Use of LCA for buildings

A comparison between literature and practice for Sweden, Turkey and the Netherlands

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Lund University

Lund University, with eight faculties and a number of researches centers and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280-degree programmers and 2 300 subject courses offered by 63 departments.

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The degree project is the final part of the master program leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Abstract

The increasing focus on the environmental classifications and energy certification systems as well as LCA in the building industry nowadays has raised the interest in the life cycle perspective of buildings among countries, municipalities, builders and researchers.

This thesis shows how Sweden is dealing with this topic comparing to the Netherlands and Turkey. By presenting a detailed literature review specialised with literature that was published in each one of the previous mentioned countries separately in addition to an overall literature review. Then compare it to the practical application of LCA within building industry, by interviewing LCA specialists in each country individually.

This research showed that the main motivation to apply LCA on buildings in practice was related to some utilized certification system. Although, there seemed to be a good awareness about the environmental effects of buildings between specialists (architectures, engineers and consultants) this knowledge was not sufficient by itself only to perform LCA. Economic aspects, governmental support and requirements of certification systems play an important role in rising the LCA use in buildings within practice.

In Turkey there was a big interest in performing LCA for the whole building in literature, not likely in practice as LCA was performed for only products, materials or parts of the building. In Sweden and the Netherlands LCA was performed for only products, materials, parts of the building or the whole building in both literature and practice.

The Netherlands was much progressed in applying LCA on their buildings in practice, in addition to they have their own standards and regulations regarding LCA. In Sweden LCA was considered seriously by some building companies, while others did apply LCA only in the big projects however, there is some building companies that do not consider LCA at all. In Turkey LCA was applied on some buildings but that was limited to the big projects and the big cities.

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Table of continents

Glossary

Atemp	the total area intended to be heated above a specific temperature expressed in degrees.
IVL	Swedish Environmental Research Institute.

Abbreviations

LCA	Life Cycle Assessment.
LCC	Life Cycle Cost.
ITU	Istanbul Technical University.
GWP	Global Worming Potential.
IES-VE	Integrated Environmental Solutions.
LEED	Leadership in Energy and Environmental Design.
BREEAM	Building Research Establishment Environmental Assessment Method.
EPD	Environmental Product Declaration
MPG	MilieuPrestatie van Gebouw = Environmental Performance of Building
EE	Embodied Energy.
BBR	The National Board of Housing, Building and Planning´s Building Regulations.
GHG	Green House Gas.
IAQ	Indoor Air Quality.
BIPV	Building Integrated Photovoltaic.
LUBsearch	Lunds Universitet Biblioteken = Lund University Libraries.

1 Introduction

The increasing activity in the construction industry during the last decades as a response to the social and economic development has a major consequence on the environment (Shengnan Genga, 2017). 40% of the global energy use is caused by buildings (Mirzaie, 2016) which raises the CO_2 emissions in the environment. With the construction industry rated as the third globally source for CO_2 emissions (CORDIS, n.d.). Performing LCA helps to determine the future environmental impacts caused by a new designed building and points out to the most important measures to be taken into consideration in order to carry out an energy efficient refurbishment (CONTRIBUTIONS, 2010). Performing LCA studies could lead to reduce environmental impacts of the products by comparing the results from the new developed products with the existing ones (CORDIS, n.d.). figure 1 provides some of the main motivations to start an LCA study within the building sector (Bionova Ltd, 2018).

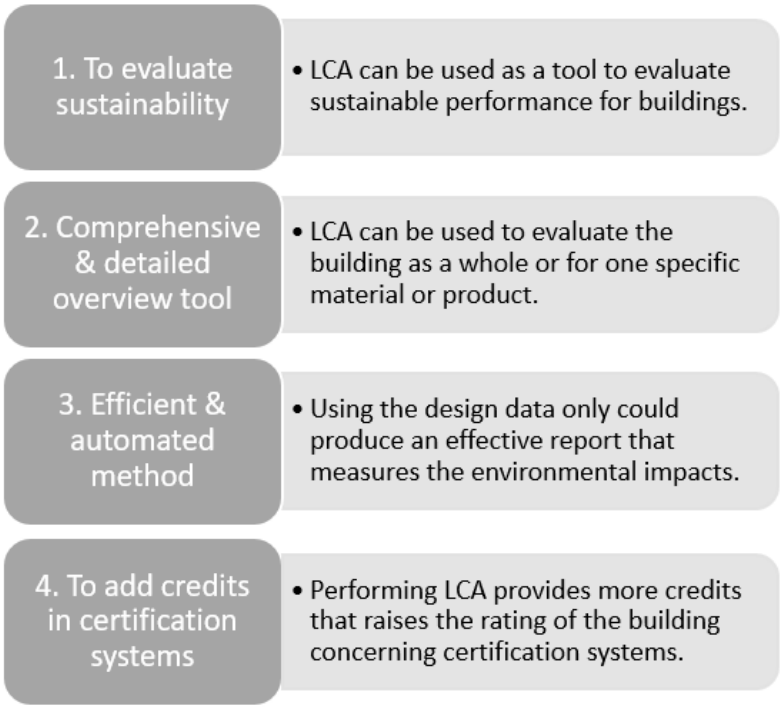

Figure 1: Motivations to do LCA study for buildings (Bionova Ltd, 2018)

1.1 LCA stages

The LCA study can be assessed for one or more of the life cycle stages of the examined material, product or building etc. Figure 2 shows LCA stages according to EN 15804 standard.

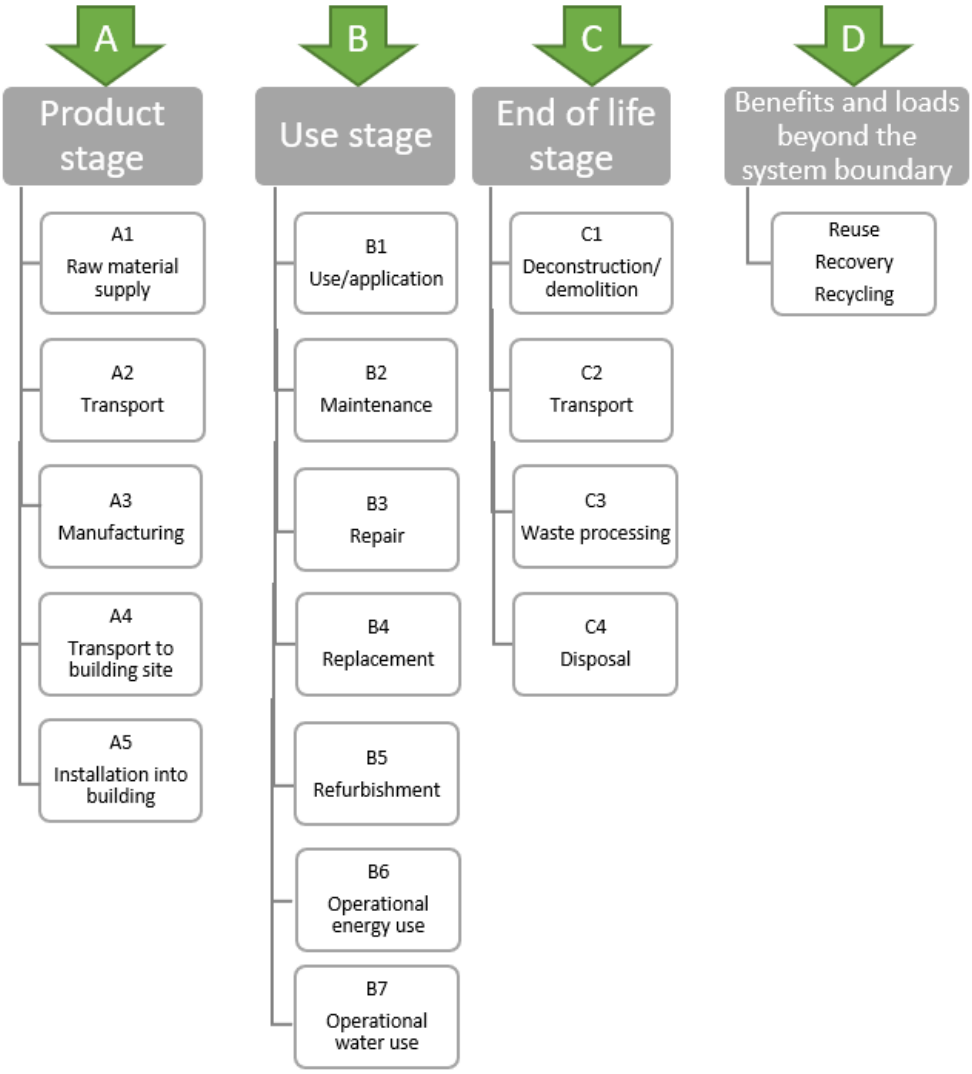

Figure 2 : Life cycle stages according to EN standard

1.2 Functional unit

The functional unit is the foundation stone to be defined in an LCA study when aiming to compare two or more products or systems. the principle of the functional unit is defining the product depending on its function (ENV/GR/110, n.d.) e.g. instead of measuring the floor area with the unit m² the utilized unit could be Atemp, in order to serve a certain purpose regarding measuring the heated floor area.

1.3 EPD&PCR

To have the environmental product declaration (EPD) meaning the ability to access the environmental impact of a product during its life cycle in a comparable way. While the product category rules (PCR) are the document which provide the instructions in order to create an EPD (The international EPD system, 2019).

1.4 Environmental impact categorizes

Figure 3 shows the main environmental impacts that could be accessed after performing LCA for a certain product, material, building etc. when showing the results of an LCA study that could contain one or more of those environmental impacts.

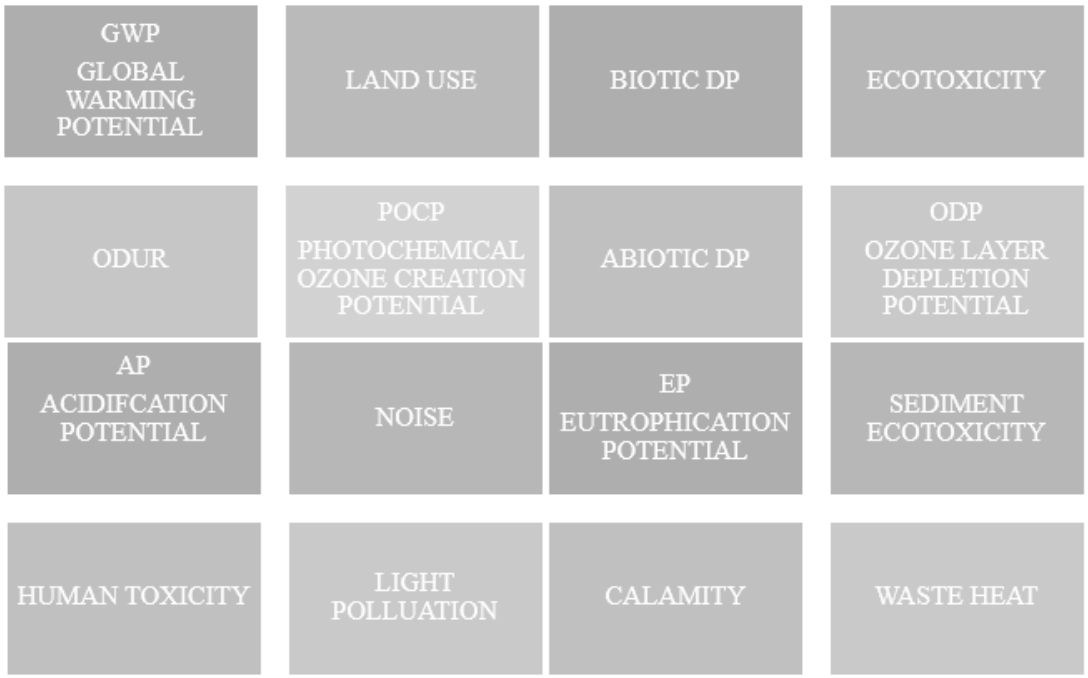

Figure 3: Environmental impact categorizes

1.5 Goal and objectives

The purpose of this study is to explore how different countries are dealing with LCA topic in the building field. The applied methods, used standards and the considered LCA stages were the main points to be explored. In order to achieve this goal this study:

- Explore the literature that was published concerning the LCA use for buildings within the chosen countries.
- Check how LCA is applied for buildings in practice, by interviewing LCA experts in the chosen countries.
- Compare the use of LCA for buildings in Sweden, Turkey and the Netherlands.

2 Methodology

2.1 Literature review

The literature was examined considering certain points, which were moulded as questions, and an attempt to answer those questions. The purpose of the literature review was to explore these points:

- Reason behind starting the study.
- Functional unit.
- Was LCA part of the paper? Or the main topic.
- Methodology to perform LCA.
- The used software.
- The parts and products of building that were included in the study.
- HVAC system role of the LCA study.
- LCA indicators.
- The used standards.
- Type of building.
- Ownership of the building.
- Whether the energy use of building was considered in the LCA study? And if the source of energy was specified or not.
- Climate type.
- Additional aspects that were considered with the LCA study e.g. economic, social, LCC, IAQ and thermal comfort.

The literature which was examined took place in four different trends:

1. General publications within the building field of the life cycle assessment.
2. Publications within Turkey.
3. Publications within the Netherlands.
4. Publications within Sweden.

Those three countries were chosen depending on a preconception scale of how much LCA use for buildings is considered in each one of them. Turkey represents countries where LCA is kind of new topic in, while the Netherlands considered one of the developed countries in this field. Sweden is expected to be one of the countries that have a good consideration of LCA use for buildings. The literature review was made to explore each country's situation regarding LCA in theoretical point of view.

The literature that was studied was in all cases English.

Limitations

- Publication period between 2014 up to present.
- Only articles within academic journals were examined.
- In the ScienceDirect database only the open access articles were checked.
- In LUBsearch database the articles are not open for public, they were accessible only if there was a valid student or staff Lund university account.

Table 1: Number of publications regarding LCA for buildings in the literature.

Search phrases		**Data bases**	
		ScienceDirect	**LUBsearch**
Life cycle assessment for buildings		4 917	3 835
Life cycle assessment for residential buildings **OR** houses **OR** apartments		32 906	161 864
Life cycle Assessment For Buildings	**AND** Turkey	56	29
	AND The Netherlands	712	87
	AND Sweden	663	149

It is important to notice that not all those results are directly related to LCA in buildings by necessary. The most relevant publications depending on their abstracts were chosen to be examined. The final number was 8 papers for each case except for the Netherlands, whereas only 3 papers were matching the topic. This number of the examined papers was due to the previous mentioned limitations.

2.2 Interviews

The interviews were done in the chosen countries to make the comparison of LCA use in buildings between them possible, by interviewing specialists in LCA in big companies in each country. The applied method in the interviews was a general interview guide approach, where the collected information was from the same general areas. A form with several questions was used in order to produce those interviews although, the interviewee had the space to talk freely about some topics more than others and to add his/her own suggestions, ideas and opinions. Some of the interviews were by personal meetings, while others were by using Skype calls. In both cases the interviewee and the interviewer could have a good communication and shared his/her knowledge about the topic. The collected data were formed and presented in narrative method in order to clarify how is LCA used for buildings in each country. Some citations were presented as well in order to express a specific idea or opinion of the interviewee.

2.3 Common points between literature and interviews

Those points were chosen to make the comparison between literature and practice possible.

- The used standards.
- The considered environmental impacts.
- The connection between LCA and LCC.
- The considered parts and products of the buildings which LCA was performed for.
- The used methods and softwares to perform LCA studies.
- The period of time then the life cycle was performed.
- The required stages in the LCA studies.
- The type and situation of the building which the LCA was performed for.
- The ownership of the building.
- The rule of the energy use of the building in the performed LCA study.

3 Background

3.1 LCA for buildings in the standards

3.1.1 LCA in the European standards

The EN 15643-1 standard formalizes the functionality and technical characteristics of the buildings regarding their environmental, social and economic performance by fulfilling the general principals and requirements presented as a series of standards. The assessment covers all types of buildings, hence the environmental, social and economic performance of any building could be assessed, whether it is the remaining service life and end of life stage of an existing building, or it is the entire life cycle of a new building. Valuation methods cannot be provided by standards which were developed under this framework since it does not set the rules for different assessment methodologies. In addition to that this framework does not set levels, classes or indicators for measuring performance. In contrary the requirements for environmental, social and economic performance in the national standards, national codes of practice, building regulations, certification schemes, client's brief, etc could set valuation methods, levels, classes or indicators for measuring performance. This framework takes into account the consequences of actions and decisions which affect the environmental, social and economic performance of the object of assessment (standards, 2010). In an attempt to develop the assessment of the integrated environmental performance of buildings, The European Committee for Standardization (CEN) stated horizontal standardised methods in 2004 (Stamatiadou, 2015). This statement was developed to sustainability by CEN TC350, and the life cycle approach was chosen to be the base for all assessment. The TC committee played role in specifying methodology and benchmarks for the sustainability assessment of buildings by proposing technical specifications, standards and technical reports. CEN-TC 350 supplied a series of standards in the framework for the sustainability assessment of buildings which covers environmental, economic and social aspects (EN 15643-1, 2010). The CEN TC350 has four stages: concept, framework, building and product, in addition that it covers five forms of performance: environmental, social, economic, technical and functional (Stamatiadou, 2015). The standards focused mainly on the product stage and building stage within the environmental performance assessment (Stamatiadou, 2015), and were defined as:

- **Building level (EN 15978)**

EN 15978 (2011) supplies the basic rules in order to access the environmental impacts of new established and already existed buildings in a life cycle perspective. It aims to create from LCA a tool in decision-making process in the building sector (Stamatiadou, 2015).

- **Product level (EN 15804)**

EN 15804 concerns in developing the environmental product declarations (EPD) of the products that are used in constructions by defining the product category rules. EPD consider a reliable source of the environmental data for products and a special type of LCA (Stamatiadou, 2015). Figure 4 shows the four stages that the TC system covers.

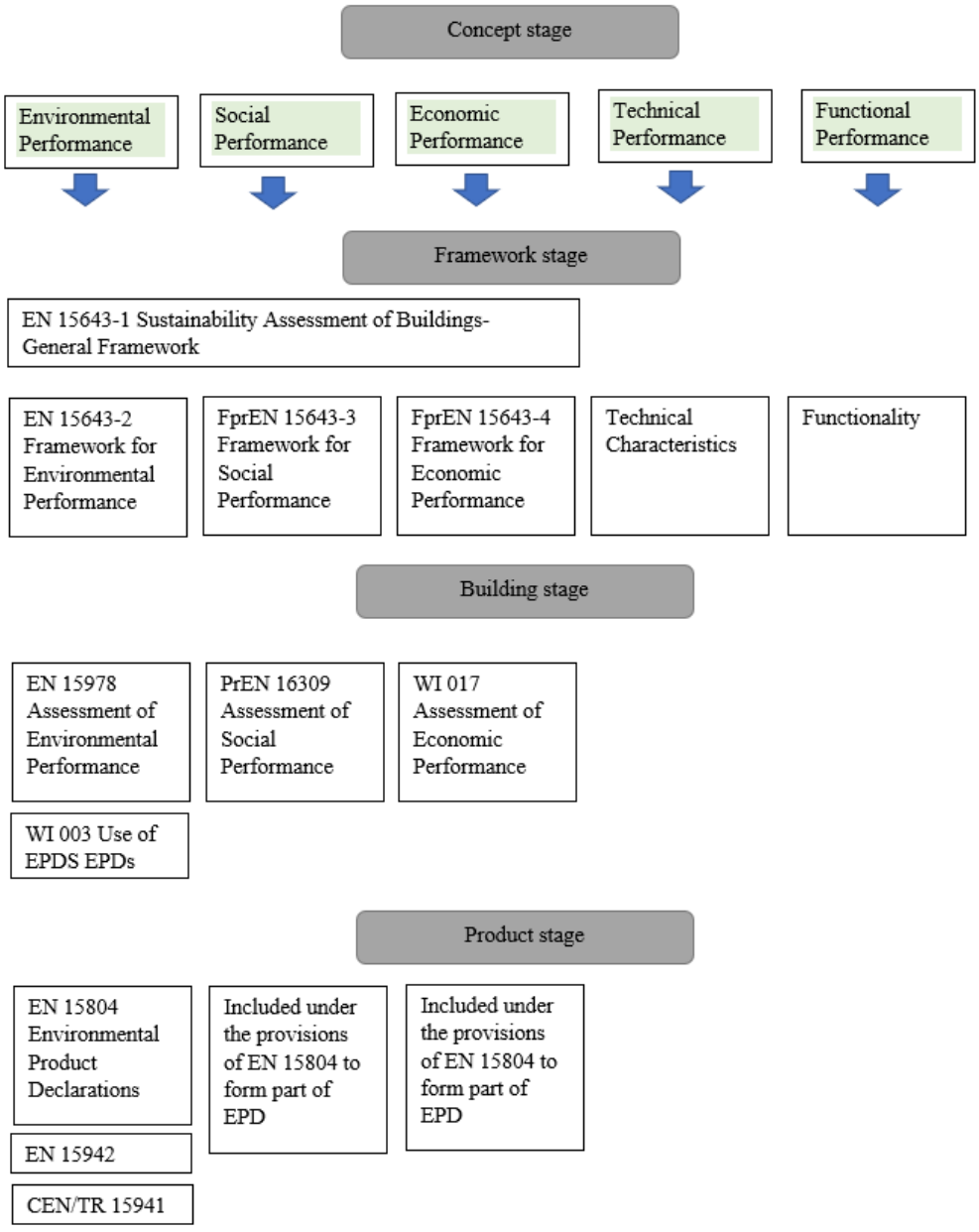

Figure 4: Work program of the CEN TC 350 (EN 15643-1,2010) (Stamatiadou, 2015)

3.1.2 LCA in the international standards

Regarding the life cycle assessment in the international aspects, the ISO 14040 (International Organization for Standardization) stated a series of standards concerning this topic see figure 5 (Stamatiadou, 2015). LCA methodology takes priority in the ISO standardizing aspects (Stamatiadou, 2015). ISO 14040 series of standards should use as the foundation stone in the process of development LCA methodology within building field, hence this series of standards cover both technical and organizational aspects of an LCA project (Stamatiadou, 2015). The ISO 14040 states the following standards:

- ISO 14040:1997 – General Principles and Framework.
- ISO 14041:1998 – Goal and Scope Definition and Inventory Analysis.
- ISO 14042:2000 – Life Cycle Impact Assessment (LCIA).
- ISO 14043:2000 – Life Cycle Interpretation.
- ISO 14044:2006 – Requirements and guidelines.
- ISO 14045:2012 – Eco-efficiency assessment of product systems.
- ISO 14046:2014 – Water footprint.
- ISO 14047:2012 – Illustrative examples on how to apply ISO 14044 to impact assessment situations.
- ISO 14048:2002 – LCA Data Documentation Format.
- ISO 14049:2012– Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis.

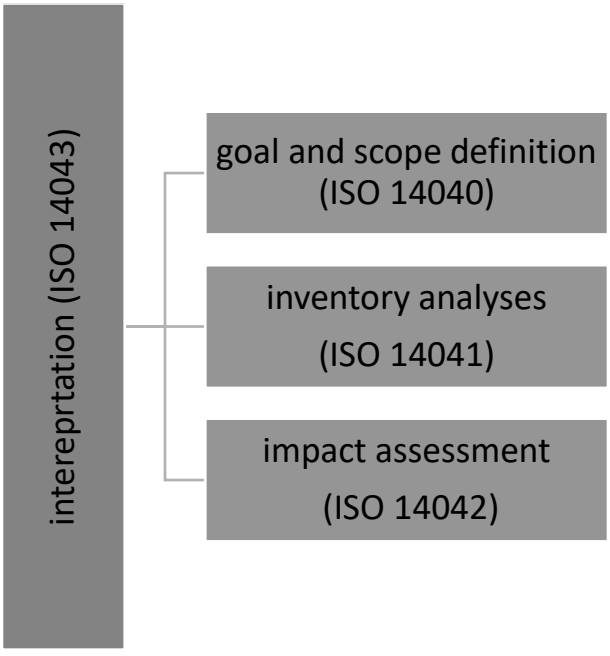

Figure 5: LCA general frame work (ISO 14044:2006) (Stamatiadou, 2015)

3.2 LCA in the certification requirements

3.2.1 BREEAM

BREEAM as an assessment method in the building industry is considered to be one of the leading around the world in specialisation for infrastructure, buildings and master planning projects. BREEAM is spread in 83 countries around the world according to BREEAM official website (BREEAM, 2019). BREEAM specifies and reverberates the rate in higher performing buildings. where it covers the three parts of the building's lifecycle while it is on the design stage as new construction, when it is in use stage and in case of renovation stage. Firstly, started on 2011, when BREAM added five extra credits for the building that LCA is performed for (Doran, 2018) which is weighted then to be less than 1% points (SGBC and BRE Global, 2018). The achieved credits are calculated for each section and then multiplied by the corresponding section weighting (SGBC and BRE Global, 2018). The achieved credits are compared to the available credits according to BREEAM's calculation method of score (BREEAM rating benchmark Levels) (rating, 2018) the building is then rated according to the score that it has achieved as:

- Pass, when its score is equal to or higher than 30%
- Good, when its score is equal to or higher than 45%
- Very good, when its score is equal to or higher than 55%
- Excellent, when its score is equal to or higher than 70%
- Outstanding, when its score is equal to or higher than 85% (BREEAM, 2011)

3.2.2 LEED

Performing LCA for the whole building or for parts of it provides 3 extra points according to the LEED certification system if two conditions are fulfilled (U.S Green Building Council, 2018):

1. A reduction of 10% at least of the environmental impacts to an improved version of the design, compared to the base case (U.S Green Building Council, 2018).
2. Presenting 3 or more of the six environmental impacts (global warming potential,
3. Ozon layer depletion, eutrophication, non-renewable energy resources depletion, acidification potential and photochemical Ozone creation potential) containing GWP as must (U.S Green Building Council, 2018).

The operational energy and energy consumption of the building should be as the requirements set by EA preconditions of energy performance (U.S Green Building Council, 2018). The building is classified according to LEED certification system as:

- certified if it achieves 40-49 points.
- Silver if it achieves 50-59 points.
- Gold if it achieves 60-69 points.
- Platinum if it achieves more than 80 points (LEED, 2019).

4 Results and analysis

4.1 Literature

The literature review is a detailed analysis depending on the main points which were defined previously.

4.1.1 Differences between LCA in the literature and practice

The main motivation behind starting an LCA study in practice in general was to gain extra points in order to reach a desired level in a certification system. However, in the literature there were several motivations that led to start each paper. That could be observed for a general perspective and for each country's own literature:

4.1.1.1 Motivations behind starting some LCA related articles

The goal to create a new method based on combining LCA with Geographical Information Systems (GIS), in an attempt to use it in environmental applications within the urban level in Europe, that lead to start a study in this field mainly in retrofitting projects (Sergio García-Pérez, 2018). Since it was not very common to calculate the embodied impacts of buildings within UK in the stage before constructing the building, a study of whole life cycle of energy and embodied carbon was performed for certain buildings due to recommendations from the government (A.M.Moncaster, 2013). The increasing demand of exploitation natural resources such as solar energy by applying building-integrated photovoltaics, especially in countries that are considered rich with solar radiation e.g. Taiwan is combined with economic and environmental concerns. Thus, many researches worked in the field e.g. accessing the life cycle cost and assessment of a building-integrated photovoltaics façade of mall building located in Taiwan (Yun-Wu Wu, 2018). The wide spread of district energy systems uses within EU whether they were used for heating or cooling requires to evaluate their environmental performance due to the decarbonisation goals set by European union commission. That could be achieved by accessing the life cycle assessment of those systems (Irene Bartlozzi, 2017). In regards to the energy use and CO_2 emissions of an office building, the life cycle of it was accessed in order to develop early-stage design strategies that manage to decrease both aspects at once, and produce a model that could be followed in similar cases in order to achieve the same goals (Afaf Azzouz, 2017). The need to prove that to hold on the already existed buildings and work on improving them by refurbishments, have the lowest carbon emissions among other options such as demolition the old buildings and establishing new ones. Façades are very important parts of the buildings during this procedure, since they play a big role in reducing CO_2 emissions by saving more energy if they were considered during the refurbishments. Therefore, the life cycle assessment was used as a tool to spot the differences in performance between buildings with double skin Façades and single skin Façades after renovation (Francesco Pomponi, 2015)

4.1.1.2 Motivations behind starting LCA literature in Turkey

Upgrading the energy performance of existing residential buildings in Turkey, considering the environmental impacts of the used retrofits technique created the need to start a study about that (Suzi Dilara Mangana, 2015). The high cost of the energy within the residential buildings as a consequence of using non-renewable resources and the negative environmental impacts of it, required to access the life cycle of those buildings in economic and environmental perspectives, in order to improve the energy performance of the residential buildings in different climate zones in Turkey (Gül KoçlarOralb, 2016).

There is an increasing demand of temporary housing in Turkey as consequences of two main reasons:

1. The high risk of natural disasters e.g. earthquakes.
2. The sudden immigration movement towards Turkey since 2011.

LCA was used as a tool to determine the environmental impacts of those houses (Nihat Atmaca, 2016). In order to find more environment friendly applications in the building field, due to the massive increasing in the global warming and ozone layer depletion as a consequence of building industry (Adem Atmaca and Nihat Atmaca, 2015). Reducing the environmental losses caused from the natural disasters and crises could be managed in a certain level by controlling the energy use and environmental impacts of the shelters that were built in those special conditions, in addition to, determining the energy use and environmental impacts of the shelters during different life span, and how does that effect those constructions behaviour (Adem Atmaca, 2018). The life cycle assessment was used to test how would replacing windows and adding thermal insulation in retrofitting process can decrease the energy consumption and resulted emissions for residential buildings, using LCA as a tool to measure that in sustainability assessment perspective (Ikbal Cetiner, 2014).

4.1.1.3 Motivations behind starting LCA literature in the Netherlands

The difficulty in comparing between the impact of the energy and the impact of the materials for the same building against each other, has created the need to develop a new methodology relying on already existed methods that set by the Dutch National Building Code. This methodology could be used to measure the overall performance of buildings, considering energy and environmental impacts of the used materials of the buildings during their life cycle in the Netherlands (E.A.Alsema, 2016). In order to understand the overall impacts of the buildings during their life cycles, a methodology was developed to evaluate the energy and environmental performance for the neighbourhood level instead of single building perspective. The energy and environmental performance for the neighbourhood level was examined to make planning approach and long-term decision-making more effective (Shalika Walker, 2018). The durability of the low energy buildings is usually accessed during the design stage. However, there are some factors that affect the expected performance of the low energy buildings during operational stages, for instance changes in applied policies within municipalities, user's behaviour, cost and climate change. In order to cover the influence of those variable factors it is beneficial to consider them by assuming different scenarios during the design stage (Rajesh Kotireddy, 2018).

4.1.1.4 Motivations behind starting LCA literature in Sweden

LCA can be used to measure the climate impacts from raising the use of bio-based materials in the new established residential buildings in Sweden considering technological change in material manufacturing (Diego Peñalozaab, 2018). The need of renovation in buildings has increased in Sweden lately due to the large number of existing old buildings that use much energy and contain old service systems. However, the proposed retrofit strategies must take the resulted CO_2 emissions into consideration together with other environmental, social and economic aspects (Linus Malmgren and Kristina Mjörnell, 2015). There is a need of critical evaluation of the common renovation techniques in Sweden in terms of energy and environmental aspects with a focus on embodied energy and GHG emissions, using LCA as a tool to perform that evaluation (Qian Wang, 2015). There is a need in Sweden to create reliable system boundaries aiming to decrease both cost and environmental impacts of new established buildings (Peter Ylmén, 2017). Deciding the most relevant tool to access the environmental footprint of materials that used in the Swedish construction industry was possible by comparing the most common LCA softwares GaBi and SimaPro to a simplified tool developed by Stockholm municipality based on Excel, environmental load profile (ELP) (Rajib Sinha, 2016). To fill the gap which previous studies concerning environmental issues have not covered before was achieved by referring to the secondary effects which are consequences of basic choices made to optimize the building design. That is done by accessing the complete life cycle of the building in terms of cost and global warming potential including the secondary effects (Peter Ylmén, 2017).

4.1.2 Literature analysis

4.1.2.1 Functional unit specification distribution

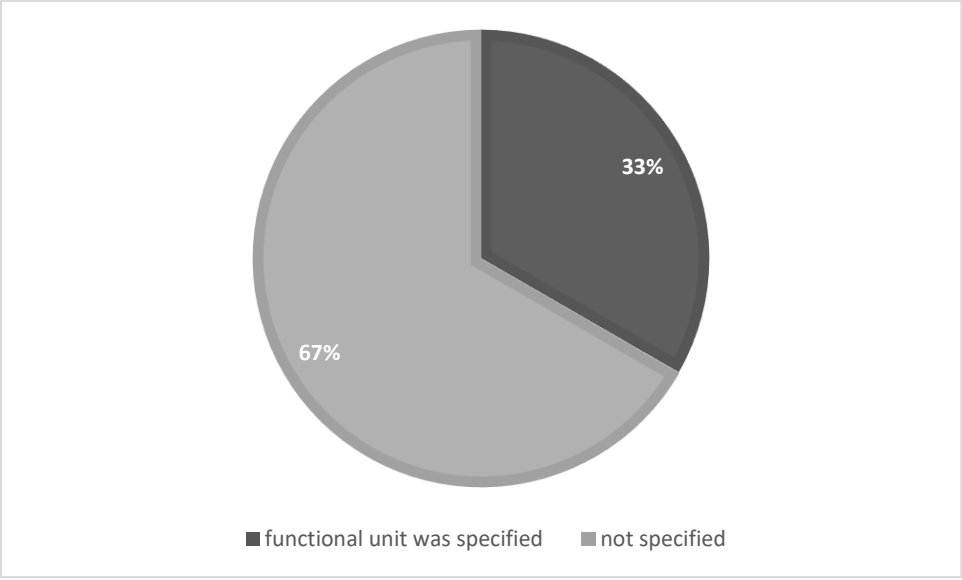

Figure 6: The distribution of determined functional unit within literature as a whole

The functional unit was only directly mentioned in few of the examined literature, while majority did not specify which functional unit the study was based on figure 6 shows the percentage of the papers when the functional unit was specified against the papers which did not mention the functional unit. Some of the functional units that were used in the literature:

- 1 m² Atemp (Peter Ylmén, 2017).
- one per retrofit area and one per heated floor area (Qian Wang, 2015).
- 1 m² of a declared unit (Sergio García-Pérez, 2018).
- 1 m² gross internal floor area (A.M.Moncaster, 2013).
- 1 m² of façade (Francesco Pomponi, 2015).
- 1 m² per year as the integrated environmental impacts were defined depending on their cost as one Euro for each m² per year (E.A.Alsema, 2016).

4.1.2.2 Methodology to perform the LCA study

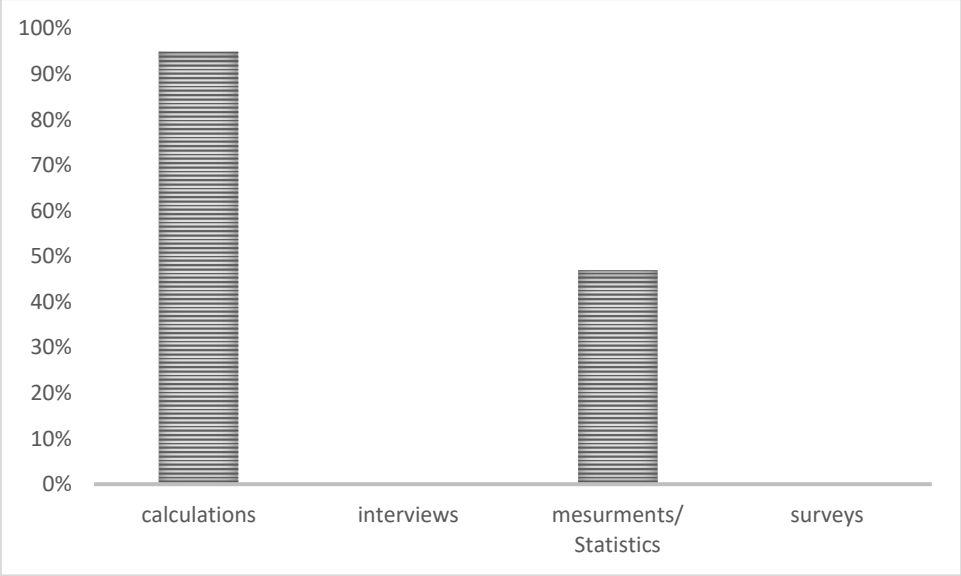

Figure 7: The used methodologies to perform LCA in literature as a whole

The majority of the examined literature used calculations methods in order to perform LCA. Nearly half of the literature used measurements / statistics to perform LCA although that was always combined with calculations as well, excluding one case whereas the research was all built on measurements / statistics only see figure 7. Figure 8 shows what softwares were used to perform LCA and how does the distribution among literature of them was.

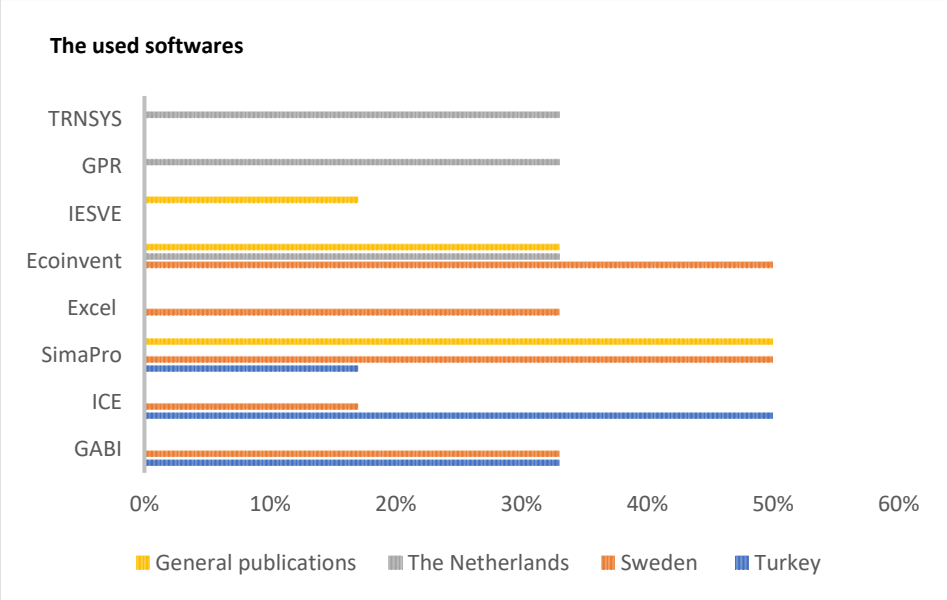

Figure 8: The ratio of used softwares

4.1.2.3 Functionality of LCA in each paper

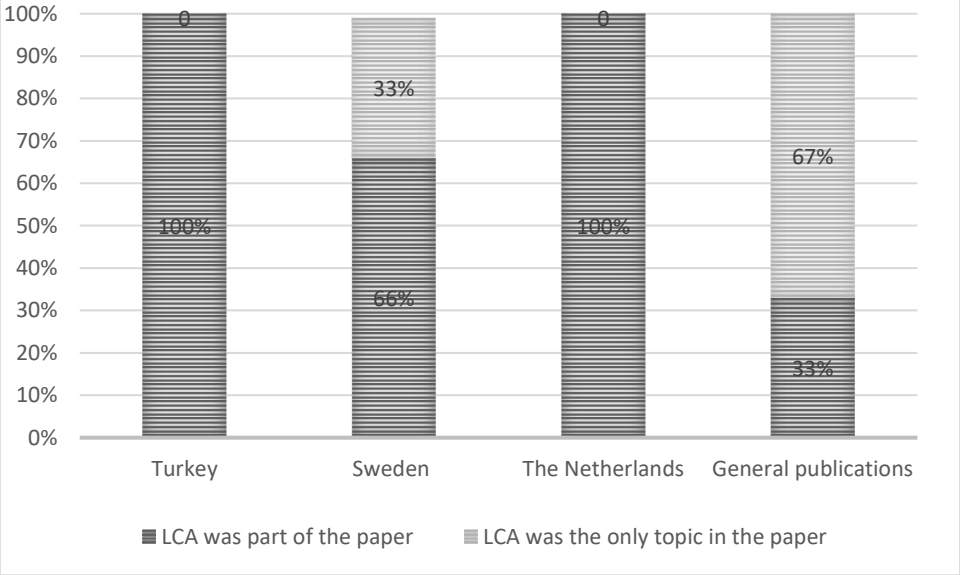

Figure 9: The distribution of how frequent LCA was the only topic in the examined literature

In many of the examined papers, LCA was only part of the paper as it considers other general aspects e.g. the energy use in the building, economical perspectives or social aspects, figure 9 shows the frequent of when LCA was the only topic was mentioned in the paper for the literature that was examined in each case. Although some papers focused only on LCA, especially in the general publications as the LCA was the only discussed topic in 67% of the

papers. However, there were some special tasks that were performed together with LCA as in (Qian Wang, 2015), where the task was to evaluate different retrofit strategies in two perspectives

- How much each proposed strategy provides energy savings.
- How does each proposed strategy perform within LCA.

In (Sergio García-Pérez, 2018) the LCA was performed in combination with geographical information systems in order to specify the appropriate thermal retrofit strategies.

4.1.2.4 Conditions distribution of examined buildings

The main conditions that were examined are the type, status and ownership of the buildings that LCA was performed for. Figure 10 shows the type distribution of the buildings that were discussed in the literature for each case.

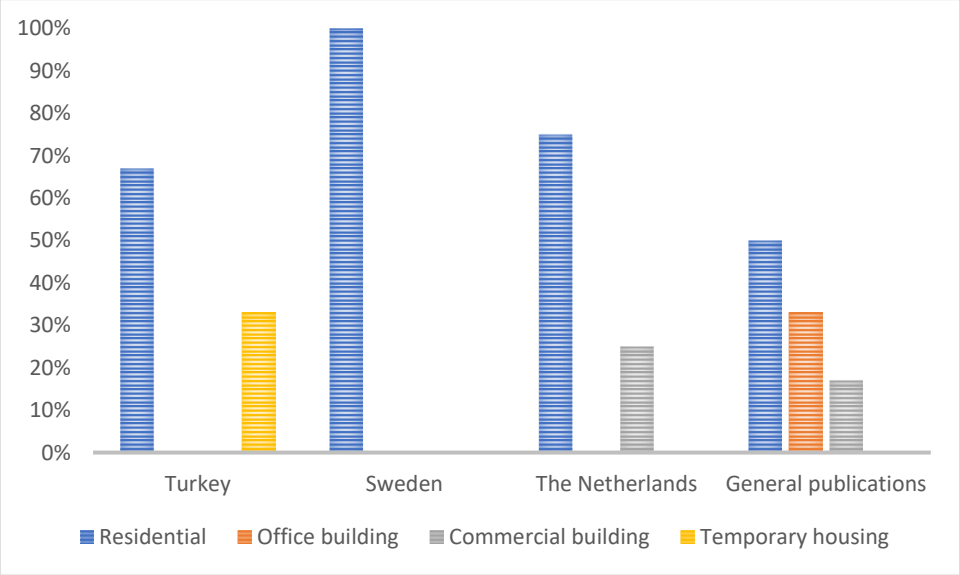

Figure 10: Type distribution of examined buildings

Figure 11 shows the age of the buildings in addition to the renovated buildings that LCA was performed for within literature for each case separately.

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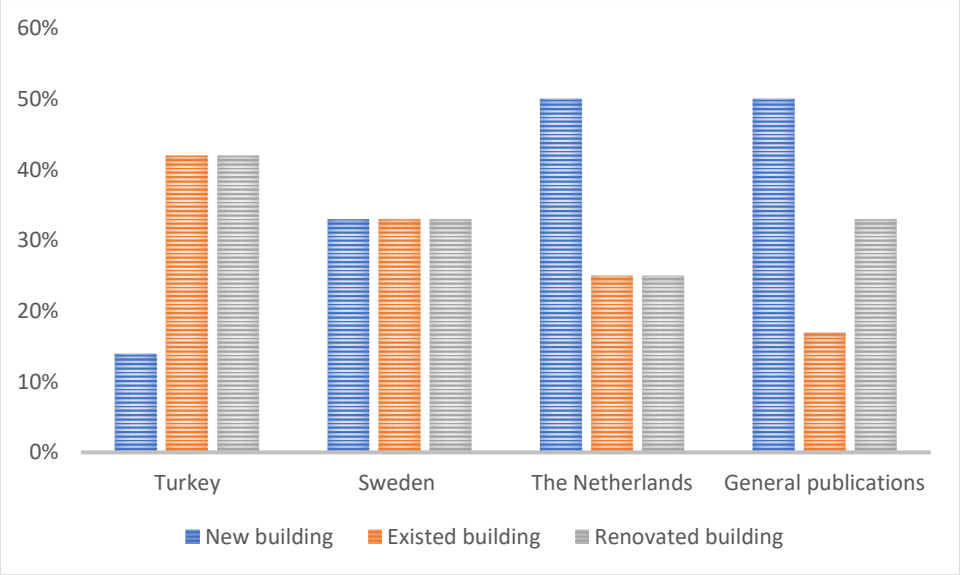

Figure 11: Statues distribution of the examined buildings

Figure 12 shows how much percentage of the buildings that LCA was performed for were owned by private people against how many were owned by public organizations. In the Netherlands one third of the literature combined in the same study both public and private buildings in the same study. In Sweden all the buildings' type was residential, in terms of apartments. Apartments are owned by municipalities usually in Sweden, therefore they considered as governmentally owned buildings.

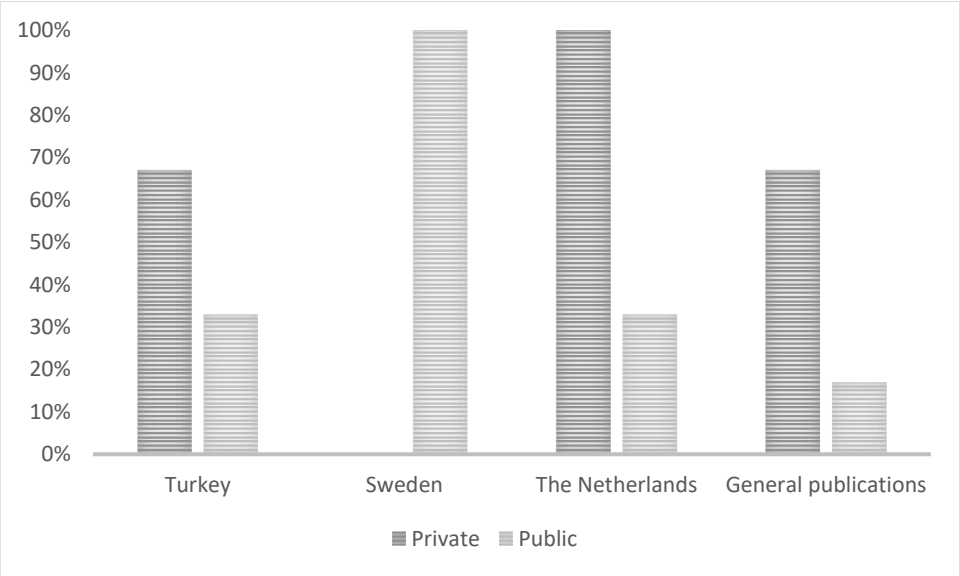

Figure 12: Ownership distribution for the examined buildings

4.1.2.5 Additional aspects were considered together with LCA

The energy use of the buildings was considered in more than 90% of the cases. However, there were two papers that performed the LCA calculations excluding the energy use of the building. However, the source of the used energy was specified in many of the literature hence it has an effect on LCA results. Figure 13 shows some of the sources of energy that were used for heating/cooling in the buildings and their frequency in the literature. The energy source of the buildings is varied in each country mostly the natural gas and electricity are used while the coal is less mentioned. However, in the chosen Swedish literature to be examined, there was no mentioning of which was the energy source although, the energy was considered in the LCA study for some cases but the energy source was not specified.

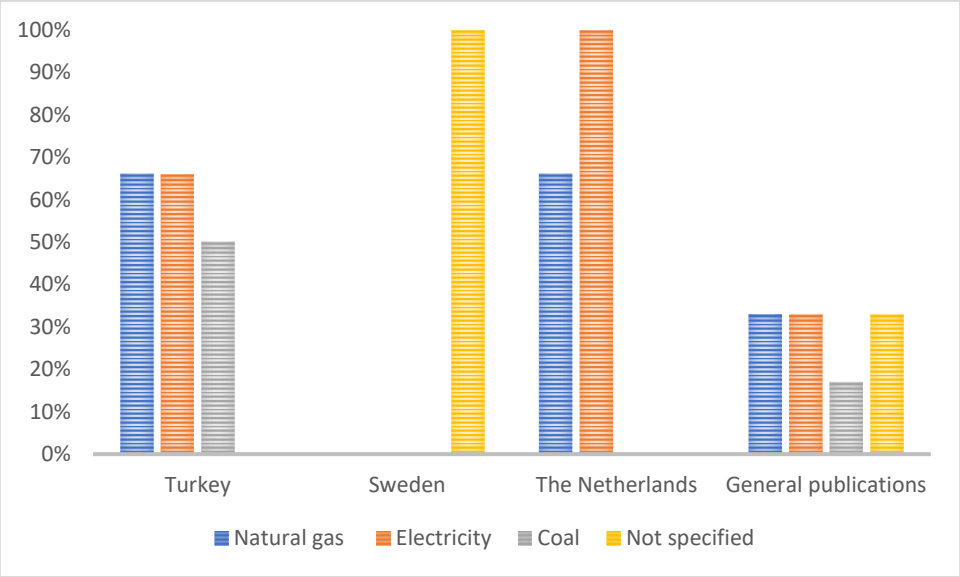

Figure 13: Source of used energy for heating/cooling

Some papers considered other aspects while performing LCA for their buildings e.g. social, economic and thermal comfort, figure 14 shows how often those aspects were considered in the literature concerned LCA.

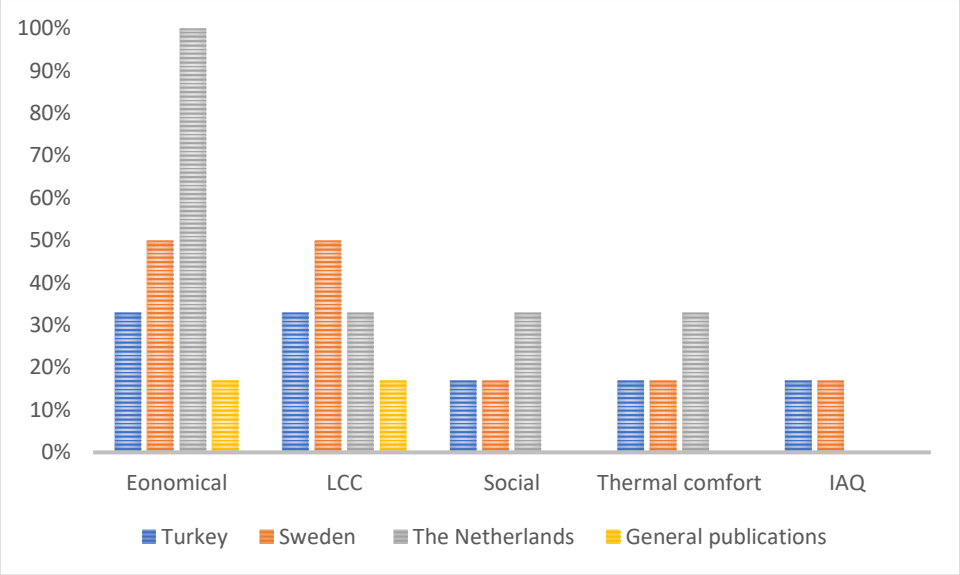

Figure 14: Extra aspects that were considered within LCA studies

4.1.2.6 Climate specification

The climate was described briefly in some studies for instance in (Afaf Azzouz, 2017) as it was humid with warm summers climate, in addition to some graphs for radiation and wind rose were provided. Or it was named as in (Yun-Wu Wu, 2018) subtropical climate. The climate zoon was specified in (Irene Bartlozzi, 2017) Mediterranean climate zone. There were attempts to observe the climate effect on buildings' behaviour using LCA results as a comparison in (Gül KoçlarOralb, 2016) where they studied those types of climate: temperate humid, temperate dry, hot humid, hot dry and cold. Figure 15 shows how many of the examined literature did specify the climate and how many did not, but specified the city or the country which give an idea of the prevailing climate of that area. The climate specification gives an idea of the energy use the building is going to have in terms of heating and cooling which effects the LCA study when the energy use is included in it.

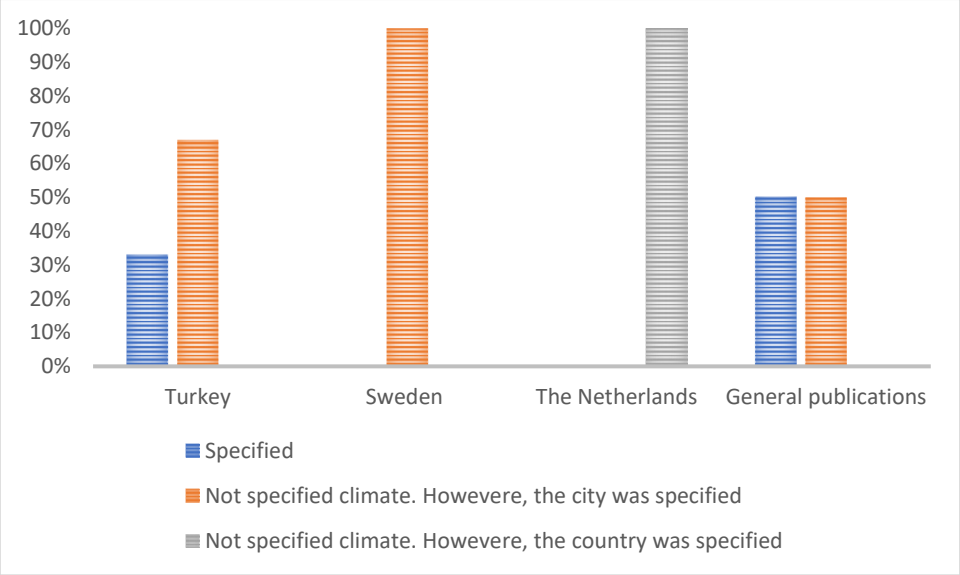

Figure 15: Distribution of climate specification within LCA studies

4.1.2.7 The period of time that LCA was performed for

The period of time that LCA was performed for was varied depending on each case. Therefore, there was no fixed regulations for a specific country whereas, the choice was related to the goal that each paper aimed to achieve, figure 16 shows the period of time in years which LCA was performed for, and how often that cycle was repeated in the examined literature. There was only one paper that considered the life cycle as 5 years since that paper examined the LCA for shelters constructed in refugee camps in Turkey.

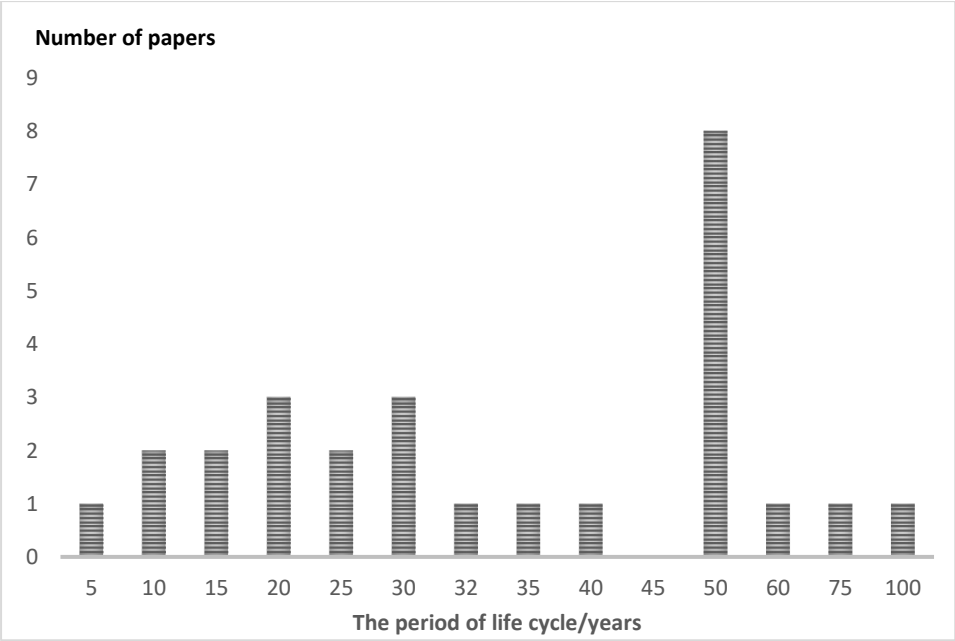

Figure 16: The distribution of the consumed time to perform LCA in each paper

4.1.2.8 Considered parts of buildings in the LCA calculations

The LCA was performed in many cases within the literature for the whole building. The whole building hereby stands for the basic parts of it (exterior and interior walls, slabs, roofs, foundations and windows). Figure 17 shows how often the building studied as a whole during its LCA for each type of the examined literature in addition to clarify when the HVAC system was including in the studies.

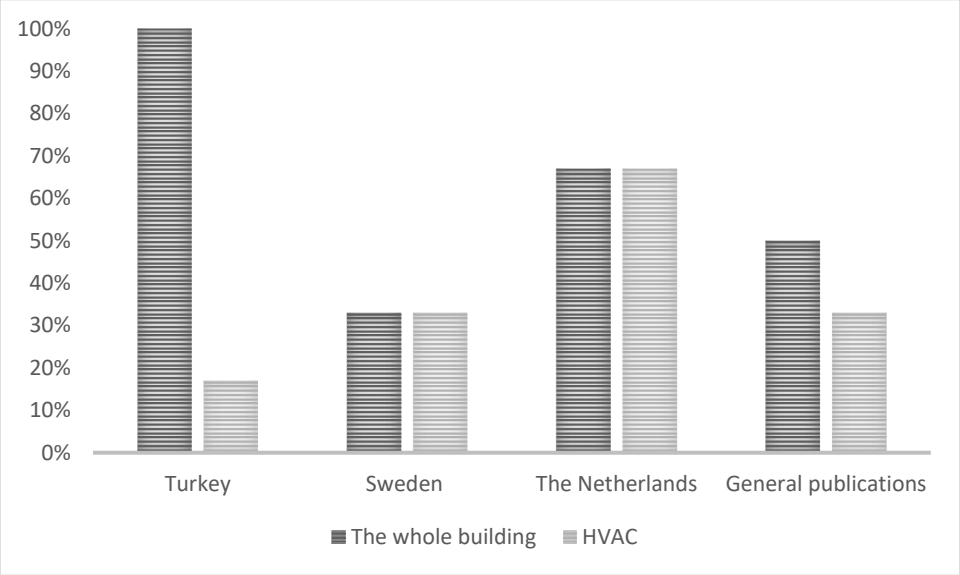

Figure 17: The distribution of the considered parts of the buildings in LCA within literature

It is not by necessary that HVAC system was included in the study when the building was studied as whole. There were some LCA studies that wanted to evaluate the used HVAC system and therefore they concerned only in studying it. Other studies were concerned in combining HVAC systems with some other parts or products of the building therefore they didn't perform the LCA for the whole building.

4.1.2.9 Environmental impacts and embodied energy

Figure 18 shows the main environmental impacts in addition to the embodied energy (EE) and how often they were considered in the examined literature. There was only one paper which considered GWP, CO_2 and GHG emissions together with the rest environmental impacts e.g. Eutrophication Potential (EP), Acidification Potential (AP)...etc, those environmental impacts were not added to the graph because they were not considered ever again in any of the rest of the papers, therefore there was no frequency to them.

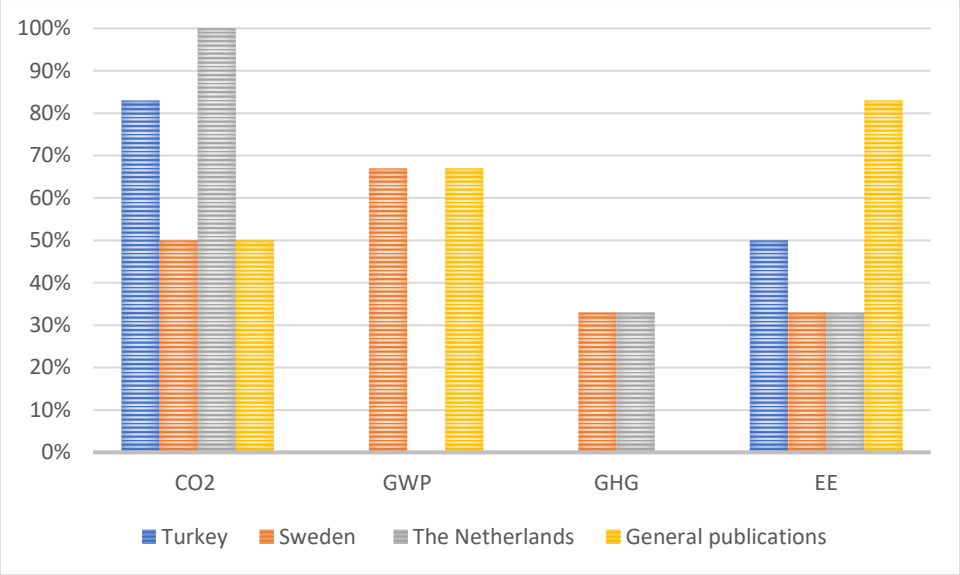

Figure 18: The frequency of the considered environmental impacts and embodied energy

4.1.2.10 LCA stages

LCA was always performed for the production stage for all cases that were examined. Figure 19 shows the 4 stages of LCA, and how often they were considered while performing LCA studies in the examined literature for each case.

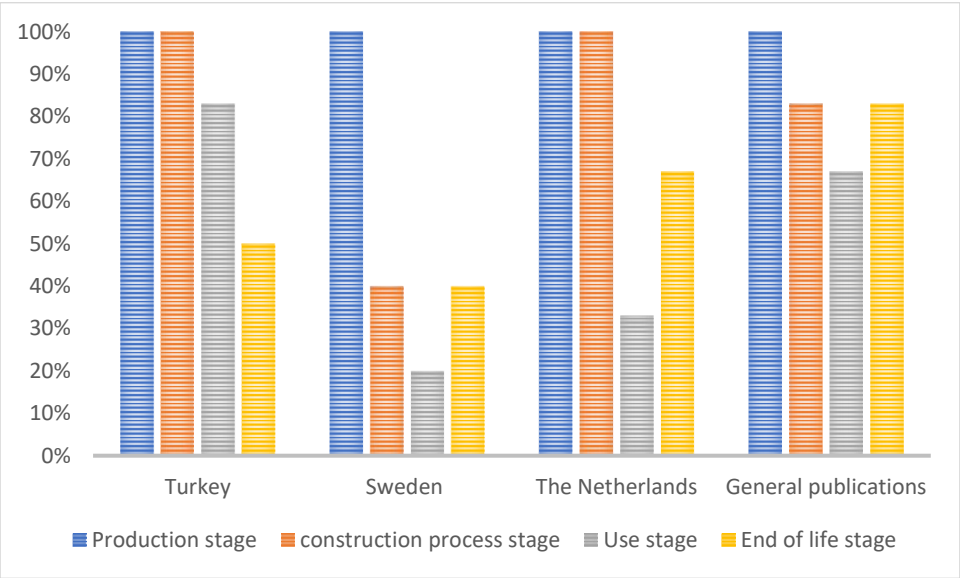

Figure 19: Frequency of the use of each stage of LCA within the examined literature.

4.1.2.11 The mentioned standards and committees

Figure 10 shows what standards were used in the literature for all cases and how frequent the CEN TC 350 committee was mentioned, except for the Netherlands hence they used local standards in all the examined literature, for instance Bouwbesluit 2012 (National Building Code 2012), "MilieuPrestatie van Gebouwen" (MPG), EPG (E.A.Alsema, 2016) and RVO. Current dutch building standards (Rajesh Kotireddy, 2018). In almost half of the Turkish literature the European standards were not directly named, but CEN TC 350 was mentioned instead, meaning that the European standards were used.

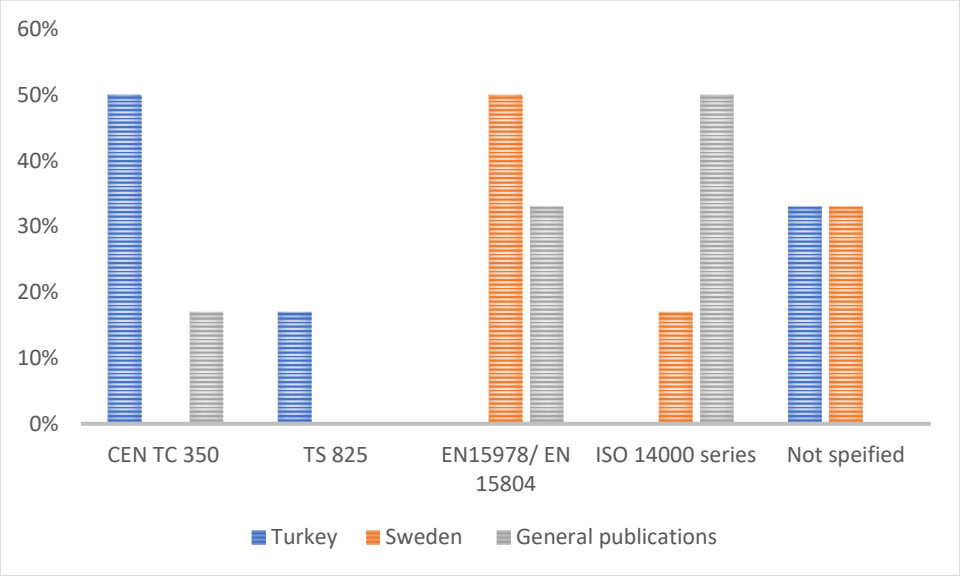

Figure 20: The mentioned standards and committees in the examined literature.

4.1.3 Findings from LCA related general publications

The combination between LCA and GIS created an effective method to access the environmental impacts of the thermal improvements within the renovation process. That was done by comparing different insulation materials within the retrofit procedure taking into consideration different urban morphologies. However, it could be upgraded by including the whole life stages, the use stage and end-life stage in addition to consider the operational energy, economic perspective and social aspects (Sergio García-Pérez, 2018). Performing the life cycle assessment as whole (from cradle to grave) gave an overall design tool which is more accurate than when it is performed from cradle to gate only, hence the resulted environmental impacts using the whole life cycle were almost as the double magnitude compared to the resulted environmental impacts when considering cradle to gate approach only. As a target to reduce embodied energy and carbon emissions it is highly recommended to perform an LCA study in early design stage in order to make the right decisions (A.M.Moncaster, 2013). Since the solar exploitation in generating clean energy is a recent application in Taiwan, it needs more governmental support within the feed-in tariff and the interest rate of principle costs. more studies are needed so they can be used as a reference for future developments in the field (Yun-Wu Wu, 2018). Applying the district energy systems in the building sector whether for heating or cooling plays an important role to the energy sustainability. In order for the studies which determine the environmental impacts of applying such a system they should be accessed during the design and planning phases (Irene Bartlozzi, 2017). Performing the life cycle assessment at early stages of the design process of the building is more effective in reducing the energy use and the environmental impacts of the building. Applying some effective strategies could achieve 16.3% saving in carbon emissions during the life cycle of the building and 13.4% energy use reduction, that could be achieved by for example applying natural ventilation together with CHP and PV systems in addition to replacing the used materials in the structure and envelop of the building with others which performed better depending on their LCA results (Afaf Azzouz, 2017). The results of life cycle assessment showed that single skin façades performed worse than double skin façades in 98% of the cases in terms of energy consumption and 85% of the cases in terms of CO2 emissions, as the operational and embodied Energy and carbon were considered (Francesco Pomponi, 2015).

4.1.4 Findings from the Turkish literature

Considering energy efficient strategies during the retrofit process showed a better environmental impact while performing the life cycle assessment. The different climate zone requires different retrofit strategies in order to keep the environmental impacts in good level, in addition to that more retrofit strategies need to be accessed and improved considering their effects on the residential buildings within their energy and environmental performance together (Suzi Dilara Mangana, 2015). The energy efficient techniques which aimed to be applied whether in new constructed buildings or during renovation process cannot be described efficiently, unless the life cycle of the building was accessed in terms of economic and environmental perspectives (Gül KoçlarOralb, 2016). For the temporary housing case the worst performance regarding energy use and environmental impacts was during the operation phase, as it consumes 86– 88% of the primary energy requirements and 95–96% of CO_2 emissions, the container houses showed worse performing than the refabricated houses towards energy use and CO_2 emissions. Therefore, the operation phase is the most critical part of the life cycle of a disaster house to be observed (Nihat Atmaca, 2016). Residential buildings within cities proved to be more energy consumed and emit more CO_2 comparing with residential buildings within country side. That is due to differences between buildings' structure, social aspects and air conditioning usage. performing LCA helped to realize the importance of choosing construction materials with low EE intensity in order to keep the building energy efficient and reduce its environmental impacts (Adem Atmaca and Nihat Atmaca, 2015). For the container type of houses that was built in Turkey for refugee camps, it was observed that with increasing the life span, the energy use and environmental impacts were decreased (Adem Atmaca, 2018). Considering environmental and economical perspectives this study showed that adding thermal insulation to the exterior walls, floor, roof floor and floor above the unheated basement, presented the best results. The best performance was gained from applying XPS and then EPS. While, RW gave the lowest improvement during the retrofit process for bot environmental and economic aspects together (Ikbal Cetiner, 2014).

4.1.5 Findings from the Dutch literature

The developed methodology to assess the building's energy and environmental impacts of the used materials during the life cycle could be used to evaluate the overall performance of the building in a very simple way without the need to use the common LCA calculation tools. Hence, this methodology is based on two already existed methods that are quite used in the building sector within the Netherlands, that simplify the access of the integrated environmental impacts. Those two methods are developed depending on the Dutch National Building Code (E.A.Alsema, 2016). Accessing the life cycle assessment of the buildings from cradle to grave approach considering neighbourhood level, provides a sufficient comprehensive consciousness to the decision makers on the amount of consumed energy, costs and CO2 emissions. That methodology is more than just guiding to the decision makers, it considers as a tool to determine the durability of the infrastructure in cities (Shalika Walker, 2018). Combining between the best and the worst possible scenarios provides an effective way in assessing the performance robustness of low-energy buildings comparing to studying combination between other possible scenario that resulted from changing one of the variable factors (occupants behaviour, cost and climate change) for each case, that methodology reduces the consuming time to perform this calculations during the design stage by 98% (Rajesh Kotireddy, 2018).

4.1.6 Findings from the Swedish literature

Testing eight future scenarios showed that raising the use of bio-based materials e.g. wood in the new established residential buildings in Sweden, gave lower climate impacts. Tis was in addition to the big influence of the technological change in material manufacturing on the GHG emissions (Diego Peñalozaab, 2018). Combining LCA and LCC together could be used as an effective evaluation tool for the renovation alternatives, due to the increasing need of renovation strategies in Sweden. This tool makes the decision easier to make (Linus Malmgren and Kristina Mjörnell, 2015). In order to decide if the aimed retrofit strategy is effective in terms of energy efficient and environmental impacts the type of the building must be considered firstly in order to make the choice profitable. However, it was found that for most types of buildings combining low-temperature heating system with operate circulation pumps had a huge impact on decreasing both energy consumption and embodied energy of the building (Qian Wang, 2015). When setting up the system boundaries it is important to notice that even the small choices of the used products has a high impact on terms of cost and environmental matters (Peter Ylmén, 2017). Environmental load profile (ELP) can be used as a tool to determine the environmental footprints during the design stage instead of more complicated often used tools hence, it is more user friendly and less cost consuming. However, it needs to be developed and modified. In addition to observe that usually this tool considers only the data of one region in this case the Swedish data were specified within the tool itself (Rajib Sinha, 2016). Neglecting the secondary effects of the building design during the construction phase would obstruct reaching accurate results in terms of cost and environmental performance of the building. As for one case study showed that 30 % of global warming potential and 25% of extra cost were caused by secondary effects. The term secondary effects stand for the changes that occurred in the design but they were not aimed by themselves during an attempt to reach the optimize design in terms of energy efficient and environmental impacts. One example of them is elongating the floor in order to withstand the thicker walls after adding more insulation to them in order to improve their performance. It is

important to consider the secondary effects in LCA and LCC in order to get more accurate results. (Peter Ylmén, 2017).

4.2 Interviews

4.2.1 Turkey

Table 2: Interviewees' names and positions within Turkey

Organization	Interviewee	Position
ITU	TA	Associate professor
Energy institute	TB	Project research assistant
ERKE	TC	Owner and director
Green building consultancy	TD	Environmental engineer

4.2.1.1 TA

TA had many contacts and projects within different European countries, companies and consultants in the LCA field. She stated that the way which researchers in Turkey deal with LCA is similar to the used methods and techniques within Europe. However, Turkey has not yet developed their own standards concerning energy performance and energy efficiency in buildings. The involved people in this area refer usually to the European standards depending on the conditions. The used methodology was developed relying on the local conditions and using some special softwares. SimaPro and Gabi are popular used softwares among researchers, developers and professionals in the LCA for building projects in Turkey. Those softwares are generally used for LCA studies including buildings, materials or transportation using similar methodologies for each case depending on the local conditions for Turkey. Regarding the approach which Turkey has made concerning LCA for buildings TA said:

" in the application of the life cycle analysis Turkey as so many European countries and some of the American states, is at the beginning "

The projects which have been done in ITU, were considered from gate to grave stage. As how the researchers at ITU deal with LCA in their projects TA said:

" How could you define the problem, based on the terminology which you are going to apply "

TA meant that one needs to define which "terminology" of LCA is going to be applied e.g. cradle to gate and then decide how should LCA be applied. Looking over beyond the grave stage for materials is not a common procedure among practical projects in Turkey. However, it is something considered to be interesting for researchers at ITU, as they want to take the study further, after the life time of the material in order to find out how is it possible to take advantages of it and whether it could be recycled or reused again for other purposes after its life time has ended. According to TA that kind of information should be provided from the industrials who are responsible for producing those material. For the current time this information is available for limited materials while it is missing for the majority of the

materials which are used in the building industry. The lack of provided information concerning LCA of the available materials in the market, is a consequence of the lack awareness among the suppliers regarding the effects of this materials together with the extra work which will be needed in order to define this kind of information.

" Companies are not like researchers, companies work is based on their financial concern "

If the companies don't have the feedback, the information about the payback time or the financial benefits which they are going to earn, then they would not be much interested in investigating the LCA for the materials which they are supplying. However, the environmentally and sustainably importance of doing LCA would not be a sufficient motivation for companies to do so. Governmental support could push on developing a new trend that LCA study acts an important role in it.

" If government provides certain kind of incentive at the beginning, saying that if you define your material concerning its life cycle assessment, we are going to give you some kind of incentives like tax reduction "

In Turkey this has not been established yet, it has not developed yet a methodology which support companies to go further towards LCA studies. However, Turkey easily adapt with what happening in the world, the environmental concerns becoming a very important issue nowadays all around the world.

"life cycle assessment should be a design, as it should have been started at very early stages of the design process "

" we are as architectures or engineers while we design our building, we should make our decisions about selecting the material based on what kind of LCA that material has "

Although this is not an easy process, it requires a very serious work from the beginning in addition to the governmental support could make the process smother by providing some benefits to the suppliers so they would attach LCA results for each material they produce, that would create a great help to architectures and engineers in making the choice about what materials to be used. One practical example of the rule which governmental support could play, is PV application which has grown in Turkey fast lately after the government has encouraged this system. The energy performance analysis, energy sustainable developments and energy efficiency are becoming hot topics in Turkey nowadays, hence LCA would be the next step.

"the more we get into the energy efficiency of buildings, the more we learn about that. I think LCA would spread more widely in the coming five years"

The goal of the current projects and researchers that are done by ITU, is to raise the awareness between people, professionals and building companies towards how energy efficiency in buildings is related to sustainability and the possible impacts towards environmental issues.

" I am sure this kind of projects is going to go further later on "

Some researchers showed that many of the traditional buildings in Tukey were considered to be energy efficient and environment friendly hence, local materials were used to establish

those buildings. In addition to that traditional buildings in Turkey were designed to integrate the environmental conditions very well. This shows that the concern about environment and energy efficiency in buildings is not an unfamiliar topic in Turkey. However, that was the case until the concrete came into Turkey and was used as a replacement of local materials, that led buildings to become less energy efficient and environment friendly.

> *" in 2002 some energy standards were set by government regarding the heating load and thermal performance in buildings "*

Before this time Turkey did not have any specific regulations regarding the energy performance of buildings. Therefore, LCA studies in buildings are considered to be quite new for Turkey. The current situation of LCA in Turkey nowadays is that LCA is taken in consideration in research much more than it is in practice.

4.2.1.2 TB

Corresponding to the regulations which were set by government in 2002 regarding energy performance for buildings, researchers aiming for Turkey to have its own standards concerning LCA. As for the current project that TB is the LCA responsible in it he said:

> *"we are refereeing to the EN 15978 standard in our project "*

The standard defines the LCA stages which should be done. This project went through the stages up to the C stage, end of life. The importance of having a local standard for LCA in Turkey, is that most of the materials which are used in the building industry are local materials which requires local standard that adapt the regional conditions. There is an attempt in Turkey nowadays, to expand the LCA studies beyond researches towards practice. It is extremely important that practice accompanied with researches both go at the same trend.

> *"practice always should go together with all this methodology and terminology "*

The companies which supply the software in connection with LCA, are the majority users of LCA among Turkey currently. Hence, the suppliers of software are responsible to teach people how to use it, in addition to that they do the simulations for their clients when they require that.

> *" Those companies also provide certain type of services for somebody who wants to calculate his/her building's life cycle analysis "*

Although not so many construction companies go for details concerning environmental issues such as LCA calculations, but it is something growing in Turkey recently.

> *" As I know that when constructions companies do LCA, they do it only for products "*

> *" Many companies might care, but they do not have the consideration yet about what the life cycle assessment of the used materials could be "*

Many building companies in Turkey nowadays aiming to get LEED certifications. The main target for this companies is to be as green as possible even though there would be no financial benefits behind being part of this certification program. The companies who aim for getting LEED certifications for their buildings, concern doing LCA calculations. However, the

importance of doing LCA is not only about doing the simulations, as a matter of fact, it is how to integrate this life cycle assessment methodology in the construction.

> *" Doing LCA analysis for a building does not mean that all the used materials are green or sustainable "*

> *" the problem in Turkey right now is that the producers of building materials are not in the LCA business yet "*

To be able to establish a green building some certified products shall be used and green materials as well. Most of this products and materials are not produced in Turkey, so the construction companies need to buy them from somewhere else. The transportation process leads to raise the carbon dioxide emissions. In order to get extra point from using certified products, that raises the cost and the carbon dioxide emissions due to long transportation, which creates a huge struggle in Turkey and considered to be non-sense application for now. It is not only about doing LCA for buildings which could improve them, it is more that the used products and materials should adapt the local environment.

> *" We have to look at the life cycle assessment from a bigger perspective, including transportation and everything "*

Most of researchers which have been done in Turkey concerning LCA up until now, considered only materials or products of the building. As for the current project which ITU are working on right now they said:

> *" We are looking on the LCA in our project as a whole. When we first started our research, we began with a literature review, we could not find a research which took the whole building in calculating LCA "*

. the project was done by considering the energy performance of the building in district area. The simulations were done for two cases, base line scenario and after renovation scenario. The LCA simulations which were done for base line scenario considered only electric and heating consumption of the building, while for after renovation scenario the LCA simulation were done considering the products which were used like glass, PV or insulation material in addition to the energy consumption of the building after renovation.

> *" the decreased amount of the energy performance in the building after renovation, was similar to the decreased amount of global worming potential "*

The project will carry on, for the best line scenario and all the calculations regarding the energy performance and the LCA analysis will be done in the coming months. This project is a European project, it was very helpful according to the staff of ITU, since it allowed them to compare how the LCA analysis differ between Turkey and other countries. The energy consumption was decreased by approximately 60% and GWP was decreased by approximately 55%.

> *" This dramatically good results were due to that the buildings which we had were not energy efficient at all "*

The LCC was calculated for this project together with LCA although, it was done by other partners. For constructors the most important is the financial concept therefor, doing LCA analysis did not affect in the decision of choosing the used materials. There is an attempt to optimise the low cost with the good environmental impacts in the building industry.

" as researchers, in practice we always like to find what is best for the environment, but what is best for the constructers is a different storey "

However, for this practice project which contains residential buildings, conference house and two guest houses, the researchers at ITU are working together Turkish constructers, which is a challenge since up until now it is not common in Turkey to have LCA expert in the construction companies.

4.2.1.3 TC

The environmental studies in the building field is a growing industry recently in Turkey. Therefore, more consultancy companies were established. The owner of ERKE company TC stated that

" No LCA study for a whole building was done in Turkey up until now"

It is a matter of fact that LCA is considered in Turkey only for big projects, especially in the big cities.

" We have clients all over Turkey "

ERKE company was responsible on doing LCA studies for more than 100 projects in Turkey.

4.2.1.4 TD

As an environmental engineer whom specialized in LCA, TD never done an LCA study particularly for a whole building. However, the LCA simulations concerning buildings are more about materials and products.

" We usually do LCA for parts of the building, like ceramic tiles, cement, concrete or elements "

More detailed parts of the building e.g. HVAC system, are not considered in the simulations which ERKE company perform usually regarding LCA.

" We might consider HVAC system if we were doing LCA for the building as a whole "

One of the used software to do the LCA study is One click software, which considered to be a simple way to do simulations. Although, another software is used for projects which concern only buildings which is IES-VE, following certain steps in order to analyze the deliberate building. For more general simulations regarding LCA for materials, Gabi software is used. However, TD thinks that Gabi is not a suitable software to perform simulations related to LCA for buildings. Thus, specifying the structure elements, building life usage, building water consumption and energy consumption kind of complex procedure using Gabi.

" one click is the best, because you can put all your data easily to the program "

In the LCA studies concerning buildings, the process passes certain steps according to TD, starting with raw materials taken from nature directly then producing the structure

considering the energy and water consumption. The life cycle assessment is done usually for 50 or 60 years. The LCA studies are according to LEED or BREEAM requirements, considering ISO standards regarding LCA. Although the most common used certifications system in Turkey is LEED rather than BREAM.

> *" We do not have so much chance for BREAM projects in Turkey "*

The main reason behind doing the LCA simulations in the building industry in Turkey, is to be certified as platinum level by LEED certification. Having the results of LCA will add extra three points within LEED requirements, which became quite popular among clients of ERKE company lately. The main obstruction of performing LCA studies in the building industry, is due to economic aspects. Thus, doing LCA study is considered to be a costly procedure therefor, the used softwares are quite expensive in addition to the lack of experts in LCA field in Turkey nowadays. However, the case will not remain the same in the coming years according to TD's expectations, due to the growing interest in the environmental matters among buildings manufacturers.

> *" We don't have any green building certification system in Turkey other than LEED and BREAM "*

Counting LEED and BREAM projects in Turkey means counting all the green buildings in the country, which is a slight amount comparing to all building projects which were done in the same period of time. Lately the Turkish government for new built hospitals to be fulfilled green building certification particularly LEED certification. Therefore, more LCA studies were performed specially for newly established governmental hospitals.

> *" the government wants to create a local green building certification system, but that needs time "*

The common type of buildings which LCA is done for, is a mixed group consists of residential buildings, schools, hospitals, hotels and especially both offices and factory buildings. Except for hospitals all other types of buildings which LCA study is done for, are owned by private companies or ordinary people whom are not related to governmental institute. The motivation behind doing LCA and getting the certifications, is that the manufacturers want to advertise their buildings as green buildings which will raise the estimated value of those buildings.

> *" I think it is not only environment responsibility which makes our customers want to get the certifications, they have other reasons "*

One common application which LCA is involved in, is using EPD certified products in the buildings, that has become quite popular recently in Turkey.

> *" We worked on cement, steel, ceramic tiles and some furniture, where we have been asked to provide EPD certification "*

Product category rules (PCR) is the main factor which determines what stages the LCA study shall go through. The PCR usually is sent by verification companies such as UL and IBU, containing all the needed instructions in order to do the LCA simulations. The results of LCA study are sent then by ERKE company to the verification companies. For most of the studies which have been done in Turkey the raw materials, production and transportation were to be considered mainly. As for end of life stage, PCR sets that it needs to be studied in a few cases. However, if a recycling program was set by the Turkish government for the wasted construction materials that would lead to study the D stage in LCA as well. The report which

will be sent to the verification companies should contains all the assumptions that were made during the LCA study.

> *" you have to be honest and you have to specify all the assumptions in your report "*

The PCR define the functional unit and the environmental impacts that should be considered in the LCA study as well, that makes the PCR the base which the LCA will build on.

> *" PCR is our bible for LCA, PCR are like a standard and we have to follow it "*

The LCA studies that done by ERKE company, are performed before the construction is established. Therefore, doing an LCA doesn't slow down the process of constructing any type of building. The consumed period of time in order to complete an LCA is depending on the available data of the project, products and materials usually it consumes between 3 to 5 months. The outputs from LCA usually determine if any changes are needed to be done in the project. In most cases the materials which have high impacts are replaced with others that fulfill the requirements. However, changing the design of the building counting on LCA results, is something hardly ever done though, changing some products or materials is more common. In addition to considering other conditions e.g. instead of buying certain type of material from one manufactory, replacing it with another one which is closer to the site. Thus, the transportation impact will be minimized and the LCA results will be improved. Generally, the responsible on making the decision if any changes are going to be done in the building, is the costumer who has requested the LCA of the building to be done. The LCC is usually studied together with LCA for the same project when it is a BREAM project, but when it is LEED project then ERKE company only provide LCA to the client.

> *" If there was no BREAM and no LEED no client would be interested in doing LCA for their building "*

LCC is done in the same software that LCA is done with, when LCC is required to be performed. The only difference is using the financial data instead, to the same project.

> *" If you did LCA for one project then it is really easy to get LCC results to the same project "*

The main obstructive in performing LCA studies for buildings is the lack of provided data. In that case some assumptions are needed to be made. Two types of reports are made after the LCA study is done EPD report and LCA report. LCA report is a secret report between the client, consultant and the verifier whereas it contains all the details about manufacturing, production and all the data. While EPD report is meant to be published, whereas it contains some general information without specifying product formula, it takes the rule as a summary for the LCA report.

> *" it is really hard sometimes to make the LCA report when a lot of assumptions were made "*

It is more preferably in Turkey to study LCA for parts of the building, rather than performing it for the whole building.

4.2.2 The Netherlands

Table 3: interviewees' names and positions within the Netherlands.

Organization	Interviewee	Position
Danuma Weg Constructive partner company.	NA	Architectural model / construction physicist
DGMR Consultancy engineering firm.	NB	Specialist building physics and sustainability

4.2.2.1 NA

For one construction to be established, more than one company could be involved. Dantuma Weg is a constructive partner company located in the Netherlands, which is responsible on designing and drawing the building. The constructing process is not included in Dantuma Wegs' duties. However, doing LCA studies is one of the company's main role, in the case that the municipality recommended attaching LCA results to the design documents. Sometimes the municipality wants to know if the life cycle assessment is taken into consideration for building projects before the constructing of the building has started. During the documentary process of a building project, the municipality would like to examine the used materials and their influence on the environment therefor LCA studies are required.

> *" the municipality concerns on how much footprint the building has on the environment "*

Sometimes LCA studies are required by clients, in addition to some cases where LCA is not done at all for a certain project.

> *" Mainly nowadays we started to get more into the LCA in the company "*

Yearly between 15 to 25 of the projects that are done by Dantuma Weg company LCA studies are considered in, which equals to almost 50% of the total. The used standard in the LCA studies which are done by Dantuma Weg is the European standard EN 15978 in addition to the Dutch building regulation as a reference. The aim of doing LCA study is not only about getting LEED or BREAM certifications, since LCA is done for some buildings although they are not certified.

> *" Our goal is to get the life cycle assessment impacts as low as possible "*

For each project there is a value of the LCA impacts, which is determined by municipality, depending on the Dutch regulations whereas the results should be below the value that set by the municipality. The climate change, land use and Ozon layer depletion are the main impacts to be considered while performing LCA. There was a special Dutch software which was

adopted by Dantuma Weg in order to perform the required LCA studies. However, that software was replaced later on with One click LCA software. The LCA studies are carried out for a 20 years period of time. Considering the product stage and construction process stage. The LCA study is always done during the design process before the building started constructing.

> *" We consider only the first stage of LCA, we do not go further after calculating the impacts of the construction during the use stage "*

> *" We usually do the LCA study in really early stage of the project, before even getting the license from the municipality "*

By license NA meant building permit. One more benefit of doing LCA that, if the results showed high impacts of a certain material or product then Dantuma Weg company neglect it for the coming projects. However, it is not likely that for the ongoing project's materials or products to be changed only depending on LCA results.

> *" the products and materials which we use now are the ones which has the lowest environmental impacts depending on the LCA studies which has been done for 10 years "*

The LCA studies are usually done to the building as a whole.

> *" We consider the building from the foundation up to the roof "*

A lot of LCA studies on buildings are done in the Netherlands nowadays, aiming to achieve a better level of constructions which have lower impacts on the environment. A huge recycling processes are established in the Netherlands lately. EPD is considered in the LCA studies as a part of the used software. It is more common that LCA is performed on residential buildings that other types of buildings, hence Dantuma Weg company is more focused on constructing residential and new built buildings, no renovation projects where LCA is considered in. In some projects LCC is doing in parallel with LCA in the case that was recommended by the municipality. However, connecting LCC to LCA is a long process which determines more calculations therefore the main focus is usually only on LCA. Doing an LCA calculation is a smooth process which doesn't influence the project approach as NA expressed. The LCA reports show the aspects which were taken into consideration such as transportation and whatever was included also. The main limitation in performing an LCA is the need to do some hand calculations to complement the study. In the case that the used software could stand for all the needed calculations, not much difficulties will remine since getting the needed data is obtainable in the Netherlands as NA experienced.

4.2.2.2 NB

The applied standards within the LCA studies that are done by DGMR company are according to the Netherlands Enterprise Agency regulations. The LCA was considered in the projects with attention to all aspects and details of the environmental performance of buildings.

> *" I see that the MPG is done quite systematically "*

The aspects that are considered in the LCA studies are mainly the materials of floors, facades, interior walls and installations. Although the energy performance of the building (operational

energy) is considered as well however, it is calculated in another module. The shadow cost is simulated as single indicator or several weighted indicators. Several recommended tools making use of the same database of materials with corresponding LCA of material provided by manufacturers or cooperatives

" the used tools to determine LCA are according to a certain standard "

The parts of the building which are going to be studied are determined by certain rules, that destine to include or not adjacent building e.g. parking spaces. Regarding the effect of the LCA study on the design and materials choosing NB said:

"one of the conclusion of my LCA study was that the LCA calculation of material by manufacturer should be more precise or updated "

Materials missing from the database or out-dated are the main limitations in performing LCA studies for buildings. It is mandatory for every new building of more than 100m² for all projects that are done by DGMR company to contain LCA results of the building. However, for renovated buildings the LCA study concerns only the new materials to be used. About the connection between LCC and LCA in their projects NB said:

" the architects had a good idea of the cost implication and took that into consideration but no LCC thought, just investment cost "

The LCA application in the Netherlands is systematically, but clients might say how important it is to them to get a good score for their buildings. Performing LCA in these specific methods for buildings is widely spread in the Netherlands, but it is not the case for a full LCA from the scratch.

" the data in the database of material is not exactly like an EPD "

For architects or consultants reaching and using EPD is really easy process in the Netherlands. The investigation in LCA gives good input to improve the design work as NB experienced so far.

4.2.3 Sweden

Table 4: interviewees' names and positions within Sweden.

Organization	Interviewee	Position
WSP Management and consultancy services company.	SA	Senior consltant
WSP	SB	Department manager building physics
NCC Construction company.	SC	sustainability specialist
Skanska Multinational construction and development company.	SD	Green development manager

4.2.3.1 SA

Performing LCA in buildings helps in environmental management and legalizations for buildings. Whether some regular environmental information, risk analysis or LCA study are going to be performed concerning a certain building, it is something decided by the client.

> *" When I started as LCA specialist in 2001 there was less interest in the LCA "*

During the eighties and nineties LCA was not accessed in the building industry in Sweden, it was more a material for research projects. It is noticed that recently there was an attempt to make LCA easier to perform within Sweden.

> *" I see a growing interest in LCA the past 5 years "*

LCA use is growing as a screening tool, in order to examine the influence that the building industry has on the environment. So many impacts of LCA are considered as factors affecting the environment, however the main factor to be considered within Sweden is the climate change.

> *"By time it has been less effort to put in LCA researchers and thereby a greater industry interest "*

The clients of WSP company who seek for LCA studies, are mainly industry manufactures and region municipalities.

> *" we have done a lot of studies for Skåne region, when it comes to the climate and the Carbon footprint from transport for the whole region "*

> *" I would say the greatest industry for LCA is in the building sector and infrastructure "*

One application for LCA in Sweden is performing it in constructing tunnels and highways since the transport authority in Sweden aiming to be climate neutral in the future. The process which the organizations in Sweden correspond to LCA results is, trying to lower the impacts by changing the materials and use more efficient processes. One main reason to perform LCA is to gain more points in order to win some tenders for big projects which were offered by the municipality. The environmental impacts of a building have lately been added to some other factors such as economic aspects, quality and labour that determine whether one company could get an offer to win the tender.

> *" the environmental aspects don't have the highest priority but they need to be in the offer "*

The LCA studies are mainly done for materials and products although, there were some studies which covered the whole building. However, they don't exceed 10% of the total studies done by WSP. Most of the work which is done by WSP company regarding LCA in buildings, is helping the producers in creating EPD and LCA for their products.

" Basically what is driving the LCA is that customers are asking for studies as one requirement of their buying process "

The help of a consultant company such as WSP is requested by companies involved in the building industry, mainly because they do not have LCA experts working with them and they lack the needed resources therefore they are not able to perform LCA within the company itself. Hence LCA is part of LEED and BREAM, performing it gains extra points to get the certification. Although, it is not by necessary the main motivation behind performing LCA for buildings in Sweden. In order to achieve the gold status on Miljöbyggnad, which is a Swedish certification system, in addition to some other desired levels, LCA can be performed for the target building. This can be done by using a special simplified calculation tool provided by Miljöbyggnad or by a another LCA tool. By using the Miljöbyggnad´s special tool, the only resulted impact is GWP. However, SimaPro and Gabi are the main used software in performing LCA for buildings by WSP. However, SA thinks that performing LCA using Gabi and SimaPro is kind of sophisticated method.

" They are often far more complicated than you need for the actual study "

By having either EPD figures or general figures collected from SimaPro, it is possible to create an Excel sheet in order to simulate LCA in more sufficient way than using some special LCA software according to SA's experience.

"For me LCA is a methodology and how to perform this methodology is my speciality "

The department which perform LCA in the company is a deferent department from the one which is responsible on the applied certification system for the same building. LCA studies are done for official buildings mostly, e.g. hospitals, schools and congress hotels rather than residential buildings.

" When there is a large building being built in the city it is always a question of having some certification "

However, it is not by necessary that when some certification system is applied on the building that LCA was done to the same building, although performing LCA becoming more important in order to gain extra points to get the building certified. Therefore, considering the current situation in Sweden half of the newly built projects do obtain LCA for some parts or for the whole building according to SA's perspective. Considering that when there are international builders this become more important. Although, Sweden is already advanced in the applications of LCA in buildings, but the awareness of its importance is growing constantly. Although, some building companies in Sweden nowadays still don't take LCA in consideration at all, they could have some knowledge but no real application is done.

"I see that sometimes we have customers that when we do small LCA studies just to indicate the used products, they get surprised about what LCA might give "

The previous LCA studies that done by WSP considered only one indicator at once, mostly that indicator was GWP. Submitting several indicators at once could confuse the customers and make the LCA results complicated therefore, WSP settled for one indicator at once. However, that is the case for now and it is able to be changed soon, other indicators might take the priority in the coming future. Most studies that done by WSP considered the stages from A1 to A3, cradle to gate only. In some studies, A4 is added as the transport to whether the building site or the central warehouse. As a percentage of 10% to 20% of all cases, the use

and recycling phases are considered in the studies. Essentially what defines the scope that the study will go through and what stages to be considered is the customer's will. The limitations while performing an LCA study represented in, difficulties to get environmental impacts for a certain material in the database or when the suppliers of the used materials don't provide specificity figures for their materials, then assumptions need to be done in order to perform LCA.

> *" to do an LCA is to keep track on the material use, energy use etc over the whole project and that is something normally you should to track any way "*

Therefore, SA did not experience that performing LCA could slow down the process of a building project, unless the person who is on charge of it is not experienced enough. The main difficulty of the people doing LCA for the first time is that they do not know what assumptions to make, even though that will take more time but it doesn't slow down the project as a whole. EPD is normally used when they are available, otherwise when EPD is done, but not published for a certain material then the person on charge could ask for a permission to access that certain EPD from the responsible company on it. If LCA affecting in changing the used materials or products which have proven that they have high environmental impacts, is something SA thinks should be a priority. However, 50% approximately of the manufacturers do take the LCA results into consideration and invest those results in developing the examined product or material. A new LCA study is done to the developed material or product and if they prove sufficient improvement, then they are approved to be used as parts of the building.

4.2.3.2 SB

According to SB the use of LCA for buildings in Sweden is not very common nowadays although, it has increased lately however, that progress considered to be slow.

> *" for the last 5 or 10 years we were expecting LCA to soon come regarding buildings, but it has not really happened "*

The demand for LCA which involve buildings nowadays is basically for parts of the building. LCA usually performed for the façade, glass or roof that is usually when the building is going to have BREEAM or BREEAM.SE certifications. However, it is not very often to do LCA by necessary when applying the certification system on the building. No whole building LCA study was performed ever by SB's department.

> *" I think doing LCA for a whole building is too complicated, too expensive and what shall they do with the information "*

One large application for LCA in Sweden is, to compare two different façade alternatives. In addition to the economic costs and U-values, LCA results play main role in making decision. The new version of the Swedish certification system Miljöbyggnad 3.0 demands to include LCA results for structure.

> *" we are supposed to compare structures, for example concrete versus wood "*

The used tool to perform LCA is One click LCA. The modules are prepared in order to perform LCC as well. During the last year LCA was performed for three projects, which is

considered to be a real progress to the department. Despite the large number of the certified building projects that are done annually by the department, three projects that have included LCA can considered as a good start. It is a matter of fact that this number will increase in the coming future.

> *" I won't say LCA use is very growing in Sweden, I would say it has started to grow "*

One thing that is increasing constantly in Sweden, is EPD for building components.

> *" I think people in the building industry are a bit scared of LCA as a tool for the whole building "*

However, it is easier to perform LCA as a tool to compare between alternatives. Performing LCA for structure in the design stage is a good choice for the sake of, it is manageable, easy to get volume and weight for the structure. In some cases, the results of LCA studies are taken in consideration in order to make changes within the building. However, some customers decide not to take action counting on LCA results, that could be due to financial aspects mainly. According to SB there are two main problems in performing LCA practically

- It is not possible to count on LCA results since there are no benefits economically.
- It is very hard to perform LCA in some cases.

The complex in performing LCA is clearly appeared, when the used products are not produced inside Sweden. Some data could be hard to collect in addition to the transportation would increase the environmental impacts.

> *" LCA is a small component in the certification systems "*

When the target is the platinum stage in certification system, considering that LCA would add only 3 points while the target is 80, it is more efficient to consider solar energy for instance. Focussing in other environmental fields which guarantee more points on the certification scales is more required by customers. LCA was performed mainly for hospitals, offices and schools, LCA was never performed for residential buildings. That is due to the fact is the expensive certification are required the most for offices buildings. That would make the building more desired commercially in addition to raise its value. Recently LCC was connected to LCA, for same project both studies were presented simultaneously starting from 2017. That does not include all the projects, but only when it is asked. The indicators to be shown are depending on the applied certification system requirements. However, climate change is the main indicator to be considered in most cases.

4.2.3.3 SC

LCA studies are one of many different tasks that NCC company does in the building business. Performing LCA in the building projects that are done by NCC is something new and not very advanced yet.

> *" LCA in the building business is still immature "*

The main obstructions in performing LCA for buildings are:

- There are no specific laws or regulations to follow regarding the topic.

- The extra cost which combines performing LCA, which are considered to be expensive.
- The low demand of LCA studies for building projects among customers.
- The lack of knowledge regarding LCA.

The interest in LCA started to appear in NCC company some years ago, different calculations were made to see the buildings' impact on climate change specifically. The LCA studies included parts of the building for some projects while they covered the whole buildings in others. Up until now NCC was never asked to perform LCA for a whole building from their clients. However, in the few projects which covered the whole building the purpose behind that was, the company's desire to develop its methodology regarding LCA calculations. LCA is performed for all types of buildings e.g. residential, hospitals or schools. Usually there is no certain type where LCA is required to be performed for rather than others. LCA performed basically when some certification system is applied on the building and LCA was one of the requirements.

> *" When we do LCA on a wall, floor or a window, it is because we are having a certification "*

one other reason to perform LCA is that NCC company aims to build more environmentally friendly buildings. Performing LCA for buildings is hard in this field particularly comparing to other applications of LCA. Hence, every building is an individual case and has something different from the others. Therefore, performing LCA in production or industry is easier than it in building field, since it follows the same approach.

> *" NCC is a little bit behind Volvo for example, because I think it is easier for them to do the LCA calculations than us "*

> *" it is not easy for us to copy paste from every time as it is in industry or something like that "*

The adopted standard by NCC is the European standard concerning buildings EN 15978. The used softwares by NCC to calculate LCA are GABI and One click LCA, which both of them have the standard in their default sittings. NCC company is investigating the possible methods and the available softwares to do the calculations of LCA in order to improve this process. SBUF (Swedish building developing fund) is providing the financial support to the investigation project aiming to compare different softwares and methodologies regarding LCA in order to define what is most relevant to perform LCA in the building field. Generally, what define which indicators to be considered during a project are, the requirements in the certification system. However, that is not stable for all projects, some projects shall include certain indicators that could be different than what other projects cover. Mainly, CO_2 emissions are considered in big ratio of the projects that are done by NCC. For most projects that done by NCC, LCA studies are performed from A1 to A5 in addition to the use stage. LCA studies are done for both new established buildings and renovated ones. The lack of the input data and the needed EPD are the main limitations that face the staff at NCC while performing LCA. In some cases, LCA could play a role in changing the used materials in the building e.g. the used materials in the exterior walls were changed in one project relaying on the results of LCA. However, that is not the case for many projects due to that LCA is done later on when it became harder and more complicate to change materials. Currently LCA used as a tool to gain more points in the used certification system rather than using it as a decision maker tool.

> *" There are so many steps when building a house and LCA is not yet the most important of them "*

Furthermore, that is going to change in the near future due to many reasons, one of them is that the National Boars of Housing Building and Planning has lately started to raise the attention in this concern. A new proposition was made by the National Boars of Housing Building and Planning T for making climate declaration compulsory for every new established building.

> *" Maybe in a couple of years every new building must do this kind of calculations, because it is going to be in the Swedish regulation system for buildings "*

NCC company performed LCC studies for their projects, but that was never combined with LCA study at the same time, although SC thinks it is an interesting thing to do since she believes that there is a strong connection between LCA and LCC, regarding connecting LCA to LCC SC said:

> *" This is something we have to take into consideration since we want to build climate and environmentally friendly buildings but we also need to think about the costs "*

4.2.3.4 SD

Skanska company has now its own specialist group that works mainly with LCA studies for the building projects that are established by the company. Although LCA studies in the construction field is not a new topic, but it was not very commonly used in Sweden up until lately.

> *" LCA is not a new technology, it is theoretical and complex that's why many people tend to think it is a new field "*

Around 2009 Skanska has started to work with LCA concept. Back then it was not very common among building companies in Sweden to do LCA calculations.

> *" I think we were the first construction company who started to work together with IVL "*

IVL provided database and methodology to Skanska company so it was possible to form its own LCA tool. Nowadays Skanska use its own software Eco2 which was developed within the company itself to perform the LCA studies. This software was based on the same principle as the other commonly used LCA softwares were based on. The reason behind using this special software was because the company wanted a system where it is easy to go from generic data to use its own data. In addition to that this tool combine between LCA and economic calculations. The company use the European standards in the calculations EN15978/ EN 15804. When the budget of the project is high then LCA calculations are performed. Almost all the projects that are done by Skanska do have LCA results included except for the very small projects. Skanska Color Palette is an internal method to classify buildings that are done by Skanska company. In order for any building to classified as green according to Skanska Color Palette, it needs to fulfil some requirements, LCA is one of them. Therefor there is no certain type of building that LCA is required in, rather than other, as long as the building aimed to certified as green. Usually LCA is not performed as whole, in all its stages. As the production is the only considered system boundary with an approach from

cradle to gate. That is done for all the building including all the used materials. Using the special software of the company, it is not difficult at all to perform LCA for the whole building. A lot of environmental indicators are considered from Skanska perspective. However, LCA is not the only used tool in considering those indicators. LCA was chosen to calculate the environmental loads regarding climate change only. Hence, SD has the vision that it is not effective to include all the environmental indicators in the LCA study.

> *" We consecrate on climate because we know LCA is the perfect methodology for climate but it is not for the other indicators, there are other tools that work just as fine or better for the other indicators "*

> *" When I was younger, I wanted everything to be included in LCA, I thought it is the only way to go "*

If many indicators were considered at once in an LCA study then some of them will margin the importance of others therefor, it is better to focus only on one indicator according to SD opinion. That make the process smoother and faster to separate tools in calculating different environmental indicators. If LCA was performed in an early phase of the project then it doesn't slow down the project progress. Usually LCA is done twice, firstly as a pre-study in very early stage and depending on it some changes are made in order to improve the results, secondly after the project is done another LCA study is performed in order to see influence of the changes which were done and whether they performed better or worse. Couple of years ago LCA was not considered as a decision maker tool, since the company was exploring whether the results are repayable to make changes depending on. Nowadays the goal of Skanska is to reach climate neutrality in its buildings therefore, LCA is taking more into consideration. Although, it is not common that LCA is requested by clients to be performed, it is more a strategy of the company. One exception of those clients was Trafikverkets, as they asked for LCA results in the projects that Skanska is going to perform for them and they had their own methodology regarding it. LCC is usually performed by the company but it is not connected to LCA. Although, the economic perspective is considered in combination with LCA but not in a long-term perspective as life cycle.

> *" If you have a lot of time you could do LCC connected to LCA, but normally you wouldn't "*

When performing LCA studies for certain projects using Eco2 software the service life is considered then only during production stage. However, for climate neutrality projects the considered period of time to perform LCA is 50 years of service time. Normally the C stage of LCA is not considered in the projects that done by Skanska however, there is an attempt to raise the use of recycled materials at early phases of the building projects in order to decrease the environmental loads.

> *" If you are a theoretical person then it is easy to say, yea include the recycling, but we are more interested in working with facts and what we can change "*

The transportation is included in all cases almost when performing LCA. In the projects which aimed to achieve climate neutrality all the required materials were transported using trains as much as possible in order to minimize the impacts of transportation. Hence, renovation projects are not the main business of Skanska company, LCA was performed mainly for new buildings projects.

5 Discussion

5.1 Comparison between literature and practice (Turkey)

The type of buildings that LCA was performed for in the Turkish literature were mainly residential buildings and almost 30% of the literature considered temporary housing e.g. post-disaster temporary housing. In practice TB performed LCA for residential buildings, conference house and two guest houses. TD performed LCA for a mixed group of buildings types such as residential buildings, schools, hospitals, hotels and especially both offices and factory buildings.

The Turkish literature considered the existing and renovated buildings more than the new buildings, in practice TB performed LCA for both renovated and new buildings while TD was responsible on new constructed buildings mainly.

In the Turkish literature almost 70% of the buildings which LCA was performed for were privately owned. TD mentioned that except for the governmental hospitals all of the other projects that she performed LCA for, were privately owned.

The most used softwares to perform LCA in the Turkish literature were ICE, Gabi and SemaPro respectively. In practice TA used both Gabi and SemaPro to perform LCA while TD mentioned One click, IES-VE and Gabi as the used softwares to perform LCA.

The energy consumption of the buildings was considered within the Turkish literature and specified as natural gas, electricity and coal. In practice TB mentioned that only electric and heating consumption were considered in their project.

LCC was performed together with LCA only in 30% of the examined literature, TB mentioned that LCC was performed as well for their project together with LCA. TD stated that LCC is usually studied together with LCA for the same project.

All the examined Turkish literature considered the whole building excluding HVAC system while performing LCA, except for one paper which considered the whole building including HVAC system. However, in practice all the participants mentioned that LCA is performed for products or materials only and no whole building LCA was performed by them.

The CO_2 emissions was calculated in 80% of the examined Turkish literature. In practice TB mentioned GWP as the main environmental impact.

The production and construction stages were considered in all the examined Turkish literature while the use stage was considered in almost 80% and the end of life stage was considered in 50%. In practice TA considered both construction stage and use stage, there was no consideration of end of life treatment. TD did consider the production, construction and use stages, end of life stage was studied in few cases. TB did consider all the stages: production, construction, use and end of life stages.

In the examined Turkish literature, some did not specify which standard was used, while some publications mentioned TS 825. In practice both TA and TB did consider the European standards while TD did consider the ISO standard.

5.2 Comparison between literature and practice (The Netherlands)

Most of the buildings which the Dutch literature considered to perform LCA for were residential buildings in addition to a few cases of commercial buildings. NA said that LCA performed mainly for residential buildings in practice in their company.

Half of the cases which the Dutch literature concerned performing LCA for were new established buildings while the rest were either for already existed buildings or for renovated ones. In practice NA performed LCA for only new buildings and NB performed LCA mainly for new buildings, in the case of renovation they performed LCA for only the materials which used within the retrofit process.

Most of the buildings within the Dutch literature were privately owned. In practice, LCA is widely applied for most of the projects in the Netherlands therefore both cases exist, since LCA is a demand of some municipalities.

The mentioned softwares in the Dutch literature to be used during performing LCA for buildings are: TRNSYS, GPR and Ecoinvent. In practice NA using one click LCA for their projects.

The energy use of the buildings was always included in the LCA studies in the Dutch literature and the energy source was specified as mostly electricity and natural gas. In practice NA does not include the energy use of the building since they do not consider the use stage of the building within the LCA study, as for NB they do consider the energy consumption of the building while performing LCA study.

LCC was performed together with LCA in 30% of the Dutch literature, while there was an economic consideration combined with LCA for all the cases. In practice NA perform LCC in parallel with LCA for some cases, when it is recommended by the municipality, as for NB they do not perform LCC usually together with LCA but they simulate the investment cost instead.

In 60% of the examined Dutch literature the whole building was included in the LCA study. In practice NA usually consider the whole building to perform LCA for, while NB considers parts of the building, some materials and products to perform LCA for.

The Dutch literature considered the CO_2 emissions mainly in addition to GHG emissions as well. In practice NA consider the climate change, land use and Ozon layer depletion in their LCA studies.

The production and construction stages are always considered in the Dutch literature while the use stage was only considered in 30%. In practice NA considers only the production and construction stages while NB considered use stage in addition to production and construction stages.

For both literature and practice in the Netherlands the used standards were according to the Dutch regulations system, although NA does consider the European standards as well in their LCA studies.

5.3 Comparison between literature and practice (Sweden)

The Swedish literature which was examined, performed LCA on residential buildings only. In practice both SA and SB performed LCA for official buildings mostly, e.g. hospitals, schools and congress hotels rather than residential buildings, while SC performed LCA for all types of buildings without specifying one type rather than others. SD performed LCA for almost all their projects except for the very small projects. Hence Skanska aims to certify almost all its projects as green according to Skanska Color Palette, there is no certain type of buildings that LCA is performed for rather than others.

The examined Swedish literature did consider all types of buildings: new established, renovated and already existed buildings. In practice SC performed LCA for both new and renovated buildings, while SD concerned in performing LCA mainly for new buildings projects.

All the buildings which LCA was performed for in the examined Swedish literature were privately owned. While all the participants said that they did perform LCA for both privately and governmentally owned buildings.

The mentioned softwares in the Swedish literature to be used during performing LCA for buildings are: Ecoinvent, Excel, ICE, SimaPro and Gabi. In practice SA uses Excel mainly in addition to Gabi and SimaPro, SB uses One click LCA and SC uses both Gabi and One click LCA. As for SD, Skanska use its own software Eco2 which was developed within the company itself to perform the LCA studies.

The source of the energy that is used in the building was never specified during performing LCA studies in the examined Swedish literature. In practice SA mentioned that the energy use of the building is considered while performing LCA study for very few projects. SD did not consider the energy use of the building while performing LCA studies.

Half of the examined Swedish literature performed LCC together with LCA while the other half hade economic consideration but not as a life cycle. In practice SB performed LCC together with LCA for some projects when it is asked from the clients, while SC has never performed LCC together with LCA. As for SD they never performed LCC together with LCA although the economic perspective is considered in combination with LCA but not in a long-term perspective as life cycle.

In Sweden only 30% of the examined literature considered the whole building while performing LCA. In practice SA usually performs LCA for materials and products of the building, LCA was performed for the whole building in few cases only. SB never performed LCA for the whole building, it was just performed for parts of the building. SC usually performs LCA for parts of the buildings, in the few cases that LCA was performed for the whole building, that was just because the company wanted to develop its methodology. While SD considered the whole building while performing LCA.

The environmental impacts which were simulated in the examined Swedish literature were GWP, CO_2 and GHG emissions respectively. In practice SA considered GWP mostly, SC considered CO_2 emissions for most of their projects while SB and SD considered the climate change.

In the examined Swedish literature, the production stage was always considered, the construction and end of life stages were considered in almost 40% while the use stage was considered in very few cases. In practice SA usually considers only the production stage and for very few cases the use and end of life stages were added too. SD considered only

production stage, cradle to gate. While SC considered the production, construction and the use stages for their projects.

Half of the Swedish examined literature considered the European standards: EN15978/ EN 15804 while less than 20% considered the international standards, the rest did not specify which standards were used. In practice both SC and SD depend on the European standards in performing their LCA studies.

5.4 Comparison between Sweden, Turkey and The Netherlands

In the Netherlands both in literature and practice the LCA was considered mainly in residential buildings, that was not the case in Sweden the literature did consider only residential buildings, not in practice. In Turkey both literature and practice considered different types of buildings.

In Turkey the literature considered the renovated and existed buildings more than the new buildings, that was not the case in practice, while in the Netherlands both literature and practice focused more on new established buildings. In Sweden there was a similarity between literature and practice in the buildings' types that LCA was performed for.

In Turkey the literature and practice concerned in performing LCA for buildings which are privately owned rather than buildings that are governmentally owned. In both Sweden and the Netherlands, the literature concerned more in the privately-owned buildings while in practice LCA was performed for both cases.

For all the three countries there was no completely matching between literature and practice in the used softwares. As the most frequent software to be used in the literature is not by necessary the most used one in practice.

The energy source was more specified in the literature rather than it is in practice. The energy use of the building is included in some projects within the three countries. However, there was more focusing on it in the literature than it is in practice.

In Turkey performing LCC together with LCA was more used in practice rather than it in the literature. In Sweden it was the opposite case, as the literature concerned more in performing LCC together with LCA than practice, as in practice there was more consideration of the economic aspects not in a life cycle perspective. In the Netherlands there was a similarity between literature and practice, as both performed LCC together with LCA for few cases while the majority considered economic aspects together with LCA only.

There was a contrary between literature and practice in Turkey, as all the literature considered the whole building while performing LCA, while in practice only materials, products or parts of the building were considered to perform LCA. For both Sweden and the Netherlands both literature and practice contained both cases, performing LCA for the whole building or for only parts of it.

For all the three countries there is matching between literature and practice in their consideration of the considered system boundaries.

For both Sweden and Turkey, the European standards were mostly considered in practice. As for the Netherlands, the used standards were according to the Dutch regulations system in both literature and practice.

The Netherlands indeed was much progressed in performing LCA in practice:

- Having their own standards and regulations.
- Some municipalities set performing LCA as one condition for the building to be approved on.

In Sweden the situation was varied, as some companies seriously considered LCA in their projects while others applied LCA for some of their projects. However, there are still companies that do not perform LCA in their projects at all. In Turkey LCA application is existed but it is still limited to the big cities and big projects.

However, the case was different for the literature review process. The Netherlands had the lowest publications while there were really good detailed studies that were published about LCA within Turkey and Sweden. But that could be due to the fact that only the publications which were published in English were examined.

In general, there was a big interest in accessing LCA in the retrofit applied strategies within literature in Turkey, that could be due to the fact that there is a great need to retrofit exciting buildings in Turkey. In addition to that the environmental issues (LCA specifically) was not widely spread some years ago. Therefore, the literature tends to cover that issue by focusing on the environmental performance on the applied retrofit strategies.

Within the Netherlands it was not enough to use the LCA for buildings or life cycle assessment expressions only to find the articles. As noticed from the search process that the focus in the Netherlands was on the local conditions. Therefore, a lot of literature was in Dutch in addition to that LCA is more common to be used in practice than researches in the Netherlands.

Although the thermal comfort is one of the effective factors within energy efficiency field it was only considered in 3 papers of all the examined literature, and never mentioned from the interviewees to be considered during LCA studies in practice.

There was a connection between studying the thermal comfort and the social aspects. As all the only 3 papers which studied the building performance during its life cycle depending on social aspects, they combined that with discussing the thermal comfort towards the same buildings. Those indicators were not given much importance in practice, as the participants in this research did not mention how much consideration they awarded the social aspects when performing LCA studies.

The IAQ was rarely combined with LCA studies in literature, although it is an important indicator to be accessed.

LCA was not studied in literature individually in most cases due to that the energy use of the building was often considered thereby, there were attempts to reduce that by suggesting some improvements or retrofit strategies in the case of renovation. Some papers were excluded from that as LCA was the base of it, and either the energy consumption of the building was neglected, or it was included in the study but not directly calculated, other ways were used to measure it e.g. the energy consumption of the building taken from the bills of the studied building when it is a renovation case. However, the energy use was a priority to include in the LCA study in practice as it was observed from interviewing the LCA experts in different countries.

" If you are a theoretical person then it is easy to say, yea include the recycling, but we are more interested in working with facts and what we can change " SD

This citation summarises a very important finding, the difference between literature and practice. Whereas in the literature there was much consideration in theories and general benefits of LCA towards environment. In practice there was a big focus on the application of LCA and the certain gains of that, whether that was to achieve some certification system or a specific goal for the building company.

6 Conclusions

Those conclusions are valid within the time this study was made in. Any possible changes in the regulations and application would affect them.

1. There are no common regulations regarding the use of LCA in buildings that apply within any of the three investigated countries as a whole.
2. The difference in the LCA use for buildings between different countries may be due to the different constitutions set by governmental organizations for example municipalities.
3. More cooperation between the LCA experts and the building certification experts in same department for the same company could make the process smoother.
4. Including LCA in all certification systems for buildings would increase the interest in performing it.
5. Raising the gaining points from performing LCA in the certification scales would raise the demand for LCA in the building market.
6. Performing LCA in early stages of the building projects is more effective, since any possible changes are feasible by then. Performing LCA at later stage will be more of a declaration and will not give possibilities for changes to better environmental solutions
7. Getting the building certified is the main motivation behind performing LCA in practice for buildings in Turkey. While it is getting the building approved on, or due to recommendations from the municipalities in the Netherlands. Environmental management is the main motivation to perform LCA in Sweden.
8. For all the three countries it was observed that, in practice, usually the simpler softwares are more desirable and to show only one or two environmental impacts is more common, not like in literature.
9. In practice the LCA was performed for materials, products or parts of the buildings for all the three countries, while in the literature there was more consideration about the energy use and specifying the energy source.

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8 Appendix

Questions that were used in the interviews:

1. What is the standard that is considered in the LCA studies?
2. How do you consider LCA in your projects?
3. What are the aspects you consider in your study regarding LCA?
4. What indicators did you consider?
5. What tools are used to determine LCA? And if you used the tools from IVL or miljobygnnad did you receive any help from the suppliers?
6. What parts of the building did you consider in your study for LCA?
7. Did you change the building's materials considering your study for LCA? How did your LCA study effect your design and choices in general?
8. What are the stages you considered in your LCA study (A1-A3 **production** A4-A5 **construction**, B **use stage**, C **end of life**, D **reuse recycle**….?)
9. What are the limitations that faces you while doing your LCA studies?
10. How much percentage of your projects LCA study was performed in?
11. Do you consider LCA in your renovation projects?
12. Have you made an LCC study for your projects? If so, was there any connection between LCC and LCA?
13. For how long have you used LCA and for how many projects?
14. Is it normally your clients that requires LCA or do you normally suggest to use it?
15. From your experience - is it common to use LCA in your country?
16. Is it easy to find EPDs for the materials that are used?
17. Do you experience that LCA is complicated and extensive and slowdowns the projects or do you experience that the investigation gives good input to improve the design work?
18. Do you experience that your readers require more LCA articles and more knowledge about LCA?
19. Is LCA more commonly used for certain type of buildings?
20. Do your customers demand LCA? In how big ratio of your projects?

Questions that were used in the literature review:

1. How is LCA examined in literature? And how does that differ from practical application of it?
2. What was the reason behind starting that paper? Should I go paper by paper?
3. What functional unit was used?
4. Is the LCA part of the paper or is it what the paper all about?
5. What was the used methodology to perform LCA calculations?
6. Was the paper based on calculations, interviews, survey or measurements?
7. How does it differ between each country's perspective?
8. What was the period of time which the LCA study covered? What stage was LCA performed?
9. Was it for new established building or retrofit one? And what type of buildings? Were them private or public? What software?
10. What type of climate did the paper considered?
11. Was the energy use of the building considered in the LCA study?
12. Were the economic aspects taken into consideration while considering LCA? What about social?
13. Was there any attempt to connect IAQ and thermal comfort to LCA? Or others?
14. The study was for parts of the building (materials, products, HVAC system)? Or the whole building?
15. Was the energy source specified? What is the influence on LCA?
16. What indicators were considered? And what stages? And what standards?
17. What is common between them all
18. The conclusion of every paper?