Assessing circular buildings

A balance between circularity and life cycle costs of a building

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Assessing circular buildings: A balance between circularity and life cycle costs of a building

by

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In partial fulfillment of the requirements for the degree of

Master of Science

in Construction Management and Engineering

at Delft University of Technology

Student number: 4827198

Project duration: January 2020 – August 2020

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Preface

This is the Master thesis report written as a part of the M.Sc. program in Construction Management and Engineering at TU Delft., The Netherlands. This research was conducted in collaboration with ABT BV, a consultancy firm in the Netherlands specialized in integrated building engineering. My passion for sustainability and circularity made me want to align my research in these fields. Since then it has been a stressful, yet beautiful journey that I will remember for a long time. I would like to take a moment and thank some of the people who have been a part of this journey.

First of all, I would like to thank **Charles Boks** and **Annebeth Muntinga** for giving me the opportunity to work at ABT. It has been a pleasure working with you both and the company. Sustainability is one of the core values within ABT and working alongside a team with such ambitions was worthwhile. I would like to thank them for their guidance and time dedicated to helping me finish my research. Thank you for always responding to my queries and for giving me meaningful insights whenever needed. I would further like to thank my colleague, Kubra Peker for taking time out of her schedule to provide me the data required for this research.

I would also like to thank my committee members for the constant support I received throughout my thesis journey. I would like to express my heartfelt thanks to **Prof. Dr. Ir. J.W.F. Wamelink** who became the chair of my committee and provided me the right direction and guidance during various milestones of the project. I sincerely thank you for believing in me and for being very considerate.

I express my deepest gratitude to **Dr. Ir. Martine van den Boomen** for playing an integral role as my supervisor. From ideating about the topic; Commenting on the report; Structuring; Calculations, you have helped me everywhere possible. I sincerely thank you for your assistance during the research and the time dedicated to helping me finish my work on time. It would have certainly not been possible without your guidance and motivation.

I would also like to thank **Dr. D.F.J Schraven** for his constant supervision. Your approach and attention to detail have helped me improve my work. The constant push for better quality and the comments during our meetings certainly helped me a lot in writing this report.

Above all, I would like to thank my family and friends for supporting me throughout the journey. I would like to thank my parents, who had nothing but smiles to encourage and motivate me through the past months. Thank you, mom and dad. I have reached this far only because of you both.

Next, I would like to thank my friends in Delft, especially Nikhil, Yash, Atul, Akshay, Jyotsni, Abhishek who constantly cheered me up during the past two years and have given me the best memories of my Master's life. Finally, I would like to thank all my friends back home for constantly checking on me and made sure I never missed home.

Enjoy reading the report!

Khyathi

Delft

19th August 2020

Summary

Introduction

Being one of the world's largest waste generator, the construction industry is responsible for a train of events such as global warming, climate change, and depletion of natural resources. Materials are exhausted globally to a large extent and the waste produced in the processes is not treated properly. The increase in the consumption of products and materials is a result of an increase in the demands of infrastructure and buildings. Besides, urbanization makes the situation even worse which leads to resource scarcity.

A "take-make-dispose" or popularly known as linear economy is the process that is adopted to treat the waste currently, where large quantities of resources end up as waste after demolition of the building. This only takes us far away from dealing with the problems resulting from the construction sector. Therefore, an alternative to the dominant linear economy model that directly helps to solve some of the adverse effects of the industry is to be adopted. This grabs our attention towards a rather new concept of Circular Economy (CE) with the goal to potentially minimize the aforementioned pending issues arising from the construction sector through recirculation of building materials. Based on the concept of regenerative principles, CE assures to overcome the inconsistency between economic and environmental prosperity (Pomponi, F., & Moncaster, A., 2017).

The concept of a circular economy is still in its infancy with a lot of research dedicated to improving the credibility of the concept. Several actors have started to re-think about the conventional building practices. However, due to the unfamiliarity of its economic feasibility, many are still reluctant for investing in circularity as they believe circular construction to be more expensive (BNP Paribas, 2019; Brein, G., 2015; Van Eijk., 2015). Currently, stakeholders focus on short-term goals and profit (Schoenmaker, D., & Schramade, W., 2019). This suggests that stakeholders will most likely not engage and collaborate on achieving CE without an economic incentive. Hence a better comprehension of the impact of circular buildings on costs is needed to prompt the use of circular economy within the construction industry.

The main challenge for companies is to overcome the lack of understanding of the available circular strategies and their effect on their business (Cluzel, F., 2017; Bet, B., 2018). To encourage companies for the adoption of circularity, it is important to focus on selecting such circular strategies and linking them to financial outcomes (Cluzel, F., 2017). Achieving this will help in carrying out a sound economic evaluation of construction projects, while trying to leverage the benefits of CE (Akinade O., 2017). Based on the brief introduction, it is evident that the insight in possible circular intervention strategies and their contribution to life cycle costs and circularity is important for a transition to a circular economy.

Objective

The objective of this research is to investigate how buildings can be made more circular. This is done by first making an inventory of possible circular interventions and grouping the interventions to relevant layers of the building. The application of such interventions intends to gradually increase the circularity of the building. This gradual increase in circularity calls for a comparison of a traditional building with its circular twin. Furthermore, the aim is to compare the alternatives based on the life cycle costs and a circularity measure, so that stakeholders are in a better position to invest/favor circularity in general. Finally, the objective is to present a way to invest in circular projects by merging the methods described above. Based on the objective, the following question is formulated:

"How can a traditional building be made more circular and compared based on life cycle costs and a circularity measure to enhance the acceptance of circularity within the building sector?"

Research approach

To answer the above research question, the report is divided into different phases/chapters where a sub-question that helps to get to the answer of the main research question is introduced at the beginning of each chapter and it is answered at the end of the same chapter. A literature review is conducted for phase 1 to develop a better understanding of the most important concepts in relation to this research. The focus gradually narrows down from Circular Economy in general to a more detailed aspect regarding buildings. The assessment of circular buildings is also covered under this phase. Phase 2 of the study focuses on the methods used to obtain the result. The literature review revealed the need for several methods to conduct the research, and hence three methods are further elaborated in phase 2. In phase 3 of the research, the methods discussed are applied to a case study to obtain the results. Hence, the case study, its results and analysis are provided in phase 3. This is followed by the discussion and implications of the results in phase 4, which also contains further insights and limitations of the research. A conclusion note with recommendations is presented at the end of the study. This research is conducted with ABT B.V., a consultancy firm in the Netherlands specialized in integrated building engineering.

Results

A circular building is defined as *"A building that is developed, used and reused without unnecessary resource depletion, environmental pollution and ecosystem degradation. It is constructed in an economically responsible way and contributes to the wellbeing of people and the biosphere. Here and there, now and later. Technical elements are demountable and reusable, and biological elements can also be brought back into the biological cycle"* (Circle economy, 2018). Then the literature study reveals that the breakdown of building into layers would help in discovering the financial reality of the buildings. This would also help in gradually improving the circularity of a building by implementing the circular intervention strategies layer-wise. Next, the R framework is selected to operationalize the activity level of CE in the built environment. Also, the building layer dimension and circular intervention dimension are cross-related to each other for the purpose of cost engineering in this study. As far as the assessment of circular buildings is concerned, only making an economic evaluation of a building is not considered enough. Measuring the circularity of the building is equally important. The material circularity index (MCI) is used to measure the level of circularity and discounted cash flow analysis for assessing life cycle costs (LCC).

To obtain the circular interventions applicable for a building, semi-structured interviews are conducted within ABT B.V. The results from the interviews are categorized into the most recurring circular intervention strategies and building layers. The activities are therefore categorized into circular strategies- reduce, reuse, and recycle. The building layers under consideration are site, structure, skin, and space plan. The results of the interviews are presented in Table 8.

Thereafter, a case is selected to apply the methods for a fair comparison of the measure of circularity and life cycle costs. The activities collected from interviews are analyzed and the most appropriate ones are utilized to generate 4 alternate scenarios to the base case. Finally, the assessment of life cycle costs and circularity is done for the base case and each alternative. The summary of the MCI and LCC calculations for all the alternatives are presented in Figure 20. The results reveal that the operation, maintenance, and replacement (OMR) costs and the end of life (EOL) costs decrease with a gradual increase in circularity level. This could help in the reduction of life cycle costs which would otherwise be higher. Further, to get a higher increase in the circularity of a building, higher mass components of the building should be targeted. Similarly, life cycle costs can also be reduced to a certain extent by reducing the investment costs for higher mass components either by reusing most of the components or reducing the amount of certain materials. It is also observed that buildings with longer life span have a lower increase in life cycle costs as compared to buildings with a shorter life span.

Conclusion

Based on the analysis, it is concluded the comparison as such can help in a parallel tracking of both circularity level and life cycle costs of a building, which in turn aids in taking both the factors into account for decision making. Thus, both the costs and circularity of a building are quantified. It is important to present both measures for a fair comparison.

A building can be made more circular by searching for circular activities that can replace a non-circular activity by using a circular strategy framework- in this case, R-strategy is used. The application of circular activities or interventions are to be categorized layer-wise to carefully examine the impact of the activity on the circulatory level and costs associated with the building. This can be done by diving the building into different layers- In this case, Stewart Brand layers are used. The circularity of the building is to be increased gradually. Further, several alternatives can be generated to analyze the best-case scenario that can justify both the circularity and cost of a building. This is done by using a circularity measure and life cycle costing- in this case, Material circularity index and discounted cash flow analysis are used respectively. Finally, the results can be analyzed and presented to make a selection by quantifying both circularity and cost. This makes sure circularity in buildings is not compromised for costs associated with the building. This way, stakeholders are better aware of the opportunities and can make better decisions in selecting circular projects which could lead to enhance acceptance of circularity within the building sector.

The study also implies that the logical flow of concepts and methods are required to attain the required results. It starts from the application of circular interventions to a building gradually so that there is a noticeable change in the level of circularity. This helps in making a building more circular and it can be considered as the first step to quantify circularity. Another approach implied by this research is the application of circular intervention layer-wise. Improving the circularity of a building layer-wise could be a new way forward to get a better overview of the overall impact of the interventions on the costs of a building.

Limitations and recommendations

The important limitations are listed here. The study was carried out on a very large project. The investment costs are very huge and have some costs that could have been very different for other buildings. Hence, the method can be adopted for projects of all sizes, but the results may not be valid for all projects. The end of life costs has been calculated by taking input from experts who are involved in costing. But in reality, the costs could vary depending on the suppliers and the market. Considering MCI, the method used to calculate it does not consider input and output of reusing for materials and functional units due to the unavailability of data. This could have a different influence on the measure of circularity.

Following the research, some of the recommendations are listed here. Establishing a good network between the actors involved with circular ambitions such as clients, contractors and suppliers will help realize circular ambitions much easier. More projects will be encouraged if there is enough knowledge related to the successful implementation of circular projects, their effects on costs in reality, the performance of the building, etc. Certain weightage of the total score to win a contract could be allotted to the circularity of a building in the decision-making process. Creating design alternatives with calculations for both circularity measure and costs should be a part of the preliminary design stage.

Recommendations for further research include- Researching on how the stakeholders can be included in the entire process. An effective collaboration platform between the client, contractors, and suppliers could be researched. Multiple circularity indicators can be combined so that the results are not based only on one type of measurement of circularity. Other economic incentives for investing in circular projects within the building sector are to be researched for enhancing circular project implementation.

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List of Abbreviations

BCI- Building circularity index

CE- Circular economy

EAC- Equivalent Annual Cost

EMF- Ellen MacArthur Foundation

LCA- Life cycle assessment

LCC- Life cycle costs

MCI- Material circularity index

MPG- MilieuPrestatie Gebouwen

NPV- Net present value

1. Introduction

It is suggested that a building can be considered sustainable if its environmental burden is less when compared to its environmental carrying capacity (Eberhardt, L. C. M., 2019). But this is not often the case in the current phase of urbanization. It is important to keep up with the ever-increasing globalization with minimal disturbance to the environment around us. 'Circularity' is one of the newly emerging concepts which hopes to resolve such problems to save the world, save ourselves. This research investigates how a traditional building can be made more circular by gradually adding circular intervention strategies. Moreover, it entails how insights in life cycle costs and circularity between a traditional building and its circular counterpart can impact the acceptance of circularity and enhance its implementation. The research starts with a general introduction to circularity. What is the current problem? Why there is a necessity for a transformation to a circular economy? What is already being done as a part of this transformation? What is the gap of research for a better acceptance/approval of the new circularity concept?

1.1. Why the construction sector needs circular economy

The worldwide pattern towards urbanization is anticipated to continue, with the current global urban population of 54% to increase to about 60% by 2025. With this escalation in urbanization, the growing pace of demands on infrastructure and buildings increases, which leads to an increase in the consumption of products and services (Circle economy, 2018). Around 40% of the global materials are exhausted by the construction sector, while it generates 35% of the world's waste- most of which is either landfilled or incinerated (Ghisellini, 2016). As a result, an ample portion of the environmental impact is caused due to this trend of growing world population demands, consumption of natural resources, and generation of large amounts of waste. This also leads to resource scarcity (Eberhardt, L. C. M., 2019).

Manufacturing of most building materials requires large quantities of material and energy resources, which are either down-cycled or end up as waste after the demolition of the building. This is called the "take-make-dispose" or linear economy (Ness, 2008). These observations suggest that the construction sector is far behind regarding complying with the UN sustainability goals. As a result, a raising need to find alternative solutions to the conventional way of construction has been recognized. Therefore, shifting our attention towards a rather new concept of Circular Economy (CE) with the goal to provide a better alternative to the dominant linear economy model is worthwhile (Ness, 2008).

CE principles can potentially minimize the aforementioned pending issues arising from the construction sector through the recirculation of building materials. It is a concept that is based on regenerative principles (Ellen MacArthur Foundation, 2013) and it assures to overcome the inconsistency between economic and environmental prosperity (Pomponi, F., & Moncaster, A., 2017).

1.2. The definition of a circular economy

The late 1970s marked the emergence of the concept of CE. Pearce and Turner, who were environmental economist pioneers of their time (1989), essentially presented the idea of CE system building based on the past investigations of ecological economist Boulding in 1966 (Ghisellini, P., Cialani, C., & Ulgiati, S., 2016). Finally, in 2013 the Ellen MacArthur Foundation (EMF) accounts for the latest hypotheses such as cradle to cradle, regenerative design, biomimicry, etc. which adds a significant contribution to further development of CE.

Since then, various scholars and practitioners have tried to explain the concept as per their understanding. This can be seen in an elaborated review conducted by (Kirchherr, J., Reike, D., & Hekkert, M., 2017) in which they analyzed around 114 definitions to critically examine the various CE conceptualizations. Since the last decade, the idea has additionally being picked up by local, national governments and policymakers (Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J., 2017). But the most well-known definition of CE is the one described by the Ellen MacArthur Foundation, which emphasizes on the expressions “restorative or regenerative”. Hence for this study, the definition by EMF will be used as a guideline – “*A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles*”.

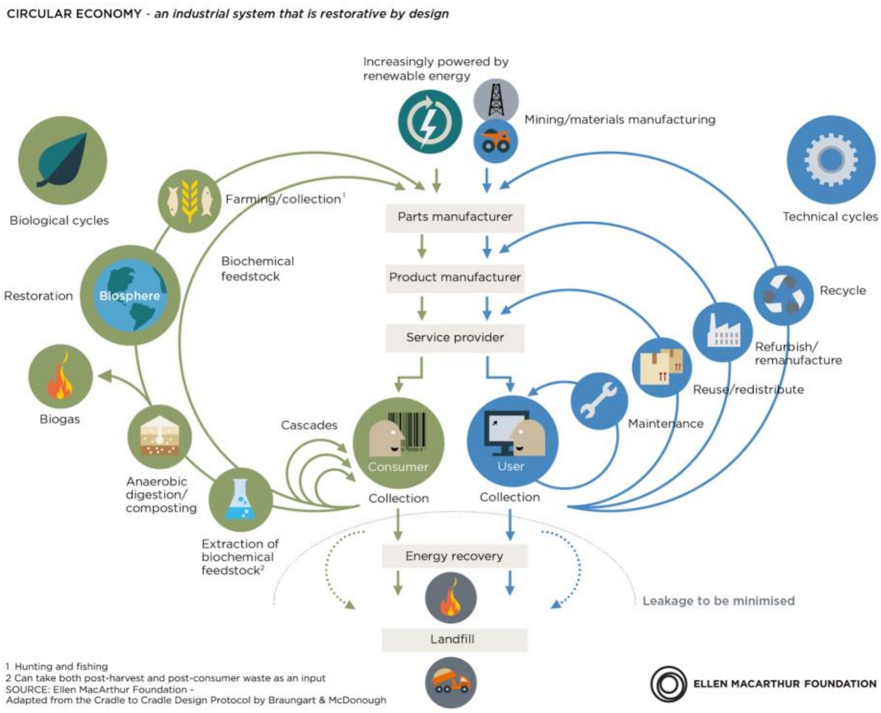


Figure 1: Circular economy- an industrial system that is restorative by design (EMF, 2013)

The diagram above (Figure 1), prepared by EMF depicts how technological (Blue line) and biological (Green line) based materials and products cycle through the economic system. This diagram also serves as the basis for principles of circular value creation to reap the benefits of a circular product. The way forward towards restorative development demands radically alternative design solutions that oversee the entire life cycle of a process and its interaction with the environment with less material, energy, and environmental costs (Ghisellini, P., Cialani, C., & Ulgiati, S., 2016).

But like any other new emerging concept, the switch to a circular economy in the construction industry offers many challenges (Adams, 2017). Based on the previous research, the challenges to its incorporation include- limited knowledge and awareness amongst the stakeholders; a fragmented supply chain; and a lack of incentives to implement the circular economy in building projects (Adams, K., Osmani, M., Thorpe, T., & Hobbs, G., 2017).

Currently, stakeholders focus on short-term goals and profit (Schoenmaker, D., & Schramade, W., 2019). This is not in line with long-term goals such as sustainability. However, by working together towards a long-term partnership with long term investments may lead to a collective gain (long term savings) that is larger than the individual benefits resulting from acting alone (Schoenmaker, D., & Schramade, W., 2019). This suggests that stakeholders will most likely not engage and collaborate on achieving CE without an economic incentive. Hence a better comprehension of the impact of circular buildings on costs is needed to prompt the use of circular economy within the construction industry.

1.3. The transformation to a circular economy

In the past four decades, there is a rapid increase in the middle-class population worldwide which has led to an increase in raw materials extraction by three times (The United Nations, 2015). Therefore the transition from linear to a circular economy is an international confrontation. The steps taken to achieve this on various levels are represented in the figure below (Figure 2).

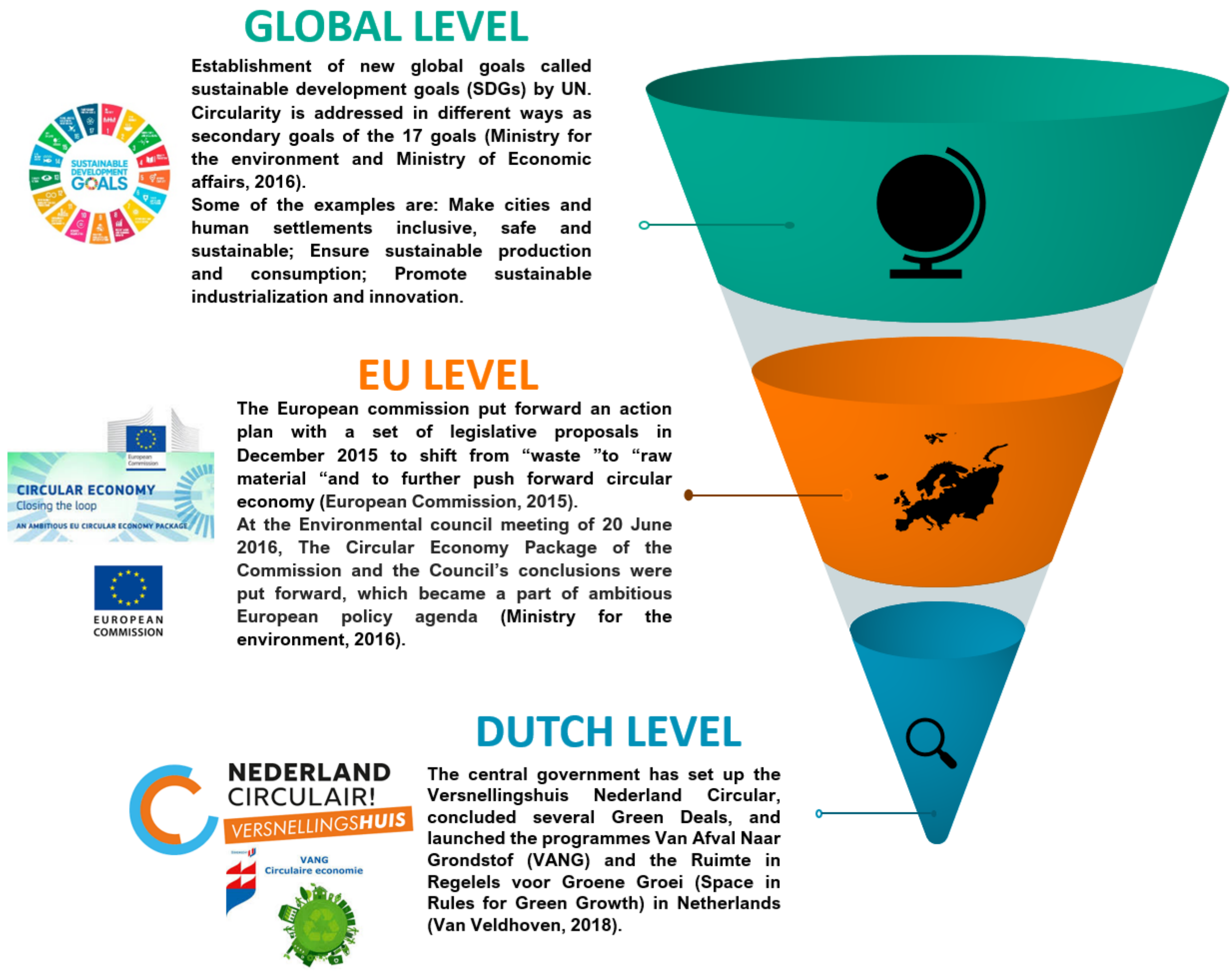


Figure 2: Actions to support the circular economy on different levels (Own illustration)

1.4. Problem definition

The circular economy has gained a lot of momentum in the past years, leading to a number of actors from the building sector to re-think about the conventional building practices. However, as the actors are not sure of the economic feasibility, many are still reluctant for investing in circularity as they believe circular construction to be more expensive (BNP Paribas, 2019; Brein, G., 2015; Van Eijk., 2015; Marc Doodeman., 2019).

Most of these assumptions are made without taking into consideration the entire life cycle of the product. Often, initial cost (construction cost) is the deciding cost factor for projects which is pre-determined to be minimum, but that does not necessarily improve the lifetime performance of buildings (Othman Subhi Alshamrani, 2015).

A major pitfall in the construction sector is that- everything is accounted/taken into consideration, except the demolition, recycling, and after the useful life of a building. As greenfield projects are cheaper, many buildings are left vacant causing a brake on the urban renewal cycle, as a result of which the sources of potential building materials are left unused (Schut, E., Crielaard, M., & Mesman, M., 2016). This hampers urban renewal and hence it is important to develop a clear vision to solve this situation, for instance by taking into consideration all the life cycle management activities in relation to CE to add circularity to the buildings.

Whilst major strides have been made to explore the principles and models of CE, less thought has been given to gradually increasing circularity in ongoing construction practice (greenfield and brownfield) and systematically comparing the costs and circularity of traditional and circular buildings. This gets us to think about- What is circular economy and what how can it be applied in the building sector? What impact does this have on costs on a circular building? Can insights related to costs help stakeholders to settle on better choices when it comes to investments in circular projects? What are the circular interventions that can be pertained to costs and how is it done differently than the traditional/linear way?

The main challenge for companies is to overcome the lack of understanding of the available circular strategies and their effect on their business (Cluzel, F., 2017; Bet, B., 2018). To encourage companies for the adoption of circularity, it is important to focus on selecting such circular strategies and linking them to financial outcomes (Cluzel, F., 2017). Achieving this will help in carrying out a sound economic evaluation of construction projects, while trying to leverage the benefits of CE (Akinade O., 2017). Based on the brief introduction, it is evident that the insight in possible circular intervention strategies and their contribution to life cycle costs and circularity is important for a transition to a circular economy.

1.5. Objective of the research

The objective of this research is to investigate how buildings can be made more circular. This is done by first making an inventory of possible circular interventions and grouping the interventions to relevant layers of the building. The application of such interventions intends to gradually increase the circularity of the building. This gradual increase in circularity calls for a comparison of a traditional building with its circular twin. Furthermore, the aim is to compare the alternatives based on the life cycle costs and a circularity measure, so that stakeholders are in a better position to invest/favor circularity in general. Finally, the objective is to present a way to invest in circular projects by merging the methods described above.

1.6. Research question

How can a traditional building be made more circular and compared based on life cycle costs and a circularity measure to enhance the acceptance of circularity within the building sector?

Sub-questions:

1. ***What is circular economy for buildings and how is it assessed?***
   Literature review

2. ***What are the circular interventions that can be applicable for traditional buildings?***
   Making an inventory of activities that can be done circular, for which costs can be attributed based on insights gained from practitioners (inventory or identification stage). The framework for selecting such activities can be obtained from available literature and experts.

3. ***How do life cycle building costs and a circularity measure vary when the relevant circular interventions are implemented?***
   Link the activities found in the previous step to financial outcomes and contributions to circularity.

4. ***What are the implications of the comparison based on building life cycle costs and a circularity measure?***
   Based on the findings, make a conclusion for investing in circular projects.

1.7. Research design

Phase 1: Literature review

In Phase 1 of the research, a literature study is conducted to understand the key definitions and concepts of circular buildings required for this study. The main aim is to develop a literature-based framework that can be used to collect the required activities for the further development of this research. Sub-question 1 can be answered after this phase.

Phase 2: Research methodology

The insights gained from Phase 1 will form the basis for the second phase of research. Semi-structured interviews are conducted with professionals for a market-based perspective of circular activities and how they can be implemented, along with what are the traditional alternatives for the same? This will help to compare the scientific viewpoint with professional practice. Sub-question 2 can be answered following this phase.

Phase 3: Life Cycle Costs and Circularity Analysis

This phase comprises of linking the activities found in the previous phase with life cycle costs and a circularity measure for several alternative scenarios. This will be done by taking a case (building) and computing the life cycle costs (LCC) and circularity indices for comparison. Different scenarios are presented for the same base case. A sensitivity analysis is conducted for changing variables. The case study with the results provided by the LCC and circularity measure will be discussed in this section. Sub-question 3 can be answered after this phase.

Phase 4: Discussion, conclusion, and recommendations

In the last phase, a comparison will be made between the results from the scientific and practical findings within this study. Here the implications of the LCC and circularity analyses emerging from the case study will be discussed in a wider context. How can the building sector benefit from the approach presented? Will such an approach lead to embracing more circularity and enhance its implementation in current practice? What is necessary for the adaptation of such an approach? Also, the limitations of this research will be presented. Sub-question 4 and hence the main research question will be answered at the end of the section. This phase will finalize with conclusions and recommendations capturing the essence of this research.

The thesis outline is illustrated in the figure below (Figure 3).

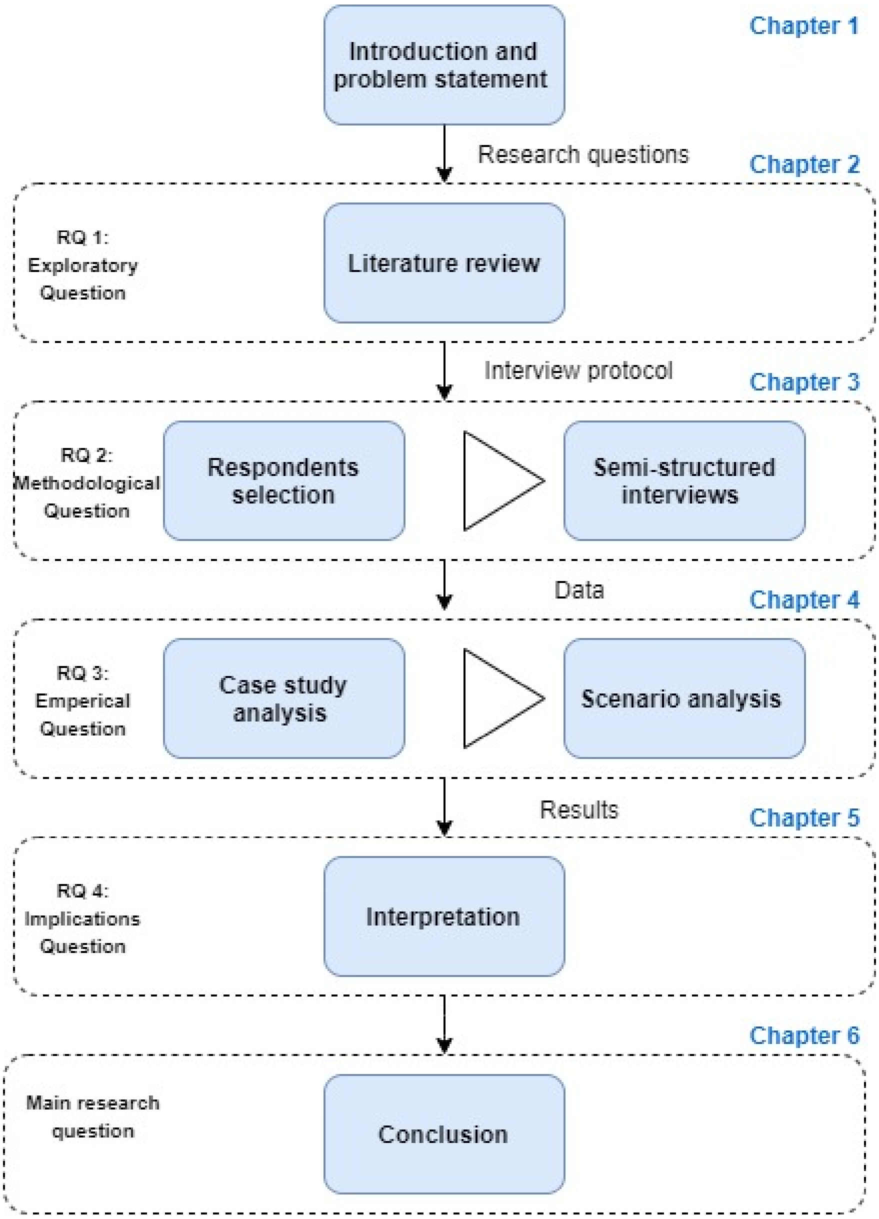


Figure 3: Thesis outline (Own illustration)

1.8. Relevance of the study and scope

Scientific relevance

Research in the field of CE has been a popular one with the number of publications increasing drastically every year. Nevertheless, there seems to be a delay in its implementation, in other words, disruption between the scientific aspects of CE and its execution in the real world. One such main barrier is the economic feasibility of building projects where investors are hesitant to invest in circular construction as they are unaware of the results of their investments (Bet. B, et al, 2018). Many presume that it is more expensive to build circular buildings than conventional ones (BNP Paribas., 2019; Marc Doodeman., 2019; Brein, G., 2015). This is not necessarily the case if the entire life cycle of the building is considered. Moreover, for a fair comparison also a circularity measure should be part of the life cycle costs analysis. The available literature focusing on implementing CE recognizes the barrier of economic feasibility but fails to explain how to overcome it or how to make a sound economic evaluation. Therefore, this research aims to contribute to the unfamiliarity of the topic.

Practical relevance

As a thrust for The Netherlands to achieve a circular economy in the construction sector by 2050, it is important to eradicate the obstacles that hamper the transition. This research will help the practitioners to check financially viable investments for circular projects in the practical world. Hence, stakeholders will be better aware of the opportunities offered by CE and implement it in their practices.

Societal relevance

The essence of the development of a circular economy is to maintain a stable relationship between the natural world and human activities. Only by making circular projects economically feasible, will encourage investors to undertake such projects. This indirectly helps in reducing the world's menacing problems such as global warming, climate change, and depletion of natural resources and hence this topic of research is believed to have high societal relevance. Hopefully, the implementation of CE will also get communities stronger as the regenerative loops get closer.

Scope of research

The study will be carried out within The Netherlands. The scope of research will be on buildings as there has been limited research on the application of CE in the built environment (Thornback, J., 2017). The focus will be on materials and how the costs vary with circular interventions in that particular impact area. This is because it is often observed that materials are one of the impact areas that are inadequately taken into account for. But it is very essential to close the material cycles as optimally as possible (Circle economy, 2018). My graduation assignment at ABT B.V will facilitate access to practitioners and cases that will help achieve the objective of the research.

2. Literature study

The literature study seeks to develop a better understanding of the most important concepts in relation to this research. The first sub-question to be answered by this section is:

What is circular economy for buildings and how is it assessed?

To answer this question, the focus gradually narrows down from Circular Economy in general to a more detailed aspect regarding buildings. The chapter is divided into four sections. In section 2.1, the concept of circular economy in the built environment is introduced. Section 2.2 explores the various concepts in relation to circular buildings such as the need for a breakdown of buildings into layers (2.2.1), the impact areas of circular buildings (2.2.2) and circular strategies (2.2.3). Section 2.3 gives a brief description of the important concepts to assess circularity, namely measurement of circularity (2.3.1) and evaluation of costs of circular buildings (2.3.2). Finally, in section 2.4, the findings of the literature study will be presented.

For this section, the sources and data were collected from Google Scholar, Scopus and the TU Delft repository by using the following keywords- “Circular economy”, “Circular buildings”, “Circularity in buildings”, “Circular economy in built environment”, “Life cycle costs in circular buildings”, “Investing in circular buildings”.

2.1. Circular economy in the built environment

Cities are one of the most crucial intervention focal points to create sustainable communities and to reduce the anthropogenic impact on the environment. Built environment within these cities has the ability to reduce the impact owing to its platform that can bring energy and circular transition together. The built environment is currently responsible for creating a high negative impact on the environment and at the same time making the buildings not future proof (Circle economy, 2017). It is the sector in which the transition to CE is most crucial due to the pressure it imposes on the natural environment.

To understand the concept of CE in the built environment, the most accessible way is to conduct a literature review as the knowledge within the sector is still in its early development stage. For this, the focus is on the most recent research done in the field.

The Dutch construction industry uses an overwhelming amount of about 250 million tonnes of raw materials, in which it produces around 23 million tonnes of demolition waste. Keeping these aspects in mind, CE in built environment is an approach to decrease waste produced and material depletion (Circle economy, 2017). It is crucial to design the buildings carefully to keep the materials in a circular flow always. When considering CE in built environment, importance should not only be given to the new buildings or yet to be constructed buildings, but also the existing stock. It is said that in the northern hemisphere countries alone, 75-90% of the existing building stock were standing in 2015 owing to their prolonged time span. Reports also state that around 80% of buildings were built before the 1960s which indicates that the buildings are to have a life span of at least 60-90 years (Pomponi & Moncaster, 2017). Hence, if CE is to be realized in buildings, concentrating only on the greenfield projects will not be sufficient. This is where circular economy can influence the way things have been done in the past.

Though there is incremental progress in circular transition in general, the building industry is still in its infancy as it battles to embrace CE in its sector efficiently as compared to the other industry sectors (Pomponi & Moncaster, 2017). CE in the built environment is still considered relatively new in its approach and implementation and it requires further research to ascertain its suitability within the building industry (Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J., 2017). Most of the research is either based around the cities or construction materials, and very less focus on buildings as illustrated in the figure below (Figure 4). For this study, CE in the built environment will be the same as the definition provided by EMF (Chapter 1) as it stresses the importance of CE principles and can be applicable to almost all sectors.

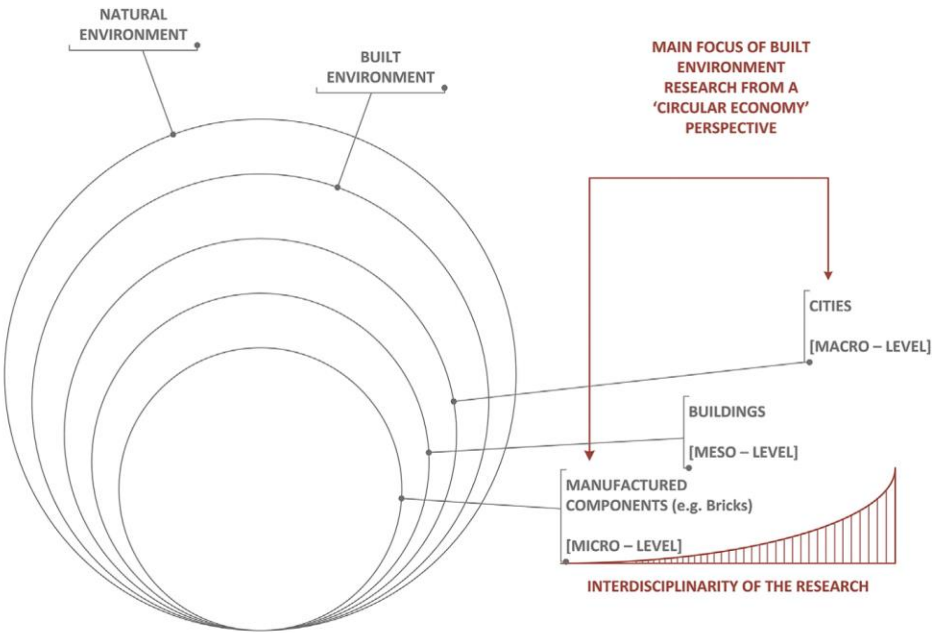


Figure 4: Framing of built environment research (Pomponi & Moncaster, 2017)

2.2. Circular buildings

'Circular buildings' or 'circularity in buildings' are some of the new terms that have been emerging lately. Very few researchers have actually tried to clearly define what the term means in relation to circular economy.

Researchers Leising, Quist and Bocken in 2018 define CE approach for circular buildings as "*A lifecycle approach that optimizes the buildings' useful lifetime, integrating the end-of-life phase in the design and uses new ownership models where materials are only temporarily stored in the building that acts as a material bank*" (Leising, E., Quist, J., & Bocken, N., 2018).

Another well-known definition is by Pomponi and Moncaster, 2017, "*a building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles*"

In the transition agenda for circular construction given by the Dutch government in 2016, circular building is defined as "*the development, use and reuse of buildings, area's and infrastructure, without avoidable depletion of natural resources, pollution of the environment or negatively impacting ecosystems. Construction which is economically responsible and contributes to the wellbeing of humans and animals, now and in the future*" (Circle economy, 2018).

Table 1: Category of emphasis in the definition of circular building from various sources

	Emphasis on				
Description by	**Life cycle of building**	**End of life use**	**Environmental impact**	**Human welfare**	**Elemental level of building**
Leising, Quist and Bocken (2018)	✓	✓			✓
Pomponi and Moncaster, (2017)	✓			✓	✓
Dutch government (2016)	✓		✓	✓	
Circle economy (2018)	✓	✓	✓	✓	✓

However, the following definition from (Circle economy, 2018) is most widely used - *"A building that is developed, used and reused without unnecessary resource depletion, environmental pollution and* *ecosystem degradation. It is constructed in an economically responsible way and contributes to the wellbeing of people and the biosphere. Here and there, now and later. Technical elements are demountable and reusable, and biological elements can also be brought back into the biological cycle".*

Table 1 shows the outline of the frequently mentioned definitions of circular buildings in literature. Out of the four, the reference from (Circle economy, 2018) seems to be the most complete definition of circular buildings. Other sources that have given an attempt to define circular buildings, do so in a restricted approach by identifying only few aspects of CE in their definition, hence they are not as complete as the definition from (Circle economy, 2018). Therefore, it is considered to be the most suitable definition for this study as it combines the need to consider the whole life cycle of a buildings along with considering its impact on the environment (Table 1). Also, this definition is in unison with the definition of circularity by EMF, which has also been the most influential framework of CE to date.

The review of sections 2.1 and 2.2 is illustrated below (Figure 5). The diagram below also distinguishes the different layers of built environment research that was illustrated in (Figure 4) by Pomponi & Moncaster. The main focus of this research thus digs deeper into the system level of the built environment to Building level, with a focus on circular buildings.

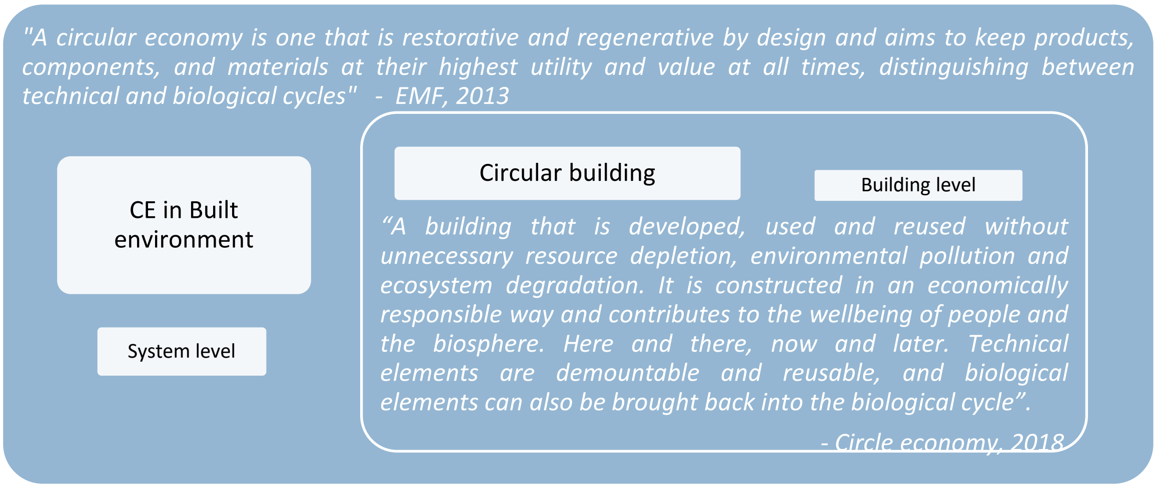


Figure 5: Definition of CE in the built environment and Circular building used for this study (Own illustration)

2.2.1. Layers of a building

One of the reasons why applying circular measures to the built environment is difficult is because of the unique characteristics of difference in the lifespan of the elements, products, and materials within a building. A more detailed approach is demanded due to varying lifespan of layers. The breakdown of building into layers is essential to provide a detailed insight into the value of buildings. By acknowledging the building as a compilation of several layers instead of one whole entity, it creates a new perspective and makes it easier to estimate the residual value (Slot, N. A, 2019). The financial reality of the buildings can only be reflected by considering the detailed depreciation of the separate layers (Fischer, A., 2019). This demarcation will help to create minimum waste with maximum value.

One of the most famous research in this field is by Brand in 1994, where he highlights the shearing layers of buildings. He decomposed the building into various layers to evaluate their life span separately as shown below (Figure 6 and Figure 7).

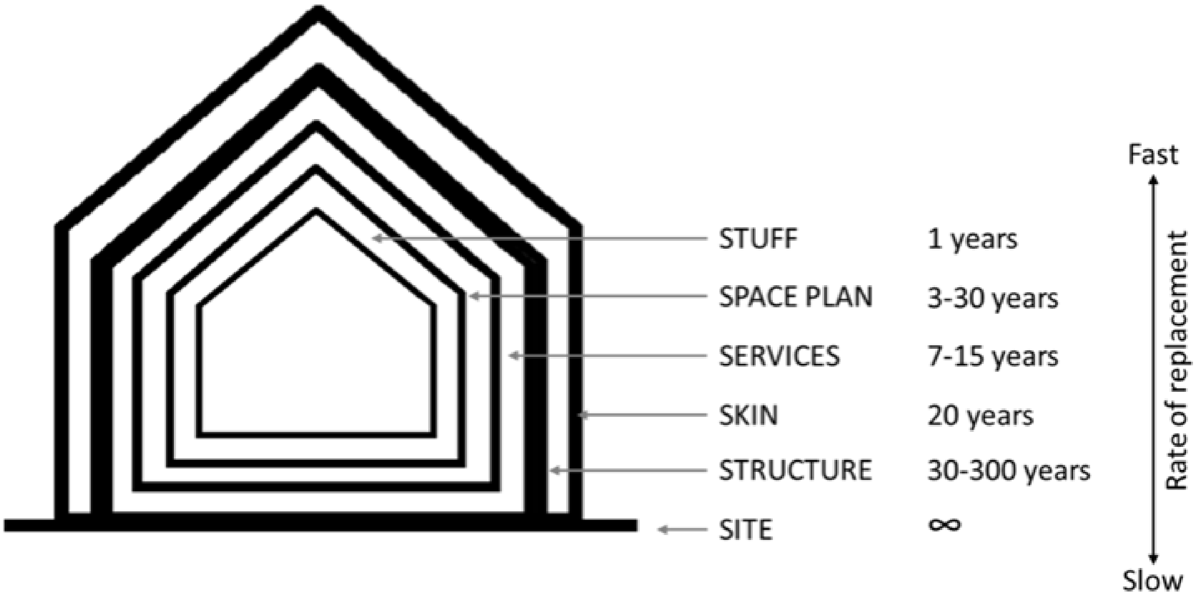


Figure 6: Building elements in relation to lifespan adapted from (Brand, 1994) retrieved from (Eberhardt, L. C. M., Birgisdottir, H., & Birkved, M., 2019)

One building- Six layers

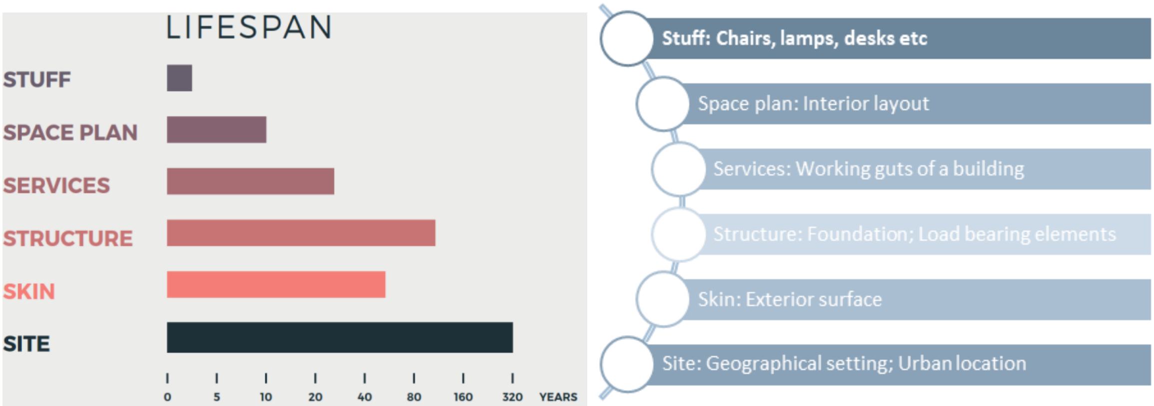


Figure 7: Six layers of building adapted from (Brand, 1994)

These layers directly affect the amount invested on them and the environmental effect of it (Brand, 1995). A need for distinctive retrieval for reuse or recycling over the life cycle of building arises as the building layers have different functions and characteristics along with changing rates of replacement. This also means a difference in environmental and economic value (Eberhardt, L. C. M., Birgisdottir, H., & Birkved, M., 2019). As a result, buildings can act as an entity of temporary storage to facilitate the exploitation of short term and long-term benefits.

2.2.2. Impact area

As the term ‘circularity in buildings’ can often be misunderstood, it is worthwhile to understand the scope of this research. A building’s circularity can be improved by influencing different impact areas. According to research conducted by (Metabolic, 2017), there are seven impact areas that circular buildings can influence positively. These are often referred to as the seven pillars of the circular economy as shown below (Figure 8). This helps to approach problems systematically.

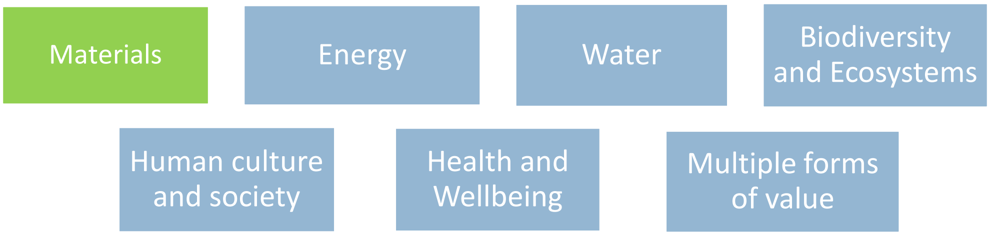


Figure 8: Seven pillars of circular economy

Out of the lot, Materials, Energy, and Water are associated with physical resource flows and represent key impact areas for realizing circular buildings (Circle economy, 2018). In line with the definition of a circular building for this study, the focus will be on materials and how the costs vary with circular interventions. This is because it is often observed that materials are one of the impact areas that are inadequately taken into account for. But it is very essential to close the material cycles as optimally as possible (Circle economy, 2018).

2.2.3. Circular strategies (The R framework)

To operationalize the activity level of CE in built environment, we now shift our focus to a framework that allows the right amount of detail to list down more specific circular interventions required for a case study.

Most of the available frameworks are for designing circular business models or policies such as in Lewandowski, M., 2016; Bocken, N. M., De Pauw, I., Bakker, C., & van der Grinten, B., 2016; Elia, V., Gnoni, M. G., & Tornese, F., 2017; Mentink, B. A. S., 2014. Very few scholars have spoken specifically to circular strategies in the building sector. One of the few is the work done by the Redevco foundation in 2018 where they researched a framework for circular buildings. In this report, they considered a set of 7 strategies and made analysis for important pillars of circular economy. Out of these strategies, three strategies focus on material use and the other four on business model. Another notable framework is called the ReSOLVE framework developed by McKinsey in 2018 that focuses on principles to support circularity, but again not specific to activities in relation to circular buildings.

One of the most widely known frameworks that fit the demand of this research is the 9R framework (Appendix A). Numerous R frameworks have not only been used in various literature, but also by practitioners for a very long time. This can be regarded as one of the most simple yet adequate ways to address the strategies or activities that are in line with CE. The framework is a core principle of CE as it can be addressed as the "how-to" of CE (Kirchherr, J., Reike, D., & Hekkert, M., 2017). For a long time, the 3R framework (Reduce, Reuse, Recycle) was considered to be the most prominent one. But since the concern to change the way of building process thinking is increasing on a daily basis, scholars proposed R framework beyond 3R, including 4R, 6R, and 9R.

The use of this framework is significant for this research as it facilitates and provides a basis for the upcoming phases of this research. For instance, to operationalize the activity level of CE in buildings so that cost elements can be attributed to the same. This is the ground principle for the use of this particular framework over others.

In order to minimize waste and reduce the usage of natural materials and resources, the framework puts forward several circular strategies. The frequently occurring R's in the framework are shown in (Figure 21- Appendix A). In the figure, the strategies are arranged in the order of priority as per their contribution to the levels of circularity. As the materials (namely R0 TO R2) prevail in the loop for the longest time, they are assumed to have the highest level of circularity. As a rule of thumb, these strategies are considered to have the most environmental benefits. They can also be used after their function in a particular product is over, along with retaining maximum quality. Recycling and recovery are considered to have the lowest priority. But recycling, although has the lowest value in term of level of circularity according to the figure, it is treated to be most predominant with comparatively easy techniques to achieve the same (Fischer, A., 2019). Although the figure seems to be a perfect fit for circular strategies, it is to be noted that the framework has been initially developed for product chains and not in particular to the building sector. As a result, some of the terms such as (Repair, refurbish, remanufacture, and repurpose) are less frequently used in the literature for the building sector.

Below (Table 2) is a table that includes the most frequently used terms and their explanation in the building sector.

Table 2: R strategy used for this study (Own illustration)

Strategy	Explanation
Refuse	Refuse can be used to refer to the concept of design life cycle where the use of certain specific hazardous materials and production processes are refused to avoid unwanted waste.
Rethink	Making a product use more intensive
Reduce	Reduce may refer to the use of less material per unit of construction or 'dematerialization'.
Reuse	The main aim of this concept can be considered as the need to bring materials or components back into the economy after its initial use. Most of the time, this term is explicitly used only for reusing components and materials with the same purpose.
Recycle	Though at the bottom of the framework, it is one of the most frequently used concepts in circular buildings. Can also be referred to as a concept used to avoid the use of any virgin material in the building.
Recover	In literature, recovery means incineration of materials with energy recovery.

The use of circular building layers (Section 2.2.1) and circular strategies (Section 2.2.3) is relevant to this study owing to its individual importance in the context of this research. Whereas, as the final aim of this study is to allocate cost and circularity aspects to the activities, there is a need to combine the building layer dimension and circular intervention dimension. Hence it can be said that these two dimensions are cross-related to each other for the purpose of cost engineering. The close interaction allows the maximum coverage of both activities and all layers of a building (Figure 9). In this way, the framework below also serves as an analytical framework for further analysis of this research. This ensures a fully integrated approach in dealing with the comparison of a traditional and circular building based on cost.

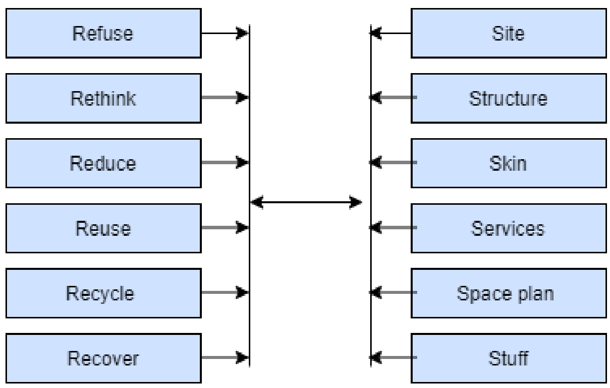


Figure 9: Combining building layer dimension and circular intervention dimension (Own illustration)

2.3. Assessment of a circular building

In the past, investments made on buildings were based solely on the costs associated with a building. This has brought in the inconsistency between economic and environmental prosperity. But on the contrary, the measurement of circularity should also be considered as a strong decision criterion for a circular building. Hence it could be said that a combination of both costs and circularity associated with a building should be considered as decision criteria for investing in building projects. Hence the two most essential concepts to be covered for the evaluation of a circular building in this study are:

1. Measurement of circularity
2. Evaluation of the associated costs

2.3.1. Measurement of circularity

This section focusses on making an inventory of some indicators that are used for monitoring level of circularity. The list of indicators that have been commonly discussed in the literature and related to the circular economy are included in the table below:

Table 3: Inventory of the available tools to measure circularity (Own illustration)

Indicator	Link to CE	Indicator's methodology status and availability	Relevance to the study	Source
Raw Material Consumption (RMC)	It measures global material usage related to domestic production and consumption activities. RMC decreases with an increase in circularity. This is reflected as the RMC reduces when there is a lesser need for virgin stock.	Available in the EU's Raw Material Scoreboard.	Only assess the raw materials but not the other factors necessary for this research.	SUMMA, 2019
Material Circularity Indicator (MCI)	MCI measures circularity by providing an index for the degree of circularity of a specific product: it gives a value between 0 and 1 where higher circularity is indicated by a higher MCI.	Only the methodology for calculation is available. The developers- Granta software is not open source	Used to assess the waste scenario and lifespan of material. It gives a quantitative score which is easy for comparison.	MacArthur, E. (2015)
End of Life Recycling Input Rate (EOL-RIR)	The EOL-RIR is an indicator used to meet materials demand in terms of recycling contribution. It calculates the ratio of recycled material inputs (coming from the EU) to total material inputs in it.	Still under development. Available in the EU's Raw Material Scoreboard and EC Monitoring framework for the CE.	Only measures one of the circular strategy (recycling). Hence not the best fit.	SUMMA, 2019
Basket of Products (BoP) indicators	The EU Consumer Footprint measures the potential environmental impacts of consumption, based on the LCA of products and services purchased and used in one year by an EU citizen.	Currently developed by the EC. Not included in a scoreboard.	Particular products can be assigned specific CE strategies while calculating the LCA. But not widely used as it is still under development.	SUMMA, 2019
Milieuprestatie gebouwen (MPG)	It is used to estimate the environmental impact of the building per m^2 of gross floor area. This impact is reflected in shadow costs per m2 of GFA per year.	MPG is based on international standards and is already being adapted for Dutch markets. One of the software, MPGcalc is a free Windows software.	The shadow price is calculated only for one life cycle and is mostly used as a sustainability index.	dgmrsoftware.nl
Platform CB'23	The core measurement method calculates different aspects that are important in circular construction. This is done by a set of indicators related to the quantity of materials used, the quantity of materials available for the next cycle (output), the quantity of materials lost (output), and influence on the quality of the environment.	Only a guide version 1 is available. Yet to completed with another version to be released in 2020.	It is claimed to be a fully-fledged core measurement method that can be applied broadly for measuring circularity, but has not been tested yet.	platformcb23, 2019

Out of the lot, three of the indicators were applicable for this research.

At first, the **MPG** seemed to be a good fit, which was also the tool used by ABT B.V. According to the Dutch standard, this value cannot be more than €1,0/m2 GFA/year for office buildings in the Netherlands. It is to be noted that the MPG score is similar to the EBP score (Dutch national integrated indicator for the environmental performance of buildings, based on EN 15804) which are commonly used tools for measurement of sustainability. Though there is no fine gap between the terms sustainability and circularity, tools that exclusively focus on material circularity in the construction sector is preferred. Hence the option was put on hold.

The latest development in measuring circularity is the **Platform CB'23**. The main argument put across from the developers was that an overall score to measure the circularity is not necessary for circular construction transition phase. One of the main reasoning for it is that an aggregated score hides a lot of information and therefore it is difficult to detect which choices influence the scores. Though this seems to be a valid argument, it can be said that an overall score is a robust way to deliver results, especially in the preliminary design stage where various options can be weighed against each other to choose the most appropriate option. Also, as the tool is still in its infancy, hence the option was discarded.

The next option that was studied in detail is the **MCI**. The indicator is conceptualized by the Ellen MacArthur Foundation & Granta Design in 2015 and can be used as a decision-making tool at any stage of design.

"It measures the extent to which linear flow has been minimized and restorative flow maximized for its component materials, and how long and intensively it is used compared to a similar industry-average product"

Since the development of MCI, there has been further use of the tool in other applications. One such example is the **Building circularity level (BCI)** developed by Verberne in 2016. It is calculated by focusing on (i) the use of materials (MCI) and (ii) the detachability of materials. But due to some differences in concept between MCI and BCI, the former is used in this study. The following are the reasons:

- Utility X is determined differently. For BCI, the utility factor is given by

$$X = \frac{Lp}{L\ sys}$$

Equation 1

Where: L_p = lifetime of the product and

L_{sys} = lifetime of the system it belongs to (e.g., structure, skin, space plan, etc.,).

Which is evidently different from the one that is used in MCI proposed by EMF and Granta Design as seen in (Equation 8**- Appendix D**). Due to this change in the utility, the level of circularity changes if the product changes its system as X depends on the system it belong to as seen in Equation 1. The current research investigates the inclusion of circular intervention strategies in a building keeping the lifetime of the system constant. Therefore:

- If the detachability of materials is kept in mind while defining the variables, MCI is sufficient to measure the circularity.

- Also, considering the size of the case study, in terms of a variety of materials used and building layers, it would be onerous to calculate the BCI owing to the limited time to complete this research.

As the main concept of MCI is to retain the material in a loop as long as possible, regardless of the system, BCI is considered unnecessary for this study. Therefore, MCI from EMF and Granta Design is considered to be the most appropriate tool to measure circularity for this study.

The implementation of the MCI for the current research is elaborated on in Chapter 3: Methodology.

2.3.2. Evaluation of costs of a circular building

Investing in circular buildings is relatively a new domain and is not very prevalent owing to its unfamiliarity of costs in relation to circular intervention strategies. This is where life cycle costing methods can play an important role. LCC is used to understand these cash flows where the construction costs over the economic life of investment are considered to be secondary to the total cash flow, and the residual value of materials (Circle economy, 2017). LCC has been used for assessment of buildings for a long time now, but not as frequently for circular buildings.

An LCC model is necessary to complement CE and closed-loop of flow elements to attain a true sustainable future (Bradley, R., 2018). It is a useful tool for choosing between investment alternatives and to decide trade-offs for optimal budget estimation. When considering circular buildings, LCC can be considered as one of the most appropriate methods to measure the economic performance of building products. (Circle economy, 2018) as it is standardized particularly for the construction sector (Rieckhof, R., 2018). For this research, the term LCC will be used for assessing the life cycle costs that include all costs connected to the selected case study such as investments, operation and maintenance costs, replacements, and salvage values.

Traditional discounted cash flow analysis over the life cycle of the building is used as a measure for comparison of the life cycle costs of various alternatives. The implementation of the discounted cash flow analysis for the current research is elaborated on in Chapter 3: Methodology.

2.4. Conclusion

The main aim of this literature study is to understand the main concepts used in this study. The first sub-question attempted to be answered is:

What is circular economy for buildings and how is it assessed?

By this point, it is understood that it is crucial to design the buildings carefully in order to keep the materials in a circular flow always. For this study, the following definition from Circle economy (2018) is used to describe a circular building: -*"A building that is developed, used and reused without unnecessary resource depletion, environmental pollution, and ecosystem degradation. It is constructed in an economically responsible way and contributes to the wellbeing of people and the biosphere. Here and there, now and later. Technical elements are demountable and reusable, and biological elements can also be brought back into the biological cycle".* As the definition explores many imperative aspects such as life cycle, environmental impact, human welfare, end of life use- as opposed to other definitions mentioned in the literature, it is considered to be the most relevant to this study.

According to many sources, by acknowledging building as a compilation of several layers instead of one whole entity, a new perspective is created. This perspective makes it easier to gradually implement circular intervention strategies, estimate their life cycle costs, and contribution to the circularity of the building. The financial reality of the buildings can hence be reflected by the breakdown of building into layers as it provides a detailed insight into the value of buildings. This demarcation will help to create minimum waste with maximum value. In addition, the focus of the study will be on materials and how the costs vary with circular interventions in relation to the materials used. This is because it is often observed that materials are one of the impact areas that are inadequately taken into account for. Further, the framework used to operationalize the activity level of CE in the built environment is the R framework. Also, the building layer dimension and circular intervention dimension are cross-related to each other for the purpose of cost engineering in this study.

As far as the assessment of circular buildings is concerned, only making an economic evaluation of a building is not considered enough. Measuring the circularity of the building is equally important. The material circularity index (MCI) shall be used to measure the level of circularity and discounted cash flow analysis for assessing life cycle costs (LCC).

Finally, it can be concluded that the important concepts that are to be elaborated in detail in the further sections of this study are-

1. Circular interventions to increase the level of circularity of a building
2. Measurement of circularity of a building
3. Evaluation of the life cycle costs of a building

3. Methods

This chapter explicates the methods used for the analyses identified for this research. The literature research in the previous chapter revealed three essential analyses: (1) an analysis to obtain circular intervention strategies for a building, (2) an analysis to measure the circularity of a building and (3) an analysis to compare life cycle costs of various alternatives for a building. The current chapter elaborates on the implementation methods of these three analyses. It answers the question of how the analyses are performed and provides the foundation for Chapter 4 where the analyses are performed on a case study and where the results are presented. The important methods reported in this section are based on the concepts covered in the literature study:

Concepts	Section
Inventory of circular intervention strategies for buildings	3.1
Measurement of circularity of buildings	3.2
Economic evaluation of buildings	3.3

Section 3.1 provides *the approach* to answer sub-question 2: *What are the circular interventions that can be applicable for traditional buildings?* Section 3.1 reveals a method on how to gain insights from practitioners about their views on circularity in buildings and making an inventory of activities that can be done for a circular building. Different types of strategies are presented, and a selection is made. Sections 3.1.1 and 3.1.2 further elaborates on the method used to carry forward the research. 3.1.3 is about the interview protocol and analysis. Sub-question 3 is answered in Chapter 4 where alternatives are presented for gradually improving circularity by adopting intervention strategies for a case study of a building based on the inventory.

Section 3.2 elaborates on the approach followed to assess the material circularity index (MCI) whereas sections 3.3 does the same for assessing the life cycle costs of a traditional building and alternatives which improve the circularity. These two sections provide *the approaches* for answering sub-question 3: *How do life cycle building costs and a circularity measure vary when the relevant circular interventions are implemented?* Again, the actual answers to this sub-question are presented in Chapter 4 as results for the case study.

Finally, section 3.4 summarizes the conclusion of this chapter on methods applied.

3.1. Method for inventory of circular intervention strategies for buildings

One of the important steps in technical research is the approach taken to conduct the research. In other words, the strategy to be followed. This study follows a qualitative approach which involves typically collecting data in participants setting, particular to general theme data analysis and finally interpreting the meaning of data. There are several research strategies for a qualitative research approach as shown below.

Table 4: Different research strategies (Verschuren, P., Doorewaard, H., & Mellion, M., 2010)

Questions such as	
Who, what, where, how many, how much?	**How, why?**
Survey	Experiment
Archival analysis	History
	Case Study

As for this particular sub-research question, “**Survey**” seems to be the best fit as the aim is to make an inventory of as many activities as possible for a circular building, which demands more breadth than depth. Further, a survey can be conducted either by questionnaires or interviews. Out of the two, **interviews** are the best-fit approach for a qualitative study (Verschuren, P., Doorewaard, H., & Mellion, M., 2010), hence interviews will be used as a ‘method’ for collecting data.

3.1.1. Interview method

There are several ways in which an interview can be conducted. An outline of the different types and explanation is given below.

Table 5: Different types of interview methods (Source: Kajornboon, A. B., 2005)

Type of interview	Description
Structured	Questions in this type of interview are often very specific and a fixed range of answers are expected by interviewees. Also referred to as closed, pre-coded interviews, all respondents will be asked the same questions in the same sequence.
Semi-structured	The interviewer covers a list of questions, key themes, and issues. Also, the order of questions can be changed depending on the interviewee's line of answering. The respondents are allowed to build his/her style of conversation. Within each topic, the interviewer can ask questions as per his/her understanding to carry forward the conversation.
Unstructured	It is a very flexible method where it is not necessary to follow a strict interview protocol. In this type of interview, interviewees are pushed to answer frankly, openly, and give as many details as possible.
Non-directive	This is a unique type of interview method where the interviewer only listens without taking the lead. The conversation is led by the interviewee. Therefore, the questions are usually not pre-planned.

For this sub-section of research, the most favorable type of interview for a qualitative analysis should be selected. Gaining insights about the circular interventions from practitioners is the priority and hence researchers should be able to probe his/her way to explore the opinions and views of the interviewee. The best fit for this would be the **semi-structured interviews** as it gives the freedom to conduct interviews with the above points in mind. Whereas, structured interviews are too rigid and the respondents may not have sufficient information to carry forward the conversation. On the other hand, unstructured and non-directive types are too flexible and offer very less or no direction to explore. One of the disadvantages of a semi-structured interview is that sometimes interviewees drift away from the topic, which should be taken care of by the interviewer.

3.1.2. Selection of the candidates for the interviews

After selecting the method to conduct research, with semi-structured interviews as the strategy, interviewees have to be selected for the process. The general criteria for selection are as follows:

- The respondents have/is involved in projects related to the building sector.
- They have used principles of circularity in one or more projects.
- They have more than 5 years of experience within the industry.

Apart from this, the respondents are selected only

- If they have experience in one of the layers of a building (as explained in section 2.2.1) namely - Site, structure, skin, services, space plan, and stuff.
- They can be an expert in one or more layers.
- The group should also be balanced, in the sense that all the layers should be explored.

This is done to cover encompass the maximum volume of a building and hence different views can be gathered. A total of 7 interviews were conducted based on the above criteria. The description is given in the table below (Table 6).

Table 6: List of interviewees for semi-structured interviews

Interviewee reference	Organization	Role in the organization	Building layer expert
A	ABT B.V	Senior consulting engineer	Major: Structure Minor: Site and skin
B	ABT B.V	Building physicist and sustainability engineer	Skin and only for insulation
C	ABT B.V	Senior consultant (MEP)	Major: Services Minor: Skin
D	ABT B.V	Structural engineer	Structure
E	ABT B.V	Building engineer	Major: Skin, Spaceplane Minor: Structure
F	ABT B.V	Existing buildings specialist	Major: Skin, Spaceplane Minor: Structure
G	ABT B.V	Building sustainability engineer	Structure and skin

3.1.3. Interview protocol and analysis

The framework (Figure 9) forms the basis for formulating the interview questions. The approximate duration of the interview is about 40-45 minutes. The main aim of the interview is to find out

- Whether they are aware of the circular economy and practices?
- What are the activities that can be applied to make the building more circular and what are the traditional alternatives for the same?

In addition, attention will be paid such that the questions are as open as possible and not to steer the response of interviewees in a specific direction. Further, the interviews will follow an interview protocol to maintain consistency. The protocol (Appendix B) consists of three parts:

- The interview starts with an introduction to the interview. Also, the other topics to be addressed are: Research objective; purpose, structure, and confidentiality of the interview.
- The content of the actual interview will again be divided into 4 categories: General; Circular economy; Stewart Brand model of building layers and circular interventions.
- Closing remarks

Due to the situation at the time of conducting these interviews, face to face interviews are not possible, therefore skype interviews are taken. The interviews will be transcribed from audio-recordings. The schematic flow of the steps taken to conduct interviews is shown below (Figure 10):

Figure 10: Schematic flow of the steps taken to conduct interviews (Own illustration)

3.2. Measurement of circularity of the building (MCI)

Based on the conclusion derived from section 2.3.1 of the literature study, MCI will be used as a method to evaluate the circularity of the building in this research.

The first version of the tool kit (2015) focused almost exclusively on only technical cycles and non-renewable materials. The main limitation of this approach was the exclusion of the bio-based materials in the calculation. However, owing to its importance the new version of the MCI tool (2019) has both technical and biological materials within the methodology which makes it suitable for its use in the study.

The diagram below (Figure 11) describes the flow of materials taken into account to arrive at the MCI score and the details of the calculation are provided in Appendix D. It gives a value between 0 and 1, where the higher value corresponds to a higher level of circularity. The abbreviations and their definitions are presented in Appendix C.

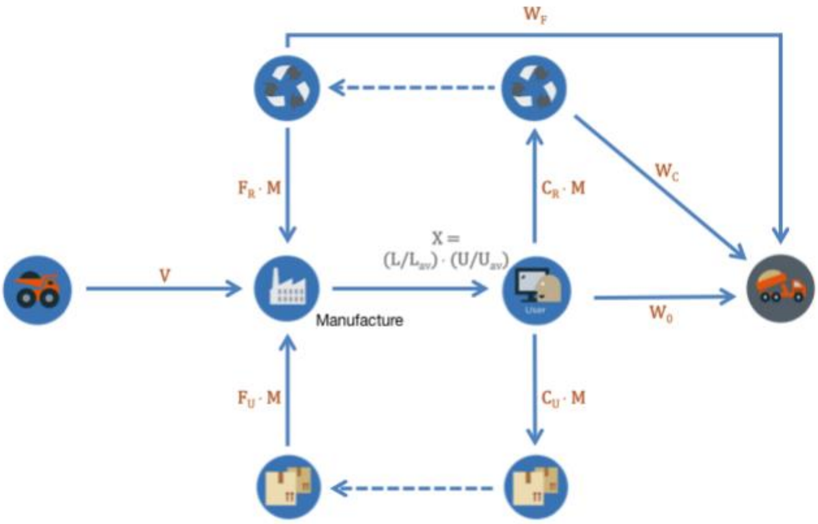


Figure 11: Diagrammatic representation of material flows (Ellen Macarthur Foundation, 2019)

But for this study, only the recyclability percentage and bio-based percentage have been considered for the analysis. The MCI scores have been developed by using the other input variables as constant. One of the reasons is the lack of availability of other input data and also MCI here is used only to compare the different alternatives and see the difference relative to the base case. Hence, extensive calculations have been made simpler by keeping the other input variables as constant.

3.3. Economic evaluation of building (LCC)

The method for assessment of life cycle cost is traditional discounted cash flow analysis over a normative life cycle of 50 years and a real interest rate of 4%. The calculations are carried out conform to the ISO 15686-5:2017(en) Buildings and constructed assets — Service life planning — Part 5: Life-cycle costing. Cash flows are projected on a timeline and discounted to their present values conform:

$$PV[0,T] = C_0 + \frac{C_1}{(1+r)^1} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_T}{(1+r)^T}$$

Where C_0, C_1,.., C_T are the costs occurring in the indexed years, T = the normative life cycle, and r is the real discount rate.

The present value PV of a periodic series of costs with a start time (T_{start}), interval (N), end time (T_{end}) and initial cost C_0, can also be calculated directly as follows (Van den Boomen, Leontaris, & Wolfert, 2019):

$$PV[0,T_{end}) = C_0 \cdot \frac{K^{T_{start}} - K^{T_{end}}}{1 - K^N}$$

$$with$$

$$K = \frac{1}{1+r}$$

The end time (T_{end}) is the time where the next periodic costs would have been projected. I.e. a series of costs starting at year 25 with a cyclic occurrence of 15 years within a bounded time horizon of 50 years has the following parameters: T_{start}=25, N=15 and T_{end}= 55. The formula directly calculates the present value of costs of occurrence at t = 25, t = 40 years.

Further, present values are also transformed into their Equivalent Annual Cost (EAC) conforming to:

$$EAC = PV \cdot \frac{r(1+r)^T}{(1+r)^T - 1}$$

The building costs can be distributed into different phases for LCC calculations as shown below.

Table 7: Distribution of building costs

Phase of use	Costs covered	Description
Pre-use	Direct costs Construction costs	The costs included are preliminary costs (Direct costs) and Construction costs. It includes investment costs that are required for the building. As it is necessary to compare multiple scenarios, there is no need for a detailed estimate of construction costs. Such estimates are usually used for a detailed design stage when the project has crossed several phases of cost estimation.
Use	Maintenance costs Replacement costs	Only operational and maintenance costs are included in the use phase of the building. The energy and water consumption costs are exempted from the analysis for this study. As energy, and also water consumption to some extent, are interdependent, these costs are usually calculated for the whole building rather than per building layer. Hence, they are excluded from the estimation. The standards of costs for maintenance and operation vary from one building to another and hence it is substantial to use engineering judgment for cost estimation. The costs will be calculated based on net present value for the building lifespan
Post-use	Disposal/Demolition costs Residual costs	Contrary to the take-make-dispose system, where the building components or materials have no value at the end of their use, residual values are established for materials within circular economy to keep them in a loop. This is essential for two reasons- (i) Not to waste the useful materials source (ii) Lower LCC may be the outcome of the inclusion of residual value. However, there is a lack of extensive research or practice in estimating these values. There are very less companies that actually have a list of end of life costs as a part of their cost estimation (especially the residual values). The values will, therefore, be calculated based on experts in the field and expert assumptions based on different scenarios.

3.4. Conclusion

The methods used for some of the important concepts of this study are therefore concluded as shown below.

Concepts	Methods used to obtain the result
Inventory of circular intervention strategies for buildings	Semi-structured interviews
Measurement of circularity of buildings	MCI
Economic evaluation of buildings	LCC

The main aim of this chapter is to explicate *the approaches* required to answer sub-question 2 and sub-question 3. The actual answers are provided in Chapter 4.

> *SQ 2: What are the circular interventions that can be applicable for traditional buildings?*
> *SQ 3: How do life cycle building costs and a circularity measure vary when the relevant circular interventions are implemented?*

In order to answer sub-question 2, semi-structured interviews were selected to be the most appropriate method. An interview protocol and set of questions are formulated for the same (Appendix B). A group of 7 respondents are selected based on the criteria mentioned in the chapter. Based on the interview questions, the activities gathered from the interviews are listed in Appendix E and the following chapter. If any activity is repeatedly mentioned by more than one respondent, it is mentioned only once to avoid repetition. These activities are to be analyzed and the most appropriate ones are to be selected for a case study that follows in the next chapter.

In order to answer sub-question 3, the approaches Material Circularity Index and Life Cycle Costing Analysis were selected and elaborated upon.

The methodology to be followed further is given below, in which the methods used are highlighted in blue.

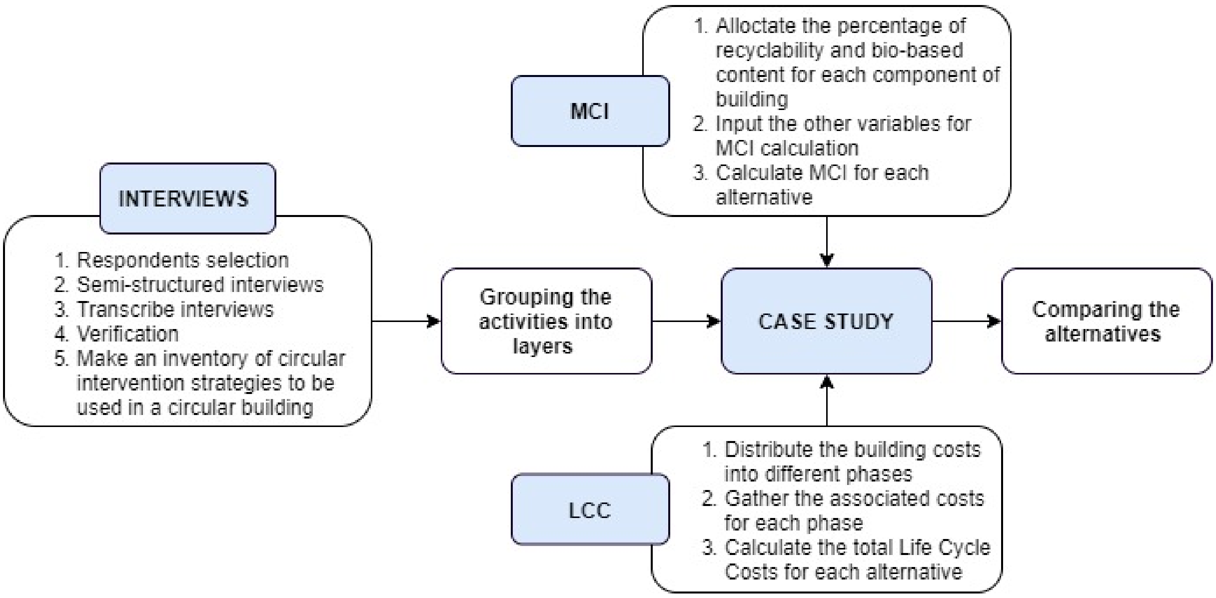


Figure 12: Methods used further in this study (Own illustration)

4. Case Study – Analyses and results

This chapter provides the answers to sub-question 2 and sub-question 3. The approaches for answering these questions are presented in Chapter 3. Chapter 5 discusses the implications of the results.

SQ 2: What are the circular interventions that can be applicable for traditional buildings?
SQ 3: How do life cycle building costs and a circularity measure vary when the relevant circular interventions are implemented?

These questions are answered partly on a generic level and partly by means of a case study. First, the generic results from the interviews are presented in section 4.1. Then the case study is introduced in paragraph 4.2. It is a traditional building that can be made more circular by a selection of intervention strategies from paragraph 4.1. In paragraph 4.3, four circular alternatives are displayed compared to the base case of the case study. The assessment of life cycle costs and circularity is done for each alternative conforming to the methods explicated in the previous chapter and the results are presented in the current chapter. The analysis and discussion of results of the case study are presented in section 4.4, which also constitutes a sensitivity analysis with two input variables- timespan of the building and discount rate. Finally, the conclusion and hence the answers for sub-questions 2 and 3 are provided at the end (paragraph 4.5).

4.1. Identified interventions

The aim of the interviews as mentioned in section 3.1.3 will be analyzed separately.

1. **Are the respondents aware of the circular economy and practices?**
   Almost all the respondents were aware of circular economy in general. It was defined as an economy where there is no waste. However, it seemed as if they had a similar line of thought for a circular building as well. In other words, CE in buildings is generally mixed with the general concept of CE which is not specific to the Built environment. But some of the respondents took into consideration the unique characteristics of circularity in buildings, i.e., the different life span of building layers, and hence they had a difference in opinion.
   It is also observed that circular buildings in their view had mostly to do with reuse and recycling of materials.

2. **What are the activities that can be applied to make the building more circular?**
   Based on the interview questions, the activities gathered from the interviews are listed below. If any activity is repeatedly mentioned by more than one respondent, it is mentioned only once to avoid repetition. The complete list of answers is presented in Appendix E. The most feasible and recurring interventions mentioned by the interviews are presented in the table below.

Table 8: Different intervention activities based on design strategies and building layers (Source: Interviews)

Design strategies	Site	Structure	Skin	Space plan	General
Reduce	Geotechnics and structure together are 60% of building generally. So if there is a chance to minimize the use of materials anywhere in the building, these elements should be targeted as there you can have the quick wins and the big gains		PV panels for facades of buildings instead of conventional materials	Use of geopolymer concrete	As much as possible, the layers of building services and structure should not be mixed. Separate systems should be planned. This way the components with shorter lifespan can be changed easily. It also makes it easier to put a different function to that building Reduce of materials should always be a priority. Less materials will cost less as well

Reuse	Use of old brick for roads. Another alternative could be brick with geo-polymer concrete.	Connections between building components for example between concretes, columns, beams or steel are sometimes welded and you cannot demount anymore. Instead possible connects can be bolted	Old window frames so that can be reused as in the case of EU council in Brussels where they reused façade elements	Use of chalk hemp block for inside of a building for load bearing	For floor, several options can be explored: Floor - Wooden floor slab - Steel structure and steel conc floor - Steel structure and Hollow core slab - Pre fab conc structure with hollow core slab - Pre fab conc structure with MC2 concrete floor
	Having a concrete basement and a wooden building on top of it, so that it can be replaced based on its functionality.	Use of low quality slag produced from coal burning plants, waste burning plants, steel plants instead of sand and aggregates		Majority of wall finishes is just paint. But we can also add wooden cladding to wall, which are made of certain percentage of reusable materials	Steel coming for electro furnace process instead of blast furnace is more environmental friendly
					Reuse of basic materials such as bricks, by just cleaning it up
	Making the structure demountable	Use of crushed concrete from old buildings			Using outside façade of an old building to inside of another building. Facades almost more than 30 years old are not good enough to be used again outside of a building, but can be used indoors.
Recycle	Use of recycled concrete to the maximum limit	Use of timber for structure. And even timber buildings, there is often a lot of steel and glue in it, which is not a very circular way of constructing it. Alternatively, use pins that can easily be removed and has less glue in it.	Use of bio-based panels, bio-based insulation for skin	A lot can be done with bio-based materials	Use of recycled concrete to the maximum limit
	Use of recycled sand, very fine crushed concrete or stone	Use of recycled polymer product can be shredded and used as a filling in new material.	Use of bio-based panel for the roof instead of a composite panel which is normally made out of oil	Glass is a highly recyclable material, if you look at insulation and either it can be from sustainable source or it can be reused from old material.	Recycled sand, very fine crushed concrete or stone
	Asphalt used for the purpose of site can already be made with a high recycled content, but can be pushed further to 100% recycled content	Use of recycled steel profiles	Wooden materials for façade	Recycled carpet and tiles	Instead of using a lot of wood for furniture or in general for stuff, use it in structures
			Recycled aluminum and recycled steel for window frames	Use of glass for glazing as recycling is at a high level for glass.	Steel should be produced in a more sustainable way

Out of the lot, some activities that seemed most fit for the case study and scenario development are selected and used (Highlighted in green). Only a few activities that could be used without causing a lot of change in the calculations from base case are therefore selected.

4.2. Description of the case study

Located in the west of the Nethrelands, is the design of the redevelopment of a multinational company building taking place. The campus will provide the opportunity to showcase the company's commitment to sustainable design and the energy transition. The new building is part of the Office Headquarters Redevelopment Programme (HQP) and forms the heart of its Campus in the Hague.

The current building, which dates back to the 1950s, is exhibiting structural integrity and asbestos problems. A new building is considered to be more efficient than a renovation for this case. The chosen scenario means that both the old building and the neighboring hotel accommodation buildings will be demolished and a new building will be constructed on-site. The goal is for the new office to be a Net Zero building. The new building will house various amenities for the campus with a focus on circularity and demount-ability.

Furthermore, the topic of circularity will play a key role in the building's story. It will be part of the building's DNA by focusing on the reusability of materials and maximizing the prefabrication of elements, thereby contributing to the topical issue of sustainable design within the building sector.

The theme of Circularity is closely related to all aforementioned themes since it positively affects the topics of safety, productivity, and sustainable design which form the core values of the company. The following actions are planned to be used as parameters for each of the disciplines/design teams involved in the design of building: - Reduce – Reuse – Recycle – Redesign – Renewable.

This case was chosen in particular because of the circular ambitions put forward by the client. Also, the initial cost calculations or the preliminary cost calculations (only the direct and construction costs) had just been finished at the time of research and hence can be used for cost estimation of different alternatives with all components described in detail. One other reason for the selection of the case is that the cost estimation is done per layer of the building (as shown in Appendix G) and hence is a perfect fit for this research.

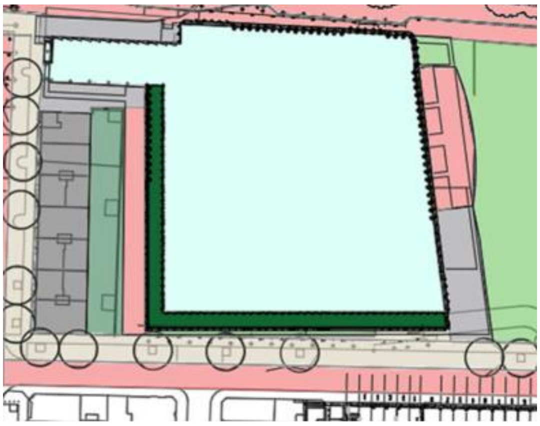


Figure 13: Site plan of the building campus

4.3. Development of scenario and results

The scenarios are developed with an intention to increase the level of circularity of the building compared to the base case. In order to do so, circular interventions are introduced in each scenario in one or more layers of the building. The change in activities compared to the base case, are selected from the interview responses.

	Base case	Improve circularity in Substructure	Improve circularity in Superstructure and Roof	Improve circularity in Superstructure and Facade	Improve circularity in internal walls, finishing, and ceiling
Base case	X				
Scenario 1	X	X			
Scenario 2	X	X	X		
Scenario 3	X	X	X	X	
Scenario 4	X	X	X	X	X

The order of grouping of circular intervention strategies in particular scenarios is a choice motivated by insights gained during the research. However, also other combinations could have been chosen. Listing all possibilities would have resulted in numerous combinations. The case study results will show that compared to an entire building, life cycle costs do not change that much and do not depend much on the order of grouping. Therefore, the order of grouping in practice should be based on technical feasibility. Calculating the MCI and LCC of all possible combinations does not add to the purpose of the current research.

Below are the results of the base case and the alternative scenarios with the change in MCI scores and LCC calculations.

Base case: Traditional building

The base case is derived from the preliminary design where most of the methods used are traditional or rather linear way of construction. The base case consists of 7 layers (Substructure, Superstructure, Roof and finishing, I and finishing, Internal walls and finishing, Internal floor and finishing, Ceiling internal and external) which group components, their elements, and materials. Approximately 150 elements are included in the base case for which materials, volumes, costs, and frequencies were collected. Based on this inventory, the MCI and discounted life cycle costs were calculated as presented below.

Circularity measure (MCI) for the base case

Layer	**Total volume**	**Total recycled content**	**Total bio-based content**	**% Recycled**	**% Biobased**	**% Compliant**
Structures	30794,65	6768,24	1914,23	21,98%	6,22%	28,19%
Envelope	5218,54	353,40	203,68	6,77%	3,90%	10,67%
Interior Materials	3775,87	1211,79	223,63	32,09%	5,92%	38,02%
MEP	2875,20	574,46	0,00	19,98%	0,00%	19,98%
Finishes	1837,95	1144,96	0,00	62,30%	0,00%	62,30%
Total	44502,21	10052,85	2341,55	22,59%	5,26%	27,85%
MCI (0 to 1)						0,66

Net Present Value of Life Cycle Costs for the base case

	Net present value	**Equivalent annual costs**
Pre-use phase costs	€ 100.091.470	€ 4.659.278
Use phase costs	€ 18.365.476	€ 854.917
Post-use phase costs	€ 852.290	€ 39.674
Total life cycle costs	€ 119.309.236	€ 5.553.869

Note: All numbers mentioned are based on limited information and only used for this research. They do not represent any real values of the case study.

Scenario 1: Improve circularity in substructure

Change in layer: Substructure (Site)

The changes made in the base case are added to Scenario 1. In other words,

Scenario 1= Base case + New changes.

Traditional alternative in Base case	Scenario 1
- **A huge amount of the basement floor surface is covered by underwater concrete along with CSM walls.**	- The basement floor is to be constructed as an integrated pit via a gel injection method. This solution reduces materials compared to other methods such as underwater concrete. Furthermore, the use of recycled content in the concrete mix is considered for accomplishing a higher circularity index.
- **Use of cement in grout for anchors and piles**	- Use of slag ash in grout for anchors and piles.

Circularity measure (MCI) for scenario 1

Layer	Total volume	Total recycled content	Total bio-based content	% Recycled	% Biobased	% Compliant
Structures	33479,45	8916,09	1914,23	26,63%	5,72%	32,35%
Envelope	5218,54	353,40	203,68	6,77%	3,90%	10,67%
Interior Materials	3775,87	1211,79	223,63	32,09%	5,92%	38,02%
MEP	2875,20	574,46	0,00	19,98%	0,00%	19,98%
Finishes	1837,95	1144,96	0,00	62,30%	0,00%	62,30%
Total	47187,02	12200,70	2341,55	25,86%	4,96%	30,82%
MCI						0,68

Net Present Value of Life Cycle Costs for scenario 1

	Net present value	Equivalent annual costs
Pre-use phase costs	€ 96.909.430	€ 4.511.153
Use phase costs	€ 18.365.476	€ 854.917
Post-use phase costs	€ 636.333	€ 29.621
Total life cycle costs	€ 115.911.239	€ 5.395.691

Scenario 2: Improve circularity in superstructure and roof

Change in layer: Superstructure, Roof (Skin)

The changes made in Scenario 1 are added to Scenario 2. In other words,

Scenario 2= Base case + Changes made in Scenario 1 + New changes.

Traditional alternative in scenario 1	Scenario 2
- **Floor elements from the basement until the top level are to be constructed with concrete.**	- Floors (Structure, load-bearing) Level 1 to 4 of the building is to be constructed in a hybrid structure consisting of steel beams and timber floor slabs. Not only it adds to the bio-based and recyclability of the layer, but also reduces the environmental by approximately 1500 barrels of oil. The steel structure and floor panels can easily be disassembled and reused in another structure as they are bolted and screwed at the connections.
- **All three levels, namely basement, Level 2, and the top roof closed surface are constructed using concrete as the main material.**	Roof (Structure, load-bearing) - The roof shape is to be built with a wooden structure (Level 2 and top roof closed surface) and is optimized to minimize the amount of materials needed. The wooden structure reduces the environmental impact of the materials used and increases the possibilities for reuse and recycling.

Circularity measure (MCI) for scenario 2

Layer	Total volume	Total recycled content	Total bio-based content	% Recycled	% Biobased	% Compliant
Structures	33479,45	9933,59	5984,25	29,67%	17,87%	47,55%
Envelope	5218,54	752,74	379,86	14,42%	7,28%	21,70%
Interior Materials	3775,87	1211,79	223,63	32,09%	5,92%	38,02%
MEP	2875,20	574,46	0,00	19,98%	0,00%	19,98%
Finishes	1837,95	1144,96	0,00	62,30%	0,00%	62,30%
Total	47187,02	13617,55	6587,75	28,86%	13,96%	42,82%
MCI						0,72

Net Present Value of Life Cycle Costs for scenario 2

	Net present value	Equivalent annual costs
Pre-use phase costs	€ 99.434.500	€ 4.628.696
Use phase costs	€ 18.365.476	€ 854.917
Post-use phase costs	€ 298.224	€ 13.882
Total life cycle costs	€ 118.098.201	€ 5.497.495

Scenario 3: Improve circularity in superstructure, roof, and façade

Change in layer: Superstructure, Façade (Skin)

The changes made in Scenario 2 are added to Scenario 3. In other words,

Scenario 3= Base case + Changes made in Scenario 2 + New changes.

Traditional alternative in scenario 2	Scenario 3
- **Initially, the building frame constructions are made up of concrete, steel, and few wooden components.**	- Extra timber structures are to be added for building frame constructions
- **External wall opening** **The frame is made from aluminum along with glass elements**	- External wall opening The frame is to be made from recycled wood and is composed of triple glass elements

Circularity measure (MCI) for scenario 3

Layer	Total volume	Total recycled content	Total bio-based content	% Recycled	% Biobased	% Compliant
Structures	33479,45	9958,07	5984,25	29,74%	17,87%	47,62%
Envelope	5218,54	728,78	451,76	13,97%	8,66%	22,62%
Interior Materials	3775,87	1211,79	223,63	32,09%	5,92%	38,02%
MEP	2875,20	574,46	0,00	19,98%	0,00%	19,98%
Finishes	1837,95	1144,96	0,00	62,30%	0,00%	62,30%
Total	47187,02	13618,07	6659,65	28,86%	14,11%	42,97%
MCI						0,73

Net Present Value of Life Cycle Costs for scenario 3

	Net present value	Equivalent annual costs
Pre-use phase costs	€ 101.120.122	€ 4.707.162
Use phase costs	€ 18.265.755	€ 850.275
Post-use phase costs	€ 251.930	€ 11.727
Total life cycle costs	€ 119.637.806	€ 5.569.164

Scenario 4: Improve circularity in substructure, roof, façade, internal walls, finishing and ceiling

Change in layer: Façade(Skin), Internal walls and finishing (Space plan), Ceiling internal and external (Space plan)

The changes made in Scenario 3 are added to Scenario 4. In other words,

Scenario 4= Base case + Changes made in Scenario 3 + New changes.

Base case	Scenario 4
- **Regular Pier brick elements are used for façade of the building.**	- The façade of the main building is constructed by prefabricated elements. These are delivered from factory, complete with glass (or mineral wool insulation) spanning from floor to floor. It remains possible to replace the glass in case of transport of handling damage during construction.
- **Internal wall openings (doors and windows) Elements made using steel.**	- Internal wall openings (doors and windows) Elements replaced by wood elements
- **Ceiling internal and external Plasterboard ceiling, double grid, single panel with insulation and Climate ceiling combined heat and cold used for the ceiling.**	- Ceiling internal and external Replaced by recycled wood

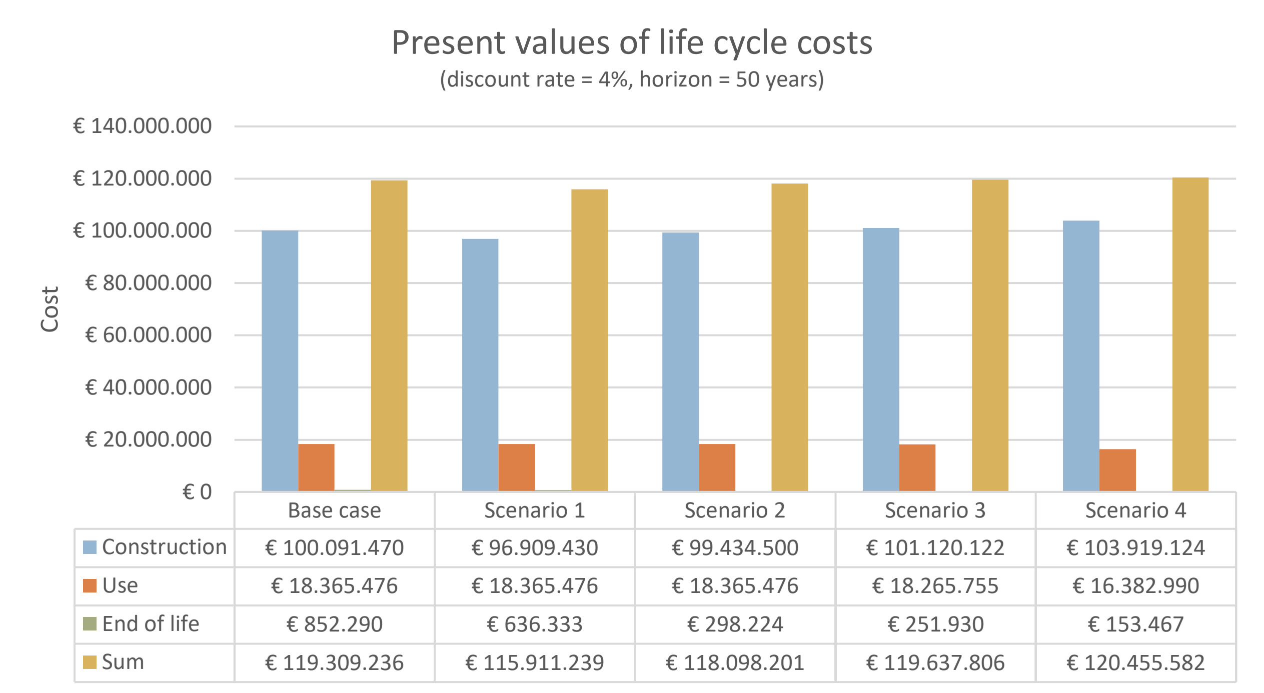
Circularity measure (MCI) for scenario 4

Layer	Total volume	Total recycled content	Total bio-based content	% Recycled	% Biobased	% Compliant
Structures	33479,45	9958,07	5984,25	29,74%	17,87%	47,62%
Envelope	5218,54	1328,78	451,76	25,46%	8,66%	34,12%
Interior Materials	3775,87	722,99	1528,57	19,15%	40,48%	59,63%
MEP	2875,20	541,72	147,36	18,84%	5,13%	23,97%
Finishes	1837,95	1144,96	0,00	62,30%	0,00%	62,30%
Total	47187,02	13696,52	8111,95	29,03%	17,19%	46,22%
MCI						0,75

Net Present Value of Life Cycle Costs for scenario 4

	Net present value	Equivalent annual costs
Pre-use phase costs	€ 103.919.124	€ 4.837.456
Use phase costs	€ 16.382.990	€ 762.631
Post-use phase costs	€ 153.467	€ 7.144
Total life cycle costs	€ 120.455.582	€ 5.607.231

Change in the Net Present Value of Life Cycle Costs through the scenarios



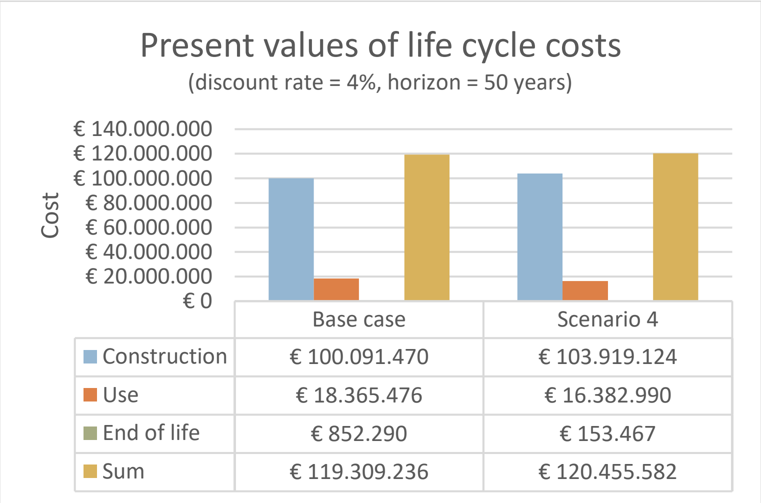
	Base case	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Construction	€ 100.091.470	€ 96.909.430	€ 99.434.500	€ 101.120.122	€ 103.919.124
Use	€ 18.365.476	€ 18.365.476	€ 18.365.476	€ 18.265.755	€ 16.382.990
End of life	€ 852.290	€ 636.333	€ 298.224	€ 251.930	€ 153.467
Sum	€ 119.309.236	€ 115.911.239	€ 118.098.201	€ 119.637.806	€ 120.455.582

Figure 14: Comparing life cycle costs (Discounted) of all alternatives

4.4. Analysis and discussion of results

Several observations can be made from the results shown in the previous chapter.

1. Comparing the base case with the final circular scenario with the highest circularity (scenario 4).



	Base case	Scenario 4
Construction	€ 100.091.470	€ 103.919.124
Use	€ 18.365.476	€ 16.382.990
End of life	€ 852.290	€ 153.467
Sum	€ 119.309.236	€ 120.455.582

Figure 15: Comparing LCC (Discounted) of the base case and final scenario

Here it can be noticed that although the construction costs have a difference of about almost 4 million euros (4% increase in investment costs for the circular alternative), the total life cycle costs differ only by 1.1 million euros (0.95% increase in costs). This is due to the observation that both the use phase costs such as operation, maintenance, and replacement costs and the end of life costs decreases with an increase in the level of circularity. This is explained by the figure below where a comparison is made between the variation of end of life costs (Figure 16) and variation of operation, maintenance and replacement (OMR) costs (Figure 17) with an increase in circularity. Because of the size of the project, the end of life costs seems to be negligible. But if more and more components of the building in general are made either demountable or reusable, the residual value could increase drastically and hence the end of life costs would decrease even further. Here, it is important to notice the variation of operation, maintenance, and replacement (OMR) costs and end of life (EOL) costs with respect to intervention of circular activities. Both seem to decrease with the introduction of more circular activities as shown below.

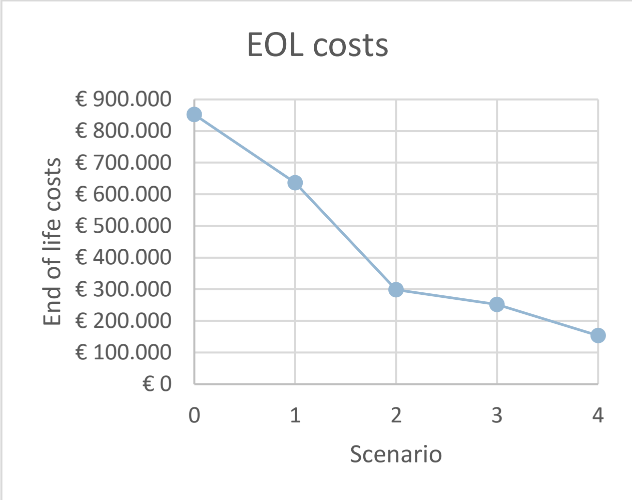


Figure 16: EOL costs (discounted) variation across scenarios

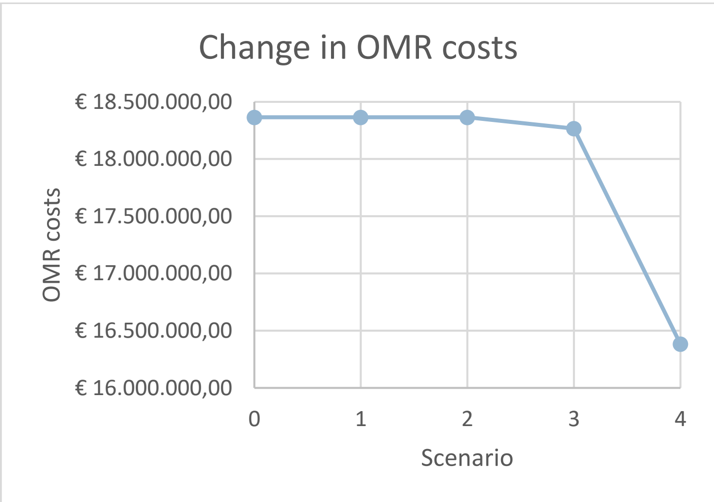


Figure 17: OMR life cycle costs (discounted) variation across scenarios

In the above figure, it can be seen that the discounted OMR life cycle costs of the first three alternatives seem to be the same. This is because all the activities introduced in these scenarios belong to either sub-structure or superstructure and hence the OMR cost does not change for these three alternatives. Hence it can be said that OMR cost can play a significant role in the reduction of life costs in parallel with increasing circularity only when applied to layers other than site and structure. This is seen in about 11% decrease in OMR costs in the final scenario as compared to the base case.

And coming to the change in the level of circularity between the initial and final case (scenario 4), there is a change of about 13%, which can of course be increased by introducing more circular interventions.

Finally, the case study shows that when considering life cycle costs, introducing circular interventions can be more beneficial compared to traditional building.

2. Influence of layers in LCC and level of circularity

It can be noticed that scenario 2 had the highest increase in the level of circularity (MCI) compared to other alternatives. This is because, the changes were introduced in the superstructure and roof of the building, which constitutes about 60-70% of the building's mass. Whereas the changes introduced in other layers, though contributed to an increase in circularity but not by a huge margin. Furthermore, the effect of other input variables that were not included in this study could also influence the level of circularity differently.

And when LCC is considered, the construction costs were decreased by a huge amount in scenario 1 by using the circular strategy "Reduce". Here a huge amount of usage of underwater concrete was avoided by using an alternative method which reduced the construction costs by a great amount and hence there is a huge difference in LCC between the two alternatives. Here too, such a great decrease in costs is observed as the activity has been changed in structure which constitutes the highest percentage by mass in the building.

Hence, it can be said that to get the best-case scenario in terms of LCC and circularity level, higher mass building components could be targeted with an aim to decrease the construction costs. As already established in the previous paragraphs that the OMR and EOL will anyway decrease because of circular activities, focusing on decreasing construction costs could add to a decrease in LCC.

3. Balance between the measure of LCC and level of circularity

Given a choice based solely on economic considerations, scenario 1 might have been chosen out of all the alternatives because of the least LCC. But if observed more carefully, the increase in the level of circularity is not a lot when compared to the base case. This is where the balance between LCC and circularity measurement should play a role. In case the deciding criteria for selecting a project depends on both economic and environmental factors, then there should be a certain percentage of deciding criteria assigned to both cost and circularity measure. In that case, scenario 2 or 3 which has a higher increase in circularity along with a lower LCC as compared to the base case could be chosen over scenario 1. Scenario 4 though has the highest level of circularity has a high level of construction costs, which may be due to an increase in purchase costs of circular materials. This also can be considered in respect to choosing alternatives, i.e., try to make the building as circular as possible until a stage is reached where the purchase cost starts shooting up. This method might help to choose alternatives that are both economically and environmentally beneficial.

4. Sensitivity analysis

Sensitivity analysis is made to check how the life cycle costs are affected based on changes in variables- the time span of the building and the discount rate. As the results of life cycle costs are most dependent on these two variables, they are selected as the input variables.

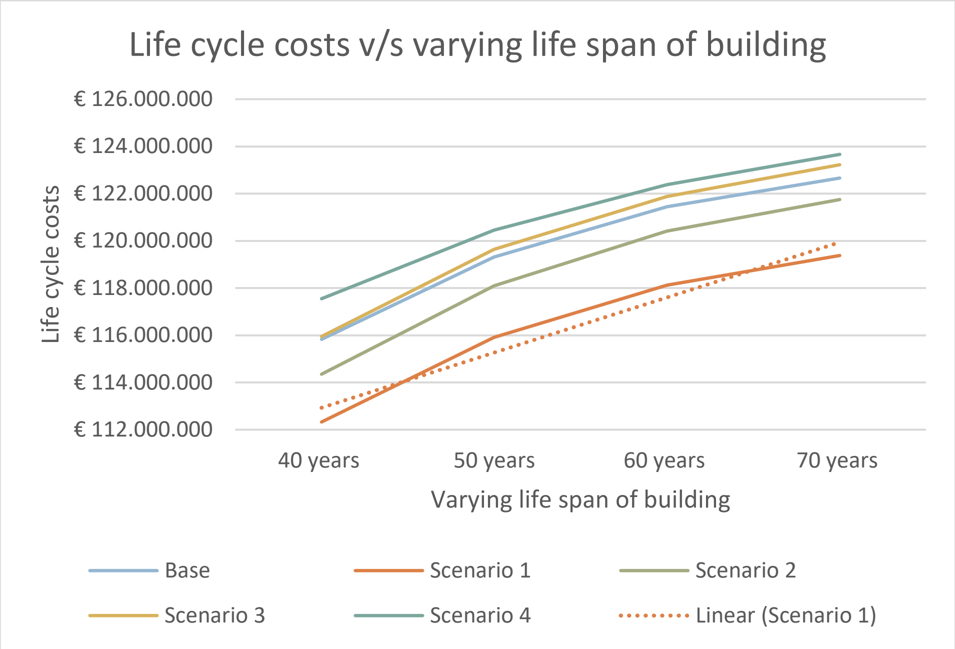


Figure 18: Variation of life cycle costs with varying life span of the building

The figure above shows the variation of life cycle costs with a change in life span of the building. The previous calculations were based on a life span of 50 years and hence other time horizons (40, 60, 70 years) were also explored. An observation worth mentioning is that the life cycle costs decrease with a small percentage as the life span of the building increases. For example, taking scenario 1 (a thread line is inserted in the figure above for distinction)- the increase in LCC from 40 years to 50 years is 3.01%. Similarly, the increase in LCC costs from 50 to 60 years is 1.9% and final increase (from 60 to 70 years) is around 1%. Therefore, there is a pattern of decrease in the incremental rate of life cycle costs. Only with a difference in 10 years, some amount can be saved. Beyond 70 years is usually not in practice for buildings and is considered redundant anyway. Therefore, it can be concluded that long term investments of buildings are beneficial than short term investments in certain cases.

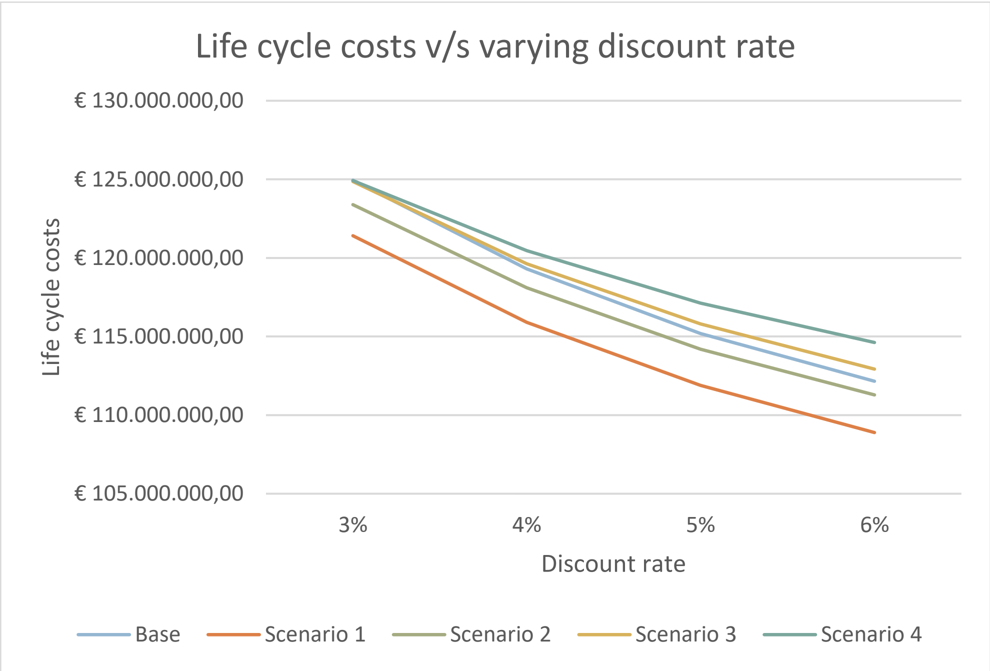


Figure 19: Variation of life cycle costs with varying discount rate

The significance of the graph is highlighted by the difference in the trend lines of the scenarios (for a particular discount rate) rather than the absolute values conveyed by the trendline of each scenario.

The LCC for a building depreciates at a slower rate for lower discount rates. For such cases, it would take a much longer time to reduce the LCC of a building. Therefore, it is important to implement circular strategies in such buildings to lower the LCC at a faster rate with time. Hence, the future is more important where buildings whose LCC discount at a lower rate. On the contrary, when the discount rates are higher, the LCC of a building after certain years tends to be lesser than for a case with a lower discount rate. The relative savings are of circularity are not accounted for that much.

In addition to this, the above graph also describes the different scenarios that can be chosen for implementing circularity. The difference in the trendline (at least for the base case, scenarios 3 and 4) at a lower discount rate is very less. It implies that regardless of the chosen scenario, the LCC output generated would almost be the same. Contrastingly, the choice of a particular scenario would impact the generated LCC for buildings with a higher discount rate (for which the concept of circularity does not hold much importance).

These outcomes are indicative and are a result of specific scenarios used for this study and for a fixed range of discount rates (3 to 6%) and hence cannot be generalized for all cases. Also, the difference between the trendlines is not very huge.

4.5. Conclusion

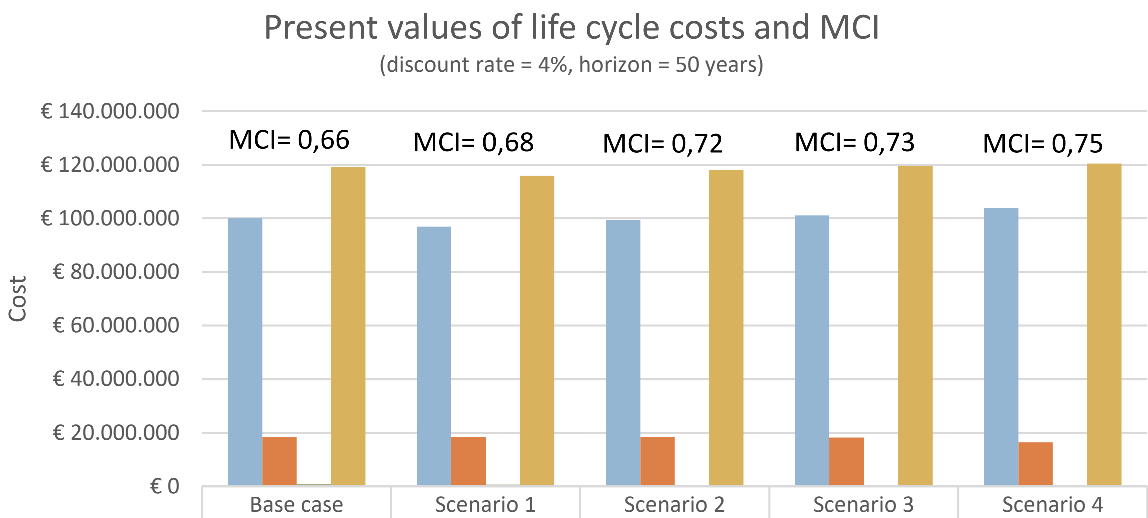
This chapter aims to answer the sub-question 2 and sub-question 3.

> SQ2: *What are the circular interventions that can be applicable for traditional buildings?*

To answer this sub-question, semi-structured interviews were conducted based on the procedure detailed in chapter 3. Based on the interviews, a set of activities belonging to the different layers of a building are compiled. The inventory is presented in section 4.1 of the current chapter. The results from the interviews are also categorized into the most recurring circular strategies and building layers. Hence, the activities were categorized into circular strategies- reduce, reuse, and recycle. Nevertheless, the complete list of activities mentioned in the interviews are compiled in Appendix E. The building layers under consideration are site, structure, skin, and space plan. Important interventions that belonged to a building in general (not particular to a layer) are also included in Table 8.

> *SQ 3: How do life cycle building costs and a circularity measure vary when the relevant circular interventions are implemented?*

The results of the sub-question 3 provide the basis to arrive at the answer for sub-question 3. The activities collected from interviews are analyzed and the most appropriate ones are utilized to generate 4 alternate scenarios to the case study. The assessment of life cycle cost and circularity is done for the base case and each alternative by calculating the Material circularity index and life cycle costs. Below is a summary of the MCI and LCC calculations for all the alternatives.



	Base case	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Construction	€ 100.091.470	€ 96.909.430	€ 99.434.500	€ 101.120.122	€ 103.919.124
Use	€ 18.365.476	€ 18.365.476	€ 18.365.476	€ 18.265.755	€ 16.382.990
End of life	€ 852.290	€ 636.333	€ 298.224	€ 251.930	€ 153.467
Sum	€ 119.309.236	€ 115.911.239	€ 118.098.201	€ 119.637.806	€ 120.455.582

Figure 20: Summary of MCI and LCC calculations for all alternatives

5. Discussion

In this chapter the findings of the case study will be expanded to a generic discussion answering sub-question 4:

What are the implications of the comparison based on building life cycle costs and a circularity measure?

Here, a comparison will be made between the results from the scientific and practical findings within this study. The implications of the LCC and circularity analyses emerging from the case study are discussed in a wider context. How can the building sector benefit from the approach presented? Will such an approach lead to embracing more circularity and enhance its implementation in current practice? What is necessary for the adaptation of such an approach? Also, the limitations of this research will be presented. Sub-question 4 will be answered at the end of the section.

Summary of findings of the case study

The development of various circular alternatives to the base case helped in analyzing the impact of circularity on the costs of a circular building. It is observed that the OMR costs and EOL costs decrease with a gradual increase in the circularity level. This will help in the reduction of life cycle costs which would otherwise be higher. Further, to get a higher increase in the circularity of a building, higher mass components of the building should be targeted. Similarly, life cycle costs can also be reduced to a certain extent by reducing the investment costs for these higher mass components either by reusing most of the components or reducing the amount of certain materials. A comparison as such can help in a parallel tracking of both circularity level and life cycle costs of a building, which in turn aids in taking both the factors into account for decision making. It is also observed that buildings with longer life span have a lower increase in life cycle costs as compared to buildings with a shorter life span.

5.1. Comparison between results from the scientific and practical findings

In the introduction of this research, it was mentioned that many investors are hesitant to choose circular projects due to the lack of understanding of the economic feasibility of such projects (BNP Paribas, 2019; Brein, G., 2015; Van Eijk., 2015). Other challenges that were listed in the literature study include limited knowledge and awareness amongst the stakeholders (Adams, K., Osmani, M., Thorpe, T., & Hobbs, G., 2017).

This study thus addresses the research gap by developing a method to check the economic feasibility of circular buildings by a systematic comparison of different circular alternatives. This is done by incorporating three important aspects in the process: Application of circular interventions to gradually improve circularity combined with an MCI and LCC analysis. This way, not only economic feasibility is obtained, but also equal importance is given to the environmental feasibility of the building. Hence this study has contributed to the knowledge gap of how to make buildings more circular keeping in mind both the economic and environmental impact of such a building.

The research is in consent with the need for alternative design solutions that oversee the entire life cycle of a process and its interaction with the environment with less material, energy, and environmental costs. (Ghisellini, P., Cialani, C., & Ulgiati, S., 2016). But along with such alternative design solutions, it should be seen that the increase in investment costs should not be compromised. As mentioned already, the mindset of investors is changing slowly and only by showing the benefits of circular interventions over a long term, will encourage such investors to take up circular projects.

The research also adds to the challenge of a lack of understanding of the available circular strategies and their effect on their business (Cluzel, F., 2017; Bet, B., 2018). This is can be solved by focusing on the application of circular interventions in a building layer-wise, linking them to financial outcomes, and finally comparing the different alternatives to find the most feasible option.

The implications of the LCC and circularity analyses emerging from the case study

The study provides a new insight into an integrated assessment of circular buildings. The study also implies that a logical flow of concepts and methods are required to attain the required results. It starts from the application of circular interventions to a building gradually so that there is a noticeable change in the level of circularity. This is the first step to quantify circularity. Another approach implied by this research is the application of circular intervention layer-wise. Improving the circularity of a building layer-wise could be a new way forward to get a better overview of the overall impact of the interventions on the costs of a building. This way a decision-maker can make a balanced approach between LCC and MCI. It is important to present both measures for a fair comparison as currently, we are not yet able to include shadow prices or real costs of non-circular interventions in LCC.

The results build on the existing hypothesis stating that the financial reality of the buildings can only be reflected by considering the detailed depreciation of the separate layers (Fischer, A., 2019). But adding a circularity measure by introducing circularity layer-wise reflects the circular reality of buildings. Therefore, the research implies that quantification of both circularity and cost should go hand in hand for the assessment of circular buildings.

Will this approach lead to embracing more circularity and enhance its implementation in current practice?

While the scientific application of the research has been discussed above, it could be successfully implemented in current practice, especially during the preliminary stage of the project. During the preliminary design of the project, usually, different alternatives are compared to each other for the assessment of preliminary cost estimations. This is where this research can be of use. While only the cost comparison is done for buildings without circular ambitions, an integrated method to compare both cost and circularity level can be adopted for projects with circular ambitions to compare the alternatives available. Whereas the calculations can be done easily, the input required is enormous. In particular, the end of life costs for life cycle costing and the input required for MCI is a lot. Hence, this process of obtaining information can be smoothened only by good cooperation between different actors in the building sector. Hence a close collaboration between clients, contractors, and the suppliers is necessary for the successful implementation of this method in current practice. An integrated approach calls for integrated work collaboration.

Also by using the approach, stakeholders are kept informed of the process and hence can make better decisions regarding investing in circular projects. By showing that gradual improvement is possible, stakeholders in the current practice could more willingly involve in projects with circular ambitions and hence lead to enhance circularity in the building sector.

5.2. Conclusion

This chapter aims to answer the sub-question 4.

SQ4: What are the implications of the comparison based on building life cycle costs and a circularity measure?

The methods elaborated in chapter 3 were used on a case (chapter 4) to check the variation of life cycle costs and circularity measure of various circular alternatives to the base case. The results obtained are analyzed to answer this sub-question. Based on the analysis, it was concluded the comparison as such can help in a parallel tracking of both circularity level and life cycle costs of a building, which in turn aids in taking both the factors into account for decision making. Thus, both the costs and circularity of a building are quantified. It is important to present both measures for a fair comparison.

The study implies that a logical flow of concepts and methods are required to attain the required results. It starts from the application of circular interventions to a building gradually so that there is a noticeable change in the level of circularity. This is the first step to quantify circularity. Another approach implied by this research is the application of circular intervention layer-wise. Improving the circularity of a building layer-wise could be a new way forward to get a better overview of the overall impact of the interventions on the costs of a building.

5.3. Limitations of this research

Given the time constraint and difficulty of data collection, there are some limitations to this research. The limitations are as follows:

1. The results of the research could be different depending on the case study. The case study under observation had some costs that could have been very different for other buildings.

2. The study was carried out on a very large project. The investment costs are very huge. The method could be adopted for projects of all sizes, but the results may not be valid for all projects.

3. The end of life costs has been calculated by taking input from experts who are involved in costing. But in reality, the costs could vary depending on the suppliers and the market.

4. The method used to calculate MCI does not consider input and output of reusing for materials and functional units due to the unavailability of data. This could have a different influence on the measure of circularity.

5. All building layers were not considered for the study due to the size of the project. The effect on circularity and life cycle costs based on the application of circular activities on layers such as services and stuff was not taken into account.

5.4. Directions for further research

The discussion and limitations of the research open up space for additional suggestions for future research on the topic of assessment of circular buildings. This is will help in making the process of implementing circularity in the building sector smoother. Following are the recommendations for further research:

1. The process of including a circularity assessment along with cost assessment needs further research. The steps needed to follow to successfully implement the integrated methods could be evaluated and tested.

2. Researching on how the stakeholders can be included in the entire process will help in gaining their trust in order to invest in circular projects.

3. Similar to the point mentioned above, the collaboration between the client, contractors, and suppliers should be researched. An effective communication platform will lead to better collaboration such that all the actors can benefit from engaging in such a collaboration

4. Multiple circularity indicators can be combined so that the results are not based only on one type of measurement of circularity. For example, the design for disassembly could influence the design or circularity of buildings in a different way. Hence an integrated method to check the level of circularity could be researched.

5. Other economic incentives for investing in circular projects within the building sector are to be researched for enhancing circular project implementation.

6. The application of the integrated method suggested for assessment of circular buildings could be extended and developed for infrastructure projects as well.

6. Conclusions and recommendations

A lack of understanding of the economic feasibility of circular projects has been one of the barrier of the implementation of circularity within the building sector. To answer the gap of research, the following main research question and sub-questions were formulated:

Main research question:

How can a traditional building be made more circular and compared based on life cycle costs and a circularity measure to enhance the acceptance of circularity within the building sector?

Sub-questions:

1. *What is circular economy for buildings and how is it assessed?*
2. *What are the circular interventions that can be applicable for traditional buildings?*
3. *How do life cycle building costs and a circularity measure vary when the relevant circular interventions are implemented?*
4. *What are the implications of the comparison based on building life cycle costs and a circularity measure?*

The structure of the report follows the flow of research sub-questions to reach to the main research question. Hence each chapter after the introduction chapter has been followed by a similar structure- a research question is introduced at the beginning of the chapter and it was answered at the end of the chapter. The keys points of the main research question and the sub-questions are summarized below:

6.1. Summary of answers to research questions

To answer the main research questions, first, the sub-questions are answered in order.

SQ1: What is circular economy for buildings and how is it assessed?

A literature study was conducted to understand the key definitions and concepts of circular buildings required for this study. The following definition from Circle economy (2018) was used to describe a circular building: *"A building that is developed, used and reused without unnecessary resource depletion, environmental pollution and ecosystem degradation. It is constructed in an economically responsible way and contributes to the wellbeing of people and the biosphere. Here and there, now and later. Technical elements are demountable and reusable, and biological elements can also be brought back into the biological cycle".*

Further, it was decided to acknowledge a building as a compilation of several layers instead of one whole entity to get a detailed insight into the value of buildings. The main purpose of this demarcation was to gradually implement circular interventions, estimate their life cycle costs and their contribution to the circularity of the building. Next, the R framework was selected to operationalize the activity level of CE in the built environment. Also, the building layer dimension and circular intervention dimension are cross-related to each other for the purpose of cost engineering in this study

Finally, it was concluded that the following were to be considered for assessing circular buildings-

1. Circular interventions to increase the level of circularity of a building
2. Measurement of circularity of a building
3. Evaluation of the life cycle costs of a building

For the assessment of circular buildings, only an economic evaluation of a building is not considered enough. Measuring the circularity should be given equal importance. Hence, for the two aspects, material circularity index (MCI) shall be used to measure the level of circularity and discounted cash flow analysis for assessing life cycle costs (LCC).

SQ2: What are the circular interventions that can be applicable for traditional buildings?

In order to answer sub-question 2, semi-structured interviews were selected to be the most appropriate method. Based on the interviews, a set of activities belonging to the different layers of a building were compiled. The inventory is presented in section 4.1 of chapter 4. The complete list of activities mentioned in the interviews is compiled in Appendix E. The results from the interviews are also categorized into the most recurring circular strategies and building layers. Hence, the activities were categorized into circular strategies- reduce, reuse, and recycle. The building layers under consideration are site, structure, skin, and space plan. Important interventions that belonged to a building in general (not particular to a layer) are also presented in section 4.1.

SQ 3: How do life cycle building costs and a circularity measure vary when the relevant circular interventions are implemented?

Several methods were used to arrive at the answer to this sub-question. Firstly, circular activities were obtained as mentioned in the previous sub-question. Secondly, the Material circularity index (MCI) is used to assess the level of circularity of a circular building. Thirdly, a discounted cash flow analysis is used for assessment of life cycle cost (LCC). The activities collected from interviews were analyzed and the most appropriate ones were utilized to generate 4 alternate scenarios to the case study. Finally, the assessment of life cycle cost and circularity is done for the base case and each alternative. The summary of the MCI and LCC calculations for all the alternatives were presented in Figure 20.

SQ 4: What are the implications of the comparison based on building life cycle costs and a circularity measure?

The results obtained from the previous sub-question were analyzed to arrive at the answer to the implications of this research. The study implies that a logical flow of methods as shown in the previous steps are required to attain the required results. It starts from the application of circular interventions to a building gradually so that there is a noticeable change in the level of circularity. Then a circularity measure is used to check the impact of circular interventions on the building. This is the first step to quantify circularity. Together with a life cycle costing analysis, an integrated method is designed to give equal importance to economic and environmental factors associated with a building. Another implication of this research is the application of circular interventions layer-wise. Improving the circularity of a building layer-wise could be a new way forward to get a better overview of the overall impact of the interventions on the costs of a building.

Main research question:

How can a traditional building be made more circular and compared based on life cycle costs and a circularity measure to enhance the acceptance of circularity within the building sector?

The answers from the previous sub-questions serve as a basis to answer the main research question. A traditional building can be made more circular by searching for circular activities that can replace a non-circular activity by using a circular strategy framework- in this case, R-strategy is used. The application of circular activities or interventions are to be categorized layer-wise to carefully examine the impact of the activity on the circulatory level and costs associated with the building. This can be done by diving the building into different layers- In this case, Stewart Brand layers are used. The circularity of the building is to be increased gradually. Further, several alternatives can be generated to analyze the best-case scenario that can justify both the circularity and cost of a building. This is done by using a circularity measure and life cycle costing- in this case, Material circularity index and discounted cash flow analysis were used respectively. Finally, the results can be analyzed and presented to make a selection by quantifying both circularity and cost. This makes sure circularity in buildings is not compromised for costs associated with the building. This way, stakeholders are better aware of the opportunities can make better decisions in selecting circular projects which could lead to enhance the acceptance of circularity within the building sector.

6.2. Recommendations

The following recommendations are made to suggest how the building sector can implement the findings of the research and to make it more circular:

1. Establish a good network between the actors involved with circular ambitions. Good ties between the clients, contractors, and suppliers will help realize circular ambitions much easier.

2. Knowledge transfer between the actors is very crucial. More projects will be encouraged if there is enough knowledge related to the successful implementation of circular projects, their effects on costs in reality, the performance of the building, etc.

3. Introducing circularity measure as a criterion to award contracts. Certain weightage of the total score to win a contract could be allotted to the circularity of a building in the decision-making process. Only if the competitors can show that they have considered the effect of various circular interventions into the project, they will be included in the race.

4. Creating design alternatives with calculations for both circularity measure and costs should be a part of the preliminary design stage. Introducing such a measure will also help in brainstorming available circular strategies that can be used for the project.

5. Strict regulations from the government regarding reducing the use of virgin materials and focus on circular loops within every sector can help boost the practice of circular economy.

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Appendix A- Circular strategies in order of priority (R strategy)

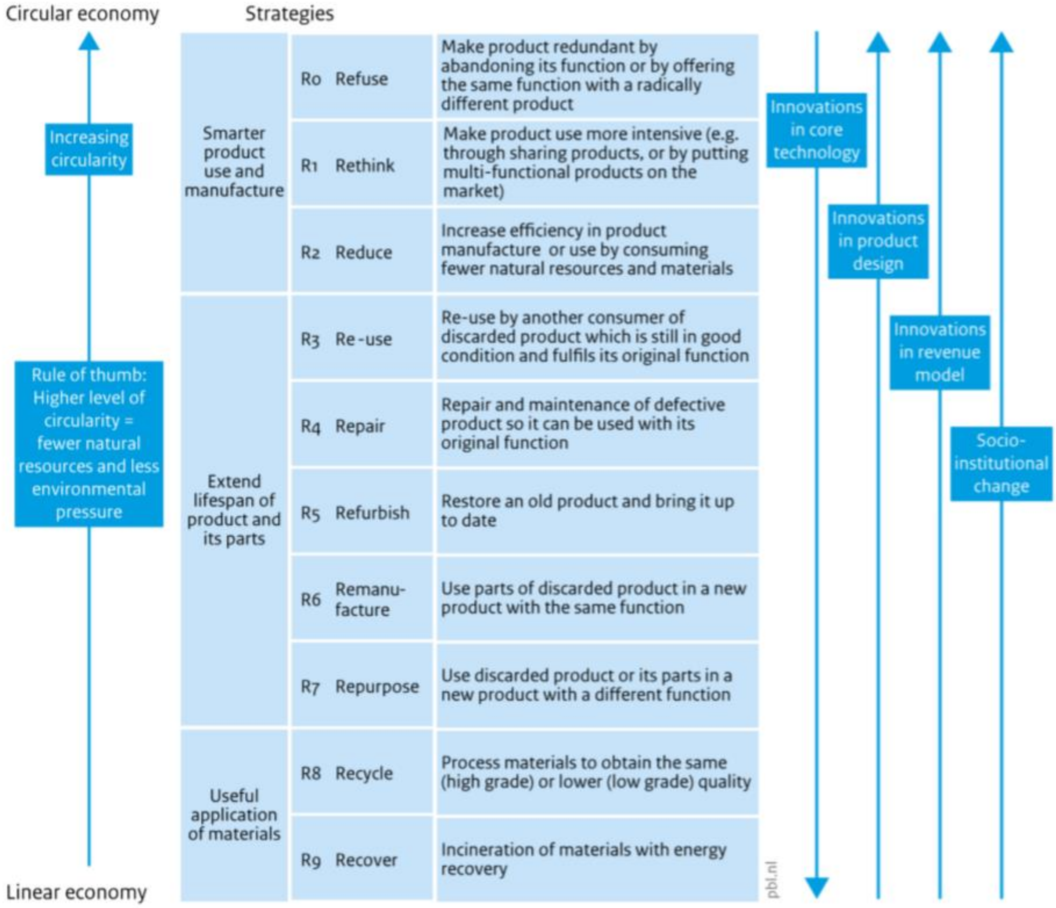


Figure 21: Circular strategies in order of priority (Source: Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A., 2017

Appendix B- Interview protocol

Interview protocol

Date	
Interviewee	
Email of Interviewee	
Organization	
Interviewer	Khyathi Rudraraju
Email of Interviewer	k.rudraraju@abt.eu

Introduction

Introduction of the interviewer

- Second year of Masters in Construction Management and Engineering, TU Delft
- Started graduation assignment in collaboration with ABT B.V. and TU Delft in the month of January
- Research interest – Sustainability/ Circularity/ Life cycle costs. Curious to know the impact of circularity in costs of a circular building.
- Progress until now

Research objective

The aim of the research is to show how current building designs can be improved with alternative circular interventions to improve circularity and find out what is the difference between costs of a traditional and circular building when the interventions are applied.

Purpose of the interview

Interviews are planned to get a good idea of how things are being done in practice. Semi-structured interviews will be conducted with professionals for a market based perspective of circular activities and how they can be implemented along with what are the traditional alternatives for the same activities.

Confidentiality of the interview

Before the interview starts, I would like to address few points.

1. How would you like to be mentioned during reporting?
    - Name, function, organization
    - Only function and organization
    - Anonymous
    - Otherwise

2. Is it okay to record this interview as the analysis will be based on the interview. However, a summary of the interview will be sent to be reviewed by you within one week.
    - Yes
    - No
    - Any objections

3. As mentioned, the summary of the interview will be sent to you via email with a week. In case I don't hear back within a time frame of two weeks, I have the consent to use the document for my research. Do you agree with this?
    - Yes
    - No
    - Any objections

Interview structure

Based on the objective, the interview questions will be divided into three parts. The first part will focus on general introduction and on circular economy in real world. Second- Introduction and questions based on Stewart Brand model of building layers. Third- More specifics about the circular interventions that can be applicable to traditional buildings based on the interviewee's expertise and follow up questions. Lastly, the interview will end with closing remarks.

Pre-interview comment

I would like to make it clear that there are no correct or wrong answers in this interview context. This interview is conducted to know about your perspective and recommendations based on your expertise. Please let me know if any question is unclear or needs more explanation. If you consider any of the questions controversial or rather unpleasant, you can choose not to answer. Do you have any questions so far?

Semi-structured interview questions

General

Experience in the industry?

Role in the company?

Circular economy

What according to you is circular economy in general? Your views regarding it.

What are circular buildings? Do you see it in any way different from CE in general?

Are you currently working on any project that uses circular principles or activities?

Do you think circular building is more costly than a traditional one? Reason?

What are the factors affecting the progress?

Stewart brand model

Are you aware of the Stewart Brand model?

What is your expertise in relation to this model?

Have you tried to apply any circular interventions for the layer of your expertise?

Interventions

Given a traditional building, what activities in your **expertise** can be or are performed in relation to circularity (to increase the circularity of the building)? As many activities as possible

What would be the alternative in traditional case?

Traditional	Circular

Other Interventions in specific to materials?

Are you aware of the 9R framework? If so, do you have some activities in mind with relation to that framework that is applicable for circular building? (If already not mentioned above)

Can the cost aspect of this activity be obtained?

How would the interventions affect other building activities or process that are preceding or succeeding it?

Which activity would be most feasible and why?

How do you measure the level of circularity? Any in-house tools?

Do you see any increase in the value of building after applying the interventions? (Residual?)

Would the clients be interested investing in such kind of projects?

Concluding remarks

Thank you for participating in this interview. The summary of the interview will be sent within a week. If there is any mistake in transcribing, please let me know so that I can make the necessary changes before using it in the report.

Lastly, If I have any further questions, will you be willing to have another conversion?

- Yes
- No

Appendix C- Abbreviations used in the calculation of MCI

Table 9: Abbreviations used in the calculation of MCI (Ellen MacArthur Foundation, 2019)

Symbol	Definition
M	Mass of a product
F_R	Fraction of mass of a product's feedstock from recycled sources
F_U	Fraction of mass of a product's feedstock from reused sources
F_S	Fraction of a product's biological feedstock from Sustained Production. Biological material that is recycled or reused is captured as recycled or reused material, not biological feedstock.
V	Material that is not from reuse, recycling or, for the purposes of this methodology, biological materials from Sustained Production.
C_C	Fraction of mass of a product being collected to go into a composting process
C_E	Fraction of mass of a product being collected for energy material satisfies the requirements for inclusion.
C_R	Fraction of mass of a product being collected to go into a recycling process
C_U	Fraction of mass of a product going into component reuse
E_C	Efficiency of the recycling process used for the portion of a product collected for recycling
E_E	Efficiency of the energy recovery process for biological materials satisfying the requirements for inclusion.
E_F	Efficiency of the recycling process used to produce recycled feedstock for a product
B_C	The carbon content of a biological material, by default a value of 45% is used unless supported by evidence to the contrary.
W	Mass of unrecoverable waste associated with a product
W_O	Mass of unrecoverable waste through a product's material going into landfill, waste to energy and any other type of process where the materials are no longer recoverable
W_C	Mass of unrecoverable waste generated in the process of recycling parts of a product
W_F	Mass of unrecoverable waste generated when producing recycled feedstock for a product
LFI	Linear Flow Index
$F(X)$	Utility factor built as a function of the utility X of a product
X	Utility of a product
L	Actual average lifetime of a product
L_{av}	Average lifetime of an industry-average product of the same type

U	Actual average number of functional units achieved during the use phase of a product
U_{av}	Average number of functional units achieved during the use phase of an industry-average product of the same type
MCI_p	Material Circularity Indicator of a product

Appendix D- Steps to calculate MCI

Input required for the calculation of MCI (Ellen MacArthur Foundation, 2019)

Restoration of material flows at product (and company) levels is based on the following four principles:

• **Input in the production process**: This includes the input from virgin, recycled materials and reused components

• **Utility during use phase**: The time the product is used as compared to average industry life of the product of a similar type.

• **Destination after use**: The amount of material that is collected for recycling, for reuse and that goes into landfill.

• **Efficiency of recycling**: The efficiency of the recycling processes used to produce recycled input and to recycle material after use.

The above data is necessary for all the components and materials which is called the **bill of materials** to calculate the MCI.

Material circularity can be calculated with the information from the detailed bill of materials. Further the MCI can be summed over each individual sub-assembly, part, and/or material ($_X$).

Note: A subscript ($_X$) is used to denote a quantity for a specific sub-assembly, part, or material X.

Material Circularity Indicator is constructed by computing

1. Virgin feedstock
2. Unrecoverable waste
3. Utility factor

1. Calculating Virgin Feedstock

If the fraction of feedstock from virgin sources is given by $(1 – F_R – F_U – F_S)$

$$\text{Mass of virgin material: } V = M\,(1 – F_R – F_U – F_S)$$

Equation 2

Where: **M** is the mass of the finished product

Fraction of mass of a product's feedstock from

$\mathbf{F_R}$ recycled sources

$\mathbf{F_U}$ reused sources

$\mathbf{F_S}$ biological feedstock from Sustained Production

2. Calculating Unrecoverable Waste

- The amount of waste going to landfill or energy recovery $(\mathbf{W_O})$ is

$$W_O = M(1 – C_R – C_U – C_C – C_E)$$

Equation 3

Where: $\mathbf{C_R}$ Fraction of mass of a product being collected to go into a recycling process

C_U Fraction of mass of a product going into component reuse

C_C Fraction of mass of a product being collected to go into a composting process

C_E Fraction of mass of a product being collected for energy

- The amount of waste generated in the recycling process **(W_C)** is given by

$$W_C = M(1 - E_C)C_R$$

Equation 4

Where: E_C Efficiency of the recycling process used for the portion of a product collected for recycling

- The amount of waste generated to produce any recycled content used as feedstock **(W_F)** is given by

$$W_F = M\,\frac{(1-EF)FR}{EF}$$

Equation 5

Where: E_F Efficiency of the recycling process used to produce recycled feedstock for a product

- The overall amount of unrecoverable waste is given by

$$W = W_O + \frac{WF + WC}{2}$$

Equation 6

3. Calculating the Linear Flow Index

It measures the proportion of material flowing in a linear fashion i.e., coming from virgin materials and that end up as unrecoverable waste. It is calculated by

$$LFI = \frac{V + W}{2M + \frac{WF - WC}{2}}$$

Equation 7

4. Calculating Utility

The utility X has two components: one accounting for the length of the product's use phase (lifetime) and another for the intensity of use (functional units).

$$X = \left(\frac{L}{Lav}\right) \times \left(\frac{U}{Uav}\right)$$

Equation 8

Where: **L** Actual average lifetime of a product

L_{av} Average lifetime of an industry-average product of the same type

U Actual average number of functional units achieved during the use phase of a product

U_{av} Average number of functional units achieved during the use phase of an industry-average product of the same type

5. Calculating the Material Circularity Indicator

Finally, the Material Circularity Indicator of a product can now be defined by considering the Linear Flow Index of the product and a factor $F(X)$

$$MCI_p = 1 - LFI \cdot F(X)$$

Equation 9

Where:

F(X) built as a function F of the utility X that determines the influence of the product's utility on its MCI.

$$F(X) = \frac{0.9}{X}$$

Equation 10

Appendix E- Interview answers

The strategies recognized by respondents through the interview is illustrated below and is followed by the intervention activities based on their expertise.

Table 10: Area of importance given by the respondents

	A	B	C	D	E	F	G
Refuse							
Reduce							
Rethink							
Reuse							
Recycle							
Recover							

Respondent A

- Use of Geo-polymer as a binder instead of sand and aggregates dug out from soil for Portland cement concrete .
- Use of low quality slag produced from coal burning plants, waste burning plants, steel plants instead of sand and aggregates.
- Use of crushed concrete from old buildings.
- Instead of using a lot of wood for furniture or in general for stuff, use it in structures.
- Use of Aluminum in buildings that has been produced with electrolysis or solar or wind. This can be achieved only in the case of Aluminum and not in steel as the melting point of aluminum is low.
- In case of Site, use of old brick for roads. Another alternative could be brick with geo-polymer concrete.
- Asphalt used for the purpose of site can already be made with a high recycled content, but can be pushed further to 100% recycled content.
- Steel should be produced in a more sustainable way.
- Use of Wooden piles is an excellent option in some cases.

Respondent B

- As much as possible, the layers of building services and structure should not be mixed. Separate systems should be planned. This way the components with shorter lifespan can be changed easily. It also makes it easier to put a different function to that building.
- Connections between building components for example between concretes, columns, beams or steel are sometimes welded and you cannot demount anymore. Instead possible connects can be bolted.
- Use of timber for structure. And even timber buildings, there is often a lot of steel and glue in it, which is not a very circular way of constructing it. Alternatively, use pins which can easily be removed and has less glue in it.
- Use of recycled polymer product can be shredded and used as a filling in new material.
- Site- Geotechnics and structure together are 60% of building generally. So if there is a chance to minimize the use of materials anywhere in the building, these elements should be targeted as there you can have the quick wins and the big gains. And skin is second for the building material count and has a lot of materials that have a high environmental impact.
- Use of bio based panels, bio based insulation for skin. Same for space plan, a lot can be done with bio based materials.

- Use of bio based panel for the roof instead of a composite panel which is normally made out of oil. But this option can be used for a fire class rating of B. They are well performing in terms of moist and thermal insulation, but they are not performing the best for fire.
- Use of a new technology where eggplant is used for cover plates.
- Use of chalk hemp block for inside of a building for load bearing
- Push the use of recycled concrete to the maximum limit.
- Use of recycled sand, very fine crushed concrete or stone.
- Old window frames so that can be reused as in the case of EU council in Brussels where they reused façade elements.
- Use of recycled aluminum and recycled steel for window frames..

Respondent C

- Glass is a highly recyclable material, if you look at insulation and either it can be from sustainable source or it can be reused from old material.
- There has been a lot of evolving technique in skin specially glazing, insulation etc. If the right materials are used, then you can have an optimal skin for a very long period.
- Reuse of ducts in services. Wrong sizing is not a problem as long as it has good base materials.
- Wall sockets are usually made of hard plastic materials made out of petrol products. New alternative is to use material made out of maze.
- Piping usually in the form of PVC can be made with recycled materials and can also be recycled.
- Reuse of basic materials such as bricks, by just cleaning it up.
- Use of glass for glazing as recycling is at a high level for glass.
- Using outside façade of an old building to inside of another building. Facades almost more than 30 years old are not good enough to be used again outside of a building, but can be used indoors.
- Use of activated concrete. That is use heating and cooling systems outside concrete.
- Having a concrete basement and a wooden building on top of it, so that it can be replaced based on its functionality.

Respondent D

- For floor, use of geo polymer concrete is advisable.
- Reduce of materials should always be a priority. Less materials will cost less as well.
  For floor, several options can be explored: Floor
    - Wooden floor slab
    - Steel structure and steel conc floor
    - Steel structure and Hollow core slab
    - Pre fab conc structure with hollow core slab
    - Pre fab conc stricture with MC2 concrete floor

- Use of recycled steel profiles.
- One of the innovative way of crushing concrete is by the use of smart crusher. A smart crusher separates cement out of existing concrete and those parts can be reused in new structures and hence it will require less additional cement.

Respondent E

- Making the structure demountable.
- Services - ducts and channeling can be possibly made from cardboard. Footprint and circularity will increase.
- Wall finishes-   Majority of wall finishes is just paint. But we can also add wooden cladding to wall, which are made of certain percentage of reusable materials.

Respondent F

- Wooden materials for façade.

Respondent G

- Interior: recycled carpet and tiles
- Steel coming for electro furnace process instead of blast furnace is more environmental friendly.
- PV panels for facades of buildings.

CODE	Component	Maintenance/Replacement	Activity	Qty	Unit	%	Net Qty	Unit	Price/Unit	Cyclus Normes	Total amount	Start year	End Year	PV(excluding 2070)	Per element	PV check
	Special timberwork on the roof	Maintenance	Cleaning, oil							5	€ 64.992,00	2025	2069	€ 248.626		€ 248.626
	Around lower roofs	Maintenance	Cleaning, oil							5	€ 3.240,00	2025	2069	€ 12.395		€ 12.395
	Bottom, insulation, epdm, detail transition to facade	Maintenance	Service											€ 3.507		€ 3.507
	Bottom, insulation, epdm, detail transition to facade	Maintenance	Service											€ 2.104		€ 2.104
	Roof snappers in the back garden	Maintenance (Paint outside)								5	€ 102.186,50	2025	2069	€ 390.913	€ 390.913	€ 390.913
	the new connection to C05 and C16	Maintenance	Dakraam hout schw. bu. nieuw systeem	2.587	m2	50%	1293,5	m2		25	€ 131.937,00	2045	2069	€ 49.492	€ 49.492	€ 49.492
	Terras South West and North, and green area	Maintenance								20	€ 23.460,00	2040	2069	€ 15.593		€ 15.593
	Balustrade roofs glass, top roof, terraces	Maintenance								5	€ 9.000,00	2025	2069	€ 34.429	€ 34.429	€ 34.429
31	External wall openings (doors and windows)												2069			€ 0
	Elements tripple glass en closed parts	Replacement	Replacement of the frame							40	€ 5.999.250,00	2060	2069	€ 1.249.578		€ 1.249.578
	Finishing inner surface of closed facade basement	Maintenance								10	€ 227.808,00	2030	2069	€ 375.555		€ 375.555

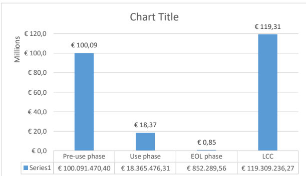
		Base case				Pre-use phase	Use phase (PV)		End-of-life phase		LCC
Layer	Code	Component	Elements	Materials	Direct cost	Construction	OMR	Disposal	Residual value	EOL (PV)	
Substructure	11.3	Ground. excavations. additions			€ 1.739.064	€ 521.719		€ 0	€ 0	€ 0	€ 2.260.783
	11.4	Support works. sheet pile	Tubex support piles	Steel tubular pole (reir	€ 83.300	€ 24.990		€ 17.150	€ 1.176	€ 2.248	€ 110.538
			CSM walls 550mm thick around the building pit, HE360B	Profiled steel (sheet pile) (conc with steel)	€ 2.328.134	€ 698.440		€ 1.126.500	€ 450.600	€ 95.108	€ 3.121.682
			Others		€ 2.245.000	€ 673.500		€ 0	€ 0	€ 0	€ 2.918.500
	11.5	Dewatering (drainage)	Dewatering (drainage)		€ 158.240	€ 47.472		€ 0	€ 0	€ 0	€ 205.712
	13	Floor bed (On ground)	Under water concrete	Concrete	€ 2.058.353	€ 617.506		€ 1.305.150	€ 223.740	€ 152.168	€ 2.828.027
			Concrete slabs on top of UWC (underwater concrete)	Reinforced Concrete	€ 974.374	€ 292.312		€ 360.150	€ 61.740	€ 41.990	€ 1.308.676
			Sandfill between slabs	Sand	€ 84.699	€ 25.410		€ 19.358	€ 25.166	-€ 817	€ 109.292
			Floor bed on top of UWC	Reinforced Concrete	€ 2.013.606	€ 604.082		€ 783.090	€ 134.244	€ 91.301	€ 2.708.989
	16	Basement	foundation footing strips, pads etc		€ 274.744	€ 82.423		€ 1.337.000	€ 229.200	€ 155.881	€ 513.049
	17	Deep foundation (pile foundations)	Pile foundations, anchor block Gewi 63,5mm 25m1	tiranti	€ 1.500.000	€ 450.000		€ 180.000	€ 26.166	€ 21.646	€ 1.971.646
			Fundex combination GI 460/560 with grout injection	piles	€ 1.469.487	€ 440.846		€ 245.000	€ 16.800	€ 32.111	€ 1.942.444
					€ 14.929.001	€ 4.478.700				€ 591.636	€ 19.999.337
					€ 19.407.701						
Super structure	21	External walls (structure, load bearing)	External walls basement	Concrete	€ 691.114	€ 207.334		€ 176.400	€ 30.240	€ 20.567	€ 919.015
	22	Inner walls (structure, load bearing)	Cores and other elements	Concrete	€ 776.086	€ 232.826		€ 271.635	€ 46.566	€ 31.670	€ 1.040.582
	23	Floors (structure, load bearing)	Floorslab 350mm dik, 100 kg reinforcement	Concrete	€ 3.537.722	€ 1.061.317		€ 1.238.230	€ 212.268	€ 144.366	€ 4.743.404
			Concrete floorslab 400mm	Concrete	€ 1.407.869	€ 422.361		€ 505.400	€ 86.640	€ 58.925	€ 1.889.155
			Concrete floor 600 mm PT	Concrete	€ 418.751	€ 125.625		€ 151.620	€ 25.992	€ 17.677	€ 562.054
			Atrium boundary in flued form included edge beam	Not based on material	€ 112.000	€ 33.600		€ 0	€ 0	€ 0	€ 145.600
			HEM beams	Steel	€ 583.200	€ 174.960		€ 19.440	€ 23.328	-€ 547	€ 757.613
	27	Roofs (structure, load bearing)	Roof basement	Concrete	€ 329.625	€ 98.888		€ 102.550	€ 17.580	€ 11.956	€ 440.469
			Roof level 2	Concrete	€ 113.925	€ 34.178		€ 39.874	€ 6.836	€ 4.649	€ 152.751
			Top roof closed surface	Concrete	€ 495.010	€ 148.503		€ 66.000	€ 0	€ 9.287	€ 652.800
	28	Building frame constructions (other primary elements)	Concrete structure basement	Concrete	€ 959.386	€ 287.816		€ 110.614	€ 18.962	€ 12.897	€ 1.260.098
			Steel structure	Steel	€ 1.500.201	€ 450.060		€ 19.665	€ 24.582	-€ 692	€ 1.949.570
			Wood structure	Wood	€ 4.415.250	€ 1.324.575		€ 147.175	€ 588.700	-€ 62.128	€ 5.677.697
			Extra		€ 682.000			€ 0	€ 0	€ 0	€ 682.000
					€ 16.022.139	€ 4.602.042				€ 248.626	€ 20.872.807
					€ 20.624.181						
Roof and finishing	27	Roof completion	Special timberwork on the roof		€ 243.723	€ 73.117	€ 323.769	€ 21.664	€ 0	€ 3.048	€ 643.657
			Arround lower roofs		€ 67.500	€ 20.250	€ 33.206	€ 1.350	€ 0	€ 190	€ 121.146
			Bottom, insulation, epdm, detail transition to facade		€ 147.000	€ 44.100	€ 8.132	€ 1.500	€ 0	€ 211	€ 199.443
			Bottom, insulation, epdm, detail transition to facade		€ 60.120	€ 18.036	€ 4.879	€ 900	€ 0	€ 127	€ 83.162
	37	Roof openings	Glass transparant roof modules	dakraam meranti	€ 3.286.904	€ 986.071	€ 1.072.002	€ 30.720	€ 25.600	€ 720	€ 5.345.697
			Glare control above workspace	Solidscreen	€ 68.795	€ 20.639	€ 142.872	€ 1.032	€ 0	€ 145	€ 232.450
			Roof snappers in the back garden for B1	Aluminium, geanodiseerd	€ 48.600	€ 14.580	€ 390.913	€ 81	€ 24.300	-€ 3.408	€ 450.685
			Glass elements in the roof above the new connection to C05 and C16		€ 20.000	€ 6.000	€ 49.492	€ 240	€ 200	€ 6	€ 75.497
			Access to the roof		€ 8.000	€ 2.400	€ 15.527	€ 12	€ 120	-€ 15	€ 25.912
	47	Roof finishing (covering)	High reflective covering	app dakbedekking	€ 649.928	€ 194.978		€ 81.240	€ 0	€ 11.431	€ 856.338
			Paths and safety lines		€ 135.402	€ 40.621	€ 1.124.109	€ 10.832	€ 0	€ 1.524	€ 1.301.656
			Special structure toproof elements	aluminium	€ 883.050	€ 264.915	€ 270.247	€ 17.661	€ 41.209	-€ 3.314	€ 1.414.899
			Terras South West and North, and green areas	street bricks	€ 309.200	€ 92.760	€ 135.254	€ 15.460	€ 0	€ 2.175	€ 539.390
			Balustrade roofs glass, top roof, terraces and fitness terrace	Staal; gepoedercoat; glasplaat vulling	€ 562.500	€ 168.750	€ 34.429	€ 9.000	€ 7.500	€ 211	€ 765.890
			Certificated materials for LEED requirements		€ 130.800			€ 0	€ 0	€ 0	€ 130.800
					€ 6.621.522	€ 1.947.217	€ 3.604.831			€ 13.053	€ 12.186.623
					€ 8.568.739						
Facade and finishing	31	External wall openings (doors and windows)	Entrance to basement	aluminuim Triple glass; glazed dry	€ 50.000	€ 15.000	€ 12.460	€ 300	€ 250	€ 7	€ 77.467
			Entrance to loading bay	Triple glass; glazed dry	€ 178.200	€ 53.460	€ 43.409	€ 972	€ 810	€ 23	€ 275.092
			Structural glazing	Triple glass; glazed dry	€ 2.110.406	€ 633.122	€ 570.619	€ 20.256	€ 16.880	€ 475	€ 3.314.622
			Elements tripple glass en closed parts	Triple glass; glazed dry	€ 5.999.250	€ 1.799.775	€ 1.740.146	€ 75.780	€ 63.150	€ 1.777	€ 9.540.948
			Windows	Triple glass; glazed dry	€ 486.560	€ 145.968	€ 164.354	€ 9.732	€ 8.110	€ 228	€ 797.111
			Emergency exits	VMRG doors +add glass panes	€ 75.000	€ 22.500	€ 16.787	€ 180	€ 150	€ 4	€ 114.291
			Entrance CN-EN 2.1	No Material	€ 350.000	€ 105.000	€ 72.979	€ 800	€ 0	€ 113	€ 528.091
			Entrance EJ - 01	No Material	€ 250.000	€ 75.000	€ 52.150	€ 800	€ 0	€ 113	€ 377.263
	41	Facade finishing (cladding	Scaffolding		€ 288.460	€ 86.538		€ 0	€ 0	€ 0	€ 374.998
			Sun screening	Solidscreen	€ 519.229	€ 155.769	€ 899.785	€ 8.901	€ 0	€ 1.252	€ 1.576.035
			Finishing inner surface of closed facade basement	Spray plaster	€ 115.186	€ 34.556	€ 633.809	€ 0	€ 0	€ 0	€ 783.550
			Steel ceramic sun shading		€ 213.444	€ 64.033	€ 44.438	€ 2.510	€ 1.757	€ 106	€ 322.022
			Sun shading horizontal		€ 190.800	€ 57.240	€ 151.523	€ 3.180	€ 2.226	€ 134	€ 399.698
			Curved lines roof level		€ 171.000	€ 51.300	€ 68.894	€ 11.400	€ 0	€ 1.604	€ 292.798
			Pier Brick elements external		€ 1.019.990	€ 305.997	€ 505.866	€ 75.000	€ 45.000	€ 4.221	€ 1.836.075
			Pier Brick elements on the inside		€ 640.000	€ 192.000	€ 165.927	€ 50.000	€ 30.000	€ 2.814	€ 1.000.742
			Closed elements in the elements on floor levels	Aluminium vlak (sandwich-aluminium kern)	€ 170.000	€ 51.000	€ 0	€ 6.800	€ 0	€ 957	€ 221.957
			Demonstration showcase related to Showroom on level 0 grid line 1, 14		€ 142.800	€ 42.840	€ 2.641	€ 0	€ 0	€ 0	€ 188.281
			Canopy main entrance	steel	€ 300.000	€ 90.000	€ 8.537	€ 1.000	€ 1.200	-€ 28	€ 398.508
			Glare control all glass elements	internal sunshading	€ 516.000	€ 154.800		€ 10.750	€ 0	€ 1.513	€ 672.313
			Other		€ 549.448	€ 164.834		€ 0	€ 0	€ 0	€ 714.282
			Certificated materials for LEED requirements		€ 216.800	€ 65.040		€ 0	€ 0	€ 0	€ 281.840
					€ 14.552.573	€ 4.365.772	€ 5.154.325			€ 15.313	€ 24.087.983
					€ 18.918.345						
Internal walls and finishing	22	Internal walls	Acoustic MS double, MS2	MWA+Gipskartonplaat systeemwand	€ 362.174	€ 108.652	€ 133.653	€ 38.805	€ 5.174	€ 4.732	€ 609.211
			Brandwerend MS double, MS1	Glaswol MWA+Gipskartonplaa	€ 465.652	€ 139.696	€ 184.290	€ 58.200	€ 7.760	€ 7.098	€ 796.735
			Normal walls MS single, MS3	MWA+Gipskartonplaat systeemwand	€ 646.738	€ 194.021	€ 280.226	€ 97.005	€ 12.934	€ 11.830	€ 1.132.816
	32	Internal wall openings (doors and windows)	Acoustic elements	Glaswol MWA	€ 698.477	€ 209.543	€ 24.639	€ 11.640	€ 4.656	€ 983	€ 933.642
			Fire protected	Steel structure inner wall with doors and	€ 931.303	€ 279.391	€ 19.718	€ 9.315	€ 3.726	€ 786	€ 1.231.198
			Normal elements	Steel	€ 1.047.716	€ 314.315	€ 43.751	€ 34.920	€ 13.968	€ 2.948	€ 1.408.730
			Special (high) elements	Steel	€ 1.455.161	€ 436.548	€ 28.784	€ 17.460	€ 6.984	€ 1.474	€ 1.921.967
			Flexibel walls	Steel	€ 300.000	€ 90.000	€ 7.939	€ 5.000	€ 0	€ 704	€ 398.643
			Doors. included hinges and locks	Hout; geschilderd: alky	€ 493.000	€ 147.900	€ 29.796	€ 0	€ 0	€ 0	€ 670.696
			GLASS - INTERIOR WALL PANEL FI-03	Staal frame element; g	€ 1.187.640	€ 356.292	€ 247.354	€ 39.585	€ 15.834	€ 3.342	€ 1.794.628
			MIRROR - INTERIOR PANEL FI-06	Staal frame element; g	€ 28.000	€ 8.400	€ 5.832	€ 600	€ 240	€ 51	€ 42.283
			GLASS PANEL BENT - WOOD INTERLAYER FI-09	Houten frame, eknel gl	€ 37.500	€ 11.250	€ 7.811	€ 225	€ 90	€ 19	€ 56.580
			other elements		€ 141.855	€ 42.557	€ 29.494	€ 2.655	€ 1.062	€ 224	€ 214.129
	42	Internal wall finishing	Wall finishing assumption	Spray plaster	€ 43.860	€ 13.158	€ 80.308	€ 0	€ 0	€ 0	€ 137.326
			Wall finishing assumption	Spray plaster	€ 213.424	€ 64.027	€ 213.128	€ 0	€ 0	€ 0	€ 490.580
			Wall finishing assumption	Spray plaster	€ 905.434	€ 271.630	€ 497.336	€ 0	€ 0	€ 0	€ 1.674.400
			Wall finishing assumption	Spray plaster	€ 248.710	€ 74.613	€ 160.725	€ 0	€ 0	€ 0	€ 484.048
			Wall finishing assumption	Spray plaster	€ 1.920.813	€ 576.244	€ 468.937	€ 0	€ 0	€ 0	€ 2.965.994
			Based on material schedule (GYPSUM WALL BOARD - INTERIOR L4 FI-01)	Gipspleister	€ 26.364	€ 7.909	€ 36.199	€ 0	€ 0	€ 0	€ 70.472
			Based on material schedule (GYPSUM WALL BOARD - INTERIOR L5 FI-02)	Gipspleister	€ 44.950	€ 13.485	€ 49.382	€ 0	€ 0	€ 0	€ 107.817
			Based on material schedule (GLASS PANEL BENT - WOOD INTERLAYER FI-09)	wooden frame, single g	€ 3.750	€ 1.125	€ 1.478	€ 0	€ 315	-€ 44	€ 6.309
			Based on material schedule (BATHROOM WALL TILE FI-12)	Glazed ceramic tiles	€ 15.130	€ 4.539	€ 7.400	€ 0	€ 0	€ 0	€ 27.069
			Based on material schedule (WOOD WALL PANELS FI-14)	wooden wall	€ 439.565	€ 131.870	€ 231.377	€ 0	€ 52.752	-€ 7.423	€ 795.389
			Based on material schedule (ACOUSTIC WALLS FI-15)	Acoustic cellulose spra	€ 89.100	€ 26.730	€ 21.752	€ 0	€ 8.316	-€ 1.170	€ 136.412
			Based on material schedule (PAINTED CONCRETE FI-21)	Wall paint	€ 60.720	€ 18.216	€ 108.275	€ 0	€ 0	€ 0	€ 187.211
			Finishing with colored paint (concrete columns basement)	Paint	€ 87.150	€ 26.145	€ 44.401	€ 0	€ 0	€ 0	€ 157.696
			Finishing fire protected and esthetic (columns GF - top floor)	Paint	€ 264.000	€ 79.200	€ 273.101	€ 0	€ 0	€ 0	€ 616.301
			Finishing with fire protected paint (columns in atrium special curved)	Paint	€ 900.000	€ 270.000	€ 46.610	€ 0	€ 0	€ 0	€ 1.216.610
			Finishing with fire protected paint (columns atrium special)	Paint	€ 200.000	€ 60.000	€ 49.655	€ 0	€ 0	€ 0	€ 309.655
			Insulation walls in loading dock	Rock wool	€ 30.100	€ 9.030		€ 0	€ 0	€ 0	€ 39.130
			Certificated materials for LEED requirements		€ 191.500	€ 57.450		€ 0	€ 0	€ 0	€ 248.950
					€ 13.479.786	€ 4.043.936	€ 3.333.352			€ 25.553	€ 20.882.627

Rate	4%	
Time	50	
	disposal	residual
Concrete	175	30
Sand	8	13
Steel	0.08	0.1
	0.08	€ -365.66

Layer	Code	Component	Elements	Materials	Direct cost	Construction	OMR	Disposal	Residual value	EOL (PV)	
					€ 17.523.722						
Internal floor and finishing	23	Floor items (non-load bearing, balconies, arcade, suspended)	Special elements		€ 150.000	€ 45.000		€ 0	€ 0	€ 0	€ 195.000
			Atrium stair elements GFL > L01	Wooden floor element	€ 290.000	€ 87.000	€ 0	€ 5.800	€ 0	€ 816	€ 377.816
	33	Voids	Temporary floors during construction		€ 622.871	€ 186.861		€ 0	€ 0	€ 0	€ 809.732
			Panelized skin boarders		€ 250.000	€ 75.000		€ 5.000	€ 0	€ 704	€ 325.704
			Railing along the edges, curved glass	glass + steel	€ 720.000	€ 216.000		€ 7.200	€ 4.200	€ 422	€ 936.422
	43	Floor finishes	Bicycle and Carparking		€ 358.482	€ 107.545	€ 650.109	€ 50.190	€ 0	€ 7.062	€ 1.123.198
			Service and Storage		€ 138.046	€ 41.414	€ 208.633	€ 16.107	€ 0	€ 2.266	€ 390.360
			Circulation	Anhvdriet	€ 195.954	€ 58.786	€ 161.485	€ 12.467	€ 0	€ 1.754	€ 417.979
			Fitness centre	Anhydriet+polystyreen	€ 115.718	€ 34.715	€ 69.907	€ 5.397	€ 0	€ 759	€ 221.100
			Health, hospitality	replaced by ceramic tiles	€ 1.018.618	€ 305.585	€ 421.692	€ 31.689	€ 0	€ 4.459	€ 1.750.355
			Sanitair	ceramic tiles	€ 66.500	€ 19.950	€ 33.154	€ 3.724	€ 0	€ 524	€ 120.128
			Learning centre	replaced by tiles with small thickness	€ 354.663	€ 106.399	€ 100.224	€ 8.211	€ 0	€ 1.155	€ 562.441
			Worksettings	replaced by tiles with small thickness	€ 540.627	€ 162.188	€ 269.528	€ 30.275	€ 0	€ 4.260	€ 976.603
			Drywalk entrance, EMCO three zones	replaced by tiles with small thickness	€ 120.000	€ 36.000	€ 41.754	€ 1.400	€ 0	€ 197	€ 197.951
			Other finishes to be defined control cell	replaced by tiles with small thickness	€ 902.594	€ 270.778	€ 492.916	€ 63.182	€ 0	€ 8.891	€ 1.675.179
			Cement screed or trowel finishing basement levels	NeMO zandcement	€ 192.693	€ 57.808	€ 1.164.756	€ 102.768	€ 0	€ 14.461	€ 1.429.718
			Cement screed ground floor level	Anhydriet	€ 145.323	€ 43.597	€ 118.408	€ 46.504	€ 0	€ 6.544	€ 313.871
			Computerfloor L1 till L4	aluminium+profielen staal	€ 1.718.449	€ 515.535	€ 644.638	€ 164.976	€ 274.960	-€ 15.476	€ 2.863.146
			Extra acoustic insulation	20mm gipskartonplaat + 10mm steewol	€ 112.500	€ 33.750		€ 22.500	€ 3.000	€ 2.744	€ 148.994
			Certificated materials for LEED requirements		€ 120.200	€ 36.060		€ 0	€ 0	€ 0	€ 156.260
					€ 8.133.238	€ 2.439.971	€ 4.377.205			€ 41.543	€ 14.991.956
					€ 10.573.209						
Ceiling internal and external	45	Ceiling internal and exter	Carparking and MEP B02	Wall paint	€ 215.089	€ 64.527	€ 602.725	€ 0	€ 0	€ 0	€ 882.340
			Service and Storage	Plasterboard ceiling, double grid, single panel with insulation	€ 161.053	€ 48.316	€ 60.420	€ 13.806	€ 0	€ 1.943	€ 271.732
			Circulation	Climate ceiling combined heat and cold	€ 222.675	€ 66.803	€ 104.852	€ 10.686	€ 106.860	-€ 13.533	€ 380.796
			Fitness centre	Plasterboard ceiling, double grid, single panel with insulation	€ 135.004	€ 40.501	€ 50.613	€ 4.626	€ 0	€ 651	€ 226.769
			Health, hospitality	Climate ceiling combined heat and cold	€ 679.079	€ 203.724	€ 276.065	€ 27.162	€ 271.620	-€ 34.398	€ 1.124.469
			Sanitair	Plasterboard ceiling, double grid, single panel with insulation	€ 37.240	€ 11.172	€ 13.969	€ 3.192	€ 0	€ 449	€ 62.831
			Learning centre	Climate ceiling combined heat and cold	€ 354.663	€ 106.399	€ 151.357	€ 10.638	€ 106.380	-€ 13.472	€ 598.947
			Worksettings	Climate ceiling combined heat and cold	€ 648.752	€ 194.626	€ 264.698	€ 25.950	€ 259.500	-€ 32.863	€ 1.075.213
			Roof in sight, extra ceiling for acoustics	Acoustic plasterboard ceiling	€ 399.600	€ 119.880	€ 149.897	€ 19.980	€ 0	€ 2.811	€ 672.188
			Control cel		€ 589.594	€ 176.878	€ 221.169	€ 35.376	€ 0	€ 4.978	€ 992.619
					€ 3.442.749	€ 1.032.825	€ 1.895.764			-€ 83.435	€ 6.287.903
					€ 4.475.574						
			Total		€ 100.091.470		€ 18.365.476			€ 852.290	€ 119.309.236

Graph

Pre-use phase	€ 100.091.470,40
Use phase	€ 18.365.476,31
EOL phase	€ 852.289,56
LCC	€ 119.309.236,27

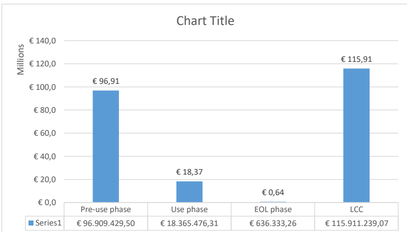


Scenario 1					Pre-use phase		Use phase	End-of-life phase			LCC			
Layer	Code	Component	Elements	Materials	Direct cost	Construction	OMR	Disposal	Residual value	EOL (PV)				
Substructure	11.3	Ground, excavations, additions			€ 2.018.903	€ 605.671		€ 0	€ 0	€ 0	€ 2.624.574	Rate	4%	
	11.4	Support works, sheet piles	Steel sheet pile AZ36 temporary	Steel	€ 900.996	€ 270.299		€ 0	€ 0	€ 0	€ 1.171.295	Years	50	
			Sheet piles ZA36 permanent near entrance building	Steel	€ 120.750	€ 36.225		€ 53	€ 63	-€ 1	€ 156.974			
			Groutankers	Steel anchors	€ 340.448	€ 102.134		€ 0	€ 0	€ 0	€ 442.582			
			Stalen purlins (ringgordingen)	Steel	€ 103.488	€ 31.046		€ 0	€ 0	€ 0	€ 134.534			
			Extra cost second groutanker line because of waterpressure	steel	€ 45.000	€ 13.500		€ 0	€ 0	€ 0	€ 58.500			
			Jetgrouten	Concrete	€ 181.748	€ 54.524		€ 92.400	€ 15.840	€ 10.773	€ 247.045			
			Soft gel injectie	gel	€ 1.621.996	€ 486.599		€ 0	€ 0	€ 0	€ 2.108.595			
			Temporary propping		€ 58.500	€ 17.550		€ 0	€ 0	€ 0	€ 76.050			
			Separate pit for the tunnels		€ 240.000	€ 72.000		€ 0	€ 0	€ 0	€ 312.000			
												Concrete	175	30
	11.5	Dewatering (drainage)	Dewatering (drainage)		€ 158.240	€ 47.472		€ 0	€ 0	€ 0	€ 205.712	Sand	8	13
	13	Floor bed (On ground)	Concrete floor bed on sand	Concrete	€ 3.497.008	€ 1.049.102		€ 1.331.750	€ 228.300	€ 155.269	€ 4.701.380	Steel	0,08	0,1
	16	Basement	foundation footing strips, pads etc		€ 274.744	€ 82.423		€ 1.337.000	€ 229.200	€ 155.881	€ 513.049			
	17	Deep foundation (pile foundations)	Pile foundations, anchor block Gewi 63,5mm 25m1	tiranti	€ 1.500.000	€ 450.000		€ 180.000	€ 26.166	€ 21.646	€ 1.971.646			
			Fundex combination GI 460/560 with grout injection	piles	€ 1.469.487	€ 440.846		€ 245.000	€ 16.800	€ 32.111	€ 1.942.444			
					€ 12.531.308	€ 3.759.392				€ 375.679	€ 16.666.380			
					€ 16.290.700									
Super structure	21	External walls (structure, load bearing)	External walls basement	Concrete	€ 691.114	€ 207.334		€ 176.400	€ 30.240	€ 20.567	€ 919.015			
	22	Inner walls (structure, load bearing)	Cores and other elements	Concrete	€ 776.086	€ 232.826		€ 271.635	€ 46.566	€ 31.670	€ 1.040.582			
	23	Floors (structure, load bearing)	Floorslab 350mm dik, 100 kg reinforcement	Concrete	€ 3.537.722	€ 1.061.317		€ 1.238.230	€ 212.268	€ 144.366	€ 4.743.404			
			Concrete floorslab 400mm	Concrete	€ 1.407.869	€ 422.361		€ 505.400	€ 86.640	€ 58.925	€ 1.889.155			
			Concrete floor 600 mm PT	Concrete	€ 418.751	€ 125.625		€ 151.620	€ 25.992	€ 17.677	€ 562.054			
			Atrium boundary in flued form included edge beam	Not based on material	€ 112.000	€ 33.600		€ 0	€ 0	€ 0	€ 145.600			
			HEM beams	Steel	€ 583.200	€ 174.960		€ 19.440	€ 23.328	-€ 547	€ 757.613			
	27	Roofs (structure, load bearing)	Roof basement	Concrete	€ 329.625	€ 98.888		€ 102.550	€ 17.580	€ 11.956	€ 440.469			
			Roof level 2	Concrete	€ 113.925	€ 34.178		€ 39.874	€ 6.836	€ 4.649	€ 152.751			
			Top roof closed surface	Concrete	€ 495.010	€ 148.503		€ 66.000	€ 0	€ 9.287	€ 652.800			
	28	Building frame constructions (other primary elements)	Concrete structure basement	Concrete	€ 959.386	€ 287.816		€ 110.614	€ 18.962	€ 12.897	€ 1.260.098			
			Steel structure	Steel	€ 1.500.201	€ 450.060		€ 19.665	€ 24.582	-€ 692	€ 1.949.570			
			Wood structure	Wood	€ 4.415.250	€ 1.324.575		€ 147.175	€ 588.700	-€ 62.128	€ 5.677.697			
			Extra		€ 682.000			€ 0	€ 0	€ 0	€ 682.000			
					€ 16.022.139	€ 4.602.042				€ 248.626	€ 20.872.807			
					€ 20.624.181									
Roof and finishing	27	Roof completion	Special timberwork on the roof		€ 243.723	€ 73.117	€ 323.769	€ 21.664	€ 0	€ 3.048	€ 643.657			
			Arround lower roofs		€ 67.500	€ 20.250	€ 33.206	€ 1.350	€ 0	€ 190	€ 121.146			
			Bottom, insulation, epdm, detail transition to facade		€ 147.000	€ 44.100	€ 8.132	€ 1.500	€ 0	€ 211	€ 199.443			
			Bottom, insulation, epdm, detail transition to facade		€ 60.120	€ 18.036	€ 4.879	€ 900	€ 0	€ 127	€ 83.162			
	37	Roof openings	Glass transparant roof modules	dakraam meranti	€ 3.286.904	€ 986.071	€ 1.072.002	€ 30.720	€ 25.600	€ 720	€ 5.345.697			
			Glare control above workspace	Solidscreen	€ 68.795	€ 20.639	€ 142.872	€ 1.032	€ 0	€ 145	€ 232.450			
			Roof snappers in the back garden for B1	Aluminium, geanodiseerd	€ 48.600	€ 14.580	€ 390.913	€ 81	€ 24.300	-€ 3.408	€ 450.685			
			Glass elements in the roof above the new connection to C05 and C16		€ 20.000	€ 6.000	€ 49.492	€ 240	€ 200	€ 6	€ 75.497			
			Access to the roof		€ 8.000	€ 2.400	€ 15.527	€ 12	€ 120	-€ 15	€ 25.912			
	47	Roof finishing (covering)	High reflective covering	app dakbedekking	€ 649.928	€ 194.978	€ 0	€ 81.240	€ 0	€ 11.431	€ 856.338			
			Paths and safety lines		€ 135.402	€ 40.621	€ 1.124.109	€ 10.832	€ 0	€ 1.524	€ 1.301.656			
			Special structure toproof elements	aluminium	€ 883.050	€ 264.915	€ 270.247	€ 17.661	€ 41.209	-€ 3.314	€ 1.414.899			
			Terras South West and North, and green areas	street bricks	€ 309.200	€ 92.760	€ 135.254	€ 15.460	€ 0	€ 2.175	€ 539.390			
			Balustrade roofs glass, top roof, terraces and fitness terrace	Staal; gepoedercoat; glasplaat vulling	€ 562.500	€ 168.750	€ 34.429	€ 9.000	€ 7.500	€ 211	€ 765.890			
			Certificated materials for LEED requirements		€ 130.800		€ 0	€ 0	€ 0	€ 0	€ 130.800			
					€ 6.621.522	€ 1.947.217	€ 3.604.831			€ 13.053	€ 12.186.623			
					€ 8.568.739									
Facade and finishing	31	External wall openings (doors and windows)	Entrance to basement	aluminuim Triple glass; glazed dry	€ 50.000	€ 15.000	€ 12.460	€ 300	€ 250	€ 7	€ 77.467			
			Entrance to loading bay	Triple glass; glazed dry	€ 178.200	€ 53.460	€ 43.409	€ 972	€ 810	€ 23	€ 275.092			
			Structural glazing	Triple glass; glazed dry	€ 2.110.406	€ 633.122	€ 570.619	€ 20.256	€ 16.880	€ 475	€ 3.314.622			
			Elements tripple glass en closed parts	Triple glass; glazed dry	€ 5.999.250	€ 1.799.775	€ 1.740.146	€ 75.780	€ 63.150	€ 1.777	€ 9.540.948			
			Windows	Triple glass; glazed dry	€ 486.560	€ 145.968	€ 164.354	€ 9.732	€ 8.110	€ 228	€ 797.111			
			Emergency exits	VMRG doors +add glass panes	€ 75.000	€ 22.500	€ 16.787	€ 180	€ 150	€ 4	€ 114.291			
			Entrance CN-EN 2.1	No Material	€ 350.000	€ 105.000	€ 72.979	€ 800	€ 0	€ 113	€ 528.091			
			Entrance EJ - 01	No Material	€ 250.000	€ 75.000	€ 52.150	€ 800	€ 0	€ 113	€ 377.263			
	41	Façade finishing (claddings)	Scaffolding		€ 288.460	€ 86.538	€ 0	€ 0	€ 0	€ 0	€ 374.998			
			Sun screening	Solidscreen	€ 519.229	€ 155.769	€ 899.785	€ 8.901	€ 0	€ 1.252	€ 1.576.035			
			Finishing inner surface of closed facade basement	Spray plaster	€ 115.186	€ 34.556	€ 633.809	€ 0	€ 0	€ 0	€ 783.550			
			Steel ceramic sun shading		€ 213.444	€ 64.033	€ 44.438	€ 2.510	€ 1.757	€ 106	€ 322.022			
			Sun shading horizontal		€ 190.800	€ 57.240	€ 151.523	€ 3.180	€ 2.226	€ 134	€ 399.698			
			Curved lines roof level		€ 171.000	€ 51.300	€ 68.894	€ 11.400	€ 0	€ 1.604	€ 292.798			
			Pier Brick elements external		€ 1.019.990	€ 305.997	€ 505.866	€ 75.000	€ 45.000	€ 4.221	€ 1.836.075			
			Pier Brick elements on the inside		€ 640.000	€ 192.000	€ 165.927	€ 50.000	€ 30.000	€ 2.814	€ 1.000.742			
			Closed elements in the elments on floor levels	Aluminium vlak (sandwich-aluminium kern)	€ 170.000	€ 51.000	€ 0	€ 6.800	€ 0	€ 957	€ 221.957			
			Demonstration showcase related to Showroom on level 0 grid line 1, 14		€ 142.800	€ 42.840	€ 2.641	€ 0	€ 0	€ 0	€ 188.281			
			Canopy main entrance	steel	€ 300.000	€ 90.000	€ 8.537	€ 1.000	€ 1.200	-€ 28	€ 398.508			
			Glare control all glass elements	internal sunshading	€ 516.000	€ 154.800	€ 0	€ 10.750	€ 0	€ 1.513	€ 672.313			
			Other		€ 549.448	€ 164.834	€ 0	€ 0	€ 0	€ 0	€ 714.282			
			Certificated materials for LEED requirements		€ 216.800		€ 0	€ 0	€ 0	€ 0	€ 216.800			
					€ 14.552.573	€ 4.300.732	€ 5.154.325			€ 15.313	€ 24.022.943			
					€ 18.853.305									
Internal walls and finishing	22	Internal walls	Acoustic MS double, MS2	Glaswol MWA+Gipskartonplaat	€ 362.174	€ 108.652	€ 133.653	€ 38.805	€ 5.174	€ 4.732	€ 609.211			
			Brandwerend MS double, MS1	Glaswol MWA+Gipskartonplaat	€ 465.652	€ 139.696	€ 184.290	€ 58.200	€ 7.760	€ 7.098	€ 796.735			
			Normal walls MS single, MS3	Glaswol MWA+Gipskartonplaat	€ 646.738	€ 194.021	€ 280.226	€ 97.005	€ 12.934	€ 11.830	€ 1.132.816			
	32	Internal wall openings (doors and windows)	Acoustic elements	Glaswol MWA	€ 698.477	€ 209.543	€ 24.639	€ 11.640	€ 4.656	€ 983	€ 933.642			
			Fire protected	Steel structure inner wall with doors and glass opening	€ 931.303	€ 279.391	€ 19.718	€ 9.315	€ 3.726	€ 786	€ 1.231.198			
			Normal elements	Steel	€ 1.047.716	€ 314.315	€ 43.751	€ 34.920	€ 13.968	€ 2.948	€ 1.408.730			
			Special (high) elements	Steel	€ 1.455.161	€ 436.548	€ 28.784	€ 17.460	€ 6.984	€ 1.474	€ 1.921.967			
			Flexibel walls	Steel	€ 300.000	€ 90.000	€ 7.939	€ 5.000	€ 0	€ 704	€ 398.643			
			Doors, included hinges and locks	Hout; geschilderd: alkyd	€ 493.000	€ 147.900	€ 29.796	€ 0	€ 0	€ 0	€ 670.696			
			GLASS - INTERIOR WALL PANEL FI-03	Staal frame element; glas pan	€ 1.187.640	€ 356.292	€ 247.354	€ 39.585	€ 15.834	€ 3.342	€ 1.794.628			
			MIRROR - INTERIOR PANEL FI-06	Staal frame element; glas pan	€ 28.000	€ 8.400	€ 5.832	€ 600	€ 240	€ 51	€ 42.283			
			GLASS PANEL BENT - WOOD INTERLAYER FI-09	Houten frame, eknel glas	€ 37.500	€ 11.250	€ 7.811	€ 225	€ 90	€ 19	€ 56.580			
			other elements		€ 141.855	€ 42.557	€ 29.494	€ 2.655	€ 1.062	€ 224	€ 214.129			
	42	Internal wall finishing	Wall finishing assumption	Spray plaster	€ 43.860	€ 13.158	€ 80.308	€ 0	€ 0	€ 0	€ 137.326			
			Wall finishing assumption	Spray plaster	€ 213.424	€ 64.027	€ 213.128	€ 0	€ 0	€ 0	€ 490.580			
			Wall finishing assumption	Spray plaster	€ 905.434	€ 271.630	€ 497.336	€ 0	€ 0	€ 0	€ 1.674.400			
			Wall finishing assumption	Spray plaster	€ 248.710	€ 74.613	€ 160.725	€ 0	€ 0	€ 0	€ 484.048			
			Wall finishing assumption	Spray plaster	€ 1.920.813	€ 576.244	€ 468.937	€ 0	€ 0	€ 0	€ 2.965.994			
			Based on material schedule (GYPSUM WALL BOARD - INTERIOR L4 FI-01)	Gipspleister	€ 26.364	€ 7.909	€ 36.199	€ 0	€ 0	€ 0	€ 70.472			
			Based on material schedule (GYPSUM WALL BOARD - INTERIOR L5 FI-02)	Gipspleister	€ 44.950	€ 13.485	€ 49.382	€ 0	€ 0	€ 0	€ 107.817			
			Based on material schedule (GLASS PANEL BENT - WOOD INTERLAYER FI-09)	wooden frame, single glass	€ 3.750	€ 1.125	€ 1.478	€ 0	€ 315	-€ 44	€ 6.309			
			Based on material schedule (BATHROOM WALL TILE FI-12)	Glazed ceramic tiles	€ 15.130	€ 4.539	€ 7.400	€ 0	€ 0	€ 0	€ 27.069			
			Based on material schedule (WOOD WALL PANELS FI-14)	wooden wall	€ 439.565	€ 131.870	€ 231.377	€ 0	€ 52.752	-€ 7.423	€ 795.389			

			Based on material schedule (ACOUSTIC WALLS FI-15)	Acoustic cellulose spray plaste	€ 89.100	€ 26.730	€ 21.752	€ 0	€ 8.316	-€ 1.170	€ 136.412
			Based on material schedule (PAINTED CONCRETE FI-21)	Wall paint	€ 60.720	€ 18.216	€ 108.275	€ 0	€ 0	€ 0	€ 187.211
			Finishing with colored paint (concrete columns basement)	Paint	€ 87.150	€ 26.145	€ 44.401	€ 0	€ 0	€ 0	€ 157.696
			Finishing fire protected and esthetic (columns GF - top floor)	Paint	€ 264.000	€ 79.200	€ 273.101	€ 0	€ 0	€ 0	€ 616.301
			Finishing with fire protected paint (columns in atrium special curved)	Paint	€ 900.000	€ 270.000	€ 46.610	€ 0	€ 0	€ 0	€ 1.216.610
			Finishing with fire protected paint (columns atrium special)	Paint	€ 200.000	€ 60.000	€ 49.655	€ 0	€ 0	€ 0	€ 309.655
			Insulation walls in loading dock	Rock wool	€ 30.100	€ 9.030	€ 0	€ 0	€ 0	€ 0	€ 39.130
			Certificated materials for LEED requirements		€ 191.500	€ 57.450	€ 0	€ 0	€ 0	€ 0	€ 248.950
					€ 13.479.786	€ 4.043.936	€ 3.333.352			€ 25.553	€ 20.882.627
					€ 17.523.722						
Internal floor and finishing	23	Floor items (non-load bearing, balconies, arcade, suspended)	Special elements		€ 150.000	€ 45.000	€ 0	€ 0	€ 0	€ 0	€ 195.000
			Atrium stair elements GFL > L01	Wooden floor element	€ 290.000	€ 87.000	€ 0	€ 5.800	€ 0	€ 816	€ 377.816
	33	Voids	Temporary floors during construction		€ 622.871	€ 186.861	€ 0	€ 0	€ 0	€ 0	€ 809.732
			Panelized skin boarders		€ 250.000	€ 75.000	€ 0	€ 5.000	€ 0	€ 704	€ 325.704
			Railing along the edges, curved glass	glass + steel	€ 720.000	€ 216.000	€ 0	€ 7.200	€ 4.200	€ 422	€ 936.422
	43	Floor finishes	Bicycle and Carparking		€ 358.482	€ 107.545	€ 650.109	€ 50.190	€ 0	€ 7.062	€ 1.123.198
			Service and Storage		€ 138.046	€ 41.414	€ 208.633	€ 16.107	€ 0	€ 2.266	€ 390.360
			Circulation	Anhydriet	€ 195.954	€ 58.786	€ 161.485	€ 12.467	€ 0	€ 1.754	€ 417.979
			Fitness centre	Anhydriet+polystyreen	€ 115.718	€ 34.715	€ 69.907	€ 5.397	€ 0	€ 759	€ 221.100
			Health, hospitality	replaced by ceramic tiles	€ 1.018.618	€ 305.585	€ 421.692	€ 31.689	€ 0	€ 4.459	€ 1.750.355
			Sanitair	ceramic tiles	€ 66.500	€ 19.950	€ 33.154	€ 3.724	€ 0	€ 524	€ 120.128
			Learning centre	replaced by tiles with small thickness	€ 354.663	€ 106.399	€ 100.224	€ 8.211	€ 0	€ 1.155	€ 562.441
			Worksettings	replaced by tiles with small thickness	€ 540.627	€ 162.188	€ 269.528	€ 30.275	€ 0	€ 4.260	€ 976.603
			Drywalk entrance, EMCO three zones	replaced by tiles with small thickness	€ 120.000	€ 36.000	€ 41.754	€ 1.400	€ 0	€ 197	€ 197.951
			Other finishes to be defined control cell	replaced by tiles with small thickness	€ 902.594	€ 270.778	€ 492.916	€ 63.182	€ 0	€ 8.891	€ 1.675.179
			Cement screed or trowel finishing basement levels	NeMO zandcement	€ 192.693	€ 57.808	€ 1.164.756	€ 102.768	€ 0	€ 14.461	€ 1.429.718
			Cement screed ground floor level	Anhydriet	€ 145.323	€ 43.597	€ 118.408	€ 46.504	€ 0	€ 6.544	€ 313.871
			Computerfloor L1 till L4	aluminium+profielen staal	€ 1.718.449	€ 515.535	€ 644.638	€ 164.976	€ 274.960	-€ 15.476	€ 2.863.146
			Extra acoustic insulation	20mm gipskartonplaat + 10mm steewol	€ 112.500	€ 33.750	€ 0	€ 22.500	€ 3.000	€ 2.744	€ 148.994
			Certificated materials for LEED requirements		€ 120.200	€ 36.060	€ 0	€ 0	€ 0	€ 0	€ 156.260
					€ 8.133.238	€ 2.439.971	€ 4.377.205			€ 41.543	€ 14.991.956
					€ 10.573.209						
Ceiling internal and external	45	Ceiling internal and external	Carparking and MEP B02	Wall paint	€ 215.089	€ 64.527	€ 602.725	€ 0	€ 0	€ 0	€ 882.340
			Service and Storage	Plasterboard ceiling, double grid, single panel with insulation	€ 161.053	€ 48.316	€ 60.420	€ 13.806	€ 0	€ 1.943	€ 271.732
			Circulation	Climate ceiling combined heat and cold	€ 222.675	€ 66.803	€ 104.852	€ 10.686	€ 106.860	-€ 13.533	€ 380.796
			Fitness centre	Plasterboard ceiling, double grid, single panel with insulation	€ 135.004	€ 40.501	€ 50.613	€ 4.626	€ 0	€ 651	€ 226.769
			Health, hospitality	Climate ceiling combined heat and cold	€ 679.079	€ 203.724	€ 276.065	€ 27.162	€ 271.620	-€ 34.398	€ 1.124.469
			Sanitair	Plasterboard ceiling, double grid, single panel with insulation	€ 37.240	€ 11.172	€ 13.969	€ 3.192	€ 0	€ 449	€ 62.831
			Learning centre	Climate ceiling combined heat and cold	€ 354.663	€ 106.399	€ 151.357	€ 10.638	€ 106.380	-€ 13.472	€ 598.947
			Worksettings	Climate ceiling combined heat and cold	€ 648.752	€ 194.626	€ 264.698	€ 25.950	€ 259.500	-€ 32.863	€ 1.075.213
			Roof in sight, extra ceiling for acoustics	Acoustic plasterboard ceiling	€ 399.600	€ 119.880	€ 149.897	€ 19.980	€ 0	€ 2.811	€ 672.188
			Control cel		€ 589.594	€ 176.878	€ 221.169	€ 35.376	€ 0	€ 4.978	€ 992.619
					€ 3.442.749	€ 1.032.825	€ 1.895.764			-€ 83.435	€ 6.287.903
					€ 4.475.574						
			Total		€ 96.909.430		€ 18.365.476			€ 636.333	€ 115.911.239

Graph

Pre-use phase	€ 96.909.429,50
Use phase	€ 18.365.476,31
EOL phase	€ 636.333,26
LCC	€ 115.911.239,07

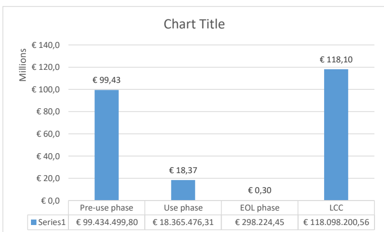


Scenario 2						Pre-use phase	Use phase		End-of-life phase		LCC			
Layer	Code	Component	Elements	Materials	Direct cost	Construction	OMR	Disposal	Residual value	EOL (PV)				
Substructure	11.3	Ground, excavations, additions			€ 2.018.903	€ 605.671		€ 0	€ 0	€ 0	€ 2.624.574			
	11.4	Support works, sheet piles	Steel sheet pile AZ36 temporary	Steel	€ 900.996	€ 270.299		€ 0	€ 0	€ 0	€ 1.171.295	Rate	4%	
			Sheet piles ZA36 permanent near entrance building	Steel	€ 120.750	€ 36.225		€ 53	€ 63	-€ 1	€ 156.974	Year	50	
			Groutankers	Steel anchors	€ 340.448	€ 102.134		€ 0	€ 0	€ 0	€ 442.582		disposal	residual
			Stalen purlins (ringgordingen)	Steel	€ 103.488	€ 31.046		€ 0	€ 0	€ 0	€ 134.534			
			Extra cost second groutanker line because of waterpressure	steel	€ 45.000	€ 13.500		€ 0	€ 0	€ 0	€ 58.500			
			Jetgrouten	Concrete	€ 181.748	€ 54.524		€ 92.400	€ 15.840	€ 10.773	€ 247.045			
			Soft gel injectie	gel	€ 1.621.996	€ 486.599		€ 0	€ 0	€ 0	€ 2.108.595			
			Temporary propping		€ 58.500	€ 17.550		€ 0	€ 0	€ 0	€ 76.050			
			Separate pit for the tunnels		€ 240.000	€ 72.000		€ 0	€ 0	€ 0	€ 312.000			
												Concrete	175	30
	11.5	Dewatering (drainage)	Dewatering (drainage)		€ 158.240	€ 47.472		€ 0	€ 0	€ 0	€ 205.712	Sand	8	13
	13	Floor bed (On ground)	Concrete floor bed on sand	Concrete	€ 3.497.008	€ 1.049.102		€ 1.331.750	€ 228.300	€ 155.269	€ 4.701.380	Steel	0,08	0,1
	16	Basement	foundation footing strips, pads etc		€ 274.744	€ 82.423		€ 1.337.000	€ 229.200	€ 155.881	€ 513.049			
	17	Deep foundation (pile foundations)	Pile foundations, anchor block Gewi 63,5mm 25m1	tiranti	€ 1.500.000	€ 450.000		€ 180.000	€ 26.166	€ 21.646	€ 1.971.646			
			Fundex combination GI 460/560 with grout injection	piles	€ 1.469.487	€ 440.846		€ 245.000	€ 16.800	€ 32.111	€ 1.942.444			
					€ 12.531.308	€ 3.759.392				€ 375.679	€ 16.666.380			
					€ 16.290.700									
Super structure	21	External walls (structure, load bearing)	External walls basement	Concrete	€ 691.114	€ 207.334		€ 176.400	€ 30.240	€ 20.567	€ 919.015			
	22	Inner walls (structure, load bearing)	Cores and other elements	Concrete	€ 776.086	€ 232.826		€ 271.635	€ 46.566	€ 31.670	€ 1.040.582			
	23	Floors (structure, load bearing)	Floorslab 350mm dik, 100 kg reinforcement	B01	€ 603	€ 181				€ 0	€ 784			
			Concrete floorslab 400mm	Ground floor	€ 1.259.310	€ 377.793		€ 452.060	€ 77.496	€ 52.706	€ 1.689.809			
			Concrete floor 600 mm PT		€ 1.789.880	€ 536.964		€ 29.626	€ 48.142	-€ 2.605	€ 2.324.239			
			Total timber floors							€ 0	€ 0			
			320mm stressed skin floor panel	Mezzanine	€ 441.250	€ 132.375		€ 52.950	€ 105.900	-€ 7.451	€ 566.174			
			320mm stressed skin floor panel	Level 1	€ 1.185.000	€ 355.500		€ 142.200	€ 284.400	-€ 20.009	€ 1.520.491			
			320mm stressed skin floor panel	Level 2	€ 1.074.250	€ 322.275		€ 128.910	€ 257.820	-€ 18.139	€ 1.378.386			
			320mm stressed skin floor panel	Level 2 entrance	€ 40.500	€ 12.150		€ 9.000	€ 18.000	-€ 1.266	€ 51.384			
			320mm stressed skin floor panel	Level 3	€ 875.750	€ 262.725		€ 105.090	€ 210.180	-€ 14.787	€ 1.123.688			
			320mm stressed skin floor panel	Level 4	€ 707.000	€ 212.100		€ 84.840	€ 169.680	-€ 11.938	€ 907.162			
			Atrium boundaries in fluid form included edge beam		€ 115.800	€ 34.740		€ 17.370	€ 34.740	-€ 2.444	€ 148.096			
			extra mass up to 250kg		€ 360.240	€ 108.072		€ 540.360	€ 1.080.720	-€ 76.035	€ 392.277			
			Outdoor terrace as a cantilever		€ 148.750	€ 44.625		€ 12.750	€ 25.500	-€ 1.794	€ 191.581			
	27	Roofs (structure, load bearing)	Roof basement	Concrete	€ 270.900	€ 81.270		€ 102.550	€ 17.580	€ 11.956	€ 364.126			
			Roof level 2	Timber	€ 109.550	€ 32.865		€ 18.780	€ 18.780	€ 0	€ 142.415			
			Top roof closed surface	Timber	€ 511.650	€ 153.495		€ 102.330	€ 102.330	€ 0	€ 665.145			
	28	Building frame constructions (other primary elements)	Concrete structure basement	Concrete	€ 959.386	€ 287.816		€ 110.614	€ 18.962	€ 12.897	€ 1.260.098			
			Steel structure	Steel	€ 1.500.201	€ 450.060		€ 19.665	€ 24.582	-€ 692	€ 1.949.570			
			Wood structure	Wood	€ 4.415.250	€ 1.324.575		€ 147.175	€ 588.700	-€ 62.128	€ 5.677.697			
			Extra		€ 682.000			€ 0	€ 0	€ 0	€ 682.000			
					€ 17.914.470	€ 5.169.741				-€ 89.495	€ 22.994.716			
					€ 23.084.211									
Roof and finishing	27	Roof completion	Special timberwork on the roof		€ 243.723	€ 73.117	€ 323.769	€ 21.664	€ 0	€ 3.048	€ 643.657			
			Arround lower roofs		€ 67.500	€ 20.250	€ 33.206	€ 1.350	€ 0	€ 190	€ 121.146			
			Bottom, insulation, epdm, detail transition to facade		€ 147.000	€ 44.100	€ 8.132	€ 1.500	€ 0	€ 211	€ 199.443			
			Bottom, insulation, epdm, detail transition to facade		€ 60.120	€ 18.036	€ 4.879	€ 900	€ 0	€ 127	€ 83.162			
	37	Roof openings	Glass transparant roof modules	dakraam meranti	€ 3.286.904	€ 986.071	€ 1.072.002	€ 30.720	€ 25.600	€ 720	€ 5.345.697			
			Glare control above workspace	Solidscreen	€ 68.795	€ 20.639	€ 142.872	€ 1.032	€ 0	€ 145	€ 232.450			
			Roof snappers in the back garden for B1	Aluminium, geanodiseerd	€ 48.600	€ 14.580	€ 390.913	€ 81	€ 24.300	-€ 3.408	€ 450.685			
			Glass elements in the roof above the new connection to C05 and C16		€ 20.000	€ 6.000	€ 49.492	€ 240	€ 200	€ 6	€ 75.497			
			Access to the roof		€ 8.000	€ 2.400	€ 15.527	€ 12	€ 120	-€ 15	€ 25.912			
	47	Roof finishing (covering)	High reflective covering	app dakbedekking	€ 649.928	€ 194.978	€ 0	€ 81.240	€ 0	€ 11.431	€ 856.338			
			Paths and safety lines		€ 135.402	€ 40.621	€ 1.124.109	€ 10.832	€ 0	€ 1.524	€ 1.301.656			
			Special structure toproof elements	aluminium	€ 883.050	€ 264.915	€ 270.247	€ 17.661	€ 41.209	-€ 3.314	€ 1.414.899			
			Terras South West and North, and green areas	street bricks	€ 309.200	€ 92.760	€ 135.254	€ 15.460	€ 0	€ 2.175	€ 539.390			
			Balustrade roofs glass, top roof, terraces and fitness terrace	Staal; gepoedercoat; glasplaat vulling	€ 562.500	€ 168.750	€ 34.429	€ 9.000	€ 7.500	€ 211	€ 765.890			
			Certificated materials for LEED requirements		€ 130.800		€ 0	€ 0	€ 0	€ 0	€ 130.800			
					€ 6.621.522	€ 1.947.217	€ 3.604.831			€ 13.053	€ 12.186.623			
					€ 8.568.739									
Facade and finishing	31	External wall openings (doors and windows)	Entrance to basement	aluminuim Triple glass; glazed dry	€ 50.000	€ 15.000	€ 12.460	€ 300	€ 250	€ 7	€ 77.467			
			Entrance to loading bay	Triple glass; glazed dry	€ 178.200	€ 53.460	€ 43.409	€ 972	€ 810	€ 23	€ 275.092			
			Structural glazing	Triple glass; glazed dry	€ 2.110.406	€ 633.122	€ 570.619	€ 20.256	€ 16.880	€ 475	€ 3.314.622			
			Elements tripple glass en closed parts	Triple glass; glazed dry	€ 5.999.250	€ 1.799.775	€ 1.740.146	€ 75.780	€ 63.150	€ 1.777	€ 9.540.948			
			Windows	Triple glass; glazed dry	€ 486.560	€ 145.968	€ 164.354	€ 9.732	€ 8.110	€ 228	€ 797.111			
			Emergency exits	VMRG doors +add glass panes	€ 75.000	€ 22.500	€ 16.787	€ 180	€ 150	€ 4	€ 114.291			
			Entrance CN-EN 2.1	No Material	€ 350.000	€ 105.000	€ 72.979	€ 800	€ 0	€ 113	€ 528.091			
			Entrance EJ - 01	No Material	€ 250.000	€ 75.000	€ 52.150	€ 800	€ 0	€ 113	€ 377.263			
	41	Facade finishing (claddings)	Scaffolding		€ 288.460	€ 86.538	€ 0	€ 0	€ 0	€ 0	€ 374.998			
			Sun screening	Solidscreen	€ 519.229	€ 155.769	€ 899.785	€ 8.901	€ 0	€ 1.252	€ 1.576.035			
			Finishing inner surface of closed facade basement	Spray plaster	€ 115.186	€ 34.556	€ 633.809	€ 0	€ 0	€ 0	€ 783.550			
			Steel ceramic sun shading		€ 213.444	€ 64.033	€ 44.438	€ 2.510	€ 1.757	€ 106	€ 322.022			
			Sun shading horizontal		€ 190.800	€ 57.240	€ 151.523	€ 3.180	€ 2.226	€ 134	€ 399.698			
			Curved lines roof level		€ 171.000	€ 51.300	€ 68.894	€ 11.400	€ 0	€ 1.604	€ 292.798			
			Pier Brick elements external		€ 1.019.990	€ 305.997	€ 505.866	€ 75.000	€ 45.000	€ 4.221	€ 1.836.075			
			Pier Brick elements on the inside		€ 640.000	€ 192.000	€ 165.927	€ 50.000	€ 30.000	€ 2.814	€ 1.000.742			
			Closed elements in the elements on floor levels	Aluminium vlak (sandwich-aluminium kern)	€ 170.000	€ 51.000	€ 0	€ 6.800	€ 0	€ 957	€ 221.957			
			Demonstration showcase related to Showroom on level 0 grid line 1, 14		€ 142.800	€ 42.840	€ 2.641	€ 0	€ 0	€ 0	€ 188.281			
			Canopy main entrance	steel	€ 300.000	€ 90.000	€ 8.537	€ 1.000	€ 1.200	-€ 28	€ 398.508			
			Glare control all glass elements	internal sunshading	€ 516.000	€ 154.800	€ 0	€ 10.750	€ 0	€ 1.513	€ 672.313			
			Other		€ 549.448	€ 164.834	€ 0	€ 0	€ 0	€ 0	€ 714.282			
			Certificated materials for LEED requirements		€ 216.800	€ 65.040	€ 0	€ 0	€ 0	€ 0	€ 281.840			
					€ 14.552.573	€ 4.365.772	€ 5.154.325			€ 15.313	€ 24.087.983			
					€ 18.918.345									
Internal walls and finishing	22	Internal walls	Acoustic MS double, MS2	MWA+Gipskartonplaat systeemwand	€ 362.174	€ 108.652	€ 133.653	€ 38.805	€ 5.174	€ 4.732	€ 609.211			
			Brandwerend MS double, MS1	Glaswol MWA+Gipskartonplaat	€ 465.652	€ 139.696	€ 184.290	€ 58.200	€ 7.760	€ 7.098	€ 796.735			
			Normal walls MS single, MS3	MWA+Gipskartonplaat systeemwand	€ 646.738	€ 194.021	€ 280.226	€ 97.005	€ 12.934	€ 11.830	€ 1.132.816			
	32	Internal wall openings (doors and windows)	Acoustic elements	Glaswol MWA	€ 698.477	€ 209.543	€ 24.639	€ 11.640	€ 4.656	€ 983	€ 933.642			
			Fire protected	Steel structure inner wall with doors and glass	€ 931.303	€ 279.391	€ 19.718	€ 9.315	€ 3.726	€ 786	€ 1.231.198			
			Normal elements	Steel	€ 1.047.716	€ 314.315	€ 43.751	€ 34.920	€ 13.968	€ 2.948	€ 1.408.730			
			Special (high) elements	Steel	€ 1.455.161	€ 436.548	€ 28.784	€ 17.460	€ 6.984	€ 1.474	€ 1.921.967			
			Flexibel walls	Steel	€ 300.000	€ 90.000	€ 7.939	€ 5.000	€ 0	€ 704	€ 398.643			
			Doors, included hinges and locks	Hout; geschilderd: alkyd	€ 493.000	€ 147.900	€ 29.796	€ 0	€ 0	€ 0	€ 670.696			
			GLASS - INTERIOR WALL PANEL FI-03	Staal frame element; glas par	€ 1.187.640	€ 356.292	€ 247.354	€ 39.585	€ 15.834	€ 3.342	€ 1.794.628			
			MIRROR - INTERIOR PANEL FI-06	Staal frame element; glas par	€ 28.000	€ 8.400	€ 5.832	€ 600	€ 240	€ 51	€ 42.283			
			GLASS PANEL BENT - WOOD INTERLAYER FI-09	Houten frame, eknel glas	€ 37.500	€ 11.250	€ 7.811	€ 225	€ 0	€ 32	€ 56.592			
			other elements		€ 141.855	€ 42.557	€ 29.494	€ 2.655	€ 1.062	€ 224	€ 214.129			
	42	Internal wall finishing	Wall finishing assumption	Spray plaster	€ 43.860	€ 13.158	€ 80.308	€ 0	€ 0	€ 0	€ 137.326			
			Wall finishing assumption	Spray plaster	€ 213.424	€ 64.027	€ 213.128	€ 0	€ 0	€ 0	€ 490.580			
			Wall finishing assumption	Spray plaster	€ 905.434	€ 271.630	€ 497.336	€ 0	€ 0	€ 0	€ 1.674.400			

			Wall finishing assumption	Spray plaster	€ 248.710	€ 74.613	€ 160.725	€ 0	€ 0	€ 0	€ 484.048
			Wall finishing assumption	Spray plaster	€ 1.920.813	€ 576.244	€ 468.937	€ 0	€ 0	€ 0	€ 2.965.994
			Based on material schedule (GYPSUM WALL BOARD - INTERIOR L4 FI-01)	Gipspleister	€ 26.364	€ 7.909	€ 36.199	€ 0	€ 0	€ 0	€ 70.472
			Based on material schedule (GYPSUM WALL BOARD - INTERIOR L5 FI-02)	Gipspleister	€ 44.950	€ 13.485	€ 49.382	€ 0	€ 0	€ 0	€ 107.817
			Based on material schedule (GLASS PANEL BENT - WOOD INTERLAYER FI-09)	wooden frame, single glass	€ 3.750	€ 1.125	€ 1.478	€ 0	€ 315	-€ 44	€ 6.309
			Based on material schedule (BATHROOM WALL TILE FI-12)	Glazed ceramic tiles	€ 15.130	€ 4.539	€ 7.400	€ 0	€ 0	€ 0	€ 27.069
			Based on material schedule (WOOD WALL PANELS FI-14)	wooden wall	€ 439.565	€ 131.870	€ 231.377	€ 0	€ 52.752	-€ 7.423	€ 795.389
			Based on material schedule (ACOUSTIC WALLS FI-15)	Acoustic cellulose spray plast	€ 89.100	€ 26.730	€ 21.752	€ 0	€ 8.316	-€ 1.170	€ 136.412
			Based on material schedule (PAINTED CONCRETE FI-21)	Wall paint	€ 60.720	€ 18.216	€ 108.275	€ 0	€ 0	€ 0	€ 187.211
			Finishing with colored paint (concrete columns basement)	Paint	€ 87.150	€ 26.145	€ 44.401	€ 0	€ 0	€ 0	€ 157.696
			Finishing fire protected and esthetic (columns GF - top floor)	Paint	€ 264.000	€ 79.200	€ 273.101	€ 0	€ 0	€ 0	€ 616.301
			Finishing with fire protected paint (columns in atrium special curved)	Paint	€ 900.000	€ 270.000	€ 46.610	€ 0	€ 0	€ 0	€ 1.216.610
			Finishing with fire protected paint (columns atrium special)	Paint	€ 200.000	€ 60.000	€ 49.655	€ 0	€ 0	€ 0	€ 309.655
			Insulation walls in loading dock	Rock wool	€ 30.100	€ 9.030	€ 0	€ 0	€ 0	€ 0	€ 39.130
			Certificated materials for LEED requirements		€ 191.500	€ 57.450	€ 0	€ 0	€ 0	€ 0	€ 248.950
					€ 13.479.786	€ 4.043.936	€ 3.333.352			€ 25.566	€ 20.882.639
					€ 17.523.722						
Internal floor and finishing	23	Floor items (non-load bearing, balconies, arcade, suspended)	Special elements		€ 150.000	€ 45.000	€ 0	€ 0	€ 0	€ 0	€ 195.000
			Atrium stair elements GFL > L01	Wooden floor element	€ 290.000	€ 87.000	€ 0	€ 5.800	€ 0	€ 816	€ 377.816
	33	Voids	Temporary floors during construction		€ 622.871	€ 186.861	€ 0	€ 0	€ 0	€ 0	€ 809.732
			Panelized skin boarders		€ 250.000	€ 75.000	€ 0	€ 5.000	€ 0	€ 704	€ 325.704
			Railing along the edges, curved glass	glass + steel	€ 720.000	€ 216.000	€ 0	€ 7.200	€ 4.200	€ 422	€ 936.422
	43	Floor finishes	Bicycle and Carparking		€ 358.482	€ 107.545	€ 650.109	€ 50.190	€ 0	€ 7.062	€ 1.123.198
			Service and Storage		€ 138.046	€ 41.414	€ 208.633	€ 16.107	€ 0	€ 2.266	€ 390.360
			Circulation	Anhydriet	€ 195.954	€ 58.786	€ 161.485	€ 12.467	€ 0	€ 1.754	€ 417.979
			Fitness centre	Anhydriet+polystyreen	€ 115.718	€ 34.715	€ 69.907	€ 5.397	€ 0	€ 759	€ 221.100
			Health, hospitality	replaced by ceramic tiles	€ 1.018.618	€ 305.585	€ 421.692	€ 31.689	€ 0	€ 4.459	€ 1.750.355
			Sanitair	ceramic tiles	€ 66.500	€ 19.950	€ 33.154	€ 3.724	€ 0	€ 524	€ 120.128
			Learning centre	replaced by tiles with small thickness	€ 354.663	€ 106.399	€ 100.224	€ 8.211	€ 0	€ 1.155	€ 562.441
			Worksettings	replaced by tiles with small thickness	€ 540.627	€ 162.188	€ 269.528	€ 30.275	€ 0	€ 4.260	€ 976.603
			Drywalk entrance, EMCO three zones	replaced by tiles with small thickness	€ 120.000	€ 36.000	€ 41.754	€ 1.400	€ 0	€ 197	€ 197.951
			Other finishes to be defined control cell	replaced by tiles with small thickness	€ 902.594	€ 270.778	€ 492.916	€ 63.182	€ 0	€ 8.891	€ 1.675.179
			Cement screed or trowel finishing basement levels	NeMO zandcement	€ 192.693	€ 57.808	€ 1.164.756	€ 102.768	€ 0	€ 14.461	€ 1.429.718
			Cement screed ground floor level	Anhydriet	€ 145.323	€ 43.597	€ 118.408	€ 46.504	€ 0	€ 6.544	€ 313.871
			Computerfloor L1 till L4	aluminium+profielen staal	€ 1.718.449	€ 515.535	€ 644.638	€ 164.976	€ 274.960	-€ 15.476	€ 2.863.146
			Extra acoustic insulation	20mm gipskartonplaat + 10mm steewol	€ 112.500	€ 33.750	€ 0	€ 22.500	€ 3.000	€ 2.744	€ 148.994
			Certificated materials for LEED requirements		€ 120.200	€ 36.060	€ 0	€ 0	€ 0	€ 0	€ 156.260
					€ 8.133.238	€ 2.439.971	€ 4.377.205			€ 41.543	€ 14.991.956
					€ 10.573.209						
Ceiling internal and external	45	Ceiling internal and external	Carparking and MEP B02	Wall paint	€ 215.089	€ 64.527	€ 602.725	€ 0	€ 0	€ 0	€ 882.340
			Service and Storage	Plasterboard ceiling, double grid, single panel with insulation	€ 161.053	€ 48.316	€ 60.420	€ 13.806	€ 0	€ 1.943	€ 271.732
			Circulation	Climate ceiling combined heat and cold	€ 222.675	€ 66.803	€ 104.852	€ 10.686	€ 106.860	-€ 13.533	€ 380.796
			Fitness centre	Plasterboard ceiling, double grid, single panel with insulation	€ 135.004	€ 40.501	€ 50.613	€ 4.626	€ 0	€ 651	€ 226.769
			Health, hospitality	Climate ceiling combined heat and cold	€ 679.079	€ 203.724	€ 276.065	€ 27.162	€ 271.620	-€ 34.398	€ 1.124.469
			Sanitair	Plasterboard ceiling, double grid, single panel with insulation	€ 37.240	€ 11.172	€ 13.969	€ 3.192	€ 0	€ 449	€ 62.831
			Learning centre	Climate ceiling combined heat and cold	€ 354.663	€ 106.399	€ 151.357	€ 10.638	€ 106.380	-€ 13.472	€ 598.947
			Worksettings	Climate ceiling combined heat and cold	€ 648.752	€ 194.626	€ 264.698	€ 25.950	€ 259.500	-€ 32.863	€ 1.075.213
			Roof in sight, extra ceiling for acoustics	Acoustic plasterboard ceiling	€ 399.600	€ 119.880	€ 149.897	€ 19.980	€ 0	€ 2.811	€ 672.188
			Control cel		€ 589.594	€ 176.878	€ 221.169	€ 35.376	€ 0	€ 4.978	€ 992.619
					€ 3.442.749	€ 1.032.825	€ 1.895.764			-€ 83.435	€ 6.287.903
					€ 4.475.574						
			Total		€ 99.434.500		€ 18.365.476			€ 298.224	€ 118.098.201

Graph

Pre-use phase	€ 99.434.499,80
Use phase	€ 18.365.476,31
EOL phase	€ 298.224,45
LCC	€ 118.098.200,56



CODE	Component	Maintenance/Replacement	Activity	Qty	Unit	%	Net Qty	Unit	Price/Unit	Cyclus Normas	Total amount	Start year	End Year	1
	Substructure													
	Superstructure													
	Roof and finishing													
27	Roof completion													0
	[illegible]	Maintenance	Cleaning, ad	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13,00	5	€ 64.992,00	2025	2069	0
		Replacement	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	€ 3.240,00	2025	2069	0
		Replacement	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
	Bottom, insulation, epdm, detail transition to facade	Maintenance	Service	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Replacement	Replacement	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
	Bottom, insulation, epdm, detail transition to facade	Maintenance	Service	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Replacement	Replacement	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
37	Roof openings													0
	[illegible]	Replacement	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
	[illegible]	[illegible]	Dakraam hout schw. bi. vervoln syst	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
	[illegible]	[illegible]	Dakraam hout schw. bu. vervoln syst	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
	Glass elements in the roof above the [illegible]	Maintenance	Dakraam hout schw. bu. nieuw [illegible]	2.587	m2	50%	1293,5	m2	[illegible]	25	€ 131.937,00	2045	2069	0
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
47	Roof finishing (covering)												2069	0
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Terras South West and North, and [illegible]	Maintenance	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20	€ 23.460,00	2040	2069	0
	Balustrade roofs glass, top roof, [illegible]	Maintenance	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	€ 9.000,00	2025	2069	0
	Facade and finishing													0
31	External wall openings (doors and windows)												2069	0

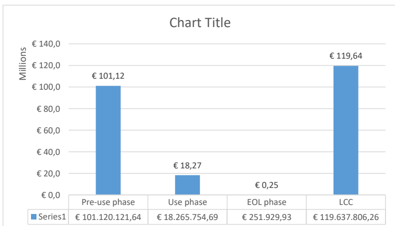
[illegible]

Scenario 3						Pre-use phase	Use phase	End-of-life phase			LCC			
Layer	Code	Component	Elements	Materials	Direct cost	Construction	OMR	Disposal	Residual value	EOL (PV)				
Substructure	11.3	Ground, excavations, additions			€ 2.018.903	€ 605.671		€ 0	€ 0	€ 0	€ 2.624.574			
	11.4	Support works, sheet piles	Steel sheet pile AZ36 temporary		€ 900.996	€ 270.299		€ 0	€ 0	€ 0	€ 1.171.295	RATE	4%	
			Sheet piles ZA36 permanent near entrance building		€ 120.750	€ 36.225		€ 53	€ 63	-€ 1	€ 156.974	Years	50	
			Groutankers		€ 340.448	€ 102.134		€ 0	€ 0	€ 0	€ 442.582		disposal	residual
			Stalen purlins (ringgordingen)		€ 103.488	€ 31.046		€ 0	€ 0	€ 0	€ 134.534			
			Extra cost second groutanker line because of waterpressure		€ 45.000	€ 13.500		€ 0	€ 0	€ 0	€ 58.500			
			Jetgrouten		€ 181.748	€ 54.524		€ 92.400	€ 15.840	€ 10.773	€ 247.045			
			Soft gel injectie		€ 1.621.996	€ 486.599		€ 0	€ 0	€ 0	€ 2.108.595			
			Temporary propping		€ 58.500	€ 17.550		€ 0	€ 0	€ 0	€ 76.050			
			Separate pit for the tunnels		€ 240.000	€ 72.000		€ 0	€ 0	€ 0	€ 312.000			
												Concrete	175	30
	11.5	Dewatering (drainage)	Dewatering (drainage)		€ 158.240	€ 47.472		€ 0	€ 0	€ 0	€ 205.712	Sand	8	13
	13	Floor bed (On ground)	Concrete floor bed on sand	Concrete	€ 3.497.008	€ 1.049.102		€ 1.331.750	€ 228.300	€ 155.269	€ 4.701.380	Steel	0,08	0,1
	16	Basement	foundation footing strips, pads etc		€ 274.744	€ 82.423		€ 1.337.000	€ 229.200	€ 155.881	€ 513.049			
	17	Deep foundation (pile foundations)	Pile foundations, anchor block Gewi 63,5mm 25m1	tiranti	€ 1.500.000	€ 450.000		€ 180.000	€ 26.166	€ 21.646	€ 1.971.646			
			Fundex combination GI 460/560 with grout injection	piles	€ 1.469.487	€ 440.846		€ 245.000	€ 16.800	€ 32.111	€ 1.942.444			
					€ 12.531.308	€ 3.759.392				€ 375.679	€ 16.666.380			
					€ 16.290.700									
Super structure	21	External walls (structure, load bearing)	External walls basement	Concrete	€ 691.114	€ 207.334		€ 176.400	€ 30.240	€ 20.567	€ 919.015			
	22	Inner walls (structure, load bearing)	Cores and other elements	Concrete	€ 776.086	€ 232.826		€ 271.635	€ 46.566	€ 31.670	€ 1.040.582			
	23	Floors (structure, load bearing)	Floorslab 350mm dik, 100 kg reinforcement	B01	€ 603	€ 181				€ 0	€ 784			
			Concrete floorslab 400mm	Ground floor	€ 1.259.310	€ 377.793		€ 452.060	€ 77.496	€ 52.706	€ 1.689.809			
			Concrete floor 600 mm PT		€ 1.789.880	€ 536.964		€ 29.626	€ 48.142	-€ 2.605	€ 2.324.239			
			Total timber floors							€ 0	€ 0			
			320mm stressed skin floor panel	Mezzanine	€ 441.250	€ 132.375		€ 52.950	€ 105.900	-€ 7.451	€ 566.174			
			320mm stressed skin floor panel	Level 1	€ 1.185.000	€ 355.500		€ 142.200	€ 284.400	-€ 20.009	€ 1.520.491			
			320mm stressed skin floor panel	Level 2	€ 1.074.250	€ 322.275		€ 128.910	€ 257.820	-€ 18.139	€ 1.378.386			
			320mm stressed skin floor panel	Level 2 entrance	€ 40.500	€ 12.150		€ 9.000	€ 18.000	-€ 1.266	€ 51.384			
			320mm stressed skin floor panel	Level 3	€ 875.750	€ 262.725		€ 105.090	€ 210.180	-€ 14.787	€ 1.123.688			
			320mm stressed skin floor panel	Level 4	€ 707.000	€ 212.100		€ 84.840	€ 169.680	-€ 11.938	€ 907.162			
			Atrium boundaries in fluid form included edge beam		€ 115.800	€ 34.740		€ 17.370	€ 34.740	-€ 2.444	€ 148.096			
			extra mass up to 250kg		€ 360.240	€ 108.072		€ 540.360	€ 1.080.720	-€ 76.035	€ 392.277			
			Outdoor terrace as a cantilever		€ 148.750	€ 44.625		€ 12.750	€ 25.500	-€ 1.794	€ 191.581			
	27	Roofs (structure, load bearing)	Roof basement	Concrete	€ 270.900	€ 81.270		€ 102.550	€ 17.580	€ 11.956	€ 364.126			
			Roof level 2	Timber	€ 109.550	€ 32.865		€ 18.780	€ 18.780	€ 0	€ 142.415			
			Top roof closed surface	Timber	€ 511.650	€ 153.495		€ 102.330	€ 102.330	€ 0	€ 665.145			
	28	Building frame constructions (other primary elements)	Concrete structure basement	Concrete	€ 547.173	€ 164.152		€ 71.006	€ 12.173	€ 8.279	€ 719.604			
			Steel structure	Steel	€ 6.986.156	€ 2.095.847		€ 18.536	€ 23.170	-€ 652	€ 9.081.351			
			Wood structure	Wood	€ 2.627.673	€ 788.302		€ 39.300	€ 157.200	-€ 16.590	€ 3.399.385			
			Timber structure	Timber	€ 269.735	€ 80.921		€ 146.595	€ 0	€ 20.628	€ 371.283			
			Certificated materials for LEED requirements		€ 214.800					€ 0	€ 214.800			
					€ 21.003.170	€ 6.236.511				-€ 27.907	€ 27.211.774			
					€ 27.239.681									
Roof and finishing	27	Roof completion	Special timberwork on the roof		€ 243.723	€ 73.117	€ 323.769	€ 21.664	€ 0	€ 3.048	€ 643.657			
			Arround lower roofs		€ 67.500	€ 20.250	€ 33.206	€ 1.350	€ 0	€ 190	€ 121.146			
			Bottom, insulation, epdm, detail transition to facade		€ 147.000	€ 44.100	€ 8.132	€ 1.500	€ 0	€ 211	€ 199.443			
			Bottom, insulation, epdm, detail transition to facade		€ 60.120	€ 18.036	€ 4.879	€ 900	€ 0	€ 127	€ 83.162			
	37	Roof openings	Glass transparant roof modules	dakraam meranti	€ 3.286.904	€ 986.071	€ 1.072.002	€ 30.720	€ 25.600	€ 720	€ 5.345.697			
			Glare control above workspace	Solidscreen	€ 68.795	€ 20.639	€ 142.872	€ 1.032	€ 0	€ 145	€ 232.450			
			Roof snappers in the back garden for B1	Aluminium, geanodiseerd	€ 48.600	€ 14.580	€ 390.913	€ 81	€ 24.300	-€ 3.408	€ 450.685			
			Glass elements in the roof above the new connection to C05 and C16		€ 20.000	€ 6.000	€ 49.492	€ 240	€ 200	€ 6	€ 75.497			
			Access to the roof		€ 8.000	€ 2.400	€ 15.527	€ 12	€ 120	-€ 15	€ 25.912			
	47	Roof finishing (covering)	High reflective covering	app dakbedekking	€ 649.928	€ 194.978		€ 81.240	€ 0	€ 11.431	€ 856.338			
			Paths and safety lines		€ 135.402	€ 40.621	€ 1.124.109	€ 10.832	€ 0	€ 1.524	€ 1.301.656			
			Special structure toproof elements	aluminium	€ 883.050	€ 264.915	€ 270.247	€ 17.661	€ 41.209	-€ 3.314	€ 1.414.899			
			Terras South West and North, and green areas	street bricks	€ 309.200	€ 92.760	€ 119.661	€ 15.460	€ 0	€ 2.175	€ 523.796			
			Balustrade roofs glass, top roof, terraces and fitness terrace	Staal; gepoedercoat; glasplaat vulling	€ 562.500	€ 168.750	€ 34.429	€ 9.000	€ 7.500	€ 211	€ 765.890			
			Certificated materials for LEED requirements		€ 130.800			€ 0	€ 0	€ 0	€ 130.800			
					€ 6.621.522	€ 1.947.217	€ 3.589.238			€ 13.053	€ 12.171.029			
					€ 8.568.739									
Facade and finishing	31	External wall openings (doors and windows)	Entrance to basement	Recycled wood + glass	€ 40.000	€ 12.000	€ 10.820	€ 625	€ 2.500	-€ 264	€ 62.556	50.000		
			Entrance to loading bay	Recycled wood + glass	€ 142.560	€ 42.768	€ 37.564	€ 2.025	€ 8.100	-€ 855	€ 222.037	178.200		
			Structural glazing	Recycled wood + glass	€ 1.688.325	€ 506.497	€ 501.400	€ 42.200	€ 168.800	-€ 17.814	€ 2.678.408	2.110.406		
			Elements tripple glass en closed parts	Recycled wood + glass	€ 4.799.400	€ 1.439.820	€ 1.543.340	€ 157.875	€ 631.500	-€ 66.645	€ 7.715.915	5.999.250		
			Windows	Recycled wood + glass	€ 389.248	€ 116.774	€ 269.494	€ 20.275	€ 81.100	-€ 8.559	€ 766.958	486.560		
			Emergency exits	Recycled wood + glass	€ 60.000	€ 18.000	€ 14.327	€ 375	€ 1.500	-€ 158	€ 92.168	75.000		
			Entrance CN-EN 2.1	Recycled wood + glass	€ 280.000	€ 84.000	€ 61.497	€ 18.000	€ 60.000	-€ 5.910	€ 419.587	350.000		
			Entrance EJ - 01	Recycled wood + glass	€ 200.000	€ 60.000	€ 43.949	€ 15.000	€ 50.000	-€ 4.925	€ 299.024	250.000		
	41	Façade finishing (claddings)	Scaffolding		€ 288.460	€ 86.538		€ 0	€ 0	€ 0	€ 374.998			
			Sun screening	Solidscreen	€ 519.229	€ 155.769	€ 899.785	€ 8.901	€ 0	€ 1.252	€ 1.576.035			
			Finishing inner surface of closed facade basement	Spray plaster	€ 115.186	€ 34.556	€ 633.809	€ 0	€ 0	€ 0	€ 783.550			
			Steel ceramic sun shading		€ 213.444	€ 64.033	€ 44.438	€ 2.510	€ 1.757	€ 106	€ 322.022			
			Sun shading horizontal		€ 190.800	€ 57.240	€ 151.523	€ 3.180	€ 2.226	€ 134	€ 399.698			
			Curved lines roof level		€ 171.000	€ 51.300	€ 68.894	€ 11.400	€ 0	€ 1.604	€ 292.798			
			Pier Brick elements external		€ 1.019.990	€ 305.997	€ 505.866	€ 75.000	€ 45.000	€ 4.221	€ 1.836.075			
			Pier Brick elements on the inside		€ 640.000	€ 192.000	€ 165.927	€ 50.000	€ 30.000	€ 2.814	€ 1.000.742			
			Closed elements in the elments on floor levels	Aluminium vlak (sandwich-aluminium kern)	€ 170.000	€ 51.000	€ 0	€ 6.800	€ 0	€ 957	€ 221.957			
			Demonstration showcase related to Showroom on level 0 grid line 1, 14		€ 142.800	€ 42.840	€ 2.641	€ 0	€ 0	€ 0	€ 188.281			
			Canopy main entrance	steel	€ 300.000	€ 90.000	€ 8.537	€ 1.000	€ 1.200	-€ 28	€ 398.508			
			Glare control all glass elements	internal sunshading	€ 516.000	€ 154.800		€ 10.750	€ 0	€ 1.513	€ 672.313			
			Other		€ 549.448	€ 164.834		€ 0	€ 0	€ 0	€ 714.282			
			Certificated materials for LEED requirements		€ 216.800	€ 65.040		€ 0	€ 0	€ 0	€ 281.840			
					€ 12.652.690	€ 3.795.807	€ 4.963.811			-€ 92.556	€ 21.319.752			
					€ 16.448.497									
Internal walls and finishing	22	Internal walls	Acoustic MS double, MS2	MWA+Gipskartonplaat systeemwand	€ 362.174	€ 108.652	€ 133.653	€ 38.805	€ 5.174	€ 4.732	€ 609.211			
			Brandwerend MS double, MS1	Glaswol MWA+Gipskartonplaat	€ 465.652	€ 139.696	€ 184.290	€ 58.200	€ 7.760	€ 7.098	€ 796.735			
			Normal walls MS single, MS3	MWA+Gipskartonplaat systeemwand	€ 646.738	€ 194.021	€ 280.226	€ 97.005	€ 12.934	€ 11.830	€ 1.132.816			
	32	Internal wall openings (doors and windows)	Acoustic elements	Glaswol MWA	€ 698.477	€ 209.543	€ 24.639	€ 11.640	€ 4.656	€ 983	€ 933.642			
			Fire protected	Steel structure inner wall with doors and glass	€ 931.303	€ 279.391	€ 19.718	€ 9.315	€ 3.726	€ 786	€ 1.231.198			
			Normal elements	Steel	€ 1.047.716	€ 314.315	€ 43.751	€ 34.920	€ 13.968	€ 2.948	€ 1.408.730			
			Special (high) elements	Steel	€ 1.455.161	€ 436.548	€ 28.784	€ 17.460	€ 6.984	€ 1.474	€ 1.921.967			
			Flexibel walls	Steel	€ 300.000	€ 90.000	€ 7.939	€ 5.000	€ 0	€ 704	€ 398.643			
			Doors, included hinges and locks	Hout; geschilderd: alkyd	€ 493.000	€ 147.900	€ 29.796	€ 0	€ 0	€ 0	€ 670.696			
			GLASS - INTERIOR WALL PANEL FI-03	Staal frame element; glas par	€ 1.187.640	€ 356.292	€ 247.354	€ 39.585	€ 15.834	€ 3.342	€ 1.794.628			
			MIRROR - INTERIOR PANEL FI-06	Staal frame element; glas par	€ 28.000	€ 8.400	€ 5.832	€ 600	€ 240	€ 51	€ 42.283			
			GLASS PANEL BENT - WOOD INTERLAYER FI-09	Houten frame, eknel glas	€ 37.500	€ 11.250	€ 7.811	€ 225	€ 90	€ 19	€ 56.580			
			other elements		€ 141.855	€ 42.557	€ 29.494	€ 2.655	€ 1.062	€ 224	€ 214.129			

	42	Internal wall finishing	Wall finishing assumption	Spray plaster	€ 43.860	€ 13.158	€ 80.308	€ 0	€ 0	€ 0	€ 137.326
			Wall finishing assumption	Spray plaster	€ 213.424	€ 64.027	€ 213.128	€ 0	€ 0	€ 0	€ 490.580
			Wall finishing assumption	Spray plaster	€ 905.434	€ 271.630	€ 497.336	€ 0	€ 0	€ 0	€ 1.674.400
			Wall finishing assumption	Spray plaster	€ 248.710	€ 74.613	€ 160.725	€ 0	€ 0	€ 0	€ 484.048
			Wall finishing assumption	Spray plaster	€ 1.920.813	€ 576.244	€ 468.937	€ 0	€ 0	€ 0	€ 2.965.994
			Based on material schedule (GYPSUM WALL BOARD - INTERIOR L4 FI-01)	Gipspleister	€ 26.364	€ 7.909	€ 36.199	€ 0	€ 0	€ 0	€ 70.472
			Based on material schedule (GYPSUM WALL BOARD - INTERIOR L5 FI-02)	Gipspleister	€ 44.950	€ 13.485	€ 49.382	€ 0	€ 0	€ 0	€ 107.817
			Based on material schedule (GLASS PANEL BENT - WOOD INTERLAYER FI-09)	wooden frame, single glass	€ 3.750	€ 1.125	€ 1.478	€ 0	€ 315	-€ 44	€ 6.309
			Based on material schedule (BATHROOM WALL TILE FI-12)	Glazed ceramic tiles	€ 15.130	€ 4.539	€ 7.400	€ 0	€ 0	€ 0	€ 27.069
			Based on material schedule (WOOD WALL PANELS FI-14)	wooden wall	€ 439.565	€ 131.870	€ 231.377	€ 0	€ 52.752	-€ 7.423	€ 795.389
			Based on material schedule (ACOUSTIC WALLS FI-15)	Acoustic cellulose spray plast	€ 89.100	€ 26.730	€ 21.752	€ 0	€ 8.316	-€ 1.170	€ 136.412
			Based on material schedule (PAINTED CONCRETE FI-21)	Wall paint	€ 60.720	€ 18.216	€ 108.275	€ 0	€ 0	€ 0	€ 187.211
			Finishing with colored paint (concrete columns basement)	Paint	€ 87.150	€ 26.145	€ 44.401	€ 0	€ 0	€ 0	€ 157.696
			Finishing fire protected and esthetic (columns GF - top floor)	Paint	€ 264.000	€ 79.200	€ 273.101	€ 0	€ 0	€ 0	€ 616.301
			Finishing with fire protected paint (columns in atrium special curved)	Paint	€ 900.000	€ 270.000	€ 46.610	€ 0	€ 0	€ 0	€ 1.216.610
			Finishing with fire protected paint (columns atrium special)	Paint	€ 200.000	€ 60.000	€ 49.655	€ 0	€ 0	€ 0	€ 309.655
			Insulation walls in loading dock	Rock wool	€ 30.100	€ 9.030		€ 0	€ 0	€ 0	€ 39.130
			Certificated materials for LEED requirements		€ 191.500	€ 57.450		€ 0	€ 0	€ 0	€ 248.950
					€ 13.479.786	€ 4.043.936	€ 3.333.352			€ 25.553	€ 20.882.627
					€ 17.523.722						
Internal floor and finishing	23	Floor items (non-load bearing, balconies, arcade, suspended)	Special elements		€ 150.000	€ 45.000		€ 0	€ 0	€ 0	€ 195.000
			Atrium stair elements GFL > L01	Wooden floor element	€ 290.000	€ 87.000	€ 106.386	€ 5.800	€ 0	€ 816	€ 484.202
	33	Voids	Temporary floors during construction		€ 622.871	€ 186.861		€ 0	€ 0	€ 0	€ 809.732
			Panelized skin boarders		€ 250.000	€ 75.000		€ 5.000	€ 0	€ 704	€ 325.704
			Railing along the edges, curved glass	glass + steel	€ 720.000	€ 216.000		€ 7.200	€ 4.200	€ 422	€ 936.422
	43	Floor finishes	Bicycle and Carparking		€ 358.482	€ 107.545	€ 650.109	€ 50.190	€ 0	€ 7.062	€ 1.123.198
			Service and Storage		€ 138.046	€ 41.414	€ 208.633	€ 16.107	€ 0	€ 2.266	€ 390.360
			Circulation	Anhydriet	€ 195.954	€ 58.786	€ 161.485	€ 12.467	€ 0	€ 1.754	€ 417.979
			Fitness centre	Anhydriet+polystyreen	€ 115.718	€ 34.715	€ 69.907	€ 5.397	€ 0	€ 759	€ 221.100
			Health, hospitality	replaced by ceramic tiles	€ 1.018.618	€ 305.585	€ 421.692	€ 31.689	€ 0	€ 4.459	€ 1.750.355
			Sanitair	ceramic tiles	€ 66.500	€ 19.950	€ 33.154	€ 3.724	€ 0	€ 524	€ 120.128
			Learning centre	replaced by tiles with small thickness	€ 354.663	€ 106.399	€ 100.224	€ 8.211	€ 0	€ 1.155	€ 562.441
			Worksettings	replaced by tiles with small thickness	€ 540.627	€ 162.188	€ 269.528	€ 30.275	€ 0	€ 4.260	€ 976.603
			Drywalk entrance, EMCO three zones	replaced by tiles with small thickness	€ 120.000	€ 36.000	€ 41.754	€ 1.400	€ 0	€ 197	€ 197.951
			Other finishes to be defined control cell	replaced by tiles with small thickness	€ 902.594	€ 270.778	€ 492.916	€ 63.182	€ 0	€ 8.891	€ 1.675.179
			Cement screed or trowel finishing basement levels	NeMO zandcement	€ 192.693	€ 57.808	€ 1.164.756	€ 102.768	€ 0	€ 14.461	€ 1.429.718
			Cement screed ground floor level	Anhydriet	€ 145.323	€ 43.597	€ 118.408	€ 46.504	€ 0	€ 6.544	€ 313.871
			Computerfloor L1 till L4	aluminium+profielen staal	€ 1.718.449	€ 515.535	€ 644.638	€ 164.976	€ 274.960	-€ 15.476	€ 2.863.146
			Extra acoustic insulation	20mm gipskartonplaat + 10mm steewol	€ 112.500	€ 33.750		€ 22.500	€ 3.000	€ 2.744	€ 148.994
			Certificated materials for LEED requirements		€ 120.200	€ 36.060		€ 0	€ 0	€ 0	€ 156.260
					€ 8.133.238	€ 2.439.971	€ 4.483.590			€ 41.543	€ 15.098.342
					€ 10.573.209						
Ceiling internal and external	45	Ceiling internal and external	Carparking and MEP B02	Wall paint	€ 215.089	€ 64.527	€ 602.725	€ 0	€ 0	€ 0	€ 882.340
			Service and Storage	Plasterboard ceiling, double grid, single panel with insulation	€ 161.053	€ 48.316	€ 60.420	€ 13.806	€ 0	€ 1.943	€ 271.732
			Circulation	Climate ceiling combined heat and cold	€ 222.675	€ 66.803	€ 104.852	€ 10.686	€ 106.860	-€ 13.533	€ 380.796
			Fitness centre	Plasterboard ceiling, double grid, single panel with insulation	€ 135.004	€ 40.501	€ 50.613	€ 4.626	€ 0	€ 651	€ 226.769
			Health, hospitality	Climate ceiling combined heat and cold	€ 679.079	€ 203.724	€ 276.065	€ 27.162	€ 271.620	-€ 34.398	€ 1.124.469
			Sanitair	Plasterboard ceiling, double grid, single panel with insulation	€ 37.240	€ 11.172	€ 13.969	€ 3.192	€ 0	€ 449	€ 62.831
			Learning centre	Climate ceiling combined heat and cold	€ 354.663	€ 106.399	€ 151.357	€ 10.638	€ 106.380	-€ 13.472	€ 598.947
			Worksettings	Climate ceiling combined heat and cold	€ 648.752	€ 194.626	€ 264.698	€ 25.950	€ 259.500	-€ 32.863	€ 1.075.213
			Roof in sight, extra ceiling for acoustics	Acoustic plasterboard ceiling	€ 399.600	€ 119.880	€ 149.897	€ 19.980	€ 0	€ 2.811	€ 672.188
			Control cel		€ 589.594	€ 176.878	€ 221.169	€ 35.376	€ 0	€ 4.978	€ 992.619
					€ 3.442.749	€ 1.032.825	€ 1.895.764			-€ 83.435	€ 6.287.903
					€ 4.475.574						
			Total		€ 101.120.122		€ 18.265.755			€ 251.930	€ 119.637.806

Graph

Pre-use phase	€ 101.120.121,64
Use phase	€ 18.265.754,69
EOL phase	€ 251.929,93
LCC	€ 119.637.806,26



Component	Maintenance/Replacement	Activity	Qty	Unit	%	Qty	Unit	Price	Cycle	Total amount	Start year	End year
Finishing inner surface of closed facade basement	Maintenance	Maintenance	2880	m2	100%	2880	m2	79,10	10	€ 227.808,00	2030	2069
Closed elements in the elments on floor levels	Replacement	Replacement (Cleaning is already incl.)	850	m2	100%	850	m2	200,00	50	€ 170.000,00	2070	2069
Internal wall openings (doors and windows) (32)												2069
GLASS - INTERIOR WALL PANEL FI-03	Replacement	Replacement	2.639	m2	100%	2639	m2	450,00	40	€ 1.187.550,00	2060	2069
MIRROR - INTERIOR PANEL FI-06	Replacement	Replacement	40	m2	100%	40	m2	700,00	40	€ 28.000,00	2060	2069
GLASS PANEL BENT - WOOD INTERLAYER FI-09	Replacement	Replacement	15	m2	100%	15	m2	2.500,00	40	€ 37.500,00	2060	2069
Based on material schedule (GYPSUM WALL BOARD - INTERIOR L4 FI-01)	Cleaning - Maintenance	Binnenwandafw. pleisterwerk reinigen	659	m2	100%	659	m2	8,32	10	€ 5.482,88	2030	2069
Based on material schedule (GYPSUM WALL BOARD - INTERIOR L5 FI-02)	Cleaning - Maintenance	Binnenwandafw. pleisterwerk reinigen	899	m2	100%	899	m2	8,32	10	€ 7.479,68	2030	2069
Based on material schedule (GLASS PANEL BENT - WOOD INTERLAYER FI-09)	Replacement	Replacement	15	m2	100%	15	m2	250,00	25	€ 3.750,00	2045	2069
Based on material schedule (BATHROOM WALL TILE FI-13)	Replacement	Replacement	178	m2	100%	178	m2	85,00	25	€ 15.130,00	2045	2069
Based on material schedule (WOOD WALL PANELS FI-14)	Replacement	Replacement	2.512	m2	100%	2512	m2	175,00	25	€ 439.600,00	2045	2069
Based on material schedule (ACOUSTIC WALLS FI-15)	Cleaning - Maintenance	Binnenwandafw. pleisterwerk reinigen	396	m2	100%	396	m2	8,32	10	€ 3.294,72	2030	2069
Based on material schedule (PAINTED CONCRETE FI-21)	Maintenance	Painting over	2.024	m2	100%	2024	m2	32,45	10	€ 65.678,80	2030	2069
Finishing with colored paint (concrete columns basement)	Maintenance	Painting over	830	m1	100%	830	m1	32,45	10	€ 26.933,50	2030	2069
Finishing fire protected and esthetic (columns GF, top floor)	Maintenance	Painting over	2.200	m1	100%	2200	m1	32,45	5	€ 71.390,00	2025	2069
Finishing with fire protected paint (columns in atrium special curved)	Maintenance	Cleaning	600	m1	100%	600	m1	3,64	1	€ 2.184,00	2021	2070
Finishing with fire protected paint (columns atrium special)	Maintenance	Painting over	400	m1	100%	400	m1	32,45	5	€ 12.980,00	2025	2069
Certificated materials for LEED requirements	Nothing	None										2069
Floor items (non-load bearing, balconies, arcade, suspended) (23)												2069
Railing along the edges, curved glass	everyday cleaning (not needed)	None										2069
Other finishes to be defined control cell	Replacement	Replacement of the joints	9.026	m2	100%	9026	m2	45,71	30	€ 412.578,46	2050	2069
Cement screed or trowel finishing basement levels	Maintenance	Maintenance	12.846	m2	100%	12846	m2	55,00	10	€ 706.530,00	2030	2069
Certificated materials for LEED requirements	Nothing	None										2069
Roof in sight, extra ceiling for acoustics	Only replacing	Replacement	3.330	m2	100%	3330	m2	84	25	€ 279.720,00	2045	2069

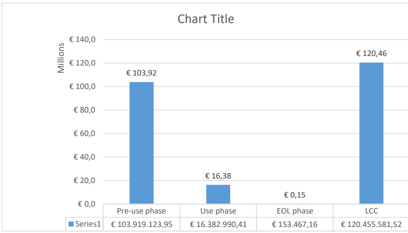
PV (ex 2070)	Per element	Present value
€ 3.507		€ 3.507
€ 2.104		€ 2.104
€ 390.913	€ 390.913	€ 390.913
€ 49.492	€ 49.492	€ 49.492
€ 15.593		€ 15.593
€ 34.429	€ 34.429	€ 34.429
		€ 0
€ 999.662		€ 999.662

Layer	Code	Component	Elements	Materials	Direct cost	Construction	OMR	Disposal	Residual value	EOL (PV)	LCC			
Scenario 4					Pre-use phase		Use phase		End-of-life phase		LCC			
Substructure	11.3	Ground, excavations, additions			€ 2.018.903	€ 605.671		€ 0	€ 0	€ 0	€ 2.624.574	Rate	4%	
	11.4	Support works, sheet piles	Steel sheet pile AZ36 temporary		€ 900.996	€ 270.299		€ 0	€ 0	€ 0	€ 1.171.295	Year	50	
			Sheet piles ZA36 permanent near entrance building		€ 120.750	€ 36.225		€ 53	€ 63	-€ 1	€ 156.974			
			Groutankers		€ 340.448	€ 102.134		€ 0	€ 0	€ 0	€ 442.582		disposal	residual
			Stalen purlins (ringgordingen)		€ 103.488	€ 31.046		€ 0	€ 0	€ 0	€ 134.534			
			Extra cost second groutanker line because of waterpressure		€ 45.000	€ 13.500		€ 0	€ 0	€ 0	€ 58.500			
			Jetgrouten		€ 181.748	€ 54.524		€ 92.400	€ 15.840	€ 10.773	€ 247.045			
			Soft gel injectie		€ 1.621.996	€ 486.599		€ 0	€ 0	€ 0	€ 2.108.595			
			Temporary propping		€ 58.500	€ 17.550		€ 0	€ 0	€ 0	€ 76.050			
			Separate pit for the tunnels		€ 240.000	€ 72.000		€ 0	€ 0	€ 0	€ 312.000			
												Concrete	175	30
	11.5	Dewatering (drainage)	Dewatering (drainage)		€ 158.240	€ 47.472		€ 0	€ 0	€ 0	€ 205.712	Sand	8	13
	13	Floor bed (On ground)	Concrete floor bed on sand	Concrete	€ 3.497.008	€ 1.049.102		€ 1.331.750	€ 228.300	€ 155.269	€ 4.701.380	Steel	0,08	0,1
	16	Basement	foundation footing strips, pads etc		€ 274.744	€ 82.423		€ 1.337.000	€ 229.200	€ 155.881	€ 513.049			
	17	Deep foundation (pile foundations)	Pile foundations, anchor block Gewi 63,5mm 25m1	tiranti	€ 1.500.000	€ 450.000		€ 180.000	€ 26.166	€ 21.646	€ 1.971.646			
			Fundex combination GI 460/560 with grout injection	piles	€ 1.469.487	€ 440.846		€ 245.000	€ 16.800	€ 32.111	€ 1.942.444			
					€ 12.531.308	€ 3.759.392				€ 375.679	€ 16.666.380			
					€ 16.290.700									
Super structure	21	External walls (structure, load bearing)	External walls basement	Concrete	€ 691.114	€ 207.334		€ 176.400	€ 30.240	€ 20.567	€ 919.015			
	22	Inner walls (structure, load bearing)	Cores and other elements	Concrete	€ 776.086	€ 232.826		€ 271.635	€ 46.566	€ 31.670	€ 1.040.582			
	23	Floors (structure, load bearing)	Floorslab 350mm dik, 100 kg reinforcement	B01	€ 603	€ 181				€ 0	€ 784			
			Concrete floorslab 400mm	Ground floor	€ 1.259.310	€ 377.793		€ 452.060	€ 77.496	€ 52.706	€ 1.689.809			
			Concrete floor 600 mm PT		€ 1.789.880	€ 536.964		€ 29.626	€ 48.142	-€ 2.605	€ 2.324.239			
			Total timber floors							€ 0	€ 0			
			320mm stressed skin floor panel	Mezzanine	€ 441.250	€ 132.375		€ 52.950	€ 105.900	-€ 7.451	€ 566.174			
			320mm stressed skin floor panel	Level 1	€ 1.185.000	€ 355.500		€ 142.200	€ 284.400	-€ 20.009	€ 1.520.491			
			320mm stressed skin floor panel	Level 2	€ 1.074.250	€ 322.275		€ 128.910	€ 257.820	-€ 18.139	€ 1.378.386			
			320mm stressed skin floor panel	Level 2 entrance	€ 40.500	€ 12.150		€ 9.000	€ 18.000	-€ 1.266	€ 51.384			
			320mm stressed skin floor panel	Level 3	€ 875.750	€ 262.725		€ 105.090	€ 210.180	-€ 14.787	€ 1.123.688			
			320mm stressed skin floor panel	Level 4	€ 707.000	€ 212.100		€ 84.840	€ 169.680	-€ 11.938	€ 907.162			
			Atrium boundaries in fluid form included edge beam		€ 115.800	€ 34.740		€ 17.370	€ 34.740	-€ 2.444	€ 148.096			
			extra mass up to 250kg		€ 360.240	€ 108.072		€ 540.360	€ 1.080.720	-€ 76.035	€ 392.277			
			Outdoor terrace as a cantilever		€ 148.750	€ 44.625		€ 12.750	€ 25.500	-€ 1.794	€ 191.581			
	27	Roofs (structure, load bearing)	Roof basement	Concrete	€ 270.900	€ 81.270		€ 102.550	€ 17.580	€ 11.956	€ 364.126			
			Roof level 2	Timber	€ 109.550	€ 32.865		€ 18.780	€ 18.780	€ 0	€ 142.415			
			Top roof closed surface	Timber	€ 511.650	€ 153.495		€ 102.330	€ 102.330	€ 0	€ 665.145			
	28	Building frame constructions (other primary elements)	Concrete structure basement	Concrete	€ 547.173	€ 164.152		€ 71.006	€ 12.173	€ 8.279	€ 719.604			
			Steel structure	Steel	€ 6.986.156	€ 2.095.847		€ 18.536	€ 23.170	-€ 652	€ 9.081.351			
			Wood structure	Wood	€ 2.627.673	€ 788.302		€ 39.300	€ 157.200	-€ 16.590	€ 3.399.385			
			Timber structure	Timber	€ 269.735	€ 80.921		€ 146.595	€ 0	€ 20.628	€ 371.283			
			Certificated materials for LEED requirements		€ 214.800					€ 0	€ 214.800			
					€ 21.003.170	€ 6.236.511				-€ 27.907	€ 27.211.774			
					€ 27.239.681									
Roof and finishing	27	Roof completion	Special timberwork on the roof		€ 243.723	€ 73.117	€ 323.769,09	€ 21.664	€ 0	€ 3.048	€ 643.657			
			Arround lower roofs		€ 67.500	€ 20.250	€ 33.206,07	€ 1.350	€ 0	€ 190	€ 121.146			
			Bottom, insulation, epdm, detail transition to facade		€ 147.000	€ 44.100	€ 8.132,00	€ 1.500	€ 0	€ 211	€ 199.443			
			Bottom, insulation, epdm, detail transition to facade		€ 60.120	€ 18.036	€ 4.879,20	€ 900	€ 0	€ 127	€ 83.162			
	37	Roof openings	Glass transparant roof modules	dakraam meranti	€ 3.286.904	€ 986.071	€ 1.072.001,81	€ 30.720	€ 25.600	€ 720	€ 5.345.697			
			Glare control above workspace	Solidscreen	€ 68.795	€ 20.639	€ 142.871,53	€ 1.032	€ 0	€ 145	€ 232.450			
			Roof snappers in the back garden for B1	Aluminium, geanodiseerd	€ 48.600	€ 14.580	€ 390.912,53	€ 81	€ 24.300	-€ 3.408	€ 450.685			
			Glass elements in the roof above the new connection to C05 and C16		€ 20.000	€ 6.000	€ 49.491,79	€ 240	€ 200	€ 6	€ 75.497			
			Access to the roof		€ 8.000	€ 2.400	€ 15.526,83	€ 12	€ 120	-€ 15	€ 25.912			
	47	Roof finishing (covering)	High reflective covering	app dakbedekking	€ 649.928	€ 194.978		€ 81.240	€ 0	€ 11.431	€ 856.338			
			Paths and safety lines		€ 135.402	€ 40.621	€ 1.124.109,23	€ 10.832	€ 0	€ 1.524	€ 1.301.656			
			Special structure toproof elements	aluminium	€ 883.050	€ 264.915	€ 270.247,29	€ 17.661	€ 41.209	-€ 3.314	€ 1.414.899			
			Terras South West and North, and green areas	street bricks	€ 309.200	€ 92.760	€ 135.254,35	€ 15.460	€ 0	€ 2.175	€ 539.390			
			Balustrade roofs glass, top roof, terraces and fitness terrace	Staal; gepoedercoat; glasplaat vulling	€ 562.500	€ 168.750	€ 34.429,33	€ 9.000	€ 7.500	€ 211	€ 765.890			
			Certificated materials for LEED requirements		€ 130.800			€ 0	€ 0	€ 0	€ 130.800			
					€ 6.621.522	€ 1.947.217	€ 3.604.831,05			€ 13.053	€ 12.186.623			
					€ 8.568.739									
Facade and finishing	31	External wall openings (doors and windows)	Entrance to basement	Recycled wood + glass	€ 40.000	€ 12.000	€ 14.110,57	€ 625	€ 2.500	-€ 264	€ 65.847	50.000		
			Entrance to loading bay	Recycled wood + glass	€ 142.560	€ 42.768	€ 48.081,34	€ 2.025	€ 8.100	-€ 855	€ 232.555	178.200		
			Structural glazing	Recycled wood + glass	€ 1.688.325	€ 506.497	€ 734.781,46	€ 42.200	€ 168.800	-€ 17.814	€ 2.911.789	2.110.406		
			Elements tripple glass en closed parts	Recycled wood + glass	€ 4.799.400	€ 1.439.820	€ 734.781,46	€ 157.875	€ 631.500	-€ 66.645	€ 6.907.356	5.999.250		
			Windows	Recycled wood + glass	€ 389.248	€ 116.774	€ 265.186,27	€ 20.275	€ 81.100	-€ 8.559	€ 762.650	486.560		
			Emergency exits	Recycled wood + glass	€ 60.000	€ 18.000	€ 15.902,46	€ 375	€ 1.500	-€ 158	€ 93.744	75.000		
			Entrance CN-EN 2.1	Recycled wood + glass	€ 280.000	€ 84.000	€ 58.547,94	€ 18.000	€ 60.000	-€ 5.910	€ 416.638	350.000		
			Entrance EJ - 01	Recycled wood + glass	€ 200.000	€ 60.000	€ 41.884,82	€ 15.000	€ 50.000	-€ 4.925	€ 296.960	250.000		
	41	Façade finishing (claddings)	Scaffolding		€ 288.460	€ 86.538		€ 0	€ 0	€ 0	€ 374.998			
			Sun screening	Solidscreen	€ 519.229	€ 155.769	€ 899.784,57	€ 8.901	€ 0	€ 1.252	€ 1.576.035			
			Finishing inner surface of closed facade basement	Spray plaster	€ 115.186	€ 34.556	€ 633.808,68	€ 0	€ 0	€ 0	€ 783.550			
			Steel ceramic sun shading		€ 213.444	€ 64.033	€ 44.438,47	€ 2.510	€ 1.757	€ 106	€ 322.022			
			Sun shading horizontal		€ 190.800	€ 57.240	€ 151.523,36	€ 3.180	€ 2.226	€ 134	€ 399.698			
			Curved lines roof level	Pre-fab	€ 171.000	€ 51.300	€ 65.040,41	€ 11.400	€ 51.300	-€ 5.614	€ 281.726			
			Pier Brick elements external	Pre-fab	€ 1.019.990	€ 305.997	€ 38.032,25	€ 45.000	€ 305.997	-€ 36.726	€ 1.327.294			
			Pier Brick elements on the inside	Pre-fab	€ 640.000	€ 192.000	€ 145.646,24	€ 30.000	€ 192.000	-€ 22.795	€ 954.851			
			Closed elements in the elments on floor levels	Aluminium vlak (sandwich-aluminium kern)	€ 170.000	€ 51.000	€ 0,00	€ 6.800	€ 0	€ 957	€ 221.957			
			Demonstration showcase related to Showroom on level 0 grid line 1, 14		€ 142.800	€ 42.840	€ 2.641,22	€ 0	€ 0	€ 0	€ 188.281			
			Canopy main entrance	steel	€ 300.000	€ 90.000	€ 8.536,59	€ 1.000	€ 1.200	-€ 28	€ 398.508			
			Glare control all glass elements	internal sunshading	€ 516.000	€ 154.800		€ 10.750	€ 0	€ 1.513	€ 672.313			
			Other		€ 549.448	€ 164.834		€ 0	€ 0	€ 0	€ 714.282			
			Certificated materials for LEED requirements		€ 216.800	€ 65.040		€ 0	€ 0	€ 0	€ 281.840			
					€ 12.652.690	€ 3.795.807	€ 3.902.728,09			-€ 166.331	€ 20.184.894			
					€ 16.448.497									
Internal walls and finishing	22	Internal walls	Acoustic MS double, MS2	MWA+Gipskartonplaat systeemwand	€ 362.174	€ 108.652	€ 133.652,94	€ 38.805	€ 5.174	€ 4.732	€ 609.211			
			Brandwerend MS double, MS1	Glaswol MWA+Gipskartonplaat	€ 465.652	€ 139.696	€ 184.290,35	€ 58.200	€ 7.760	€ 7.098	€ 796.735			
			Normal walls MS single, MS3	MWA+Gipskartonplaat systeemwand	€ 646.738	€ 194.021	€ 280.226,31	€ 97.005	€ 12.934	€ 11.830	€ 1.132.816			
	32	Internal wall openings (doors and windows)	Acoustic elements	Glaswol MWA	€ 698.477	€ 209.543	€ 24.638,96	€ 11.640	€ 4.656	€ 983	€ 933.642			
			Fire protected	Wood	€ 1.210.694	€ 363.208	€ 19.717,52	€ 15.525	€ 11.644	€ 546	€ 1.594.166	931303		
			Normal elements	Wood	€ 1.362.031	€ 408.609	€ 43.751,43	€ 58.200	€ 43.650	€ 2.047	€ 1.816.439	1047716		
			Special (high) elements	Wood	€ 1.891.709	€ 567.513	€ 28.783.84	€ 29.100	€ 21.825	€ 1.024	€ 2.489.030	1.455.161		
			Flexibel walls	Wood	€ 390.000	€ 117.000	€ 7.939,03	€ 15.000	€ 10.000	€ 704	€ 515.643	300.000		
			Doors, included hinges and locks	Hout; geschilderd: alkyd	€ 493.000	€ 147.900	€ 29.796,00	€ 0	€ 0	€ 0	€ 670.696			
			GLASS - INTERIOR WALL PANEL FI-03	Staal frame element; glas pan	€ 1.187.640	€ 356.292	€ 247.353,65	€ 39.585	€ 15.834	€ 3.342	€ 1.794.628			
			MIRROR - INTERIOR PANEL FI-06	Staal frame element; glas pan	€ 28.000	€ 8.400	€ 5.832,09	€ 600	€ 240	€ 51	€ 42.283			
			GLASS PANEL BENT - WOOD INTERLAYER FI-09	Houten frame, eknel glas	€ 37.500	€ 11.250	€ 7.810,84	€ 225	€ 90	€ 19	€ 56.580			
			other elements		€ 141.855	€ 42.557	€ 29.493,73	€ 2.655	€ 1.062	€ 224	€ 214.129			
	42	Internal wall finishing	Wall finishing assumption	Spray plaster	€ 43.860	€ 13.158	€ 80.307,63	€ 0	€ 0	€ 0	€ 137.326			
			Wall finishing assumption	Spray plaster	€ 213.424	€ 64.027	€ 213.128,32	€ 0	€ 0	€ 0	€ 490.580			
			Wall finishing assumption	Spray plaster	€ 905.434	€ 271.630	€ 497.336,04	€ 0	€ 0	€ 0	€ 1.674.400			
			Wall finishing assumption	Spray plaster	€ 248.710	€ 74.613	€ 160.725,12	€ 0	€ 0	€ 0	€ 484.048			
			Wall finishing assumption	Spray plaster	€ 1.920.813	€ 576.244	€ 468.937,24	€ 0	€ 0	€ 0	€ 2.965.994			
			Based on material schedule (GYPSUM WALL BOARD - INTERIOR L4 FI-01)	Gipspleister	€ 26.364	€ 7.909	€ 36.198,86	€ 0	€ 0	€ 0	€ 70.472			
			Based on material schedule (GYPSUM WALL BOARD - INTERIOR L5 FI-02)	Gipspleister	€ 44.950	€ 13.485	€ 49.382,05	€ 0	€ 0	€ 0	€ 107.817			
			Based on material schedule (GLASS PANEL BENT - WOOD INTERLAYER FI-09)	wooden frame, single glass	€ 3.750	€ 1.125	€ 1.477,84	€ 0	€ 315	-€ 44	€ 6.309			

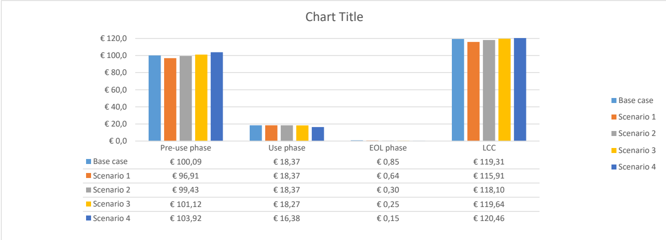
			Based on material schedule (BATHROOM WALL TILE FI-12)	Glazed ceramic tiles	€ 15.130	€ 4.539	€ 7.399,55	€ 0	€ 0	€ 0	€ 27.069	
			Based on material schedule (WOOD WALL PANELS FI-14)	wooden wall	€ 439.565	€ 131.870	€ 231.377,47	€ 0	€ 52.752	-€ 7.423	€ 795.389	
			Based on material schedule (ACOUSTIC WALLS FI-15)	Acoustic cellulose spray plast	€ 89.100	€ 26.730	€ 21.752,27	€ 0	€ 8.316	-€ 1.170	€ 136.412	
			Based on material schedule (PAINTED CONCRETE FI-21)	Wall paint	€ 60.720	€ 18.216	€ 108.275,37	€ 0	€ 0	€ 0	€ 187.211	
			Finishing with colored paint (concrete columns basement)	Paint	€ 87.150	€ 26.145	€ 44.401,46	€ 0	€ 0	€ 0	€ 157.696	
			Finishing fire protected and esthetic (columns GF - top floor)	Paint	€ 264.000	€ 79.200	€ 273.101,10	€ 0	€ 0	€ 0	€ 616.301	
			Finishing with fire protected paint (columns in atrium special curved)	Paint	€ 900.000	€ 270.000	€ 46.609,77	€ 0	€ 0	€ 0	€ 1.216.610	
			Finishing with fire protected paint (columns atrium special)	Paint	€ 200.000	€ 60.000	€ 49.654,74	€ 0	€ 0	€ 0	€ 309.655	
			Insulation walls in loading dock	Rock wool	€ 30.100	€ 9.030		€ 0	€ 0	€ 0	€ 39.130	
			Certificated materials for LEED requirements		€ 191.500	€ 57.450		€ 0	€ 0	€ 0	€ 248.950	
					€ 14.600.040	€ 4.380.012	€ 3.333.351,55			€ 23.962	€ 22.337.365	
					€ 18.980.052							
Internal floor and finishing	23	Floor items (non-load bearing, balconies, arcade, suspended)	Special elements		€ 150.000	€ 45.000		€ 0	€ 0	€ 0	€ 195.000	
			Atrium stair elements GFL > L01	Wooden floor element	€ 290.000	€ 87.000	€ 106.385,63	€ 5.800	€ 0	€ 816	€ 484.202	
	33	Voids	Temporary floors during construction		€ 622.871	€ 186.861		€ 0	€ 0	€ 0	€ 809.732	
			Panelized skin boarders		€ 250.000	€ 75.000		€ 5.000	€ 0	€ 704	€ 325.704	
			Railing along the edges, curved glass	glass + steel	€ 720.000	€ 216.000		€ 7.200	€ 4.200	€ 422	€ 936.422	
	43	Floor finishes	Bicycle and Carparking		€ 358.482	€ 107.545	€ 650.109,17	€ 50.190	€ 0	€ 7.062	€ 1.123.198	
			Service and Storage		€ 138.046	€ 41.414	€ 208.633,36	€ 16.107	€ 0	€ 2.266	€ 390.360	
			Circulation	Anhydriet	€ 195.954	€ 58.786	€ 161.484,58	€ 12.467	€ 0	€ 1.754	€ 417.979	
			Fitness centre	Anhydriet+polystyreen	€ 115.718	€ 34.715	€ 69.907,14	€ 5.397	€ 0	€ 759	€ 221.100	
			Health, hospitality	replaced by ceramic tiles	€ 1.018.618	€ 305.585	€ 421.692,32	€ 31.689	€ 0	€ 4.459	€ 1.750.355	
			Sanitair	ceramic tiles	€ 66.500	€ 19.950	€ 33.153,51	€ 3.724	€ 0	€ 524	€ 120.128	
			Learning centre	replaced by tiles with small thickness	€ 354.663	€ 106.399	€ 100.224,09	€ 8.211	€ 0	€ 1.155	€ 562.441	
			Worksettings	replaced by tiles with small thickness	€ 540.627	€ 162.188	€ 41.754,00	€ 30.275	€ 0	€ 4.260	€ 748.829	
			Drywalk entrance, EMCO three zones	replaced by tiles with small thickness	€ 120.000	€ 36.000	€ 41.754,00	€ 1.400	€ 0	€ 197	€ 197.951	
			Other finishes to be defined control cell	replaced by tiles with small thickness	€ 902.594	€ 270.778	€ 492.915,90	€ 63.182	€ 0	€ 8.891	€ 1.675.179	
			Cement screed or trowel finishing basement levels	NeMO zandcement	€ 192.693	€ 57.808	€ 1.164.756,27	€ 102.768	€ 0	€ 14.461	€ 1.429.718	
			Cement screed ground floor level	Anhydriet	€ 145.323	€ 43.597	€ 118.407,83	€ 46.504	€ 0	€ 6.544	€ 313.871	
			Computerfloor L1 till L4	aluminium+profielen staal	€ 1.718.449	€ 515.535	€ 644.638,22	€ 164.976	€ 274.960	-€ 15.476	€ 2.863.146	
			Extra acoustic insulation	20mm gipskartonplaat + 10mm steewol	€ 112.500	€ 33.750		€ 22.500	€ 3.000	€ 2.744	€ 148.994	
			Certificated materials for LEED requirements		€ 120.200	€ 36.060		€ 0	€ 0	€ 0	€ 156.260	
					€ 8.133.238	€ 2.439.971	€ 4.255.816,04			€ 41.543	€ 14.870.568	
					€ 10.573.209							
Ceiling internal and external	45	Ceiling internal and external	Carparking and MEP B02	just paint	€ 279.616	€ 83.885	€ 440.892,22	€ 0	€ 0	€ 0	€ 804.393	215089
			Service and Storage	Recycled wood	€ 209.369	€ 62.811	€ 42.294,04	€ 46.020	€ 115.050	-€ 9.713	€ 304.760	161053
			Circulation	Recycled wood	€ 289.478	€ 86.843	€ 58.457,26	€ 35.620	€ 89.050	-€ 7.518	€ 427.260	222675
			Fitness centre	Recycled wood	€ 175.505	€ 52.652	€ 35.428,84	€ 15.420	€ 38.550	-€ 3.255	€ 260.331	135004
			Health, hospitality	Recycled wood	€ 882.803	€ 264.841	€ 178.306,15	€ 90.540	€ 226.350	-€ 19.110	€ 1.306.839	679079
			Sanitair	Recycled wood	€ 48.412	€ 14.524	€ 9.778,54	€ 10.640	€ 26.600	-€ 2.246	€ 70.468	37240
			Learning centre	Recycled wood	€ 461.062	€ 138.319	€ 91.010,84	€ 35.460	€ 88.650	-€ 7.485	€ 682.907	354663
			Worksettings	Recycled wood	€ 843.378	€ 253.013	€ 170.349,92	€ 86.500	€ 216.250	-€ 18.257	€ 1.248.483	648752
			Roof in sight, extra ceiling for acoustics	Recycled wood	€ 519.480	€ 155.844	€ 104.927,67	€ 66.600	€ 166.500	-€ 14.057	€ 766.194	399600
			Control cel		€ 766.472	€ 229.942	€ 154.818,21	€ 117.920	€ 294.800	-€ 24.889	€ 1.126.343	589594
					€ 4.475.574	€ 1.342.672	€ 1.286.263,70			-€ 106.531	€ 6.997.979	
					€ 5.818.246							
			Total		€ 103.919.124		€ 16.382.990			€ 153.467	€ 120.455.582	

Graph

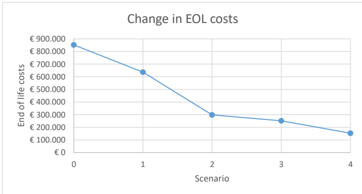
Pre-use phase	€ 103.919.123,95
Use phase	€ 16.382.990,41
EOL phase	€ 153.467,16
LCC	€ 120.455.581,52

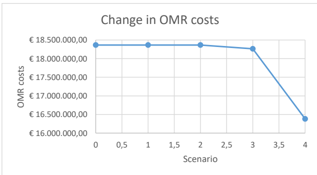


Graph1	LCC costs of all alternatives		
Base	Pre-use phase	€ 100,09	€ 100.091.470,40
	Use phase	€ 18,37	€ 18.365.476,31
	EOL phase	€ 0,85	€ 852.289,56
	LCC	€ 119,31	€ 119.309.236,27
1	Pre-use phase	€ 96,91	€ 96.909.429,50
	Use phase	€ 18,37	€ 18.365.476,31
	EOL phase	€ 0,64	€ 636.333,26
	LCC	€ 115,91	€ 115.911.239,07
2	Pre-use phase	€ 99,43	€ 99.434.499,80
	Use phase	€ 18,37	€ 18.365.476,31
	EOL phase	€ 0,30	€ 298.224,45
	LCC	€ 118,10	€ 118.098.200,56
3	Pre-use phase	€ 101,12	€ 101.120.121,64
	Use phase	€ 18,27	€ 18.265.754,69
	EOL phase	€ 0,25	€ 251.929,93
	LCC	€ 119,64	€ 119.637.806,26
4	Pre-use phase	€ 103,92	€ 103.919.123,95
	Use phase	€ 16,38	€ 16.382.990,41
	EOL phase	€ 0,15	€ 153.467,16
	LCC	€ 120,46	€ 120.455.581,52



Graph 2	Eol costs variation of all alternatives	
EOL	0	€ 852.289,56
	1	€ 636.333,26
	2	€ 298.224,45
	3	€ 251.929,93
	4	€ 153.467,16

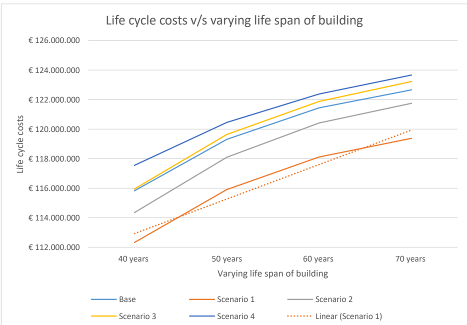




Graph 3	OMR cots variation of all alternatives	
OMR costs	0	€ 18.365.476,31
	1	€ 18.365.476,31
	2	€ 18.365.476,31
	3	€ 18.265.754,69
	4	€ 16.382.990,41

Graph	variation of LCC over diff life span	
40 years	0	€ 115.826.906,24
	1	€ 112.325.197,28
	2	€ 114.349.783,94
	3	€ 115.947.965,40
	4	€ 117.547.711,34
50 years	0	€ 119.309.236,27
	1	€ 115.911.239,07
	2	€ 118.098.200,56
	3	€ 119.637.806,26
	4	€ 120.455.581,52
60 years	0	€ 121.444.712,42
	1	€ 118.116.779,18
	2	€ 120.413.435,29
	3	€ 121.874.889,69
	4	€ 122.382.730,44
70 years	0	€ 122.658.391,69
	1	€ 119.377.791,16
	2	€ 121.748.553,02
	3	€ 123.222.657,50
	4	€ 123.661.928,98

	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 4						
40 years	€ 115.826.906,24	€ 112.325.197,28	€ 114.349.783,94	€ 115.947.965,40	€ 117.547.711,34	3,01%	3,19%		3,28%	3,18%	2,47%
50 years	€ 119.309.236,27	€ 115.911.239,07	€ 118.098.200,56	€ 119.637.806,26	€ 120.455.581,52	1,79%	1,90%		1,96%	1,87%	1,60%
60 years	€ 121.444.712,42	€ 118.116.779,18	€ 120.413.435,29	€ 121.874.889,69	€ 122.382.730,44	1,00%	1,07%		1,11%	1,11%	1,05%
70 years	€ 122.658.391,69	€ 119.377.791,16	€ 121.748.553,02	€ 123.222.657,50	€ 123.661.928,98						



Graph	Variation of LCC over diff discount rate	
3%	0	€ 124.944.353,94
	1	€ 121.412.229,59
	2	€ 123.389.196,84
	3	€ 124.860.566,25
	4	€ 124.919.877,07
4%	0	€ 119.309.236,27
	1	€ 115.911.239,07
	2	€ 118.098.200,56
	3	€ 119.637.806,26
	4	€ 120.455.581,52
5%	0	€ 115.198.067,13
	1	€ 111.882.191,79
	2	€ 114.197.726,16
	3	€ 115.794.814,39
	4	€ 117.129.211,03
6%	0	€ 112.156.995,40
	1	€ 108.891.636,36
	2	€ 111.286.260,83
	3	€ 112.926.447,06
	4	€ 114.620.403,78

	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 4
3,00%	€ 124.944.353,94	€ 121.412.229,59	€ 123.389.196,84	€ 124.860.566,25	€ 124.919.877,07
4,00%	€ 119.309.236,27	€ 115.911.239,07	€ 118.098.200,56	€ 119.637.806,26	€ 120.455.581,52
5,00%	€ 115.198.067,13	€ 111.882.191,79	€ 114.197.726,16	€ 115.794.814,39	€ 117.129.211,03
6,00%	€ 112.156.995,40	€ 108.891.636,36	€ 111.286.260,83	€ 112.926.447,06	€ 114.620.403,78