SUSTAINABLE AND LOW-CARBON CONSTRUCTION OF PUBLIC BUILDING IN FINLAND

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ABSTRACT

The aim of this Bachelor's thesis was is to investigate the benefits of low-carbon public building in Finland. The thesis describes prerequisites for a green building construction tendency in the world and locally in Northern Europe and Finland. Also, this study presents information about the importance of sustainability aspects in making of public buildings procurement decisions. An analysis of the market of low-carbon emission buildings was made to show the present importance and actuality of such kind of constructions for care of the climate change and environment. The methodology of greenhouse gases emissions evaluation was made to give a clear understanding of the subject calculation process.

During the last years sustainable aspects have become one of the most studied and discussed topics in the construction sector. Many countries are especially focusing on greenhouse emissions. In the European Union buildings are consuming 40% of the total energy consumption and construction industry gives one third of CO_2 emissions to the atmosphere in total. The introduction of legislation restricting gas impacts during all stages of construction life cycle from cradle to grave is expected to eliminate negative impacts and to create positive impacts on climate and natural environment.

Keywords sustainable building, sustainable procurement, greenhouse gases
Pages 36 pages

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1 KEY CLASSIFICATIONS AND DEFINITIONS

1.1 Sustainability

In ecological sciences the term *sustainability* is made of two parts *sustain* and *ability* and means the ability of environment to withstand actions of a human being. In ecological science this term refers to the ability of biological systems to preserve and develop biodiversity. Long-lived and healthy forests wetlands and are typical examples of biologically sustainable systems. For people, environmental sustainability provides the potential to maintain quality of life and procreation, overall well-being and development (through environmental, economic and social aspects). Healthy ecosystems supply the products necessary for the life of people and other organisms. The principle of sustainable development includes four interconnected domains: ecology, culture, economics and politics. Sustainability science is the study of sustainable development and environmental science. (HEC Global Learning Centre, 2009)

Animals, humans and other organisms need healthy ecosystems and environments to survive. There are two main ways to reduce the negative impact of humanity and improve ecosystems. The first one is environmental resources management. This approach is based on information collected through geosciences, applied ecology and conservation biology. The second approach is the management of the consumption of resources, which is based on information collected through economic sciences. Also, environmental protection and environmental-friendly chemical engineering are helping to minimize negative human impacts. (HEC Global Learning Centre, 2009)

Sustainable economy is ecologically sensitive. It also takes into account social, cultural and financial aspects. Creating an economy of sustainability is a modern challenge to the world, at the level of international and national legislation, consumption, urban planning, transport, and effects on people's lifestyle and ethical consumerism. Ways to live more sustainably can be found by reorganizing the habitat, for example eco-villages and eco-cities. Economic sectors can be reappraised by using new green technologies and renewable energy sources. (Green economy, 2012)

1.2 Carbon Footprint

A carbon footprint has been defined as the amount of greenhouse gases (GHG) that have been caused by activities of organizations, transportation, production of products, or human activities. A carbon footprint in ecological sciences is an assessment of the value of greenhouse gas emissions of a certain product in carbon units. For example, the carbon footprint of natural gas is significantly less than the carbon footprint of synthetic fuel derived from coal, during which part of the coal is oxidized. The total exact amount of carbon constituting the carbon footprint cannot be reliably calculated because of the need to collect huge amounts of accurate data for this purpose, as well as the fact that carbon dioxide can be produced as a result of natural processes. (Carbon footprinting guide, 2018)

Greenhouse gases can be emitted through the Earth's atmosphere, volcanic emissions, vital activity of the biosphere, and human activity. Anthropogenic sources are production and consumption of goods and food, construction, transportation, burning of fossil fuels and biomass (including deforestation). Some industrial processes lead to significant carbon dioxide emissions (for example, cement production). (Ritchie & Roser, 2017)

For comfortability of reporting, carbon footprint is often expressed in the amount of carbon dioxide or its equivalent of other GHG emissions. The calculation of carbon dioxide equivalent value is using the relevant 100-year global warming potential units (GWP 100).A carbon footprint is measured in tonnes of carbon dioxide equivalent (tCO_2e). The carbon dioxide equivalent (CO_2e) allows the different greenhouse gases to be compared. CO_2e is calculated by multiplying the emissions of each of the six greenhouse gases by its 100 year global warming potential (GWP). (Brander, 2012, p. 2)

A carbon footprint considers seven of the Kyoto Protocol greenhouse gases: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Nitrogen trifluoride (NF_3)[3] and Sulphur hexafluoride (SF_6). GWP values for some greenhouse gases are given in Table 1. (Brander, 2012, p. 2)

Table 1. GWP 100 of GHGs. (Brander, 2012, p. 2)

Gas	GWP for 100 years
CO_2	1
CH_4	25

N_2O	298
SF_6	22800
HFCs	124-14800
PFCs	7390-12200
$(NF_3)^3$	17200

Carbon footprint is one of a family of footprint indicators, which also includes water footprint and land footprint.

1.3 Life Cycle Assessment

According to ISO 14040.2006 standard Life Cycle Assessment (LCA) is defined as a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle. (ISO 14040:2006, 2006, p. 2)

Life Cycle (LC) is defined as consecutive and interlinked stages of a product or service system, from the extraction of natural resources to the final disposal. (Life Cycle Terminology)

LCA's goal is to process with a full range of inputs or outputs of life cycle phases to evaluate environmental loads. Stages of the LCA process are shown in Figure 1. All this information collected during the evaluation of LCA is also used for identifying of opportunities for improving the environment at various points in its life cycle. (Srinivas, 2015)

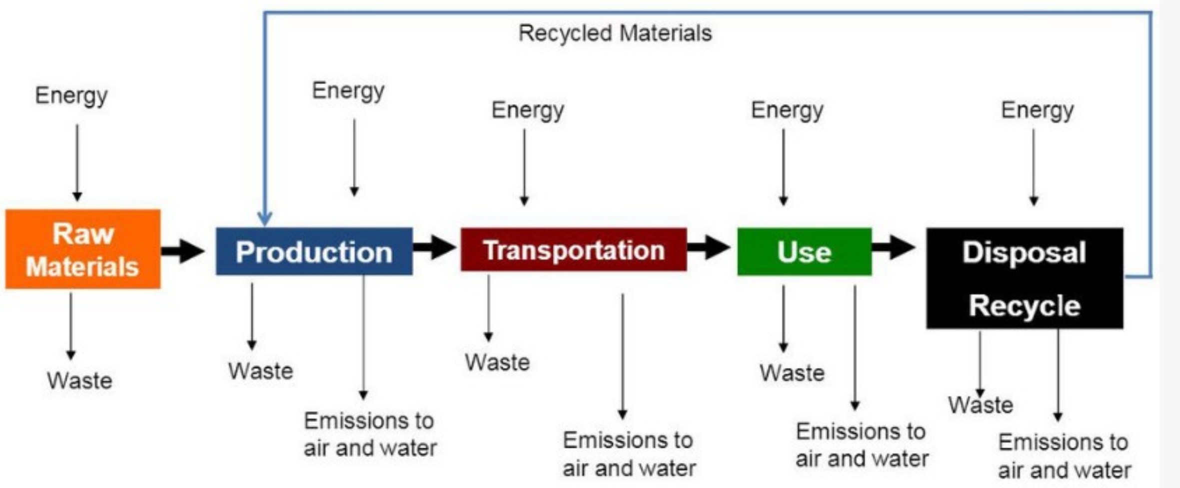

Figure 1 LCA process stages. (The Use of Life Cycle Assessment (LCA) in Fisheries, 2017)

The procedures of LCA are part of the ISO 14000 environmental management standards: in ISO 14040:2006 and 14044:2006. (ISO 14044 replaced earlier versions of ISO 14041 to ISO 14043.) GHG product life cycle assessments can also comply with specifications such as PAS 2050 and the GHG Protocol Life Cycle Accounting and Reporting Standard. (Srinivas, 2015) Framework standards for life-cycle assessment are ISO 14040 series as follows:

- International Standard ISO 14040 (1997) - principles and framework
- International Standard ISO 14041 (1998) - goal and scope definition and inventory analysis
- International Standard ISO 14042 (2000) - life cycle impact assessment
- International Standard ISO 14043 (2000) - life cycle interpretation

To analyze properly environmental impacts of processes and products during their LC there are four components of LCA defined by ISO 14040 shown in Figure 2.

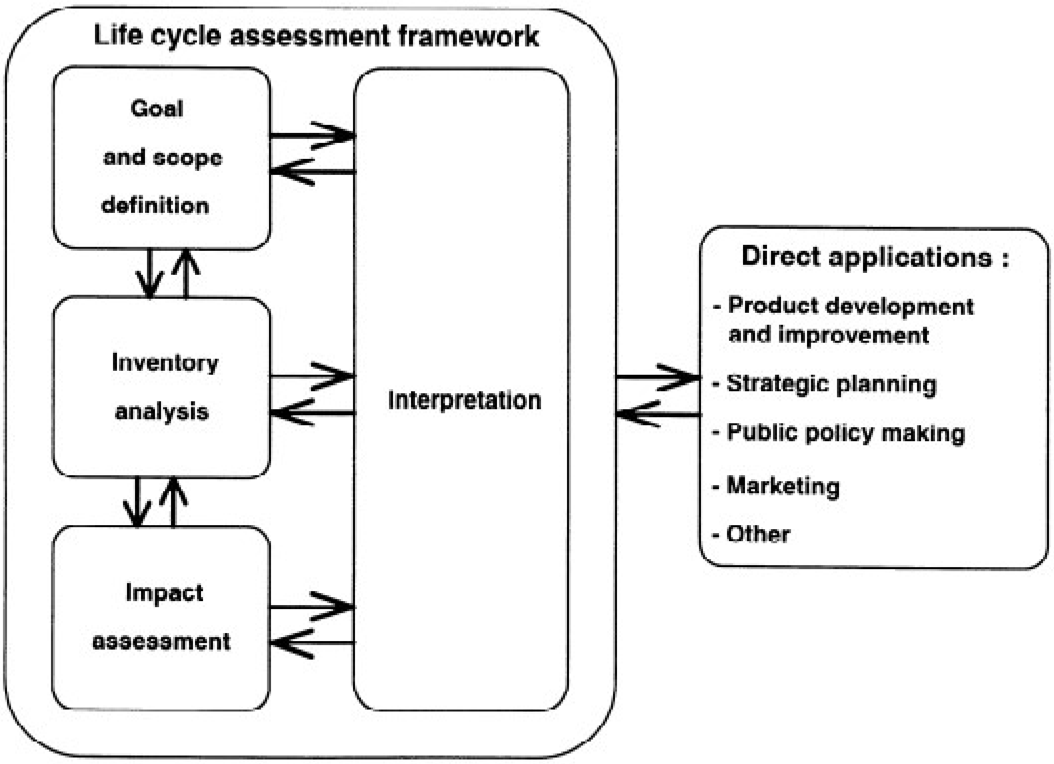

Figure 2 LCA Framework (ISO 14040:2006, 2006, p. 8)

- Goal definition and scoping: identifying the LCA's purpose and the expected products of the study, and determining the boundaries and assumptions based upon the goal definition;
- Inventory analysis: quantifying the energy and raw material inputs and environmental releases associated with each stage of production;
- Impact assessment: analyzing the impacts on human health and the environment associated with energy and raw material inputs and environmental releases quantified by the inventory;
- Interpretation: evaluating opportunities to reduce energy, material inputs, or environmental impacts at each stage of the product life-cycle.
  (The Secretariat of Government of the Presidency of the Brazil Republic and the Ministry of Planning and Development, 2017)

1.4 **Life Cycle of Building**

Building life cycle refers to the set of connected LCA stages related to the construction of a building. Building life cycle is taking into account all construction phases like design, construction, operation, demolition and waste treatment (Figure 3). (BRE Global, 2018)

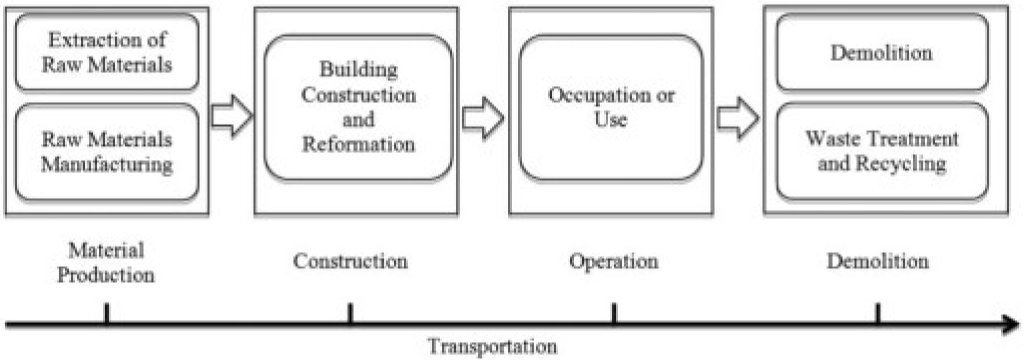

Figure 3 Building Life Cycle stages (Wu W, 2014, p. 8470)

Building LC usually starts with extraction of raw resources like iron ore, timber, stone etc. Already during the first stages appearing water, land, air emissions need to be tracked. Manufacturing phase can be subdivided into transportation of raw materials and processing stages. It ends with a delivery of ready construction materials to a retailer, contractor or construction site. During on-site construction phase different components, material and products are collected together to create the entire building. This stage is most energy consuming and producing a significant amount of emissions and waste. Building use stage is usually high energy consuming. Electricity is needed for heating, cooling, lighting, water use, etc. Renovations, maintenance and repairs might be included in use phase. Demolition stage is the end of building life cycle. Some of construction components might be recycled, disposed of or reused. This phase is considered to be the most difficult because the building designed now deals with practices of the future in the end of its life cycle. (Ragheb, 2011, pp. 16-18)

1.5 Life Cycle Inventory Methods

Life Cycle Inventory (LCI) analysis is one of four phases of Life-Cycle Assessment (LCA). It includes compilation of inputs and outputs of a product or a building from its life cycle. Three methods of LCI are used to evaluate LCA data. Nowadays, there are plenty of software programs, materials databases and case studies are released. (Huppes & Suh, 2005, pp. 687-688) However, for every specific project should be chosen one or more of three main LCI methods according to the needs and advantages. This section describes there alternative LCI methods.

1.5.1 Process LCA

Process LCA is the most widely used method of LCI analysis. Understanding of LCA is complicated, especially in construction industry. Therefore, the best understanding might be achieved with the use of this method. For the environmental impact calculation in this method a process flow diagram of all processes is used. This approach is evaluating details of construction inputs, outputs (GHG emissions) of the main phases. A certain functional unit is obtained from the amount of all environmental loadings of the building from raw material extraction till wastes, using plain algebra and by multiplying the amount of environmental interventions generated to produce them, the LCI of the product system is calculated. The calculation of product LCI must meet the following requirements listed below (Huppes & Suh, 2005, pp. 687-689):

- Each production process produces only one material or energy
- Each waste treatment process receives only one type of waste
- The product system under study delivers inputs to, or receives outputs from another product system
- Material or energy flows between processes do not have loops

This LCA method tends to be costly and time consuming. Also, according to the huge amount of data used and its propriety some of Process LCA parts might be neglected and cut off from final calculations. That's why the final results might be lower up to 3% than input-output analysis and 18% lower that hybrid analysis. In terms of construction, very few process LCAs of just construction activities have been performed and many of those that do exist are based on extremely project-specific or national-level data. (Sharrard, 2007, pp. 16-22)

1.5.2 Economic Input Output LCA

Economic Input Output LCA is the other widely used method concerning evaluation of environmental impact. This study is based on the use of environmental and economic data obtained from detailed inter-industry matrixes and public sources. (Sharrard, 2007, pp. 23-24, 32) This method was invented by Wassily Leontief in the 1930s. In his work he is described input-output of industries, how they are connected through purchase, consuming and production. Also, the so called input-output transaction tables show monetary transactions between sectors. (Huppes & Suh, 2005, pp. 690-691) EIO LCA is valid for national level researches because it uses the estimation of inputs to get outputs for the whole economy sector. There is a wide choice of data which made to put values into IO table, for example water, raw material, electricity, energy, waste, GHG emissions, etc. Comparing to Process LCA this method is not time consuming. Also, it economically-wide integrates industries, products, services of the macro-level economy. But this method of assessment is difficult, and results may contain an aggregate data.

1.5.3 Hybrid Approach

Process and Input Output LCA have their advantages and drawbacks. IO-based inventory is relatively faster than other. Its system is more complicated within the national level. Process LCI provides more accurate and detailed process information with a relatively more recent data. A hybrid LCA is a complication of two previous methods in one approach. The choice of methodology is wide. Hybrid LCA can be divided into three sub-categories: *a tiered hybrid analysis*, *an IO based hybrid analysis* and *an integrated hybrid analysis*. (Huppes & Suh, 2005, pp. 691-692)*Tiered hybrid analysis* follows a process-based analysis for the use and demolish phase as well as for several important upstream processes, and then the remaining input stages like material extraction and manufacturing are imported from an IO-based LCI. *An IO based LCA* is used mostly in disaggregating industries like IO LCA. *Integrated hybrid analysis* is a combination of IO and process LCA based on mathematical matrix framework. While IO units are economical, this method is all about physical ones. (Sharrard, 2007, pp. 33-35)

1.6 **Circular Economy**

Circular economy in general is an economy based on the renewal of resources, an alternative to the traditional linear economy (creation, use, disposal of waste).A circular economy is set to change the classic linear production model, focusing on products and services that minimize waste and other types of pollution. (Circular economy. Concept., 2017)

The basic principles of a circular economy are based on the renewal of resources, the processing of secondary raw materials, the transition from fossil fuels to the use of renewable energy sources. It obviously seems to be more sustainable than the current linear economic system. The reduction of resource inputs and outputs reduces resource depletion and environmental pollution. (Circular economy. Concept., 2017)

Also, this type of economy is considered part of the Industrial Revolution, as a result of which the rationality of resource use, including natural resources, will increase. The economy will become more transparent, predictable, and its development will be rapid and systemic. (Circular economy. Concept., 2017)

1.7 Sustainable Building

Sustainable building (also known as high performance building, green construction or green building) refers to both a structure and the application of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from planning to design, construction, operation, maintenance, renovation, and demolition. This requires close cooperation of the contractor, the architects, the engineers, and the client at all project stages. The sustainable construction practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. (Green Building, 2016)

There are four groups of different kind of impacts of the built environments. The first one is aspects of built environment: siting, design, construction, operation, maintenance, renovation, and deconstruction. The second is consumptions of the building like materials, energy, water and natural resources. The third one is environmental effects: waste, air pollution, water pollution, indoor pollution, heat islands, storm water runoff and noise. The fourth is ultimate effects: harm to human health, environmental degradation and loss of resources. (Green Building, 2016)

Although new technologies are constantly being developed to complement current practices in creating green structures, the common objective of green buildings is to reduce the overall impact of the built environment on human health and the natural environment by efficiently using energy, water, and other resources; protecting occupant health and improving employee productivity; and reducing waste, pollution and environmental degradation. (Green Building, 2016)

For example, sustainable buildings may incorporate sustainable materials in their construction (e.g., reused, recycled-content, or made from renewable resources); create healthy indoor environments with minimal pollutants (e.g., reduced product emissions); and/or feature landscaping that reduces water usage (e.g., by using native plants that survive without extra watering). (Green Building, 2016)

2 INTRODUCTION

Nowadays environmental movement is a rapidly evolving and exponentially growing tendency worldwide. The ideas of sustainability are successful in the whole world and especially in Finland. Green houses building concepts already proved their benefits in economical and environmental spheres. Numerous innovative products go to the construction markets every year which are giving plenty of benefits to builders and consumers. Country's governments and local companies are trying to put new technologies and knowledge about sustainability and energy savings into operation. But this tendency is not every time successful because of old building codes are inherently difficult to change. Furthermore, some of advantages are not yet proven and quantified scientifically, despite its usability and benefits. But everything in the construction market is changing really fast and thousands of already designed and constructed projects may affect rapid progress on this arena. At that point, the green building movement will have accomplished its purpose: to transform fundamental human assumptions that create waste and inefficiency into a new paradigm of responsible behavior that supports both present and future generations.

As we know sustainable building is 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. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Due to Its designed long time of operation, complexity of materials production, variability of greenhouse gas emissions it might be difficult to evaluate the value of environmental burdens. Moreover, harmful impacts take place during a long time of different stages, which makes LCA a necessary tool to achieve a high performance of a building. Also, it is important to concern not only about use phase, but about construction and demolition stages. For instance, the construction phase may account for up to 50 per cent of the life cycle emissions. Comparing to the planned use time of building (over 50 years) the construction stage is much shorter (about 1-2 years), which is a significant share in total emission amount. (Heinonen, Säynäjoki, Kuro, & Junnila, 2012, p. 2875)Paying attention to these phases helps to process and utilize building materials in the best way for the nature care.

3 PRINCIPLES OF SUSTAINABLE CONSTRUCTION

The main goal of sustainable construction was defined in 1994 by international construction research organization "the Conseil International du Batiment" (CIB). It was defined as "…creating and operating a healthy built environment based on resource efficiency and ecological design." Six principles of sustainable construction are explained. They can be useful during the processes of construction, design and buildings use. Those principles can be operated by decision makers during the entire life cycle of construction, from planning to disposal and can be applied to all of the resources like land, materials, water, energy, and ecosystems.

The main Principles of Sustainable Construction are (Kibert, 1994, p. 7):

1. Reduce resource consumption (reduce).
2. Reuse resources (reuse).
3. Use recyclable resources (recycle).
4. Protect nature (nature).
5. Eliminate toxics (toxics).
6. Focus on quality (quality).

3.1 Reduce

The principle of reduce leads the construction industry to minimize the consumption of all natural resources to have a smaller impact on ecology and environment. For example, minimizing of energy consumption might be made through the use of more economically effective lighting, cooling, heating, water flow systems. Also, higher performance insulation, windows, doors, fixtures and other materials should be used. (Kibert, 1994, p. 7)

3.2 Reuse

Reuse contrasts with recycling. Reused materials do not produce emissions again but minimize the consumption of raw materials. (Kibert, 1994, p. 8)

3.3 Recycle

Recyclable materials or materials from renewable sources should have priority above the others. Unfortunately, it’s not possible to say this about all construction materials, because the most common building products are not completely recyclable, but rather downcyclable, for lower-value reuse as for fill or road subbase. (Kibert, 1994, p. 8)

3.4 Nature

Most of our actions in creating of building environment cause different kind of emissions to the nature. According to last generation experience it is better to sustain environment than to restore. (Kibert, 1994, p. 8)

3.5 Toxics

Modern industry created a variety of useful products, chemicals and machinery that positively influence human life. But the industry sector emitted hazardous substances that invaded the nature and finally threaten the human health and well-being. The aim of this principle is to eliminate toxics in the indoor and exterior built environment. (Kibert, 1994, p. 9)

3.6 Quality

The indoor environmental quality of a building has a significant impact on occupant health, comfort, and productivity. (Kibert, 1994, p. 9) Among other attributes, a sustainable building maximizes daylighting, has appropriate ventilation and moisture control, optimizes acoustic performance, and avoids the use of materials with high-VOC emissions. (The WBDG Sustainable Committee, 2018)

4 ADVANTAGES AND DISADVANTAGES OF SUSTAINABLE CONSTRUCTION

Every building and every built environment have impact on the nature, human health, and economy. By promoting and adopting sustainable building strategies, it’s possible to achieve more environmental and economic advantages. Green construction methods are very flexible and useful for every kind of buildings, no matter the design, shape, load-bearing construction material. Any kind of building can go through the renovation and change parameters and materials to suitable ones to achieve necessary sustainability. But the most significant results can be obtained if all the parts of green design were accepted during the first steps of building project design. But every kind of construction method can have some drawback. That’s why it is necessary to discuss and give definitions to a variety of pros and cons of sustainable construction.

4.1 **Advantages**

4.1.1 Energy efficiency

Usually the high-performance buildings designers use the newest up-to-date innovations that are not used in the field of creating of traditional style housing. It is possible to create a more healthy and sustainable building environment. Efficiency can reduce waste streams, which is important due to the world's new tendencies for resources economy. (Green Buildings: Advantages and Disadvantages, 2018)

4.1.2 Maintenance

All of the sustainable buildings do not require or require much less and rarely maintenance than traditional buildings. For example, some of the materials do not wear out so quickly and do not need annual changing. As a result, it is possible to save money and time. Also, using of less material is good for the environment due to reducing waste to the atmosphere, enhancing and protecting biodiversity and ecosystems, and improving air and water quality. (Advantages and Disadvantages of Green Building, 2018)

4.1.3 Indoor air quality

If it is possible to use healthy and natural materials and healthy energy sources such as solar and wind power instead of coal, gasoline, wood, pellets etc, healthy air inside the house means healthy inhabitants. (Advantages and Disadvantages of Green Building, 2018)

4.1.4 Material efficiency

Sustainable buildings are usually made of sustainable materials, which are easy to renew, recycle, reuse, and utilize. Most materials are used are already made of recycled resources to reduce waste. Nowadays more than 95% of steel might be taken from recycled sources, 68% of insulation might be made of recycled textile, and 90% of all demolition materials might be recycled. (Green Buildings: Advantages and Disadvantages, 2018)

4.2 **Disadvantages**

4.2.1 Cost

The investment does not pay for itself in the short-term, or at all, and can be very costly. Big amount of expensive building materials are usually used in sustainable construction. Because of labor law compliance requirements not every construction engineer has an experience and necessary knowledge to design a building that can have enough quality. The client should pay the higher salaries to architects and engineers. The initial building price of a project is more than that of traditional building, but the savings in electricity are greater. (Advantages and Disadvantages of Green Building, 2018)

4.2.2 Time

Because of a more complicated designing and building process more time is needed to construct a sustainable house instead of a traditional one. (Advantages and Disadvantages of Green Building, 2018)

4.2.3 Weight of structure

Adding of a green roof or other installations usually influences the weight of the whole structure compared to the traditional one because of more materials and layers used. So, it might be needed to plan load-bearing structure that can have more strength to carry additional loads. (Advantages and Disadvantages of Green Building, 2018)

5 SUSTAINABLE CONSTRUCTION IN FINLAND

Finland is situated in the northern part of Europe, between the latitudes 60° and 70°. A quarter of the country extends north of the Arctic Circle. The climate of the country combines both continental and maritime depending on place and air flow. Near the Baltic Sea the temperature is higher because of inland water and air flow from the Atlantic Ocean which is warmed by Gulf Stream. The average temperature in south-western Finland is about 5.5°. (Ministry of the Environment and Statistics Finland, 2017, p. 11) Due to cold weather conditions buildings are always built with special attention to energy efficiency and sustainability. Building and maintenance cost in these conditions is higher compared to other countries, which is also challenging. (Finnish Innovation Fund Sitra, VTT Technical Research Centre of Finland, Tekes, 2011, p. 4)

The Finnish government wants to reduce the harmful emissions going from construction processes. Due to a relatively high energy use and emissions energy efficiency and sustainability of the environment are important to mitigate climate change. To compare with other countries Finnish building fund is relatively young, well-maintained and energy-efficient. Building efficiency technologies have developed for decades, now they are placing Finland on top of industry. (Finnish Innovation Fund Sitra, VTT Technical Research Centre of Finland, Tekes, 2011, p. 4)

The demand for sustainability is also changing the market. Customers, decision-makers, and especially government support the transition towards low-carbon society. Building codes guide towards low energy buildings and local renewable energy production assists in cutting the CO_2 emissions. (Finnish Innovation Fund Sitra, VTT Technical Research Centre of Finland, Tekes, 2011, p. 5)

Now Finland is a recognizable leader in a field of eco-innovations and has the second rank in Eco-innovation index. Over 40% of the Finnish public research and development findings go into energy and the environment sector (which amounted to about 0.12% of country's GDP in 2014), and over 30% are made in cleantech. Eco-innovations and intelligent construction are in priority of the Finnish government. Recently, the main priority on circular economy was added in a government strategic program and an "Action plan for research and innovation policy" was started. Moreover, Finland promotes using of BIM software and life-cycle assessment tools in the development of sustainable construction business. (European Commission, March 2018, p. 2)

5.1 Construction Industry Statistics

According to recent data the volume of building production in Finland is still growing. For the period of last 5 years the ongoing building production increased by 4.2 % year by year. (Statistics Finland) Comparing to all construction industry the biggest growth was in building construction. The turnover grew by 14% year by year from May to July. On the same period the sales volume of construction enterprises grew by 6.5 %. (Turnover and sales volume of construction enterprises grew in January, 2019) At the beginning of 2018 building permits were granted for over 40 million cubic meters. (Cubic volume covered by granted building permits decreased also in the last quarter of the year, 2018)

The total turnover of the broad construction industry in Finland was evaluated to 51.4 billion EUR in 2016. Compared to the year 2010 this number increased by 19.1%. The total turnover is divided to subsectors: 63.3% real estate activities, 11.4% manufacturing, and 10.2% engineering and architectural activities. In 2014 the gross operating surplus of the broad construction sector amounted to 6.9 billion EUR. (European Commission, March 2018, p. 7)

Building construction consumes a huge amount of electricity energy and raw materials not only during construction phase but also during lifetime. For example, in the European Union buildings consume 40% of the total energy consumption. (European Parliament, Council of the European Union, 19 of May 2010, p. 13) It is evaluated that buildings made in the year 2018 will be in use not less than 50 years. Practically the design decisions made now will have an effect for a long period of time before the building will have its first renovation or until it will be demolished. So, all of these stages like construction, use, renovation, demolishing are not only consuming valuable sources, but also emit pollutants to soil, water and air. Therefore, environmental problems are growing with the same speed as the construction industry sector.

In 2016, Finland reported a total amount of 123 million tonnes of waste generated by economic activities and households. (Statistics Finland) The share of the construction and demolition sector is about 18%, which is 14 million tonnes of building material waste. This figure is slightly more than in 2012(16 million tonnes) but much less than in 2010(24.6 million tonnes). In comparison with other European Union countries the amount of construction waste is far below the average EU-28 countries value of 34.7 million tonnes. Huge part of this waste comes from mineral wastes while hazardous material waste is around 10.5% of Finland’s total waste. (European Commission, March 2018, p. 14)

Construction and demolition waste is regulated by Finnish acts and decrees, like Government Decree on waste 179/2012 and Government Decree 561/2006 concerning to the recovery of certain wastes in earth construction. These documents refer to the reduction of the amount and harmfulness of construction and demolition phases. Moreover, it provides for the separate collection and recovery of waste so as to reuse and reclaim waste, according to Waste Act 646/2011. The target is to recover a minimum of 70% by weight of waste. Emission of greenhouse gases from construction and real estate areas amounted to a total of 2,138,986 and 4,829,214 million tonnes in 2013 and 2014. So in the year 2014 emissions increased by 125.8%, comparing to 2013. To talk about only construction sub-sector, greenhouse emissions from 2013 to 2014 decreased by 6.3% and in a longer period of 2010-2014 by 17.7%. (European Commission, March 2018, p. 14) Building’s share in the carbon footprint emission in Finland is 30-40 per cent according to an estimation (Heinonen, Säynäjoki, Kuro, & Junnila, 2012, p. 2875).

5.2 Standards for Sustainable Construction

To build a sustainable construction means the following things (Huovila, 2010, p. 7):

- intensified energy-efficiency and extensive utilization of renewable energy sources
- prolonged service life as a target
- saving of the natural resources and promotion of the use of by-products
- reducing waste and emissions
- recycling of building materials
- supporting the use of local resources
- implementation of quality assurance and environmental management systems

The goals that green public building projects follow require a strategic directive and adequate preparatory resources. A directive can be based, for example, on a municipal strategy, which can be based on, for example, the Finnish energy and climate strategy.

According to a new Finnish law sustainable house should have good indoor air quality and moisture control to avoid appearing of molds, microbes and other different indoor contaminants like particular matter, PAH compounds, VOC compounds, radon and others. A well-done sustainable building is designed by professionals who have all the needed qualifications and experience for this work. Every building's structure and service have been designed to be functional. The price for a project made by high class professionals can be expensive, but the right designs can save funds for repairing, renewing and renovation in the future.

According to Finnish standards a high quality energy efficient house could belong to energy class A or B. It is not possible to escape additional expenses during the construction of a sustainable house. The supply price requires at least 10 % more financial investments in building comparing to traditional construction. According to present prices for fuels and other energy sources, the payback period might be approximately 10 years or even less. Despite energy, living and maintenance costs of an energy efficient house still are cheaper in use than in an ordinary one.

Building energy efficient houses in Finland might be easier than in other places, in spite of the requirements of any special solutions for it. Most local manufacturers provide solutions for efficient building materials and even prefabricated house eco design. To achieve energy efficiency all kinds of structural and technical means can be used with an accent on cost effectiveness in use and in building. (Huovila, 2010)

5.3 Importance of Sustainable Construction

The biggest part of energy consumption in Finland is presented by building sector. This is more than 44% of the total energy consumption in the country. But only 34% of it is used for building heating and household electricity. The other 10% is used for building production, of which 70% is used for the production of materials and 30% for the transportation of these materials to and inside a building site. The construction sphere in Finland produces over 80 million tons of only building materials every year. Many of those materials become waste after a long period of use. Every year about 7 to 10 million tons of wastes are generated during demolition and renovation stages. This situation applies not only to housing production but also to civil engineering and facilities. The main goal of the Finnish government to increase the utilization of the waste materials up to 70% is already becoming true. (Huovila, 2010, p. 3)

One of the examples of sustainable office building is CFC-Free Low-Energy Office Building (METOP). This building was made to test new structural, electrotechnical and HVAC solutions. The objective was to provide good indoor air quality, thermal comfort and low energy consumption. The heating was measured as 13 kWh/m^2. This value was 60% lower than energy consumption in average office building in Finland. Measurements made in this building showed that there are no problems with such harmful air chemicals like radon, particles, microbes, VOC, etc. The project showed that it is possible to improve air quality, energy economy and at the same time the quality of construction of a public office building, which is important for Finnish economics and environment. (Huovila, 2010, p. 21)

5.4 Energy Certificates

Energy performance certificates are made to make people understand and compare building’s energy efficiency. Also, energy certificate can be made for enhancing the energy efficiency of buildings that are sold or rented. The document must provide important and reliable information to support the purchasing decision for a private or public person. Energy performance certificates also may raise the status of energy efficiency so that it becomes one of the design criteria for buildings. The classification scale familiar from household appliances gives an overall picture of a building's energy efficiency in a simple way. (Eco-efficiency and energy consumption in buildings, 2013)

Energy performance certificates are calculated based on some valuable building data. The most obvious, they are based on the buildings E-value, which can be obtained from some values like the building's calculated annual consumption of purchased energy, weighted with the factors of various forms of energy. The factors and definition employed are the same as in the energy efficiency regulations concerning new buildings which took effect on 1 July 2012. (Energy certificate for buildings, 2013)

Energy performance certificates have been in use in Finland since 2008 in the production of new constructions, and since 2009 in sale or rent of large buildings and new small residential buildings. The Act on a Building's Energy Performance Certificate was amended on 1 June 2013. In the near future energy certificates might be required for old small residential buildings, as in case with others. (Energy certificate for buildings, 2013)

According to the newest requirements for the new buildings the energy certificate must be done during the earlier stages of construction, like design and permit preparation stages. For existing buildings, energy performance certificates are necessary in the context of a sale or renting. E-value certificates are prepared by professionals who are qualified to prepare energy performance certificates. But an energy certificate is not required, for example, for holiday homes, protected buildings or buildings with an area less than 50 m^2. Until July 2017 energy certificates started to be required for selling or renting of small residential buildings made before 1980. (Energy certificate for buildings, 2013)

5.5 Zero Energy and Near Zero Energy Houses

In Finland the biggest expenditure in every building arises from heating issue. So, the concept of Zero Energy and Near Zero Energy houses gained popularity. A Zero Energy House produces as much energy provided by on-site renewable energy sources as the amount of energy used by people living in. The best decision for a house owner is to have a building with better insulation and sealing to achieve an effect in money economy. Economy of the energy is achieved by using a high insulation level, energy efficient furniture, equipment energy class A++, and water and electricity saving fixtures. The energy for a house can be supplied from eco-friendly sources like solar panels or ground-source heating. While existing old buildings consume from 200 to 400 kWh/(m^2*year) thermal energy for heating, future generation buildings will spend only from 20 to 50 kWh/(m^2*year). (Perlova, Platonova, Gorshkov, & Rakova, 2015, p. 1506)Investments in the beginning of construction aim to reduce building heating needs and make the project more profitable in its payback period.

One of the examples of the first near zero energy houses in Finland is the Marjala house. This is an ecological single-family house built mainly of wood, timber products and ecological materials. The designer’s main target was to create a building which is as less harmful to nature during its life cycle as possible. The house gets energy from a 10 m^2 solar panel situated on a roof and from firewood. The energy is collected in a 1500 liter hot water tank. Standby heating is provided by a 6 kW electric heater at the bottom of the tank. The heating energy of the Marjala house is 42-50% of its reference houses. The service life of the building is 50 years. (Huovila, 2010, p. 20)

5.6 Importance of Low-Carbon Constructions

It becomes more and more important to achieve climate goals. This means that buildings in addition to energy efficiency certification also require attention on the life cycle and the environmental impact. Now this is an essential part of the low-carbon public construction.

The manufacture of building materials, construction works on site, use of the building, maintenance, repairs, and eventually demolition, waste treatment and recycling, all bring their own building's carbon footprint.

Nowadays Finnish procurement law makes it possible to use environmental criteria as the public procurement criterion. Finland aims to an 80% reduction in greenhouse gas emissions by 2050 reflecting the EU policies. (Low Carbon Finland 2050)

In 2018 the European Commission granted 9.1 million euro to Finland to help mitigate the climate change. The project will be lasting for the next six years. The total budget for the project is 15.3 million euro. Local funders are the Ministry of the Environment, the Ministry of Transport and Communications, the Ministry of Agriculture and Forestry, the Energy Authority and Sitra. This project also has a target to improve energy efficiency of buildings, and to create sustainable urban structure and the conditions for low-carbon production and consumption. (EC grants €9.1m to Finland to mitigate climate change, 2018)

6 AN OVERVIEW OF THE PUBLIC CONSTRUCTION PROCUREMENT IN FINLAND

6.1 General Overview on Public Procurement

All the tendering processes in Finland must be executed by a public authority which is subject to the strict requirements of the European Union public procurement legislation directives. Public contracts are supply, service or public works contracts, provided by the state, municipalities and joint municipal authorities, unincorporated state enterprises and other contracting authorities. (Public procurement is regulated, 2017)

To follow the public procurement and to find necessary information about it the special databases are made. There are the Finnish government's procurement database HILMA and EU's database TED. Calls for bids are published in one of them in case the contracts exceed a certain sector-based threshold. Foreign companies can take part in the calls for bids on HILMA. But, they are mostly published only in the official languages i.e. Finnish and Swedish. (Public procurement is regulated, 2017)

The Ministry of Economic Affairs and Employment is responsible for the preparation of legislation concerning public procurement. According to statistics of the European Commission, in Finland over 34 billion euro (about 18% of GDP) is spent by the government, municipalities and congregations on the procurement of goods, services and public works. General tax law is not applicable for any kind of procurement to achieve more efficient use of funds. A further aim of the regulation on public procurement is to increase the competitiveness of national and European enterprises. At present, there are quite many big construction and infrastructure projects (worth millions of euro) ongoing or planned in Finland. For the international projects the calls for bids will be published in English at the TED database. (Flanders Investment & Trade, 2017)

6.2 Public Procurement Process

The regular procurement negotiation process is strictly regulated. At first, the tender notice is being published and it is going through prequalification. Secondly, the government makes a call for initial bids and they are going through negotiations. Thirdly, call for final bids is made. Final bids are reviewed and compared during the last stage of tender. After that, the contract goes to the winner. Public contracts shall be awarded based on either the most economically advantageous tender or the lowest price. But procurement system is just and fair, which means not only a simple comparison of the prices. This means that the cheapest price does not automatically win, also other factors are considered. It takes into account a variety of different economic factors, more detailed evaluation criteria are listed in the call for bids. (Flanders Investment & Trade, 2017, pp. 2-3)

But if the procurement requires some small amount of money, Finnish procurement legislation is not spread on in this case. Every contract can be awarded without a normal call of bids if the value for procurement is smaller than:

- 500.000 Euro for concessions
- 500.000 Euro for services
- 400.000 Euro for health and social care
- 150.000 Euro for public works contracts
- 60.000 Euro for supply and service contracts
- 60.000 Euro for contracts awarded as a result of design contest

There are other special service contracts with a value smaller than 300.000 Euro. However, the contracting authorities must act in a way that is fair, non-discriminatory, transparent, and enhances good administrative practice. (Flanders Investment & Trade, 2017, p. 3)

6.3 Public Procurement in Construction Area

The value of public procurement bills was about EUR 770.5 million in 2016. Over 45% of these purchases were made in municipal procurement units and the same in other contracting entities. State authorities and state-owned enterprises made around 10% of the purchases.

Approximately 30% of all public procurement involved various works, including infrastructure construction. Municipalities and municipal governments make the majority of investments in construction. In 2015, approximately 10% of the external purchases of municipalities and joint municipal authorities related to investment in building construction. Statistics for public construction purchases is shown in Figures 4 and 5 (Kuviopankki).

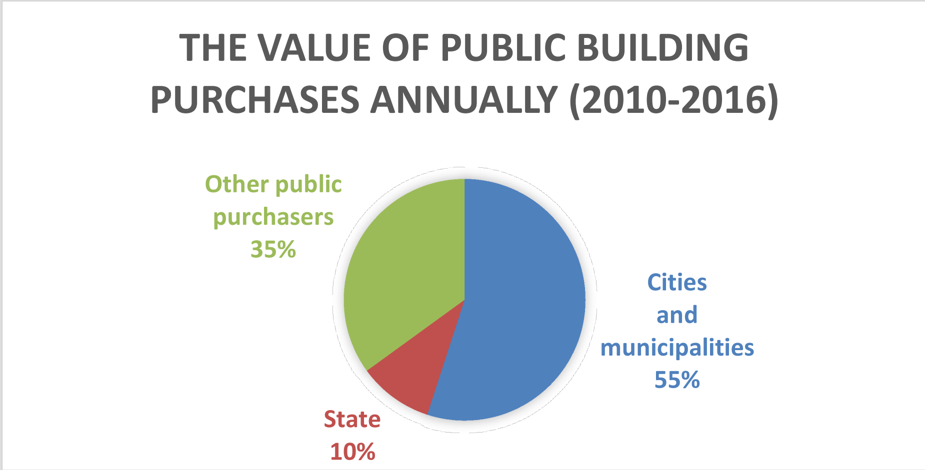

Figure 4 The value of public building purchase annually 2010-2016.

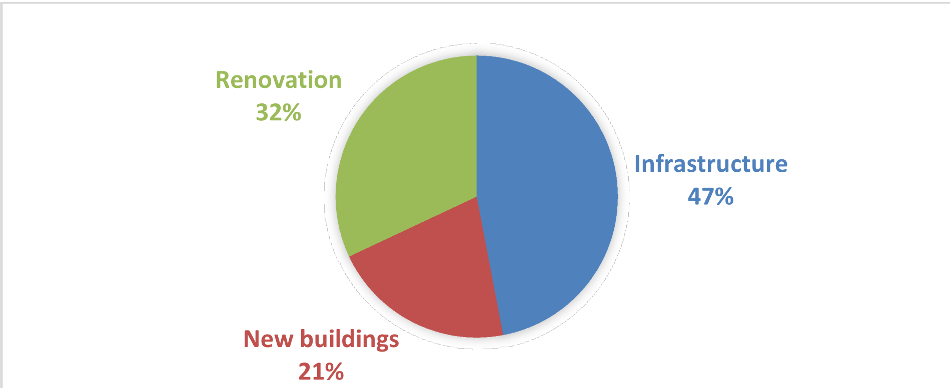

Figure 5 The value of public purchase of different construction areas.

The Finnish construction industry is highly organized as procurement in the construction area. There are General Conditions for Building Contracts (YSE 1998), which are the main base for any kind of construction contracts. (Halonen & Kovarskyte, 2017)

Three different main types of contracting in the construction sphere can be defined: fixed-priced contract, turnkey contract and project management contract with a maximum price. Usually, the contract is made with a government and a general contractor, who finishes the total work. Then a contractor can have couple of subcontractors who are in charge of different parts of a project. But also, the practice of divided contracts is normal. One big construction project can be divided between separate contractors for some reason. But state government can also hire one main contractor to supervise the whole project. Usually, in this case the main contractor makes the schedule, conducts site management and transfers tasks from the client to subcontractors. (Halonen & Kovarskyte, 2017)

7 SUSTAINABILITY IN PUBLIC PROCUREMENT IN FINLAND

Finnish procurement budget is over 34 billion euro. This means that the government has many reasons to make choices that will help to mitigate climate change, reduce the amount of waste and prevent the chemicalisation of the environment. The Finnish government 10 years ago passed a resolution in April 2009 that encourages all public actors to adopt sustainable procurement – the central government, regional governments and the municipal sector. (National Review, 2016)

Nature is not a discontinuous resource. Due to different poisonings and compounds in the atmosphere even the climate started to change and being warmer. It's good to start changing something inside the country in the governmental sector, especially in public procurement, which is about 18% of Finland's GDP. This amount of emissions which will not go to the atmosphere already can have an effect on the healthy environment. Nowadays there is a new challenge to the government to prepare regulations: laws, provisions and instructions. It should also take responsibility for its own solutions. Finland might be a pioneer. Setting an example sends a message to private actors and consumers that an increase in the sustainability of the natural economy is absolutely essential and necessary. (European Commission, March 2018, p. 4)

Nowadays government could take into account not only the economy of projects, but also the environmental aspects could be seen. Wise choices made today can be expensive, but they could be a reason for not having ecological problems in the future. Sustainable procurement can significantly reduce greenhouse gas emissions. (European Commission, March 2018, pp. 25-26)

7.1 Specification Stage

During the specification stage all needed criteria should be translated into a tender document i.e. criteria for low-carbon buildings related to energy, materials and innovation. The criteria are applied to be sure that construction costs and carbon footprint are optimized as much as possible. As far Finland is a member of the European Union the environmental criteria for sustainable public building are based the European Commission documents. The first set of criteria is related to an energy and material issues which are given in a pre-tender phase. Additional criteria are applied when procurement is going to tender. (Kuittinen & le Roux, 2018, pp. 17-18)

7.2 Requirements

Every tendering process is unique. The criteria are formulated by the client. In case of public building the client is the Finnish government or a local municipality. So, any changes and drafting of the tender documents is a responsibility of the client. Anyway, all the tender information can be found in the Finnish law and existing manuals. Environmental and low-carbon procurement criteria for public buildings are given in Figure 6. This can apply to new construction, reconstruction and to the management and maintenance of existing construction works. (Kuittinen & le Roux, 2018, p. 19)

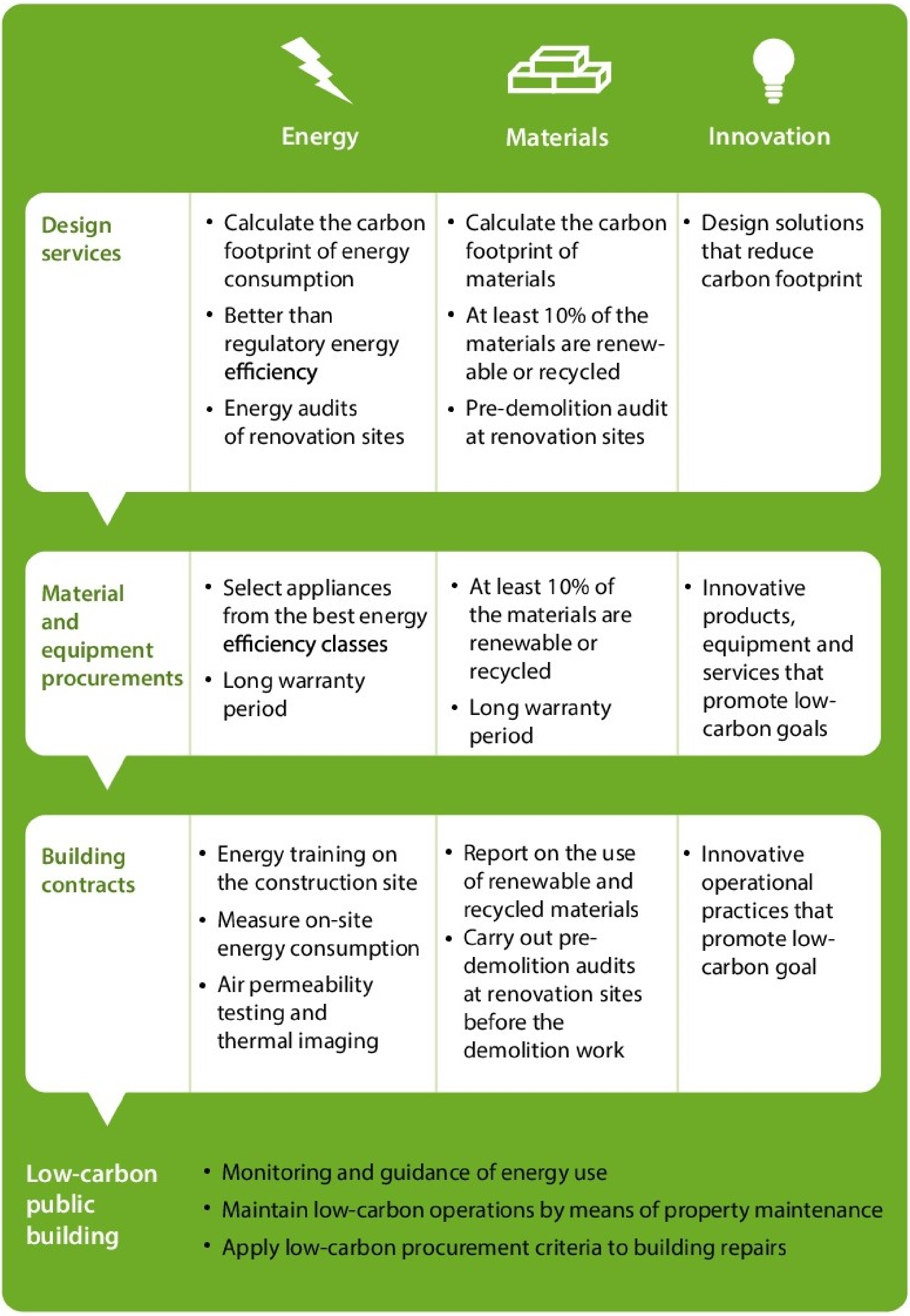

Figure 6 Procurement criteria for public low-carbon building. (Kuittinen & le Roux, 2018, p. 19)

The minimum requirements could be at least sustainable design, sustainable materials, well-planned management and maintenance plan. The criteria must ensure that tender participants have the ability to produce high quality results requiring environmental law and standards. According to this award criteria can be the lower environmental impact, calculated using life cycle analysis. The LCA analysis must be conducted according to national annexes and harmonized method for the determination of environmental impact. A low-carbon construction is a new point of design requirements. Therefore, on one hand no extensive experience in LCA and GHG emissions calculation are required from design team. But on the other hand, there should be sufficient designer’s competency related to energy efficiency and carbon footprint calculation and expertise in low-carbon building materials and construction methods. The requirements on materials and equipment set the minimum recommended criteria, but not recommend exact requirements or product seller. (Kuittinen & le Roux, 2018, p. 20)

Energy efficiency in procurement of design services has its own obligatory criteria given by the Ministry of the Environment Decree on Improving the Energy Performance in Renovations and Alterations which entered into force at the beginning of 2018. The criteria set the requirements on low-carbon new building to have 10% better energy performance and for buildings under renovation to have 20% better than regulatory level. It the design phase government and municipal authorities can only procure products and buildings with the best energy efficiency class (it also includes the use of equipment on the construction site). Also, an energy audit and pre-demolition audit should be a part of a design. For the on-site phase the minimum requirement is at least the evaluation of CO_2emissions and energy consumption, air permeability measurement and thermal imaging. The assessment of materials should be made during the design phase. The influence of material choice related to carbon footprint cannot be neglected. (Kuittinen & le Roux, 2018, p. 22)

Different kind of certifications might be taken into account in procurement with the main laws and standards. One of them is Nordic Swan Ecolabel. The criteria are made for life-cycle perspective and are designed to ensure environmental friendliness in manufacture, use and recycling stages. As a result, requirements have been set especially for the energy needs of the house, the building materials used, the manufacturing construction process, and the construction quality management. The environmental impact of the Swan-labeled house is low and the building production process takes into account the environmental activities from raw materials to the finished product. The first kindergarten building in Finland which got this Nordic Swan Ecolabel is Kenttäkadun Päiväkoti in Hyvinkää in 2017. The kindergarten tends to provide children a healthy growth environment and saves energy and repair costs of the building during the years of use. (Kenttäkadun päiväkoti, Hyvinkää, 2017)

8 LCA OF A BUILDING ACCORDING TO EUROPEAN STANDARDS

Life cycle analysis is the best benefit when it is applied at the design stage. In this case, it is possible to identify cost-optimal ways to improve the building environmental friendliness or extend its service life. During the use of the building these activities have a major impact on the low carbon content of the entire life cycle of the building. Long service life is promoted, for example, in the building's good functionality, convenient and energy-efficient use, proactive maintenance, comprehensive understanding of technical systems, and flexibility and fault tolerance solutions. (Accelerating Building Efficiency)

8.1 Framework

Life-cycle analysis is primarily related to costs and environmental impacts, which can be estimated by the European Standardization Organization (CEN) standard series. The lifecycle of the building is divided into standards. Those documents describe methodology, framework and recommendations for the evaluation of environmental performance using LCA. Standards include:

- EN 15643-1:2010; Sustainability of construction works. Sustainability assessment of buildings. General framework.
- EN 15643-2:2011; Sustainability of construction works. Assessment of buildings. Framework for the assessment of environmental performance.
- EN 15804:2012+A1:2013; Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products.
- EN 15942:2011; Sustainability of construction works. Environmental product declarations. Communication format business-to-business.
- CEN/TR 15941:2010; Sustainability of construction works. Environmental product declarations. Methodology for selection and use of generic data.
- EN 15978:2011; Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method.

8.2 Life Cycle Stages

The object of LCA is a building and its site. The study system boundary is set according to the stages given in Figure 7.

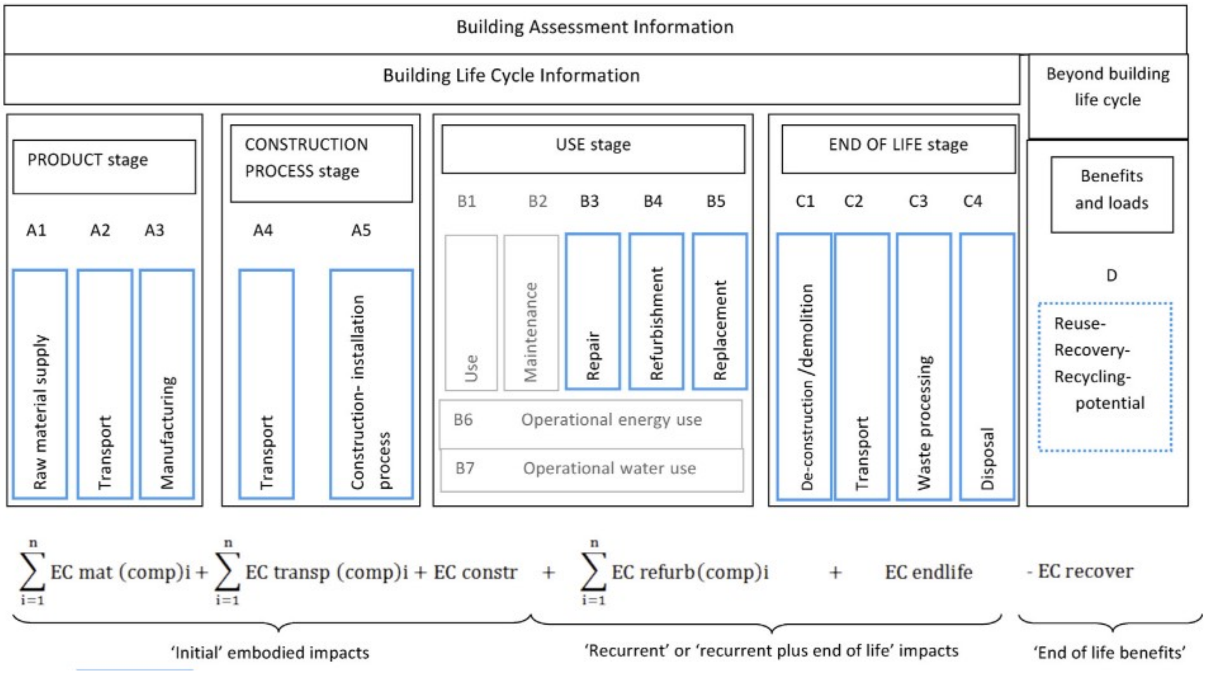

Figure 7 Life cycle stages adapted from EN 15978:2011. (Moncaster & Symons, July 2013, p. 515)

When a new building is made, the assessment should include all possible building's LC stages. Such stages as construction, demolition and use are evaluated according to data available. Demolition and deconstruction of a new building is out of system boundary, but demolition of old structures from site made as a preparation for new building construction is within the system boundary. (BRE Global, 2018, p. 13)

Stage A1-A3 includes material mining, raw material supply, raw material transporting and manufacturing. Usually data is available in products Environmental Product Declaration (EPD). If not, it can be calculated according to EN 15804. (EN 15978:2011, 2011, p. 20)

Stage A4-A5 covers variable works from material factory gate to the completion of the whole construction project. Transportation stage includes any equipment, materials, technical solutions, products, and waste movement to/from the site. Transportation of site workers is not included. The construction process includes in-situ construction, site-off construction and parts assembly, and any other combinations. Some examples of these stage activities can be ground works, landscaping, products installation, temporary works, and waste management. (EN 15978:2011, 2011, pp. 20, 22)

Stage B1-B7 scenarios shall describe environmental impact from buildings operation activities, maintenance and renovation works. Knowledge is based on existing regulation, practice and clients requirements. The following things can be included in assistance: building management activities (maintenance, repair, cleaning), use of water and use of energy (for heating, cooling, lighting, etc). (EN 15978:2011, 2011, p. 22)

Stage C1-C4 scenarios are restricted to the on-site processes. It might include deconstruction, sorting of waste, transportation from site, etc. (EN 15978:2011, 2011, p. 27)

Out of site activities like reuse, recovery and recycling scenarios are evaluated through the Module D. This module can be divided into parts, which refer to stages A(D_A), B(D_B) or C(D_C). (EN 15978:2011, 2011, p. 29)

The calculation of buildings LCA could take into account the losses of materials during all stages.

8.3 **Methodology**

Calculation of environmental performance of the building should follow the requirements of the official documents, which are listed in chapter 8.1 of this thesis. The indicator used to study the environmental impact in this methodology is GWP, but the following information and formulas could be used in different burden evaluations. The calculation steps of methodology are the following (BRE Global, 2018, p. 7):

1. Identifying the purpose of the assessment
2. Specifying the object of the assessment
3. Scenarios of the building LC
4. Quantifying the building and LC
5. Selecting the environmental data and other information
6. Calculating the environmental indicators
7. Reporting
8. Verification

As defined in National Standard (EN 15978:2011, 2011, p. 16), the relevant information about the study should be documented before this study is made.

The object of the assessment is a building and its site, so the foundation and external works are included in calculations. (BRE Global, 2018, p. 8)

Building elements that can be assessed can be divided into categories (BRE Global, 2018, pp. 8-11):

- Substructure (foundations, basements)
- Superstructure (frame, upper floors, roof, stairs, external and internal walls, windows, doors, etc)
- Internal finishes (wall, floor, ceiling finishes)
- Fittings, furnishes and equipment
- Services (sanitary installations, services equipment, disposal installations, water installations, heat source, ventilation, electrical installations, fuel installations, lift and conveyor installations, fire and lighting protection, etc)
- Prefabricated buildings and units (complete buildings, units, pods)
- Works to existing buildings (demolition, repair, cleaning, renovation, etc)
- External works (site preparation, drainage, external fixtures, making of roads, landscaping, and other services)

Assessment is made according to chosen reference study period (RSP). The default value of reference study period might be equal to the required service life (ReqSL) of a building. In some cases RSP might be shorter or longer than ReqSL. From this values can be obtained the adjustment factor f_a, as Formula 1 shows (BRE Global, 2018, p. 12):

$$f_a = \frac{RSP}{ReqSL}$$

If the reference study period is shorter than the required service life, the values of impacts obtained from the use stage B1-B7 and values of module D_B, that come from module B, are adjusted by factor f_a. (EN 15978:2011, 2011, p. 18)

If the required service life is shorter than the reference study period, there is a need to develop scenarios for buildings renovation or demolition. In case of demolition, the following construction should be changed to an equivalent new building. The aim of these scenarios is to extend the service life of construction. (EN 15978:2011, 2011, p. 18)

In all cases, modules A1-A3, A4-A5, C, D_A, and D_C are independent from adjustment factor f_a or f_a=1. (EN 15978:2011, 2011, p. 18)

For a new building the assessment scenarios are the same as shown in Figure 7. For the stages of material production (A1-A3), construction (A4-A5), use (B), and end of life (C) calculations should made according to data available. The last stage (D) is optional. The main requirements for the scenarios are transparency and clarity of data, sources, assumptions, etc. (BRE Global, 2018, p. 12)

8.4 **Estimation of GWP**

This chapter presents the methodology of the estimation of the Global Warming Potential category indicator. Formulas are given for all the stages of building's Life Cycle.

8.4.1 General

Q_m- material quantity, which values are:

From linear metre (m): Q_m – *mass per m × number of m*

From area (m^2):Q_m–*mass per m^2 × number of m^2*

From volume (m^3): Q_m– *mass per m^3 × number of m^3*

From piece/unit: Q_m– *mass per piece × number of pieces*

P – the specified construction material

Q_mP – quantity of the specified construction material

CI – category indicator (GWP), in *kg CO_2 eq*

Mod – information module (A1, A2, etc.)

$CI_{Mod}P$ unit data – category indicator unit data for P in respective information module, in *kg CO_2 eq*

Stage – life cycle stage (product stage, construction stage, etc.)

The category indicator can be obtained from Formula 2:

$$CI_{Mod}P = CI_{Mod}Punitdata \times Q_M P$$

The total value of the category indicator for the information module is a sum of the results for different materials. It can be obtained from Formula 3:

$$\Sigma CI_{Mod} = CI_{Mod}P1 + CI_{Mod}P2 + CI_{Mod}P3 + \cdots + CI_{Mod}Pn$$

The result of the whole stage of building LC is a sum of all information module values. It can be obtained from Formula 4:

$$\Sigma CI_{Stage} = \Sigma CI_{Mod1} + \Sigma CI_{Mod2} + \Sigma CI_{Mod3} + \cdots + \Sigma CI_{Mo\quad n}$$

(BRE Global, 2018, pp. 28-29)

8.4.2 Modules A1-A3

The relevant information about values of construction material category indicators of production stage (modules A1-A3) should be given by the material manufacturer. If the data of the construction materials is available and collected, it is possible to get the category indicator value of the material using the net Q_M values and category indicator value of material unit. The result is obtained from Formula 5:

$$CI_{A1-3}P = CI_{A1-3}P\ unit\ data \times Q_M P$$

The total value of category indicator for modules A1-A3 can be obtained from Formula 6:

$$\Sigma CI_{A1-3}P = CI_{A1-3}P1 + CI_{A1-3}P2 + CI_{A1-3}P3 + \cdots CI_{A1-3}Pn$$

(BRE Global, 2018, p. 29)

8.4.3 Modules A4-A5

Module A4 presents transportation stage. The category indicators of this stage are obtained from the impacts of transporting the quantity required in building. The transportation losses, damages, etc. are included in the final value of transportation stage category indicator as a loss percentage. Gross quantity can be obtained from Formula 7:

$$Gross\ Q_M P_{A4} = (Net\ quantity) + (Net\ quantity \times \%loss)$$

The module A4 can also include the transportation of the equipment to the construction site, which can be calculated using Formula 8:

$$\Sigma CI_{A4} = \Sigma CI_{A4}P + \Sigma CI_{A4}Equipment$$

The module A5 presents construction-installation process on the construction site. Also, losses of the materials might be included in calculations. Module A5 category indicator result is obtained from Formula 9:

$$CI_{A5}P = (CI_{A5}P\ unit\ data \times Q_M P) + (CI_{A1-A3}P \times \%loss) + (CI_{A4}P \times \%loss) + (CI_{A4}P\ unit\ data \times Q_M P \times \%loss)$$

(BRE Global, 2018, pp. 30-31)

8.4.4 Modules B1-B7

For the modules B1 to B5, the category indicators are derived from Formulas 2 and 3 using the net Q_M and unit data category indicator.

Modules B2 and B3 present maintenance and repair of the building. Those works can be done number of times during the life of the building. The Formulas 10 and 11 present the calculation of category indicator for maintenance or repair:

$$CI_{B2}P = Freq_{maint} \times RSP \times (CI_{maint}P\ unit\ data \times Q_M P)$$

$$CI_{B3}P = Freq_{repair} \times RSP \times (CI_{repair}P\ unit\ data \times Q_M P)$$

Where

$Freq_{maint}$ – frequency of maintenance activity (per year)

$Freq_{repair}$ – frequency of repair activity (per year)

CI_{maint} –applicable unit data for specific maintenance operation, in *kg* CO_2 *eq*

CI_{repair} –applicable unit data for specific repair operation, in *kg* CO_2 *eq*

RSP – study period in LCA study

Modules B4 and B5 present refurbishment and replacing of materials. Formulas 12 and 13 are used to evaluate category indicators:

$$CI_{B4}P = N_{replace} \times \Sigma(CI_{A1-3}P + CI_{A4}P + CI_{A5}P + CI_{C4}P)$$

$$CI_{B5}P = N_{refurb} \times \Sigma(CI_{A1-3}P + CI_{A4}P + CI_{A5}P + CI_{C4}P)$$

Where

$N_{replace}$- number of replacements during RSP

N_{refurc}- number of refurbishments during the RSP

(BRE Global, 2018, pp. 31-34)

8.4.5 Modules C1 to C4

Modules C1, C2, C3 and C4 present end of life stage. The category indicators could be derived from Formulas 2 and 3 with the use of net Q_M and unit data based on appropriate scenario. If the scenarios of the unit data are different from the required for assessment, the category indicators might be evaluated with use of comparable materials. (BRE Global, 2018, p. 34)

9 CONCLUSION

Nowadays buildings are becoming more complex. The design and production of efficient, durable and qualitative construction is becoming more challenging and time consuming. It is important to know the environmental standards, terminologies, concepts not only for engineers, but for procurement decision makers and buildings users.

During the analyses of current construction area situation it was deduced that Finland has good tendencies in the field of high performance building. Many projects were done during the last years. Despite the cold climate the standards of sustainable construction are on top level. Finland is keeping one of the leading positions in the world. The amounts of environmental impacts and wastes are decreasing according to statistics.

After a detailed analysis of the data received from reliable sources, articles and studies, it was concluded that the construction of sustainable public buildings is going to significantly reduce the environmental impacts in Finland. So, there is a need to include new environmental criteria in public procurement. Besides the suitability requirements for tenders and cost estimations, the recommended measures include the assessment of energy, material and especially innovation aspects. In long-time perspectives sustainable building reduce the cost of use, maintenance and refurbishment of a structure. The lowest CO_2 equivalent emissions could be achieved by the use of efficient building materials, HVAC installations, equipment and machinery. The effective planning of material and energy use during buildings construction and use stages helps to get better results.

It was explored that the most effective possible method of environmental indicators evaluation is life cycle assessment. The methodology described in this study shows an easy way to calculate GHG emissions of the total building or its part. It includes the most important stages of building life cycle like material manufacturing, construction, use, repairs, maintenance and demolition.

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