Chapter 17
Sustainable Construction Materials

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Abstract This chapter identifies the means by which construction materials can be evaluated with respect to their sustainability. It identifies the key issues that impact on the sustainability of construction materials and the methodologies commonly used to assess them. Examples of sustainable materials are used to identify their potential use in construction. *Learning outcomes*: on successful completion of this chapter, readers will be able to: (1) appreciate the role and impact of building materials within a building's life cycle; (2) comprehend the concepts of embodied energy, gross energy requirement (GER), and process energy requirement (PER); (3) have knowledge of renewable materials and how they are grown, processed, and used as building components; and (4) have an appreciation of sustainable construction materials in the context of green building assessment methods.

Keywords Construction materials · Life-cycle assessment · Renewable resources · Environmental impact · BREEAM

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17.1 Introduction

There are hundreds of different materials that are used in the construction of any new building. Their functions, and therefore their physical properties, can be very different. It is useful, when making comparisons, to consider materials with a similar function. Materials used for the structure of buildings require properties of strength, whereas other parts, such as the envelope, are selected for their insulation or esthetic properties. Comparisons become more complex when materials perform more than one function such as load-bearing walls that provide good thermal insulation.

There is also a need to distinguish between finite resources and renewable resources when reviewing the sustainability of a material. Some materials, despite being nonrenewable may be considered plentiful on earth; however, the consequences and impacts of mining them may be considered unacceptable. The effect of construction material selection will impact upon sustainability throughout the lifetime of both the material and that of the building itself. The need to maintain the building, replacing individual components, disposing of the old, and procuring the new will have environmental impact from cradle to grave.

17.2 Materials and Sustainability

Construction materials currently constitute between 40 and 50 % of the total materials used worldwide on an annual basis (CIB 2008). In the UK, 420 million tonnes of materials are used in construction each year, equivalent to 7 tonnes per inhabitant (Lazarus 2004). It is therefore essential that we optimize their use, minimizing the impact on the planet and increasing overall sustainability.

Optimization of use can include reducing wastage and ensuring that materials that have not reached the end of their useful life when the building has reached the end of its useful life are reused or recycled whenever possible. Some materials are difficult to separate at the time of building demolition and design of new buildings must therefore consider the deconstruction and separation of buildings to their constituent components and materials. For example, the use of cement mortars made it difficult and labor intensive to clean and reuse bricks, whereas the use of lime mortars facilitates the process. Metals, however, have commonly been separated and recycled at demolition stage primarily because of their financial value and the economic viability of doing so. Materials that are reused or recycled have the double advantage of reducing landfill as well as displacing the need for virgin materials.

Wastage of materials at the construction stage also constitutes poor sustainability and excellent guidance on good practice is available through documents from organizations such as WRAP, the UK organization with a mission of waste prevention and the construction industry research and information association (CIRIA). Modern Methods of Construction, including off-site construction have also made an impact on sustainability through mass production and improvement in working conditions reducing wastage from offcuts and aborted work.

The impact of material consumption is experienced in many ways, through depletion of natural resources, waste during construction, and disposal at the end of their useful life. They have further impacts through the energy and water consumed and pollutants emitted throughout their processing and transportation. Careful selection of materials can therefore make a significant difference to the overall environmental impact of a building.

Traditional building construction utilized local materials that were readily available which led to styles of vernacular architecture including timber and stone. Modern methods of transportation-facilitated materials being sourced from around the world and modern manufacturing processes enabled the development of construction materials which were lighter, more manageable, and easier to use than their traditional counterparts. As material science and technologies have progressed, more composite materials and products have come onto the market.

The advantages of modern materials are evident in that they may save time and money, require less skilled labor to construct, and less maintenance during the useful life of the building. On the other hand, the environmental impacts of processing and transporting these materials and the socio/economic impacts of losing a skilled workforce are less evident. Neither is the impact of consuming finite resources.

Professionals in the construction industry are responsible for the appropriate use of materials and to enable their sustainability. This requires understanding of the impacts relating to materials throughout their life cycle, from their raw components, through to their eventual disposal at the end of the useful life of the building. It also entails the ability to balance the consequences from a variety of very different impacts in order to make appropriate judgements.

Collation of data in order to make sustainability judgments is notoriously difficult and available data are often incompatible, having been established using different methodologies. Nevertheless, there are now some national databases and internationally agreed protocols that can be used to facilitate comparison of materials.

Common lifecycle analysis (LCA) procedures have been established and publications such as *Environmental Profiles* (Howard et al. 1999) have established detailed methodologies for the determination of environmental impacts of individual materials. These in turn are included in different environmental assessment models that enable the impacts of building materials to be evaluated within the broader context of the lifetime impact of a building.

17.3 World Resources

The current rate of extraction of natural resources from the planet is around 60 billion tonnes per annum and has risen dramatically in recent years (Materialflows 2011). It has risen from 40 to 60 billion tonnes per year and at the same time the world population has risen from 4.4 to 6.4 billion inhabitants.

These materials are made up of both renewable and nonrenewable resources. Renewable resources such as timber and the products of agriculture including plants, food, and animal stock must be properly managed in order to maintain their sustainability. Nonrenewable resources including fossil fuels, metals, and minerals are by definition finite and must be consumed in a sustainable way, optimizing their efficiency through carefully considered selection, minimizing waste, recycling, and reusing wherever possible.

17.3.1 Non-renewable Materials

The construction and operation of buildings place heavy demands on nonrenewable resources including fossil fuels, metals, and minerals. There are some bleak predictions concerning consumption rates of fossil fuels and possible dates when supplies will be exhausted. The incentive to conserve these resources is heightened by the realization that burning such fuels is a significant cause of carbon dioxide emissions resulting in climate change.

Some construction materials are considered plentiful within the composition of the earth; consequently less attention is directed toward managing these resources in a sustainable manner. For example, iron ore is the key ingredient of steel which constitutes a high proportion of metal used in the construction industry. World production was 2.2 billion tonnes in 2009, with world resources estimated to exceed 230 billion tonnes. In resource terms it is considered plentiful; however, there is little demand for construction in the regions where the ore is mined with resulting high cost of transportation in both financial and energy terms.

The geographical location of raw materials is also a significant factor in considering the environmental burdens of their consumption. It is the more affluent regions of the world that demand resources which are being mined further afield. Growing demand is also resulting in the increased difficulty and expense of mining as easily accessible resources are depleted and more complex mining is required.

The increased difficulty in mining certain materials leads to increased '*overburden*'. This is the amount of other material including rock and topsoil removed in order to access the required material. The overburden currently stands at around 60 %, resulting in the removal of a further 40 billion tonnes of matter to provide the total of 60 billion tonnes of materials being consumed (FOE 2009). The impact on the natural environment is considerable. Furthermore, the impact on the landscape and ecology can be devastating; however, it is the economics of production and supply that is limiting the rate at which some materials are being depleted.

17.3.2 Renewable Materials

The use of renewable materials is traditional to the construction industry. Timber is used extensively in both the structure and fittings for buildings but requires long-term resource management as the growth of trees for structural timber can be 100 years or more. However, shorter rotation plants and crops such as straw or hemp can be readily used for the construction of buildings and can be harvested on an annual basis.

An additional advantage of natural renewable materials like trees and plants is that they lock in atmospheric carbon dioxide during their growth period while emitting oxygen back into the atmosphere. They are often considered as being carbon neutral or even carbon negative when evaluating their carbon footprint and environmental impact on the planet.

The transportation implication for shorter rotation materials can be far less compared with finite resources, as they are often grown in the same region where the construction site is located. Benefits are experienced in reduced demand for fossil fuels resulting in emissions and the economic cost of transportation.

17.4 Life Cycle of Building Materials

It is important to consider building materials not just for their function within a completed building, but for their impact on the planet and the environment both before and after their functional lifetime within the building. Materials impact on finite resource depletion as well as pollution and landfill implications at the end of their useful life.

The life cycle of building materials commences with the ‘winning’ (e.g., mining) of raw materials and includes all stages in the production of construction products and components, construction of the building, maintenance, reuse or recycling, and eventual disposal at the end of its useful life. In addition, the environmental impacts also include the effects of all these processes as well as those of transportation within and between the stages in the life cycle as depicted in Fig. 17.1.

Renewable materials such as timber, together with shorter term crops such as hemp and straw, can be assessed to include the impacts from planting and growing, prior to harvesting, before the material enters the construction process. In this way, it is possible to achieve positive environmental impacts due to the sequestration of atmospheric carbon dioxide during the growth of the plants and trees.

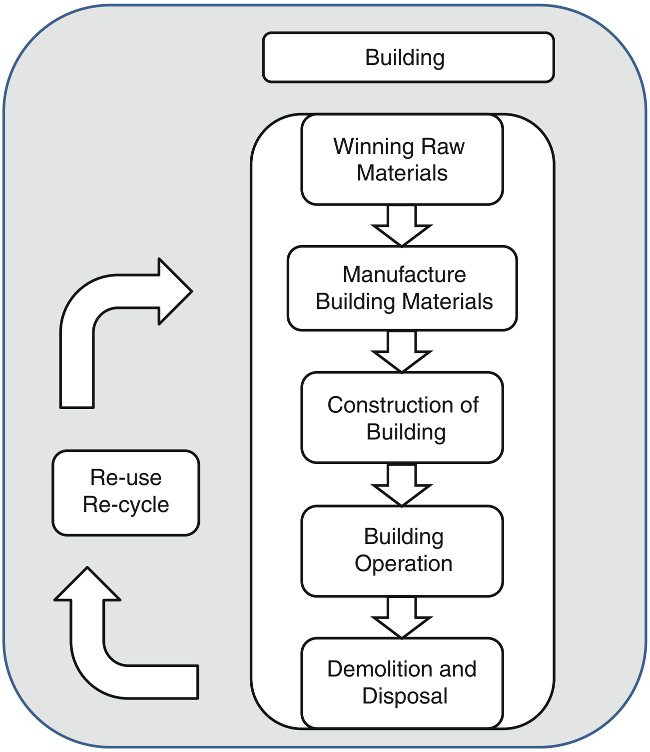


Fig. 17.1 Life cycle of building materials

17.5 Life-Cycle Assessment

The use of a lifecycle assessment (LCA) methodology can facilitate comparisons among materials. It can be used to evaluate different environmental impacts and burdens within the longer life cycle of the buildings themselves. However, many assumptions are made in establishing LCA results and comparisons among results in different databases can be misleading without a clear definition of the assumptions adopted.

Life-cycle assessment methodology is generic and is described as having four phases:

- Goal and scope definition;
- Inventory analysis;
- Impact assessment;
- Interpretation.

International standard procedures are defined in *Environmental Management Life-Cycle Assessment—principles and framework* (ISO 14040 2006).

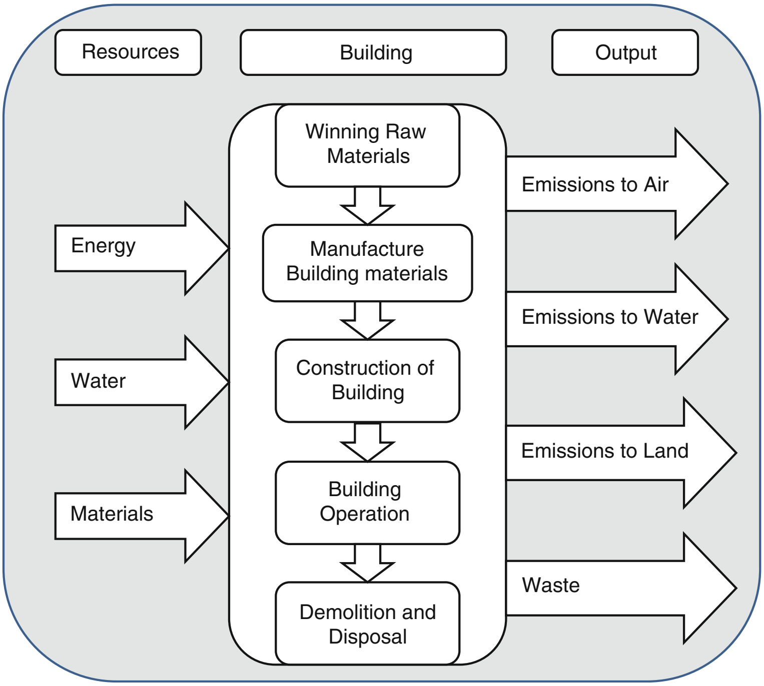


Fig. 17.2 Life cycle of environmental impacts of buildings

Assessment of the environmental impacts of buildings and their component materials include the resources they consume and the emissions they make throughout their life cycle as illustrated in Fig. 17.2.

17.5.1 Key Terms and Issues

17.5.1.1 Functional Unit

The functional unit is the basis on which the performance of a material or combination of materials can be quantified. It can be made on the basis of mass, volume, or area, or based on the overall product. Thus, when evaluating bricks or blocks they may be considered in unit terms of 'per kilogram of brick' or 'per cubic meter of brick'. However, neither of these units provides direct indication of the impact within a building, but a functional unit of 'one square meter of wall' may have better relevance. This enables the design of the wall to be taken into account as it could be constructed from single or multiple bricks in thickness.

The definition of the functional unit is important to the comparison of building components. Different materials for wall construction could be compared on the basis of the area of wall produced, but would need to enable consideration of their ability to provide a weatherproof envelope as well as structural and thermal performance.

17.5.1.2 Boundaries

The definition of system boundaries clarifies what is included or excluded from the analysis. For example, transportation is commonly included within LCA, but additional clarity is required to define whether calculations assume a one-way delivery journey or a two-way journey (with an empty return vehicle); and whether it considers only the fuel consumed or allows for the manufacture and maintenance of the vehicle and transportation network.

17.5.1.3 Useful Life

The useful life of the material defines the duration of the life cycle, identifying a need for replacement and consequently a second set of environmental impacts. It may be particularly important when selecting materials for a building, which itself will have a useful life far longer than the individual component.

A softwood window frame might need replacing after 15 years, whereas hardwood could last 25 years. Alternatively, a PVCu (plastic) frame could last even longer, say 30 years, and require less maintenance. This then needs to be considered in the context of the useful life of the building and the number of window frame replacements in a lifetime of 60 or 100 years. The resources can be evaluated in terms of energy and water embodied within the building materials and components, and impacts from emissions can be assessed through climate change, ecological damage, and effects on health both for humans as well as animals and fish. Comparison of individual materials based on the aggregation of all of the environmental impacts is a complex problem requiring an agreed methodology for assessing individual components and an agreed weighting system for summing the impacts.

The Environmental Profiles system established by the building research establishment (BRE) in the UK is commonly accepted as the basis for material choice and is used within environmental assessment methods to evaluate whole buildings, such as the code for sustainable homes (CSH) and the building research establishment environmental assessment method (BREEAM).

17.5.2 Embodied Energy

The embodied energy of a material refers to the amount of energy consumed in providing that material. There are, however, many definitions of the term *embodied energy* and in order to make fair and useful comparison among different materials, it is necessary to understand clearly which definition is being used.

A common definition of embodied energy is: *'the energy consumed up to the end of the manufacturing process'*—also referred to as *'cradle to gate'*. Other definitions include material transportation to the construction site (cradle to site), or even in the construction processes, finishing with the completed building. The latter two definitions are clearly site specific and relate only to an individual building.

The definition of embodied energy is further complicated when considering the scope of the analysis, which can include the gross energy requirement (GER) or more simply the process energy requirement (PER). The inclusion of energy for transportation of materials between processes is a further element requiring clarification before figures can be compared.

17.5.2.1 Gross Energy Requirement

The gross energy requirement is a measure of the total energy inputs to a specific material. It can be considered as the total energy consumption for which the finished material is responsible. Thus, it not only includes the total energy consumed in winning the raw materials, transporting, and manufacturing of building materials and components themselves, but also the manufacture and maintenance of all plant and machinery used in winning and processing those materials, the transportation of the labor force for all associated activities, and the repair of the damage caused during these processes.

17.5.2.2 Process Energy Requirement

Process energy requirement is the total energy consumed in the processes directly undergone by the building material or product. It will include the energy consumed by the plant and machinery throughout the processing, but not that of the second and higher generation consumptions of the machinery that made the machinery and the repair of the damage caused by the processes.

Different approaches can be adopted when evaluating PER and care is required when using published data in order to make comparisons. Common issues where clarity of assumptions and methodology is required are:

- Apportioning energy where more than one product undergoes the same process or one is a by-product of another;
- Inclusion of transportation and how return journeys of the delivery vehicle is considered;
- Apportioning transportation energy for a part load on a ship or other mode of transportation.

The building services research and information association (BSRIA) published a comprehensive document identifying assumptions made in published figures (Hammond and Jones 2011). It is based on research undertaken at Bath University in the UK and incorporates their inventory of carbon and energy (ICE).

17.5.2.3 Embodied Carbon

Interest in embodied energy is significant not only because of the impact on the depletion of fossil fuels, but also the emissions of pollutants during the consumption of these fuels. The latter is referred to as embodied carbon.

Although embodied energy and embodied carbon are directly related, the impact of any material on resource depletion and on greenhouse gas emissions can be very different. This depends on the type of primary fuel consumed and how the electricity was generated. Consumption of renewable energy may be considered to have zero emissions provided the embodied energy of the collectors and generators are neglected. Similarly, nuclear energy will also have zero carbon emissions. The embodied carbon is therefore dependent upon the fuel mix in the location where the processing takes place.

Some materials are even classed as having negative embodied carbon. This occurs when calculations include the carbon sequestered during their growth. Trees and short-term crops used for building materials sequester atmospheric carbon dioxide during their growing period, the weight of which may be greater than the emissions during manufacture.

17.6 Life-Cycle Assessment of Building Materials

Construction materials are selected primarily for their physical properties, used for structure, weather proofing, insulating, and also for their esthetic quality. Choice is also affected by value for money, including initial costs and durability. Appropriate materials must also be compared in terms of their environmental impact which may be significant and have effect outside the performance of the building itself.

Evaluation of physical properties and value for money is relatively straightforward with clear definition of units and methods of measurement. Environmental impact, however, is more complex, involving different types of impacts including emissions of different gases and pollutants to the atmosphere; consumption of other resources such as energy and water throughout their life cycle; depletion of natural resources; and finally implications for disposal at the end of their useful life. Impact types are calculated in different ways and there is no simple method of weighting these impacts within a single index to facilitate material choice. The problem is exacerbated as individual impact types will have different priorities depending on what region of the world the assessment is conducted in.

Over the years, standard procedures have been developed to help ensure that evaluation figures are comparable, with common boundary conditions and procedures of measurement. Assessment methods such as the Environmental Profiles developed by the BRE in the UK (Howard et al. 1999) have enabled materials to be compared on a common basis considering boundaries of cradle to gate, cradle to site, and cradle to grave assuming a 60-year useful life.

Table 17.1 Environmental impact categories, issues measured, and weightings for environmental profiles (*Source* Anderson et al. 2009)

Environmental impact category	Environmental issue measured	Weighting (%)
Climate change	Global warming or greenhouse gas emission	21.6
Water extraction	Mains, surface, and groundwater consumption	11.7
Mineral resource extraction	Metal ore, mineral, and aggregate consumption	9.8
Stratospheric ozone depletion	Emission of gases that destroy the ozone layer	9.1
Human toxicity	Pollutants that are toxic to humans	8.6
Ecotoxicity to freshwater	Pollutants that are toxic to freshwater ecosystems	8.6
Nuclear waste (higher level)	High and intermediate level radioactive waste from nuclear energy industry	8.2
Ecotoxicity to land	Pollutants that are toxic to terrestrial ecosystems	8.0
Waste disposal	Material sent to landfill or incineration	7.7
Fossil fuel depletion	Depletion of oil, coal, or gas reserves	3.3
Eutrophication	Water pollutants that promote algal blooms	3.0
Photochemical ozone creation	Air pollutants that react with sunlight and NO_x to produce low level ozone	0.2
Acidification	Emissions that cause acid rain	<0.1

17.6.1 Environmental Profiles

The environmental profiles of materials established by the BRE include 13 environmental issues which are weighted in accordance with those shown in Table 17.1.

These profiles are key for the analysis of materials in the UK as they are used as reference to gain credits for materials selection in BREEAM and CSH assessments.

17.7 BRE Environmental Assessment Method

There are many systems in place throughout the world to determine the environmental impact of buildings and assist building industry professionals in selecting appropriate materials and design solutions in reducing environmental impacts. One of the first systems was BREEAM for offices, published in the UK in 1993.

The assessment of new domestic housing has evolved into the CSH which has rapidly established itself as a reference for good environmental design (DCLG 2008). The system involves a star rating from one to six stars, more stars indicating greater environmental performance. Many housing associations which provide social housing require minimum standards of three or four star homes which demonstrate their commitment to improving environmental issues.

The CSH, similar to other BREEAM systems, is evaluated under nine categories namely Energy and Carbon Dioxide Emissions, Water, Materials, Surface Water Runoff, Waste, Pollution, Health and Well-being, Management, and Ecology.

The choice of materials is clearly recognized within the Materials category, but will have impact within the categories of Waste and Pollution. The Materials category includes three assessments, M1 for the processes involved in producing the building materials and M2 and M3 for the responsible sourcing of the raw materials both for the basic building construction and the finishes.

17.7.1 M1: Environmental Impact of Materials

Building materials are assessed against the *Green Guide to Specification* (Anderson et al. 2009) which itself has been based on analysis undertaken for the environmental profiles (Howard et al. 1999). The Green Guide to Specification employs all 13 categories used in the Environmental Profiles and produces a weighted performance with ratings of A+ to E, with A+ representing the best environmental performance and the lowest environmental burden.

Comparison of materials is facilitated as the Green Guide is organized by building elements including external walls, internal walls, roofs, floors, and windows. The guide rates a material against all 13 categories together with a summary rating overall. An example of the data presented is shown in Table 17.2.

It is mandatory within the Code for Sustainable Homes scoring system to achieve ratings between A+ and D for at least three of the five key elements—roof, external walls, internal walls, upper and ground floors, and windows. If this mandatory requirement is met higher credit is given to the better rated materials.

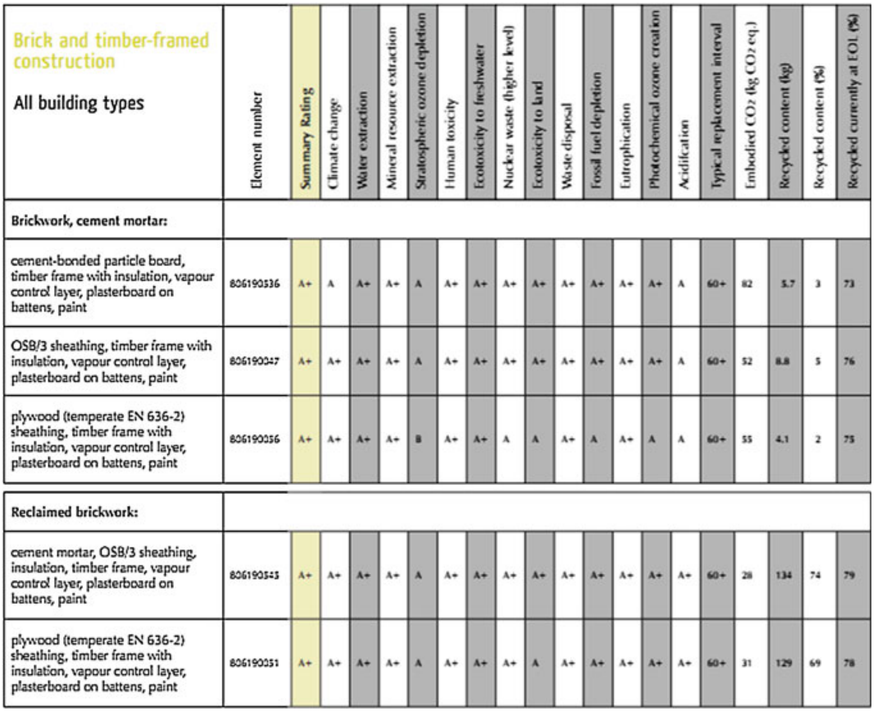
17.7.2 M2 and M3: Responsible Sourcing of Materials—Basic Elements and Finishes

Materials achieving credits within these categories are required to be certified by appropriate third-party assessments. They would normally include certification of legal sourcing of timber materials, chain of custody from source for new materials, or for the virgin component of composite recycled materials.

17.8 Renewable Building Materials

Renewable materials originate from plants and trees which can be harvested and regrown within a few human generations. They include short-term crops that grow within a seasonal life cycle as well as timber from managed forests and woodlands that may take a few hundred years to replace.

Table 17.2 Example of ratings from green guide to specification (*Source* Anderson et al. 2009)



Brick and timber-framed construction All building types	Element number	Summary Rating	Climate change	Water extraction	Mineral resource extraction	Stratospheric ozone depletion	Human toxicity	Ecotoxicity to freshwater	Nuclear waste (higher level)	Ecotoxicity to land	Waste disposal	Fossil fuel depletion	Eutrophication	Photochemical ozone creation	Acidification	Typical replacement interval	Embodied CO₂ (kg CO₂ eq.)	Recycled content (kg)	Recycled content (%)	Recycled currently at EOL (%)
Brickwork, cement mortar:																				
cement-bonded particle board, timber frame with insulation, vapour control layer, plasterboard on battens, paint	806190536	A+	A	A+	A+	A	A+	A+	A+	A+	A+	A+	A+	A+	A	60+	82	5.7	3	73
OSB/3 sheathing, timber frame with insulation, vapour control layer, plasterboard on battens, paint	806190047	A+	A+	A+	A+	A	A+	A+	A+	A+	A+	A+	A+	A+	A	60+	52	8.8	5	76
plywood (temperate EN 636-2) sheathing, timber frame with insulation, vapour control layer, plasterboard on battens, paint	806190056	A+	A+	A+	A+	B	A+	A+	A	A	A+	A	A+	A	A	60+	55	4.1	2	75
Reclaimed brickwork:																				
cement mortar, OSB/3 sheathing, insulation, timber frame, vapour control layer, plasterboard on battens, paint	806190543	A+	A+	A+	A+	A	A+	A+	A+	A+	A+	A+	A+	A+	A+	60+	28	134	74	79
plywood (temperate EN 636-2) sheathing, timber frame with insulation, vapour control layer, plasterboard on battens, paint	806190051	A+	A+	A+	A+	A	A+	A+	A+	A	A+	A+	A+	A+	A+	60+	31	129	69	78

17.8.1 *Short-Term Crops*

The CIRIA publish a handbook for crops in construction (Cripps et al. 2004) which reviews the socioeconomic benefits as well as the environmental impacts of natural construction materials. It features structural and insulation materials as well as finishes and floor coverings, identifying their physical properties as well as their ecological advantages and disadvantages.

Materials such as thatch and straw have been used in buildings for centuries. Despite this, they have generally been replaced by modern alternatives which are quicker and often require less skill to work with. Understanding the physical properties of these organic materials has led to increased interest in using them for construction, often using local sources and components of the crop that would otherwise be discarded.

Straw bale and hemp are used here to illustrate the use of short-term crops in modern construction. Straw is a by-product of cereal crops which, even during the twentieth century, was burned in fields after harvest. Hemp is used in construction because of its strong fibers, however, it also demonstrates a variety of pharmaceutical properties.

17.8.1.1 Straw Bale

Traditional straw bale has been used for the construction of domestic buildings for centuries and was facilitated by the invention of the mechanical baler which formed tighter bales of a uniform size. Straw bales appropriately stacked together can form highly insulated walls. Once the surfaces are rendered they become durable and weatherproof although attention is necessary for roof detail, where wide overhangs are required to prevent water penetration. Straw bale can be used as a structural element, generally for single-story dwellings but is more flexible as infill within a timber frame. It is difficult to define the thermal performance of straw bale construction because of the variability in the straw itself and the density of packing. However, Danish studies have estimated a design value of 0.18 W/m^2 K would be reasonable for a standard straw bale (Munch-Andersen and Andersen 2011).

17.8.1.2 Hemp

Industrial hemp is a very fast growing plant of the *Cannabis Sativa* family that has a low narcotic component. Its fibers are very strong and the longer ones are used in concrete to improve both compressive and tensile strength; it also reduces shrinking and cracking. Mixed with lime it can be used to form an infill material for a timber frame, forming a rigid material with good insulating properties that is lightweight and breathable.

Hemp is one of the fastest growing crops in the world, second to bamboo. It requires very little attention or fertilization during its growth and is a useful rotation crop. The process of photosynthesis required for plant growth captures carbon dioxide from the atmosphere, and therefore in some circumstances, leads to hemp lime construction being considered as having a negative carbon footprint. More carbon is captured during the growth period than is emitted due to energy consumption in manufacture and transport.

World leaders in the development of hemp use in modern sustainable construction include Rachael Bevan and Tom Woolley, whose book includes case study examples together with accounts of life-cycle analysis (Bevan and Woolley 2008).

17.8.2 Timber

The use of wood as a construction material can be considered as a highly sustainable option. It is a natural material which, if properly managed, is renewable and will sequester carbon throughout its period of growth. In addition, at the end of its useful life as a building material, it may be reused or recycled, may be burnt as a fuel, or will decompose naturally in landfill.

There are records of timber construction in ancient Chinese culture with evidence of *dougong* (cap and block) structural elements being used in the eighth century BC. Timber frame has been a feature of building construction in the UK for many centuries with the pattern of the timber structural framework being clearly visible in many historic towns and villages. The roof structures of the magnificent medieval cathedrals also illustrate the essential nature of timber in construction throughout history.

The growth of trees is dependent upon the sequestration of carbon through the process of photosynthesis. Trees extract carbon dioxide from the atmosphere and release oxygen, creating biomass and reducing carbon dioxide concentration in the atmosphere. The carbon is 'locked' within a structure of a tree throughout its growth and for the duration of its use within the timber products made from that tree. It is only released when the timber is eventually disposed of either through decomposing naturally or through combustion. The latter may be utilized as a fuel source.

The use of timber in construction has a long-term advantage to the environment, provided that the forests and woodlands are appropriately managed and new trees are planted to replace those that are felled. It is estimated that the average tree absorbs approximately 55 kg of CO_2 and gives off 40 kg of oxygen when growing 2 kg of wood (TTF 1998). During its growth period, a tree therefore has a positive impact on the environment through the reduction in greenhouse gases. Environmental assessments in the UK such as BREEAM and the CSH require appropriate certification such as those issued by the forest stewardship council (FSC) for timber used either for structural or finishes.

Through appropriate forest management and production, efficient use can be made of the material discarded from the felled trees for composite timber products and garden mulches. The supply of timber for the construction industry can be fully sustainable when harvested timber is replaced through replanting.

In the UK, a high proportion of construction timber is imported, yet some regions including Sussex in the southeast of England are heavily wooded. It is often quoted that the climate in England is not suited for the successful growth of construction timber as trees grow too quickly, failing to achieve the required structural properties. While rapid growth means faster absorption of CO_2, the resulting timber cannot be used directly for construction.

Traditionally, the building design, including dimensions and span widths, depended upon the size and quality of timber available and the skill of the craftsmen who constructed the buildings. Woodland management undertaken to serve the construction industry also had to compete with the demand for timber for ship construction.

Modern timber construction, however, utilizes engineered timber products as well as smaller tree sections which enable efficient use of the timber and greater flexibility with sizes. Factory manufacture of frames and panels can also improve quality and reduce wastage, again improving the resource efficiency of timber.

However, processed timber products such as glulam (glue laminated timber) provide excellent alternatives to natural timber sections and although they require energy for manufacture, they usually incorporate less embodied energy than alternative structural materials.

17.8.2.1 Timber Life Cycle

The life cycle of timber from sustainable sources can be traced through every stage from cradle to factory gate, and beyond to construction, maintenance, and to disposal when appropriate. However, the cradle to factory gate analysis is most common. It includes:

- Seed gathering and propagation;
- Seedling planting and forest management including fertilizing, protection from animals, and thinning;
- Harvesting the mature trees including forestry activities;
- Drying and seasoning felled timber;
- Processing slab wood and rough sawn timber;
- Secondary processing timber joinery;
- Transport within and between each of these stages.

Trees used for structural timber mature over many decades. Softwood forests may be harvested after 50 years but hardwood trees may take over 100 years to mature.

One important strategy for sustainable woodland management is coppicing, thinning the canopy to allow sunlight to the woodland floor on a cyclic basis which facilitates biodiversity at ground level. The vigorous growth generated in the coppiced trees also represents an accelerated rate of carbon sequestration reducing the build-up of carbon dioxide in the atmosphere.

Engineered timber products also utilize woodland coppiced materials where hardwood such as sweet chestnut is harvested through coppicing. Trees are cut down to ground level in relatively short cycles which promote vigorous growth and produce poles up to 200 mm in diameter. Traditionally, coppiced material was used for fence poles, tool handles, and a wide range of applications. Modern gluing and jointing techniques have enabled short lengths of timber with small cross-sectional areas to be jointed and laminated to produce large structural members for construction.

17.8.2.2 Engineered Timber Products

There are many environmental advantages of using timber in contemporary building construction, utilizing a material that enhances the quality of life for everyone during its growth period, and which will ultimately biodegrade to its component parts. One additional advantage of using engineered timber products is that high quality structural elements can be produced from timber that would otherwise not have been suitable for construction. It reduces waste and adds value to material for which there was little demand, and therefore encourages more active woodland management.

There is a wide variety of engineered timber products that are used in furniture, finishes, and other decorative features that are not designed for structural use. There is also some environmental concern about some of the adhesives that have been used and the potential for off-gassing. Two products, however, that are enhancing the use of timber in modern construction are *glue laminated timber* (*glulam*) and *structurally insulated panels* (SIPS).

17.8.2.3 Glue Laminated Timber

Glulam is a manufactured composite material made by finger jointing different lengths of coppiced material that has been cut to a uniform cross-section, and then further gluing individual lengths to form structural members of any desired cross-section and length. These can be bent during manufacture to form wide spanning curved beams which have a beautiful esthetic.

Techniques have been developed to utilize green coppice, thus not only reducing wastage by using short sections of material, but reducing energy which would normally be required for the drying process.

17.8.2.4 Structurally Insulated Panels

The structurally insulated panel has been created to facilitate fast, on-site construction using precision manufactured products that have been constructed in a factory and provide both load bearing and thermal insulation properties. Various sheet materials are used to sandwich insulating materials such as expanded or extruded polystyrene, or any other insulating material, including straw bales to form a composite panel. The panel is manufactured to include appropriate vapor barriers and may also include service distribution ducts.

Panels can be manufactured to many size specifications; however, there are implications with respect to handling and transportation. A typical 2.4 × 2.4 m panel can provide a complete floor height and sufficient flexibility for the design of the floor plan. The reduced number of joints improves airtightness, another advantage in the construction of low energy buildings.

17.9 Conclusions

Construction materials are required to provide many different functions for the structure, envelope, services, and esthetic of any buildings. These materials are sourced throughout the world and their mining and harvesting, transportation, and manufacture will have varying impacts on the natural environment. Consideration of their sustainability relates to all of these impacts together with social and economic factors and the finite nature of the resource. Implementation of various calculation methodologies such as LCA can highlight the extent to which energy is consumed in providing certain goods. Further, the use of renewable materials and the approach we adopt in constructing buildings will play a vital role in mitigating future carbon emissions. Selection of sustainable construction materials must therefore be based on a clear understanding of the key issues, and reduce the negative impact on people and the natural environment while promoting social wellbeing and achieving economic viability.

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