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Sustainability in the Building Construction Industry

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Thesis abstract

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Over the last two decades, the issue of carbon emissions has emerged as a critical item on the global political agenda. This has been largely driven by the effect of climate change, air pollution, and their impact on human health and well-being. Nowadays, it is not merely a topic of conversation but a serious necessity for our planet, for human beings and for future generations to survive and to be able to use fossil-free energy without environmental impacts on their health and well-being. The building and construction industry is one of the main sources of carbon dioxide emissions and other harmful gases. Thus, there must be mechanisms and techniques to stop or to gradually reduce the emission of *carbon and other hazardous gases.* To achieve this, we have to move towards more sustainability, not only in the construction industry but also in other industries polluting the environment.

So far, important measures have been developed to lead the building industry towards carbon neutrality without stopping economic growth, including operational performance, technical setups, the location and design of the building, and the use of materials minimizing embodied energy and embodied carbon. More importantly, eco-friendliness and energy-efficiency shall be taken into consideration from the product stage to the end-of-live stage of a building.
This thesis searches for different measures and strategies that reduce or remove carbon footprint in the construction industry without stopping economic growth and without any social consequences.

[1] Keywords: Climate changes, Sustainable Construction, Energy, Carbon dioxide, zero carbon

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Viimeisen kahden vuosikymmenen aikana hiilen ilmakehälle aiheuttamat ongelmat, jotka ilmenevät ilmastonmuutoksena, ilmansaasteina ja ihmisten terveyteen ja hyvinvointiin kohdistuvina ympäristövaikutuksina, ovat nousseet poliittisesti tärkeälle asialistalle ympäri maailman. Nykyään ne eivät ole vain keskustelun asia vaan vakavasti otettava ongelma koko planeetallemme. Tulevienkin sukupolvien on voitava selviytyä ja elää fossiilivapaata elämää ilman hiilen haitallisia vaikutuksia. Rakennusteollisuus on eräs pääasiallisista hiilidioksidipäästöjen ja muiden haitallisten kaasujen lähteistä. Siksi päästöjä tulisi pyrkiä järjestelmällisesti vähentämään rakennusteollisuudessa. Hiilipäästöjen ja muiden vaarallisten kaasujen asteittaiseksi pysäyttämiseksi tai vähentämiseksi tulee kehittää mekanismeja ja tekniikoita. Tämän tavoitteen saavuttamiseksi meidän on siirryttävä kohti kestävämpää kehitystä, ei vain rakennusteollisuudessa vaan myös muilla ympäristöä saastuttavilla aloilla.

Tähän mennessä on kehitetty tärkeitä toimenpiteitä, jotka edesauttavat hiilineutraaliutta rakennusteollisuudessa. Tärkeässä roolissa tässä ovat toiminnallinen suorituskyky, tekniset asetukset, rakennuksen sijainti, suunnittelu ja materiaalien käyttö, mikä vähentää hiilidioksidipäästöjä. Tuotteiden ympäristöystävällisyys ja energiatehokkuus tulee ottaa huomioon kaikissa rakennusvaiheessa eli toteutusvaiheista rakennuksen käyttöiän loppuun asti. Tässä opinnäytetyössä tutkitaan erilaisia mahdollisuuksia näiden tavoitteiden saavuttamiseksi.

[1] Asiasanat: Ilmastonmuutos, kestävä rakentaminen, hiilidioksidi, energia, kestävät materiaalit

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Terms and Abbreviations

GBCI	Green Business Certification Inc. Green Business Certification is an American organization that provides third-party credentialing and verification for several rating system relating to the built environment.
LEED	Leadership in Energy & Environmental Design. This is an American organization working and promoting sustainability specifically on building and environment.
BREEAM	Building Research Establishment Environmental Assessment Methodology
PHI	Passive House Institute
SC	Sustainable Construction
OPC	Ordinary Portland Cement
CCS	Carbon capture and storage
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
EMS	Environmental management system
ISO	International Standardization Organization
GBCI	Green Business Certification Inc. It is an independent organization that is responsible for administering various third-party sustainability certification programs for buildings, cities, and communities worldwide.

1. SUSTAINABLE DEVELOPMENT

Sustainable development has been around since the 1970s, but in 1987, the UN World Commission on Environment and Development, the so-called Brundtland Commission made it well- known. The Brundtland Commission meant by sustainable development that "the present generation must be able to satisfy their basic needs without jeopardizing the ability of future generations to get their own needs."

“Sustainable development is a model of social and structural change that optimizes economic and social benefits in the present without jeopardizing opportunities for similar benefits in the future.” (Goodland & Ledec, 1987)

Sustainable development involves addressing the three pillars of sustainability: economic, social, and environmental. Economic sustainability involves creating economic growth that is sustainable over the long-term and benefits all members of society. Social sustainability involves ensuring that social development is inclusive, equitable, and provides opportunities for all members of society to participate and benefit. Environmental sustainability involves protecting the environment and natural resources for future generations.

Sustainable development requires the cooperation and collaboration of governments, businesses, and individuals. It involves making decisions that balance economic, social, and environmental considerations and take into account the long-term impact of those decisions on society and the environment. Examples of sustainable development initiatives include renewable energy projects, conservation of natural resources, sustainable agriculture, and sustainable urban planning. Sustainable development is described below in schematic form.

Figure 1.Sustainability categories for different criteria.

2. COMPONENTS AND GUIDELINES FOR SUSTAINABLE DESIGN AND CONSTRUCTION

Over last two decades climate change due to human activities has caused disasters around the world. Scientists and different organizations are trying to find a solution to prevent any further disaster and to save the planet. The current type of construction work is literally destroying the planet and seriously damaging the environment, and on the other hand population of the world is rapidly increasing which requires more residential buildings. Buildings are the single most demanding polluters on the planet, consuming over half of all energy used in developed countries and producing over half of all climate change greenhouse gases.

The idea of green buildings began in the 1970s and was a practical response to the high prices of oil. That made people start thinking about the oil resources and made claims about how much oil and gas was left. There were very critical assumptions that in the next 30 years the planet will be out of oil and gas. Even though most of those assumptions did not come true, there are many of them that still have not been proved wrong.

Sustainable construction, also known as green building, is the practice of designing, constructing, and operating buildings in an environmentally and socially responsible manner. This approach aims to minimize the negative impact of buildings on the environment and human health, while maximizing their positive impact on the economy and society. Not only the style should make a union with nature and environment but also the building's functionality should be eco-friendly in terms of energy efficiency, water saving, natural ventilation, cooling and ecological use of daylight.

The sustainable building is made over three main principles of design (Kibert, 2016):

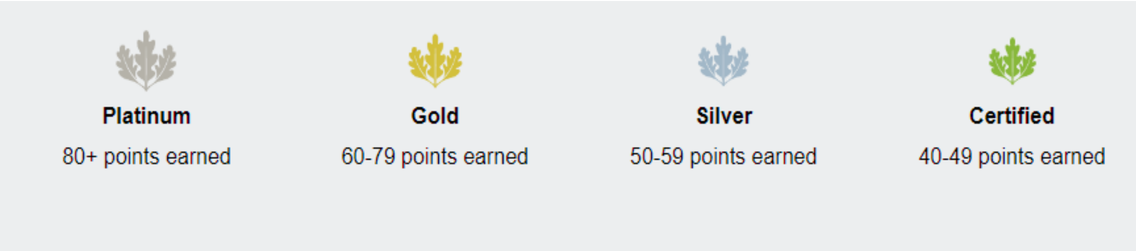
- ✓ Design for the climate or ecological sustainability
- ✓ Design for the environment or environmental sustainability
- ✓ Design for time, be it day or night, a season or the lifetime of a building and design a building that will adapt over time.

2. 1 LEED

LEED (Leadership in Energy and Environmental Design) is a green building certification program developed by the U.S. Green Building Council (USGBC) that recognizes buildings and projects that have been designed, constructed, and operated with a focus on sustainability and environmental responsibility. LEED certification is based on a point system, with buildings earning points for incorporating sustainable features and practices across several categories, including energy efficiency, water conservation, materials and resources, indoor environmental quality, and innovation in design.

There are several levels of LEED certification: Certified (40–49 points), Silver (50–59 points), Gold (60–79 points), and Platinum (80+ points). LEED certification is a globally recognized symbol of sustainability achievement, and can provide several benefits, such as reduced operating costs, increased property value, and improved occupant health and well-being.

LEED certification is available for all types of buildings, including commercial, residential, healthcare, and education facilities. In addition to building certification, LEED also offers certification for neighborhood development, homes, and cities. (LEED v4.1 2019)



Picture 1. Buildings are rated and certified by the scale.

2. 2 BREEAM

BREEAM or Building Research Establishment Environmental Assessment Methodology was established in 1990. It is the leading worldwide organization for environmental assessment method and rating system. The organization makes standards for the best sustainable building design, construction and operation and also the organization creates tools and methods to develop and design from the very beginning stage of a building, structure or any project such as designing more green and sustainable, constructing eco-friendly, selecting the most suitable and durable construction material which has the least impact on environment, reducing the maintenance cost and designing more self-sufficient building in order to create more safe and healthier residential and living and working environment. The goal for BREEAM is to comprehend all spheres of the building.

The organization is concentrated on the choice of materials, transport, and construction, comfort of the interior design, eco-friendly architectural design, long term eco-efficiency and low-cost consumption of the building in future. Using independent, licensed assessors, BREEAM assesses scientifically based criteria covering a range of issues in categories that evaluate energy and water use, health and wellbeing, pollution, transport, materials, waste, ecology, and management processes.

BREEAM focuses on the following main areas (Kibert, 2016):

- ✓ Net zero carbon
- ✓ Whole life performance
- ✓ Health and Social impact
- ✓ Circularity and impact
- ✓ Biodiversity
- ✓ Disclosures and reporting.

2. 3 Passive House

Passive house institute is a German based institute rating system for sustainable buildings. Passive houses are buildings in which a high level of comfort is achieved with the minimum energy expenditure. There are two main lines that one passive house project is focused on: first effect of the building on the environment and second comfort of human being and habitants. 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.

As Roberto and Vallentin (2014, pp. 8–9) emphasize, among the passive measures, the most substantial contribution is made by the thermal insulation of the building It means that the most obvious feature of a passive house building is the excellent thermal insulation of the entire building envelope or building as a whole. The main elements of a building such as exterior walls, roofs, ground, and ceiling slabs play important roles in this regard. Depending on the form factor of the building and the quality of the other constructional and technical components, U- values range between 0.08 and 0.18 W/m^2K.

The Passive House standard is based on several principles, including:

Super-insulation: The building envelope is highly insulated to reduce heat loss.
Airtightness: The building is designed to be airtight to prevent drafts and heat loss.
Ventilation: A mechanical ventilation system is used to provide fresh air and remove stale air, while recovering heat from the exhaust air.
Passive solar gain: The building is designed to capture and use solar energy for heating.

3. SUSTAINABLE CONSTRUCTION

Sustainable construction refers to the design, construction, and operation of buildings that are environmentally responsible and resource-efficient throughout their life cycle. The goal of sustainable construction is to minimize the negative impact of buildings on the environment and maximize their positive impact on human health, well-being, and the economy. Sustainable construction is meant using recyclable and renewable materials in building projects and minimizing energy consumption and waste production and more importantly use of renewable energy such as solar energy, wind energy, hydropower, ocean energy and ground energy. The primary goal of the sustainable construction method is to reduce its impact on our environment.

Sustainable construction does not end after the completion of the building project. The design of the building itself should have a minimal impact on the environment over the structure's lifespan (Kibert, 2016). It means that the design of the building should incorporate elements and materials that have a continuous influence on the structure's environmental impact. These can include energy- efficient roof hatches on the rooftop, solar panels, appropriate insulation to prevent heat loss, and minimizing energy consumption from the grid that mostly comes from fossil fuels and long lifespan building materials.

3.1 Cultural Sustainability

As Barthel-Bouchier (2012) emphasizes, cultural sustainability refers to the preservation, maintenance, and promotion of cultural diversity, heritage, and values. It is about ensuring that cultural practices, beliefs, and knowledge are passed down from one generation to the next, and that they are respected and valued within communities and societies. cultural sustainability can contribute to economic development. Cultural heritage sites, for example, can attract tourists and generate revenue for local communities. Cultural products and services, such as traditional crafts and cuisine, can also be marketed and sold, providing a source of income for local artisans and entrepreneurs.

Cultural sustainability is one of the dimensions of sustainable development (Jelinčić, 2022, p. 18). It means preserving related things to culture such as languages, traditions, and customs. In culturally sustainable development, diversity and balanced growth are accepted and everyone's rights are valued and respected.

3.2 Social Sustainability

Socially sustainable development means that the conditions for well-being are transferred from one generation to the next generation and the main goal of social sustainability is to reduce inequality and injustice in well-being, health, equal access to the education system, job opportunities and safety in addition as society heading towards cultural diversity due to worldwide relationship, interaction and connectivity and as well as immigration, thus respecting and accepting diversity and different culture is very important, everyone should be treated equally in every aspect of the society regardless of their background, thought, race, religion and gender.

Sustainable development action programs aim to secure equal opportunities for people to achieve fundamental rights and basic condition of life (Schandl & Walker, 2027, pp. 9–10). It is important that development is ecologically sustainable and socially fair and just. Social sustainability is often described by themes and during the time themes are changed. Traditionally and more concretely the concepts are justice, reducing poverty and securing livelihood.

3.3 Economic sustainability

Economic sustainability is a vast package or set of rules and regulation, principles, and business management to approach economic growth without engaging in harmful methods to be destructive for the environment (MPDI, 2020). Sustainable development creates operational systems that consume natural capital (also known as natural resources) slowly enough that future generations can also use those resources. Economically sustainable development is not based on excessive use or destruction of capital, such as natural resources. On a practical level, it means for instance increasing eco-efficiency and reducing material consumption. It should also be noted that in the long term, economically sustainable development is only achieved if the operation is ecologically sustainable.

3. 4 Ecological Sustainability

Ecological sustainability includes everything that relates to the Earth's ecosystems. Amongst other things, this includes the stability of climate systems, the quality of air, land and water, land use and soil erosion, biodiversity (diversity of both species and habitats), and ecosystem services (e.g., pollination and photosynthesis). When it comes to the ecological systems, it is often possible to give quite a good definition of sustainability.

Ecological sustainability refers to the ability of natural systems to persist over time, without degrading or being destroyed (Northrop & Connor, 2013). This includes maintaining the diversity and productivity of ecosystems, as well as the well-being of the organisms that depend on them, including humans. Achieving ecological sustainability requires a balance between human activities and the capacity of the natural environment to support them. This means using natural resources in a way that does not exceed their capacity for renewal, minimizing pollution and waste, and protecting biodiversity and natural habitats.

4. LEGISLATION SUPPORTS SUSTAINABLE DEVELOPMENT

Kurtelius (2001, p. 12) as well as Mumovic and Santamouris (2009, p. 23–25) emphasize that most of the strain that humans cause on their environment is related to their activities of people and goods transportation. On the other hand, the need for the activity is essentially influenced by the structure of the community and the city, for instance how the living apartments, offices, workplaces, and services are compared to each other. These things are influenced directly by planning that regulate the related issues. The aim of law of land use and building act is to organize the use of land and construction of areas in such a way that it creates the conditions for a good living environment and promotes ecologically, economically, socially and culturally sustainable development.

4.1 Role of the planning

The Finnish Land Use and Building Act (Maankäyttö- ja rakennuslaki 132/1999) which was released in 2000 states that the actual plan system according to the Land Use and Building Act includes the province and the municipal level. In addition to these levels, the Government can issue national goals that guide regional and municipal planning. Planning includes national goals such as transport network, highways and public network, long-distance railway and national ports and airports (Kurtelius, 2001; Mumovic & Santamouris, 2009, p. 23–25). Provincial goals are every activity that are at the province level. Regional goals are related to the municipalities.

5. WASTE REGULATION AND MANAGEMENT

By definition waste is any product that becomes discarded after original use, or is valueless, defective and without use (Hulley, 2021, p. 12). There are different types of waste generation during construction activities such as demolition, excavation, and construction. The waste generation is unavoidable, and the most common types of construction waste are, concrete, bricks, tiles, cement and ceramics, wood, glass, plastic, insulation and asbestos materials, bituminous mixture, coal and tar, metallic waste for instance pipes, soil, stones, paints, varnishes and adhesives.

As the United States Environmental Protection Agency (2018) explains, some common examples are municipal solid waste, consisting of (residential refuse), hazardous waste, wastewater (like sewage, consisting of bodily wastes and surface runoff), and radioactive waste, among others. Waste management includes solid and liquid wastes but excludes wastewater. Examples of liquid wastes are spent solvents and sludges. The waste management ensures they are handled and processed in a way that secures public health as well as to ensure the negative impact on environment. Through collaboration by citizens, residentials and industrials areas to fulfill this aim.

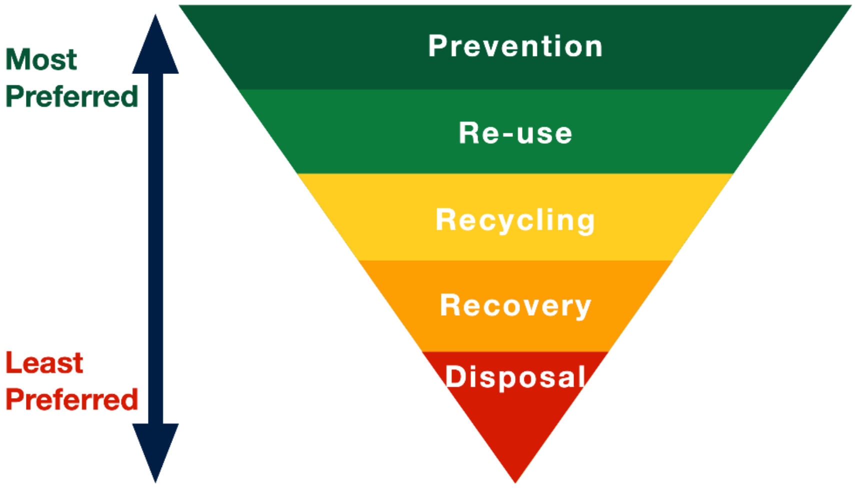


Figure 2. Different techniques can be applied to manage waste.

As the above figure shows, the hierarchy of the waste materials are:
Reduce or prevent, if possible, re-use, recycle and recover other value and dispose.

5.1 Reduction or prevention

According to Figure 2, we should reduce the waste materials as much as possible, the more the waste materials are reduced the less negative impact it will have on climate and environment. On the other hand, reducing the waste material is more economical and more eco-friendly because we save a lot of resources and energy for recycling it. For instance, we can easily prevent unnecessary waste created by offcuts, such as from pipes, building boards and timbers, by buying more appropriate sizes and lengths in the first place. We can reduce the concrete waste on the construction site by pouring concrete more carefully just on the targeted spots.

5.2 Reuse

The Finnish waste regulation which was released in 1994 accepts that the Finnish waste management should be aligned with EU equivalent waste regulation. The law suggests that the waste should be reused as much as possible. The law's purpose is to support sustainable development and regulate and save natural resources to reduce the negative impact on environment and humans' health.
The leftover materials you can repurpose for another project, such as bricks, windows, roof tiles, etc. It's also possible to pass materials on or exchange them with other construction sites, as well as join bring-back schemes. Some of these schemes allow you to return packaging to the original manufacturer.

5.3 Recycling

If creation of waste material is unavoidable and it is not technically eligible to be re-used, then the waste construction materials should be systematically recycled. A large percentage of construction waste is recyclable, including metal, paper, plastic, wood, glass, concrete, plasterboard, asphalt, and more. Therefore, it should be segregated the recyclable waste so that collectors can remove and process it properly. Keep in mind that there are also recycling schemes available for construction site materials.

5.4 Disposal

If it is determined that certain materials cannot be reduced or reused, then the only remaining options are to recycle and/or dispose them (Calkins, 2009, p. 79–84; Torgal, 2013, p. 103–107). The most practical and effective construction waste disposal method is to hire skips from a waste removal company. You should ensure that you hire the necessary number of skips to separate recycling and waste, as well as hazardous and non-hazardous waste. You also need to create a classification description and waste transfer notes before you send off waste for recycling or disposal. Incineration: Some construction waste can be burned in incinerators to generate energy. However, this method should be used with caution as it can release harmful pollutants into the air.

6. MATERIALS FOR SUSTAINABLE CONSTRUCTION

Building material is classified as environmentally friendly. It does not cause negative impact on environment at all, or the effects are minimal. Choosing the right construction materials is important because they affect our environment in many ways. The acquisition, production and transportation of raw materials have multiple environmental impacts. The choice of materials is also important to guarantee the health of residents and users.

In terms of the sufficiency of natural resources, the mitigation of climate change and the fight against other environmental problems, the importance of material efficiency is constantly emphasized (Calkins, 2009, pp. 1–4). House building is one of the biggest energy consumers of natural resources. Material efficiency promotes the construction site cleanliness, efficiency and work safety and increase the reuse of construction waste and recycling either as material or energy. By efficient utilization of materials financial profits and saving are also achieved.

6.1 Construction Materials Impact on Environment and Atmosphere

The properties of some of the most common building materials are examined below in terms of their energy consumption during their production and as well as their impact on environment and atmosphere (Calkins, 2009, pp. 53–58). It is very important to know that to the exact negative environmental effect ecological properties of these materials compare to each other or it could be impossible to tell which building material is the least harmful for the environment. Because strengths, lifetimes, or life cycle in different conditions, manufacturing methods and financial profitability even when we talk about one specific material its energy consumption vary, it is clear that it is not possible to place the materials in a clear order of prioritize which one is more eco-friendly than the others. Therefore, the properties of each construction material should be studied separately, and availability or accessibility of construction materials should be taken into consideration.

6.2 Concrete and its sustainability

Concrete is a building material that is made by mixing cement, water, aggregates (such as sand or gravel), and sometimes other additives. The cement reacts with the water to create a paste that binds the aggregates together into a hard, strong material. Concrete has been used as a construction material for thousands of years, and it is still one of the most commonly used building materials in the world. It is versatile, durable, and relatively inexpensive compared to other building materials.

Concrete can be formed into various shapes and sizes, making it suitable for a wide range of applications, from small structures like sidewalks and retaining walls to large-scale infrastructure projects like bridges, dams, and skyscrapers. One of the key advantages of concrete is its strength and durability. It can withstand a wide range of environmental conditions, including fire, water, and extreme temperatures. It is also resistant to pests and rot, making it a good choice for foundations and other below-ground applications.

However, concrete does have some environmental drawbacks (Calkins, 2009, pp. 108–115). The production of cement, which is a key component of concrete, is a major source of greenhouse gas emissions. Additionally, the extraction of aggregates can cause environmental damage, and the disposal of concrete waste can also be a problem. To address these issues, there are efforts underway to develop more sustainable forms of concrete, such as using recycled materials or developing new cement formulations that emit less carbon dioxide.

Table 1. Key environmental aspect of cement production

Air Emissions	NO_x, SO_x, Dust/ Particulates
Use of waste as fuel	Stakeholder concern over release of dioxins, other chlorinated hydrocarbons, and heavy metals
Local nuisance	Noise, vibration, dust, and visual impact
Greenhouse gases	CO_2
Land use and biodiversity	primarily associated with quarrying activities

6.3 Wood

Wood is one of the world's oldest and most used building materials, but also an important factor for the future. It is the only construction material which can be recycled completely.

Unlike the consumption of other building materials, wood use has a slowing effect on climate change. Wood is durable as well as a wise choice when choosing building or construction material. In wooden building carbon dioxide has already been stored in the structures during the growth phase of the tree and this carbon dioxide is out of the atmosphere from burdening the environment. New forest grows continuously with the help of the sun's energy at the same time binding carbon dioxide.

Wood is easily worked, structurally strong and warm, but on the other hand, forest plays a key role and offers a wide variety of environmental benefits, form habitats to carbon dioxide to air purification and, they are benefit for communities (Calkins, 2009, pp. 271–283). By cutting and harvesting the forests for building purposes we damage the environment, promote global warming and worsen climate change. According to studies, the average lifespan of wooden structures is 75 years. As much we can longer the lifespan, the greater the environmental benefits are, because we need to cut less trees from the forests for construction services and purposes. Thus, the life cycle of a tree in the forest is extended and it can serve longer for the nature.

6.4 Metals

Metal is one of the most used construction materials around the world due to its high strength-to-size ratio, durability, and workability. It can withstand harsh weather condition and doesn’t corrode or rust easily. A vast array of metal shapes, sheets, and prefabrications are available. These benefits are not very desirable regarding its impact on environment and human health from mining, production, finishing and use of metals. Impact is very huge by metals type and metals production cons a huge number of resources. It results in a huge amount of waste and this waste is sometime toxic. This toxic waste is released to air, water, and soil where it can have a big negative impact on soil, ecosystem, and human health. Lastly mining in large scale impacts habitats, air, and water around mining sites.

Metals have the endless potential of recycling whether pre- or post-consumer scrap conserves substantial energy and reduce waste and pollution in the manufacture of new metals. Metal is one of the most and long term used materials in construction industry. The recycling process is well established, and it’s recycling is economically strong. Durability of metal and installations is another key strategy in sustainable use of metals. A long use life cycle can offset the substantial resource use emission and waste resulting from a metal's manufacture.

6.4.1 Use of Metals

Metals can be extracted and made from different other components that are widely used in construction industry. These sub- components are steel and iron, stainless steel, aluminum, and copper. Among the mentioned components stainless steel is the most used material in site specialty application due to its good corrosion resistance. About half of steel raw material is recycled scrap. Ready steel structure does not burden the environment, but its greatest environmental effects come during the steel production at the very beginning of production. In steel production the blast furnace process is the stage where carbon dioxide emissions are generated, and there is no alternative method. The most common and harmful emissions that must be reduced in the steel industry are carbon dioxide, nitrogen and sulfur oxides, hydrocarbons, and heavy metals and dust emissions, which arise in production. The steel industry also loads waterways with oils and solids.

Reprocessing the steel does not deteriorate the quality of the steel, and it can be used in the production of new stainless steel (Calkins, 2009, p. 327–336). In the production of stainless steel different raw materials such as chrome, nickel and iron can be used for different needs and quality. In the production of stainless steel only small amount of emissions are produced.

7. CIRCULAR ECONOMY IN CONSTRUCTION INDUSTRY

A circular economy is a model, measurement and systematic activity that aims to promote sustainability by reducing waste and maximizing the value of resources, reduce and sensible use of natural resources and use of materials in more sustainable ways (Hulley, 2021). However, the circular economy model aims to keep resources in use for as long as possible by promoting strategies such as reusing, refurbishing, repairing, and recycling. The circular economy is not only the recycling of generated waste materials, but more of an economic model in which production and use of the products are planned so there should be generated as little waste as possible. Circular economy is based on thinking where resources are used efficiently, flows well-designed and materials given a new life – in other words materials are circulating.

The three principles of circular economy

- ✓ Design out waste and pollution.
- ✓ Keep products and materials in use.
- ✓ Regenerate natural systems: restoring and enhancing the health and function of ecosystems and their constituent parts, such as soil, water, air, plants, and animals

8 SUSTAINABLE DESIGN OF A HOUSE

As it is not a real project. It is just an example and just a presumed house. Thus, whatsoever related to this example such as planes and pictures. They are just being added into this part of the thesis for further illustration nor they are not my own drown drawings and pictures are also taken from other resources as the source's addresses are added for every single one of them.

8.1 Passive house and systems and methods used in

It is also mentioned earlier in this thesis, the passive house concept is to meet the desired comfort by consuming the minimum energy. The energy source is usually natural based energy such as sunlight etc. The passive house concept is based on a scientific, practical, and objective method and is characterized by consistency and transparency. Its energy-related targets define a clearly determined framework within which the design of the passive house takes place in construction methods or building services solutions. The only crucial factor is the energy performance of the building and its constructional and technical components. Some of the most common methods for accomplishing the passive houses are the following.

8.1.1 Solar panel

Solar energy is one of the most clean and renewable natural energy sources. Though Finland has its own unique weather condition due to its long winter and rainy weather, but still solar system is considered one the best option to remove carbon dioxide footprint in energy production sources. For example, in Helsinki there is not much sunlight during winter and days are short compared to the summer days which are long and mostly the weather is sunny. So, in the summertime can be taken the most advantage from the sunlight through solar panels. As it is shown below in the graph from the beginning of April till first of October is mostly sunny and days are long in the middle of June it is nearly nineteen hours daylight.

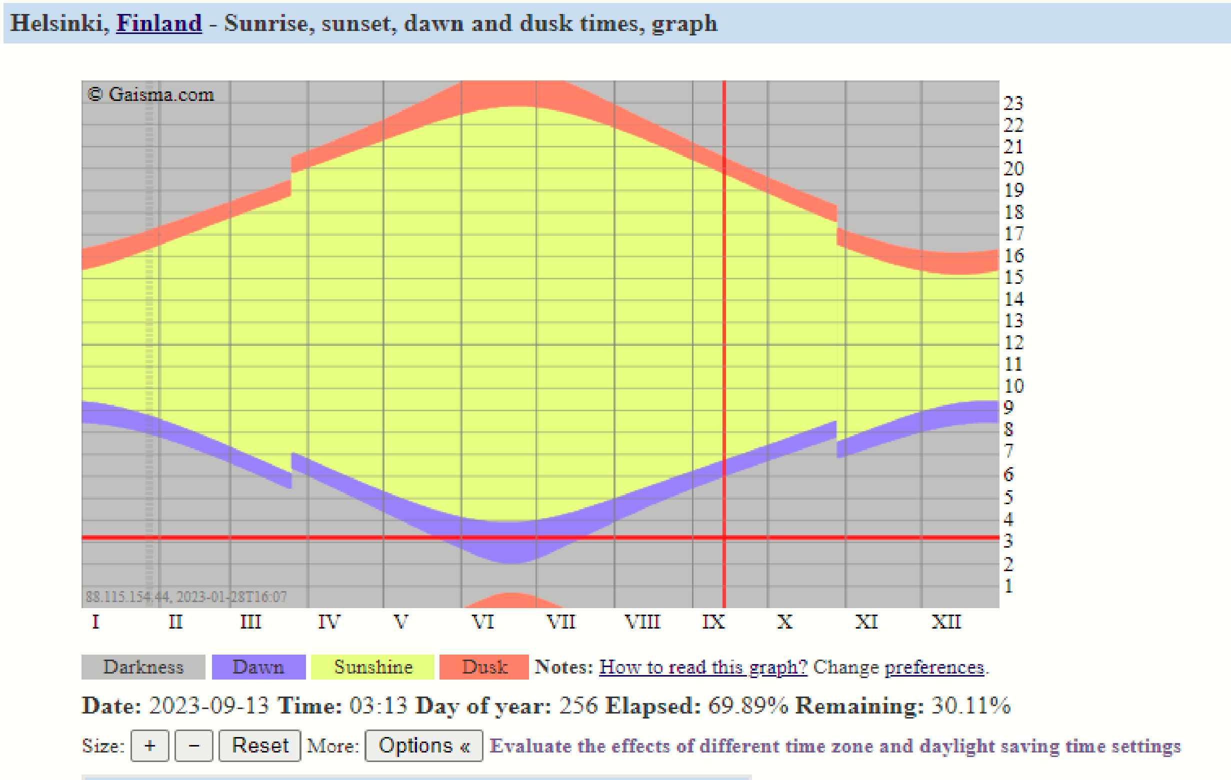


Figure 3. Sunset, sunrise, dawn, and dust times during a year in Helsinki

Solar panels are devices that convert light into electricity. They are referred to as "solar panels" because majority of the time, as a powerful source of light is the sun. Scientifically its usually called photovoltaic, which means "light electricity." In Figure 7 solar photovoltaic panels on the roof on a building are shown.

Figure 4. Photovoltaic.

Passive houses are almost always subject to high solar heat gains. It is not only about sun heat, but it is all about the relationship and balance between heat gain and heat loss.
In the market there are different kind of solar panels in regard to their energy production.

Now the concept is clear that the house heat or energy loss should be minimized as much as possible. It should be taken into consideration to design the house to save its energy as it is wanted or predeclared. To approach that goal every structure type U- values should be calculated separately and from the different structure type we select for the presumed house with the least U- value. When designing energy saving projects, special attention must be paid to each of the elements that comprise it, since each of these layers has specific qualities that will be decisive in the thermal behavior of the building as a whole.

It was also mentioned earlier that it is not a real project, it is just assumed that there is a one floor house, and it should be designed sustainable. Beside other factors which are mentioned earlier in this thesis, one of the main major factors in sustainability is energy balance and energy sufficiency. The major or main structures through which heat loose occurs are exterior walls, roofs, floor slab and joints, therefore every structure heat property should be examined separately, as its calculated below according to the formulas and norms. (Hänninen, 2022)

Note: *The best insulating materials have a U-value of close to zero – the lower the better. Building regulations currently stipulate that for a new building, the elements must have maximum U-values as follows:*

Wall – 0.3 W/m2k

Roof – 0.15 W/m2k

Windows – 1.6 W/m2k

Thermal Transmittance Calculation (U-Value)

The general formula for calculating the U-Value is:

$$U = 1/R_t \qquad (1)$$

Where:

U = Thermal Transmittance ($W/m^2 \cdot K$) *

Rt = Total Thermal Resistance of the element composed of layers ($m^2 \cdot K/W$), obtained according to:

$$Rt = Rsi + R1 + R2 + R3 + ... + Rn + Rse \qquad (2)$$

Where:

Rsi = Interior Surface Thermal Resistance (according to the norm by climatic zone)

Rse = Exterior Surface Thermal Resistance (according to the norm by climatic zone)

R1, R2, R3, Rn = Thermal Resistance of each layer, which is obtained according to:

$R = D / \lambda$

Where:

D = Material Thickness (m)

λ = Thermal Conductivity of the Material ($W/K \cdot m$) (according to each material)

The Thermal Transmittance is inversely proportional to the Thermal Resistance: the greater the resistance of the materials that make up an envelope, the lower the amount of heat that is lost through it.

$U = 1/R$

$R = 1/U$

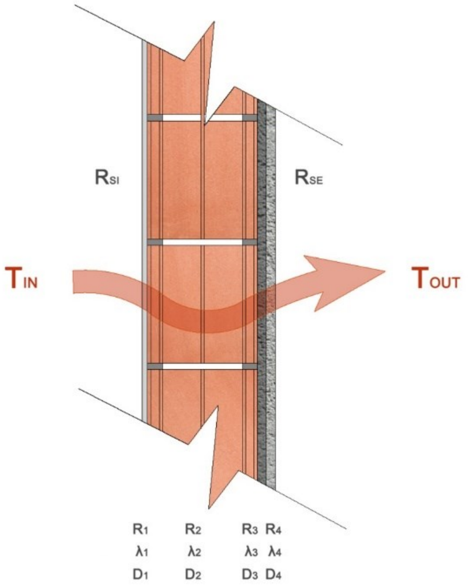
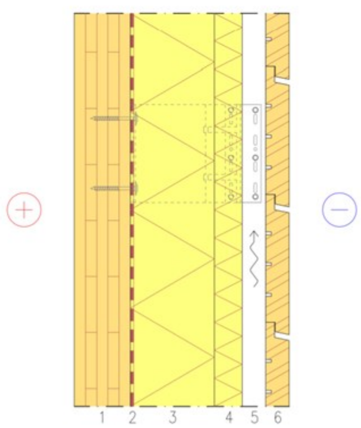


Figure 5. Heat transmission through a structure

Exterior wall U – value

I calculate some different exterior wall's U- value from different structure the one should be selected which has the closet value to the zero.

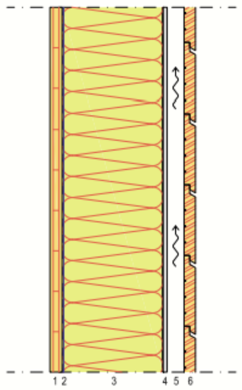
Exterior wall 1



Nro	Rakennekerros	Paksuus [mm]	Paloon reagointi
	CLT-levy RAK mukaan	100	ks. seinäpinta
	Ilman- ja höyrynsulkukangas (ilmankosteuteen reagoiva)	0,25	E
	Jäykkä mineraalivilla	150	A2-s1, d0
	Jäykkä tuulensuojamineraalivilla	50	A2-s1, d0
	Ulkoverhouksen kiinnitysjärjestelmä (alumiinikonsolit + puurangat k600) Tuuletusväli 	42 min 20	D-s2, d2
	Ulkoverhouspaneeli	min 23	D-s2, d2

U ≤ 0,17 W/m²K
$R_w + C_{tr}$ = 35 dB
R 30 (RAK mukaan CLT-levyn hiiltymämitoituksen perusteella)

Exterior wall 2



Nro	Rakennekerros	Luokka	Paksuus
1	Puulevy (jäykistävä levytys)	D-s2, d2	30 mm
2	Ilman- ja höyrynsulku	-	0,2 mm
3	Rankarunko k600	D-s2, d2	250 mm
	Mineraalivilla	A2-s1, d0	250 mm
4	Kipsikartonkilevy	A2-s1, d0	10 mm
5	Kiinnityskoolaus k600	D-s2, d2	42 mm
6	Ulkoverhouspaneeli	D-s2, d2	28 mm

U- value of this exterior is 0.147W/m^{2}K.

Conclusion: From above tow walls the second one should be selected as it has smaller U-value compared to the first wall.

Energy loses and CO_2 of the above walls:

Heat transmission through the main building structures calculates by the following formula.

$$Q_{rakosa} = \sum U_i A_i (T_s - T_u) \Delta t / 1000 \quad (3)$$

Jossa:

Qrakosa	Heat loss, kWh
Ui	coefficient of heat transmission, W/(m²K)
Ai	Building part area, m²
Ts	Inside temperature, ºC
Tu	Outside temperature, ºC
Δt	Time period, h
1000	Factor that change the unit to KW.

Tai

Q = U x A x ΔT x t, jossa

U = Structure's U-value
A = Structure area (m^2)
ΔT = Change of temperature (°C)
t = Time (s)

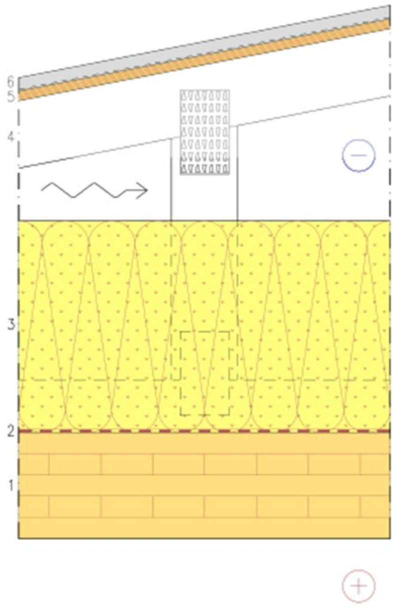
	Q_w	Q_s	Q_w+ Q_s	Q_{year}	CO_2 (gr.)
Ex. Wall 1	0. 0112 kWh (6kk=20.16 kWh)	0. 00816 kWh (6kk=1.468 kWh)	0.02036 kWh (d)	21.628 kWh	4282.344
Ex. Wall 2	0.0953 kWh (6kk=17.146 kWh)	0.007056 kWh (6kk= 1.270 kWh)	0.10235 kWh	18.416 kWh	3646.368

Description: According to the Finnish meteorology institute and ilmastokatsaus average temperature is approximately +22 °C and during the winter it is about – 7.8 °C.

According to ihmehelsinki.com District-heating emissions from the local energy company: 198 CO_2 gr/ 1kWh.

Conclusion of the calculation:
As both calculations U-value and CO_2 emission indicate that the second wall is more eco-friendly as it has smaller U-value and creates less carbon dioxide compared to the first wall.

Roof:



Nro	Rakennekerros	Paksuus [mm]	Paloon reagointi
	CLT-levy RAK mukaan Huomio! Kerrososastointi 	200	ks. kattopinta
	Ilman- ja höyrynsulkukangas (ilmankosteuteen reagoiva)	0,25	E
	Puhallusvilla (mineraalivilla)	400	A2-s1, d0
	NR-pukkiristikot k900 RAK mukaan		D-s2, d2
	Aluskatelevy RAK mukaan (kuusivaneri tai LVL)	18...19	D-s2, d2
	Konesaumapeltikate	0,6	BROOF (t2)

U ≤ 0,09 W/m²K
R 30 (RAK mukaan CLT-levyn hiiltymämitoituksen perusteella)

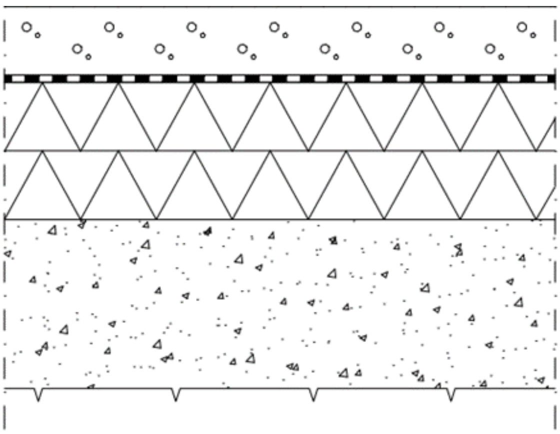
Heat loses and CO2 emission of the roof:

$Q_{rakosa} = \sum U_i A_i (T_s - T_u) \Delta t / 1000$

Roof	Q_{talvi}	$Q_{kesä}$	Q_{talvi}+ $Q_{kesä}$	$Q_{vuodess}$	CO_2 (gr.)
	0. 0594 kWh (6kk=10.692 kWh)	0. 00432 kWh (6kk=0.777 kWh)	0.06372 kWh (d)	11.469 kWh	2270.862

Floor slab:

From different floor slabs I have selected the one with the lowest U – value.



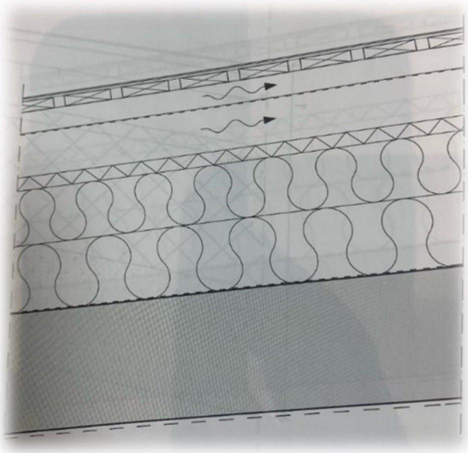
	Pintamateriaali ja käsittely huoneselostuksen mukaan
100 mm	Kantava laatta
	Suodatinkangas, N1
48 mm	XPS lämmöneriste 100 mm+ 100 mm, Finnfoam FL-300 100 mm,
	Levyjen saumat limitetään
> 300 mm	Salaojituskerros, tiivistetty vesiseulotettu sepeli, raekoko 6–32
	Louhittu kallio
U-arvo	0,16 W/m²K

Heat loses and CO2 emission of the floor slab:

$Q_{rakosa} = \sum U_i A_i (T_s - T_u) \Delta t / 1000$

Floor slab	Q_{talvi}	$Q_{kesä}$	Q_{talvi}+ $Q_{kesä}$	$Q_{vuodess}$	CO_2 (gr.)
	0.10560 kWh (6kk=19.008 kWh)	0. 00768 kWh (6kk=1.3824 kWh)	0.116328 kWh (d)	20.3904 kWh	4037.2999

Upper slab:



Peltikate, rakennusselostuksen mukaan, konesaumattu, 2-kertaiset tiivistetyt saumat.

5 mm **Vaimennuskaista,** 5x50...100, peltirivin keskellä

Ruodelaudoitus rakennesuunnitelman mukaan

50 mm **Tuuletusväli**

Korokerimat, 50x50 kattokannattajien kohdilla

Aluskate

≥ 100 mm **Tuuletusväli**

Kattokannattajat rakennesuunnitelman mukaan

Tuulensuoja, 1,2 m leveällä reunakaistalla tai tuulenohjain

225mm **Lämmöneriste,** mineraalivilla, Design=0,036 W/mK

≥ 250 mm **Kantava rakenne** rakennesuunnitelman mukaan, karkaistu kevytbetonilaatta, tiheys 450 kg/m³, λ=0,12 W/mK

Kattopinta ja pintakäsittely huoneselosteen mukaan

Vesikaton suositeltava kaltevuus vähintään 1:6.

Lämmöneristelevyjen saumat limitetään. Lämmöneristeenä voidaan käyttää myös puhallettau mineraalivillaa tai puukuituvillaa.

U- Arvo

U= 0,13W/m^{2}K.

Heat loses and CO2 emission of the roof:

$Q_{rakosa} = \sum U_i A_i (T_s - T_u) \Delta t / 1000$

	Q_{talvi}	$Q_{kesä}$	$Q_{talvi} + Q_{kesä}$	$Q_{vuodess}$	CO_2 (gr.)
Upper slab	0.0858 kWh (6kk=15.444 kWh)	0. 00624 kWh (6kk=1.1232 kWh)	0.09204 kWh (d)	19.5672 kWh	3280.3056

8.2 Water heating system

Water heating through water- circulating system is one of the most used systems nowadays in many constructions. The comprehensive properties of water-circulating floor heating have made this possible to be one of the most suitable systems to be used as environment-friendly heating system for different purposes especially for heating residential buildings.

Figure 6: Floor water heating system.

In a house with water heating system, warm water pumps into plumbing system, then water circulates through installed pipes. In this system heat rises from below upward, as a result of which heat is distributed evenly and draft-free in the room. The room air does not circulate either, because the temperatures used by the system are low and thus dust does not spread around.

Water circulation floor heating is only installed into the main heating network because when installed in the service water network, the temperature of the service water drops too much, enabling the presence of legionella bacteria. In addition, according to the guideline and instruction the lower limit value for domestic hot water is +55 °C and this too high to be used for floor heating.

8.3 Heat pump system

Heat pumps is one of the best and an energy-efficient alternative to and air conditioners for all climates (Team Espenson, 2018, p. 4–6). Like our refrigerator, heat pumps use electricity to transfer heat from a cool space to a warm space, making the cool space cooler and the warm space warmer. During the heating season, heat pumps move heat from the cool outdoors into your warm house. During the cooling season, heat pumps move heat from your house into the outdoors. Because they transfer heat rather than generate heat, heat pumps can efficiently provide comfortable temperatures for your home.

A heat pump system is a heating and cooling system that moves heat from one location to another using electricity, rather than generating heat directly. It works by extracting heat from the air, ground, or water outside a building and transferring it indoors to provide heating, or by removing heat from indoor air and transferring it outside to provide cooling.

Overall, heat pump systems can provide a cost-effective and environmentally friendly way to heat and cool buildings, particularly in areas with moderate to mild climates.

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APPENDECES

Appendix 1: Lifecycle of a Building

Appendix 2: Life stage of a Building

Appendix 3: Stage of the whole life analysis

Appendix 4: Processes used in the manufacture of wood composite

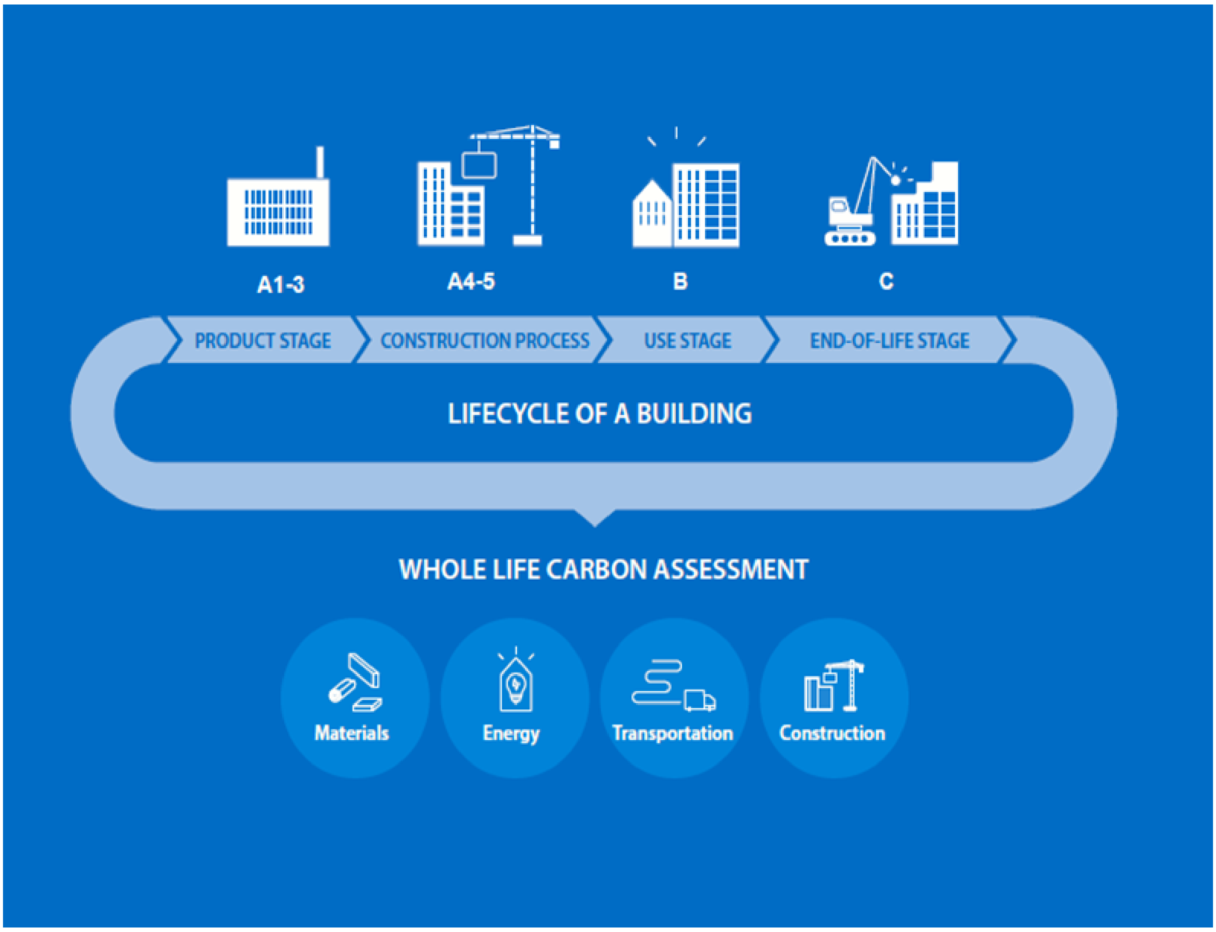
Appendix 5: schematic process of cement

Appendix 6: Passive house sample.

Appendix 7: The Passive House envelope

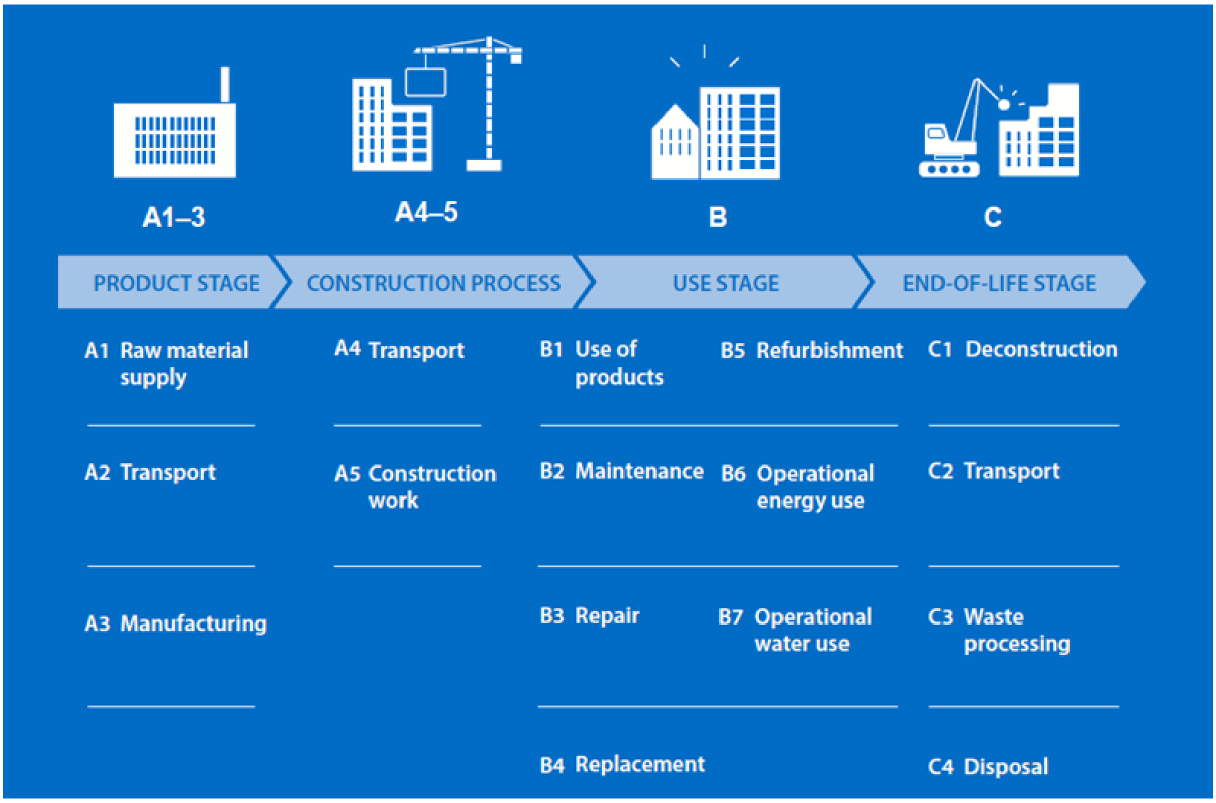
Appendix 1: Lifecycle of a Building

Source: Ministry of the environment



Appendix 2: Life stage of a Building

Source: Ministry of the environment



Appendix 3: Stage of the whole life analysis

Source: Ministry of the environment

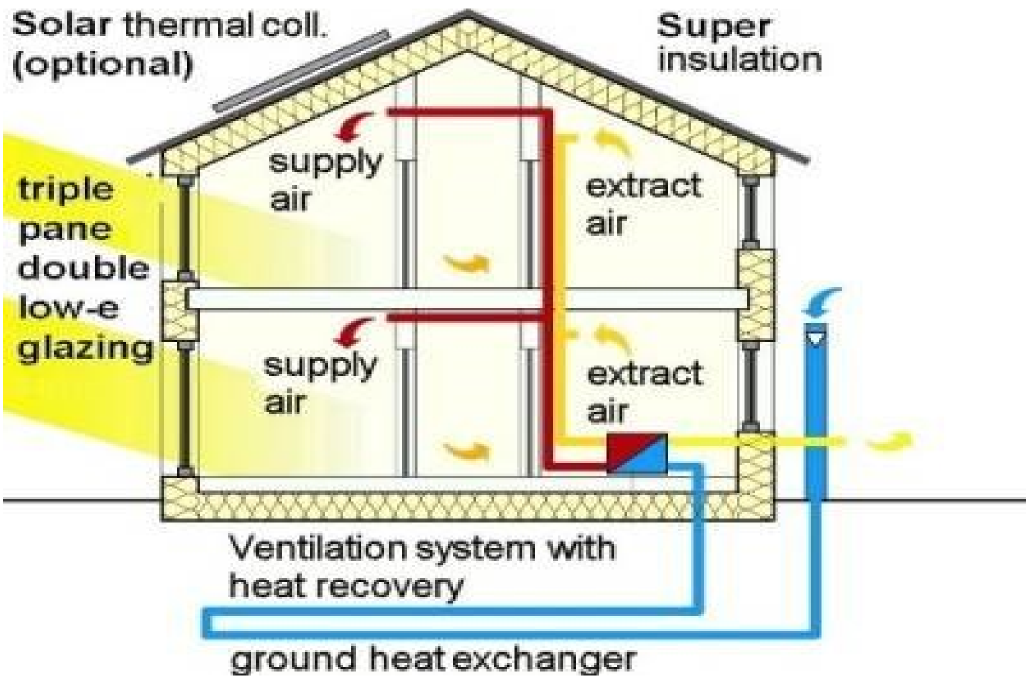
Appendix 4: Processes used in the manufacture of wood composite

Source: Ministry of the environment.

Process phase		Quantity/process	Data source
Plastic	polyethylene	Polyethylene, high density, (RER) | production Alloc Def, U	Ecoinvent
	polypropylene	Polypropylene, granulate (RER) | production | Alloc Def, U	Ecoinvent
	recycled plastic	recycled PP/PE	Väntsi & Kärki (2015)
Moulding phase		Extrusion, plastic pipes {RER} | production | Alloc Def, U	Ecoinvent
Wood waste/ plastic transport	plastic transport	full-trailer combination (40 t, full load), 150 km	LIPASTO-database
	transport of wood waste	full-trailer combination (28 t, 70% load), 50 km	LIPASTO-database
	diesel production	Diesel, low-sulphur, Europe without Switzerland, market for | Alloc Def, U	Ecoinvent

Appendix 5: Passive House Sample

Source: https://passipedia.org/basics/what_is_a_passive_house



Appendix 6: The Passive House envelope

Source: https://passipedia.org/planning/thermal_protection