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MATERIAL EVALUATION FOR A MULTIFUNCTIONAL SCHOOL BUILDING FROM THE CIRCULAR ECONOMY PERSPECTIVE

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Tämä diplomityö käsittelee materiaalitehokkuutta monitoimikoulun rakentamisessa. Työn tavoitteena on etsiä materiaalitehokkuutta lisääviä materiaaliratkaisuja, joita koulun rakentamisessa voitaisiin hyödyntää huomioiden myös materiaalien aiheuttamat päästöt. Työn suorittamiseksi hyödynnetään elinkaariarviointia, jolla tutkitaan aihetta case-kohteen avulla. Työn teoriaosio koostuu monitoimikoulun ominaisuuksien esittelystä, tavanomaisten ja vaihtoehtoisten rakennusmateriaalien sekä rakennuksen elinkaariarvioinnin esittelystä yleisellä tasolla.

Poriin on rakenteilla kaksi ominaisuuksiltaan samanlaista koulua. Elinkaariarvioinnin case-kohteena käytetään koulua, jonka suunnittelu on pidemmällä. Elinkaariarvioinnin tuloksia voidaan hyödyntää seuraavaksi valmistuvan monitoimikoulun materiaaleja valittaessa. Tutkimuksen toteuttamiseksi valitaan elinkaariarvointiin sopiva indikaattori ja luodaan viisi erilaista skenaariota materiaalien vertailemiseksi. Olemassa on laajalti erilaisia kiertotaloutta edistäviä materiaaleja, mutta hinta rajoittaa niiden käyttöönottoa rakentamisessa. Tuloksien valossa voidaan todeta, että tavanomaisten rakennusmateriaalien korvaamisella vaihtoehtoisilla voidaan saavuttaa sekä ilmastoa että kiertotaloutta koskevia hyötyjä. Kaikki vaihtoehtoiset materiaalit eivät tehosta molempia tutkittuja näkökulmia yhtäaikaisesti. Vertailluista vaihtoehtoisista materiaaleista merkittävin on vaahtolasimurske, sillä se edistää kiertotaloutta ja vähentää huomattavasti koulun elinkaaren aikaisia kasvihuonekaasupäästöjä.

ABSTRACT

Lappeenranta–Lahti University of Technology LUT
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Material evaluation for a multifunctional school building from the circular economy perspective

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Examiners:	Professor, D.Sc. (Tech.) Risto Soukka
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Supervisor:	Project manager, Anu Tuovinen

Keywords: material efficiency, materials from secondary resources, building life cycle assessment, building circularity, multifunctional school

The purpose of this Master's thesis is to evaluate the material efficiency of a multifunctional school. The aim of this study is to search material solutions for the multifunctional school, that contribute to the material efficiency by increasing the material circularity and also to examine the effects that the materials have on greenhouse gas emissions. The climate impacts and circular economy perspectives are studied through a building life cycle assessment. The theoretical part of this study presents the characteristics of the multifunctional school as well as the characteristics of the conventional and partially recycled building materials, that are considered as alternative materials. In addition, the theoretical part includes a general introduction to the life cycle assessment of the building.

Two schools with similar characteristics are planned to be built in Pori. The life cycle assessment is applied into the building of the first one. The results of the life cycle assessment can then be used as a guide for the material selection phase for the second school. To carry out the life cycle assessment, a suitable indicator is selected, and five different scenarios are created to compare materials with each other. There is a wide range of materials from secondary resources, but relatively higher costs limit their use in construction. In the light of the results, it can be concluded that by replacing some of the conventional building materials with alternative ones, circularity can be increased while also reducing the climate impacts. Not all alternative materials enhance both of the simultaneously studied perspectives. The most significant of the alternative materials used in the comparison is the foam glass aggregate, as it promotes the circularity and simultaneously reduces greenhouse gas emissions during the life cycle of the school.

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In Pori 9 December 2020

Sara-Tuuli Siiskonen

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LIST OF SYMBOLS

CO_2	carbon dioxide
CO_2eq.	carbon dioxide equivalents
CH_4	methane
CFC	chlorofluorocarbon
H_2O	water
HFC	hydrofluorocarbon
N_2O	nitrous oxide
O_3	ozone
PFCs	perfluorocarbons
SF_6	sulphur hexafluoride

Abbreviations

$ADP_{elements}$	Abiotic resource depletion potential for elements
$ADP_{fossil\ fuels}$	Abiotic resource depletion potential of fossil fuels
AP	Acidification potential
C&D	Construction and demolition
EP	Eutrophication potential
EPD	Environmental Product Declaration
EU	European Union
GHG	Greenhouse gases
GWP	Global warming potential
LCA	Life cycle assessment
LCI	Life cycle inventory analysis
LCIA	Life cycle impact assessment
MRI	Magnetic resonance imaging
ODP	Ozone depletion potential
POCP	Photochemical ozone creation potential
PRIS	Project information system

1 INTRODUCTION

Climate change includes a great number of environmental changes, but most often the concept is related to either global cooling or warming. The indisputable fact is that the planet Earth is warming, and it is not known how much and in what kind of timeframe. Anyhow, human activities do have an impact on how significant of a crisis are we facing in the future when the temperature is rising. It is estimated that an increase of 4,5 – 6 °C in global temperature can be crucial for mankind and many other species. Several effects of the global warming can be seen all around the world, but in some places, effects are more influential, such as on the coast, where sea levels are rising. (Framer 2015, 2.)

What distinguishes this climate change from the previous climate changes seen on Earth, is the traceability to human actions. Global warming is the impact of greenhouse effect where greenhouse gases (GHGs) prevent heat from escaping the Earth's surface. Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and water vapor (H_2O) are natural components of the atmosphere. As a result of human actions, the amount of natural GHGs have increased when industrialism spread widely around the world. Human has greatly affected the Earth's natural balance. For example, as a result of human activities, synthetic GHGs has been created and released to the atmosphere. Synthetic GHG compounds, perfluorocarbons (PFCs), chlorofluorocarbons (CFCs), sulfur hexafluoride (SF_6) and hydrofluorocarbons (HFCs) does not occur naturally in the atmosphere. Both synthetic and natural compounds are released into the atmosphere by human actions. Especially CO_2 and O_3 have a significant effect on atmospheric processes. (Framer 2015, 55.)

Increasing amount of released CO_2 emissions has affected on natural carbon cycle. The burning of fossil fuels, deforestation and cement production are the main reason for the augment of the carbon dioxide emissions. Current construction industry contributes using all those high CO_2 intensive processes. (Framer 2015, 13.) Processing, transportation and excavation of the construction materials are responsible of over 23 million tons of carbon dioxide emissions (Eales 2012). Therefore, re-using and circulation of construction materials in the large scale can have a great impact on reducing the environmental impacts related to producing construction materials from virgin sources. Awareness of the concept of the material efficiency is the first step towards sustainable construction.

1.1 Background

The role of sustainability and circularity has been increasing in recent years. Since 1970, the concept of circular economy has become more familiar (Geissdoerfer et al. 2017, 757–768). Also, the connection between the environmental problems and the construction sector has been substantiated (Araújo et al. 2013, 555). Buildings and construction have significant environmental impacts. Approximately one third of Finland’s greenhouse gas emissions and about 40% of energy consumption are caused by the construction sector. (Kuittinen et al. 2017, 11.) Material selections have remarkable effects on environmental impacts caused during buildings’ life cycle. Previous studies have proven that most of the greenhouse gas (GHG) emissions during buildings’ life cycle are caused by energy consumption but use of construction materials comes second. (Bruce-Hyrkäs et al. 2018, 178-183.)

With material efficiency, amount of GHG’s can be reduced, while constructing a new building. Construction and demolition waste could be partly utilized as a secondary source for raw materials. EU obliges that at least 70% of construction and demolition (C&D) waste must be recycled since 2020 (Euroopan parlamentin ja neuvoston direktiivi 2008/98/EY). Some of these demolition waste materials could be used into new building as they are, and some materials are utilizable after processing. Higher recycling rate of C&D waste can provide more materials from the secondary resources back to the construction industry. In this research, utilisation of materials from secondary resources instead of virgin materials, is studied for the use of constructing a new school building. This master’s thesis concerns material evaluation of a new multifunctional school building in Pori, Finland.

Currently there is available information of environmental impacts from several construction materials. Also, plenty of information from environmental impacts such as GHG’s caused by construction actions is available. However, material selections for the new buildings are based on experience, more or less, and long supplier relationships. Therefore, some information provided about environmental impacts of different materials are left neglected. There are no regulations in Finland that force the use of materials from secondary resources in construction. Nevertheless, there are several ecolabels and titles that can be achieved if building fulfils all required criterions (Ecolabel index 2020). Some of the criterions can include implementing materials from secondary resources instead of virgin (Kuittinen et al. 2017, 19).

In the city of Pori there are two similar school buildings to be built, the school of Vähärauma and the multifunctional school of Pohjois-Pori. The planning of the school of Vähärauma is a few months ahead than the multifunctional school of Pohjois-Pori. In order to avoid confusion between schools, the term **multifunctional school** refers to the school of Pohjois-Pori and term **school** refers to the school of Vähärauma. In this research, up-to-date building data from the school of Vähärauma is used in the design phase of the multifunctional school of Pohjois-Pori in order to reduce environmental impact through efficient material choices. Therefore, data of the conventional construction materials of the school of Vähärauma is collected and compared to the alternative material choices while the construction and planning continues. These results can be utilized in the material selection phase of the multifunctional school of Pohjois-Pori.

1.2 Objective of the study

In this research information of the benefits of the material efficiency is provided by using case building as a source. Benefits of material efficiency are studied both theoretically and with life cycle assessment (LCA) for the building. The issue is that it is not known whether the use of recycled materials is economical and worthwhile in the construction of a new multifunctional school or not. Goal of this research is to find out, what are the advantages and disadvantages of replacing conventional construction materials with materials from secondary resources from an environmental point of view. Which construction materials are the best specifically from environmental and economical point of view?

This study pursues to find answers to the research questions presented above. This study aims to guide material selection phase of constructing a new multifunctional school for the benefit of environment and material efficiency. The results of material evaluation can be utilized in the design phase of other types of buildings also. The client and financier of this thesis is CIRCWASTE - Towards a circular economy project, Resource efficient construction and housing in the Pori region. The City of Pori, as a co-financier, is implementing a circular economy project coordinated by the Finnish Environment Institute and funded by the EU's LIFE program.

1.3 Structure and limitations of the study

The research plan consists of a few phases. First phase is to present theoretical background of the multifunctional school, its functions and construction materials as generally. Then a life cycle assessment and related indicators are presented. After the theoretical approach, building’s material evaluation is done by using One Click LCA program and the add on tool, Building Circularity. Evaluation of the construction materials is performed by utilizing life cycle indicators. Only those materials from secondary resources are included into life cycle assessment that does not have significant impact on the building’s cost efficiency. The last step is to analyse results in the perspective of environmental impacts of selected indicator and circularity.

Because the project of building multifunctional school is in the design phase, only core structures with a few exceptions are under the radar while material evaluation. Safety and health issues are highlighted in this study while building a school for young children. Therefore, uncertified alternative materials are left out of the LCA. Scope of this research is school building excluding buildings located at the school yard. Construction materials below the surface of the earth are not taken into consideration in this research. The spectrum of materials when inspecting the case building is limited to the materials included in the One Click LCA program. Only materials available in Finland are included into the LCA.

2 MULTIFUNCTIONAL SCHOOL BUILDING

In this section features of multifunctional school building are presented by focusing on concepts and definitions related to multifunctional school building. Also, examples of Finnish multifunctional buildings are provided. The multifunctional school under the examination is introduced later in this section.

2.1 School environment

The main goal of the creating the new school environment is to prioritize safety and health issues. The user-oriented learning environment adapts to the needs of the users. Therefore, new schools favor adaptable open premises over conventional classrooms. Not only physical structures of the school are changing but the type of education and the use of technical equipment. Growing number of robots must be considered in the design and construction phase of new school buildings, which can have effect on material selection when some materials are easier to keep clean for example. Premises of the schools are designed for the active use of computers, which affect mostly on furnishing and placement of charging points for electrical equipment. (Project planning meeting 2 2020.)

Nowadays work tied to exact time and place is considered obsoleted. Technical development contributes flexibility. Flexibility comes with requirements to preserve efficiency of work in the current level or better. Multifunctional environment consists of several different premises for different actions. Therefore, there are fewer solid components than in conventional school building. Open concept premises are used while interaction with other students are required. For example, open concept premises are advisable for group working. In open concept premises groups of different sizes can be formed and supervised. On the other hand, education with the need of strict concentration requires closed premises as does confidential interaction. Change from conventional school premises to multifunctional may require more rules, because use premises are determined by momentary needs. Digitalization provides more flexibility, which is necessary to create a functioning school environment in multifunctional building. This facilitate fluent information sharing and decrease the amount of paper needed for the education. Typical feature of multifunctional building is space efficiency and therefore less space is needed if compared to conventional building. Multifunctional building is combination of multifunctional premises and in addition it requires different methods of work. (Senaatti 2018.)

2.2 Common features

Construction is guided by many different requirements and goals. In addition to requirement set out in laws and regulations, these include the functional and technical requirements of the constructor. Sustainable development goals can be set from ecological, social and economic perspectives. Choosing the most important perspective is done on a case-by-case basis. However, environmentally friendly construction does not prevent compliance with other regulations. Therefore, there is no need to compromise on safety or functionality while including environmental aspects into building. (Kuittinen et al. 2017, 15.)

There are several examples of already existing multifunctional schools in all over Finland. All multifunctional schools have some similarities regarding premises and their intended use purpose. There is multifunctional school in Joensuu, which serves surrounding residents in a more diverse way than conventional school (Myllylä 2019). In 2019 construction of two new multifunctional schools began, one in Savukoski and another one in Utsjoki. Purpose of multifunctionality in these schools are that those can provide rooms for afternoon club actions, day care, community college and for other afternoon use in addition to high school and primary school premises. (Lehto 2019 a, b). Also, construction of a new concrete-based multifunctional school has begun in Lahti (Lahti 2019). In Hämeenlinna a new multifunctional school was built couple years ago. There are no conventional classrooms, but education takes place in wider multifunctional premises. (Ruonaniemi 2016).

Common feature of all multifunctional schools mentioned is that they offer wide range of services which are not limited to the use of students only. They provide premises for afternoon exercising and library for the surrounding residents. As these cases proves, it is possible to utilize premises in more versatile way, which also improves the school’s rate of utilization. When there are no intended use of premises in educational purposes, those can be utilized by other users, but when other users are not desired wandering all over the school after school hours, lockable doors should be considered when designing premises.

2.3 Functionality

Finnish compulsory education consists of 9 year of education. There were 2187 schools for compulsory education in the end of 2019. Share of comprehensive schools has been increasing during the last decade, but there are still a lot of schools with grades only 1-6 or 7-9. (SVT 2020.) According to Rimpelä's statement in an interview published by Finnish news agency Yle (2016), the utilization rate of Finnish schools is only 20%. On the other hand, the utilization rate of gymnasiums placed into schools is considerably higher. The high utilization rate is reached when gymnasiums are used for recreational activities after school hours. In Finland, most of the school activities are executed in between August and June. For that reason, rate of utilization is lower in summer. (Rukonen et al. 2017, 15-21). To increase utilization rate of conventional schools, in addition to gymnasiums, other premises should be in use for a variety of purposes.

Difference between conventional school and multifunctional school is versatility of the premises. Spaces of multifunctional building are not built to serve an exclusive purpose, rather they are designed to support various activities on different occasions as versatile functional rooms. Definition of multifunctional school is a building that must primarily meet pedagogical requirements and may also be used for variety of purposes. Spaces are designed for educational purposes, but also those can be used for other occasions in the afternoon hours when spaces are exempted from educational use. The need of scheduling is emphasized while utilizing premises efficiently. Therefore, it is recommended to have electronic timetable for premises. With electronic timetable duplicate bookings can be avoided. Some of the main advantages of multifunctional school is higher utilization rate, transformability, and space efficiency. (Mustila 2017, 10-13.).

The multifunctional school, which is planned to be constructed in Pori has several features for the use after school hours. In table 1 is presented main features of the school and number of users. Number of users can variate between years. As presented in table 1, there are a lot of functions in the multifunctional building. Combination of features increases utilisation rate especially after school hours. It is possible that the school will be expanded later to comprehensive school. It is necessary to design the building that way that expansion can be done with minimal structural changes.

Table 1. Features of the planned multifunctional school in Pori. (PRIS 2020)

Number of users	
Students	600
Staff	60
Features of multifunctional school in Pori	
Day care	Early childhood education
School	Compulsory school grades 1-6
Health care	Nurse & dentist
Local library	Library & youth centre
Eating	Restaurant & cafeteria
Sports	Sport fields, exercise hall, multifunctional hall (dance & gym) and stage

In the multifunctional school there is a lot of premises for the educational use only. For example, conservatory, art and craft premises. On the other hand, premises for sports are designed for both educational and recreational activities. The versatile building serves a wide range of users in the field of sports. Premises can be reserved for recreational activity events after the school hours. Library of the school is also in use of residents of the region. In the vicinity of the library, youth centre is designed. As there are no access to the whole building after school, the youth centre provides a place for young residents from the area to access building trough the library. In addition, dental services are designed to have their own access into the building, so services can be used also after the school hours. Health care includes premise for magnetic resonance imaging (MRI). Structures in such premises are very precisely defined, and this thesis does not editorialise whether alternative materials could be utilized in these spaces.

One of the main features of a multifunctional school is that premises are designed for various purposes. Table 2 below provides examples of multifunctional premises designed for the multifunctional school in Pori. Purpose of the table 2 is to demonstrate how flexible the building is designed to be. Some parts of the building are physically convertible for different occasions. For example, grandstand in the multifunctional hall is movable to either provide more space for activities or spectators. Also, some of the premises can be divided into smaller entities by the foldable wall systems. As presented in table 2, education can be done in several premises instead of using conventional classes. All the education can not be carried out in wide spaces like squares and therefore conventional classes are also needed. Advantage of some of the designed classes is versatility for small-group areas when education requires more concentration.

Table 2. Flexibility of the multifunctional school in Pori. (PRIS 2020)

Flexibility of premises		
Premises	**Main purpose**	**Alternative purpose**
Classes besides dining area	Area for education	Cabinets
Grandstand	Provide space for spectators	Area for education
Multipurpose hall	Hall for dance and gym	Area for education (health information)
Class near library	Area for education	Club room and student union room
Squares	Wide area for educational use	Multiple small-group areas for educational use, gathering space
Sport fields	School exercise	Recreational activities
Education class for mathematics	Education of mathematics	Multiple small-group areas for educational use

Cells and the division of functions into different floors enable the creation of small-scale sub-assemblies and implementation of modern learning premises. In the multifunctional school these floors are used to divide premises by the student age groups. The school yard is also divided so that different age groups has their own parts of the outdoor areas. One of the matters which needs careful planning is the use of motor vehicles in yard areas. Once again safety is paramount, and practicality comes second.

3 OVERVIEW OF THE CONSTRUCTION MATERIALS

Selection of materials play an important role in designing a new building - the effects of material selection cover the whole life cycle. Globally 3 million tons of materials are used annually for construction activities (Eales 2012). The construction materials are selected primarily on the basis of the experience and not scientific means. (Kanniyapan et al. 2019, 652). According to EU's Raw Material Scoreboard (2018, 12) extraction of materials has grown significantly in past 10 years and source extraction are assumed to increase 119% in between of years 2015 and 2050. The largest share comes from extraction of non-metallic minerals. The rapid growth in material needs is direct consequence of growing economies, construction and manufacturing industries. In the unit of mass, minerals used for constructing, forms a large share of the material consumption. Constructions stock materials for a long time due to long life cycle of buildings. There are always some material losses during the circulation. Therefore, fewer losses occur when construction materials are bound to buildings for a long period of time resulting slower circulation. After the use phase, significant amount of demolition waste ends up disposal instead of recycling it back to the circulation. (Raw Material Scoreboard 2018, 12, 26.). Material circulation is presented more comprehensively in the chapter 3.2.

Most of the pollutants related to construction materials are due to production of them. Materials with the highest environmental impacts are often those with the highest energy consumption during the production. Energy-intensive building materials also have high carbon dioxide emissions which is the reason of several environmental impacts. Nevertheless, relation between energy consumption and environmental impacts is not linear.

Concrete is highly used construction material and the most important one. The demand of concrete has only increased during recent years. Reinforced concrete is often used for upholding structures due to its strength properties. There are several concrete products on the market, some of which are prefabricated elements and others are cast on site. (Pacheco-Torgal et al. 2013, 19.) Concrete includes approximately 12-14% cement, which is responsible of most of the environmental impacts caused by the production of concrete. Cement has one of the highest CO_2 emissions due to significant energy need during the production. Rest of the relevant environmental impacts of production of concrete are caused by transportation and extraction of aggregate. Globally, the use of concrete is twice as high as the use of other building materials combined altogether. (Petkar 2014, 37-42.)

Another very commonly used construction material is steel, which is used for example to reinforce concrete. In addition, steel has numerous uses in construction. As well as cement, steel has high energy demand which increase its environmental impacts. Globally, 4,1% of the total consumed energy is used in iron and steel industries. Metals such as iron and steel require a lot of water during the production. Environmental issues related to iron and steel industries are not limited into high energy and water consumption. It is proven that production of the iron and steel creates noise pollution, hazardous contamination, dust, and toxic waste. (Petkar 2014, 37-42.) Anyway, one of the advantages of steel as a construction material is the recyclability.

Wood is one of the oldest and traditional building materials. Due to engineering wooden products are adapting new properties to maintain the competitiveness of the material. (Zillacus 2016.) Wood as a construction material provides opportunity for both economic and environmental benefits when the production of solid wood product provides direct jobs and contributes to the maintenance of a diverse ecosystem. Wood is renewable source for construction materials which means that production of wooden products does not generate massive amount of greenhouse gases. Reason for the low quantity of generated greenhouse gases of wooden products are based on the carbon cycle, wood sequesters carbon when it is grown and releases it after it is cut. However, the wooden construction products are not recyclable. (Ritter et al. 2011, 1-9.)

Glass is most used material for transparent elements of the building, such as windows and glass doors (Zillacus 2016). Benefit of transparent elements are that those provides openings for natural light to come through, which not only illuminate the room but also decreases the amount of energy needed for lighting. Glass can also be used indoors to increase the feel of a spacious appearance.

Bricks are also one of the most common construction materials. Bricks are rigid and shaped as rectangular, which makes them easy to use. However, bricks are not one of the essential construction materials in western countries, rather those are one option among others. Other building materials, such as plastic, textiles, and stone building materials, are often incorporated into a building to some extent (Zillacus 2016). In Finland, thermal insulation is very important in a building, and it can be produced from several materials.

A share of 20% of the furan and dioxin emissions are related to the production of the following construction materials: cement, bricks, lime, glass, steel, iron and other non-ferrous metals. In addition, there are wide range of other materials used in construction such as paint, plastic, sealants, wood preservatives. Even if the quantities of those materials might seem irrelevant, production of those materials requires chlorine, which have environmental impacts of its own. Both concrete and ceramic products' wastage of the materials is substantial. Wastage means the amount of materials that never end up being used. However, all of the environmental impacts of the construction sector are not consequence of the material production and use, due to construction activities need of energy, transportation of the materials, equipment and maintenance is notable. (Petkar 2014, 37-42.)

The choice of material has an impact on the energy efficiency of the building. Materials have defined value for thermal conductance which indicates how heat flux passes through the building material. The thermal conductivity value of energy efficient materials is low while the value of permeable materials is high. In generally, energy consumption of buildings is high when compared with other sectors of economic. There is variation between countries, but globally 30-40% of the energy demand is caused by functions of buildings. Especially commercial buildings, schools and other public buildings has the highest energy consumption. High energy consumption related to heat losses can be avoided by careful building design. (Gul et al. 2015, 155-156.) Choosing right materials is one of the ways to avoid unnecessary energy consumption. Space heating is responsible of 26% of all energy consumption in Finland (OSF 2019). Space heating requirement includes heat losses through the building envelope.

The choice of equipment, the behaviour of the inhabitants and the weather conditions affect the energy consumption along with the selected building materials. As shown in figure 2 below, space heating forms the greatest share of buildings energy consumption. For that reason, designing phase with careful material selection, choosing developed building techniques and exceeding the minimum requirements is important. High quality buildings and equipment can reduce energy need of the building. (Gul et al. 2015, 155-156.)

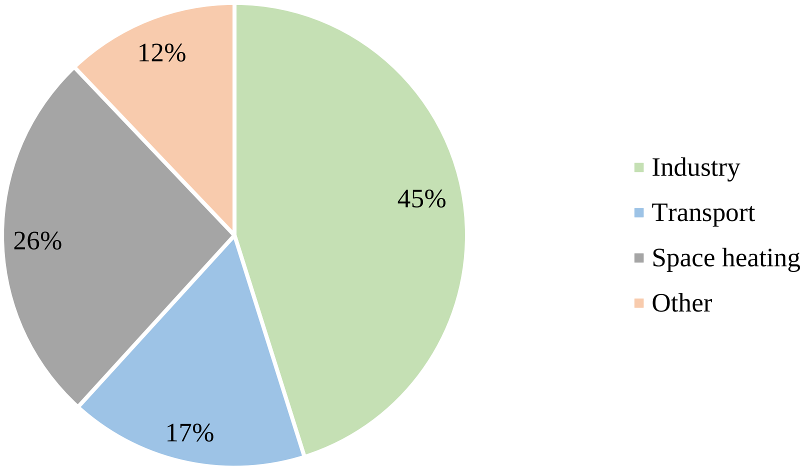

Figure 1. Energy consumption of household in Finland 2018. (OSF 2018).

3.1 Quality of the materials

Lifetime of building can be increased by using high quality materials. The higher the lifetime is the less solid waste will be generated. (Huang et al. 2013 91-92). While building the multifunctional school which estimated lifetime is 100 years, selection of materials should be emphasized to ensure longevity of the building. Careful selection of materials for the multifunctional school can also enhance energy efficiency, indoor environment, materials efficiency and can reduce health issues. Students spend on average 19-25 hours per week in school. Students can be exposed to indoor air pollutants, which are originate from building materials, upholstery, and indoor activities. In addition to indoor climate, safety in case of fire should be taken into account. (Gárcia-González et al. 2015.) Especially when the building is designed for children, safety and healthiness is emphasized.

In 2018, latest indoor climate classification was published, and it is used as an aid while designing and constructing a new building (Sisäilmayhdistys 2020). While deciding materials for the multifunctional school, indoor climate classification can be useful tool for assessing the safety and healthiness of the materials. In table 3 are presented indoor climate classifications existing in Finland. S-category classification are used to define the quality indoor environment while M-category is specified for the emissions related to materials (Sisäilmayhdistys 2020). Since 2018 there has been only one acceptable category to describe cleanliness of construction works, because lower quality implementations are not allowed (Sisäilmayhdistys 2020). P2 classification is no more valid, and therefore P1 requirements must be met.

Table 3. Indoor climate classifications in Finland. (Ahola et al. 2019)

Indoor environment category	**Quality**
S1	Individual indoor environment
S2	Good indoor environment
S3	Satisfactory indoor environment
Emission classification of building materials	**Quality**
M1	Good
M2	Satisfactory
M3	Low
Cleanliness classification of construction works	**Quality**
P1	Good
P2	Expired in 2018

In the newest release there are more than 4500 product and construction material which have M1 classification. The target level for fine particles in indoor climate is set at a maximum of 50-70% of fine particles in outdoor air. (Sisäilmayhdistys 2020.)

3.2 Materials recycling

Concept of circular economy consists of stages of the production and consumption system including re-use, repair and remanufacturing products. The circular economy seeks to separate economic growth from the consumption of limited resources when economic growth can also be achieved in a sustainable way. Circularity indicators can be seen as beneficial tools to achieve the target of the circular economy. Circular economy can’t be measured by one indicator because of the scale of the concept. Therefore, several indicators have been created to measure circular economy for each purpose. Indicators provide guiding information to contribute development in the area of circular economy. (European commission 2020 b.)

The European commission adopted Circular Economy Action Plan, which purpose is to reach more competitive and cleaner Europe by increasing sustainability and having resources kept in EU great period of time (European commission 2020 a). The European commission has also initiative of raw materials, which concerns on relying on materials from secondary resources (European commission 2008). Increasing waste recycling, minimizing disposal of recoverable waste and improving product design are ways to enhance utilization of materials (Raw Material Scoreboard 2018, 71). Simplified material circulation route is presented in the figure 2.

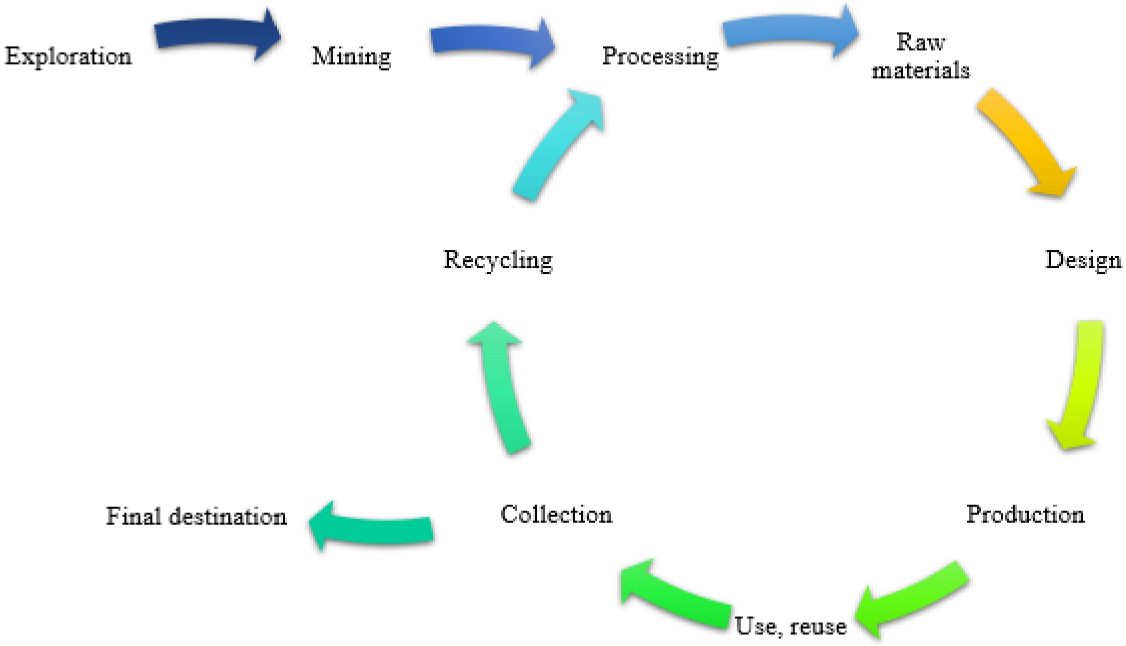

Figure 2. Material circulation. (EIT RawMaterials 2019)

Unlike the linear economy presented in the figure, circular economy includes recycling process, which returns some of the materials back to the circulation. The linear economy is known from the take, make and waste mindset, which is a huge burden on planetary boundaries as the human population has increased over the years. The linear economy is responsible for the rapid depletion of natural resources, which makes companies vulnerable to supply chain disruptions. Linear economy also contributes issues that are dangerous for our future such as climate change and loss of biodiversity. Because of the issues related to linear economy, circular economy has become more attractive alternative. (Wautelet 2018, 1.) However, not all materials can be recovered. At each stage shown in the figure, material loss occurs, and waste is generated, but the most significant material loss occurs when the materials are directed to final destination such as landfill. Final destination process of the figure includes materials directed to energy recover and landfill. By increasing the recycling rate, less materials are directed to final destination and more materials are processed for new purpose. (Raw Material Scoreboard 2018, 71.)

In Figure 3 is presented the shares of construction waste generated globally. One part of the construction materials supplied to the construction site end up as waste without being used (Eales 2012). This can be consequence of poor timing, weather conditions or failed estimation of the amount of needed materials. It is not possible to return all materials back to cycle by recycling because it might not be profitable or way of recovering them are not yet known.

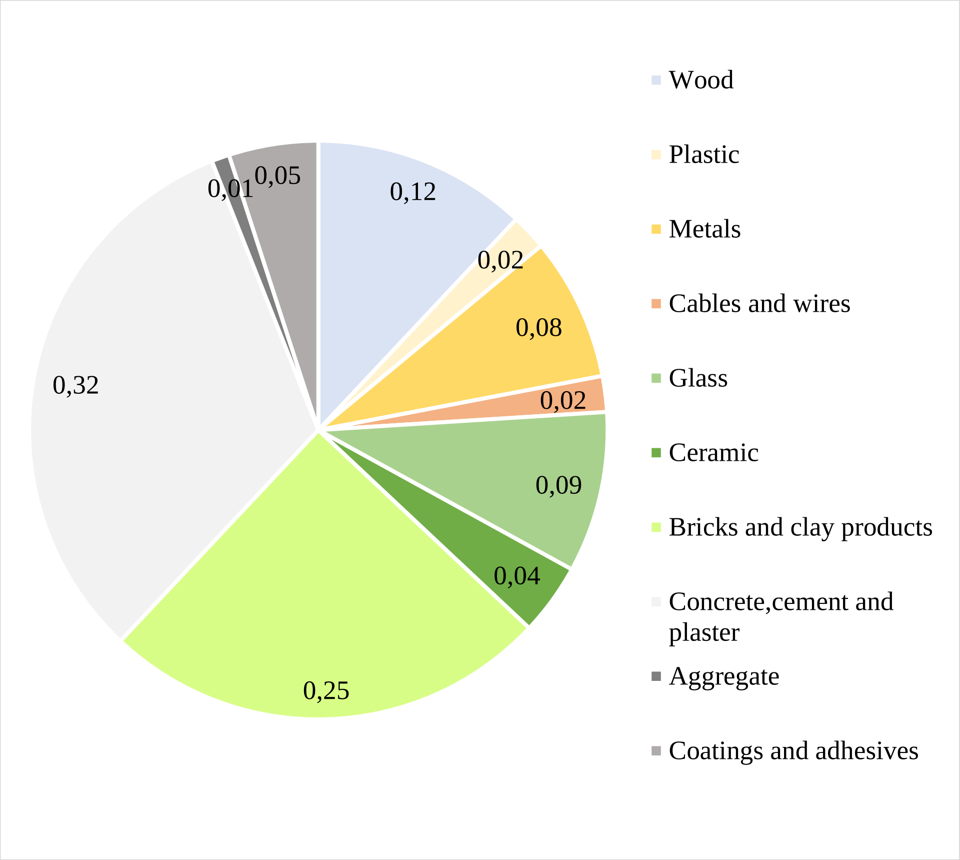

Figure 3. Construction and demolition waste shares. (Eales 2012)

Material recycling is considered as an important factor for sustainability and it advances material security. Recycling rate variates between materials where metals have the highest recycling rate. (Raw Material Scoreboard 2018, 66, 70.) One of the very commonly used construction materials is aggregate which recycling rate is assumed to be around 80% (Saarinen 2018, 95). In Finland 45% of the building's core C&D waste is recycled or re-used. In many countries the share is much less than that, but the share could also be greater as Netherlands has proven with its 90% recycling rate. (Petkar 2014, 44.) Replacing virgin materials with materials from secondary resources would contribute circular economy. Quantity of available raw materials from secondary resources does not cover whole demand and most of the resources are still needed from virgin sources. Recycling rate can be estimated differently by the points in the recycling chain. In the beginning of the chain is the end-of-life point, which mean recycling before further treatment. Recycling can also occur during recycling process. (Raw Material Scoreboard 2018, 66, 70.)

Globally, C&D waste forms one of the greatest waste flows. Excavation of virgin materials, significant energy demand of producing steel and cement and pollution has major impacts on environment. On the other hand, recycling C&D waste has multiple benefits since it reduces the need of virgin materials and amount of waste directed to disposal. (Huang et al. 2013 91-92.)

3.3 Alternative material choices

Buildings consists of multiple architectural structures. Materials from secondary resources can be included into construction. In the designing phase of a building, preliminary plan for quantities of materials from secondary resources are made. Preliminary plan must be done when choosing structure types and fillings. Preliminary plan is used as a base of procurements during the construction phase. Because of the differences in the availability of materials from secondary resources, during construction and procurement phase material flexibility should be accepted. However, the minimum requirement for the quantities of materials from secondary resources should not be passed underneath. Among other criterions 10% of materials should be renewable or recycled when building a low-carbon building. (Kuittinen et al. 2017, 42.) In the case of a multifunctional school designed in Pori, the percentage can be lower when the building does not pursue the title of low-carbon building.

Materials from secondary resources are highly different in their origin and properties. Some of these materials are close to natural materials in terms of technical and construction properties. Thus, the use purposes do not differ substantially from conventional construction materials. (UUMA 3 2020.) Renewable and recycled materials, industrial by-product materials, reused products or components are defined as materials from secondary resources. In case of material is both recycled and renewable, like thermal insulation from recycled newspaper, it must be counted in one category only to avoid duplications when calculating the real amount of materials from secondary resources. Recycled materials must be from sustainable and responsible sources. Safety, healthiness, and suitability must be taken into account and implementations ensured case-by-case. Utilization of structures and products which are used at the construction site without processing are not considered as a recycled. For example, some structures of an old building can be left in operation and these structures are not counted as a recycled while constructing a new building around the old structures. (Kuittinen et al. 2017, 42.)

In the following table 4, construction materials from secondary resources are presented. Table 4 includes only those construction materials which are available in Finland. Table 4 does not include all materials from secondary resources rather the most feasible solutions for the Multifunctional school building in Pori are provided. Most of the products and materials are not purely from secondary resources because there are added virgin ingredients during processing. Shares of recycled content of the alternative materials are also presented in the table. Share of recycled content can variate significantly between producers, therefore given percentages are not absolute for materials presented.

Table 4. Construction materials available in Finland from secondary resources.

Materials from secondary resources	Share of recycled materials	Source
Re-used components		
Beams	100%	Saarinen 2018, 95
Bricks	100%	Saarinen 2018, 95
Paving stones	100%	Saarinen 2018, 95
Pillars	100%	Saarinen 2018, 95
Recycled inflatable wool	100%	Eko-Expert 2020
Fillings		
Artificial stone/casted stone	varies	Suomen erityisjäte 2020
Concrete	up to 15%	Nieminen 2015, 68
Foam glass	99%	Foamit 2020, 3
Insulation		
Cellulose wool (wood fibre)	80%	Isocell 2019
Glass wool	80%	Isover Saint-Gobain 2020
Mineral wool	85%	Ruukki 2020
Upholstery		
Ceramic products	varies	ABL laatat 2017, 5
Plasterboard	10-30%	Wallenius 2015, 14
Polyester fibre products	up to 100%	Ewona Finland 2020
Wood-plastic composite	60%	Suomela 2020
Furnishing		
Solid surface (plastic)	30%	Durat 2020
Decoration		
Crushed bricks	100% (includes impurities)	Lätti 2016, 101
Other		
Aluminium	84%	Kingspan 2017
Blast furnace sand and gravel	industrial waste streams	UUMA 3 2020
Bottom slag from waste incineration	industrial waste streams	UUMA 3 2020
Crushed asphalt	up to 100%	Erikoismedia Oy 2012
Crushed tires	100%	UUMA 3 2020
Fly ash	industrial waste streams	UUMA 3 2020
Natural stone paving	0%	Kivitori 2020
Recycled plastic products	up to 100%	Uusiomateriaalit 2020
Steel	84%	Kingspan 2017

Concrete is commonly used construction material, therefore public buildings in Finland are often concrete based. While demolition of buildings has become more common, amount of concrete waste has been increasing. In Finland, recycled concrete waste is often utilized in a crushed form in construction below the surface of the earth. It is possible to process crushed concrete further than that like secondary material for new concrete. However, strength of concrete is compromised when there is recycled aggregate among raw materials. Quality of concrete made of recycled materials is determined by the quality of recycled concrete. Concrete can include materials from secondary resources, such as recycled aggregate and fly ash, up to 15%. (Nieminen 2015, 7-19). Cement contained in concrete has the greatest environmental impact in concrete production. Betolar has developed solution for cement free concrete, which is made from 95% recycled materials, which reaches to 90% reduction into CO_2 emissions. Like in many concrete products, Betolar's solution for producing concrete is based on replacing cement with industrial side streams such as blast-furnace slag. Betolar does not produce products itself but offers the solutions for firms which produces concrete. (Betolar 2020.)

For some of the materials presented in the table 4 have been given completely new purpose. For instance, Foamit produces foam glass aggregate from the recycled sheet glass and glass bottles. Foam glass can be used in multiple ways in construction. The technical properties change completely while processing foam glass from crushed recycled glass. The benefit of utilizing foam glass over some materials from virgin sources is lower carbon footprint (0,31 $kgCO_2/kg$) and a lightness of the material. It is the lightest crush material available on markets. Foam glass aggregate has A1 fire classification. Thanks to the foamed cellular structure, the thermal insulation of the foam glass crumb is excellent. Foam glass can be used similarly than crushed stone materials and it is classified to be lightweight aggregate. (Foamit 2020.)

The recycling rate of steel and aluminium is high in Finland because those can be recycled repeatedly without them losing their strength or quality properties. It is assumed that 84% of the steel and aluminium used in construction sector are recycled. (Kingspan 2017). Some construction materials, such as bricks, beams, pillars, and inflatable wool can be re-used without processing. Unfortunately, there are not many materials which could be used directly again in different construction site and available amount of re-used materials does not cover the demand. (Saarinen 2018, 95.)

Cellulose wool presented in the table are made out of wood fibres. Cellulose wool is manufactured from wood fibres which is already processed once as a paper. Then, from the recycled paper is manufactured cellulose wool. (Isocell 2019.) This method prolongs the circulation of materials, which could be directed straight to the energy recovery. (EIT RawMaterials 2019.)

Some of the materials are new on market, which raises question whether they are safe to use in such building as a school. Classification of materials from secondary resources can be inspected. Many materials from secondary resources presented in table 4 has M1 classification. Therefore, those materials can be conceived safe for the use of the multifunctional school.

4 LIFE CYCLE ASSESSMENT IN GENERAL

LCA is systematic method to recognize and evaluate environmental impacts related to producing and consuming product or service. LCA was developed in 1960s, but the method has evolved significantly since then. To ensure the consistency between different LCA studies, the method has been standardized. Global standards include required phases, principles, and framework of LCA. Valid standards which guide LCA research are ISO 14044 and ISO 14044. Therefore, conducted studies are comparable regardless where they are carried out. (Hauschild et al. 2018, 18-27.)

According to ISO 14044 standard, LCA consist of four main phases, which are goal and scope definition, inventory analysis, impact assessment and interpretation. All four phases are carried out by following the standard. Goal and scope definition guide the LCA study to the desired direction by setting specific objective and limitations. The life cycle inventory analysis (LCI) phase consists inventory of input and output data. On the other hand, life cycle impact assessment (LCIA) phase is conducted to help to understand meaning and significance of the results. In the last phase of LCA results of LCI and LCIA are summarized and analyzed based on the frame defined in the goal and scope definition phase. (SFS EN-ISO 14040: 2006, 7-11.)

LCA takes into consideration the whole life cycle of the product. The method focuses on the used resources and methods during the product’s life cycle. LCA is used to find those phases of the life cycle, which has the greatest environmental impacts or the greatest possibility to make improvements. Efficiency of the use of resources, such as energy and raw materials, are highlighted when searching for the possible improvements. In addition to product development, LCA can be utilized to support decision making and marketing. (Hauschild et al. 2018, 18-27.)

4.1 Conducting life cycle assessment in construction

Life cycle approach can be applied to buildings. Environmental performance of the studied building can be compared with other buildings when the LCA is performed according to the standard. In fact, it can be useful tool to help with material selection decisions. Life cycle assessment of buildings differs from the basic LCA and therefore SFS EN 15978 standard was created. Purpose of the standard is to define rules for the LCA calculations of new and already existing buildings. (SFS EN 15978, 5-7.)

According to SFS-EN 15804 (2012, 20-52) standard environmental impacts of the construction materials can be evaluated with life cycle assessment. LCA of construction materials consists of evaluation of the used resources both material and energy. With LCA, quantity of the harmful greenhouse gases (GHGs) can be studied among other substances that have impact on the environment. Just like any other products, production of the construction materials causes various environmental impacts. Environmental impacts can be categorized into few groups by the impact area: climate change, photochemical ozone formation, ozone depletion, acidification, eutrophication, water use and depletion of resources. In addition, there are a few more categories presented in SFS-EN 15804 standard which concerns particulate matter emissions, ionization radiation, eco-toxicity, human toxicity and land use related impacts.

Stages of the LCA are presented in the figure 4 below. The figure depicts the building level system boundary provided in the SFS EN 15978 standard. Assessment off buildings can be divided into four main stages: product, construction process, use and end of life stages. Stages are divided into precise construction phases. The modules are marked with the letters A, B and C to prevent mixing processes between the stages. Therefore, tracking environmental impacts back to the origin is effortless, even if the stages involve similar processes such as transportation. In addition to A, B and C modules there are fourth module D, which is implemented when there is available information on recycling, energy recovery and reuse. (SFS EN 15978, 18-31.)

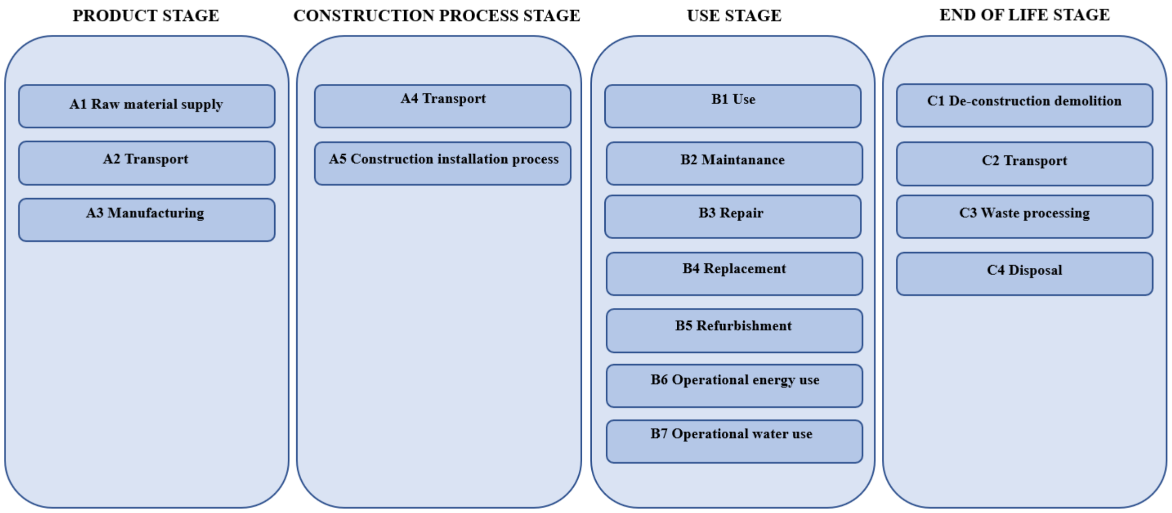

Figure 4. The stages of the building life cycle assessment. (SFS EN 15978, 21)

One Click LCA is one of the several software tools created for the assessment environmental performance of buildings. Database of the program includes over 65 000 construction materials. Program is complied with EN and ISO standards providing consistent and comparable results. Program is automatized to calculate whole life cycle impacts. With the add on tool, Building Circularity, One Click LCA provides shares of circulated materials among the life cycle assessment calculation.

4.2 Life cycle impact assessment indicators

Information provided with inventory flows, such as CO_2, CH_4, N_2O and CFCs, can be transferred into more understandable form by using indicators. LCIA indicators are used to help understanding the results of the LCA. There are broad selection of indicators describing different environmental impacts. LCIA is carried out in five steps, where indicators play an important role. At first, impact category, category indicators and characterization models must be chosen. One or more indicators can be selected for the review according to one’s needs. Then classifications of the results are completed into selected impact categories. Third step comprise category indicator result calculation, which is known as characterization. The fourth step is normalization, followed by the last step, weighting. (Hauschild et al. 2014, 3-9.) By selecting right impact category, useful information can be provided by LCA, regardless of the operation sector under the inspection. Indictors used in life cycle impact assessment to illustrate environmental impacts are introduced in table 5. Provided indicators are presented using EN 15804 characterization factors. (SFS EN 15978, 43.)

Table 5. Indicators of environmental life cycle impact assessment. (SFS EN 15978 2011, 43)

Indicator	**Unit**
Abiotic resource depletion potential for elements ($ADP_{elements}$)	kg Sb equiv
Abiotic resource depletion potential of fossil fuels ($ADP_{fossil\ fuels}$)	MJ
Acidification potential (AP)	kg SO^{2-} equiv
Eutrophication potential (EP)	kg $(PO_4)^{3-}$ equiv
Global warming potential (GWP)	kg CO_2 equiv
Ozone depletion potential (ODP)	kg CFC 11 equiv
Photochemical ozone creation potential (POCP)	kg Ethene equiv

The indicators describe effects of elementary flows in different impact categories. Indicators presented in table 5 are impact categories of the midpoint method. Contrary to midpoint method, endpoint modelling focuses on the damages at the end of the path of influence. Such indicators as ecosystem quality, human health and resource scarcity describes these endpoint impacts. Endpoint indicators gives particular information of the caused damages in the area of protection of the product system. However, more scientifically proven information is available of the indicator categories of the midpoint method. Several studies substantiate that inventory flows have impacts on midpoint indicators, while the direct relations between impacts and endpoint indicators can not always be proven. (Hauschild et al. 2014, 3-9, 23.)

In addition to indicators presented in table 5, SFS EN 15978 standard includes indicators describing resource use, waste quality and output flows. In table 6 are provided indicators, which are used to describe the use of resources. Following table is simplified version of the list of indicators presented in SFS EN 15978.

Table 6. Resource use indicators. (SFS EN 15978 2011, 43)

Indicator	**Unit**
Fresh water consumption	m^3
Non-renewable secondary fuel consumption	MJ
Primary energy consumption (renewable)	MJ
Primary energy consumption (non-renewable)	MJ
Renewable secondary fuel consumption	MJ
Secondary material consumption	kg

Disposed waste can be divided into three categories as presented in table 7. Different sort of waste has different environmental impacts and therefore it is important to categorize waste streams correctly during the life cycle assessment. Indicators in the table are describing categories of waste and output flows exceeding system boundary. Indicator of disposed non-hazardous waste covers generated waste directed into permanent storage such as landfill. (SFS EN 15978 2011, 44.) Not all of the waste can be accommodated under the indicators presented in the table. Some of the waste can be utilized after they leave the system.

Table 7. Disposed waste indicators by the quality. (SFS EN 15978 2011, 44)

Indicator	**Unit**
Disposed hazardous waste	kg
Disposed non-hazardous waste	kg
Disposed radioactive waste	kg

In addition to waste streams for disposal, there are also other output flows, which leaves the system. Indicators for these flows are presented in table 8. Indicators in the table describes those products with further purpose but which are leaving the system under the research. For example, material for energy recovery indicator describes C&D waste directed to energy recovery.

Table 8. Output flows exceeding the system boundary. (SFS EN 15978 2011, 44)

Indicator	**Unit**
Components for re-use	kg
Energy for exportation	MJ
Materials for recycling	kg
Materials for energy recovery	kg

4.3 Selection of the indicator for the material evaluation of the school in Pori

This study uses the midpoint method for the life cycle assessment of environmental performance of the construction materials. Selection of midpoint method over endpoint method is based on reliability. In the midpoint method, results are presented by utilising indicators describing caused environmental impacts. There is great amount of research data to support the reliability of these indicators. On the other hand, indicators of the endpoint method are also based on research data. However, it is more conflicted to prove that these impacts would always occur when direct connection can not be verified. (Hauschild 2014, 3-9.) Figure 5 below is provided to help understanding the impact pathway in the simplified form. Contrary to the illustrating figure, instead of just one, there wide range of environmental impacts and thus impacts on the areas of protection.

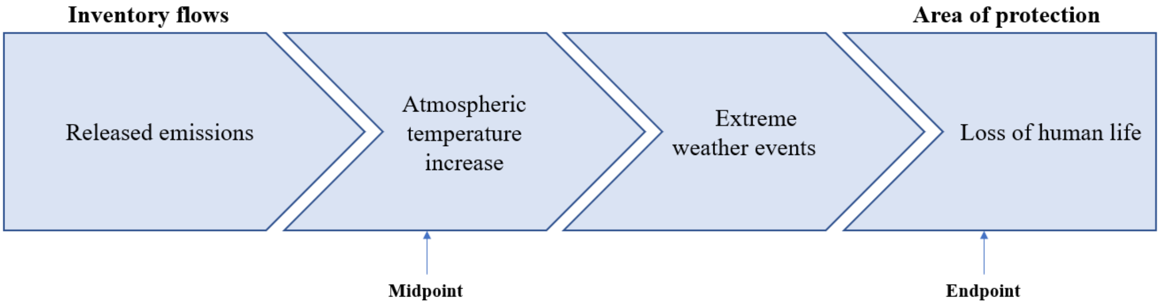

Figure 5. Simplified impact pathway for the chosen indicator, global warming potential. (Hauschild et al. 2014, 8)

Despite the fact that the aim of the research is to study the material efficiency of the school building, the chosen indicator is global warming potential. Selection of the indicator from the table 5 is based on finding the most informative indicator to evaluate environmental performance of the building alongside of building circularity. The reason for choosing GWP as an indicator for this LCA is the general objective of the European Union’s LIFE programme. LIFE programme is an instrument supporting climate and environmental actions (The European parliament and the council of the European Union 2013). As an indicator GWP provides information, which can be used to contribute constructions’ environmental performance considering the climate perspective. Material efficiency is therefore also examined from a climate perspective by comparing GWP indicator results.

The term of global warming originated from the warming of climate system which is caused by human activities. Both terms, climate change and global warming, are comparable to each other when the temperature is rising. GHG emissions are the reason for the increase in radiative forcing, and the only climate forcing agent presently taken into account in LCIA methodologies. Global warming has extensive range of impacts and many impacts spreads far from their origins, making the tracing of the impact pathway challenging. However, at the endpoint of the pathway there are several damage areas that are related to global warming. The direct ramification of GHG emissions is rising temperature of oceans and atmosphere which is followed by several types of impacts such as melting of land ice, sea level rise and extreme weather events. At the endpoint, these impacts can cause loss of human lives and damage the ecosystem its diversity. (Hauschild 2014, 8, 22, 39.)

In the case of the school of Vähärauma, GWP indicator is suitable for the assessment. Global warming potential as an indicator measures greenhouse potential of emissions. GWP takes into account greenhouse gases such as carbon dioxide, methane and CFC’s which contributes global warming. GWP is calculated in CO_2eq. (Euro pool system 2015.) Global warming potential is based on the global warming potential of each greenhouse gases. The global warming potential of a gas refers to the cumulative exposure from the emission of one unit of that gas to global warming compared to one unit of the reference gas, CO_2, given a value of 1. When the carbon dioxide is 1, values assigned to methane and nitrous oxide are 21 and 296. Value of fluorocarbons variates between 120 and 12000, whereas chlorofluorocarbons variates between 5700 and 11900. Value assigned to sulphur hexafluoride is 22200. (IPCC TAR 2001, 47.) These values describes the global warming potential in a relation to carbon dioxide and enable global warming potential to be studied as an entity considering all the greenhouse gases influencing on it.

It is essential to know how the information of the results can be utilized. Properly utilized information obtained from the environmental performance assessment of the building can contribute to the maintenance of the balance of the ecosystem. In addition to the well-being of the ecosystem, large scale improvements in material choices may promote human health and even save lives. The effects of the one or a few construction sites may not be perceptible, but they are relevant in the bigger picture. Global warming is a global problem and GHGs behind the climate change are not just affecting the place they origin, but all over the world (Hauschild 2014, 41). When LCA is implemented in the construction of the school of Vähärauma, it may have an influence on other cities and work as a trendsetter of raising environmental awareness.

5 MATERIAL EVALUATION OF THE SCHOOL BUILDING

There are two very similar schools to be built, where the other project is few moths further than the other. According to the size, the space program, the number of users and core structures, the school of Vähärauma is quite similar than the multifunctional due to which they are suitable for comparison with each other. Both schools are designed to be concrete based, which supports the idea of comparing the with each other. Even if the subject of this research is the multifunctional school, LCA is conducted for the school of Vähärauma, because there are more available data to comply the assessment. This method allows up-to-date research data to be utilized to contribute environmental performance of the new multifunctional school building. The research results are thus obtained in time to be used to make material choices for the multifunctional school building.

The subject of the LCA research is the school of Vähärauma, the construction of which is scheduled to begin on March 1, 2021. The school is being built in Vähäraumantie 91, 28600 Pori. According to project plan the school will be completed on July 1, 2022. The gross area of the three-storey school is 6660m^2 which is designed for 600 elementary school students and 60 members of staff. The designed service life of the school is 100 years for the core structures. Some structures such as yard structures, HPAC equipment and automatics are expected to be outdated sooner, but these structures are left out of the inspection. Therefore, it is assumed that all construction materials included into LCA last for 100 years without maintenance requirement. Figure 6 demonstrate the construction area and its neighborhood. In addition to the building itself, the yard area is also presented in the figure. There were two other plans where construction was shaped and located differently in the area. Other two plans were rejected by the users.

Figure 6. Location plan of the school of Vähärauma retrieved from the project information system (2020).

The construction is located in the vicinity of kindergarten where the old school of Vähärauma was placed before demolition. New school is being built at the same location, but there are not any of the old structures left to be utilized. The area is surrounded by detached house settlement. Traffic around the school area is quite restrained with the exception of school busses and escort traffic, which makes way to school safe for the young children. (PRIS 2020.)

5.1 Premises & functions of the case school

The school of Vähärauma consists of three main units which are divided by the classes. In addition to conventional classrooms, each unit has open premises which are called squares, small group premises, storages and toilets. Squares are located in the middle of unit. Squares are used for gathering spaces and teaching premises. In addition to small group premises there are even smaller spaces for the especially sensitive students which can also be used to separate students to smaller groups.

The Finnish education system includes subjects such as art and craft which requires special premises. For the handcraft education there are two units, one for soft materials and other one for hard materials. Music education also requires its own space. Music premise has special need for the materials since it must be sound insulated.

Gym is sized for full-size basketball court that can be divided into two equal sized areas with a heavy curtain. Storages near by the gym are essential for storing sport equipment. Also, a stage is being built, which is mobile by the situation. Then there are four dressing rooms with showers that must be implemented next to gym. External clients are also using the gym after the school hours so access to changing room must be effortless from the outside. Afternoon users are not allowed to wander elsewhere in school which supports the neef of effortless dress passing to the dressing rooms. There are more spaces for the physical education outside, but those are left out of the inspection.

Dining area for 200 people is located in the middle of the school. Special requirements for the materials in dining area is concerning acoustics. Next to dining area is kitchen which must be spacey enough to provide lunch for 600 students and the staff members each day. There is one entry to the kitchen where food supplies are delivered to school. Kitchen staff has premises for breaks and social interaction. Materials of the kitchen must be selected taking into account sanitation need of the premise. In addition to main kitchen administrative premises includes small kitchens for the use of staff.

Administrative premises such as principal’s office and student health care must be located in the vicinity of each other. Communication between these two must be effortless. Student health care are in use for the students and external clients. Administrative premises include offices, phone booths and room for breaks and social interaction. In additional to compulsory element of student health care, the school has dental care services which is also in use of external clients as well as students. Dental care with the x-ray does require special materials to be used.

Library of the school is in the use of all citizens as well as students. In the library, acoustics must be taken account in material choices. In addition to all above mentioned premises there must be enough space for technical equipment, cleaning tools and one S1-classified air raid shelter.

Premises are not only used by students, but also by other citizens, therefore increasing the rate of use of the school. Therefore, the building services multiple users and purposes. It is also beneficial to user when several services can be found centralized at the one place. This feature is indeed similar with the multifunctional school.

Figure 7 is the floorplan of the school of Vähärauma. Floorplan illustrates the functions and premises determined in the space program. The first floor has the most complex space program, including classrooms, squares, dining area, gym, dressing rooms, toilets, student health care including dental services, offices of the teachers and several storages.

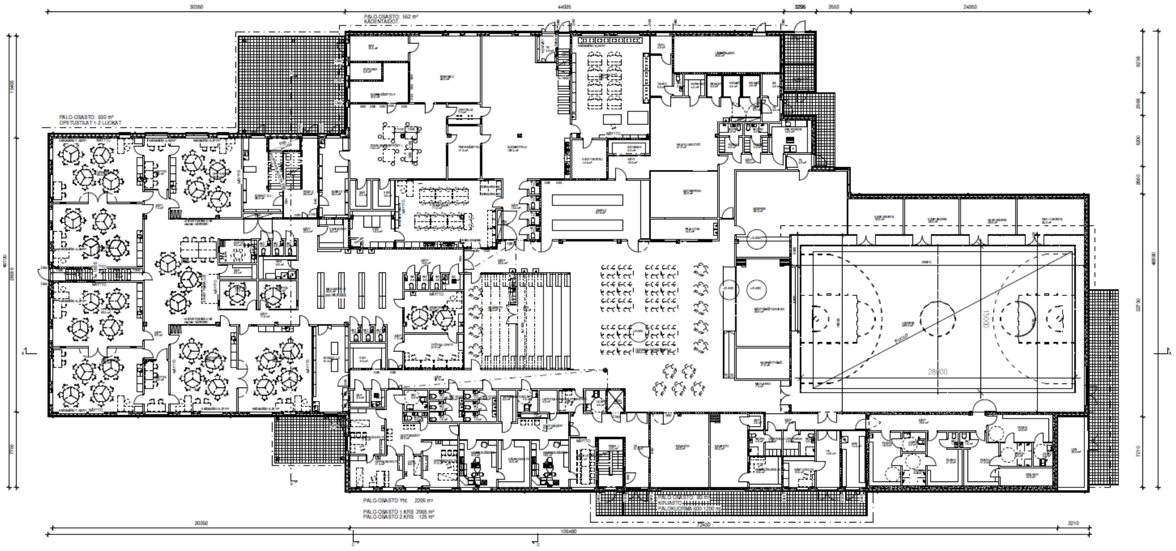

Figure 7. Floorplan of the first floor retrieved from the project bank 2020.

The figure 8 is the floorplan of the second floor. As can be seen from the figure, the area of the second floor is smaller than the first floor's due to the high spaces of the first floor. Gym and dining area, which are located on the first floor, reaches up to the second floor's roof.

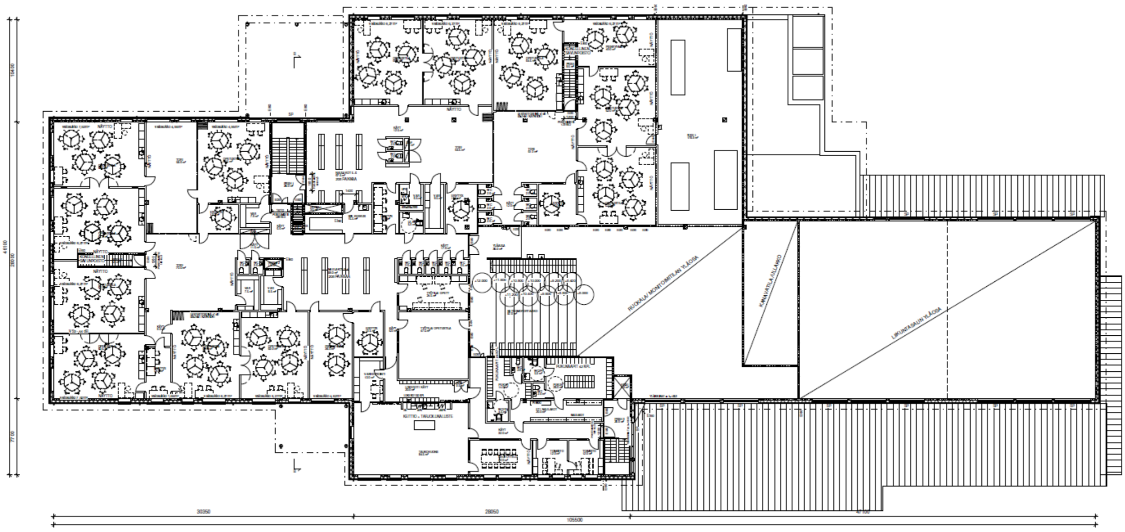

Figure 8. Floorplan of the second floor retrieved from the project bank 2020.

The figure 9 presents the floorplan of the third floor. As the figure illustrates, third floor does not include any premises for the education purposes. Even if the third floor is not in active use, there is an entrance in it for the staff. The premise of the third floor is designed for the use of building technology equipment.

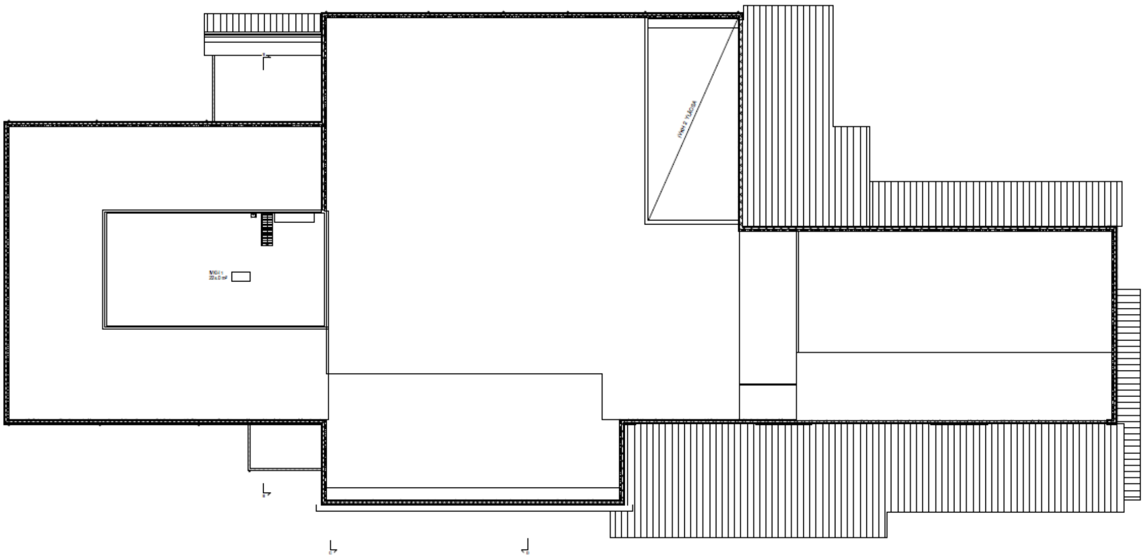

Figure 9. Floorplan of the third floor retrieved from the project bank 2020.

5.2 Structures & materials of the case school

The school is designed to be low energy building. The scope of a nearly zero-energy building requires zero net energy consumption. E-value of the school building must be under 120 kWh/m^2 without utilizing renewable self-supporting energy system. The selection of the main structures and materials is based on the life cycle costs perspective. Circularity and low carbon alternatives are taken into account in design and implementation, if they don’t affect the cost-effectiveness. The core of the school of Vähärauma is concrete-based where load-bearing structures are made with reinforced concrete pillars, beams and slabs.

5.2.1 Core structures

Core structures of the case school are presented briefly in this chapter. Only the common elements mentioned in the project plan are included. More comprehensive definitions of the materials used for each structure included into evaluation are presented in the chapter 5.2.2.

The inner layer of the external walls is made of reinforced concrete elements which is enlivened with grooved and graphic concrete layer. The U-value of the structure must meet the thermal insulation requirement of 0,17 W/m^2K. The most relevant element of load-bearing and stiffening partitions is reinforced concrete, but structures often includes other materials also to fulfill the requirements for thermal insulation and acoustics. Footings are also made from reinforced concrete by casting. The plinths are made of readymade plinth elements.

Base element of the ground floor structures is load-bearing hollow slabs. Other common elements are insulation and fiber leveling layer or concrete layer. However, the floor structures differ in different parts of the school due to some special requirements of some premises. The U-value of the structure must meet the required 0,16 W/m^2K. As well as ground floor, the intermediate floors are made out of load-bearing hollow slabs. Intermediate floors do not have U-value.

Attic floor's U-value must be at least 0,09W/m^{2}K to meet requirements. Structures includes hollow slabs and roof elements. As an insulation, attic floor has inflatable rock wool. Tin roof is mechanically seamed resulting the water to be directed to eaves and rain-water wells.

5.2.2 The construction materials

In this chapter construction materials of the core structures are presented. In the following tables 9, 10 and 11, materials and elements of the school of Vähärauma are presented. The elements and materials presented in the tables are often repeated in several parts of the structure. For example, the surface material may be implemented on both sides of the wall structures. Depending on the location there may be several surface materials in one structure. Surface materials are chosen for each premises by the room description. Provided tables gives an overview of each structure without specific supplier data. More detailed data is used to compile LCA.

The U-values of each structures are predefined by the architect and presented in the following tables. U-values are used to describe the thermal insulation of the structure. Low U-values indicates good insulation of building. A well-insulated building is comfortable to be in and some of the heat losses can be avoided saving energy and costs. More important than the U-value of an individual structure is the overall energy efficiency of the building. (Energiatehokas koti 2020.) In addition to the structures presented in tables 9, 10 and 11, U-values for external windows and doors are set to 1 W/m^{2}K. As seen from the tables 9 and 11 all structures do not have U-values. Thermal insulation of the internal structures is not required when the temperature is the same on both side of the structure.

In the table 9 is presented materials and elements used in each horizontal structures of the school. As mentioned, the school has three floors where first and second are in use of students. Ground floor of the school variates depending on the premises. In general ground floor is made from surface material, reinforced concrete slabs, EPS floor insulation and crushed stone aggregate as the bottom layer. However, wet floors, gym and air-raid shelter special requirements for the materials. U-values of the ground floor can variate between 0,15 W/m^{2}K and 0,11 W/m^{2}K. Structure of the intermediate floor is the simplest of the horizontal structures as there is no need for thermal insulation. Attic floor with the smallest U-value of all the structures has the most complicated material requirements. Attic floor is homogeneous throughout the school, except for the gym, where the hollow slabs are replaced by TT-slabs.

Table 9. The materials and elements of the horizontal structures of the school of Vähärauma.

Structure	Elements	U-value
Attic floor	surface material sheet metal, steel bitumen felt under boarding, wood air passage inflatable rock wool hollow slab/TT-slab	0,09W/m^{2}K
Intermediate floor	surface material surface concrete hollow slab	-
Intermediate floor, air-raid shelter	surface material reinforced concrete slab	-
Ground floor	surface material reinforced concrete slab EPS floor insulation crushed stone aggregate	0,15W/m^{2}K - 0,11W/m^{2}K
Ground floor, wet room	tiling mortar waterproofing system reinforced concrete slab EPS floor insulation crushed stone aggregate	0,15W/m^{2}K - 0,11W/m^{2}K
Ground floor, gym	surface material flexible surface floor filler reinforced concrete slab EPS floor insulation crushed stone aggregate	0,15W/m^{2}K - 0,11W/m^{2}K
Ground floor, air-raid shelter	surface material reinforced concrete slab EPS floor insulation crushed stone aggregate	0,15W/m^{2}K - 0,11W/m^{2}K

External wall structures are aggregated in the table 10. All of the external walls are load-bearing structures, so they need heavy materials. The facade of the building differs in different sections of the building. Facade consists of both concrete and boarded surface materials. However, reinforced concrete, insulation and surface materials are common features in all parts of the external wall.

Table 10. The materials and elements of the external wall structures of the school of Vähärauma.

Structure	Elements	U-value
External wall, precast	reinforced concrete mineral wool surface material	0,17W/m^{2}K
External wall, shell precast	reinforced concrete air passage insulation surface material	0,17W/m^{2}K
External wall, weatherboard	surface material weatherboard wall frame windshield wool mineral wool reinforced concrete	0,16W/m^{2}K

Internal wall structures are presented in table 11. Some of the structures are load bearing while other are not. For example, light partition walls are used to divide the premises, but they do not affect the stability of the building. As can be seen from the table, there are also differences in acoustic requirements between the wall structures. In these light structures, less materials are needed. As seen from the table, insulation is not mandatory element for the partition walls. In this case, insulation is added only in those structures where thermal transmittance must be avoided. Anyhow, internal partition walls do not require U-value to be considered. Common feature of the partition walls is plasterboard, which is used broadly on the walls of the school.

Table 11. The materials and elements of the partition wall structures of the school of Vähärauma.

Structure	Elements	U-value
Partition wall, load bearing	surface material reinforced concrete	-
Partition wall, classroom 44db / 48db	surface material plasterboard, hard plasterboard, regular mineral wool	-
Partition wall, classroom 60db	surface material plasterboard, hard plasterboard, regular mineral wool air passage	-

5.2.3 The alternative construction materials

The choice of alternative materials was influenced by cost efficiency, suitability by the thermal transmittance (U-value), circularity and environmental performance. Alternative materials to be added into a structure with a defined value for thermal transmittance shall not impair the U-value of the structure. At the end, three construction materials were selected for further inspection. Some materials such as wood were left out of the comparison of alternative materials because it would require dramatic changes to the structure types and was not approved by the builder of both schools. Only those materials could be studied which are found from the calculation tool and available in Finland.

Economic comparison is made case-by-case for the alternative materials presented in the table 4. Numeric values can not be presented while different materials deviate from each other enormously. Results of economic comparison are based on rough estimations of overall costs. Not only prices of the products, but installation and transportation methods also was taken into consideration.

Selected alternative materials are foam glass aggregate, inflatable cellulose wool and natural stone. Both foam glass aggregate and cellulose wool are made from recycled materials. Natural stones were chosen to represent the benefits of using natural resources instead of processed one. All selected materials describe differently the category of materials from secondary resources. There are several criteria for material selection, the most important of which is the possibility to use in a multifunctional school.

Cellulose wool can directly replace rock or mineral wool, when the U-value, application method and the costs are same. In this case, inflatable cellulose wool can be used to replace the inflatable rock wool insulation of the attic floor. Application of cellulose wool does not have effect on U-value of the structure as long as the selected product has the same U-value than rock wool. U-value of the structure is not compromised when the replacement material is added in the same amount with respect to the direction of heat flow, which is in this case upwards.

On the other hand, concrete paving can be directly replaced with natural stones, because the U-value does not need to be taken into account. Paving does not have any defined quality requirements for which natural stone is assumed to be a suitable alternative. This material produced directly from natural stone directly affects the resources used. Natural stones are produced from virgin material, but the low requirement for processing can produce significant reductions in the generation of greenhouse gases.

On the other hand, implementation of foam glass requires structural changes, which means that U-values can not be compared between individual materials, but the comparison must be made for the whole structure. Following figure 10 presents structures of the ground floor of the school. On the other hand, figure 11 presents structures of the ground floor when insulation and crushed stones are replaced with foam glass aggregate. These structure types have similar U-values, and the U-value can be increased by adding more foam glass aggregate if needed.

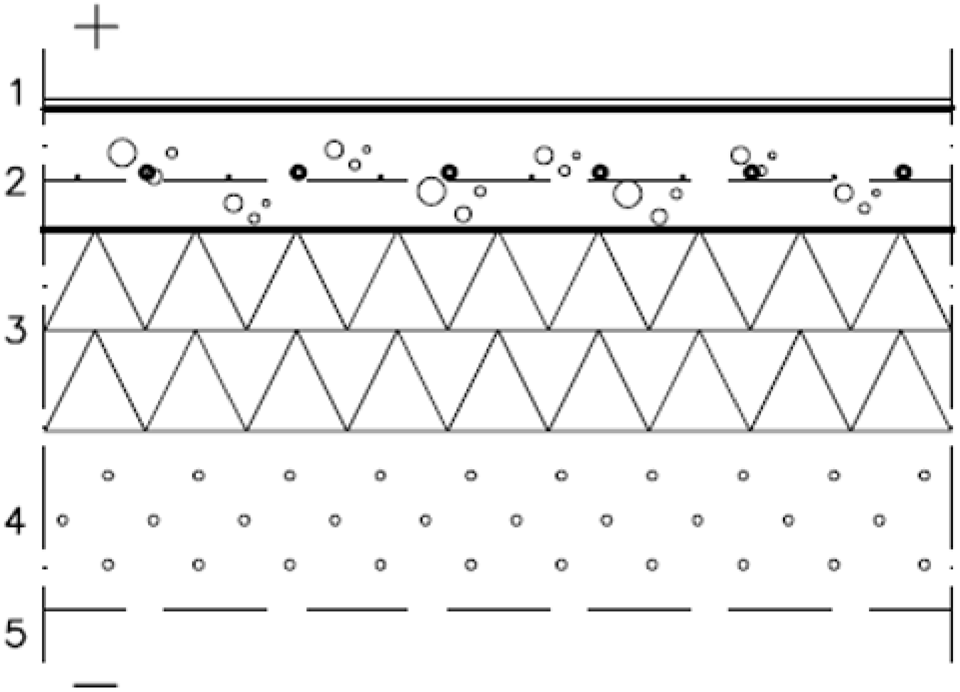

Figure 10. Structure type of the ground floor. (PRIS 2020.)

The list below presents the materials for the structure in figure 10.

1. Surface material
2. Reinforced concrete slabs, 120 mm
3. EPS 100 insulation, 100 mm + 100 mm (0,036 W/mK)
4. Crushed stones, 300 mm (size: 8…32 mm)
5. Soil

Materials of the ground floor structure are listed above. EPS 100 insulation and crushed stone aggregate are included into all ground floor structures and could be replaced with foam glass. Thickness of the materials varieties in different parts of the floor. For example, ground floor of the civil protection area is thicker than elsewhere in the school. Also, above of the reinforced concrete slabs are to be used different materials. However, materials above of concrete slabs does not influence on the capability to use foam glass aggregate as an replacement for the EPS and crushed stones.

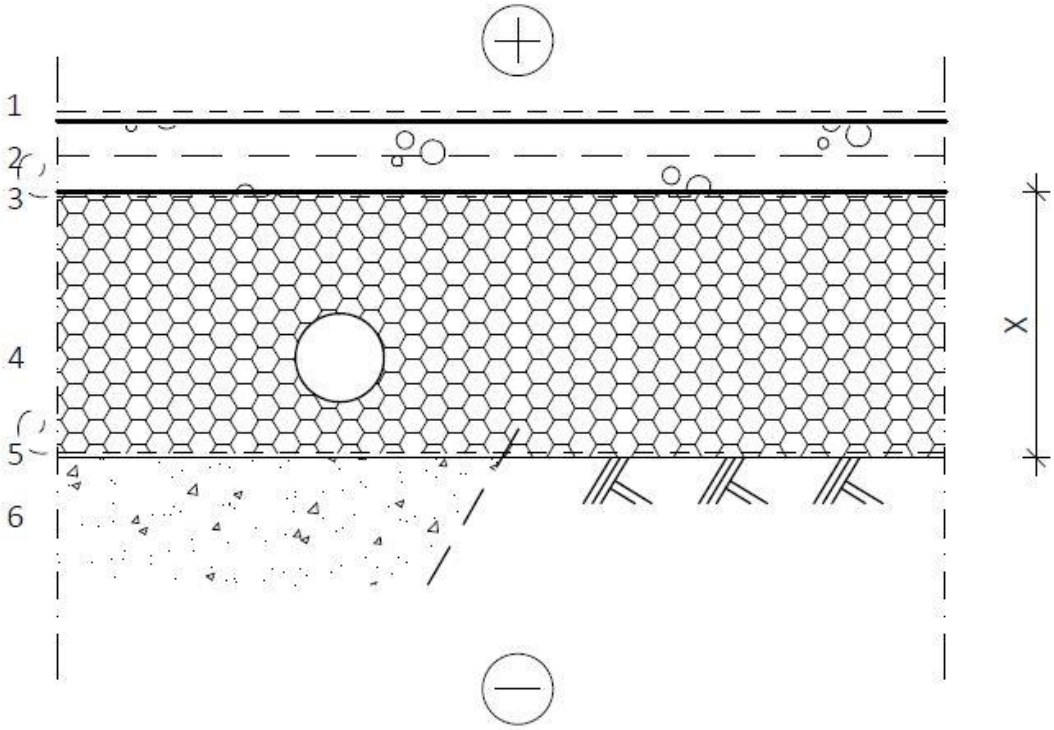

Figure 11. Structure type of ground floor with foam glass aggregate. (Foamit, 2016.)

The list below presents the materials for the structure in figure 11.

1. Surface material
2. Reinforced concrete slabs, 80 mm
3. N-type geotextile
4. Foam glass aggregate, 500 mm (size: 4…20 mm)
5. N-type geotextile
6. Soil

Materials of the ground floor structures with foam glass aggregate are listed above. Adding foam glass aggregate into the school, geotextile shall be added as well. As can be seen from the figure 11 reinforced concrete slabs are now added directly on top of the foam glass aggregate and geotextile. With the thicknesses defined at the list height of the floor stays unscathed. Therefore, adding these extra elements does not influence other structures changing the existing plans.

All of the presented alternative materials are affordable and thus would not incur significant additional costs for the project. Even if there are some deviation in the costs of acquiring the materials, installation methods can variate significantly, levelling the gap. For example, foam glass aggregate can be a little more expensive material than EPS insulation and crushed stone but requires much less installation workforce and time. In addition, the lightness of the material saves transportation costs. One of the aspects which influenced the selection of alternative materials for the assessment was diversity. Because of that, all three of the chosen materials could be applied to the building at the same time to increase environmental benefits of the building. All alternative materials fulfil quality requirements presented in this stage of the project planning. All alternative materials are selected on the basis of that they would improve circularity of the building and decreasing generated greenhouse gases during the life cycle.

Even if the alternative materials presented in this chapter are partly made out of recycled products or unprocessed resources the real benefits of implementing these materials are not known. These materials will be included in the life cycle assessment alongside conventional materials in order to assess their potential if they were later used to build a multifunctional school. To conduct the comparison of the life cycle assessment of the construction materials, several scenarios must be created. Scenarios are presented comprehensively in the chapter 5.3.1.

5.3 Life cycle assessment

Life cycle assessment of the school of Vähärauma is carried out by the standard 15804, which is based on ISO 14040 series on LCA. As presented earlier, used calculation tool is One Click LCA with an additional tool Building Circularity. One Click LCA is verified to be congruent with EN 15978 standard. Data of products and materials are based on EPDs consistent with the standard EN 15804. (Bionova 2018.)

The Life cycle assessment is conducted in four previously presented steps considering only the global warming potential of the construction materials occurred during the product stage, construction stage, use stage and end of life stage. Life cycle aspect of the research is formed when the whole life cycle of the building is inspected with the exception of the inputs given in use phase. In the goal and scope definition chapter the framework and objectives of the LCA is presented more comprehensively.

5.3.1 Goal and scope definition

Goal of this research is to calculate climate impacts of the construction materials of the school of Vähärauma in the perspective of GWP and determine if environmental performance could be improved by replacing some materials with the alternative ones. Comparison is made by creating several scenarios where some of the construction materials would be replaced with other. The research is carried out in such a way that the alternative scenarios consider only those possibilities that are rational and practical for the multifunctional school in Pohjois-Pori, for which the results are then used. GWP of the building is calculated in CO_2-equivalents.

Life cycle assessment of the school of Vähärauma is completed as cradle-to-grave assessment. In the absence of the information, use stage is assumed to have zero influence on building. Evaluation of alternative materials can be conducted without including use stage into the assessment. LCA includes inputs to the following stages: product stage, construction process stage and end of life stage. Therefore, system boundary of the research includes modules A1-A3, A4, A5 and C1-C4. Selected functional unit for the assessment is the total building area of the main building in the square meters. As the building does not yet exist, the data used to produce the study is based on assumptions and estimates of the designing team including architect’s drawings, definitions of the structure types and other project related documents.

The scenarios are implemented in such way that the first scenario, which is also known as baseline scenario, presents the building as it is intended to be built. The scenarios 1, scenario 2 and scenario 3 are similar to the first except for replacing one construction material with an alternative one. Alternative materials included into LCA are presented in chapter 5.2.3. At last, scenario 4 is presented in which all three of the alternative construction materials are utilized simultaneously. In case of the environmental performance of an alternative building material is worse than in baseline scenario it is left out of the last scenario. Following table 12 shows the building materials that will be replaced by alternative ones in each scenario. The table also includes the materials used to replace the conventional ones. The baseline scenario is not presented in the table as the scenario presents the school as it is designed.

Table 12. Conventional construction materials of the school of Vähärauma to be replaced with alternative ones.

Scenario	Conventional materials	Alternative materials
Scenario 1	Crushed stone aggregate, EPS insulation	Foam glass aggregate, Geotextile
Scenario 2	Inflatable rock wool	Inflatable cellulose wool
Scenario 3	Concrete paving	Natural rock paving
Scenario 4	Crushed stone aggregate, EPS insulation, inflatable rock wool, concrete paving	Foam glass aggregate, geotextile, Inflatable cellulose wool, natural rock paving

When the environmental performance of the building with different construction materials are assessed in the perspective of GWP, construction products for the multifunctional school can be selected by utilizing research results. In addition to environmental performance, economic has high impact on material selection, which influences on the range of alternative materials. The aim is to compare conventional construction materials with the affordable alternative materials. Even if the energy consumption of the school is not included into LCA, U-values of the alternative structures must be at least as low as the conventional materials' because the overall energy efficiency of the building can not suffer from the proposed alternative materials.

The calculation tool One Click LCA calculates life cycle impacts of the school based on entered inputs. Because the purpose of the LCA in this research is to evaluate material efficiency the only prominent categories in the calculation tool are about construction materials and building area. Building circularity are assessed with the add on tool Building Circularity. Results of building circularity are based on the entered inputs.

5.3.2 Life cycle inventory analysis

Life cycle analysis is conducted for the school building, which is already designed but not build. The processes within the system boundaries are manufacturing and transporting the construction materials to the construction site, construction of the school building and the generation and transportation of the construction waste. Use phase is also included but it is assumed to have no impact on life cycle when the purpose of the assessment is to evaluate environmental performance of the materials. Due to the lack of specific data, materials that do not belong to the previously presented core structures are not considered in the evaluation to prevent aberration. Data used in assessment is retrieved from project information system (PRIS). Calculation data is based on the area of structures when the quantities to be ordered are not yet known. Therefore, some assumptions are made to compile comprehensive assessment within the system boundaries.

All assumptions are based on descriptions of the structure types to ensure accuracy of the assessment. Definition of the structure types was presented in chapter 5.2.2. In case of description of the structure types does not define exact material to be used, the average results of the calculation tool are used for Finnish materials primarily. For example, the supplier of the reinforced concrete slabs has not been defined, so calculation is conducted by choosing typical Finnish reinforced concrete slabs specified by the calculation tool. Typical materials on a European Union scale have also been used when the calculation tool lacks suitable Finnish information. Some individual products have also been selected on the basis that they best match the description, even though no specific supplier has been mentioned. Construction material inputs for the life cycle assessment are presented by the category in table 13.

Table 13. Material inputs for the life cycle assessment.

Materials	**Data source**	
	Quantity	**Supplier**
Concrete	PRIS	Calculation tool (typical)
Steel and other metals	PRIS	Calculation tool (typical)
Insulation	PRIS	PRIS
Wood	PRIS	Calculation tool (typical)
Gypsum, gypsum board and plaster	PRIS	Calculation tool (typical)
Plastic, films and covers	PRIS	Calculation tool (typical)
Soil, paving	PRIS	Calculation tool (typical)
Floor coverings	PRIS	PRIS
Surface materials and chemicals	Assumed	Calculation tool (typical)
ceramic tiles	PRIS	Calculation tool (typical)
doors, widows and assembly parts	PRIS	Calculation tool (typical)
Foam glass aggregate	Additional	Uusiomateiraalit Oy

The materials presented in the table can be present in several different products. For example, building includes several types of concrete for different structure types of the school. Other inputs considered in an assessment are transportation of the materials to the construction site, construction process impacts and assessment period. Transportation process includes both distance to the site and transportation vehicle. Impacts of the transportation processes are based on those two inputs. For each material and product, the Nordic average determined by the calculation tool for the distance and the transportation vehicle was used for the calculation. Therefore, transportation distances variates between 20 km to 180 km and all the materials are transported along the road network.

Construction site impacts have been estimated by the calculation tool based on overall area. Site impacts of the used input are based on Nordics average including various types of waste, used fuels and electricity. Assessment period is 100 years, which is the assumed lifetime of the school. Default all materials will last the entire period without replacing and maintenance.

Building technology, furnishing, foundation, energy, and water consumption are left out of the assessment due to lacking information. This data would have provided more comprehensive life cycle assessment for the building’s overall environmental performance. However, when assessing environmental performance of construction materials for the school, that information is not necessary to provide reliable results.

Construction material inputs of the assessment are based on the areas and thicknesses of the structures. Areas used for the calculations are presented in the table 14. Areas are based on architect's drawings and definitions of the structure types. However, calculations of the areas are rough, which can induce slight aberration to the real results. Some of the structures shown in the table are presented in the unit of volume, because area does not describe them well.

Table 14. Areas and volumes of the school of Vähärauma by the structure type. (PRIS 2020)

Structure type		**Area of the structure [m^2]**
Horizontal structures	Attic floor	3850 + 4712
	Intermediate floor	2504
	Intermediate floor, air-raid shelter	126
	Ground floor	3261
	Ground floor, wet room	44
	Ground floor, gym	539
	Ground floor, air-raid shelter	110
Vertical structures	External wall, precast	31
	External wall, shell precast	1538
	External wall, weatherboard	974
	External wall, concrete	72
	Partition wall, load bearing	500
	Partition wall, classroom 44db	27
	Partition wall, classroom 48db	5496
	Partition wall, classroom 60db	131
	Partition wall, foldable (glass)	56
	Partition wall, foldable (opaque)	86
Other structures	Paving	341
	Foldable wall system (glass)	56
	Foldable wall system	86
	Doors external	63
	Doors internal	643
	Windows external	308
	Windows internal	186
Structure type		**Volume of the structure [m^3]**
Other structures	Pillars	47
	Stair structures	13

The height of the first two floors is four meters to which the areas have been calculated. The height of the third floor is 4,3 meters on average when the roof is inclined. The gross area of the first floor is 3954 m^2 and the gross area of the second floor is 2385 m^2. The gross floor area of the third floor is considerable smaller than the first two, because it is not in use of the students and staff. Area of the third floor is 213,5 m^2. The area of the attic floor is represented by two values. 3850 m^2 is the area of the horizontal section of the attic floor structure, when 4712 m^2 is the area of inclined section of the structure including eaves. Also, areas of the high premises, such as the gym, are considered separately in the calculations. Occasional lowering of the room heights is not taken into consideration in the calculation.

Material inputs considers only the main building. Other constraints related to life cycle assessment are mainly due to lack of knowledge at this stage of the project. Some materials and fixed furniture are decided later, as the project proceed. Materials below the surface of ground are left out of this inspection. Piling is one of the core structures of the building, but piling elements are not taken into consideration in the life cycle assessment. Other relevant components not considered in the life cycle assessment are toilets, sinks, showers and other furnishing products.

The biggest difference between a multifunctional school and a conventional school from a life cycle assessment perspective is the specific material needs of a multifunctional school. As the table shows there are 56 m^2 of transferable glass structures and 86 m^2 of transferable non-transparent structures. These special features are not present in a conventional school, which in turn contains more solid structures. In general, the quantity of materials used for partition walls in multifunctional school is smaller, as more open premises are preferred in the multifunctional schools.

5.3.3 Life cycle impact assessment

Results of the life assessment calculations are presented in this chapter. Input based results are obtained from the calculation tool. Selected indicator for this assessment is GWP, so the results are presented in the unit $kgCO_2eq$ or kg tCO_2eq. This section focuses on assessing generated greenhouse gases of different entities in various scenarios. Also, circularity aspect is presented in the end of this chapter.

There are five different scenarios, where the first one is baseline scenario, presenting the results of the school of Vähärauma based on data inputs of the defined structure types. Scenario 1, scenario 2 and scenario 3 are the same as the baseline scenario, but with an exception. Each one of those three scenarios have one material or structure replaced with an alternative material such as presented in the chapter 5.3.1. Scenario 1 presents result of ground floor's crushed stones and EPS insulation replacement with foam glass aggregate and geotextile. Scenario 2 replaces inflatable rock wool insulation with cellulose wool and the results entity created with alternative material are presented. Third scenario results indicate the difference between concrete paving and natural stone paving. Finally, the last scenario represents results when all alternative materials implemented into the school together as an entirety.

Figure 12 presents the global warming potential during the life cycle of the school of Vähärauma. In the figure generated greenhouse gases contributing the global warming are divided by the stages of the life cycle within the system boundary. Results presented in the figure are concerning only the core structures presented in the life cycle inventory analysis.

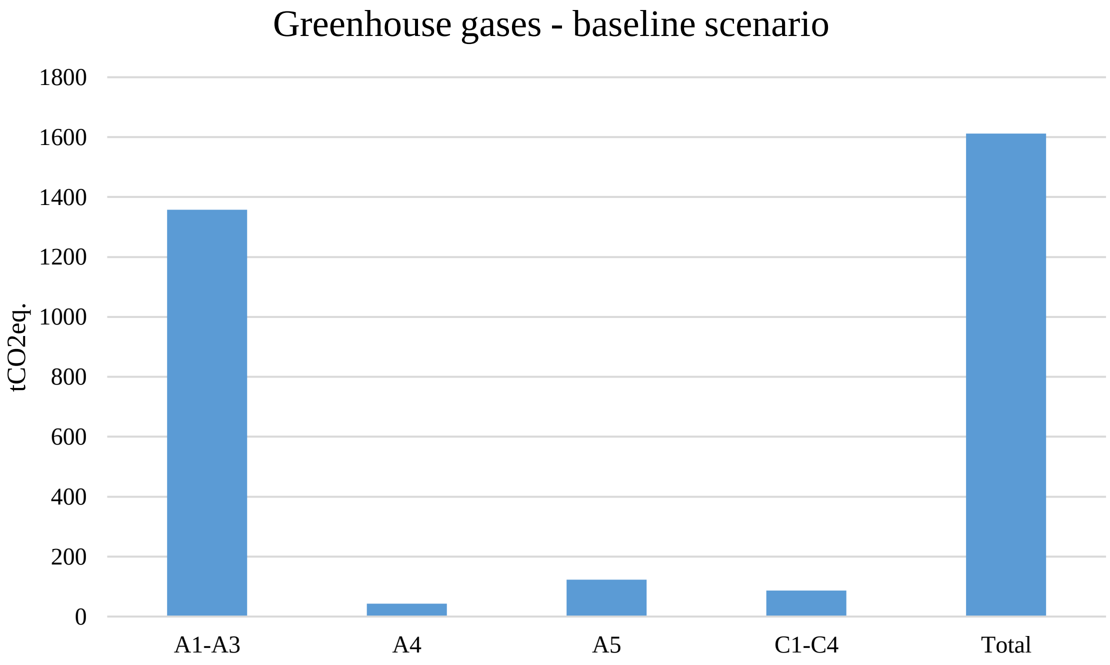

Figure 12. Greenhouse gases of the school of Vähärauma by the life cycle stages.

As can be seen from the figure, product stage A1-A3 has the most significant influence on the life cycle. Raw material supply, transport and manufacturing together forms 1358 tCO_2eq of total 1612 tCO_2eq (84.2%). In the product stage the amount of generated GHGs is significant when compared to other stages. Therefore, it provides perfect opportunity to reduce large amount of greenhouse gases by comparing and selecting less carbon dioxide intensive construction materials.

Construction stage includes modules A4 and A5. In the table module A4 represents generated greenhouse gases during the transportation of construction materials to the site. Transportation to the site by using typical Nordic transportation distances and vehicles generates 43.1 tCO_2eq of greenhouse gases. Transportation to the construction site might seem significant process for the project in the cost perspective depending on the location and used materials. However, transportation does not require marine cargo vessels or air freight, when the materials are acquired from Finland leaving the share of impact on global warming potential. Global warming potential of the stage A4 is only 2,7%. Module A5 (installation of the materials) are responsible of the generation of 123.5 tCO_2eq which is 7.7% of the total global warming potential. Installation process includes disposal of surplus and waste materials generated in the site and energy requirement during the construction.

End of life stage including modules C1-C4 generates 86.9 tCO_2eq (5.4%) of the total greenhouse gases causing the global warming potential. End of life stage results are also based on typical Nordic values of demolition operations. Influences of the construction process stage and the end of life stage are insignificant when compared to product stage where materials for the school are produced.

Once the most relevant stage of the life cycle has been discovered in the perspective of global warming potential, can be delved into its details. Product stage is responsible of 84.3% of the life cycle’s global warming potential, meaning that the production of construction materials is in the key role of generated GHGs. Figure 13 presents where the total 1612 tCO_2eq are formed.

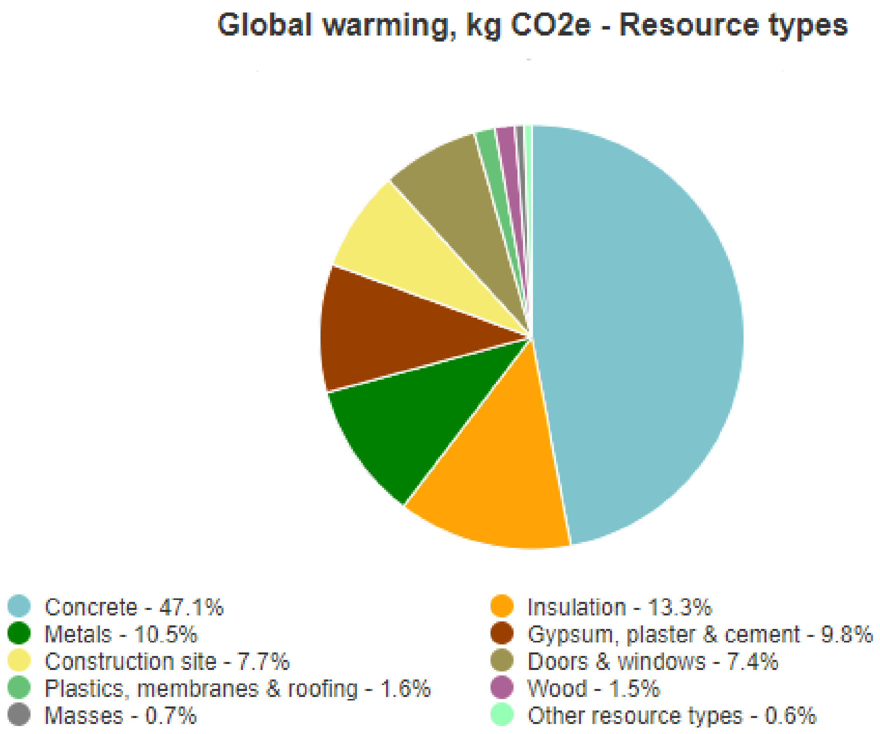

Figure 13. Impact of resource types on the global warming potential.

As the figure shows, the most relevant material in the perspective of global warming potential is concrete. Various types of concrete used for building the school generates 47.1% of the total generated GHGs, which means 758 tCO$_2$eq. The reinforced concrete slabs are in major role of that percentage share by generating 339.8 tCO$_2$eq.

Another relevant element is insulation. In the Nordic countries the importance of insulation is huge, when the four seasons causes substantial variation on the outside temperature. As can be seen from the figure, 13.3% of the life cycle’s greenhouse gases are caused by the production, transportation and the end of life treatment of the insulation materials. There are five insulation types included into building: rock wool, EPS, PUR and glass wool. Rock wool is responsible of 136.7 tCO$_2$eq which forms 63.9% of global warming potential. Share of EPS insulation is 18.8% and PUR insulation is 13.8% of the global warming potential of the thermal insulation included into the school.

The role of metals is almost invaluable in construction. In the school, metals are used for reinforcing structures especially concrete ones. Therefore, 10.5% of the GWP are formed from the operations related to processing metals. 60.9% of those greenhouse gases comes from rebar and 32% comes from the galvanized steel used for the top layer of attic floor. As the figure shows, other resource types forms greenhouse gases from the share of 0.6% to 9.8%.

Figure 14 illustrates the importance of each material for contributing the global warming. The larger the bubble is, the greater the impacts are for the climate in the perspective of GWP. The figure is formed from the values of figure 13 but the resource types are separated into smaller entities to reveal major factors.

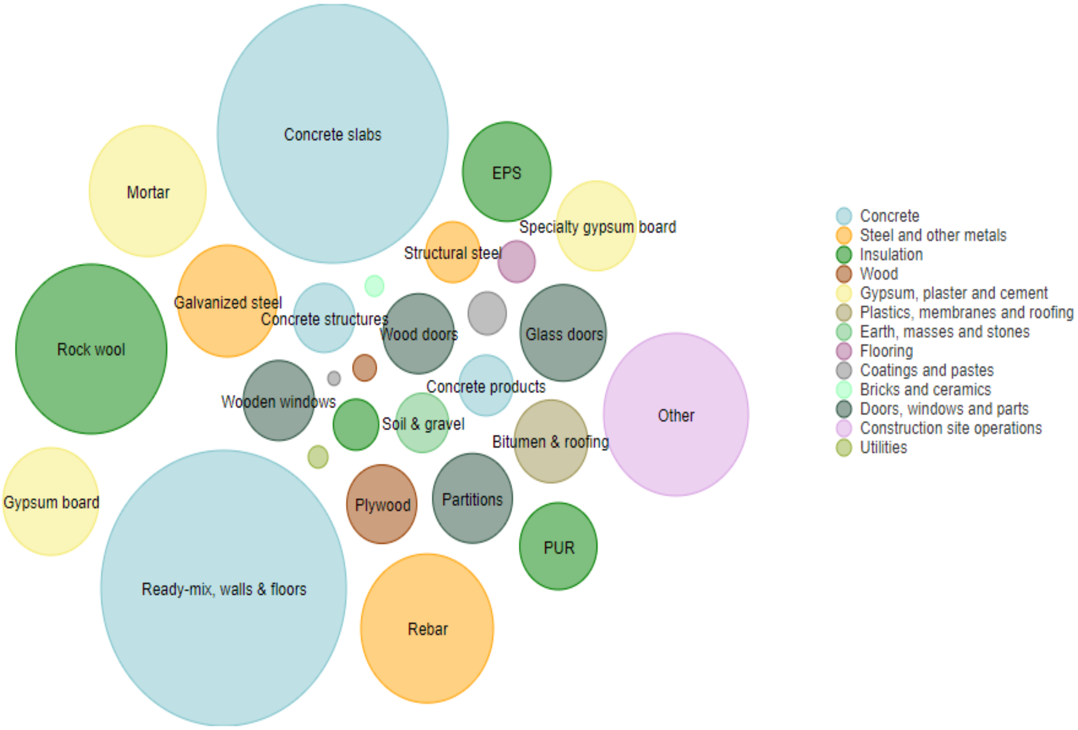

Figure 14. Bubble chart representing total life cycle impact of materials and products in the perspective of GWP.

Once the baseline scenario is reviewed comprehensively, results of the other scenarios can be compared with it. Figure 15 presents the global warming potential of each scenario by the life cycle stages. Baseline scenario is also presented in the table so the results can be compared with each other.

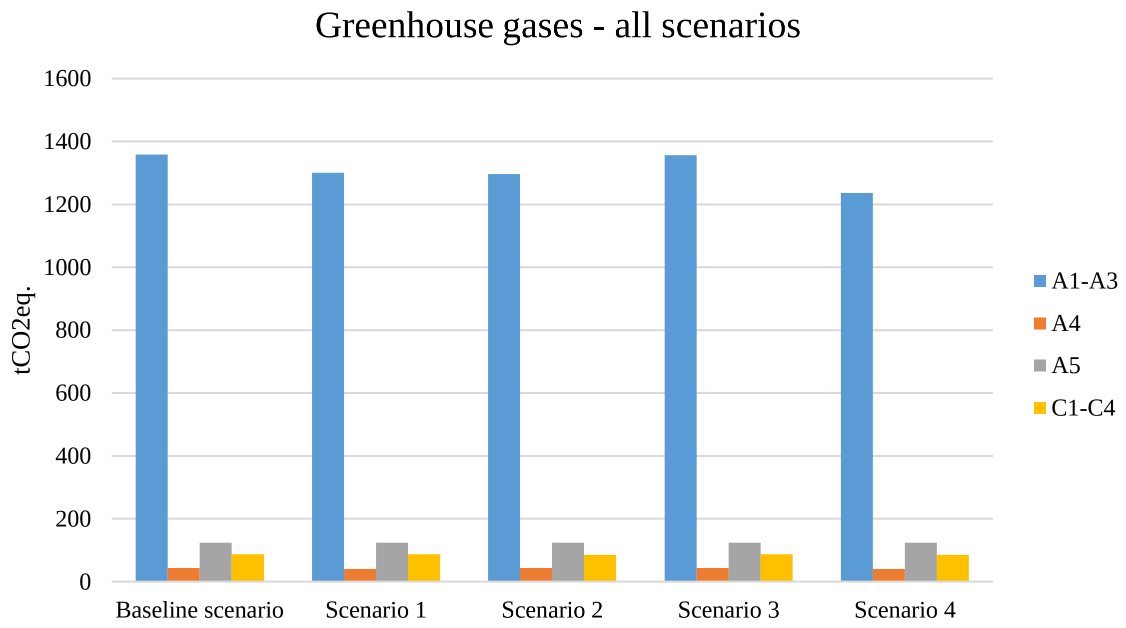

Figure 15. Greenhouse gases of each scenario presented in tCO^2eq.

As the figure shows life cycle of the school in the baseline scenario generates the most greenhouse gases, whereas the scenario 4 generates least. In all scenarios, where conventional building materials are replaced with an alternative one, the total global warming potential of the life cycle is reduced. The largest change for single exchanges material occurs in scenario 2, where inflatable rock wool is replaced with cellulose wool. Almost as huge impact is obtained in scenario 1. On the other hand, scenario 3 does not provide significant improvements when compared with the baseline scenario. Anyhow, the alterative material replacement is done for the smallest gross floor area.

The largest changes between scenarios occur in product stage, A1-A3. By replacing some of the conventional construction materials up to 62 tCO_2eq greenhouse gases can be saved from the production stage alone as the scenario 2 shows. Cellulose wool is partly made from recycled materials, which is why the total global warming potential is decreased when compared to baseline scenario. Reduction of GHGs are due to production stage, because lesser processing is needed for recycled materials than the virgin one.

Foam glass aggregate used in the scenario 1 is classified as a recycled material and thus has a reducing effect on greenhouse gases, even if the processing of recycled glass products into the aggregate requires plenty of processing. Once again, the most meaningful stage for the reduction of GHG is product stage.

Scenario 3 deviates only 2 tCO_2eq from the baseline scenario, which is directly due to production requirements of natural stone paving. Natural stone paving does not require as carbon intensive procedures as conventional concrete paving. The reduction might not seem substantial when compared to other scenarios, but it should be noted that the tiling has only been changed for the area of 341 m^2.

Impacts of construction installation process (A5) stays the same in each scenario because the changes are not large enough to destabilize greenhouse gas emissions by thousands of CO_2 equivalents. Construction installation process is the second most influencing, in terms of global warming potential, producing 123,6 tCO_2eq despite the scenario. Construction installation process is calculated with typical Nordic values which is based on the construction area of the school.

There are minor changes in modules A4 and C1-C4 between different scenarios. When compared to baseline scenario, impacts of transporting construction materials to the site decrease only in scenario 1 and scenario 4. In the scenario 1 crushed stone and EPS insulation was replaced with foam glass aggregate and geotextile. As an input of baseline scenario crushed stone aggregate is transported by dumber truck from a distance of 20 km. EPS insulation is transported by trailer combination from a distance of 180 km. Data is based on typical Nordic values and transportation methods. In scenario 1, geotextile is transported by trailer combination from a distance of 110 km. Foam glass aggregate comes from Finnish producer from a distance of a 130 km with a dumber truck. Because of the lightness of the foam glass aggregate, more material can be transported with one vehicle without exceeding the weight limits. Fewer transportation vehicle requirements reduce not only GHGs contributing the global warming, but also the cost of transportation. Global warming potential of the scenario 4 in module A4 is directly due to improvements achieved with implementation of foam glass aggregate. Other alternative materials, cellulose wool and natural rock paving have increasing effect on global warming potential of the module A4. Meaning that the inflatable cellulose wool and stone paving requires more carbon intensive transportation methods. Yet, the changes are particularly insignificant resulting the global warming potential increase only 0.1 tCO_2eq.

In the next figure is presented generated greenhouse gases of the scenarios per area. Therefore, results of the figure are presented in the unit of $kgCO_2eq./m2$. Purpose of the figure is to visualizes the benefits of alternative materials.

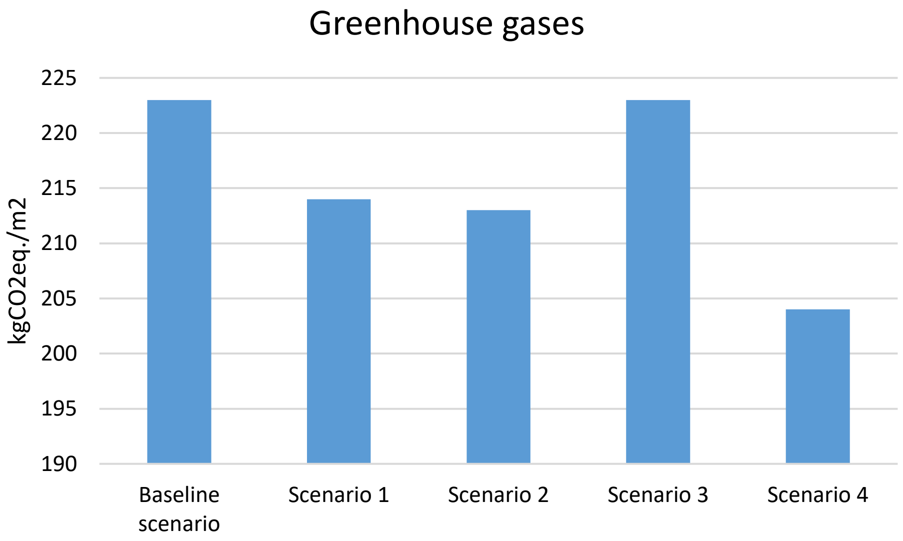

Figure 16. Greenhouse gases of each scenario of the school per square meter.

As the table shows, the amount of greenhouse gases generated per square meter is 223 $kgCO_2eq./m^2$, which is the same quantity as in scenario 3. In scenario 2 greenhouse gas reduction when compared to baseline scenario is as much as 10 $kgCO_2eq./m^2$. In the scenario 1 the amount of generated greenhouse gases per area is 214 $kgCO_2eq./m^2$, which is almost as low as in the scenario 2. As mentioned earlier the greatest improvements occur in the scenario 4, when multiple materials are replaced with alternative ones. Global warming potential per square meters of the scenario 4 is therefore only 204 $kgCO_2eq./m^2$.

The table 15 presents the total global warming potential of each scenario. In the table reductions of scenarios 1, 2, 3 and 4 are calculated in relation to baseline scenario. Results are presented in three different forms. First the results are presented in the functional unit tCO2eq, which is the reduction in the total global warming potential. Then the reductions in the results are expressed as percentages to make the effectiveness of the results easier to detect. Finally, reductions are presented in $kgCO2eq/m^2_{\text{replaced material}}$. This form of presenting results elucidates the real impact of each alternative material regardless of the area to which they are implemented in the LCA.

Table 15. CO^2equivalent reduction achieved by replacing conventional materials with alternative ones.

Scenario	**Total quantity [tCO_2eq.]**	**Reduction [tCO_2eq.]**	**Reduction [%]**	**Reduction [$kgCO_2eq/m^2_{replaced\ material}$]**
Baseline scenario	1612	-	-	-
Scenario 1	1552	60	3.8	15.2
Scenario 2	1547	65	4	13.8
Scenario 3	1610	2	0.1	5.9
Scenario 4	1486	126	7.8	14.1

As mentioned earlier the reduction in scenario 2 is the most significant of all. Astonishing 65 tCO_2eq can be reduced just by replacing inflatable rock wool of the roof structures with cellulose wool. Meaning 4% reduction when compared to the whole school building with the conventional construction materials. Scenario 1 provides 3.8% reduction of greenhouse gases with the 60 tCO_2eq reduction. Even the replacement of paving in the scenario 3 saves 2 tCO_2eq. If all alternative materials would be implemented into the school at once, the reduction would be 126 tCO_2eq, which is 7.8% of the total quantity of greenhouse gases.

As the table shows foam glass aggregate is the most influencing material when those are in the same scale. Scaled reduction of the foam glass aggregate is 15.2 $kgCO_2eq/m^2_{replaced\ material}$. Cellulose wool's environmental performance is the second best causing the scaled reduction of 13.8 $tCO2eq/m^2_{replaced\ material}$. Natural stone paving provides 5.9 $kgCO_2eq/m^2_{replaced\ material}$ reduction, which reflects that implementing that material on greater scale would dispense improvement possibility.

Next the embodied carbon of the school building can be scrutinised. Embodied carbon means the carbon footprint. Figure 17 presents the shares of embodied carbon by the life cycle stages.

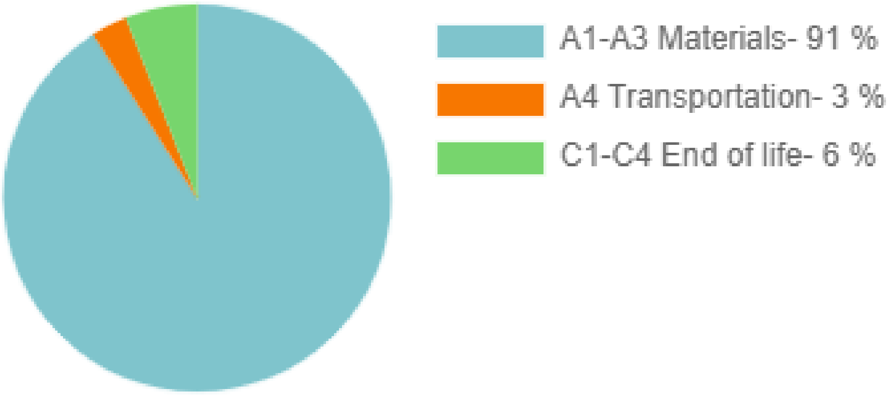

Figure 17. Share of embodied carbon by the life cycle stage.

As presented in the figure 91% of the embodied carbon are related to materials in the production stage A1-A3. Material supply, transportation of raw materials and manufacturing processes are increasing carbon footprint the most. Rest 9% of the carbon footprint consists of the processes of A4 and C1-C4 modules. Horizontal structures are responsible of 60% of carbon footprint, whereas vertical structures 31%. Remaining 10% consists of other structures and materials.

One Click LCA program's add on tool Building Circularity is designed to optimize the circulation of the materials. Building Circularity tool is used to guide the construction action from the linear economy towards circular economy. Basic concept of linear economy includes three phases: take, make and dump. On the other hand, circular economy process consists of three principles: reduce, re-use and recycle. (Bionova Ltd 2018.) Next the results of the circulation of the building is presented for different scenarios.

One of the most valuable things influencing on the selection of examined alternative materials was circularity. Some of the alternative materials increased the circularity while others were irrelevant to it. Building circularity takes into account also the transportation during the life cycle stages. Figure 18 presents the building circularity of the baseline scenario based on the mass values.

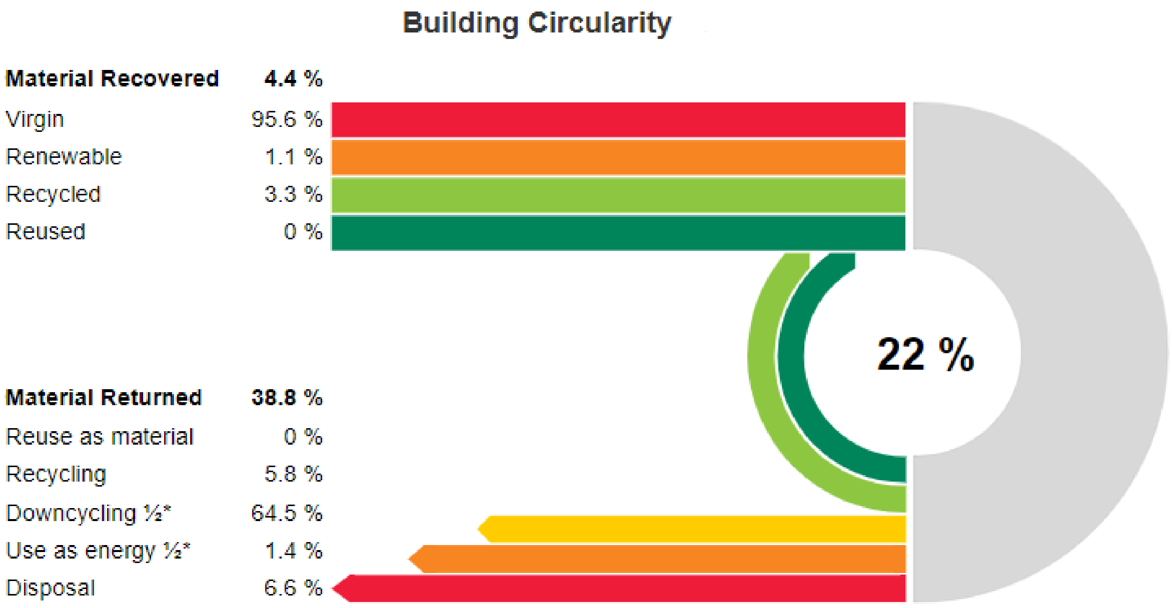

Figure 18. Building circularity of the baseline scenario.

As the figure shows, 95.6% of the materials used to build the school come from virgin sources. Only 1.1% of the materials are renewable and 3.3% recycled. Renewable materials of the baseline scenario are mostly from wooden products such as plywood. The structure type descriptions contained only little quantity of wood explaining the share of renewable materials. The share of recycled materials of the baseline scenario are mostly due to insulation type of the internal wall structures, where there is mineral wool insulation. Selected mineral wool type includes recycled materials. The building circularity score of 22% represents the total material circularity, which is based on data of both materials in use and end of life treatment of those. 5.8% of the used materials end up recycling, but none of them could be reused. 6.6% of the materials are guided directly to the disposal.

As the building circularity of the baseline scenario is already presented, the results of the other scenarios can be inspected as well. Figure 19 presents the building circularity of each scenario. Baseline scenario is also presented in the figure to elucidate the differences between other scenarios compared with it.

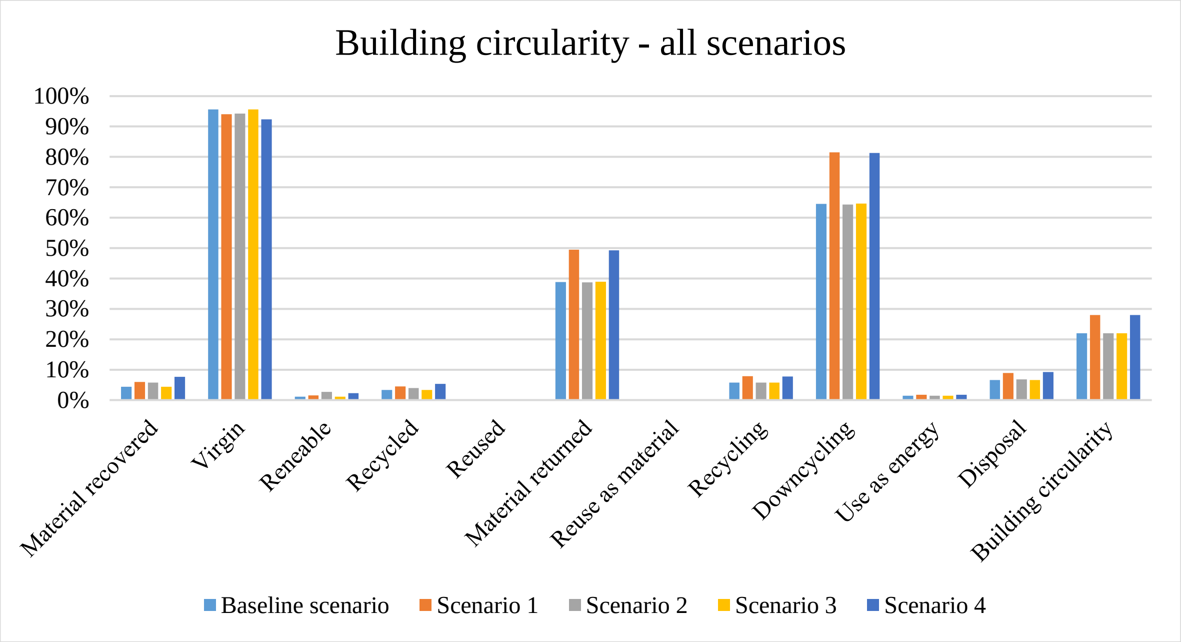

Figure 19. Building circularity of all scenarios.

The building circularity aspect are improved the best in the scenario 4, because all materials are added at once. Yet, the material replacement in the scenario 1 is the most influencing on the scenario 4, forming almost every benefit of it. As the figure shows, the score for building circularity in the scenario 1 is 28%, which is the highest of all scenarios alongside with the scenario 4. Scenario 1 stands out from others in many ways. Share of material returned is 50% whereas other scenarios with only one material replacement have 39%. Also, recycling rate increases from 6% to 8% when compared to baseline scenario. Similarly, the rate of downcycling increases from 65% to 82%. Only disadvantage of the scenario 1 is that the disposal rate increases as well.

Because of the lightness of the cellulose wool, it does not contribute share of building circularity considerably in scenario 2, when the share is mass based. Therefore, score for building circularity stays at 22% in spite of the material changes made for scenario 2. Nevertheless, share of virgin materials decreased from the baseline scenario and shares of material recovered, renewable materials and recycled materials increased a little. Changes of the scenario 3 did not influence on building circularity or the changes were too insignificant to be observed.

As originally intended, alternative materials provide opportunity to better the environmental performance of the school on the point of view of circularity and global warming potential. More impressive results for all alternative scenarios are achieved when inspected the climate perspective. Scenario 1 and 4 have the greatest improvements on the circularity point of view. Less virgin materials are needed, some waste materials can be utilized as resource and recycling rate can be improved. All these aspects are important now and in the future, when increasingly stringent regulations are being instituted to maintain a sustainable society.

5.3.4 Interpretation

Interpretation is the final phase of the life cycle assessment. In this chapter results of the life cycle inventory analysis and the life cycle impact assessment are summarized and discussed. This chapter includes conclusions and recommendations which are based on the assessment. Also, results of the assessment are inspected critically to point out possible faults.

As a conclusion, three different alternative materials are researched to find out if implementing those into the school would be rational and worthwhile. The results produced by all scenarios were positive and support the solution to utilize alternative materials for the school construction. As expected, the larger share of implemented alternative materials produces more remarkable results on lowering the amount of generated or embodied carbon and decreases the amount of required virgin materials. Comparing those materials and impacts with each other is challenging due to different intended use, volume, mass and other qualities. Presented alternative materials should not be compared together but with the conventional building materials. As presented in the table 15, foam glass aggregate has relatively greatest impact on greenhouse gases when viewed in relation to building area. Foam glass aggregate also stands out from the other alternative materials in the circularity perspective.

Next, the accuracy of the evaluation will be evaluated. At first, can be stated that the assessment is plausible within the limits of known inputs and system boundary. LCA checker of the calculation tool evaluates the embodied impacts plausibility for the school of 6660m^2. Rating of the checker is based on the similar type of buildings and gross floor area. The school of Vähärauma is concrete based, so the checker compares it to other concrete buildings with similar structures, enclosures, finishing and other materials. Overall grating for the assessment is A for each scenario. The materials which were not reliable concerns only the mass of roofing bitumen, mortar, gypsum board and plaster. Also, mass of glass was not credible, because calculation tool did not include mass of the glass inputs included into doors, windows and foldable glass walls. Roofing bitumen mass was rated unusual when it exceeded the threshold value by 1.8kg/m^2. The range of threshold value is 0.5-4 kg/m^2. Mass of bitumen is based on the structure type definitions. Mass of gypsum boards and plaster is also exceeded by 10.3 kg/m^2 when the range is 0-80 kg/m^2. Mass of mortar exceeded the threshold value only by 3.9 kg/m^2, when the range is 0.4-50 kg/m^2. The presented deviations did not reveal major errors, which would make assessment unreliable. Given grade A for plausibility reflects the fact that material inputs of the school are veritably alike with other similar buildings.

Life cycle assessment for the school of Vähärauma includes only the core materials for internal and external wall structures, attic floor structure, ground floor structures and intermediate floor structures. Plenty of materials to be included in the school are thus left out of the assessment due to lacking information. Building technology, foundation, undetermined surface materials and the impact of use stage will increase real amount of impacts. It must be noted that generated greenhouse gases of the school will be greater that the results show, which means that the global warming potential is greater in. However, some fault to the LCA can be caused by the lacking information of the use stage, when the assessment is done as cradle-to-gate.

Carbon Heroes Benchmark provided by the calculation tool presents the results of the assessment in comparable form. Grade A is the most desirable whereas G reflects poor environmental performance in the perspective of embodied carbon. In the figure 20 is presented the Carbon Heroes Benchmark of the baseline scenario. Baseline scenario achieved a B classification. None of the scenarios achieved an A classification, but the scenario 4 came the closest with the value of 204 kgCO_2eq. As the figure shows, Carbon Heroes Benchmark feature from the calculation tool also considers use stage of the building. It is known that use phase has a substantial influence on Carbon Heroes Benchmark. When the use stage of the assessment is left without inputs and only core materials are implemented into the assessment, classification B can be considered more positive than it is in reality.

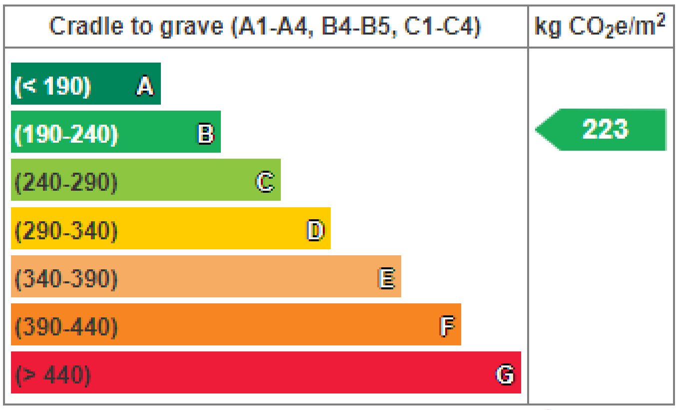

Figure 20. Carbon Heroes Benchmark of the baseline scenario, without including life cycle's processes B4-B5.

Then the results are summarized, implementing alternative materials does not have impact on the building area rather those are used to replace conventional materials from an area of the same size. Input data of the life cycle assessment are based on structure type definitions and architect's drawings, meaning that only core structures of the school are considered in LCA. In addition to baseline scenario, which presents the school as it is intended to build, four additional scenarios are created. Scenario 1, scenario 2 and scenario 3 are exactly as the baseline scenario but one conventional material or section of the structure are replaced with alternative material. Scenario 4 represents baseline scenario with the difference that all alternative materials from the above-mentioned scenarios are included in one scenario. The most significant life cycle stage in each scenario is product stage. The impact on global warming potential of product stage is many times more consequential than the other stages. The next most relevant stages are construction process stage and end of life stage in that order. The least relevant stage is transportation.

All additional scenarios have lower global warming potential than baseline scenario, meaning that all alternative materials have positive impact on building environmental performance. The greatest improvements on decreasing generated greenhouse gases are achieved in scenario 4, when 126 tCO_2eq are reduced from the baseline scenario's 1612 tCO_2eq. More than half of that reduction, 65 tCO_2eq, is based on the material replacement presented in scenario 2. Almost as significant results are reached in scenario 1 with the reduction of 60 tCO_2eq. Even the scenario 3 with the littles material replacement per area achieved 2 tCO_2eq reduction when compared to baseline scenario. The positive results of natural stone paving are also notable, but in the scale of the whole school, benefits seem small.

Yet, the global warming potential is not the only aspect studied in this life cycle assessment. Another studied object is building circularity and if recycled material could be implemented into the building. Scenario 1, scenario 2 and scenario 4 have positive impact on building circularity, decreasing the need for virgin materials whereas shares of recycled materials are increasing. Surprisingly, results of building circularity are not in line with results concerning global warming potential. Once again scenario 4 have the greatest improvements on building circularity. However, the results of the scenario 1 are nearly as positive, meaning that the material replacement in scenario 1 is the most important to increase building circularity. Also, scenario 2 have notable improvements regarding decreasing the need of virgin materials and increasing the use of recycled ones.

LCA based recommendations are given for the multifunctional school, since the planning of the school of Vähärauma are already far advanced. Replacing conventional construction materials with alternative ones can help reducing greenhouse gases and thus global warming potential of the multifunctional school and increase the use of recycled materials. Multi-perspective advance is, that alternative materials such as foam glass aggregate and cellulose wool would give recycled material a new purpose as construction material decreasing global warming potential of the school at the same time without compromising building’s energy efficiency. Even if the material had to be acquired further away than the conventional material, it can be worthwhile as the scenario 1 with the foam glass aggregate proves. However, the profitability of transporting alternative materials from further is case-specific. For the multifunctional school, only studied material in the perspective of increased transportation distance is foam glass aggregate replacing EPS insulation and crushed stone aggregate, since acquiring other alternative materials over conventional ones does not increase the transportation distance.

For the school, it is recommended that materials from the study be added to other buildings in the area also to augment the positive impact achieved with materials from secondary resources. Paving occurs to a large extent in the school area also outside the area studied, which makes it possible to reduce the global warming potential of the whole area more. If more dramatic changes would be made for the multifunctional school, adding foam glass aggregate would be possible to other structures also. As far as the cellulose wool is concerned, its panel variation could also be utilized in the wall structures to replace mineral wool panels.

6 RESULTS

This chapter presents the results of the material evaluation based on the theoretical research and the LCA. The results are compiled, and their relevance is assessed. The life cycle assessment of the multifunctional school differs from the conventional school, since the core structures includes a lot of transferable structures, such as walls. Conventionally these walls are fixed structures. Transferable structures of the multifunctional school included into life cycle assessment are made of glass and heavy fabrics. Therefore, these space dividing structures does not require plasterboard, concrete or wool, such as conventional walls.

From the theoretical point of view, it can be stated that there are numerous materials created from secondary resources, which are suitable for constructing. Not all materials from secondary resources cold be applied to building, while safety requirements must be taken into account. Many of the materials from secondary resources can be utilized for shaping and filling earth below the building as they occur as aggregate. Therefore, those materials are difficult to apply into the building.

Many aspects must be considered when evaluating materials. Sometimes it is impossible to achieve all the benefits at the same time. Therefore, it is important to prioritize those elements that are highlighted in the situation. In this research economic perspective is taken into consideration when alternative materials were selected by comparing products and prices of those. Economy is therefore the first priority. Range of alternative materials after economic comparison were narrowed substantially. As a one results it may be noted that in several cases materials from secondary resources are more expensive than conventional materials.

There are materials that improves environmental performance in several ways. As the foam glass aggregate proved in the LCA assessment both global warming potential and building circularity can be improved at once. On the other hand, natural stone paving represents materials that are able to improve only one of the desired environmental aspects.

6.1 Global warming potential

The results of the life cycle assessment said a lot about the benefits of individual materials. Materials form secondary resources can have low global warming potential, but also when they are implemented into building some carbon intensive materials are replaced whit them providing double benefit. A result of the global warming potential for the baseline scenario of the life cycle assessment is 1612 tCO_2eq. Global warming potential of other scenarios is smaller, indicating better environmental performance in the climate perspective.

When the differences between life cycle stages are so substantial in the perspective of global warming potential the most significant improvements can be achieved by intervening on the predominant life cycle stages. In this case, the most predominant stage is product stage. Needless to say, it is impossible for the builder of the school to change production of the construction materials therefore prioritizing those producers with more environmentally friendly products becomes important.

In Finland the transportation distances can variate between a few kilometers to 1100 kilometer when the materials are acquired from Finnish suppliers. Materials with better environmental performance can significantly reduce the amount of embodied carbon even if the distance between supplier and the construction site would be longer than where the conventional material are acquired. When the transportation provides opportunity to save great expenses it can affect negatively on material choices, which could make a significant improvement on buildings environmental performance. Some materials, such as thermal insulation does not change the transportation method or distance, so it does not affect the costs or GWP in that regards.

Cellulose wool provides the most significant improvements due to the area to which it can be added. Only adding inflatable cellulose wool for attic floor 4% of the overall global warming potential are reduced. The most significant single material in the perspective of reducing GWP, is foam glass aggregate with the value of 15.2 $kgCO_2eq/m^2_{\text{replaced material}}$. Also, the natural stone paving produced desired results reducing global warming potential. On the other hand, natural stone paving is the easiest material to replace the conventional one and it can be applied for the school area outside of the life cycle assessment without further research.

Then the results of the global warming potential can be exemplified by comparing it with some familiar processes. In 2015 new diesel and petrol cars generated 175 gCO_2eq/km in Europe (Helmers et al. 2019, 125). Based on the values of 2016, average Finnish citizen drives approximately 52 km per day (Kuisma 2018). On average Finnish citizen contributes global warming potential by 3.3 tCO2eq/year by driving a car. Impact on GWP of the school of Vähärauma is almost 500 times more significant. If the reduction of material replacement in scenario 3 is inspected in similar way, it corresponds 60% of the need of driving of an average Finnish person per year. Reduction of the scenario 4 corresponds to the driving needs of 38 people per year.

The result of the GWP of the school can also be compared with the total amount of generated to give comprehensive overview. In 2019 the total quantity of generated greenhouse gases was 52.8 MtCO2eq (Statistics Finland 2020). The GWP of the baseline scenario corresponds 0.03% of the total quantity of Finland’s greenhouse gases. These two example values put the results of obtained from the LCA into a perspective from which their significance is easy to reflect.

6.2 Building circularity

When it comes to the recyclability of alternative materials, there are huge differences between products. Re-used products are 100% recycled, meaning that the products are just transferred from construction site to another. Only a few suppliers have a selection of reused materials and there are not many re-used materials on the market. The supply of reused materials is not enough to meet demand. Due to uneven supply, re-used materials should not be used in multifunctional school but could be used for smaller buildings in the school area.

Some of the materials are made from recycled materials. The share of recycled components can variate depending on the manufacturer and product. However, circularity not only consist of the amount of recycled material, rather it takes into consideration every aspect of material circulation. As the LCA of building circularity proves, the actual benefits of the materials can be recognized after the inspecting the whole circulation of the material.

Life cycle assessment brought up the importance of returning materials efficiently. One important and relatively easy addition to increase building circularity is to implement more renewable materials into the building. Many elements of the multifunctional school could be replaced with renewable material such as wood, but it may increase costs.

The most astounding founding to the building circularity is foam glass aggregate. Although cellulose wool produced the greatest results in terms of global warming, it did not produce the expected results on building circularity. Cellulose wool was added for the greatest area, but the total score for building circularity is not preferable than in baseline scenario. The main reason of unexpected results is the lightness of thermal insulation. Thermal insulation is relatively much lighter than many other components of the school and building circularity is assessed on the mass-based aspect without material weighting. Results does not mean that cellulose wool would not be worthwhile in the circularity perspective, rather it contributes utilizing recycled materials instead of virgin ones. In the building circularity perspective, natural stones do not improve environmental performance.

6.3 Advantages of the use of the alternative materials

In this chapter is delved into results of each material used in LCA to replace conventional materials of the baseline scenario. Benefits and possibilities of each material are interpreted more extensively. In addition to GWP and circular economy, perspective of practical benefits that affects material selection of the multifunctional school are presented.

Foam glass aggregate as an alternative material brings many advantages alongside positive impact on GWP and building circularity. Due to its porous and airy structure, it acts simultaneous as an insulator and filling with good carrying capacity. One of the major advantages of the foam glass aggregate is the lightness of the material. Foam glass is easy to use and, thanks to its light weight, can be transported seven times as much as crushed stone at once. Construction process is faster because less work and equipment are needed. Foam glass aggregate can be installed simultaneously than crushed stone or it can be directly blown into the desired structure. In the circularity aspect, foam glass aggregate is re-usable material, so it contributes building circularity. Foam glass aggregate is also safe material for the use of multifunctional school. (Foamit 2020.) Because of all the advantages, overall costs can be even reduced when replacing EPS insulation and crushed stone aggregate with foam glass aggregate.

When the results of replacing inflatable rock wool of the attic floor with cellulose wool is that significant, implementing cellulose wool in other parts of school also would be worthwhile. In the structure definition, the internal and external wall insulators are installed as prefabricated panels. There are also cellulose wool insulation panels on the Finnish market that could be used to replace rock and mineral wool panels from other structures of the school. According to structure type definition, used insulation types of the external walls are Isover OL-E-33, λd=0,033 W/mK, Isover RKL-31 Facade λd=0,031W/mK and Kingspan Therma TW57. Those insulation panels have special features, such as wind protection, which is why they can’t be directly replaced with cellulose wool. On the other hand, internal walls include mineral wool insulation, which could be replaced with cellulose wool panels. With acquiring cellulose wool instead of mineral one huge improvement can be achieved in the climate perspective. With implementing more cellulose wool into the building, by replacing wool panels even more significant improvements can be reached. Changing the thermal insulation do not require any installation changes or extra work, so the change is easy. Cellulose wool not only reduce GWP, but also contribute circularity giving paper and carboard one more purpose before it is utilized for energy purposes after the end of life. However, the comparison is made for the inflatable wool of the roof structure, so for the comparison of the wool boards, further studies are needed to determine whether the benefits are as significant as for the inflatable wool.

Natural stone paving is the simplest replacement of the presented ones. It does not require more work, transportation or installation methods than the regular concrete paving. Although the natural stones are classified as virgin, they have considerable advantages over the highly processed alternatives available on the market. Natural stone paving has been used for centuries to construct yards, marketplaces and roads (Kivitori 2020). In Finland there are available natural stone for paving, which is manufactured from Finnish granite (Kivitori 2020), increasing the rate of employment. More significant improvements to the environmental performance on the GWP perspective can be achieved by adding natural stone paving for other parts of the school area also. LCA included only the building area of the school.

6.4 Proposals for the multifunctional school

In this chapter proposals for multifunctional school are presented in general. The addition of materials for the new multifunctional school is worth considering as they provide several benefits. The results of the life cycle assessment of the school of Vähärauma can be utilized as a guide for the multifunctional school. For the individual materials studied in life cycle assessment, the utilization of the results for a multifunctional school is easiest by using the results presented in figure 17. This way the results can be scaled to the fit the dimensions of the multifunctional school or any other similar building. In the LCA renewable materials are not studied. However, implementing renewable materials is recommendable, in the perspective of material efficiency.

Materials below the surface of the ground were left out of the study, but in Finland most of the materials from secondary resources are in the form of aggregate. Implementing these materials under the school or in the yard area would be worth studying to improve the environmental performance. It can be stated that these materials at least increase the use of recycled materials.

When choosing construction materials, it is important to familiarize yourself with the supplier and the efficiency of material production for both alternative materials and conventional materials. Different suppliers and manufactures have enormous differences in production stage even if the product seem similar. One of the proposals is to prioritize those suppliers, who offsets their emissions. Offsetting involves measuring emissions and then acquiring equivalent credits from programs that take action to prevent or reduce GHG emissions elsewhere (Vidal 2019). For example, there are concrete suppliers who does it.

When concrete is essential material in the multifunctional school, environmental impacts could be reduced by favoring suppliers or producers who does invest on offsetting.

Another perspective to be considered while choosing materials from the wide range of suppliers is the energy use of the production stage. Energy use is one of the most important influencers on the GHG emissions in the product stage. Product stage related GHG emissions could be reduced by replacing fossil-based energy production methods with renewable energy. Therefore, prioritizing those suppliers and producers who use renewable energy either partially or completely for their production.

7 DISCUSSION & CONCLUSION

In this chapter final discussion and conclusions of the results are presented. Discussion and conclusions are based on theoretical and empirical research on the subject.

7.1 Discussion

The number of materials that can be used to build a school is not yet very large, but research is being done on an ongoing basis. In the theoretical point of view, it seems that there are plenty of materials, which would improve environmental performance of the multifunctional school. Economic considerations place the greatest constraints on the range of materials, as alternative materials tend to be slightly more expensive than conventional ones. Nevertheless, even a few material replacements can improve buildings circularity and reduce the quantity of greenhouse gases generated when the material selection is made by carefully researching alternatives.

All materials from secondary resources does not reduce GHG emissions even if those would increase building circularity. Even if LCA research did not produce such results, theoretical research revealed that some materials from secondary resources are actually increasing the amount of generated GHGs due to high energy requirement for processing. Therefore, the role of studying each material case-by-case is highlighted.

Life cycle assessment of the building was used successfully to evaluate material efficiency of the school building in several scenarios. With life cycle assessment determining the most beneficial materials from secondary resources in the perspective of GWP and building circularity was possible. Results of the baseline scenario supports the fact that material efficiency is in a key role to reduce environmental burdens caused by building sector when most of the impact are caused by product stage where construction materials are manufactured. All created scenarios which represents achieved benefits of implementing alternative materials produced positive results by reducing the greenhouse gas emissions when compared to baseline scenario. Also, other alternative materials than natural stone for paving also increased building circularity.

Results of the research can be considered reliable, but it must be noted that LCA was applied into building, that does not exist yet. Therefore, data used in LCA is based on estimations of quantities and known dimensions of the school of Vähärauma. LCA of the existing building would be more accurate and results may differ from conducted research. To achieve further reductions in terms of GWP further research of the use phase would be required. In the perspective of alternative materials, this study does not comment on aspects related to their maintenance and repair, as they are assumed to be non-existent. Further studies on the service life of these materials are recommended.

7.2 Conclusion

In the building circularity and GWP perspective great improvements can be achieved by applying alternative materials into the building replacing conventional ones. It is possible to achieve more dramatic results within this framework, but in some point of the transition towards sustainable construction, priorities should be changed more environmentally friendly rather than economical to enable sustainable development to be continued. When environmental friendliness is at the bottom of the pyramid, the economy develops in time to keep up with it. Thus, in the long run, these two perspectives can be seen as coherent.

8 SUMMARY

The construction industry contributes greatly to the extraction of materials. In addition to material extraction construction sector is responsible of approximately 30% of total greenhouse gas emissions generated in Finland. Around 40% of Finland’s energy consumption is related to the construction sector. Because the construction sector is so relevant in the large-scale new methods of taking the environment into account are constantly being introduced. Since 2020 EU obligates that at least 70% of construction and demolition waste must be recycled. This obligation and environmental burdens caused by building sector are some of the reasons why new innovations to improve material efficiency are constantly being developed. One of the pathways is to use recycled materials again as construction materials.

Applying these new materials into the building can be challenging due to construction sector value long-term supplier relationships. Some of the conventional materials have been used for hundreds of years, which means that builders are familiar with those. Some of the most common construction materials such as wood and concrete are in key part of constructing a new building. In Finland, thermal insulation is also one of the essential parts of the core structures of a building. In order to take actions towards material efficiency in construction sector, new innovative material solutions must be studied.

As case buildings there are two similar schools to be built in Pori. Both schools utilize very common construction materials as the preliminary project plans shows. Planning of the school of Vähärauma is little further than the planning of the multifunctional school. Implementation of materials from secondary resources can be studied theoretically and by using LCA for material evaluation for the school of Vähärauma. However, the planning is already in that point that results can not be utilized in that school. Due to the similarity of size, building type and core materials, the results can be used as a guide for the material selection phase of the multifunctional school. The aim of the multifunctional school is that convertible premises offers modern premises for students to learn. Also, the rate of use is designed to be higher than in conventional school and therefore it provides services, such as dental services, recreational sport premises and library, for other residents of the city in afternoon hours. Both the multifunctional school and the school of Vähärauma are concrete based buildings. Not only core structures are similar, but also number of floors and users, available services, building area and solutions to make premises convertible. Material efficiency is thus studied theoretically and with the help of LCA to find out how and which materials from secondary resources can be utilized in the multifunctional school construction.

There are already wide range of materials which are produced either partly or completely from secondary resources. Research and product development continue, and thus new materials are constantly entering the market. Some of the solutions are highly innovative and others utilizes materials from secondary resources in a simpler way. In order to new materials to be able to be used in construction, they must meet certain safety and quality requirements that variates depending on the country which they are operating. In Finland there are certain requirements for implementing materials from secondary resources, which must be followed so that the building is permitted to be constructed.

Most of the materials from secondary resources available in Finland can be used only for shaping the earth beneath the construction. However, the study is limited to materials that could be used in the building itself, not beneath of it narrowing the range of materials from secondary resources. Some of the main criteria while choosing the alternative materials for further investigation by LCA are cost efficiency, material efficiency and assumed environmental benefits in the field of chosen indicator. Range of alternative materials were once again narrowed a lot. Thus, the most potential individuals stand out and were selected for further inspection by LCA. Only three materials are chosen, while each of them needs their own scenario to be created. This by no means reflect that other potential and profitable materials from secondary resources would not be available in Finland.

LCA is method that can be used to evaluate product’s or service’s environmental performance during its whole life cycle. Life cycle assessment can also be applied into building level studies. It is important in the life cycle assessment to follow the standards so that the results become consistent and can be compared with each other. Four main phases of life cycle are: goal and scope definition, inventory analysis, impact assessment and interpretation. These four phases occur in both traditional LCA and LCA applied into building level. When LCA is applied into building life cycle can be then divided into four stages: product stage, construction process stage, use stage and end of life stage. Different processes in these stages are divided into modules, so the impacts can be tracked to it sources. To study the significance of the results one or several indicators can be in the impact assessment phase. Indicators are chosen on that basis that what is the desired area of protection. In this life cycle assessment, the global warming potential is the indicator chosen to assess the impact, as the aim is to identify the effects of the building on the climate. There are several tools for life cycle assessment in building level, where One Click LCA is the one used in this study. Alongside of chosen indicator global warming potential, material circularity of the building is being researched to give comprehensive view of school's material efficiency.

The goal of the life cycle assessment of the case school is to find out if the material efficiency of the school could be improved by applying alternative materials to replace conventional ones. Therefore, five scenarios are needed, where the baseline scenario represents the school as it is intended to be built. Next three of the scenarios are exactly similar with the baseline scenario but one relevant construction material is replaced with the alternative one. Last scenario in turn presents the school if all three alternative materials would be applied into the school at once. In the life cycle assessment compiled to the school of Vähärauma only the core structures of the main building are considered. Materials to be used in the yard or below the surface are left out of the assessment.

The LCIA phase includes construction materials, areas and other essential data for continuing the LCA. The LCA is based on the areas of the school which are roughly estimated, because the planning is still ongoing and the real quantities of materials to be ordered are not available. Some assumption must be done, when all suppliers are not defined, but all used data is based on the information obtained from PRIS. Transportation distances, construction process actions and end of life treatment is based on the Nordic averages provided by the One Click LCA. In addition to conventional materials, data of selected alternative materials are presented with the area of implementation. Chosen materials are foam glass aggregate to replace EPS insulation and crushed stone on the ground floor, inflatable cellulose wool to replace stone wool of the attic floor and natural stones to replace concrete ones where paving occurs.

In the GWP perspective most remarkable results is achieved in scenario 4 where all alternative materials were implemented at once. The most remarkable single material is cellulose wool due to area of in which it is used to replace stone wool. When results are scaled for one square meter turns out foam glass aggregate provides the most significant improvements in terms of GWP and building circularity. All scenarios provided only positive impacts on building's GWP and building circularity.

Results of Life cycle assessment supports the idea of replacing conventional materials with the alternative ones. All materials included into LCA can be recommended for the multifunctional school, without them changing the cost efficiency of the project notably. Presented alternative materials does not require time consuming structural changes, expensive material acquiring or challenge installation process.

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