Chapter 1

Sustainable Development and Wooden Construction

1.1. UNDERSTANDING THE CONCEPT OF SUSTAINABLE DEVELOPMENT

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1.1.1. History of Sustainable Development

According to Bac (2008), the first questions regarding what impact the evolution of civilization could have on the environment and resources of our planet arose approximately 200 years ago. The discussion regarding whether the capacity of the Earth's limited natural resources would be able to continually support the existence of the increasing human population gained prominence with the Malthusian population theory in the early 1800s (Mensah, 2019). Thomas Robert Malthus (1766–1834) was a demographer, political economist and country pastor in England. In his famous publication *An Essay on the Principle of Population* (Malthus, 1978), he predicted that the world's population would eventually starve or, at the least, live at a minimal level of subsistence because food production could not keep pace with the growth of population (Bac, 2008). This postulation tended to be ignored for a long time in the belief that technology could be developed to solve such problems, but debates about Malthusian assumptions have continued. With time, global concerns heightened about the non-renewability of some natural resources which threaten production and long-term economic growth resulting from environmental degradation and pollution (Paxton, 1993, cit.

from Mensah, 2019).

The first truly international conference devoted exclusively to environmental issues was the 1972 Conference on the Human Environment in Stockholm, Sweden. It was attended by 113 states and representatives from 19 international organizations (Bac, 2008). There, a group of 27 experts defined the links between environment and development stating that "although in individual instances there were conflicts between environmental and economic priorities, they were intrinsically two sides of the same coin" (Vogler, 2007, p. 432, cit. from Bac, 2008). Another important result of the conference was the development of the *United Nations Environmental Programme* (UNEP) with the mission "to provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations".

The conference played a catalytic role in promoting the subsequent adoption of international agreements concerned with ocean dumping, pollution from ships, and the endangered species trade. It also adopted the *Stockholm Declaration on the Human Environment*, which included forward-looking principles, such as Principle 13, that declared the need for integration and coordination in development planning to allow for environmental protection (Bac, 2008).

In 1983, the UN General Assembly created the World Commission on Environment and Development which was later known as the Brundtland Commission, named after its Chair, Gro Harlem Brundtland, then Prime Minister of Norway and later Head of the World Health Organization (Bac, 2008). In 1987, the Commission published the Brundtland Report, entitled *Our Common Future*. It provided the definition of sustainable development: "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). Central to the Brundtland Commission Report were two key issues: the concept of needs, in particular the essential needs of the world's poor (to which overriding priority should be given); and the idea of limitations imposed by the state of technology and social organisation on the environment's ability to meet present and future needs (Kates et al., 2001, cit. from Mensah, 2019). Some critics called the Brundtland's Commission Report both optimistic and vague, but the fact still remains that the concept of sustainable development was born (Bac, 2008).

Further the UN Conference on the Environment and Development (UNCED) in Rio de Janeiro, Brazil, during the summer of 1992 was held. It is known an unprecedented historical event with the largest gathering of 114 heads of state, including 10,000 representatives from 178 countries and 1400 nongovernmental organizations represented by additional thousands. The key outputs of the Conference were: the Rio Declaration, Agenda 21, and the Commission on Sustainable Development (Bac, 2008).

Agenda 21 articulated the commitment of leaders from around the world to sustainable development by a 500-page collection of agreed healthy practices and advices for achieving sustainable development. Agenda 21 activities were organized under environmental and development themes: quality of life, efficient use of natural resources, protection of the global commons, management of human settlements, and sustainable economic growth. During the 1992 conference it was agreed that to implement Agenda 21, countries should prepare a national sustainable development strategy (Bac, 2008).

In the 1997 Kyoto conference on climate change, developed countries agreed on specific targets for cutting their emissions of greenhouse gases, resulting in a general framework, which became known as the Kyoto Protocol, with specifics to be detailed over the next few years (Bac, 2008). The USA proposed to stabilize emissions only and not cut them at all, while the European Union called for a 15 % cut. In the end, there was a trade off, and industrialized countries were committed to an overall reduction of emissions of greenhouse gases to 5.2 % below 1990 levels for the period 2008–2012. Although 84 countries signed the Protocol, indicating their intent to ratify it, many others were reluctant to take even this step. The USA has refused to ratify the Kyoto Protocol. The Kyoto Protocol still remains one of the most debated international agreements between the 'greens' and the 'neo-liberals' (Bac, 2008).

In September 2000 at the Millennium Summit held in New York, world leaders agreed on the Millennium Development Goals, most of which had the year 2015 as a timeframe and used 1990 as a benchmark. They included: 1) halving the proportion of people living on less than a dollar a day and those suffering from hunger, 2) achieving universal primary education and promoting gender equality, 3) reducing child mortality and improving maternal health, 4) reversing the spread of HIV/AIDS, 5) integrating the principles of sustainable development into country policies, 6) reducing by half the proportion of people without access to safe drinking water (Bac, 2008).

Next important event was The World Summit on Sustainable Development (WSSD) which took place in Johannesburg in 2002. The Johannesburg Summit reconfirmed the Millennium goals and complemented them by setting a number of additional ones such as halving the proportion of people lacking access to basic sanitation; minimizing harmful effects from chemicals; and halting the loss of biodiversity (Bac, 2008).

The Johannesburg Conference confirmed a trend, which appeared since the 1992 Conference, of the increasing importance of the socioeconomic pillars of sustainable development. The environmental agenda at the two previous UN conferences had been sustained by peaks in the public 'attention cycle' of major developed countries. WSSD incorporated the concept of sustainable development throughout its deliberations and was initially dubbed 'the implementation summit'. Inevitably "demands for additional financial resources and technology transfer continued, but much of the debate had already been pre-empted by the establishment of the Millennium Development Goals in 2000" (Vogler, 2007, p. 439, cit. from Bac, 2008).

In 2012, 20 years after the first Rio Earth Summit, the nited Nations Conference on Sustainable Development (UNCSD) or Rio+20 was held. The conference focused on two themes in the context of sustainable development: green economy and an institutional framework (Allen et al., 2018, cit. from Mensah, 2019). Outcomes of Rio+20 included a process for developing new sustainable development goals (SDGs), to take effect from 2015 and to encourage focused action on sustainable development in all sectors of global development agenda (Weitz et al., 2017, cit. from Mensah, 2019).

In 2015 the new 2030 Agenda for Sustainable Development was introduced with the 17 SDGs and 169 targets which demonstrate the scale and ambition of the new universal Agenda. They are integrated and indivisible and balance the three dimensions of sustainable development: the economic, social and environmental.

The Goals and targets will stimulate action over the next fifteen years in areas of critical importance for humanity and the planet (see Fig. 1.1) (UN, 2015):

1. People: To end poverty and hunger in all their forms and dimensions, and to ensure that all human beings can fulfil their potential in dignity and equality and in a healthy environment.
2. Planet: To protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations.
3. Prosperity: To ensure that all human beings can enjoy prosperous and fulfilling lives and that economic, social and technological progress occurs in harmony with nature.
4. Peace: To foster peaceful, just and inclusive societies which are free from fear and violence. There can be no sustainable development without peace and no peace without sustainable development.
5. Partnership: To mobilize the means required to implement the Agenda through a revitalized Global Partnership for Sustainable Development, based on a spirit of strengthened global solidarity, focused in particular on the needs of the poorest and most vulnerable and with the participation of all countries, all stakeholders and all people.

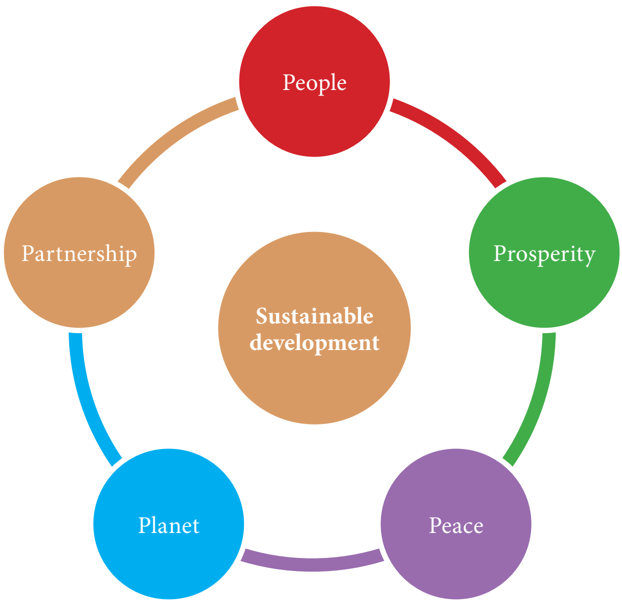

Fig. 1.1. Critical areas of sustainable development (UN, 2015).

1.1.2. Key Pillars of Sustainable Development

The three main issues of sustainable development are economic growth, environmental protection and social equality, therefore the concept of sustainable development rests on three key pillars, namely economic sustainability, social sustainability, and environmental sustainability (see Fig. 1.2).

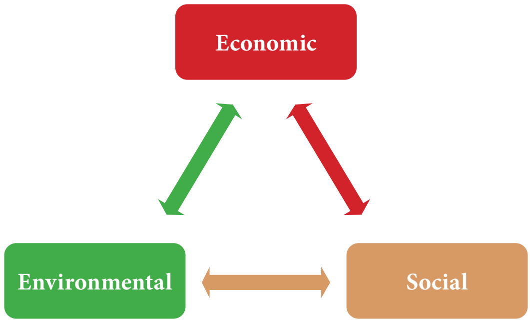

Fig. 1.2. Key pillars of sustainability.

Economic sustainability

Economic sustainability implies a system of production that satisfies present consumption levels without compromising future needs (Lobo et al., 2015). In other words, economic sustainability refers to practices that support long-term economic growth without negatively impacting social, environmental, and cultural aspects of the community (University of Mary Washington, n.d.).

There are couple of explanations of economic sustainability. The differences between two of these are due to the use of different sustainability models as a starting point. In the first of these two explanations, economic sustainability is understood to be economic development that does not have a negative impact on ecological or social sustainability. An increase in economic capital must therefore not be at the expense of a reduction in natural capital or social capital (KTH, n.d.).

In the second explanation, economic sustainability is equated with economic growth, which is considered sustainable as long as the total amount of capital increases. Increased economic capital can thus be allowed at the expense of a reduction of other assets in the form of natural resources, ecosystem services or welfare (KTH, n.d.).

No one these days seriously denies the need for sustainable business practices. Even those concerned about only business and not the fate of the planet recognize that the viability of business itself depends on the resources of healthy ecosystems – fresh water, clean air, robust biodiversity, productive land – and on the stability of just societies (Chouinard et al., 2011).

Social sustainability

Since development is about people, the people matter (Benaim & Raftis, 2008). Social sustainability encompasses notions of equity, empowerment, accessibility, participation, cultural identity and institutional stability (Daly, 1992). The social sustainability dimension largely concerns well-being, justice, power, rights and the needs of the individual (KTH, n.d.).

An individual has needs, physical and psychological, and own goals / dreams. Meeting the ability of the planet and all of the people to fulfil these at a global level is what social sustainability deals with. In this process, concepts such as justice, power, rights and trust become central to guiding to human constellations that allow to achieve full potential (KTH, n.d.).

According to the United Nations Global Compact (n.d.), from the viewpoint of business, "social sustainability is about identifying and managing business impacts, both positive and negative, on people. The quality of a company's relationships and engagement with its stakeholders is critical".

The first six of the UN Global Compact's principles focus on this social dimension of corporate sustainability, of which human rights is the cornerstone. Social sustainability also covers the human rights of specific groups: labour, women's empowerment and gender equality, children, indigenous peoples, people with disabilities, as well as people-centered approaches to business impacts on poverty. As well as covering groups of rights holders, social sustainability encompasses issues that affect them, for example, education and health (UN Global Compact, n.d.).

While it is the primary duty of governments to protect, respect, fulfil and progressively realize human rights, businesses can, and should, do their part. At a minimum, businesses can undertake due diligence to avoid harming human rights and to address any adverse impacts on human rights that may be related to their activities (UN Global Compact, n.d.).

According to Kolk (2016, cit. from Mensah, 2019) social sustainability is not about ensuring that everyone's needs are met. Rather, it aims at providing enabling conditions for everyone to have the capacity to realize their needs, if they so desire.

Environmental sustainability

The concept of environmental sustainability (sometimes called ecological sustainability) is about the natural environment and how it remains productive and resilient to support human life (Mensah, 2019). Environmental sustainability relates to ecosystem integrity and carrying capacity of natural environment (Brodhag & Taliere, 2006). The implication is that natural resources must be harvested no faster than they can be regenerated, while waste must be emitted no faster than they can be assimilated by the environment (Diesendorf, 2000, cit. from Mensah, 2019).

Amongst other things, ecological sustainability relates to the functioning of the Earth's biogeochemical system, which includes the following (KTH, n.d.):

- water (pollutants, groundwater levels, salinity, temperature, alien species);
- air (pollutants, particles, ozone layer, climate system, noise);
- land (pollutants, erosion, land use, alien species);
- biodiversity (species and habitats (natural habitats), GMOs);
- ecosystem services (e.g., pollination, photosynthesis, water purification, climate control).

Ecological sustainability sometimes also includes human health, to the extent that it is affected by the external environment in terms of pollutants, noise, etc. (KTH, n.d.).

Climate change has already shown signs of affecting biodiversity. In particular, Kumar et al. (2014) have observed that higher temperatures tend to affect the timing of reproduction in animal and plant species, migration patterns of animals and species distributions and population sizes. According to Campagnolo et al. (2018), for the sake of sustainability, all societies must adjust to the emerging realities with respect to managing ecosystems and natural limits to growth.

1.2. SUSTAINABLE CONSTRUCTION

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In many countries construction has been identified as the first sector to require specific attention in meeting the sustainable development agenda. As noted in report *Shaping the Future of Construction – A Breakthrough in Mindset and Technology* (World Economic Forum, 2016), the industry is crucial to society, the economy and the environment.

Construction is one of the first businesses that humankind developed, and it continues to shape our daily life in unique ways. Virtually all other businesses rely on the construction industry to provide and maintain their accommodation, plants and infrastructure, and construction is a determinant of where and how almost everyone lives, works and plays. For nearly the entire population of the world, the built environment heavily influences quality of life (World Economic Forum, 2016). In the United States, for instance, people on average spend nearly 90 % of their time indoors. So, the building and the materials used in its construction and finishing have a major impact on the health and well-being of its occupants (World Economic Forum, 2016). The industry is the key to the quality of life, as it produces the built environment and puts in place the physical facilities and infrastructure that determine the degree of freedom and flexibility that society may enjoy. Its products also have a long lifetime, typically for anything up to one hundred years after construction (Myers, 2013).

The construction industry is a vitally important industry for global economy. With total annual revenues of almost $10 trillion and added value of $3.6 trillion, the construction industry accounts for about 6 % of global GDP. More specifically, it accounts for about 5 % of total GDP in developed countries, while in developing countries it tends to account for more than 8 % of GDP. More than 100 million people are employed in construction worldwide (World Economic Forum, 2016).

For countries to enjoy inclusive and sustainable growth, modern and efficient infrastructure is essential. According to a 2014 estimate by the International Monetary Fund (2014), if advanced economies invested an extra 1 % of GDP into infrastructure construction, they would achieve a 1.5 % increase in GDP after four years.

As Myers (2013) notes, construction is consistently responsible for some of the most profound negative impacts – the construction industry consumes more raw materials than any other industrial sector and is responsible for a significant proportion of the world's waste and carbon dioxide emissions.

The construction industry is the single largest global consumer of resources and raw materials. It consumes about 50 % of global steel production and, each year, 3 billion tonnes of raw materials are used to manufacture building products worldwide (World Steel Association, 2015).

About 40 % of solid waste in the United States derives from construction and demolition (Environmental and Energy Study Institute, 2014). Throughout the world, such waste involves a significant loss of valuable minerals, metals and organic materials – so there is great opportunity to create closed material loops in a circular economy (World Economic Forum, 2016).

As for energy use, buildings are responsible for 25–40 % of the global total, thereby contributing hugely to the release of carbon dioxide (World Economic Forum, 2016).

Finally, construction lacks change and innovations. In nearly every other sector of the economy, technological developments have fueled changes in business attitudes. For example, the manufacturing industry has become leaner, cleaner and quicker at all tasks. On the other hand, the construction industry is old fashioned. It suffers from inertia. It is a market of few large players and many small businesses. The owners of these businesses look for job opportunities in their local areas and are not inclined to invest time or money into research and development (Myers, 2013).

The notion of sustainability, therefore, has a special relevance to construction, and a specific agenda is evolving. The construction industry's response to sustainable development is *sustainable construction* (Bourdeau, 1999).

In 1994, the first definition of sustainable construction was given by Professor Charles J. Kibert during the Final Session of the First International Conference of CIB TG 16 on Sustainable Construction as "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles" (Kibert, 1994).

Kibert (1994), compared with the traditional concerns in construction (performance, quality, cost), introduced the criteria of sustainable construction, namely resource depletion, environmental degradation and healthy environment (see Table 1.1).

Table 1.1
Traditional and Sustainability Criteria
for Building Materials, Products, and Systems (Kibert, 1994)

Traditional Criteria	Sustainability Criteria
• Performance • Cost • Quality	• Resource depletion • Environmental degradation • Healthy environment

Kibert (1994) also introduced six principles set for sustainable construction (see Table 4.2) and a conceptual model (see Fig. 1.3).

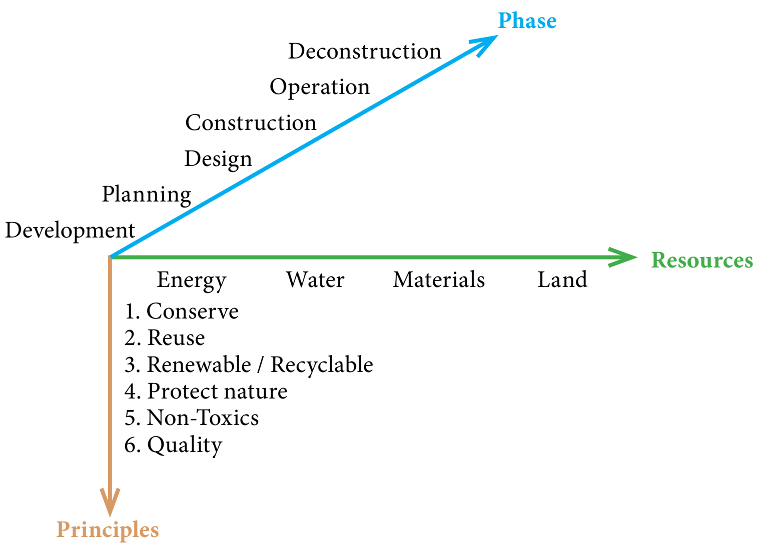

Fig. 1.3. A conceptual model for sustainable construction (Kibert, 1994).

Table 1.2
Principles Set for Sustainable Construction (Kibert, 1994)

Principle	Description
Minimize resource consumption (Conserve)	It is the starting principle because it contrasts the major problem that forces us to address sustainability in the first place: overconsumption. It leads us to the use of passive measures to provide heating, cooling, ventilation, and lighting for our structures because the minimization of energy consumption is absolutely essential. It forces us to consider high efficiency systems, high levels of insulation, low flow fixtures, and high-performance windows. It also leads us to the use of durable materials that have long lifetimes and require low maintenance.
Maximize resource reuse (Reuse)	Reuse contrasts to recycling in that reused items are simply used intact with minimal reprocessing, while recycled items are in essence reduced to raw materials and used in new products. A significant business in architectural items such as windows, doors, and bricks that can be reused in new construction and renovation has proven to be profitable, as owners and architects strive to recapture a sense of the past in new spaces. Other resources such as water can be reused via use of grey water systems and use of third main systems. Land can be used by creating new spaces in 'grey zones', areas formerly used for buildings.
Use renewable or recyclable resources (Renew / Recycle)	This principle applies to energy where renewable sources such as solar and wind power are available for use. It applies to materials such as wood. This common construction material can be supplied from certified sustainable forests that provide the buyer with a reasonable level of assurance that the suppliers are managing their resources in a manner that protects the environment. A wide range of materials have recycled or waste content from engineered wood systems, agriboard panels, tiles with recycled tire or glass content, roofing shingles made of recycled plastics, and many others. One of the problems that must be sorted out with respect to recycled materials is to determine if their content is simply convenient waste from other industries or bona fide recycled content. Products that consist of the former may be said to be down cycled or cascaded uses with the built environment serving as a convenient dumping ground for otherwise difficult to dispose of materials.

Principle	Description
Protect the natural environment (Protect nature)	Inevitably our actions in creating the built environment will impact the natural environment and its ecological systems. Considering the past negative effects on the natural environment, perhaps it is time to do better than just 'sustain', and to 'restore' where possible. Grey zones can be remediated, detoxified and returned nearly to their original state. The abuses of river straightening, marsh draining, and deforestation can be remedied by intelligent intervention in creating the future built environment. In our quest for materials we can scrutinize the impacts of materials acquisition practices, whether logging, mining, or consuming energy, to minimize environmental effects. Some of the choices are not easy but will inevitably be forced on us by global environmental effects, scarcity, or other reasons.
Create a healthy, non-toxic environment (Non-Toxics)	The outcome of this principle in a practical sense is the elimination of toxics in the indoor and exterior built environment. One of the major objectives is to achieve good indoor air quality by selecting materials that will not off-gas or contribute particulate loading to the environment. Relative to the exterior environment, landscape design should provide for the use of plants and vegetation that are hardy, drought tolerant, and insect resistant. These qualities are usually provided by vegetation native to the region. Using this so-called 'xeriscaping' strategy will minimize and perhaps eliminate the application of pesticides, herbicides, fungicides, and fertilizers that ultimately end up polluting groundwater.
Pursue quality in creating the built environment (Quality)	Although often cited and equally often abused, the notion of quality as a component of sustainable construction is vital. It includes planning of communities to reduce automobile trips, increase interpersonal activity, and provide a good quality of life. It includes excellence in design of buildings as an absolutely essential component of sustainable construction because spaces that are not valued by their occupants will, by their very nature, fall into disuse, disrepair, and disorder, contributing to the exact antithesis of what sustainability strives to achieve. Selection of materials, energy systems, design of passive energy and lighting systems, and a host of other decisions rest on the idea that significant analysis and design are required to lay out spaces, build spaces, and occupy them.

Since establishment of a model much progress to sustainable construction has been made all over the world. The International Council for Research and Innovation in Building and Construction (CIB) has carried out a study aimed to compare the vision of sustainable construction in different countries.

The study revealed that sustainable construction has different approaches and different priorities in different countries. Some of them identify economic, social and cultural as part of their sustainable construction framework, but it is raised as a major issue in a few countries only (see Table 1.3).

Table 1.3
Countries Following a Sustainable Construction Agenda (Myers, 2013)

Three-strand policy (three sustainability pillars)	Environmental strand (one sustainability pillar)
Denmark	Australia
Finland	Canada
France	Germany
Ireland	USA
Japan	
Netherlands	
Norway	
Portugal	
Sweden	
United Kingdom	

The main emphasis in national definitions is on ecological impacts to the environment (biodiversity, tolerance of nature and resources). The categories of problems identified behind the notion of sustainable construction can also be classified as follows (Bourdeau, 1999):

- physical problems linked to the issue of resources;
- biological problems linked to the life of mankind;
- sociological problems having socio-political;
- socio-economic or socio-cultural facets.

Nowadays precise definitions of sustainable construction vary from place to place and are constantly evolving to encompass varying approaches and priorities.

In the United States, the Environmental Protection Agency (EPA) defines green construction as “the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building’s life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction”. Green building is also known as a sustainable or high-performance building. Green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by (EPA, 2019):

- efficiently using energy, water, and other resources;
- protecting occupant health and improving employee productivity;
- reducing waste, pollution and environmental degradation.

European Commission [EC] defines sustainable construction as "a dynamic of developers of new solutions, investors, the construction industry, professional services, industry suppliers and other relevant parties towards achieving sustainable development". It embraces a number of aspects such as design and management of buildings and constructed assets, choice of materials, building performance as well as interaction with urban and economic development and management. Different approaches may be followed according to the local socio-economic context; in some countries, priority is given to resource use (energy, materials, water, and land use), while in others social inclusion and economic cohesion are the more determining factors (EC, 2016).

Sustainable buildings combine improved energy performance and reduced environmental impact throughout their life cycle. Their users enjoy better health and well-being and productivity gains that translate into cost savings. Buildings have the potential to reach a 90 % reduction of their greenhouse gas emissions by 2050 (EC, 2016).

Three interpretations of what sustainable construction has involved in practice in Europe are shown in Table 1.4. The key ideas that recur in these definitions are to minimize the amount of energy and resources used in the construction process, reduce the amount of waste and pollution, and to respect the various stakeholders – particularly the users – both now and in the future (Myers, 2013).

Table 1.4
Three Interpretations of Sustainable Construction (Myers, 2013)

Country	Interpretation of sustainable construction
Finland, since 1998	• Intensified energy efficiency & extensive utilisation of renewable energy resources • Increasing the sense of well-being over a prolonged service life • Saving of natural resources and promotion of the use of by-products • Reducing waste and emissions • Recycling building materials • Supporting the use of local resources • Implementation of quality assurance and environmental management systems
The Netherlands, since 1999	• Consume a minimum amount of energy and water over the life span • Make efficient use of raw materials • Generate a minimum amount of pollution and waste • Use a minimum amount of land and integrate well with the natural environment • Meet user needs now and in the future • Create a healthy indoor environment
United Kingdom, since 2000	• Minimizing the consumption of carbon-based energy • Improving whole life value by supporting best practice construction • Delivering buildings and structures that provide greater satisfaction, • Well-being and value to customers and users • Respecting and treating stakeholders more fairly • Enhancing and better protecting the natural environment • Being more profitable and using resources more efficiently

Summary of definitions reflects in sustainable construction understanding provided by Myers (2013): “Sustainable construction means designing, renovating or converting a building in compliance with environmental rules and energy-saving methods. The purpose of this holistic process is to restore and maintain harmony between the natural and built environment:

- efficient use of resources;
- efficient protection of the environment;
- economic growth;
- social progress that meets the needs of everyone”.

According to Myers (2013), in practical terms, sustainable construction can be reduced to three important messages for the way the industry should work:

- Buildings and infrastructure projects should become more cost effective to produce and run because they have been constructed with less and yield more.
- Construction projects should contribute positively to their environment by using materials and systems that are easily replenished over their full life cycle.
- Contractors and clients should, wherever possible, create higher standards of respect for people and communities involved with the project, from the site workers through to the final community of users.

1.3. SUSTAINABLE CONSTRUCTION IN WOOD

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Wood's millennial history as building material makes it one of the oldest building materials we have. Since the dawn of civilization, timber has been used as a material to construct shelters protecting human from the severe weather conditions and predators. The use of timber in construction dates back to 500 to 100 B.C., which was structurally used in roof constructions by the ancient Roman and Egyptian civilizations that majorly used stone in buildings (Radkau, 2012). In comparison, steel has only been used for buildings since the 1880s and modern concrete since the 1850s. It may therefore seem paradoxical that wood is not selected as major material for construction of public buildings due to lack of experience with wood compared to steel and concrete. The explanation is, among other things, that the large industrial-processed solid wooden elements are relatively a new invention. For example, CLT (Cross-Laminated Timber) was first introduced in the 1980s, and the experience base for wood construction is only being established. However, in Europe and North America, the number of projects in wood in recent years has been rising exponentially. For instance, Moxy hotel in Copenhagen was recently opened, which is the first Danish hotel built with cross-laminated timber (Fig. 1.4).

Fig. 1.4. Moxy hotel in Copenhagen (Hospitalitynet, 2020).

1.3.1. Modern Building Methods in Wood

There is a wealth of possibilities for the choices of building materials, from wood products to concrete. The high quality of wood material allows for the production of a wide range of products adapted to the current areas of application. The wood construction sector is also extensively regulated and specified in the European standardisation system, which ensures great geographic mobility and competition.

No matter what building materials or methods are implemented, it is important to use the materials so that their best properties are utilized for the project in question. This means that it often makes sense to use materials in hybrid constructions, e.g. in combination with other materials. It must be ensured that the solutions are designed so that materials and components fit well together for example in moisture-sensitive areas and construction movements, etc. (InnoBYG, 2017).

There are several different building systems, where requirements for span, strength and stability are crucial for the choice of materials and components, but often there will be many useful building solutions for each task. Further is a short presentation of some selected building systems for construction of wooden buildings.

Prefabricated wood elements

Prefabricated wood elements are typically constructed of studs of construction wood. The studs are typically placed with a spacing of 50–60 cm depending on the strength and rigidity requirements. The elements also can be of glued laminated timber (glulam) or laminated veneer lumber (LVL).

Glued laminated timber, also called glulam, is the oldest glued structural product (over 100 years). It is generally composed of lumber layers (2×3 to 2×12), planed and pre-finger-jointed, and then bonded together with moisture-resistant structural adhesives longitudinally (Avellan, 2018; Quebec Wood Export Bureau [QWEB], 2015) (Fig. 1.5). Large straight or curved sections can be produced, providing more stability than heavy lumber. Glulam can be used for columns, beams, or arches, in lengths mainly limited because of transport.

Laminated veneer lumber (LVL) is an engineered wood product made up with thin dried wood and bonded with adhesive (Avellan, 2018) (Fig. 1.6). It can be used for beams, walls, other structures and forming of edges. LVL is a type of structural composite lumber. Due to its composite nature, it is much less likely than conventional lumber to warp, twist, bow, or shrink, and has higher allowable stress

Fig. 1.5. Glue laminated timber (Instabuilt, n.d.).

Fig. 1.6. Laminated veneer lumber (Metsä Wood's Kerto-Qp, n.d.).

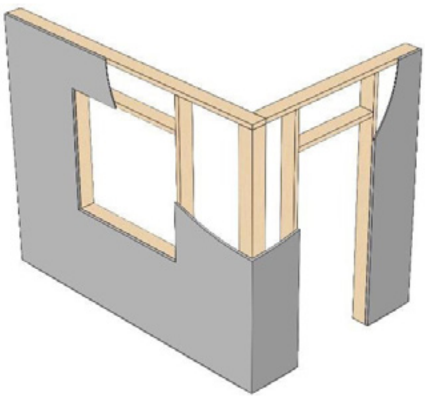

Fig. 1.7. Principle drawing of prefabricated wood elements (InnoBYG, 2017).

compared to glulam (QWEB, 2015).

The elements are covered with a windbreak, damp-proof membrane (DPM), and exterior and interior cladding (Fig. 1.7). Prefabricated wood elements can be made in a factory, as a flat element or as room size, volume elements with finished interior fitting. The prefabrication element types are determined by the needs of the individual building. It will often be the transport considerations that set the limits for the size of elements that can be manufactured.

Prefabricated wood elements can be used for walls, deck and roof elements. They can be designed as infill panels or as fully or partially load-bearing and / or stabilizing building elements.

Solid wood elements

Massive wooden elements in the 'modern' form have been known and used since the late 80s. Over the last 20 years, the development of solid wood elements has shifted to Cross Laminated Timber elements (CLT).

CLT is a solid engineered wood panel made up of cross angled timber boards which are glued (Avellan, 2018) (Fig. 1.8). It distinguishes from other products by superior thermal and acoustical performance, high fire resistance and structural strength (QWEB, 2015).

The CLT development has taken place in the Middle East and especially in Austria, Switzerland and Southern Germany. In Denmark the growth of the use of solid wood elements in the late 90s and early 00s, where several buildings using these elements saw the light of the day.

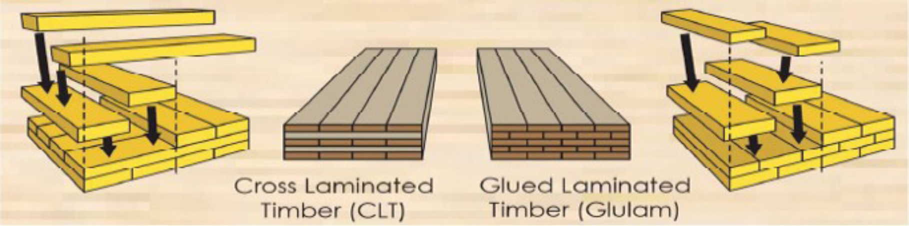

Fig. 1.8. Difference between CLT and glulam (Avellan, 2018).

Unlike the stud frame building, the massive CLT constructions have some clear advantages, for example in connection with load distribution and minimization of risk of progressive collapse (Fig. 1.9). CLT elements can be used as wall, deck or roof elements and may be included as fillers or as fully or partially bearing and / or stabilizing building elements in the building. For the heat and sound insulation, solid wood elements must be supplied with insulation to meet the requirements of the building regulations.

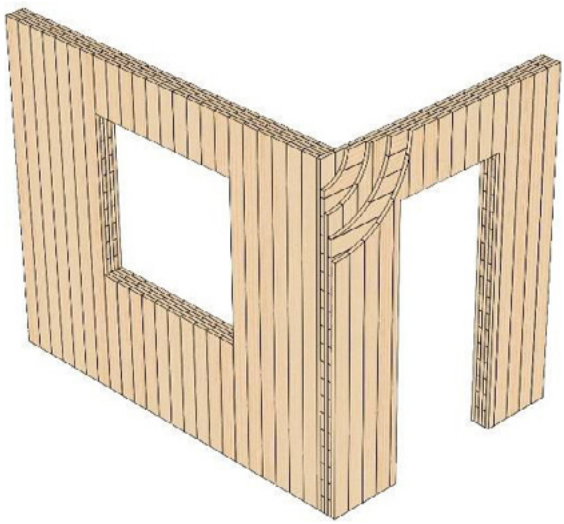

Fig. 1.9. Principle drawing of CLT elements (InnoBYG, 2017).

In recent years, existing European producers have delivered CLT to most of the world. North America now has its own production which will have an impact on European exports. For example, Structurelam in British Columbia, Canada, has delivered CLT elements to the Brock Commons in Vancouver (InnoBYG, 2017).

A common European standard for solid wood elements – EN 16351:2015, has been adopted at European level. The standard is an official journal, which is the prerequisite for the CE marking of the products in accordance with the standard. However, there are a number of CE-labeled products on the market today. However, these products are CE-labeled on the basis of individual European Assessment Documents (EADs), which in some areas makes it difficult to compare the products. For example, there are no fixed standard classes, as it is known for glulam, which means that several alternative CLT solutions can be considered in individual projects (InnoBYG, 2017).

Column-beam system and hybrid solutions

Column-beam systems are also implemented in high-rise wooden buildings. These systems can be constructed of wood products such as glulam and LVL, but can also be carried out in steel frame systems, e.g. with CLT elements or prefabricated wood elements. Systems like these will typically be referred to as hybrid solutions.

In column / beam systems in steel and the wood construction can be used as a fire protection for the steel. Column/ beam systems will form the load bearing super construction, and walls can be infill elements and the decking of load bearing CLT elements.

The many possibilities for wood products, also provide many different combinations within the product range of wooden components (Fig. 1.10). However, it is also possible to combine, for example CLT with concrete and steel in floor partitions in order to optimize the utilization of materials (Fig. 1.11). This allows for greater load bearing spans and increased passive fire resistance (InnoBYG, 2017).

Fig. 1.10. Hybrid construction with glulam column and CLT beams. Source: Acron Ostry Architects. Photo: KK Law (cit. from InnoBYG, 2017).

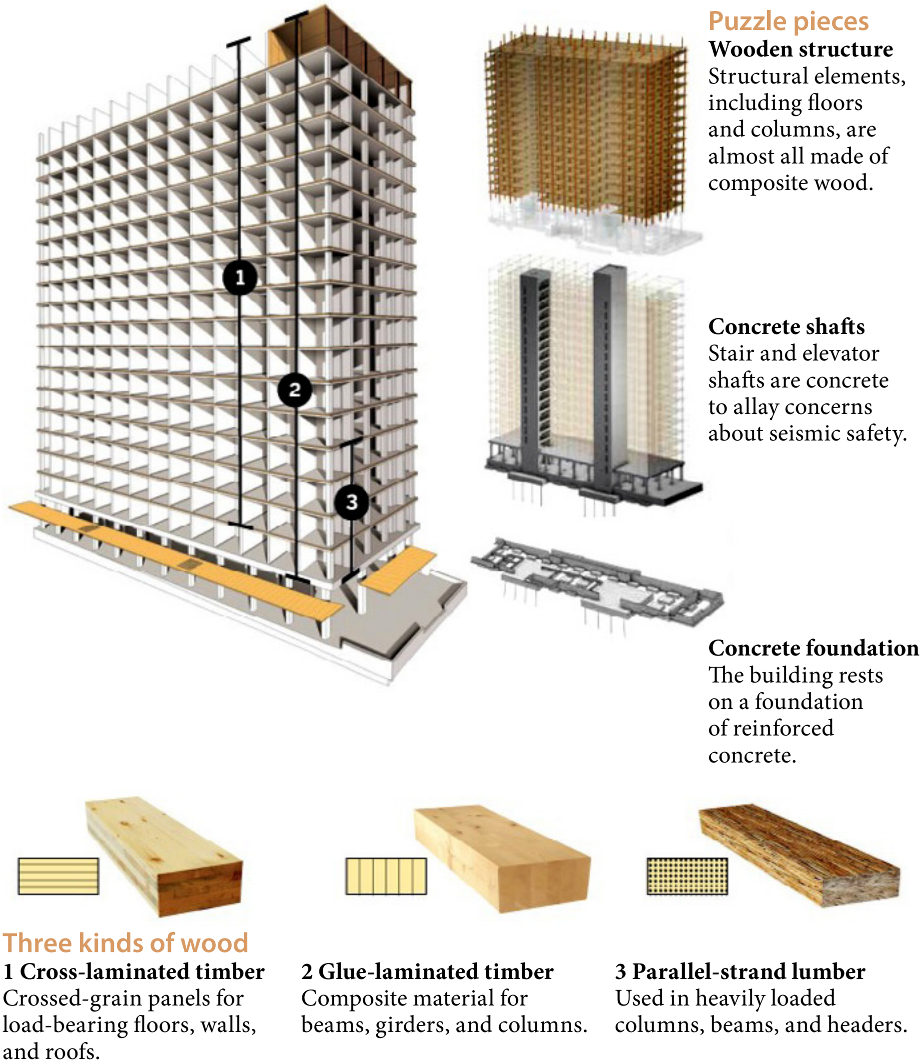

Fig. 1.11. Hybrid construction – Brock Commons (University of British Columbia and Acton Ostry Architects Inc., n.d.).

1.3.2. Sustainability of Wooden Buildings

Recent interest in timber buildings is related to sustainability and other substantial benefits of wood.

Environmental aspect

Wood is the only renewable construction material that requires very little energy for its processing (QWEB, 2015). All timber products store carbon. By nature, wood is composed of carbon that is captured from the atmosphere during tree growth. Two effects – substitution and sequestration – create positive carbon impact of timber products (Bergman et al., 2014).

Wood binds CO_2 from the atmosphere as it grows. As a rule of thumb, the tree 'consumes' the 1.6–1.8 kg CO_2 per 1 kg of wood it forms. When the tree is broken down by fungi or other natural processes, a corresponding amount of CO_2 is released to the atmosphere again. Similarly, by combustion. But when wood is part of the construction, the building works as carbon sink. For the construction of Moholt 50 in Norway, approx. 5600 m^3 or approx. 2240 tons of solid wood, if we assume a density of 400 kg/m^3, was used. The construction resulted in a storage of well 3500 tons of CO_2 – or equivalent to almost 2000 average cars annual CO_2 emissions at a driving requirement of 15,000 km/year (InnoBYG, 2017).

However, the most significant part of the CO_2 gain in wood construction is achieved through the substitution gain, which is in the saved consumption, thus saving steel and concrete production. Steel and concrete production is responsible for 9 % and 5 % of the world's total fossil energy consumption. For the production of 1 ton of concrete and 1 ton of steel, respectively, 87 kg and 1.9 tones CO_2 are emitted. Production of wood, on the other hand, stores CO_2 from the atmosphere itself, including the consumption of fossil fuels in connection (InnoBYG, 2017). Using wood substitutes could save 14 to 31 % of global CO_2 emissions and 12 % to 19 % of global fossil fuel consumption by using 34 to 100 % of the world's sustainable wood growth (Oliver et al., 2014).

Figure 1.12 presents the result of the carbon footprint of the whole-wood structure in comparison with the hybrid and steel structures by Laurent et al. (2018). The carbon impact of the structure made entirely of wood is lower

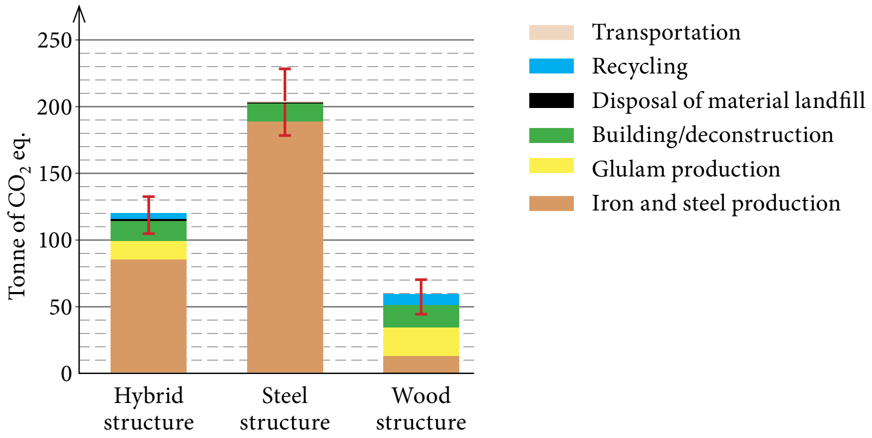

Fig. 1.12. Wood structure carbon footprint comparison (Laurent et al., 2018).

than the two others, with emissions of the order of 58.6 tons of CO_2-eq. So, the wooden structure would have emitted only half of the GHG emissions from the real (hybrid) structure and one quarter of the total GHG emissions of the steel structure. The figure shows a distribution of the contribution of the impacts, and results show that the production of glulam has a greater contribution to the wood structure GHG impact (37 %) than steel production with 22 % of the overall GHG impact. This is due to the low amount of steel needed for this structure (Laurent et al., 2018).

The study by Börjesson and Gustavsson (2000) revealed that the primary energy input (mainly fossil fuels) in the production of building materials is about 60–80 % lower for timber frames compared to concrete frames.

Petersen and Solberg (2002) compared the use of glued laminated beams at the Gardermoen airport outside Oslo with an alternative solution to steel. They found that the total energy consumption in manufacturing of steel beams is 2–3 times higher and the use of fossil fuel 6–12 times higher than in the manufacturing of glulam beams. Skullestad et al. (2016) have applied life cycle assessment to compare the climate change impact of a reinforced concrete structure to the climate change impact of an alternative timber structure for 4 buildings ranging from 3 to 21 storeys. According to attributional life cycle assessment results, the timber structures can cause a 34–84 % lower climate change impact than the reinforced concrete structures.

In addition to environmental benefits through CO_2 savings, wooden construction also fits into the mindset of circular economics (Fig. 1.13), e.g.

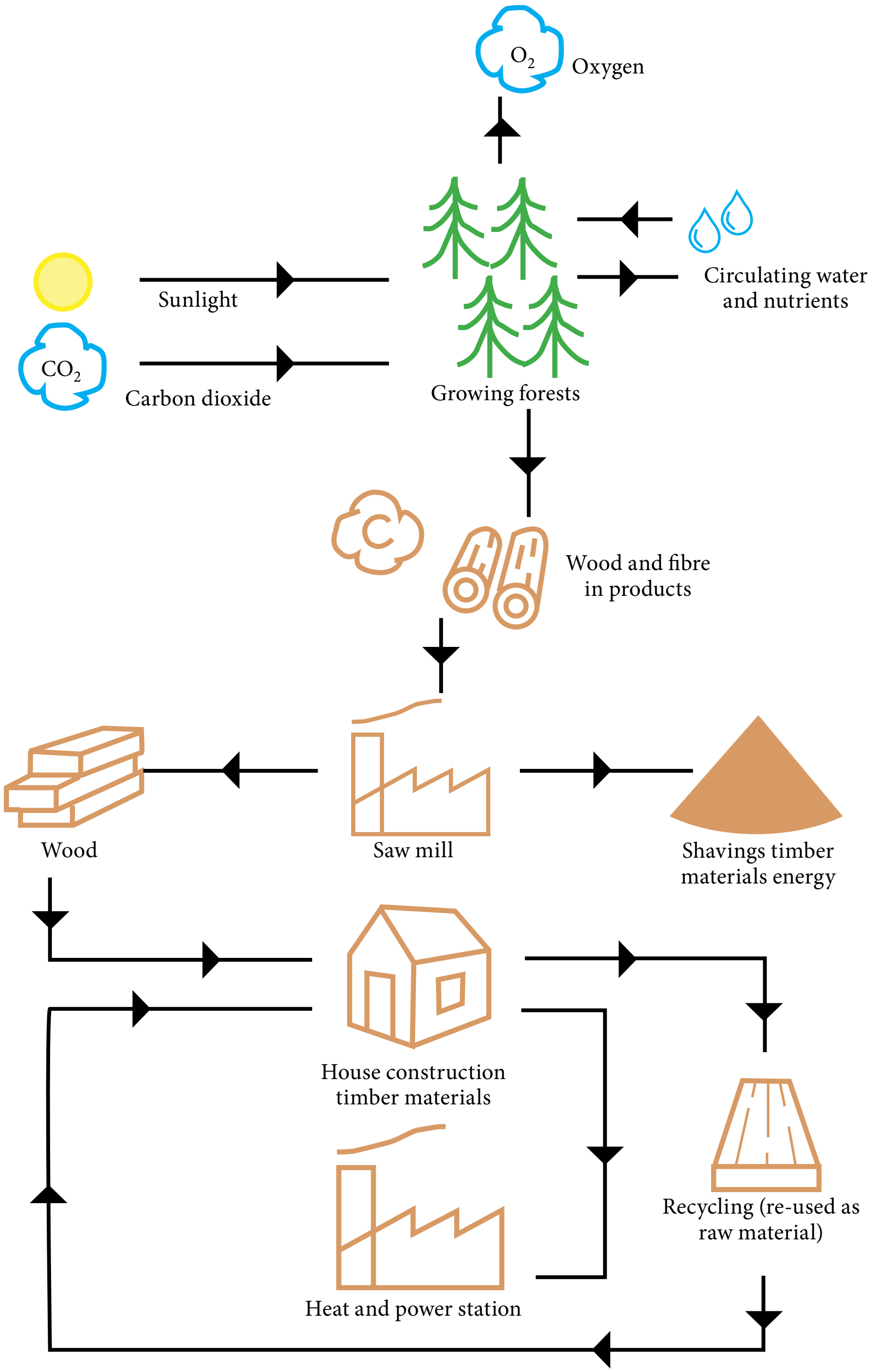

Fig. 1.13. Circular economy in wooden construction (Stora Enso, 2020).

recycling and recycling of materials resources, because the building elements can be separated, which also facilitates handling at the demolition stage.

Is there any wood at all – sustainable – to cover the growing need for wood for the buildings? If the need is to be covered sustainably, it must be assumed, for example, that the harvest of wood in the forests does not exceed the increase. The growth of wood in European forests (without Russia) is 840 million m^3, while the annual harvest is 583 million m^3 (66 %) (Forest Europe, 2015). There is thus an annual untapped harvest of 257 million m^3 of wood – or 33 % of the increase. In addition, a future increase in the annual m^3 growth can be attributed to the current increase in forest area. Europe's forest area has increased by 17.5 million hectares in the last 25 years (1990–2015), or approx. 700,000 hectares per year. For instance, in Denmark the forest area is increasing and grows by approx. 3000 hectares annually.

The crucial thing is to ensure that the construction tree comes from sustainable production. In Denmark, over 90 % of the forest area is forest and is covered by the Danish Forest law requirements for sustainability and forest cover of the areas. In addition, part of the forestry is further certified according to schemes such as FSC and PEFC. For the purpose of ensuring sustainable wood in public contracts for goods procurement, services and construction work, guidance has been provided for guidelines on the definition and documentation of sustainable wood (Ministry of the Environment, Nature Agency, 2014).

Economic aspect

Forests generate wealth and millions of jobs (see Fig. 1.14). The formal timber sector employs more than 13.2 million people. It also produces more than 5,000 types of wood-based products and generates a gross value added of over $600 billion (≈EUR 493 billion) each year. But the timber sector's economic contribution is much larger – the sector is mainly informal and its value remains largely unreported (The World Bank, n.d.).

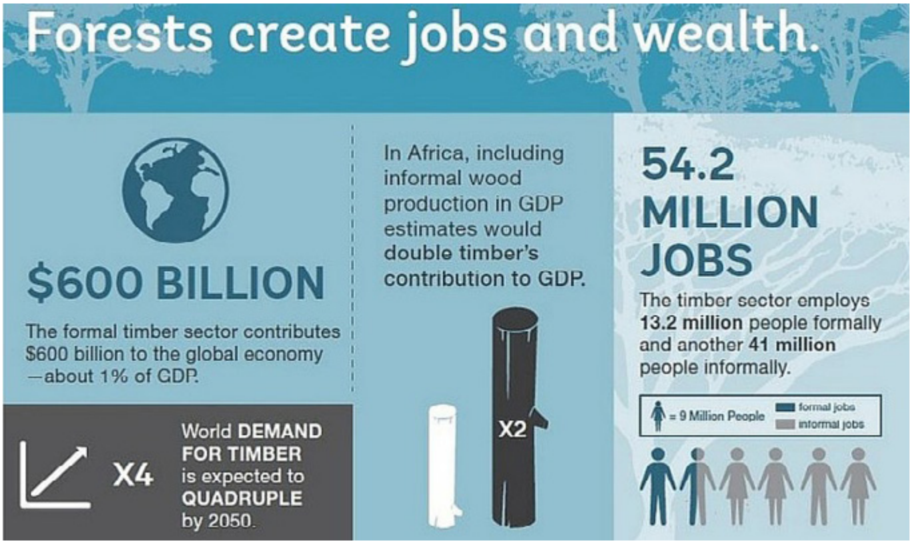

Fig. 1.14. Inputs of timber sector to global economy (The World Bank, n.d.).

Including the informal sector in GDP calculations could double the contribution of the timber sector and quadruple the number of related full-time jobs. In addition, the wood fuel industry creates jobs for tens of millions of households in the form of small-scale wood collection, charcoal production, transportation, and retail. The World Bank Group supports countries to sustainably manage natural forests, expand forest cover and develop sustainable forest industry value chains to create jobs and contribute to sustainable growth (The World Bank, n.d.).

In terms of construction, from the economic perspective, timber products are a cost-effective solution since they are structurally efficient, light weight, easy and quick to install at the construction site (QWEB, 2015). Higher speed of assembly is also linked to reduced labour hours and project cost (Franzini et al., 2018).

American Forest Foundation (n.d.) discusses cost effectiveness of building in wood in more detail:

- Wood can be locally sourced and is usually less expensive than alternative building materials.
- Wood building systems typically cost less to install. Wood is readily available and tends to be delivered quickly.
- Faster construction schedules help to keep costs down. Because wood is often readily available, adaptable and easy to use, construction is faster.

- Contractors can reduce labour and material costs with panelizing, the process of assembling roof sections on the ground and then lifting them into place.
- Using wood can save significantly on construction costs. Woodworks.org offers a cost calculator to help builders estimate cost savings from building with wood, taking into account numerous variables like material costs, speed of construction and availability of labour.

Several studies have at a theoretical level compared the cost of high-rise buildings in timber with the costs of a similar construction in concrete and / or steel. A report from Utah University (Smith et al., 2015), where experiences from 18 listed massive wood buildings in Europe and North America were collected, the average cost of solid wood constructions is estimated to be 4 % lower than for comparable buildings constructed using traditional methods. The same study assessed that the massive tree projects resulted in a 20 % reduction in the overall construction time compared to traditional construction methods.

Another example is from the USA. SD's Clover Creek Elementary (Fig. 1.15), completed in 2012, was built by using a wood framing method. Using wood framing for a school saved about 20 % in materials and installation costs. For a $10-million (≈EUR 8.2-million) project, this translates to a $2-million

Fig. 1.15. BSD's Clover Creek Elementary, USA (WoodWorks, n.d.).

(1.64-million) savings (American Forest Foundation, n.d.).

Since building traditions and principles are difficult to compare directly across national borders, it is also impossible to transfer economic and time comparisons. In England, there is talk of a significant reduction in construction time, but this compares with in situ cast concrete constructions, which, in everything else, will have a considerably longer construction time and drying time than prefabricated element building.

In assessing the economic sustainability of timber construction, it is also necessary to include the potential added value that wooden buildings can contribute. The project of BSD's Clover Creek Elementary revealed that cost-efficient wood framing leads to energy-efficient schools. Energy savings leave more money for education.

On the other hand, speaking about commercial buildings, viewed in a lifecycle perspective, the additional rental income from the new building will be a clear advantage in the economic analysis.

The choice of wood can contribute added value to the project, which could not be achieved by traditional construction methods.

The shorter construction time for wooden buildings also adds value. An example of fast construction time is from Vancouver, Canada. The construction of the Brock Commons student dormitory at the University of British Columbia (UBC) with its 18 floors was finished in 2017 (Fig. 1.16). The wood structure was complete less than 70 days after the prefabricated components arrived on site, approximately four months faster than a typical project of this size. The estimated avoided and sequestered greenhouse gases from the wood used in the building is equivalent to removing 511 cars off the road for a year. The total carbon dioxide equivalent avoided by using wood products over other materials in the building is more than 2,432 metric tons. The building was designed to meet LEED Gold certification (Think Wood, n.d.).

Social aspect

Last but not least, socio-cultural aspects such as public acceptance and appreciation of a building are also important. Is a building easy to access? Does it have an aesthetically pleasing design? How does it affect people's quality of life? ProHolz BW GmbH reports on its website that wood makes you feel good, lowers the heart rate and has a positive effect on people's health. In addition, wood breathes and regulates the indoor climate and humidity (Bioeconomy BW, n.d.).

"Wood has psychological effects on people and a similar stress-reducing effect to nature", says Marjut Wallenius, a Docent and Doctor of Psychology of

Fig. 1.16. Brock Commons Tallwood House (Acton Ostry Architects Inc., 2018).

the University of Tampere. The use of wood promotes the health and well-being of mind and body (Wood for Good, n.d.).

Based on studies carried out in Norway, Japan, Canada and Austria, wood seems to have positive effects on the emotional state of people. Environments with wooden structures cause a drop in blood pressure and pulse and have a calming effect.

But what factors in wood as a building material affect people? According to M. Wallenius “Wooden surfaces make a room feel warmer and cozier and they also have a calming effect. In these properties, wood beats all other normal surface materials” (Wood for Good, n.d.).

The answer to the question ‘what is a good material for people?’ is sought through human experience and how this positive experience manifests itself physiologically and psychologically. “One answer is the naturalness of wood, which is also found in all other natural materials such as rock, linen and silk. The naturalness and natural origin of wood is also why wood is considered a warm and cozy material in construction” (Wood for Good, n.d.).

According to observations made in research, touching a wooden surface gives people a feeling of safety and being close to nature. In studies, for example touching aluminum at room temperature, cool plastic or stainless steel caused a rise in blood pressure. Touching a wooden surface, however, did not cause such a reaction. In a comparison of different work rooms, stress level, measured as the skin’s capacity to conduct electricity, was lowest in a room with wooden furniture (Wood for Good, n.d.).

Studies have shown that compared to standard classrooms, timber classrooms give pupils a greater ability to concentrate and help to reduce stress and tension (Stora Enso, 2020).

In Canada, the government has made an official recommendation to consider building with wood as structural material in all public projects. This practice has not come to Europe yet, but there are numerous examples how wood is used in sustainable construction of public buildings.

Case studies

Case study 1. Vennesla Library and Culture House / Helen & Hard (Fig. 1.17).

The Municipality of Vennesla decided in 2005 to relocate the library to the city centre, linking together an existing community house and learning centre into a cultural centre. A café, open meeting places and a small stage were incorporated into the plan of the new building, making it a combined library and house of culture. With the new building, the municipality sought both to establish a public meeting place and to increase the quality of architecture in the urban area of Vennesla. An architectural design competition was initiated in 2008; it was won by the firm Helen & Hard from Stavanger, and the new building was ready in 2011.

27 prefabricated glue-laminated timber ribs define the spatial expression of the interior, and their offset construction allows the curves to function as spatial interfaces with inset lighting elements to provide a soft glow to the interiors and acoustic absorbents which contain the air conditioning ducts. Typical of Helen & Hard's work, the project also focuses on reducing the energy need through the use of high standard energy saving solutions in all new parts of the project. The library is a low-energy building, defined as class 'A ' in the Norwegian energy-use definition system (Archdaily, 2011). The building won several prizes, among them *Statens byggeskikkpris* for 2012 (the Norwegian state prize for good buildings).

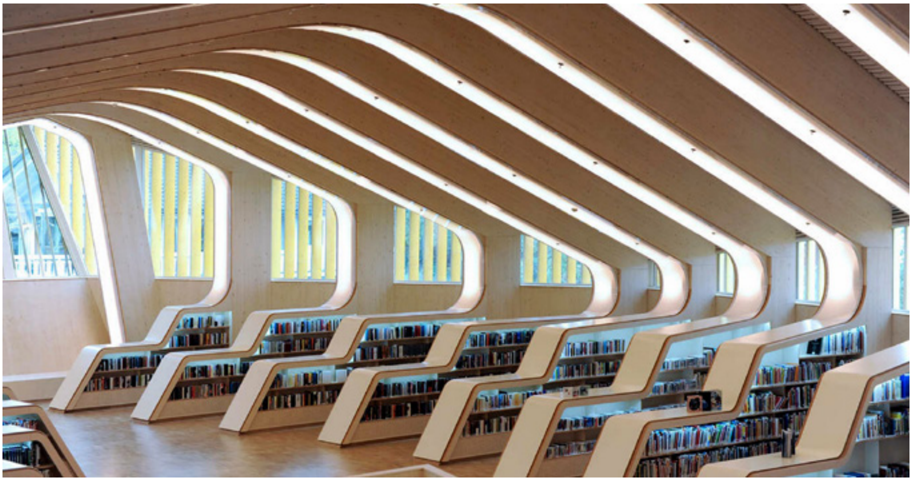

Fig. 1.17. Vennesla library in Norway. Image: Emile Ashley (New Nordic Timber, 2019).

Case study 2. Unterdorf Elementary School, Höchst, Austria (Fig. 1.18).

A fixture in Scandinavian countries, cluster schools are gaining ground in Austria. The pedagogical approach behind these types of schools involves teaching in small groups, flexible spaces and diversified, preferably outdoor, open areas. There are no classrooms along the access corridors; instead, open layouts allow for different forms of teaching and learning. In recent years, schools in the region have been architecturally implementing these requirements in different manners. The architects have delivered a radical example of this approach in the recently completed Unterdorf Elementary School (Dovetail, 2018).

In a plain, elongated, ground-level wooden building, four identical clusters are placed on the east side; the special education classes and the administrative area are located on the west side. A spacious hall connects the special education area with the gymnasium. The clusters comprise two central classrooms, an open group area and a quiet room, as well as washrooms and wardrobes around a central lounge. Each lounge is topped by an elevated, truncated pyramid through which daylight flows (Dovetail, 2018).

Fig. 1.18. Unterdorf School in Höchst, Austria. Image: Dietrich Untertrifallen (New Nordic Timber, 2019).

The entire school is of pure timber construction. The multi-layer, glued-together solid wood panel surfaces are unclad and the timber framework is visible in every room. Students benefit from the better learning environment and a pleasant, warm atmosphere within the building, which also saves on heating costs. The materials used are based on the fundamental principles of sustainability and ecological efficiency. The renewable, regional building material used dramatically reduced the gray energy factor (Dovetail, 2018).

Case study 3. World's first all-timber stadium (Fig. 1.19).

Zaha Hadid Architects has won the planning permission for the world's first wooden football stadium, which will be built in Gloucestershire, England for football club Forest Green Rovers. When complete it aims to be the world's greenest football stadium, constructed entirely from timber and powered by sustainable energy sources (Fig. 1.19).

It was the second attempt to gain planning permission for the 5,000-seat timber stadium for Forest Green Rovers football club. Zaha Hadid Architects (ZHA) changed the stadium design to include an all-weather pitch and included a different landscaping strategy. This was to mitigate worries that the stadium design did not sufficiently make up for the loss of green fields it will be built on.

Fig. 1.19. Zaha Hadid Architects stadium, UK (Block, 2019).

An improved match day transport plan was also included, following planning committee concerns about noise and traffic (Block, 2019).

ZHA's stadium design was voted through by six votes for and four against on 18 December 2019.

"This building is iconic; it could be a tourist attraction. It will be built entirely from sustainably sourced wood, including the cantilevering roof and louvred cladding." A transparent membrane will cover the stadium, allowing the grass to grow under the sunlight and minimizing shadows that could distract players during the game. The importance of using wood is not only that it is a naturally occurring material, it has very low carbon content.

This stadium will have the lowest carbon content of any stadium in the world and will be the greenest football stadium in the world.

Forest Green Rovers has already been named the world's greenest football club by FIFA. The players have adopted a vegan diet to reduce their carbon footprint, and only vegan food is served on match days. The current stadium has an organic grass pitch watered with recycled rainwater and uses solar panels to power its floodlights. The pitch is mowed by an electric 'mow bot' that uses GPS technology to automatically cut the grass, with the grass clippings given to local farmers to put on their soil (Block, 2019).

Case study 4. Norway to build the world's tallest timber building (Fig. 1.20).

Norway is set to break records for tall-timber construction with a new structure in a town just north of Oslo. Mjøstårnet will be more than 80 metres tall – 30 metres higher than what is today considered the world's tallest timber building. The building is named after its neighbour and Norway's largest lake Mjøsa and will sit on the edge of the north-eastern tip of the lake in the small town of Brumunddal.

Arthur Buchardt, investor and contracting client, has dubbed the construction "the closest we come to a skyscraper in timber" and believes "Mjøstårnet sets new standards for timber constructions". Spanning over 18 floors, the building will include apartments, an indoor swimming pool, hotel, offices, restaurant and communal areas with construction scheduled to be completed in December 2018. Moelven, a Mjøsa-local Scandinavian industrial group, will supply the timber constructions from local spruce forests required to construct the tower and the swimming pool area. The assembly and construction of

Mjøstårnet is nothing short of world-class engineering and will be managed without external scaffolding, despite the complexity of working at heights.

The construction company will primarily use cranes supplemented by lifts as needed. Timber structures are becoming increasingly popular, not least for their eco-friendly credentials. The studies show that building with wood instead of concrete can reduce CO_2 emissions by up to 30 percent. Through Mjøstårnet it is demonstrated that it is possible to construct large, complex wooden buildings. The planned construction of the Norwegian Government quarter can become a wooden landmark internationally. This project wants to help convey an important message with this project. To build with wood is to contribute to the world breathing better (McPartland, 2017).

Fig. 1.20. Mjøstårnet in Norway (McPartland, 2017).

1.4. SUSTAINABLE BUILDING RATING SYSTEMS

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Currently hundreds of environmental rating systems and sustainability certification schemes exist worldwide, and the demand for more certified buildings continue to rise. This chapter introduces an overview of leading environmental assessment methods which are relevant to the European construction industries, providing readers with a number of case studies based on timber building application and certification. Each of these systems are presented with an insight description into the history, scope and mechanism as well as the value and advantage of certification.

Why certification is important? The hotel star rating system was created to measure and classify the quality of the hotels in terms of services, rooms, and facilities. Based on the star rating your expectation as a customer will be different when you book a room. Europe and the U.S. use different hotel star rating systems, however, the concept remains the same, which is, categorizing the quality. The same theory applies to the rating certification systems of buildings by addressing the building's structure and construction process in respect of having a minimum direct and indirect impact on the built environment with regard to planning, design, construction, waste, materials, energy efficiency, maintenance, refurbishment, and demolition. Achieving high environmental rating classification requires a very strong collaboration among the client, designers and engineers in every project stage (Whole Building Design Guide [WBDG], 2019).

Generally, every prescriptive-based rating system offers a certain percentage of credits that can be achieved with the use of wood or wood products. In most cases, wood is recognized in the following areas (WoodWorks, n.d.):

- Certified wood. Credits are awarded for wood that has been third-party certified as coming from a sustainably managed forest. Different rating systems allow for different certification programs, with some more inclusive than others. While rating systems commonly reward projects that use certified wood, they do not require any demonstration that competitive materials such as concrete, steel, or plastic have come from a sustainable resource.
- Recycled / reused / salvaged materials. Many rating systems give credits for the use of products with recycled content. Wood products that qualify include finger-jointed studs, medium-density fiberboard, and insulation board.
- Local sourcing of materials. A number of systems place special emphasis on the use of local materials as an approach to reducing the environmental impacts of construction projects, rewarding materials sourced from within a certain radius - commonly 500 miles (approx. 804.672 km). However, simply tracking transportation distances ignores such critically important factors as mode of transportation and the type, efficiency, and impacts of manufacturing processes. Helen Goodland, an expert in green building and principal of Brantwood Consulting Partnership, explains that "rather than focusing solely on transportation distances, rating systems should look at life cycle assessment methodology, which quantitatively analyses not just transportation impacts, but the total environmental footprint of all materials and energy flows, either as input or output, over the life of a product from raw material to end-of-life disposal or reuse".
- Materials efficiency. Many rating systems, such as LEED, Green Globes, Built Green Canada, BREEAM, and Earthcraft reward efficient use of building materials.
- Waste minimization. Credit is often awarded for avoiding or diverting construction waste – e.g. through jobsite protocols that include pre-cut packages or off-site production of building modules.
- Indoor air quality. Most rating systems have strict limits on the use of products that contain volatile organic compounds (VOCs). Many wood products are available that verifiably meet or exceed these guidelines.

1.4.1. Building Research Establishment's Environmental Assessment (BREEAM)

The drive toward sustainable buildings grew with the launch of the Building Research Establishment's Environmental Assessment Method (BREEAM) in 1990, the first green building rating system in the world. Worldwide there are more than 571,591 BREEAM certified buildings and 2,283,771 buildings registered for assessment since it was first launched in 1990 (BREEAM, 2020). BREEAM encourages and motivates designers and builders to stand out through being innovative and use resources efficiently. Attention to the sustainability value and greener aspect of the buildings made BREEAM rated buildings to be more attractive to the marketplace, property developers and investors and also produce a sustainable environment that increases the well-being of the occupants.

The BREEAM assessment process evaluates the procurement, design, construction and operation of a development against targets that are based on performance benchmarks. Assessments are carried out by independent, licensed assessors, and developments rated and certified on a scale of Pass, Good, Very Good, Excellent and Outstanding. BREEAM measures sustainable value in a series of categories, ranging from energy to ecology. Each of these categories addresses the most influential factors, including low impact design and carbon emissions reduction; design durability and resilience; adaption to climate change; and ecological value and biodiversity protection (BRE, 2020).

BREEAM is used by owners, users, building managers and designers to demonstrate their environmental commitment, reduce the running costs and to reduce the impact that their buildings have on the environment (BREEAM, 2020).

Drivers:

- building regulations;
- towards zero carbon from 2019 for all buildings;
- UN framework Convention on Climate Change & Kyoto;
- legally binding commitments for the reduction of greenhouse gases;
- EU Renewable Energy Directive 15;
- 15 % of energy consumption should be from renewable source by 2020;
- Climate Change Act 2008;

- legal obligation to Government to reduce carbon dioxide emissions by at least 80 % by 2050;
- planning system;
- national ambitions will be tested through the planning system, both at regional and local level (BRE, 2020).

The Building Research Establishment has standard models for several types of development: offices, schools and education, light industrial, warehousing (non-retail), residential retail, prisons, courts and health (BRE, 2020).

While BREEAM focuses on achieving certain economic and social benefits, it also aims to mitigate the impact of construction process and buildings on the built environment as well as provide a rating system enabling buildings to be recognised based on their sustainability approach which encourages global demand for developing more sustainable buildings.

BREEAM aims to achieve the following highlighted fundamentals:

- To distinguish buildings of reduced environmental impact in the marketplace.
- To ensure that the best environmental practice is incorporated in building design, operation, management and maintenance.
- To set criteria and standards surpassing those required by regulations.
- To inform the design process.
- To raise the awareness of owners, occupants, designers and operators of the benefits of buildings with a reduced impact on the environment and the benefits of building to best environmental practice standards.
- To allow organisations to demonstrate progress towards corporate environmental objectives:

  - ensure quality through an accessible, holistic and balanced measure of sustainability impacts;
  - use quantified measures for determining sustainability;
  - adopt a flexible approach, avoiding prescriptive specification and design solutions;
  - use best available science and practice as the basis for quantifying and calibrating a cost-effective performance standard for defining sustainability;
  - seek economic, social and environmental gains jointly and simultaneously;
  - provide a common framework of assessment that is tailored to meet

the 'local' context, including regulation, climate and sector;
- integrate construction professionals in the development and operational processes to ensure wide understanding and accessibility;
- adopt third party certification to ensure independence, credibility and consistency of the label;
- adopt existing industry tools, practices and other standards wherever possible to support developments in policy and technology, build on existing skills and understanding and minimize costs;
- use stakeholder consultation to inform ongoing development in accordance with the underlying principles and the pace of change in performance standards (accounting for policy, regulation and market capability) (BRE Global, 2016).

The benefit of sustainable development could be considered as a key attraction by most of the industry professionals. Many researches have been conducted recently to outline the true value of BREEAM and how it benefits different stakeholders, including developers, landlord and end users. This section summarises the value of BREEAM certified buildings:

- Reduced running costs through greater energy and water efficiency, and reduced maintenance.
- Healthy, comfortable and flexible internal environments.
- Access to local amenities.
- Less dependence on the car.
- Allowing developers to be one step ahead of regulation.
- Demonstrating compliance with environmental requirements from occupiers, planners, development agencies and developers.
- Environmental improvement – in support of a wider corporate strategy or as a standalone contribution.
- Occupant benefits: a better place for people to work and live.
- Marketing: a selling point to potential tenants or customers.
- Financial: achieving higher rental incomes and increased building efficiency.
- Best practice: providing a thorough checklist or tool for comparing buildings.
- Client request: responding to the requirements of users (BRE Global, 2016).

BREEAM categories

Awarding credit scoring system is based on the environmental impact of each category. The 10 categories are not carrying equal weight, and each credit within the category has a different weight, e.g. two credits granted do not equal 2 %. The key principles for each BREEAM category have been summarized as follows (Fig. 1.21):

- Management – management policies, building commissioning and procedural issues.
- Health and Well-being – indoor and external issues affecting health and well-being of building occupants, e.g. thermal conditions, daylighting, glare, etc.
- Energy – operational energy (and CO_2 emissions) of the completed development. The energy category is heavily dependent on the expected carbon emissions (including Low Carbon and Renewable Technologies); however, it also includes credit points relating to metering and sub-metering.
- Transport – a series of transport and site access related credit points, e.g. cyclist facilities, public transport links, deliveries, etc.

Fig. 1.21. BREEAM categories (BRE, 2020).

- Water – credit points relating to efficient water use of base building and tenant services.
- Materials – environmental implications of building materials including responsible sourcing and lifecycle impacts.
- Waste – rewards for recycling and management of waste products both during construction and once in operation.
- Land Use and Ecology – credit points to encourage the use of brownfield sites, rehabilitation of contaminated land as well as conservation and enhancement of the site ecology.
- Pollution – reduction and / or elimination of air, water and light pollution.
- Innovation – additional credits available by significantly exceeding particular BREEAM requirements, using BREEAM accredited professionals, or being genuinely innovative in approach (BRE Global, 2016).

BREEAM provides Innovation scores based on any performance level which is beyond the standard performance acknowledged by the BREEAM assessment criteria. Innovation scores could be achieved either through exceeding the standard performance criteria specified by BREEAM assessment guide, or by providing a certain new technology or an innovative idea in terms of the design, construction method or construction process. To gain the innovation credit, the developers should assign a registered BREEAM Assessor to submit a standalone application to BRE Global. For each innovation credit an extra 1 % could be achieved up to maximum of 10 credits.

Category	Weighting
Management	12 %
Health & Well-Being	15 %
Energy	19 %
Transport	8 %
Water	6 %
Materials	12.5 %
Waste	7.5 %
Land Use & Ecology	10 %
Pollution	10 %
Innovation	10 %

BREEAM Score	
Pass	30 %
Good	45 %
Very good	55 %
Excellent	70 %
Outstanding	85 %

Fig. 1.22. BREEAM certification (BRE, 2020).

BREEAM benchmarks

When it comes to awarding the final certificate, BREEAM Rating scales from Pass to Outstanding. To achieve a specific rating, a sequence of obligatory minimum standards must be obtained. Once the required minimum standards are achieved, the development can aim for additional credit scores to obtain the required and expected credit rating. Figure 1.22 is summarizing the weighting percentage and the required credits to gain a certain level of BREEAM certification.

BREEAM continues to provide the national and international market with a robust framework towards a more sustainable construction industry, consequently thousands of stakeholders and developers delivered better and greener buildings which have minimum impact on the built environment (Fig. 1.23).

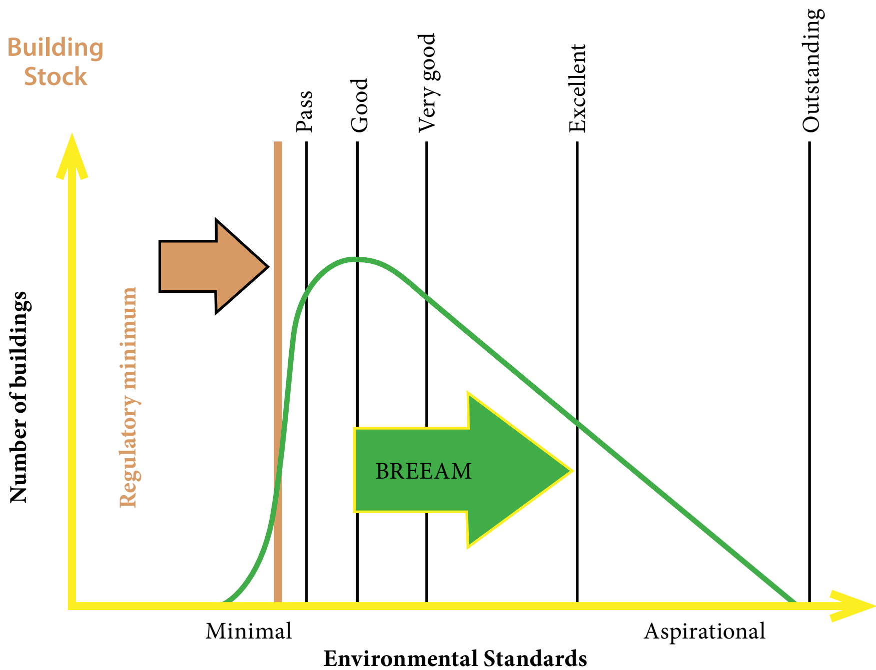


Fig. 1.23. BREEAM and environmental standards (BRE Global, 2016).

BREEAM effectiveness

Input is expected to be needed from a wide range of people (the architect and building services designers have the largest share, the project manager, structural engineer and contractors) all have a part to play.

The BREEAM assessor should also be appointed early.

Clients can use BREEAM to specify the environmental sustainability performance of their buildings in a way that is quick, comprehensive and visible in the marketplace.

Agents are allowed to use BREEAM to promote the environmental credentials and benefits of a building to potential clients.

Design teams can use BREEAM as a tool to improve the performance of the buildings and their own experience and knowledge of environmental aspects of sustainability (Parker, 2012).

The BREEAM schemes

BREEAM develops and manages a number of BREEAM schemes nationally and internationally. Each scheme has been created to assess the various stages of building's impact which include:

- BREEAM New Construction: for new, non-residential buildings in the UK.
- BREEAM International New Construction: for new residential and non-residential buildings in countries around the world. This scheme makes use of assessment criteria that take account of the circumstances, priorities, codes and standards of the country or region in which the development is located.
- BREEAM In-Use: a scheme to help building managers reduce the running costs and improve the environmental performance of existing buildings.
- BREEAM Refurbishment: provides a design and assessment method for sustainable housing refurbishment projects, helping to cost effectively improve the sustainability and environmental performance of existing dwellings in a robust way.
- BREEAM Communities: focusses on the master planning of whole communities (BRE 2020).

Green Book Live platform has been created by the BRE Global, which is an independent body, providing certification for sustainable services and products globally. Conducting many researches to improve the built environment it aims to "Protect People, Property and the Planet". This free online platform provides developers and BREEAM assessors to identify green products and sustainable services which reduce developments negative impact on the environment.

The BREEAM assessment process

BREEAM assessors have a vital role during the process of BREEAM certification, and they are leaders who drive the construction industry towards building a more sustainable world. Most of the planning authorities and city councils across the United Kingdom made it compulsory for the commercial

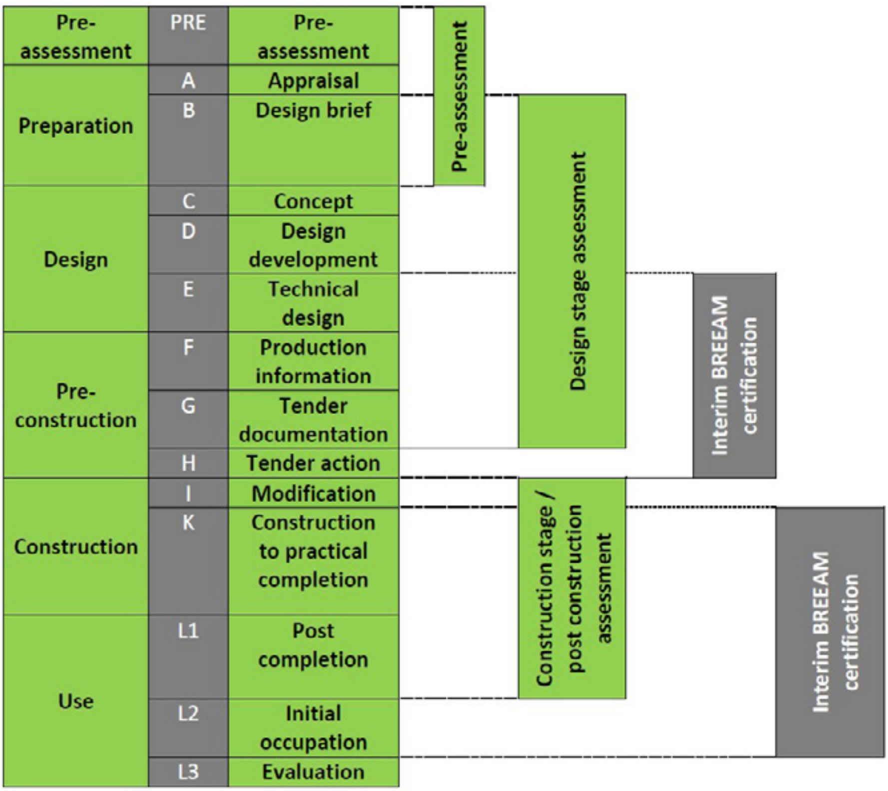


Fig. 1.24. BREEAM assessment process and certification timeline (BRE, 2020).

buildings, residential buildings and also any other publicly funded domestic refurbishment or building to be assessed under the BREEAM scheme. This request is coming either as a conditional grant of planning permission or as a part of the contract to obtain funding for the social housing. BREEAM certification process is undertaken in five stages (Fig. 1.24) (BRE, 2020):

1. Registration: It is important to make sure that the project is formally registered with the BRE and the registration checklist has been completed.

2. Pre-assessment: This process is undertaken at a very early stage, even before the design has been confirmed, to secure the funding and planning permission. At this stage the design team work closely with the assessor to set up a pragmatic baseline for the project which can provide solutions and options to achieve the best performance. The assessor explains the BREEAM criteria and establishes a score target based on the information available. After the first meeting with the assessor the design team agrees a period of time to review and add any more information required for the process and confirm their commitment to the agreed BREEAM rating. At this stage the assessor prepares and issues the pre-assessment report to BRE.

3. Initial Guidance / Design & Procurement Assessment: In this stage the assessor will complete a guidance report explaining the required performance and documentation to achieve each credit. Based on the agreed target, available information and all the approved documentation by the design team, the assessor will complete and submit the Design & Procurement Assessment report to BRE for quality check and also to receive the Design & Procurement Assessment.

4. Post Construction Review (PCR): The process has no formal construction stage; however, the assessor continues to provide support and advice during the construction phase and collects and records all the evidence and documentation required for the Post Construction Review report. The PCR is undertaken after the project completion. The key purpose of this stage is to make sure that the completed development is meeting the agreed criteria during the design and procurement stage. The assessor will visit the site and take photos of the implemented technology, systems, construction methods, materials and features of the building, creating a photographic file as an additional evidence to support the required documentation for the 'as built' report.

5. Final Certification: Once all the evidence, documentation and required information has been submitted and the agreed target has been achieved, the BRE will issue the final certificate.

The assessors' role is vital to the project, they are the active link between the design team and the certification body. Qualified BREEAM assessor understands the scheme, the process, rating criteria and can provide the interpretation for each technical issue as well as work with the designing team to help and provide advice on how to collect scores and achieve the end target. The assessor has the duty of communicating between the BRE and the client. For any extra information, evidence or request, the assessor should coordinate with the project team to prepare the requirements which should be submitted with the final report. The engagement of the assessor in the very early stage has a positive impact on the whole project and helps achieving the agreed target without affecting the design and the proposed budget, also securing the seamless integration of the methodology of any development. If the assessor is appointed at a late stage, the required changes could be compromised, the performance and extra costs could be needed to cover the requested changes (BRE, 2020).

Case studies

Case study 1. GlaxoSmithKline: A BREEAM Outstanding carbon neutral laboratory (Fig. 1.25).

The building is a hub that will catalyse new collaboration with industry. It is the latest landmark development to be undertaken by the University of Nottingham, and it is unique in the UK not only in its design but also in its focus on world leading research activity in sustainable chemistry.

Project Overview:

Scheme & Version: New Construction 2011: Higher Education
Stage: Final
Location: Nottingham, UK
Score & Rating: 94.1 % Outstanding
Size: 4,199 m^2 (GIFA), 2,319 m^2 (NIFA)
Green Strategy

The building achieved full credits in the Water and Materials Sections of BREEAM and scored at least 90 % in the Management, Energy, Land Use &

Ecology, and Innovation sections.

Management. A focus on sustainability integration to ensure delivery of a functional and sustainable asset was considered during every stage of the project. Early-stage sustainability targets were set in cooperation with the University during the Strategic Definition Stage of the project. The BREEAM performance targets were agreed during Conceptual Design, and a target rating of Outstanding was established. A BREEAM AP has been engaged throughout the project to provide advice on maximizing the positive environmental impacts of the building.

Health and well-being. Natural ventilation strategies are integrated into the design in conjunction with mechanical ventilation strategies. In particular the carbon neutral laboratory is naturally ventilated – which is unusual and unique for a laboratory. Fresh air intake and exhaust air discharge are supplied and controlled via the roof mounted wind catchers, which are prominent visual features for the project.

Energy. The project features innovative energy saving strategies designed to meet the carbon neutral goal. Energy required to run the laboratory is met by renewable and low carbon sources such as the PV array covering 45 % of the roof area and sustainable biofuel CHP. The project achieved 15 credits and 5 innovation credits under BREEAM Ene 01 and used this as an Alternative Compliance Path to receive full point value for LEED Energy Performance, On-Site Renewable Energy and Green Power credits. The building also includes LED lighting with a building average of 5.4 Watt/m^2.

Fig. 1.25. GlaxoSmithKline, UK (BREEAM, 2020).

The building has sub-meters that are installed on major energy consuming systems, including space heating, domestic hot water, cooling, fans, lighting, small power, IT room, lifts, and laboratories.

Transportation. The project's campus location encourages the use of public transportation networks. The building is served by multiple bus services connecting it to the wider Nottingham area and major transport hubs. The site is situated near basic amenities and services, including cafes, libraries, a sports centre and a student union, which reduces the need for building users to make multiple journeys. Cycling facilities are provided for building occupants. New cycle spaces were added to the design, shower & changing facilities, and sheltered cycle storage, which will be accessible from the street to the front of the building.

Water. The project achieved full credits in the water category. The BREEAM calculator tool calculated water consumption to be just 5.47 m^3 per person per year. This represents a 63.99 % improvement in water efficiency compared to the baseline for the building. This was achieved through the use of water efficient fittings alone. The project's green roof consists of drought tolerant, native species that do not require an irrigation system to be installed. All major water uses are separately metered within the building allowing high use activities to be identified by the building management. A leak detection system was installed to monitor water use and alert building managers to potential issues during operation, allowing them to be resolved.

Materials & waste. The building is unique in that timber is featured prominently in design. Timber was sustainably sourced through PEFC and FSC certification schemes and was used for the frame, walls and floors. The building has been recognised by the Structural Timber Awards 2016 for the innovative use of timber. The team received points for resource efficiency and additional points for the total construction by meeting the BREEAM efficiency benchmark of waste generated per 100 m^2; yielding 3.8 tonnes/100 m^2.

Land use and ecology. The project was developed on land that was previously occupied by the Raleigh factory. Some contaminated land was identified by a specialist who recommended a remediation strategy, including a clean capping layer for asbestos contamination, restriction of infiltration through contaminated source areas, and ground gas protection measures. This land would have otherwise remained contaminated and undeveloped. Bird boxes and a biologically diverse green roof on the project provide a welcoming environment for local species, and also a 5-year landscape management plan was implemented and includes management of protected habitats.

Pollution. The project team specified equipment designed to decrease greenhouse gas emissions arising from the leakage of refrigerants from building systems. A flood risk consultant was appointed to analyse surface water run-off from the site and minimize water course pollution. Sustainable Drainage Systems (SuDS) were integrated into the design, e.g. the green roof, a dry swale, trapped gully, filter drains minimize surface water runoff. Detailed photometric plans and calculations were completed to demonstrate that the external lighting installations met ILE Guidance for reducing light pollution.

Innovation. The creation of a carbon assessment calculator which focused on life cycle embodied carbon emissions of products on the project. The buildings' net zero goals, low energy laboratory systems, and natural ventilation strategies are particularly innovative for a laboratory use type (BREEAM 2020).

Case study 2. Timber Building - BREEAM Outstanding Adapt Enterprise Centre (Fig. 1.26).

The Enterprise Centre at the University of East Anglia opened in autumn 2015. The 3,400 square metre building is one of the largest timber frame structures in the UK and has achieved BREEAM Outstanding. The building aimed to demonstrate that natural products can provide attractive alternatives

Fig. 1.26. The Enterprise Centre at the University of East Anglia, UK (BRE, 2015).

to conventional technologies. Some of the key findings from the research carried out by the BRE Sustainable Products team paved the way for this groundbreaking building are as follows:

- Despite the presence of Red Band Needle Blight (RBNB), this project has shown that the disease does not have a negative effect on the timber properties.
- If innovative twin laminates form a structural frame and flooring, as detailed in this report, are selected, then the 36,000 houses could store an additional 194,400 tCO_2. This would also unlock a key substitution effect for replacing the blocks in the structure. A house with 60 m^3 blocks in its walls has a net emission of 12 tCO_2 per house associated with the embodied energy in the blocks. This equates to a saving of 432,000 tCO_2 for 36,000 houses.
- Timber technology can add to a limited managed resource in the region. Innovative engineering of wood can utilize more of the standing tree in the construction product; create more construction products per hectare of woodland and store more carbon in our buildings. One of the possible products studied was an innovative inside out beam (Fig. 1.27). This

Fig. 1.27. Structures and interior (BRE, 2015).

beam uses 85 % of the round wood in the final product. A square beam of equivalent performance uses no more than 50 % of the round wood in the product. This is not in conflict with existing supply chains.

- The East of England region can be creative with woodland resource and productivity but it needs a radical change in strategy. For example, if an inside out beam requires a tree of half the maturity of the equivalent square cut beam; in the same time period a hectare yields two times as many beams and possibly up to four times as many beams if planting density can be increased.
- Corsican pine from Thetford forest is of sufficient quality to be used in a range of structural construction product end uses. It meets as a minimum machine strength grading ‘C16’ class (BRE, 2015).

1.4.2. Leadership in Energy and Environmental Design (LEED®)

LEED® (*Leadership in Energy and Environmental Design*) was developed and piloted in the USA in 1998 as a consensus-based building rating system based on the use of existing building technology. The LEED® has been developed through the U.S. Green Building Council (USGBC) member committees. It is the most widely used green building rating system in the world with 1.85 million square feet of construction space certifying every day. More than 79,000 projects are participating in LEED® across 160 countries and territories, comprising over 15 billion square feet (LEED, 2019).

LEED® certification provides independent verification of a building or neighbourhood's green features, allowing for the design, construction, operations and maintenance of resource-efficient, high-performing, healthy, cost-effective buildings. LEED is the triple bottom line in action, benefiting people, planet and profit (LEED, 2019).

LEED® works for all buildings at all phases of development, from new construction to existing buildings, as well as all building sectors, from homes to hospitals to corporate headquarters. LEED for Building Design and Construction (LEED® BD+C) provides a framework for building a holistic green building, giving the chance to create a healthy, resource-efficient, cost-effective building. LEED for Building Operations and Maintenance (LEED® O+M) is designed for existing buildings and leads to increasing of operational efficiency. LEED® for Interior Design and Construction (LEED® ID+C) enables project teams who may not have control over whole building operations to develop indoor spaces that are better for the planet and for people. LEED® for homes provides certification for homes that are built to be healthy, providing clean indoor air and incorporating safe building materials to ensure a comfortable home, using less energy and water means. LEED® for Neighbourhood Development (LEED ND) was engineered to inspire and help create better, more sustainable, well-connected neighbourhoods. It looks beyond the scale of buildings to consider entire communities (LEED, 2019).

Fig. 1.28. LEED credit categories (DMCC, 2020).

LEED credit categories

LEED® projects earn points across nine basic areas that address key aspects of green buildings (see Table 1.5, Fig. 1.28). Based on the number of points achieved, a project earns one of four LEED rating levels: Certified, Silver, Gold or Platinum (Fig. 1.29).

LEED-certified buildings have been proven to benefit in a number of ways. These include (DMCC, 2020):

- higher operating efficiency and lower operating costs;
- promoting occupants' well-being and comfort and thus increasing their productivity;
- increased waste diversion from landfills;
- energy and water conservation;
- reduction in greenhouse gases;
- an increased real estate value; and
- contribution to a sustainable planet.

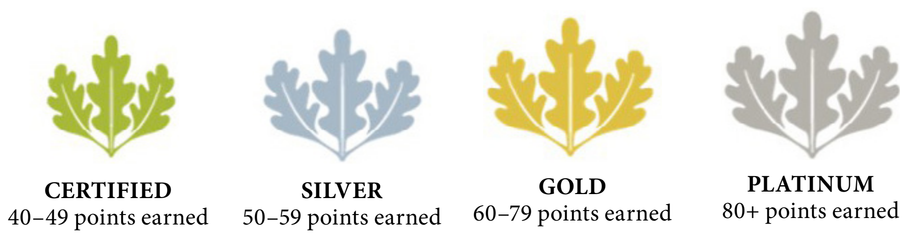


Fig. 1.29. LEED rating levels (DMCC, 2020).

Table 1.5
Description of LEED® Categories (Banyan Water, 2019)

Category	Description
Integrative process	Beginning in pre-design and continuing throughout the design phases, the category identifies and uses opportunities to achieve synergies across disciplines and building systems.
Location and transportation	The category rewards thoughtful decisions about building location with credits that encourage compact development, alternative transportation, and connection with amenities such as restaurants and parks.
Sustainable sites	The category focuses on the environment surrounding the building and awards credits for projects that emphasize the vital relationships among buildings, ecosystems, and ecosystem services. It focuses on restoring project site elements integrating the site with local and regional ecosystems and preserving the biodiversity that natural systems rely on.
Water efficiency	The category addresses water holistically, looking at indoor use, outdoor use, specialized uses, and metering. The section is based on an 'efficiency first' approach to water conservation.
Energy and atmosphere	The category approaches energy from a holistic perspective, addressing energy use reduction, energy-efficient design strategies, and renewable energy sources.
Materials and resources	The category focuses on minimizing the embodied energy and other impacts associated with the extraction, processing, transport, maintenance, and disposal of building materials. The requirements are designed to support a life-cycle approach that improves performance and promotes resource efficiency.
Indoor environmental quality	The category rewards decisions made by project teams about indoor air quality and thermal, visual, and acoustic comfort. Green buildings with good indoor environmental quality protect the health and comfort of building occupants.
Innovation	The purpose of this LEED category is to recognize projects for innovative building features and sustainable building practices and strategies.
Regional priority	Because some environmental issues are particular to a locale, volunteers from USGBC chapters and the LEED International Roundtable have identified distinct environmental priorities within their areas and the credits that address those issues. These regional priority credits encourage project teams to focus on their local environmental priorities.

LEED credit for building in wood

On April 5, 2016, the U.S. USGBC released a pilot Alternative Compliance Path (ACP) for wood and paper products in its LEED® 2009 and LEED v4 rating systems which enables all certified products to be eligible for LEED®

credit. Builders and architects can now use wood and paper products certified to the Sustainable Forestry Initiative (SFI), American Tree Farm System (ATFS), Canadian Standards Association (CSA) and Programme for the Endorsement of Forest Certification (PEFC) standards to achieve a point in the 'certified wood' ACP under LEED® 2009 and achieve a point in the 'sourcing of raw materials' ACP under LEED v4 (Sustainable Forestry Initiative, 2016). This is in addition to the existing credit for wood products certified by FSC as having been obtained from responsibly managed sources.

In order to count towards a LEED® point, the user must first know the following (Sustainable Forestry Initiative, 2016):

- 100 % of the forest products are from legal (noncontroversial) sources;
- 70 % are from responsible sources;
- the remainder must be certified sources as evidenced by a chain of custody certification (CoC).

Although some LEED® credits can be obtained based on the percentage of certified wood used on a project, the new program greatly increases the sources of wood for which credits can be received. In addition to providing certainty to contractors that the wood they use has been obtained from legal sources, the program aims to reduce unregulated and environmentally harmful logging, which is a problem in those countries that lack the rigorous environmental enforcement mechanisms such as exist in the United States. The program also incentivizes the use of wood as a building material that is both sustainable and can sequester carbon for decades (C. Smith & H. Smith, 2016).

USGBC's move comes as new technology has resulted in the development of structural wood building products, such as cross-laminated timber that performs at least as well as less sustainable materials. Cross-laminated timber consists of three, five or seven layers of wood beams laid at right angles to one another and bound together with a specially designed adhesive. Use of this product in building construction carries several advantages. The resulting timbers can be cut to desired dimensions, yielding structural components that are lighter than concrete and steel, yet just as strong and durable. Surprisingly, the adhesive used in producing cross-laminated timbers creates wood products that are highly fire resistant. Another advantage of building with light, cut-to -order structural wood is that the job can be completed more quickly, with less noise, waste, and labour costs than structures utilizing more traditional building materials. And, unlike cross-laminated timbers, most of the traditional building materials have a larger carbon footprint and do not carry comparable 'green' certification (C. Smith & H. Smith, 2016).

USGBC's announcement of greater opportunities for LEED® credits through the use of wood in building construction is the latest evidence of the increased viability of wood as a structural component in major building projects. This announcement, coupled with the already growing interest in and government support for the use of structural wood, such as cross-laminated timbers, is almost certain to continue as part of the search for environmentally friendly and structurally sound building materials (C. Smith & H. Smith, 2016).

Case studies

Case study 1. John W. Olver Design Building (Fig. 1.30).

Located in Amherst, the University of Massachusetts (USA) has established a new design pavilion. The University decided to use wood as the main structural material in order to have a sustainable structure respectful of the environment. The John W. Olver Design Building, a showcase for best practices in sustainability and state-of-the -art wood construction technology, has been awarded LEED Gold certification (University of Massachusetts, 2018).

Fig. 1.30. John W. Olver Design Building, USA (Nordic Structures, 2017).

Called the most technologically advanced cross-laminated timber (CLT) building in the country when it opened in 2017, the Design Building houses three academic units: the Department of Architecture, the Building and Construction Technology Program (BCT) and the Department of Landscape Architecture and Regional Planning. Built of CLT timber and glue-laminated columns, the 87,000-square-foot facility saves the equivalent of more than 2,300 metric tons of carbon when compared to a traditional energy-intensive steel and concrete building (University of Massachusetts, 2018).

The building's multi-disciplinary layout, organized around an interior courtyard of exposed timber and an exterior landscaped courtyard and outdoor classroom, fosters collaboration across the disciplines. It intentionally features exposed structural elements and service systems for teaching, while its Trimble Technology Lab provides advanced tools for design research and development. Key building features for sustainability and LEED certification are as follows (University of Massachusetts, 2018):

- Central to campus, the building is well situated on a walkable site with access to public transportation and promoting use of alternative transportation.
- The previously developed site and landscape was restored with more than 20 % native vegetation and provides open space equal to the building footprint.
- The intensive / extensive vegetated green roof combined with white TPO membrane roofing and light-coloured hardscape (77 % site area) mitigates heat island effects.
- Water efficient fixtures achieve a potable water reduction of 35 % below EPAct 2003 standards.
- Efficient drip irrigation system reduced potable water consumption by 66 % compared to a typical irrigation system.
- Efficient HVAC systems, low-energy lighting design and controls, and a high-performance insulating envelope with electrochromic glass results in a predicted annual energy cost savings of 42.85 %.
- The comprehensive commissioning efforts provided by the design team and owner, combined with ongoing measurement and verification efforts will ensure that the building is operating efficiently and in accordance with all design objectives.
- 88 % of construction waste materials were diverted from landfill.
- 10.7 % of the total building materials (by cost) was manufactured using recycled materials and 13.8 % were regionally sourced. Unfortunately,

the raw materials for the CLT were sourced just beyond the 500-mile radius.

- A whopping 97.3 % of the new wood was FSC-Certified, including 100 % of the CLT.
- In addition to designing for thermal comfort, indoor air quality is improved with CO_2 sensors and associated HVAC controls in all densely occupied spaces.
- 90.5 % of all regularly occupied spaces have access to exterior views.

The Wall Street Journal named the Design Building one of the best new buildings of 2017.

Case study 2. UniCredit Pavilion in Milan (Fig. 1.31).

The UniCredit Pavilion, created by Italian architect Michele de Lucchi, is a modular structure which aims to promote social functions and experimental activities, hosting cultural events, conferences, exhibitions and concerts. The structure, which can accommodate up to 700 people, is build adjacent to the UniCredit's headquarters in the Porta Nuova district in Milan. UniCredit CEO Federico Ghizzoni stated that they wanted a building to reflect the European identity of the brand, but still be representative for Italian architecture (arch20, n.d.).

Fig. 1.31. The UniCredit Pavilion in Milan, Italy (Grozdanic, 2017).

It speaks to all categories of users, since it hosts also a nursery for up to 50 children. The building will blend into the urban surroundings through the elevated ground floor, lifted more than one metre above ground, and designed with laminated timber and a glass-ribbed structure, but also with the overall organic shape and transparent surfaces. Two 12-metre-long panels, designed as wings, can be opened or closed, displaying two huge screens towards the park and Piazza Gae Aulenti (arch20, n.d.).

The wooden UniCredit building is powered by the sun. The pavilion has no foundations – it was constructed on a reinforced concrete podium above a parking facility. Inspired by the shape of a seed, the design of the building combines lamellar larch beams with glass. The open structure accentuates accessibility, strengthened by two large wings equipped with monitors for events open to the general public. Thanks to its strong focus on environmental sustainability, the LEED Gold-certified project has won the first prize at this year's WT SmartCity Award competition (Grozdanic, 2017).

1.4.3. Passive House (Passivehaus)

Passive House is a voluntary and international leading design standard for low energy buildings which reduces the building's ecological footprint and also provides a high level of occupant comfort while using minimum energy for heating and cooling. These buildings are built with careful attention to detail and robust design based on a set of serious principles developed by the Passivhaus Institute in Germany. Throughout the construction process a set of rigid criteria and quality assurance should be followed to obtain the PH certificate (Passivhaus Institute [PHI], 2015). Passive House is not a brand name but a true construction concept that can be applied by anyone, anywhere (Bootland, 2011).

Passive House design principles

Passive House buildings require a set of design principles used to obtain a quantifiable and rigorous standard of energy efficiency within a specific quantifiable comfort standard (PHI, 2015):

- high levels of insulation (Fabric U-value <0.15 W/m^{2}K;

Windows <0.8 W/m²K);
- minimal thermal bridging;
- continuous air barrier to achieve <0.6 ach @ 50 Pa;
- provide controlled ventilation and heat recovery during heating season with MVHR; can use natural ventilation in summer;
- maximize use of solar and internal heat gains & protect against overheating and triple glazing windows (U-values below 0.8 W/(m²K) (Fig. 1.32).

Design certification criteria:

- Space heat demand of <15 kWh/m²/yr – how much energy is needed to heat the building.
- Pressure test result <0.6 ach @ 50 Pa – how much air leaks through the fabric of the building.
- Primary energy <120 kWh/m²/yr – how much energy is needed to power all of the activities within the building (heating, hot water, lighting, cooking, appliances, active cooling).
- Frequency of overheating in summer <10% - how many times the temperature within the building exceeds 25 °C (PHI, 2015).

There are many benefits of Passive House (PHI, 2015), these are discussed further.

Comfort. The Passive House Standard offers a new level of quality pairing a maximum level of comfort both during cold and warm months with reasonable construction costs. Passive House buildings are praised for the high level of comfort they offer. Internal surface temperatures vary little from indoor air temperatures, even in the face of extreme outdoor temperatures. Special windows and a building envelope consisting of a highly insulated roof and floor slab as well as highly insulated exterior walls keep the desired warmth in the house – or undesirable heat out.

Quality. Passive House buildings are praised for their efficiency due to their high level of insulation and their airtight design. Another important principle is 'thermal bridge free design': the insulation is applied without any 'weak spots'

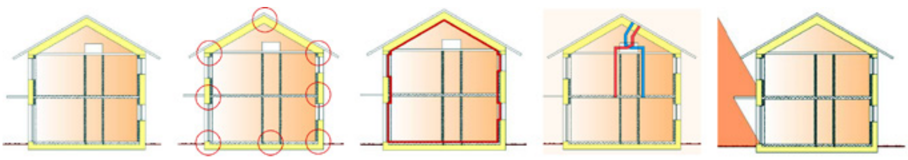


Fig. 1.32. Passive House design principles (Bootland, 2011).

around the whole building so as to eliminate cold corners as well as excessive heat losses. This method is another essential principle assuring a high level of quality and comfort in Passive House buildings while preventing damages due to moisture build up.

Ecology / Sustainability. Passive House buildings are eco-friendly by definition – they use extremely little primary energy, leaving sufficient energy resources for all future generations without causing any environmental damage. The additional energy required for their construction (embodied energy) is rather insignificant compared with the energy they save later on. This seems so obvious that there is no immediate need for additional illustrations. It is rather worth mentioning though, that the Passive House standard provides this level of sustainability for anyone wishing to build a new construction or renovating an older one at an affordable price – a contribution to protecting the environment. Be aware that the principles are all published and the design tools are made available for all architects.

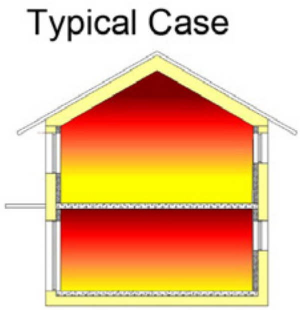
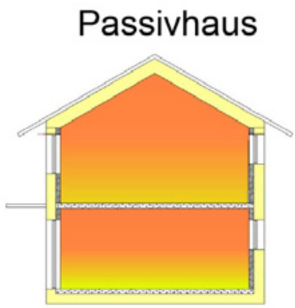
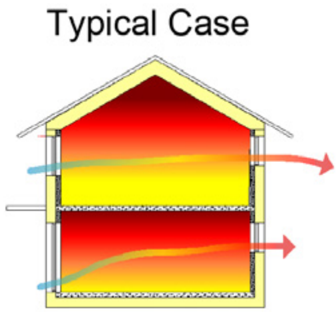
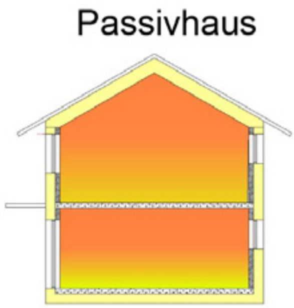
Affordability. Are Passive House buildings a good investment? Passive House buildings not only save money over the long term, but are also surprisingly affordable to begin with. The investment in higher quality building components required by the Passive House Standard is mitigated by the elimination of expensive heating and cooling systems. Additional financial support increasingly available in many countries makes building a Passive Houses all the more feasible.

Measurement results. The Passive House concept delivers – the savings are real, there is no performance gap. Passive Houses allow for space heating and cooling related energy savings of up to 90 % compared with typical building stock and over 75 % compared to average new builds. Passive Houses use less than 1.5 l of oil or 1.5 m^3 of gas to heat one square metre of living space for a year – substantially less than common ‘low-energy’ buildings. Vast energy savings have been demonstrated in warm climates where typical buildings also require active cooling.

Heating & Cooling. Make efficient use of the sun, internal heat sources and heat recovery, rendering conventional heating systems unnecessary throughout even the coldest of winters. During warmer months, Passive Houses make use of passive cooling techniques such as strategic shading to keep comfortably cool. A ventilation system imperceptibly supplies constant fresh air, making for superior air quality without unpleasant draughts. A highly efficient heat recovery unit allows for the heat contained in the exhaust air to be re-used.

The vast energy savings in Passive House buildings are achieved by using especially energy efficient building components and a quality ventilation system. There is absolutely **no cutting back on comfort**; instead, the level of comfort is considerably increased (Passivhaus Trust, 2013) (Table 1.6).

Table 1.6
Comparison of Thermal Comfort in a Typical House and Passive House (Passipedia, 2014)

Thermal comfort: Movement of air	
	
• Feels 'draughty' • Heat loss through infiltration can be over a 1/3rd of total • Increased risk of interstitial condensation	• No draughts • Heat losses through leakage reduced to less than 1/10th of typical case • Dry building fabric
Thermal comfort: Air & surface temperatures	
	
• Stratification • Clear variation between surface and air temperatures	• Even temperatures • Surface temperature similar to air temperature

A Passive House in Germany costs around 3 % to 8 % extra, which includes the following:

- savings from the need for smaller heating and cooling systems;

- greater costs of thicker insulation, better windows and ventilation systems, certified components (especially outside Germany);
- savings in running costs, especially with rising energy prices;
- financial support available for Passive Houses in some countries (Passipedia, 2014).

A common misconception is that Passive House only applies to cold weather climates, while it actually works equally in warm and hot climates. High levels of airtightness and insulation work equally well in protecting buildings from overheating provided that there is adequate solar shading. Passive House buildings have been constructed in every major European country (see Fig. 1.33), Australia, China, Japan, Russia, Canada, the USA and South America; a research station has even been constructed to the Passive House standard in Antarctica (Passipedia, 2014).

Fig. 1.33. Spread of Passive House buildings in Europe (Passipedia, 2014).

PHPP – Passive House Planning Package

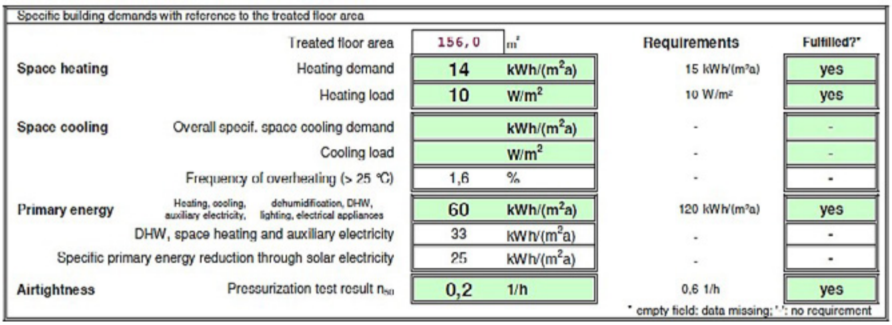
Modelling with Passive House Planning Package (PHPP) is more than just an energy balance. The **Passive House Planning Package (PHPP)** contains everything necessary for designing a properly functioning Passive House. The PHPP prepares an energy balance and calculates the annual energy demand of the building based on the user input relating to the building's characteristics.

The main results provided by this software programme include:

- the annual heating demand [kWh/(m²a)] and maximum heating load [W/m²];
- summer thermal comfort with active cooling: annual cooling demand [kWh/(m²a)] and maximum cooling load [W/m²];
- summer thermal comfort with passive cooling: frequency of overheating events [%];
- annual primary energy demand for the whole building [kWh/(m²a)] (Passipedia, 2014).

The actual PHPP programme is based on Excel (or an equivalent spreadsheet software programme) with different worksheets containing the respective inputs and calculations for various areas (Fig. 1.34). Among other things, the PHPP deals with the following aspects:

- dimensioning of individual components (building component assemblies including U-value calculation, quality of windows, shading, ventilation, etc.) and their influence on the energy balance of the building in winter as well as in summer;



Specific building demands with reference to the treated floor area

	Treated floor area	156,0	m²	Requirements	Fulfilled?*
Space heating	Heating demand	14	kWh/(m²a)	15 kWh/(m²a)	yes
	Heating load	10	W/m²	10 W/m²	yes
Space cooling	Overall specif. space cooling demand		kWh/(m²a)	-	-
	Cooling load		W/m²	-	-
	Frequency of overheating (> 25 °C)	1,6	%	-	-
Primary energy	Heating, cooling, auxiliary electricity, dehumidification, DHW, lighting, electrical appliances	60	kWh/(m²a)	120 kWh/(m²a)	yes
	DHW, space heating and auxiliary electricity	33	kWh/(m²a)	-	-
	Specific primary energy reduction through solar electricity	25	kWh/(m²a)	-	-
Airtightness	Pressurization test result n_{50}	0,2	1/h	0,6 1/h	yes

* empty field: data missing; '-': no requirement

Fig. 1.34. Spreadsheet of Passive House Planning Package (Passipedia 2014).

- dimensioning of the heating load and cooling load;
- dimensioning of the mechanical systems for the entire building: heating, cooling, hot water provision;
- verification of the energy efficiency of the building concept in its entirety (Passipedia, 2014).

The PHPP can be used all over the world and is now available in several languages. Some of the translated versions contain additional calculations based on regional standards (similar to the German EnEV) in order to allow use as official verification of energy efficiency in the respective countries. Taking into account renewable energy sources and refurbishment of existing buildings (EnerPHit), the PHPP is continuously being validated and expanded in line with measured values and new findings (Passipedia, 2014).

*design*PH has been developed by the Passivhaus Institute to provide a 3D modelling interface that works together with PHPP (Passive House Planning Package). The *design*PH gives quick results using automatic analysis. The plugin provides an automatic analysis algorithm which can infer element types and area groups. Surfaces are given a colour-code so that it is possible to visually verify in the 3D model that all the heat-loss surfaces have been correctly taken into account. After importing a model to PHPP, the primary inputs on the Areas, Windows & Shading sheets will be mostly complete. This enables a result for specific space heat demand to be calculated quickly using default values, potentially saving significant time. *design*PH is an iterative design tool and also provides a preliminary simplified energy balance when the analysis process runs. This allows you to refine the design before exporting, facilitating a more effective iterative design process, and rule out poorly performing design options early on (*design*PH, 2018).

A number of built-in features in *design*PH allow for a quick model editing and a thermal analysis of a building. For editing a building model, *design*PH provides the following features (Fig. 1.35):

- Create and edit model geometry using the standard Sketchup drawing tools.
- Assign U-Values to surfaces. Once a geometric model has been created, thermal and material properties can be assigned to it. This can be done manually or by using the innovative automatic inference function that is built-in to *design*PH. This feature means that you can create a simple model and obtain a rough energy balance result without having to make any manual property assignments to the model.

- Assign properties to window elements. The window toolbar allows you to insert quickly window elements and assign them properties like frame, glazing or reveal properties.
- Consider shading elements. You can draw surfaces that are shading window components. *design*PH recognizes horizontal, vertical and horizontal shading surfaces and exports them into PHPP.
- Assign thermal bridges. You can assign lines as thermal bridges. *design*PH sums thermal bridges to ambient, floor slab or perimeter thermal bridges and exports them into PHPP.
- Assign a climate region for calculation of heat balance in the climate tab of the dialog window.
- Export to PHPP. When you have an initial design that is close to achieving the result you are aiming for, the model data can be exported to PHPP to add further detail and perform verification. The PPP file created by *design*PH can be imported into PHPP. Please see the PHPP v8 documentation for more details (designPH, 2018).

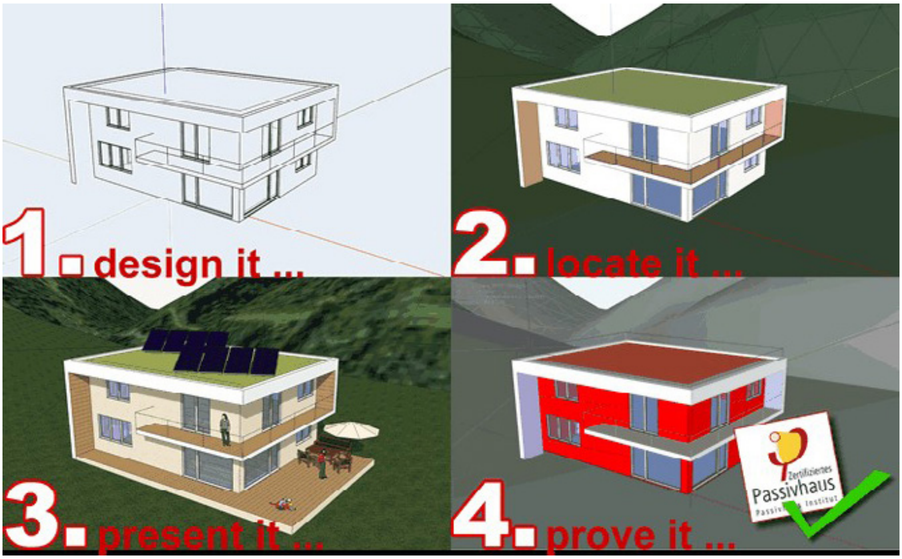


Fig. 1.35. Functions of *design*PH (*design*PH, 2018).

Certification for buildings, products and designers

Over twenty years of experience demonstrates that the high levels of comfort and energy savings associated with the Passive House Standard is achieved through independent quality testing. All certified Passive House buildings undergo a rigorous compliance process. Certification is also available for specific components, designers / consultants & tradespeople (Table 1.7).

Table 1.7
Certification Areas (Pasivhaus Trust, 2020)

Certified Passive House Passive House Institute classic | plus | premium	**Buildings.** All proposed Passive House designs must undergo energy modelling conducted via the Passive House Planning Package (PHPP.) Tests ensure that these targets are met by completing the quality assurance process. A certificate is only issued if the exactly defined criteria have been met without exception.
DESIGNER CERTIFIED PASSIVE HOUSE DESIGNER	**Designers.** Certification for designers / consultants who have the expertise to deliver Passive House buildings. The qualification covers training on PHPP, a design tool used to inform the design process and to assess or verify compliance with the Passive House Standard.
CERTIFIED PASSIVE HOUSE TRADESPERSON TRADESPERSON	**Tradespeople.** Contractors have developed their basic building knowledge & understand key Passive House principles such as airtightness.
cool, temperate climate phB CERTIFIED COMPONENT Passive House Institute	**Components.** Certified products have undergone independent uniform testing. This allows useful quick comparisons and eases the task for designers to confidently specify high-quality, energy-efficient products.

Passive House continues to expand largely across the UK and Europe. A new evaluation procedure, focusing on 'Primary Energy Renewable' (PER), serves as a basis for this, and the Passivhaus Institute in Germany introduced new and more demanding categories (Fig. 1.36). In addition to the existing PH standards, there are (Passive House Plus) and (Passive House Premium) standards. These new standards include the use of renewable energies.

Passive House Plus & Premium

PLUS: A building certified to Passive House Plus not only drastically reduces energy use but it also produces as much energy as occupants consume, turning them into Passive House Powerhouses. The energy generated must come from renewable sources and provide enough energy to operate the building throughout the whole year.

PREMIUM: Far more energy is produced than required to operate the building. Passive House Premium is, therefore, a challenging goal for the particularly ambitious building owners and designers who want to go beyond what economic and ecological considerations already propose (Passivhaus Trust, 2020).

The heating demand of a Passive House may not exceed 15 kWh/(m²a). This will continue to apply, but with the introduction of the new categories, the overall demand for renewable primary energy (PER) will be used instead of the primary energy demand. In the case of the **Passive House Classic** category, this value will be 60 kWh/(m²a) at the most. A building built to **Passive House Plus** is more efficient as it may not consume more than 45 kWh/(m²a) of renewable primary energy. It must also generate at least 60 kWh/(m²a) of energy in relation to the area covered by the building. In the case of **Passive House Premium**, the energy demand is limited to just 30 kWh/(m²a), with at least 120 kWh/(m²a) of energy being generated by the building (Passipedia, 2020).

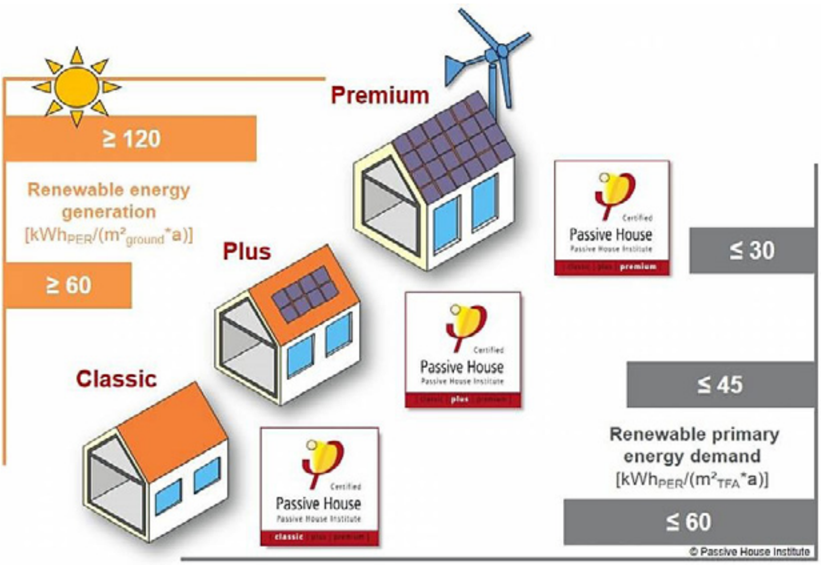


Fig. 1.36. Passive House categories (Passipedia, 2020).

Case studies

Case Study 1. Hackbridge Primary 1st Passive House Plus School in the UK (Fig. 1.37).

The £ 9M (≈EUR 10M) scheme timber frame school has been designed to achieve the Passive House Plus requirement and to become the first certified Passive House Plus building in the UK. The renewables used on the school include both an extensive photovoltaic array in combination with an interseasonal ground source heat pump with bore holes, using the car park

Fig. 1.37. Hackbridge primary school (Passivhaus Trust, 2020).

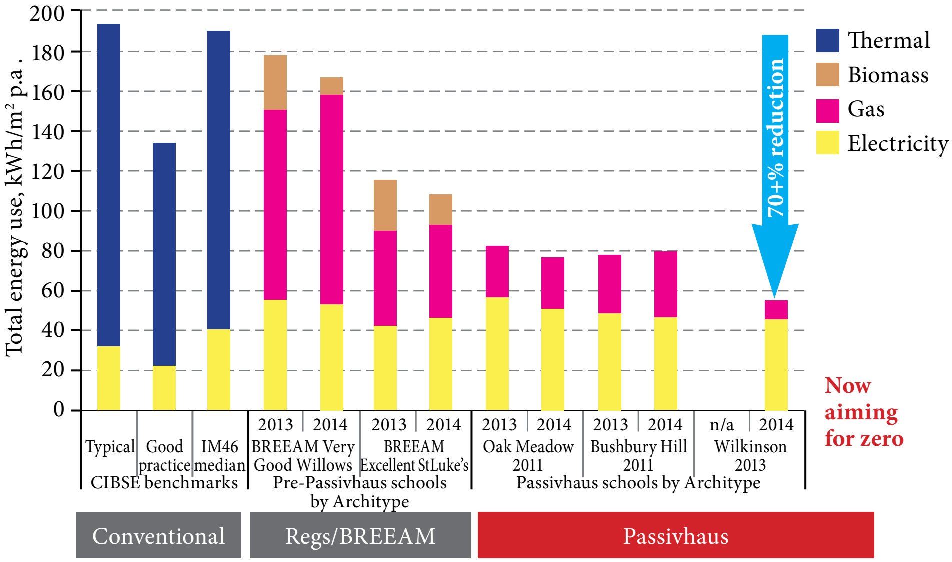


Fig. 1.38. Recorded total energy consumption (Passivhaus Trust, 2020).

as a collector. Due to its sensitive ecological setting the project has involved extensive ecological aspects, including the de-canalization of an old culvert system that has been returned to swales, wild flower gardens, sustainable drainage systems utilising swales and ponds and a biodiverse green roof under the PV array (Passivhaus Trust, 2020).

The design of this primary school and nursery follows a low embodied carbon philosophy with timber materials throughout, and the concrete ground floor slab has a high level of Ground Granulated Blastfurnace slag (GGBs) to reduce carbon impact. On top of this sits a timber frame with OSB fins framing out the main columns and beams forming a duvet zone of insulation around the structure.

Recorded total energy consumption for Passive House schools is much lower compared to typical schools (Fig. 1.38).

Case Study 2. Hadlow College Non-Domestic New-Build – UK Passive House Awards 2012 (Fig. 1.39).

Project Overview:

Name: Hadlow College RRC

Type: Teaching facility / Visitor Centre

Build type: Timber frame, GSHP, free air night-time cooling

Location: Tonbridge, Kent

Budget: £537,000 (≈EUR 603,000)

Construction costs: £1484/m^2 (≈EUR 1667)

Total Floor Area: 308 m^2

Fig. 1.39. Hadlow College (Passivhaus Trust, 2020).

This iconic building is a showcase of low carbon technology constructed in 2010. One of the first educational establishments in the UK to achieve Passive House certification it uses just 10 % of the typical energy uses of an equivalent modern building. It was built using prefabricated structured insulated panels and was erected in just 3 days and water and airtight within 10 days. Located at the College Dairy on Blackmans Lane, the building is a sympathetic conversion of and extension to redundant calf sheds. It includes a visible energy monitoring display to showcase the consumption of the building (Passivhaus Trust, 2020).

The centre is designed to focus on researching, developing, influencing and supporting the sustainable rural regeneration agenda in the UK.

Its features include (Passivhaus Trust 2020):

- passive solar design;
- underfloor heating powered by a ground source heat pump, and cooling unit to prevent overheating in summer;
- triple glazed windows;
- automatic clerestory windows to aid ventilation;
- water-less urinals, low flush toilets (2 litres instead of 7), timed water-saver taps and moderated flow showers;
- walls insulated to 400 mm;
- timber frame wall panels with recycled 'blown' cellulose insulation and clad in larch from sustainably-managed forests, and no metal in the superstructure;
- a number of walls deliberately constructed of dense concrete blocks, designed to absorb the heat from low sunlight;
- provision for a green roof.

Case study 3. The BC Passive House Factory, Canada (Fig. 1.40).

The BC Passive House Factory is located in Pemberton, British Columbia, Canada — a small town situated within a vast mountain range. "The main inspiration for the design came from the belief that the industrial, everyday buildings that make up a vast amount of our built environment can be just as important, and well-considered, as our 'public' buildings".

Encompassing 1,500 square metres, the facility was designed for the manufacture of prefabricated wall panels intended to be used for buildings that consume minimal energy, often known as Passive House constructions. It was conceived as a ‘simple, light-filled wooden box’ that would exemplify the client’s mission to promote wood construction, prefabrication, energy efficiency and sustainable design. It is made using the panels created by the client, BC Passive House, and thus serves as a demonstration project. It will help the company promote its super-insulated wall system that is airtight yet breathable, which helps prevent mould growth.

The firm used glue-laminated Douglas fir to construct the post-and-beam structure. Solid wood walls are made of CLT panels, and the factory ceiling consists of plywood and prefabricated timber boards.

The roof is made of prefabricated wood boards, with plywood sheathing that spans from beam to beam. A high-efficiency, heat-recovery ventilation system helps reduce carbon emissions. When comparing the structure to a similar building made of concrete, the firm estimates that the BC Passive House Factory will emit 971 less tons of carbon dioxide per year (McKnight, 2016).

Fig. 1.40. The BC Passive House Factory (McKnight, 2016).

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