Integrated sustainability assessment methodology for heritage: *Is there a way to integrate the value assessment with the life cycle assessment to get an integrated method to measure sustainability in heritage projects?*

Abstract: This paper will focus on defining an integrated methodology to measure sustainability in heritage buildings. The research will focus on the Life Cycle Assessment; this assessment is one of the most common methods to measure sustainability in different processes. After that it will look at a value assessment and see how these two methodologies can be combined. Integration of both assessments is possible in the early phase of the life cycle assessment. Reusing a building is always better than to construct a new building with the same properties. The main impact on the environment occurs in the operation phase, where the materialization has the biggest impact on the direct biodiversity. How both assessments can be combined will be further explained during this paper.
Keywords: Life Cycle Assessment, Heritage, Integrated methodology for sustainability.

Introduction: The built environment in the world has quickly grown into a complex grid of functions, housing, transporting network. Worldwide the built environment is responsible for 40 per cent of the total energy demand, depletion of resources and greenhouse emissions, to understand what causes these demands we have to understand the processes behind the built environment (OECD, 2003). The life cycle assessment (also referred to as LCA) is a methodology to measure the sustainability of these processes. The methodology of the LCA is accepted all over the world as one of the leading methods to define sustainability. The methodology is broken up in four phases; firstly the goal and scope are defined. After that the inventory analysis has to be made, in this phase all the elementary flows of each material are analyzed and defined. In the third phase, the impact assessment, calculations are made to see what the impact is on the environment. In the last phase, interpretation phase, conclusions are drawn. The life cycle assessment is an interactive assessment where during the research changes in each phase can be made.

Where the assessment is one of the best ways to calculate the impact of an object on the environment, it runs into trouble when heritage buildings have to be calculated. The numerical assessment does not take heritage values into account. During this research we will try to identify the possibilities to combine the value assessment for heritage with a life cycle assessment. The question asked during this research is: To what extend can a life cycle assessment be used to value heritage sites that will be renovated to a sustainable center, and where does a LCA has it shortcomings? The question will be answered after a theoretical understanding of the life cycle assessment and a case study, where this assessment is used on the question reuse versus newly built buildings. In section one, we will look into the history of sustainability and where our present definition of sustainability was created. In the second chapter we look closer at the different kind of phases each building has. During these phases we will define the different elementary flows and how these impact the environment. In chapter three till six we will describe the different phases of the life cycle assessment. The paper ends with a case study and a conclusion on how both assessments can be combined.
The methodology used to answer the question in this paper will be a study of literature and the use of a case study as example how the LCA is applied. The literature will be used to get a theoretical understanding of the life cycle assessment.

1. When did sustainability became a dominant topic:

Around 8000-10000 BC. the first agrarian communities emerged around New Guinea, South America and larger communities in China and India. These communities settled in a place and lived there for a certain time (Marsh, 1864). The survival of these communities relied on a stable way of providing food, water and other resources. These people already understood the meaning of the natural environment on their survival, everything they need relied on it . One of these early communities established to settle in Sri Lanka till 307 BC, this community were able to sustain themselves to live in a harmonious way with nature (Mackee, Obbard, & Briffett, 2001). The most accepted meaning of sustainability, development which meets the needs of current generations without compromising the ability of future generations to meet their own needs (Unece), already can be applied on these early communities.

During the 18th and 19th century the industrial technologies took a leap forwards. Man were able to extract new resources from the earth on a bigger scale this made the use of fossil fuels a more common thing. During this period the Romantic movement, that were most active between 1800 and 1850, expressed their concerns of the impact that the industrial revolution had on the environment. We can say that this movement was the main reaction on the industrial revolution (Britannica). Their believes were that having a close connection with nature would be mentally and morally healthy. At the end of the 19th century Eugenius Warming was the first person to study the relationship between plant and environment, contributing knowledge un the topic sustainability (Goodlang, 1975).

In the early 20th century economists began to think of resource management, this ended up in two rules. The Hotelling's rule sad something about the most socially and economically profitable extraction path of resources. It stated that the price of an resource would rise when the interest and sale of the resource grew (Hotelling, 1931). The second rule was the Hartwick's rule, this rule sad something about the investment we have to make in capital, to offset the loss in declining stocks of non-renewable resources (Hartwick, 1977). Both rules says something about the valuing of non-renewable resources and what is needed to replace them.

Near the end of the 20th century the global awareness grew for a sustainable way for development. The United Nations asked for an independent organization that would focus on the environmental problems and address the topic of sustainable development solutions. In 1984 the resolution got approved and the new commission was created, the Brundtland Commission formally known as the World Commission on Environment and Development (EPA). Goal of the organization was to identify sustainability problems worldwide, create awareness of these problems and search for solutions and how these solutions could be implemented. The Brundtland Commission criticized the former definitions of sustainable developments. In the former definitions they saw the environment and developments as two separated things. The commission saw this differently "…the "environment" is where we live; and "development" is what we all do in attempting to improve our lot within that adobe. The two are inseparable" (Brundtland, 1987). To create an equal worldwide way of sustainable development they created a framework that can be followed by each country, upcoming economies and advanced ones. They presented this framework in a report at the next climate summit in Rio de Janeiro in 1992.They redefined sustainable developments as: developments which meets the needs of current generations without compromising the ability of future generations to meet their own needs (Unece). This definition is the most widely accepted definition for sustainable developments nowadays. In the years after the Brundland commission redefined sustainability, a few methods were developed and accepted worldwide. Methods like Life Cycle Inventory, Life Cycle Assessment, Ecological Footprint Analysis, Cradle to Cradle, Dematerialization and Decarburization. The life cycle assessment is one of the most complete assessments when looking to the impact that a building has through the different lifecycle phases.

2. Life cycle stages:

Each object in the built environment goes through five stages throughout its lifespan, where each stage has its own unique impact on the environment. To understand how each phase impacts the environment they will be shortly explained.

Raw material extraction phase:
Each element needed for a building is created out of raw materials such as iron ore, limestone, copper, timber and water. Some of these materials got processed in other components needed in building like steel and cement. Most of these materials take a long time to form in the earth's crust. In most cases the extraction of these raw materials is greater than the reserves making it impossible to get a balance between extraction and creation. In the long run this will end up in the depletion of the resource, these resources are labeled as non-renewable materials, materials such as iron ore, limestone and petroleum fall within this group. Taking iron ore as example, on an annual basis the extraction of iron ore in the world was 3.2 billion tones in 2015 (Survey, 2005, p. 85) whereas the currently accessible iron ore reserves lay around 230 billion tones. Depletion of this resource has been estimated by (Brown, 2006, p. 109) to be within 60 years from now.

The depletion of resources is not the only impact this stage has on the environment. During the process of extracting resources a great amount of energy and water is used, the energy needed relies mostly on fossil fuel, another non-renewable resource. Secondly the remaining landscape after the extraction is done, after the materials are depleted in the mines the corporations leave the site leaving behind a contaminated landscape. Loss of biodiversity and landscape, contaminated ground water with a high concentration of chemicals and erosion is left behind. The impacts of these facets last for years after closing of the mine (LCA ITBE, 16).

Manufacturing phase:

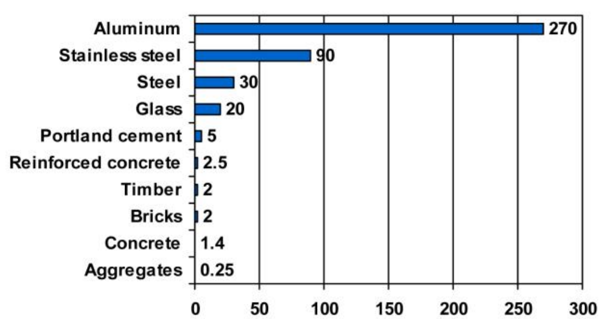

Figure 1, Energy data sheet (NRMCA, 2008)

In this phase the raw materials get converted to more useful products like concrete, steel, aluminum and glass. The manufacturing phase is one of the most energy intensive phases. For example 65 per cent of the embodied energy in concrete is needed to make cement (Zapata & Gambatese, 2005), in the total process of making a ton of cement 5 Giga Joule is used. This is a small fraction of the embodied energy in stainless steel or aluminum, that are sitting around 90 GJ per ton stainless steel and 270 GJ per ton aluminum (NRMCA, 2008, p. 8). These numbers has to be put into perspective because the amount of aluminum used in a building is far less than the amount of concrete. The impact on the environment is done mainly by the way the energy is being produced. The biggest problem of the energy consumption is the quantity needed. Today this is easier to produce by non-renewable energy sources like coal power plants.

Construction phase:
Where the materials being used during construction are already finished in the manufacturing phase, this phase still uses large quantities of water, energy and waste. This phase is characterized by its complexity and the use of various technologies. Typical for this phase is the amount of waste produced due to human error, accidental damage, off-cuts (Crawford, 2011, p. 18).

Operation phase:
After the first three phases the building is completed and it can be used. The operation phase is most of the time the longest phase. For a common living house this phase is characterized by energy and water usage for daily use. The impact on the environment can easily be brought back in this phase when sustainable technologies are used. Also how the building is designed in the first place contribute to the impact the building has during this phase. Zoning the right rooms at different facades helps the consumption of energy during day- and nighttime. Water can be collected and reused and energy can be produced by solar cells, wind energy or other sustainable energy sources. This phase also included all the maintenance and refurbishments done on the building (Crawford, 2011, pp. 18-20).

Demolition phase:
For every building there is a moment where reusing/ refurbishing comes to an end. Materials that are at their end and can't be repaired, the new demands of the users or the technological advancements are influences when this moment occurs (Langston, Wong, Hui, & Shen, 2008). The impact that this phase has on the environment is mostly determined on the quantity of materials that can't be reused and the way the other materials are processed. While reusing materials reduce the use of new materials it also has and environmental impact.

Knowing the flows in the different phases of a building allows us to make calculations and improve it. The life cycle assessment is one of the most complete assessments when looking to the impact that a building has through the different lifecycle phases. By understanding this assessment it is possible to design/improve a building that has a minimal impact on the environment without losing the balance between user and design. The life cycle assessment consists out of a framework with four different phases linked to each other. These phases will be studied in the next chapters, after that we will look at a case study and see how the method can be applied when dealing with heritage sites.

What makes this procedure of steps an assessment lays in the cyclical process of interpreting and valuing the outcome and adjusting different components in the four phases to get to the best solution.

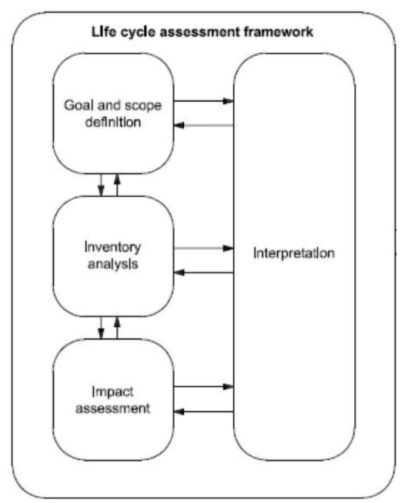

Figure 2: Stage life cycle assessment (ALCAS, 2015, p. 11)

3. Goal and scope:
This is the most important phase in the life cycle assessment. The purpose is to define what the research goal is, and what boundaries the assessment needs to get the right calculations and conclusions. The phase itself is divided in two parts: the goal, where the intentions of the research is made clear and the scope, who defines the approach, boundaries, assumptions that have to be made and the limitation that can occur when researching the questions.

The goal states:

- The intended application
- The reasons for carrying out the study
- The intended audience
- Whether the results are intended to be used in comparative assertions intended to be disclosed to the public. (14040 International Standard, 2006, p. 11)

A life cycle assessment can be done on all fabricated systems; we will focus on the built environment alone. When defining the intentions of a LCA, looking only on the built environment, can variate on different scale. For the large scale you can research what kind of building has the least impact on the environment. On smaller scale you can research what building material has the least impact, for instance a wooden construction versus a steel construction. In both cases the LCA is done to research what design solution has the least impact on the environment. When looking at heritage sides such as Westfort (working with an existing monumental environment), we can define a few goals, for a better understanding on how the scope works, there are three examples that can be applied to a site like Westfort:

- A life cycle assessment to research if replacing the declined objects such as facades, wooden frameworks and roofs or restoration of these objects has the least impact on the environment.
- A life cycle assessment to research on the operation phase of the current buildings, how much energy and water are used during this phase and how can we improve this by applying for example a better thermal skin or water/energy saving measurements.
- What is the environmental impact of increasing the density of Westfort, and what design is best suited here.

Research studies like these are done to get a better understanding on the impact that design solutions have on the environment while retaining the heritage. The audience we address for this research is primary the designers and clients as well for the people involved from government functions and heritage institutions. In the end we want to formulate the best solutions suited for the environment as well for the heritage and address these solutions in a report.

The scope:
The main function of the scope is to further define the boundaries and calculations that have to be done. A LCA is an interactive technique where the scope can change during the research. When starting the life cycle assessment the first boundaries are defined. This is a hypothesis, where some assumptions are been made. During the calculation phase the problem can occur that the data does not match the goal defined for the research. In this case the scope has to change, changes in the scope such as the system boundaries or impact categories are common during this process. (14041 International Standard, 1998, p. 4)

In the scope to following expect are further defined:

- The product system to be studied
- The functions of the product system
- The functional unit
- The system boundary
- Allocation procedures
- Impact categories selected and methodology of impact assessment, and subsequent interpretation to be used
- Data requirements
- Assumptions
- Limitations
- Initial data quality requirements
- Type of critical review, if needed
- Type of format of the report required for the study (14040 International Standard, 2006, p. 11)

System boundaries:
The first step of the scope is to identify the system boundaries. Explained earlier there are five different phases in the total lifecycle of a building:

- Raw materials acquisition phase
- Material manufacturing phase
- Construction phase
- Operation phase
- Demolition phase

Each of the phases is characterized by their own waste flow and impact on the environment.

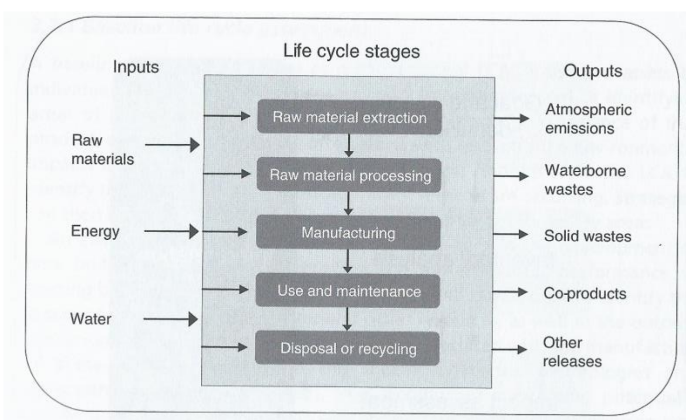

Figure 3: Input and Output flows lifecycle (Crawford, 2011, p. 18)

Not all the phases have to be included in each LCA. How the goal is defined in the first step will define the boundaries of the LCA. For instance looking at the second example for Westfort;

“A life cycle assessment to research on the operation phase of the current buildings, how much energy and water are used during this phase and how can we improve this by applying for example a better thermal skin or water/energy saving measurements.”

When we do not consider that recycling of materials is an option we can leave the demolition phase out of the calculation where the other four will be used. Just calculating the operations phase will not be enough in this case, because of the reason we add extra measurement to save energy and water. These measurements normally need materials, the embodied energy of these materials have to be included the get the most reliable calculation. We include the embodied energy because fabricating the materials take energy, sometimes more than the savings it give during the operation phase.

Impact categories selection and methodology of impact assessment:
To get a useful comparison of the data calculated in the second phase of the LCA the impact categories have to be identified. There are ten common impact categories that can be chosen from, these categories are again related to the goal that we want to be achieve in a LCA (Crawford, 2011, p. 55).

Impact category	Definition
1. Global warming	Increase in the Earth’s average temperature
2. Depletion of minerals and fossil fuels	Consumption of non-renewable energy or material resources
3. Photochemical oxidation (smog)	Emission of substances to air
4. Human toxicity	Human exposure of an increased concentration of toxic substances in the environment
5. Ozone depletion	Increase of stratospheric ozone breakdown
6. Eutrophication	Increased concentration of chemical nutrients in water and on land
7. Water use	Consumption of water
8. Land use	Modification of land for various uses
9. Acidification	Emission of acidifying substances to air and water
10. Eco toxicity	Emission of organic substances and chemicals to air, water and land

By choosing one of the impact categories data can be compared between the calculations. For the first research goal of Westfort, where the impact is calculated for replacing or reusing specific objects. An impact category like depletion of minerals and fossil fuels can tell more than eco toxicity. It many cases multiple impact categories can be choses, for instance the third research goal for Westfort: “What is the environmental impact of increasing the density of Westfort, and what design is best suited here.” Categories as; depletion of minerals and fossil fuels, global warming, water use and land use can be chosen. Weighting each category with each other is necessary when calculations are done over multiple categories.

Functional unit:
Defining of the functional unit or performance characteristics is needed to get comparable data in the second phase of the LCA (European Environment Agency, 1998, p. 55). Each building consists of separate parts like foundation, floor, walls, doors, windows and roof. For each part there is an optimal unit to measure the quantity of it. For walls this can be per meter wall and for floors and foundations square meters are often used.

Data quality:
Defining to what extent the quality of the data have to be is naturally reflected in the quality of the final assessment. There are five different indicators to test the quality of the data:

- Precision: measure of the variability of the data values for each data category;
- Completeness: percentage of locations reporting primary data from the potential number in existence for each data category in a unit process;
- Representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest;
- Consistency: qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis;
- Reproducibility; qualitative assessment of the extent to which information about the methodology and data values allows an independent practitioner to produce the results reported in the study (European Environment Agency, 1998, p. 57).

This stage of the scope is important to qualify how scientific underpinned the life cycle assessment will be.

Limitations:
The biggest limitation for each life cycle assessment are time and money. The time and research done in the second phase of the LCA, the inventory analysis, consumes allot of time. The more time spend in this phase create quantitative and qualitative better data that can be used during the calculations.

4. Inventory analysis:

The most time consuming and hardest part of the LCA when done right is the inventory analysis. In this phase you identify the different material flows and the data associated with these flows. For each material used during construction, data needs to be collected for input flows (energy, water and raw materials) and output flows (emissions to air, discharges to soil and water and quantity of waste material)(Crawford, 2011, p. 81).

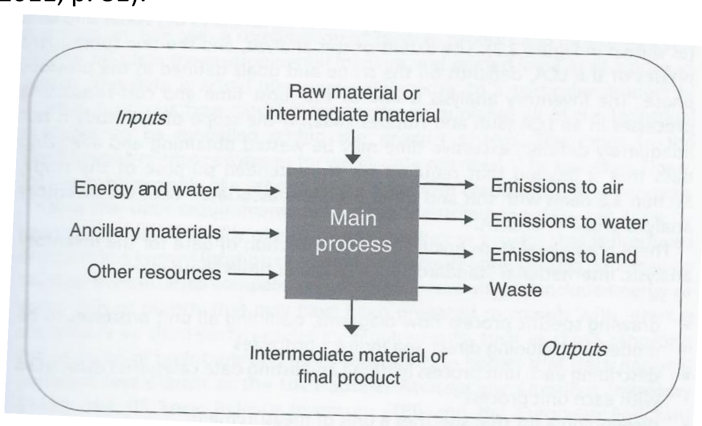

Figure 4: Input and Output flows per phase (Crawford, 2011, p. 18)

The best way to start this process is by making flowcharts for each material, identifying what input and output each stage has and retrieving the data. Manufactures of the materials are the best source to start with. For steel as example you start with the last one in the chain, steel beam manufacturer. From there you go further back to the furnaces and end up at the coal mines. For each step you have to identify the different input and outputs leaving in the end an overview of the complete chain.

Standardization or databases can be used during this process but will influence the precision of the calculation in the end.

5. Impact assessment:

In the impact assessment the calculations of the inventory analysis will be compared to a reference system, this is done in specialized programs. The methodology behind the programs follows several international guidelines. The reference system is based on a reference unit for each impact category; the different categories are shown in the picture.

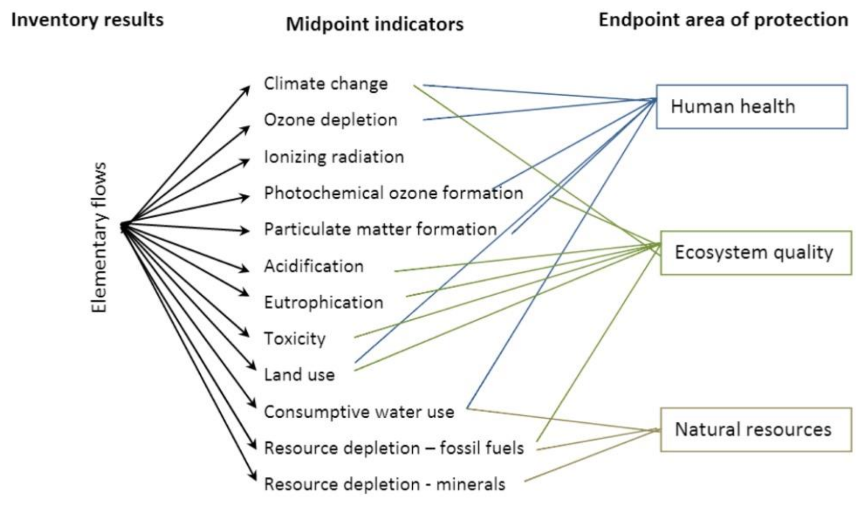

Figure 5: Impact categories (Renoef et al., 2015, p. 12)

Each impact category is influenced by several substances, where each has its own impact on the environment. Looking at the category climate change substances like: Carbon dioxide (CO_2), Methane (CH_4) and Nitrogen dioxide (NO_2) are the most common ones, but the list is allot longer with over 30 known substances that influence the climate change. Each substance has its own impact Methane for example inflicts 62 times more damage than the same amount of Carbon dioxide (Albritton, Derwent, Isaksen, Lam, & Wuebbles, 1996). Most of the impact categories follow the methodology of the Institute of Environmental Sciences University of Leiden (further referred to as CML) where a few follow a different reference system. In the following part each category will be explained further and what reference system is used the most in practice.

Global warming:
The main impact that humans have on the global warming is through release of greenhouse gases (further referred to as GHGs). Although there are other sources that contribute to global warming such as aerosols and black carbon they are rarely included to the climate impact assessment. The most common GHGs are CO_2, CH_4 and N_2O, but a great variation of hydrocarbon GHGs are included. The GHGs leads to accumulation of the atmosphere, where more solar radiation is absorbed in the ozone layer and re-emitted as heat to the earth, rising the global temperature and effect a chain of events like polar ice melting, change in rainfall patterns ect. The main source of GHGs is fuel combustion, which is associated with almost all human activity (Renoef et al., 2015, p. 16).

In practice the most common method is the one developed by the Intergovernmental Panel of Climate Change called the Global Warming Potential (GWP). They use the amount of kilograms CO_2 as reference unit over a time span of 100 years.

Resource depletion:
Resource depletion can be categorized into biotic and abiotic resources, both can be split into subcategories (Finnveden, 1996):

Abiotic	Biotic
Deposits e.g. fossil fuels, mineral ores **Aquifers, sediments, clay, peat, gravel ect.** **Funds e.g. ground water, lake, soil** **Natural flow resources e.g. air, water, solar radiation and ocean currents**	Funds e.g. fauna and flora

Both categories have renewable and non-renewable resources, the calculation of the non-renewable resources are the most interesting ones, non-renewable is in this instance where the current rate of use is bigger than the reserves. Looking at the abiotic resources these are the deposits and for biotic resources the harvesting of the rainforest.

As reference method created by the Institution of Environmental Sciences in Leiden is the most recommended one, using the atom Antimony (Sb) as reference unit (BRE, 2005, p. 3). CML has two ways to quantify the impact, for solid resources like ores sediments and clay the equivalent to Antimony in kilograms is used. For fossil fuels or other combustible resources the amount of energy is calculated in mega joule (Renoef et al., 2015, p. 20).

Ozone depletion:
Ozone depletion is focused on the depletion of O_3 molecules in the stratospheric layer. This layer ranging from an altitude of 10-40km is one of our protection screens for ultraviolet radiation. This radiation decreases our immune system and increases the chance on skin cancer. O_3 is an extremely reactive molecule formed out of O_2 and O atoms, the presence of these ozone molecules is due an ongoing reaction of breaking in the stratospheric layer this process is normally balanced out. Through ozone depleting substances like chlorofluorocarbons (CFCs) who react with the O_3 the system get out of balance and more ozone is broken down then made. As a reference system defined by the World Meteorological Organization is the most common one in practice, using the reference unit chlorofluorocarbon-11 expressed in kg CFC-11 equivalent (BRE, 2005, p. 4).

Photochemical ozone formation (smog):
Where ozone depletion in the stratospheric layer is a problem, ozone formation on ground level can also occur. O_3 on ground level has a damaging effect on plant and human health resulting in irritated eyes and problems with breathing. Ozone can form on ground level due the reaction between organic compounds and hydroxyl radicals (OH). The reference system used is made by the United Nations Economic omission (UNECE) using kilogram ethane (C_2H_2) as reference unit equivalent (European Environment Agency, 1998, p. 86).

Acidification:
Acidification captures the impacts of acidifying of water and air. Substances accounted for acidifying are Nitrogen oxides and Sulphur oxides. When reaction with water or soil the PH drops making it acidic, this can lead to depletion of fauna. The phenomenon acid rain is also caused by this reaction with water in

the air. The most followed reference system is the one created by CML and uses the kilogram Sulphur dioxide (SO_2) equivalent as reference unit (BRE, 2005, p. 3).

Eutrophication:
Eutrophication captures the impact of nitrates (N) and phosphates (P) on water and land. Where both are crucial for containing life, a concentration to high will encourage algae growth and depletion of oxygen in water. The eutrophication is an important impact category when dealing with disposal of organic compounds (livestock production, food processing, and wastewater treatment and disposal ect.). Also the combustion of fuel creates nitrogen and phosphates. So in general when dealing with production systems the eutrophication impact should be accounted for. The most followed reference system is the one created by CML and uses the kilogram phosphate (PO_4) equivalent as reference unit (Renoef et al., 2015, pp. 25-28).

Toxicity:
Toxicity captures the impact of toxics to humans and to the ecosystem. The most common substances being toxic are pesticides, heavy metals, hormones and organic chemicals (Renoef et al., 2015, p. 33).The impact for humans as well as the one on the ecosystem use the same reference system, the one created by CML and uses kilogram 1,4 dichlorobenzene equivalent as reference unit (BRE, 2005, pp. 3-4).

Water use:
The scarcity of water is becoming a bigger problem, globally water use has increased twice the rate of the population (Water, 2012), where most of the watersheds used to provide us with fresh water already have water stress. Due this new problem old reference systems did not work anymore. The BRE Environmental Profiles methodology has changed its parameters for water use. In their new approach they include all water extraction except:

- Sea water
- Water used industrially and returned with no change in quality
- Water stored in storing lakes
- Rainwater collected

The measurement unit stays the same as m^3 of water (BRE, 2005, p. 6).

6. Interpretation:
Interpretation is the last phase of the LCA, this phase is in interaction with the other three phases and can't be separated. During the LCA process, conclusions can already be found during the calculation phase, making small adjustments can already occur, this is the interpretation we give to findings. The process of interpreted the data can be separated in three steps:

- Identify the significant environmental issues
- Evaluate the data of these issues for completeness, sensitivity and consistency.
- Check if the conclusions meet the goal and scope of the LCA if the data does not match the goal and scope of the research, the researcher has to go back to step 1 and 2 till it does.

Identify the significant environmental issues is done by structuring the data. Using diagrams and shards is an easy way to structure the different inputs and outputs of the model. This has to be done to both the inventory analysis and the impact assessment, to make the information easily analyzable for other researchers.

Evaluation, this is the second step, involving three elements. Starting with a completeness check, this qualitative check of the data and processes has to be done to check what the consequences are of the data gaps in the inventory phase. Sometimes it is impossible to find the complete data stream of a material, the completeness check is done to see if more data has to be collected for the inventory phase or not. The sensitivity check is the second part of the evaluation and focusses on the effect of variations in the parameters. Small changes in the inventory phase can have significant results during the environmental impact phase. To identify these parameters that influence the impact on the environment can help to improve the design. The last step of the evaluation is the consistency check. The objective of this step is if the methods, procedures and treatment of data are done consistency during the research. This can be compared with other studies as well, see if there methodology, procedures and data collection are different to yours.

The identifying and evaluation phase are constantly done during the research. These two ways of interpretation helps to improve the LCA process and finally the outcome of the design.

The last part of the interpretation phase are, the conclusions and recommendations. This follows the standards for normal research done. The most important part is to find a clear way to present the conclusions to a larger audience (European Environment Agency, 1998, pp. 68-72).

7. Case study reuse or new constructed residential living United States:

The Preservation Green Lab did a research on the life cycle assessment related to building research. This research focusses on the difference in environmental impact between new built houses versus reuse / refurbished houses. To see how this LCA is used in practice I will use one of their examples as case study. This study is choses because it is one of the most detailed ones done on reusing buildings. There are not many other studies that had the resources to make this assessment. Secondly the study is done on multiple climate zones in the United States, this helps us to see what the impact of the climate is on the end results. The data can't be compared to Westfort because of climatically different and materialistic differences. The built environment in South Africa is also different than the one in the United Stated. The case study can be used to get a global understanding how a LCA can be done on the built environment and the results can be used to get a possible outcome in the case study Westfort.

The research was focused on a few different kinds of buildings such as: Single-family Residential, Commercial Office, Warehouse, and Elementary Schools. For this case study we will only look at the research done on the Singe-family Residential, in total they took four different cities in the United States with different climate properties. For the residential houses they defined the following scenarios:

- Newly built house with normal energy performance.
- Newly built house with advanced energy performance.
- Rehabilitation-and-retrofit of an existing building with normal energy performance.
- Rehabilitation-and-retrofit of an existing building with advanced energy performance.

In the case of advanced energy performance extra energy efficiency measures are taken to decrease the energy use during the operation phase with 30%.

The boundaries of the research were defined as followed:

- Rehabilitated and newly constructed buildings are assessed of the total life span, extraction of material till demolishing the building
- The 'new built building' scenario include the complete demolishment of the previously existing structure
- The 'rehabilitation-and-retrofit' scenario includes any demolition necessary for building improvements, renovation and retrofitting.
- In both scenarios energy use and replacement of materials due to normal wear and tear are included throughout the assumed 75-year life span.
- All impact categories are assessed and evaluated (Frey et al., 2012, p. 28)

Data collection of building materials was done by the Ecoinvent database v2.2 (SCLCI 2010). This database has a reliable source for materials that do not exist out of multiple components. To remain the consistency and efficacy in data sources the model assemblies the multiple component materials as single components.

The building properties for the new constructed as for the rehabilitation and retrofit building were as followed:

New constructed residential	Rehabilitation and retrofit residential
Space summary: Square footage: 2360 (220m^2) **Program:** 3 bedrooms, 2.5 bathroom, below-grade partial basement	**Space summary:** Square footage: 2479 (230m^2) **Program:** 3 bedrooms, 2.5 bathroom, below-grade partial basement. (added master bath and kitchen expansion)
Core and shell: **Structure type:** dimensional lumber, prefab truss system **Envelope:** 2x6 wood framing, batt insulation, wood windows, cedar shingle roofing **Cladding:** Cedar shingle **Glazing:** 18% **HVAC System:** Gas furnace, air conditioning	**Core and shell:** **Structure type:** dimensional lumber **Envelope:** 2x4 wood framing, batt insulation, wood windows, asphalt roofing **Cladding:** Cedar lap **Glazing:** 14% **HVAC System:** Gas furnace

Looking at the results we find out that in all the different cases renovation is always better than a new construction. This is not unexpected because during the operation phase both energy uses are about the same. The differences are made during the first three phases of a building, the embodied energy of raw material till construction is allot higher for new building then for the materials used for renovated building. Where this conclusion is not unexpected, there are still some interesting conclusions when looking deeper at the calculations (Frey et al., 2012, pp. 61-72).

First the climate impact between a new constructed advanced energy saving building versus a renovated basic energy saving building. Comparing these two types we see that adding a few energy saving measurements to the renovated building ads allot more value than the new building. Where the operation phase of the new constructed building is a lot lower than the renovated one, the lack of materials added to the renovated building balance this out. For a single resident building it takes about 38-50 years before the new building has less impact then a renovated building. This tells us that reusing

a building, even when this does not meet the highest standards of energy savings, it is still better on the long-term.
Secondly the impact of materializing in both cases, reuse and new build. When looking to the different impact categories: climate change, human health, resources and ecosystem quality. We see that for the first three categories the energy used during the operation phase has the most impact where the materialization of the building has the biggest impact on the ecosystem.

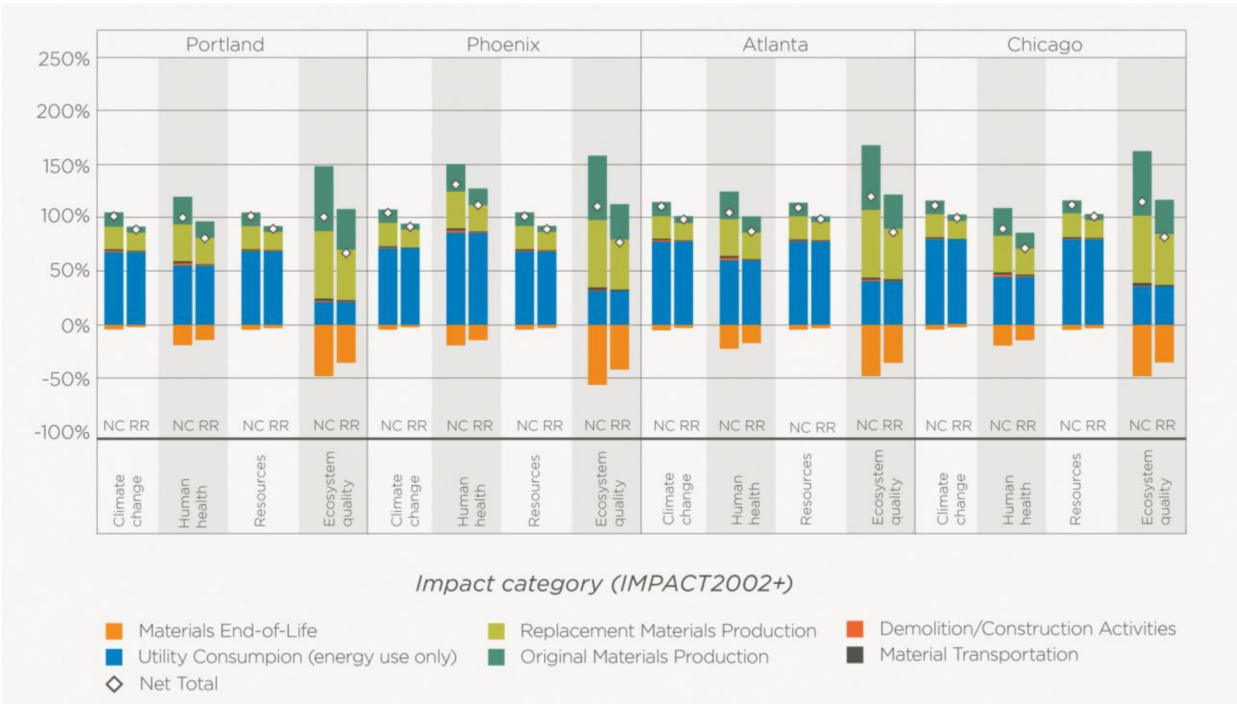

Figure 6: Impact single residential, (Frey et al., 2012, p. 69)

Especially when we look to restoration project where the footprint of the building is increased, we see that this has a significant impact on the ecosystem. For a designer it is important to know that zoning and renovating buildings without increasing the footprint contribute allot to the impact that the building has on the environment. Next to that the selection of environment friendly material decreases the direct impact on the ecosystem.

8. Value assessment:
There are a few different heritage value typologies from different scholars and organizations. I will address a few values that I use during my assessments of the heritage sides. The values I use are from two different value typologies, the one of Reigl and the one of the Burra Charter. Firstly I will address each value shortly and after that I will relate them to Westfort.

Social Value:
Social values follow the notion of social capital, a concept used in social sciences. The way heritage enables social connections, networks and other relations is the social value. The social values of a heritage site might include the use of a site for social gatherings such as celebrations, markets, picnics, or ball games activities that do not necessarily capitalize directly on the historical values of the site but, rather, on the public-space, shared-space qualities (de la Torre, 2002, p. 11).

Cultural/ Symbolic Value:
History and heritage are core elements for each culture. Cultural values are used to build cultural affiliation in the present and can be historical, political, ethnic, or related to other means of living together (for instance, work- or craft-related). As used in this typology, cultural/symbolic value refers to those shared meanings associated with heritage that are not, historical.

Historical Value:
The historical value is the value of the site that embodies, convey or stimulate a relation or reaction on the past. The historical value can occur from the material age, from the events or association with people, rarity, technological qualities or from archival potentials. There are two subtypes of historical value. The education value, this value lies in the potentials to gain knowledge out of the embodied heritage on site. The second subtype is the artistic value, the value that describes how uniqueness of the heritage related to its timeframe or related to a specific individual/architect.

Age Value:
When we buy a new house we expect that it is perfect. But when we look at heritage we also expect marks/scars of the past. Almost all building from the past have marks of the use, time and the decline of materials. These marks feel natural to use when we look at heritage, we do even expect them to happen. These imperfections happen when the heritage is ageing and has significant value on how we see and interpreted heritage.

Aesthetic Value:
Where the ageing of an object is valued as age value, the way we interpreted heritage is valued as aesthetic value. Aesthetic value is defined on how we sense a heritage site, this is mostly done by sight but also smell, sound and feeling are important. When a person visits an architectural site heritage or not, the building and context evokes a feeling. This feeling could be seen as valuable for the sensory experience it offers (de la Torre, 2002, pp. 11-13).

9. Valuing Westfort:

When looking at Westfort there are four values that really capture the uniqueness of Westfort, the Aesthetic, Historical, Social and Cultural values are very high in Westfort. The Age value is definitely present in Westfort in the form of decline. In my opinion this value is the least valuable in Westfort because the decline is going so fast that some of the architecture will be lost soon. The Historical value in Westfort is high because of a few reasons. Firstly the remaining scars of the Apartheid in South Africa that can be found in the remaining of the walls. Segregation of races was in the roots of the Westfort urban planning where clusters have been made to separate different genders and races. These remainders of urban planning and walls have a historical value. Secondly the use of Westfort as the only remaining active leprosy colony makes it unique and historically valuable.
The Social and cultural values are also present in Westfort. The way of urban planning with clusters and open areas encourage the people to have social interaction with each other. Where Westfort was a place to go to and never leave again, social interaction between residents was important.
Every person visiting Westfort nowadays has a special feeling of the place. Where the decline of Westfort is present and can be seen, the place still has some kind of romantic and beautiful feeling.

Looking back to the research question: To what extend can a life cycle assessment be used to value heritage sites that will be renovated to a sustainable center, and where does a LCA has it shortcomings?

The life cycle assessment is a methodology that only uses numerical input and outputs to define the value for sustainability. This is the main shortcoming when valuing heritage sides such as Westfort where some of the values can't be expressed in a number. The numerical approach can be of great use when you want to define how sustainable the design solutions are made in the project. It is an advanced method to find the right balance of energy efficiency measurements and design esthetics. The shortcomings in this methodology are that it does not take the values of a historical building into account. If replacing stained glass in a church is better for the energy performance and overall impact on the environment, the life cycle assessment will always suggest the solution of replacing it. In this assessment it will not account the other values that the stained glass has in its historical context.
The question is how to use the life cycle assessment in these cases. Where it is purely numerical changes will not possible in the second and third phase of the assessment, inventory analysis and third phase. What is open for change is the first and fourth phase where the boundaries of the assessment and the interpretation of it are defined.

The most important things that can be changed in the life cycle assessment are the scope boundaries in the first phase. Creating a clear check list what has to be remained, restorated or changed can create a more narrowed down scope of options that can be researched. This can be done by combining a value assessment method with the life cycle assessment. The designer first have to make a clear and detailed value assessment, especially on building and detail level a clear conclusion has to be made and which parts of the design give possibility to change. After a clear understanding has been made these can be translated to scope boundaries in the life cycle assessment. For example of the stained glass the boundary can be made that a second window can be placed in front of the first, to remain the stained glass and improve the performance of the building as well. In the interpretation phase we have to reflect if the right values from a historical point of view are remained.

Within sustainability, the reuse of existing and historical buildings is encouraged. When we study the results from the case study we showed that reusing a building instead of building a new one is the most sustainable way. The problem erases when dealing with historical buildings and the values addressed to them. A balance has to be found between the resilience and possibility for change of these buildings. Dealing with these assignments the question raises on the way these buildings can be reinvented and transformed to have a new function for the future without losing its original values.

In the case of Westfort we can say that upgrading the urban context and architecture is the best way to approach this side. Demolishing the buildings and built new low cost buildings, like in the surrounding neighborhoods, will lose the special and valuable urban setup that Westfort has. Next to that building new houses will have a larger impact on the ecological environment then reusing the existing buildings. As proven in the Case study, newly built buildings do not perform better then reusing the buildings. When upgrading Westfort the materialization should be taken into account. Creating a bigger footprint and the materials itself has the biggest impact on the ecological environment. One who is already threatened in Westfort.

Written by: Gijs van Suijlichem Bsc. Masters Student Heritage and Architecture TU Delft.

References:

Albritton, D., Derwent, R., Isaksen, I., Lam, M., & Wuebbles, D. (1996). *Trace gas radioactive forcing indices*. Cambridge: Cambride University Press.

BRE. (2005). Green guide to specification, bre materials industry briefing note 3a: characterisation.

Britannica, E. (31-10-2014). Romanticism. Retrieved 15-01-2016, from http://www.britannica.com/art/Romanticism

Brown, L. R. (2006). *Plan B 2.0 rescuing a planet under stress and a civilization in trouble*. New York: W. W. Norton & Co.

Brundtland, G. H. (1987). Our Common Future, Chairman's Foreword *report A/42/427*. Oslo, Norway United Nations

Crawford, R. H. (2011). *Life cycle assessment in the built environment*. New York: Spon Press.

de la Torre, M. (2002). Assessing the Values of Cultural Heritage. Los Angeles: The Getty Conservation Institute.

EPA, E. P. A. History of Sustainability. Retrieved 15-01-2016, from http://yosemite.epa.gov/r10/oi.nsf/8bb15fe43a5fb81788256b58005ff079/398761d6c3c7184988256fc40078499b!OpenDocument

European Environment Agency. (1998). *Life Cycle Assessment - A guide to approaches, experiences and information sources* (Vol. 6). Luxembourg: Office for Official publications of the european communities.

Finnveden, G. (1996). *Part III: "Resources" and related impact categroies.* . Brussels.

Frey, P., Dunn, L., Cochran, R., Spataro, K., McLennan, J., DiNola, R., . . . Heider, B. (2012). The Greenest building: Quantifying theenvironmental Value of building reuse-a report by the US National Trust for historic preservation.

Goodlang, R. J. (1975). The tropical origin of ecology: Eugen Warming's jubilee. *Oikos, 26*, 240-245.

Hartwick, H. (1977). Intergenerational Equity and the Investing of Rents from Exhaustible Resources. *American Economic Review, 66*, 972-974.

Hotelling, H. (1931). The Economics of Exhaustible Resources. *Journal of Political Economics, 39*, 137-175.

International Standard. (1998). *Environmental management-Life cycle assessment-Goal and scope definition and inventory analysis*. Geneva.

International Standard. (2006). *Environmental management-Life cycle assessment-Principles and framework*. Geneva.

Langston, C., Wong, F., Hui, E., & Shen, L. Y. (2008). Strategic assessment of building adaptive reuse opportunities in Hong Kong. *Building and Environment, 43*(10), 1709-1718.

Mackee, J., Obbard, J., & Briffett, C. (2001). Environmental Assessment in Sri Lanka: Its Status and Potential for the Introduction of Strategic Environmental Assessment. *Journal of Environmental Assessmet Policy & Management, 3*, 209.

Marsh, G. P. (1864). *Man and Nature; Physical Geography as Modified by Human Action*. Cambridge: Belknap Press of Harvard University Press.

NRMCA. (2008). Concrete CO2 Fact Sheet. Silver Spring: National Ready Mixed Concrete Association.

OECD. (2003). *Environmentally Sustainabe Buildings - Challenges and policies*. Paris: Organisation for eEconomic Co-Operation and Development.

Renoef, M. A., Grant, T., Sevenster, M., Logie, J., Ridoutt, B., Ximenes, F., . . . Lane, J. (2015). Best practice guide for life cycle impact assessment (LCIA) in Autralia: Autralian life cycle assessment society.

Survey, U. G. (2005). Mineral commodity summaries, US geological survey. Retrieved 20 March 2016, from http://minerals.usgs.gov/minerals/pubs/mcs/2015/mcs2015.pdf

Unece. Sustainable development - concept and action. Retrieved 15-11-2015, from http://www.unece.org/oes/nutshell/2004-2005/focus_sustainable_development.html

Water, U. (2012). Retrieved 26 March 2016, from www.unwater.org/statistics_use.html

Zapata, P., & Gambatese, J. A. (2005). Energy consumption of asphalt and reinforced concrete pavement materials and construction. *Journal of Infrastructure Systems, 11*(1), 9-20.