn softwood used in the UK is imported from the EU [47]. There are no UK-based CLT and LVL manufacturers, and at the time of writing, one UK-based glulam manufacturer who also uses UK grown timber [48]. The UK government aims to increase the use of homegrown wood in construction, including increasing tree planting across the UK to 30,000 hectares per year by 2024. However, the target set in December 2019 was not even halfway met by June 2022 [49].

Concrete

About half the GGBS (the main constituent of lower-carbon cement) used in the UK is imported. As it is a co-product, it is not made on demand, and instead depends on the location and productivity of steel blast furnaces. There is a domestic supply, but this is fully utilised at about 13% of the UK's total cement demand. The national average is 27% so the difference is made up by imports mainly from the EU, topped up by shipments from Asia. The UK's trade balance of GGBS could mean future availability is constrained, for example if exporting nations start to use up their own supply or if the cost becomes prohibitive.

Some cement is also imported, but aggregates tend to be sourced from within the UK.

Transportation of timber

Social Value

Felled timber

Socio-economic impact of transportation

Transporting construction materials requires heavy goods vehicles and significant infrastructure, and carries a socio-economic burden in terms of pollution, noise and accidents. Avoiding road transport is key to reducing the socio-economic impact of transport. The timber supply chain is more heavily reliant on road transport than concrete.

Timber

Timber is mainly transported by road. Transporting timber from forests to industrial sites causes the majority of emissions of the timber supply chain, about 76,500 tonnes of CO_2 annually. The direct emissions of timber transport are over 33% higher on forest roads compared to public roads, a further negative impact on potentially sensitive natural environments [50].

Concrete

Primary aggregates are the largest material flow in the UK, with 200 million tonnes transported in 2019. The transportation is about as efficient as it can be: 85% of aggregates and 100% of ready-mix concrete are transported less than 30 miles by road, with the rest transported by rail, river or sea [51]. Rail and water transport is key for reducing the socio-economic impacts of transportation. However, this shift is limited in by the lack of appropriate rail infrastructure and distance to inland waterways.

Marine aggregates make up 20% of aggregate use in the UK. Dredging vessels transport up to 10,000 tonnes to coastal and estuarine towns and cities, mainly in London and the Southeast [52].

Concrete transport lorries

05

Circularity

Circularity means closing materials loops, eliminating waste, and ultimately using no new virgin resources. It is the opposite of our current make-use-dispose materials cycle. There are many strategies, applicable at different scales, to increase circularity in building materials. In general, concrete is less reusable as it is poured and sets into specific forms that are hard to disassemble. Timber can easily be disassembled and reconfigured, but it is less durable than concrete. Understanding circularity strategies, and the benefits and drawbacks of each material means they can be used where they make the most sense.

HEYNE TILLETT STEEL

Circularity

Use less stuff

The most powerful circularity strategy is to "use less stuff". This can be achieved by reusing buildings and building elements and making and using any new materials as efficiently as possible.

Timber

- Reuse of sawn timber is straightforward. Timber joists and studs (if in good condition) are simple to salvage and reuse [53] – contractors have been doing this for decades. Timber elements can also be cut up and reassembled, for example the ETH Gridshell made from salvaged timber, cut into struts and reassembled [54].
- Reuse of engineered timber is in its infancy: there are no rules against the reuse of timber in mass timber products, but also no standards or regulations on how to do it [55]. Certain institutes are researching and testing using reused timber planks in new CLT slabs, and this is a growing field [55].
- Timber manufacturing processes are highly efficient: cuttings and chips are used in OSB and chipboard, and resulting biomass is burnt to power the factory and replace fossil fuels [56] [57].
- Engineered timber products like I-joists (OSB web, LVL flanges) are an efficient use of material [57].

Concrete

- Reuse of concrete frames in-situ is common practice but needs extensive checks on site to confirm the structure was built as designed. This requires investigations from slabs, beams and columns to check strength and condition and opening up works to verify reinforcement and element sizes [58]. From experience this can be challenging.
- Reusing concrete off site is far less common and much trickier, although there are some examples. Wall panels were reused in a residential project in Finland [59], and EPFL built a post-tensioned concrete footbridge from reused wall panels in Switzerland [60]. This is a nascent field.
- Precast concrete can be detailed to be reused although this is also not common.
- Some forms of concrete construction, such as pre- or post-tensioning, and ultra-high strength concretes, are an efficient use of material as they reduce the total volume of concrete needed.

Timber gridshell being assembled

Timber gridshell made of salvaged timber, cut into struts and reassembled by ETH Zurich students

Circularity

Extend lifetime of materials at their highest value

Keeping materials in use for as long as possible, and avoiding the need to replace them pre-emptively, is the second circularity strategy. The materials can be designed for maximum longevity based on their application, for adaptability and flexibility during the use, and then for disassembly and reuse at the end of the building's life. Concrete generally has higher durability especially in aggressive environments, so its use should be prioritised in long-life elements such as foundations and infrastructure. Timber is easier to disassemble and reuse.

Timber

- Timber in moist environments (above 20% moisture content) is susceptible to biological decay, especially if the moisture content fluctuates. The longevity can be maximised with a combination of correct material selection, detailing, and understanding of how this biological material's aesthetics change as it ages [56] [61].
- Numerous historical buildings demonstrate that sawn timber structural elements can last for centuries [62] [63].
- CLT was only invented in 1985 and is too new to have gone through one life in-use [64] [56]. However, extensive lab tests have shown the durability of the material and glues is at least 60 years if used in correct environments.
- Timber structures can easily be adapted to add strength and reconfigure openings. Joisted floors can be doubled up or strengthened using steel plates. Glulam beams can be reinforced with angled steel screws or surface mounted fibre-reinforced polymers.
- Timber structures are assembled from components and involve no wet trades. The connections can be made reversible using screws and bolts rather than nails, or innovative reversible connection types such as Sherpa connections [65].
- Some engineered timber products contain no glue or nails, making them even more suitable for disassembly. These include dowel-laminated timber, interlocking CLT and friction-fixed glulam [56].

Concrete

- Concrete is highly durable when designed and detailed correctly. When used internally it easily achieves design life of 50-100 years, and often far longer. In optimum service conditions (i.e., in the absence of excessive moisture), concrete continues to gain strength as it ages [58].
- Self-healing and self-cleaning concretes are being developed to further the durability and ease of maintenance of concrete [59].
- It is slightly more difficult in general to alter concrete structures, but usually possible. If a concrete structure needs to be strengthened for additional load or change in use, many strengthening details are possible including strengthening with carbon fibre [58].
- In situ concrete is a composite material and has "permanent" monolithic connections so it is not easily disassembled. Precast concrete structural and façade systems exist that can be disassembled, for example the CD20 system [59] although this is not common practice as structural precast systems often include a small amount of in situ concrete.

Concrete is highly durable and can achieve a long design life in challenging conditions

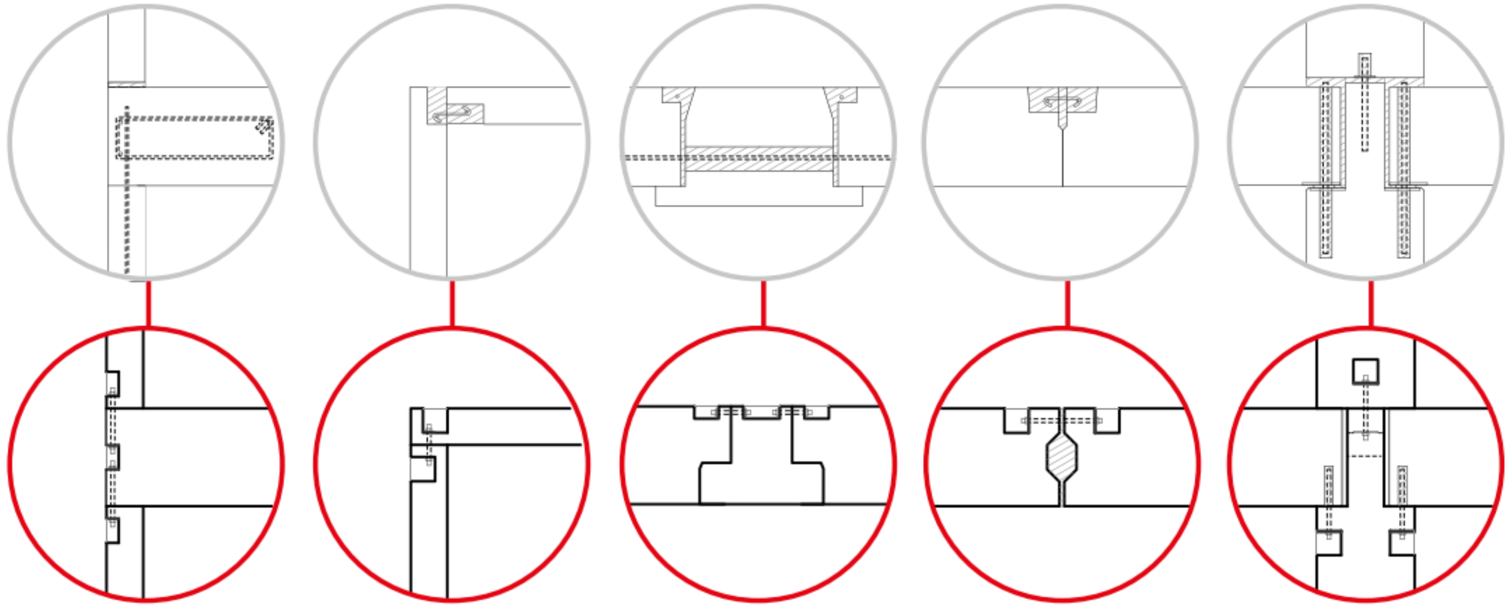

Figure 5 - Standard precast concrete connection details (top row) and reversible alternatives (bottom row), to allow for eventual disassembly and reuse. ©Kupfer C., Fivet C. (2021)

Circularity

Eliminate waste and pollution

The last circularity strategy relevant to building materials is to eliminate waste and pollution from the materials cycle. Elements must be reused, refurbished or as a last resort, recycled, to make sure nothing ends up in landfill as waste.

Timber

- The production of engineered timber achieves high waste diversion [56]. For example, the Wiehag factory in Austria generates enough energy from waste biomass, sawdust and offcuts to supply all the kiln drying, electricity and heating needs, and excess offcuts and power are sold [65].
- Mass timber elements can be manufactured offsite, meaning waste is minimised and construction becomes a process of assembly on site [56].
- Currently, in the UK, less than 1% of timber from construction demolition ends up in landfill, which is positive. However, over half of timber waste is incinerated for energy [66]. While this avoids landfilled waste and displaces some fossil fuels, it is not considered circular practice.
- Waste rates for engineered timber on construction sites are very low, less than 1%. For sawn timber this increases to 10% [67].
- Timber can only be downcycled into products made of smaller elements. Solid timber can be cut down and recycled as shorter sections or packaging, then chipped for OSB, chipboard, mulch or animal bedding, and finally burnt for fuel [68]
- Chemical treatments to increase the durability and fire resistance of timber, as well as gluing can severely limit the recyclability of timber [56].

Concrete

- In situ concrete construction waste rates are estimated around 5%, which considering concrete is the second-most used material after fresh water, adds up to a significant volume. Precast concrete waste rates are lower (1%) due to offsite manufacturing [67].
- In the UK landfill taxes divert about 90% of demolished concrete going to landfill. However, the remaining 10% still represents a significant volume going to landfill.
- Cement replacements are often industrial co-products like PFA and GGBS, which reduces waste from the coal and steel industries [69].
- Concrete can only be downcycled. Demolished concrete is crushed to separate reinforcing steel (which is recycled) and then the resulting crushed concrete can be used as fill for example in road sub-base [59] or in certain conditions as aggregate in new concrete [69].

Timber can be manufactured offsite, minimising waste

Executive Summary

Biodiversity

Impacts of timber and concrete supply chains on the biodiversity crisis.

- Plummeting biodiversity is a big issue in the industry.
- Both materials have significant biodiversity impacts (felling/quarrying).

Timber:

- High areas of forest required - 50 times more land per m^3 of timber than equivalent concrete.
- Forests can be managed to promote biodiversity.
- Specifications must adopt FSC / PEFC.
- Easily downcycled and use in biomass avoids much waste sent to landfill at end of life.

Concrete:

- All quarry activity destroys habitats.
- Quarries and mines take up 0.9% of UK land mass and half are in sensitive AONB and National Parks.
- Damaging secondary effects (noise, dust, pollution, waste, traffic, sea dredging).
- Quarry restoration promotes long-term regeneration.
- Although well recycled, large volumes sent to landfill.

Key Takeaways:

- Both materials require careful specification to mitigate damage to biodiversity.
- On balance, timber generally performs better from a biodiversity perspective.

Embodied Carbon

Direct life cycle carbon emissions from manufacture, transport, construction, use and disposal.

Timber:

- Store of carbon through sequestration - reduces emissions.
- Long-life products required to store carbon for long time.
- Substituting concrete with mass timber can reduce the carbon emissions (A1-5) by 69%, depending on project scale, geometry and location.
- Must be sustainably sourced.
- Lighter material, needs smaller foundations and advantageous for retrofit projects.

Concrete:

- 97% of embodied carbon from cement.
- Through carbonation, concrete can reabsorb a small part of the carbon emitted from cement manufacturing.
- Opportunities to replace cement with GGBS.
- Promising cement replacement technologies.

Key Takeaways:

- 'Right Material - Right Place' - One material not a direct substitution for the other.
- On balance, concrete is generally the poorer performer.

Health & Wellbeing

The physical & mental health and well-being of building users and site operatives during construction.

Building Users:

- Choice of material on operational energy use is negligible. A building's size and shape is more important.

  Timber:

  - Lower stress, improved creativity, focus & productivity.
  - Lower blood pressure, improved air quality.
  - Low VOC emissions products must be used.

  Concrete:

  - Benefits in thermal mass, but requires effective detailing.

During Construction:

- Both materials are potentially hazardous in construction.

  Concrete:

  - Hazards on site due to site works and exposure to dust and other irritants (contact & respiratory).
  - Hazards due to nature of construction (typically in-situ).

  Timber:

  - Chemical risks typically managed in controlled environment.
  - Benefited by off-site manufacture.

Key Takeaways:

- Timber buildings offer a notable benefit to building user.
- Risks on-site more prevalent with concrete construction.
- On balance, concrete is generally the poorer performer.

Social Value

Impacts on humans, in terms of jobs, livelihoods, and quality of life.

Employment in the UK:

- Timber (forestry and mills): 33,000 jobs.
- Concrete (aggregates industry): 88,000 jobs.

Social:

- Physical and mental benefits of forests to general public, so long as they are made available for public access.

Socio-economic:

- Timber heavily reliant on road transport.

Material Supply and Demand:

- 94% of sawn soft wood imported from EU.
- Only one UK based glulam manufacturer, all other engineered timber is imported from EU.
- Concrete aggregates from domestic supply and only a small proportion of cement is imported from EU.
- Domestic supply of GGBS fully utilised at 13% of UK cement demand and half of UK GGBS demand imported from EU and Asia.

Key Takeaways:

- Concrete generally sourced close to project.
- On balance, timber is generally the poorer performer depending on forest location and management.

Circularity

Closing materials loops, eliminating waste and ultimately using no new virgin resources.

- Both materials can be detailed for dismantling.

Timber:

- Timber can be more effectively re-purposed.

Concrete:

- Concrete highly durable with long design life.
- Concrete much more challenging to reuse in secondary market.

Key Takeaways:

- On balance, timber is more effective for dismantling & reuse.

Bibliography

[1] World Economic Forum and AlphaBeta, 'New Nature Economy Report II - The Future of Nature and Business', 2020. [Online]. Available: www.weforum.org

[2] Planning Advisory Service, 'Biodiversity Net Gain for local authorities'. Accessed: Feb. 09, 2023. [Online]. Available: https://www.local.gov.uk/pas/topics/environment/biodiversity-net-gain-local-authorities

[3] Convention on Biological Diversity, 'COP15: Final text of Kunming-Montreal Global Biodiversity Framework'. Accessed: Oct. 24, 2023. [Online]. Available: https://www.cbd.int/article/cop15-final-text-kunming-montreal-gbf-221222

[4] Gresham House, 'Global Timber Outlook 2020', 2020. [Online]. Available: www.greshamhouse.com

[5] Forestry Commission, 'Plant Health - International trade and controlled consignments, 2017-2021', Oct. 2022. Accessed: Oct. 24, 2023. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1111810/planthealth-trade-statsnotice-20oct2022.pdf

[6] Preferred by Nature, 'NGOs: PEFC fails to deliver key values'. Accessed: Feb. 09, 2023. [Online]. Available: https://www.preferredbynature.org/newsroom/ngos-pefc-fails-deliver-key-values

[7] Climate for Ideas, Forests of the World, and Greenpeace, 'On the ground 2011 - the controversies of PEFC and SFI', 2011.

[8] X. Ma, 'Correspondence with TDUK'. Feb. 10, 2023.

[9] Mineral Products Association, '50 Years of "Net Gain"'. Accessed: Oct. 24, 2023. [Online]. Available: https://www.mineralproducts.org/Campaigns/Quarries-and-Nature/50-Years-of-Net-Gain.aspx

[10] British Geological Survey, 'Mine & Quarry', MineralsUK. Accessed: Oct. 24, 2023. [Online]. Available: https://www2.bgs.ac.uk/mineralsuk/mines/home.html

[11] J. Palmer, A. van Breada, L. Cervantes, M. (Dr.) Hettiarachchi, and D. Vernick, 'Biodiversity and sand mining: Key Ecological Impacts', Jan. 2022. Accessed: Oct. 24, 2023. [Online]. Available: https://envirodm.org/wp-content/uploads/2022/03/Sand-and-Biodiversity-Fact-Sheet-2-1.pdf

[12] UN Environment Programme, 'Natural Resource Use in the Group of 20: Status, trends, and solutions | Resource Panel'. Accessed: Feb. 09, 2023. [Online]. Available: https://www.resourcepanel.org/reports/natural-resource-use-group-20

[13] Global Cement and Concrete Association, 'Biodiversity & Land Use'. Accessed: Feb. 10, 2023. [Online]. Available: https://gccassociation.org/sustainable-building-materials/facts-fallacies/biodiversity-landuse/

[14] C. Wong, 'Tree plantations with diverse species grow better than monocultures', New Scientist. Accessed: Feb. 10, 2023. [Online]. Available: https://www.newscientist.com/article/2321178-tree-plantations-with-diverse-species-grow-better-than-monocultures/

[15] Swedish Forest Industries Federation, 'Positive development for biodiversity in the forests'. Accessed: Feb. 10, 2023. [Online]. Available: https://www.forestindustries.se/forest-industry/forest-management/positive-development-for-biodiversity/

[16] Sustainable Build, 'The Impact of Quarrying'. Accessed: Feb. 10, 2023. [Online]. Available: https://sustainablebuild.co.uk/the-impact-of-quarrying/

[17] A. J. Bloodworth, P. W. Scott, and F. M. McEvoy, 'Digging the backyard: Mining and quarrying in the UK and their impact on future land use', Land use policy, vol. 26, no. SUPPL. 1, pp. S317–S325, Dec. 2009, doi: 10.1016/J.LANDUSEPOL.2009.08.022.

[18] DEFRA, 'A Strategy for the Conservation and Sustainable Development of our Marine Environment', 2002.

[19] V. L. G. Todd et al., 'A review of impacts of marine dredging activities on marine mammals', ICES Journal of Marine Science, vol. 72, no. 2, pp. 328–340, Jan. 2015, doi: 10.1093/ICESJMS/FSU187.

[20] MPA and The Crown Estate, 'Marine aggregate extraction 2021', 2022. Accessed: Feb. 10, 2023. [Online]. Available: https://www.thecrownestate.co.uk/media/4242/the-area-involved-24th-annual-report.pdf

[21] Aggregate Industries, 'Aggregate Industries works with Yorkshire Wildlife Trust to turn quarry into wildlife haven'. Accessed: Feb. 10, 2023. [Online]. Available: https://www.aggregate.com/news-and-resources/press-releases/aggregate-industries-supports-ywt-at-ripon-city-wetlands

[22] Green Policy Platform, 'Valuing the Net Benefits of Ecosystem Restoration: The Ripon city quarry in Yorkshire'. Accessed: Feb. 10, 2023. [Online]. Available: https://www.greengrowthknowledge.org/case-studies/valuing-net-benefits-ecosystem-restoration%C2%A0-ripon-city-quarry-yorkshire

[23] Construction Products Association, 'Construction Waste - How Much is There?', V1, 2022. Accessed: Oct. 24, 2023. [Online]. Available: https://www.constructionproducts.org.uk/media/557062/how-much-construction-waste-is-there.pdf

[24] SL Recycling, 'What are the Negative Effects of Landfill?' Accessed: Oct. 24, 2023. [Online]. Available: https://www.slrecyclingltd.co.uk/what-are-the-negative-effects-of-landfill/

[25] E. Possan, E. F. Felix, and W. A. Thomaz, 'CO_2 uptake by carbonation of concrete during life cycle of building structures', Journal of Building Pathology and Rehabilitation, vol. 1, no. 1, Dec. 2016, doi: 10.1007/s41024-016-0010-9.

[26] A. Himes and G. Busby, 'Wood buildings as a climate solution', Developments in the Built Environment, vol. 4, Nov. 2020, doi: 10.1016/J.DIBE.2020.100030.

[27] C. A. S. Hill, 'The Environmental Consequences Concerning the Use of Timber in the Built Environment', Frontiers in Built Environment, vol. 5. Frontiers Media S.A., Oct. 25, 2019. doi: 10.3389/fbuil.2019.00129.

[28] Timber Development UK, 'Assessing the carbon-related impacts and benefits of timber in construction products and buildings', Nov. 2021.

Bibliography

HEYNE TILLETT STEEL

[29] IstuctE, 'The efficient use of GGBS in reducing global emissions'. Accessed: Oct. 23, 2023. [Online]. Available: https://www.istructe.org/resources/guidance/efficient-use-of-ggbs-in-reducing-global-emissions/#:~:text=This%20paper%20concludes%20that%20whilst,be%20used%20where%20required%20technically.

[30] H. L. Gauch, C. F. Dunant, W. Hawkins, and A. Cabrera Serrenho, 'What really matters in multi-storey building design? A simultaneous sensitivity study of embodied carbon, construction cost, and operational energy', Appl Energy, vol. 333, p. 120585, Mar. 2023, doi: 10.1016/j.apenergy.2022.120585.

[31] S. Augustin and D. Fell, 'Wood as a Restorative Material in Healthcare Environments', Canada , 2015. Accessed: Jan. 17, 2023. [Online]. Available: https://www.ekkist.co/wp-content/uploads/2018/05/Wood-as-a-Restorative-Material-in-Healthcare-Environments.pdf

[32] Work in Mind Org, 'What role wood can play in impacting building occupants' wellbeing? Free webinar has the answers – Work in Mind'. Accessed: Jan. 17, 2023. [Online]. Available: https://workinmind.org/2022/04/27/what-role-wood-can-play-in-impacting-building-occupants-wellbeing-free-webinar-has-the-answers/

[33] BM TRADA, Procuring engineered timber buildings: a client's guide. BM TRADA Group, 2019.

[34] A. Knox and H. Parry-Husbands, 'Workplaces: Wellness + Wood = Productivity', 2018. Accessed: Jan. 18, 2023. [Online]. Available: https://assets.ctfassets.net/fqjwh0badmlx/1sm3iELG79J0j7xOP6kPW7/a1dc483345d724fcc2dc9de177f2e883/Make_It_Wood_-_Wellness___Wood_report.pdf

[35] Jieying Wang, 'CONSTRUCTION MOISTURE MANAGEMENT-CROSS LAMINATED TIMBER', Canada, 2020. [Online]. Available: www.fpinnovations.ca

[36] M. Yauk, J. Stenson, M. Donor, and K. Van Den Wymelenberg, 'Evaluating Volatile Organic Compound Emissions from Cross-Laminated Timber Bonded with a Soy-Based Adhesive', Buildings, vol. 10, no. 191, Oct. 2020, Accessed: Jan. 19, 2023. [Online]. Available: https://www.mdpi.com/2075-5309/10/11/191

[37] Global Cement and Concrete Association, 'Concrete and Sustainability'. Accessed: Jan. 18, 2023. [Online]. Available: https://gccassociation.org/concrete-and-sustainability/

[38] Andrew Minson, 'Concrete and Well-being'. Accessed: Jan. 18, 2023. [Online]. Available: https://www.linkedin.com/pulse/concrete-well-being-andrew-minson/

[39] A. de Rijke, 'Timber is the new concrete'. Accessed: Jan. 19, 2023. [Online]. Available: https://drmmstudio.com/article/timber-is-the-new-concrete/

[40] Forestry Commission, 'Sustainable Forestry - Social and environmental benefits of forestry', 2004. Accessed: Feb. 10, 2023. [Online]. Available: https://forestry.gov.scot/publications/601-social-and-environmental-benefits-of-forestry-factsheet/viewdocument/601

[41] M. H. Ramage et al., 'The wood from the trees: The use of timber in construction', Renewable and Sustainable Energy Reviews, vol. 68, pp. 333–359, Feb. 2017, doi: 10.1016/J.RSER.2016.09.107.

[42] Forest Research, 'Forestry Statistics and Forestry Facts & Figures', Forestry Statistics 2023. Accessed: Nov. 01, 2023. [Online]. Available: https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/

[43] UK Concrete, 'This is UK Concrete', 2020. Accessed: Oct. 24, 2023. [Online]. Available: https://thisisukconcrete.co.uk/getmedia/b0c070e8-d998-4fc6-b203-cdf9754d6bbb/This-Is-UK-Concrete-2020.aspx

[44] Minerals UK, 'Aggregates'. Accessed: Feb. 10, 2023. [Online]. Available: https://www2.bgs.ac.uk/mineralsuk/mines/aggregates.html

[45] MPA, 'Minerals in Designated Landscapes - Position Statement', 2022. Accessed: Feb. 10, 2023. [Online]. Available: https://www.gov.uk/government/publications/

[46] K. Connell-Skinner, 'Russia's invasion of Ukraine creates timber supply chain challenges for construction', Environment Journal. Accessed: Feb. 10, 2023. [Online]. Available: https://environmentjournal.online/articles/feature-russias-invasion-of-ukraine-creates-timber-supply-chain-challenges-for-construction/

[47] Forest Research, 'Origin of wood imports'. Accessed: Feb. 10, 2023. [Online]. Available: https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2018/trade-2/origin-of-wood-imports/

[48] Buckland Timber, 'Our Story'. Accessed: Oct. 24, 2023. [Online]. Available: https://www.bucklandtimber.co.uk/our-story/

[49] Confor, 'Confor accuses UK Government of "total policy failure" on tree planting'. Accessed: Feb. 10, 2023. [Online]. Available: https://www.confor.org.uk/news/latest-news/confor-accuses-uk-government-of-total-policy-failure-on-tree-planting/

[50] Timber Transport Forum, 'Road Haulage Decarbonisation Overview Report', 2022. [Online]. Available: www.timbertransportforum.org.uk

[51] MPA, 'Sustainable Development Report 2020/2021', 2022.

[52] The Crown Estate, 'Marine aggregates - Capability & Portfolio 2019', 2019. Accessed: Feb. 10, 2023. [Online]. Available: https://www.thecrownestate.co.uk/media/3633/2019-capability-portfolio-2019.pdf

[53] Arup, 'Evaluating re-use potential: Material profiles and vision for project workflow', 2021.

[54] R. Kunzler, 'A wooden dome made solely from waste', Globe Magazine, Apr. 2022.

[55] A. Stenstad, S. L. Bertelsen, and R. Modaresi, 'Evaluating the use of secondary timber in Cross Laminated Timber (CLT) production', 17th Annual Meeting of the Northern European Network for Wood Science and Engineering, 2021.

Bibliography

HEYNE TILLETT STEEL

[56] A. Campbell, 'Mass timber in the circular economy: Paradigm in practice?', Proceedings of the Institution of Civil Engineers: Engineering Sustainability, vol. 172, no. 3, pp. 141–152, 2019, doi: 10.1680/jensu.17.00069.

[57] C. Law, 'Timber and the circular economy', TRADA Timber 2020 Industry Yearbook, 2020.

[58] J. Burridge, 'Reusing concrete structures: one step closer to a circular economy', Concrete Quarterly, 2021.

[59] W. Salama, 'Design of concrete buildings for disassembly: An explorative review', International Journal of Sustainable Built Environment, vol. 6, no. 2, pp. 617–635, 2017, doi: 10.1016/j.ijsbe.2017.03.005.

[60] C. Fivet, C. Kupfer, and M. Bastien-Masse, 'Le beton de reemploi, ressource territoriale a mobiliser', Les Cahiers D'espaceSuisse - Section Romande, 2022.

[61] TRADA, 'Design life for wood and wood-based products', 2018.

[62] B. Johnson, 'Greensted Church - The Oldest Wooden Church in the World', Historic UK. Accessed: Oct. 24, 2023. [Online]. Available: https://www.historic-uk.com/HistoryMagazine/DestinationsUK/Greensted-Church-The-Worlds-Oldest-Wooden-Church/

[63] Z. Que et al., 'Traditional Wooden Buildings in China', in Wood in Civil Engineering, IntechOpen, 2017. doi: 10.5772/66145.

[64] E. Lehman, 'October 15, 1934: Glued Laminated Timber Comes to America', Forest History Society. Accessed: Oct. 24, 2023. [Online]. Available: https://foresthistory.org/october-15-1934-glued-laminated-timber-comes-to-america/

[65] C. Law, 'TDUK sustainability series - timber and the circular economy', 2021.

[66] M. Cramer and D. Ridley-Ellis, 'A case study of timber demolition recycling in the UK', 2020. [Online]. Available: https://www.researchgate.net/publication/355748090

[67] IStructE, How to calculate embodied carbon. 2020.

[68] Wood for Good, 'Encompassing the circular economy', Wood for Good. Accessed: Jan. 13, 2023. [Online]. Available: https://woodforgood.com/news-and-views/2020/07/29/encompassing-the-circular-economy/

[69] Global Cement and Concrete Association, 'Circular economy'. Accessed: Jan. 19, 2023. [Online]. Available: https://gccassociation.org/sustainability-benefits-of-concrete/circular-economy/#:~:text=Concrete production may also require,natural resources and reducing landfilling.

Photography Credits

[Cover Page – Image 1] ©Dirk Lindner

[Page 2 – Image 2] ©Matthew Smith

[Page 3 – Image 3] ©Shutterstock

[Page 4 – Image 4] Tree plantation ©Shutterstock

[Page 5 – Left Image 5] Active Quarry ©Shutterstock

[Page 5 – Right Image 6] Former Quarry ©Shutterstock

[Page 6 – Image 7] ©Jim Stephenson

[Page 8 – Image 8] ©Architonic

[Page 9 – Image 9] ©Jack Hobhouse

[Page 10 – Image 10] ©Guy Archard

[Page 10 – Image 11] ©Jack Hobhouse

[Page 11 – Top Image 12] HTS site photo archive

[Page 11 – Bottom Image 13] HTS site photo archive

[Page 12 – Image 14] ©Shutterstock

[Page 13 – Left Image 15] ©Shutterstock

[Page 13 – Right Image 16] ©Shutterstock

[Page 14 – Left Image 17] ©Shutterstock

[Page 14 – Right Image 18] ©Shutterstock

[Page 15 – Image 19] ©Shutterstock

[Page 16 – Top Image 20] ©Daniel Winkler

[Page 16 – Bottom Image 21] ©Nicole Davidson

[Page 17 – Top Image 22] ©Shutterstock

[Page 18 – Image 23] ©Robert Greshoff Photography

HEYNE
TILLETT
STEEL