Research Report

PRESERVING THE PAST, ENERGIZING THE FUTURE

Assessing the interplay of intervention stratgies on Heritage Value and Energy Efficiency

AR3AH105 Graduation Studio
Adapting 20th Century Heritage

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Abstract

This research explores the challenge of revitalizing heritage properties, facing periods of vacancy, and the potential risk of demolition. Focusing on sustainability aspects, the study delves into the embodied energy and operational energy.
The research seeks a balanced approach, identifying material and strategies that optimize both operational efficiency and heritage value while minimizing increases in embodied energy. The conclusion emphasizes the importance of analyzing building strengths and weaknesses, reducing material consumption, and incorporating sustainable technologies to achieve a comprehensive and sustainable redevelopment approach.

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1. Research Introduction

1.1 Concept and relations

As society changes rapidly, so do the norms and values within a society, within the built environment, the same principle applies. Renewed requirements and expectations are placed on the already existing building stock because of environmental reasons (Fatorić & Egberts, 2020).
Meanwhile, the constant developments in architecture and technology continues to reshape the building landscape. In this ever-evolving scenario, buildings are sometimes slated for demolition to make way for new construction (Wassenberg, 2011).

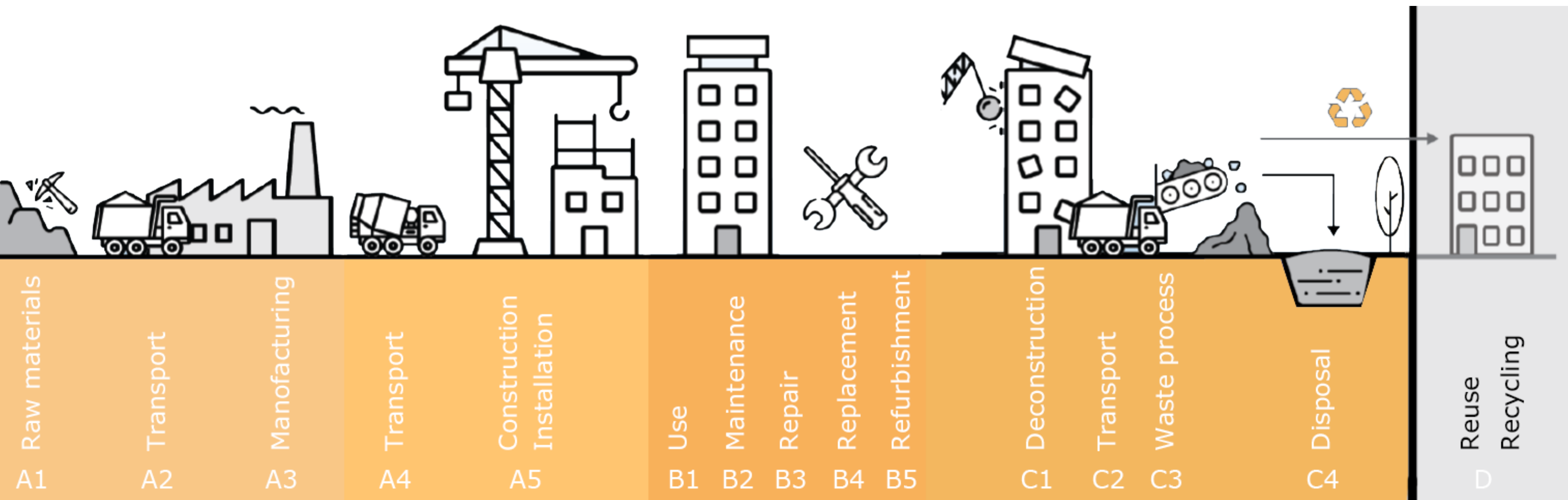
Amid this ever-evolving landscape, heritage buildings emerge as distinct buildings due to their historical and cultural significance (Clarke et al., 2019). The preservation of these structures becomes a matter of great importance, as they embody priceless aspects of our collective heritage.
However, despite their values, heritage properties can face challenges, including periods of vacancy (Ministry of Education, Culture and Science, 2022). This raises the crucial question of how such properties can regain meaning and purpose, but also if such revitalization is feasible at all.
If not, heritage buildings may be at risk of demolition (Amsterdam Sloopt, 2023). Therefore it becomes important to assess different strategies upon their impact on heritage. When exploring alternative solutions for the redevelopment of heritage buildings, it becomes important to examine whether sufficient attention is given to sustainability aspects in these interventions (Bertolin & Loli, 2018).
In the pursuit of the admired sustainable redevelopment, it becomes essential to consider the energy implications associated with construction and building use (Lidelöw et al., 2019). What is the impact of such interventions on embodied energy and the operational energy use of a property?

The concept of embodied energy contains the total energy expenditure throughout a material's life cycle (Dixit, 2017). Therefore embodied energy offers a holistic perspective on the environmental impact of construction materials. The embodied energy of material exists out of three phases (Guidetti & Ferrara, 2023), these are:

- Construction stage (A)
- Use stage (B)
- End-of-life stage (C)

To this, the quantity beyond system (D) (Guidetti & Ferrara, 2023) is often added as the fourth stage. Each stage has its subcomponents (see figure), by adding these values together you arrive at the total amount of embodied energy for a material. In the formula, this looks as follows:

$$EEex = EE(A_{ex}) + EE(B_{ex}) + EE(C_{ex}) + EE(D_{ar})$$



By looking at the whole life cycle of construction materials, it can be concluded that the embodied energy, measured in [MJ/m³], becomes a crucial indicator for assessing the sustainability of construction practices.

Operational energy, on the other hand, accounts for the energy consumed during a building's use, encompassing heating, cooling, water provision, lighting, and machinery operation (Ding & Ying, 2019). Minimizing operational energy becomes a central goal in sustainable heritage redevelopment, given the buildings' substantial contribution to global energy consumption (Dixit, 2017). However, when dealing with heritage buildings, improving operational energy efficiency poses a unique challenge. Structures of heritage buildings often feature outdated systems that may not align seamlessly with modern energy conservation practices (Lidelöw et al., 2019). Striking a balance between enhancing energy efficiency and preserving the heritage value of a building requires innovative solutions and a holistic understanding of the interplay between heritage conservation and sustainable operational energy practices (Akande et al., 2014).

1.2 Problem Statement

Despite the growing recognition of heritage value and the need for sustainable redevelopment (Aigwi et al., 2023), the challenge remains in implementing interventions that improve both the operational efficiency and the heritage value of a property, without significantly increasing the embodied energy. This research focuses on identifying strategies that offer a balanced approach where sustainability and heritage conservation go hand in hand.

1.3 State-of-the-art

At the moment, there are a great number of studies on the key concepts of my research (heritage, value assessment, embodied energy, operational energy). Although these studies can be used for a literature review, they do not give a direct answer to the research question of this research. More interesting academic articles occur when a relation between the different concepts is made. The academic report by Ding and Ying (2019), for example, calculates analysis for 2 different scenarios. Demolishing a property or, redeveloping it. The academic report by Ding and Ying (2019), for example, calculates analysis for 2 different scenarios. Demolishing a property or, redeveloping it. Another example is the work by Loussos et al (2015) comparing different strategies for facade renovation. Here, they look at the impact on both embodied and operational energy. Thus, several studies are highlighting the importance of energy efficiency in construction and investigating this. However, in the area of heritage, research on this is lacking. So there is no discussion of the impact of these interventions on both energy efficiency and the heritage value of a property and the relation between them. This is where this research tries to distinguish itself.

1.4 Aims & Objectives

This study outlines and assesses the impact of different intervention strategies on three aspects. It looks at the impact on heritage value, operational energy, and embodied energy. With this, the study aims to provide insights, in terms of the relation between energy efficiency of redevelopment strategies and the impact these strategies have on the heritage value. These insights can be instrumental during a decision-making point, in which different possible scenarios are being discussed.

1.5 Research Question

The research question for this research is: ***How can redevelopment interventions achieve a balanced approach that enhances both operational efficiency and heritage value, while minimizing the increase in embodied energy?***

Along with other sub-questions such as:

- In what ways do the operational energy and the embodied energy of heritage buildings differ from more common structures?
- What strategies have been employed in the revitalization of heritage buildings to improve the operational energy of the building?
- How do different materials contribute to the embodied energy of heritage building components?
- How do different strategies contribute to the embodied energy and the operational energy of a heritage building?

1.6 Methodology

1.6.1 Theoretical Framework

In terms of heritage, it is essential to understand different values of heritage (Clarke et al., 2019, Lidelöw et al. (2019). Concerning this study, we derive the heritage values from the literature of Tarrafa Peira da Silva & Pereira Roders (2012). They combined the cultural values introduced in the literature of ICOMOS Australia (199), Manson (2002), Pereira Roders (2007) & English Heritage (2008). The values are distinguished in the literature according to eight categories, these are social, economic, political, historical, aesthetic, scientific, ecological, and age values. All of these categories contain secondary values, that allow a more specific value assessment of each category.

Fig 2. The values framework (Tarrfa Peira da Silva & Pereira Roders, 2012)

1.6.2 Methods

This research is about exploring the relationship between sustainability and the value assessment of heritage buildings. Because the focus in terms of sustainability lies on the embodied and operational energy of a building, the methodology that will be applied is similar to the methodology in the research of Loussos et al. (2015). This study focuses on the extent to which design choices affect operational energy and embodied energy.

In my research, an additional step is added to the methodology of Loussos et al.(2015). Namely, an analysis of the case study. The analysis focuses on three indicators:
- the heritage value of the building
- the embodied energy
- operational energy,

The analysis should give insight into the current state of the building in terms of these indicators. In addition, the analysis reveals what parts contain a lot of embodied energy and should therefore be preserved, where the heritage value of the building lies, and what the operational energy of the building would be if the building were used today.

After the analysis is done the focus shifts towards a literature review. The literature review focuses on different design strategies related to the three concepts, embodied energy, operational energy, and heritage.
Then a material comparison is made that focuses on the embodied energy of different materials. The comparison will classify the different materials, from this, a materials palette will emerge. From this palette, it can be concluded which materials are the most sustainable.

Subsequently, with the use of the material palette, different design strategies will be tested in the design case. A division has been made of different elements of a building where interventions can be made (A-E). In this report, we look at strategies focused on the facade, the roof, and then a combination of all elements, from A to E.

Each strategy will have some different variants. These will be compared with their impact on embodied energy, operational energy, and heritage value. The results of these comparisons will be displayed in a graph. This graph will form the basis for decisions that will be made during the design phase of this project and can be seen as the end product of the research.

The calculations in the study will be done in different programs. To calculate the embodied energy, the Grasshopper program will be used. In addition, the ClimateStudio software will be used to calculate the operational energy. The material database of NIBE will act as a source for the validation of the material values. The lower the embodied energy and the operational energy of the material, the more sustainable the material is (Koezjakov et al., 2018).

In terms of the embodied energy and the operational energy, it is more concrete to assess the strategies, because they are based upon calculations and numbers. However, this does not count for the heritage value of a building. Therefore a pivotal aspect of this analysis lies in the classification and evaluation of these interventions in terms of their impact on the heritage value. Based on the

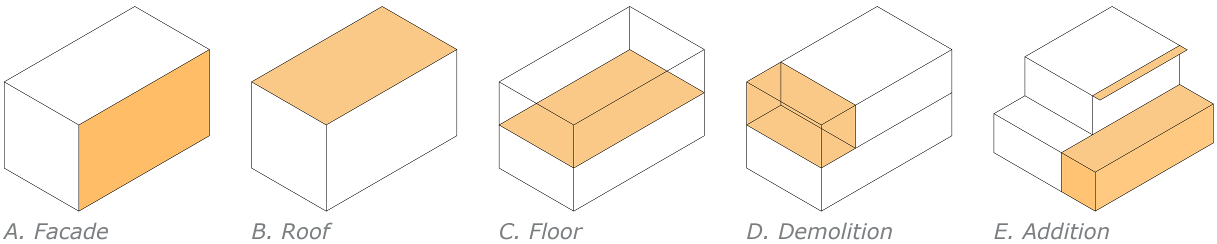


Fig 3. The different elements of a builiding for interventions (own image, 2023)

the literature of Tarrafa Peira da Silva & Pereira Roders (2012) the strategies will be rated and subsequently compared with each other.
A rating system has been developed to classify the interventions.

- The Heritage Value is lost: A rating of 1 means that the heritage value has been completely lost. Significant alterations have irreparably damaged the heritage value of the building.
- The Heritage Value is diminished: The rating of 2 means that the heritage value has notably been reduced. Some values do remain, however, the interventions have diminished the overall significance of the heritage building.
- The Heritage Value is altered: Although new elements and changes have been made, the original character of the building has been maintained. The design has transformed noticeably but includes the heritage value of the old building.
- The Heritage Value is maintained: The heritage value has been preserved, and there have been some small alterations that do not damage the significance of the old building.
- Heritage Value is fully preserved: A rating of 5 shows that the building has been virtually unchanged

2. Analysis of Desing Case

To delve into the research case, various facets of the property are examined.

1. The property's heritage value is evaluated by referencing the insights provided in the study conducted by Tarrafa Peira da Silva & Pereira Roders (2012). The building is subjected to a detailed analysis based on these values.
2. This examination explores the embodied energy within the building, it is an assessment of the materials employed. This involves examining the supporting structure, identifying common materials, and pinpointing areas with the highest embodied energy – areas that need preservation or maximal reuse.
3. The operational energy of the property is lastly examined, by delving into the buildings physical values, complemented by the use of the Climate Studio program. This comprehensive analysis enables the calculation of the current energy requirements for making the building habitable.

Through this analytical process, strengths and weaknesses come to the fore, paving the way for a SWOT analysis that offers a depiction of the building's overall condition.

2.1 Heritage analysis

2.1.1 General Information

The chosen case is located in Amsterdam Nieuw-West, an urban district in Amsterdam that was built on a large scale after World War II. Part of this urban expansion was the Western Garden Cities (ProWest - promotion Western Garden Cities, n.d.). The characteristic of this urban structure is the open building style, with lots of greenery located between the buildings (Havinga et al., 2020).
The chosen case, located at Plesmanlaan 1, is located in the southern part of Amsterdam Nieuw-West, in the Slotervaart neighborhood. The building formerly occupied the function of a Call center. These buildings used to be needed to connect telephones.

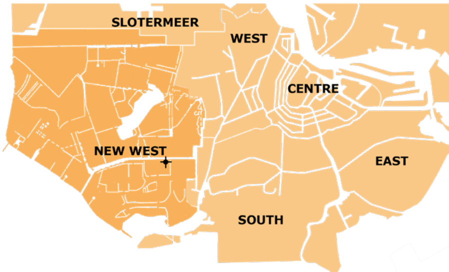


Fig 4. Urban districts of Amsterdam (Own image, 2024)

However, currently the building is largely empty, as telephone exchanges have become obsolete in this era. The building was designed by Bastiaan Johannis Odink and was built in 1960. In addition to the telephone exchange on Plesmanlaan, Odink also designed 2 other telephone exchanges elsewhere in Amsterdam (Amsterdamopdekaart, 2017). These contained a similar style, but have been demolished in recent years. With this, the telephone exchange in Slotervaart is the only one still standing. The building has become a listed monument in Amsterdam for this reason.

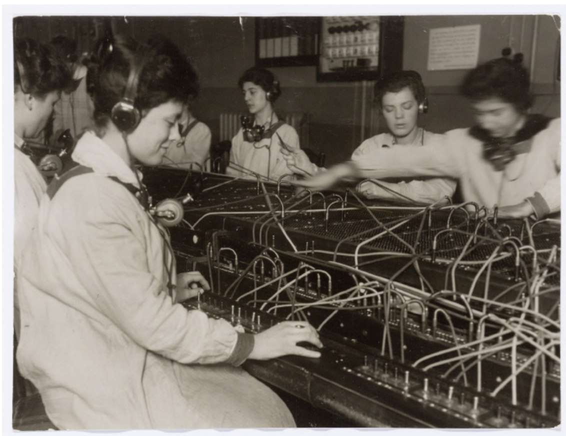
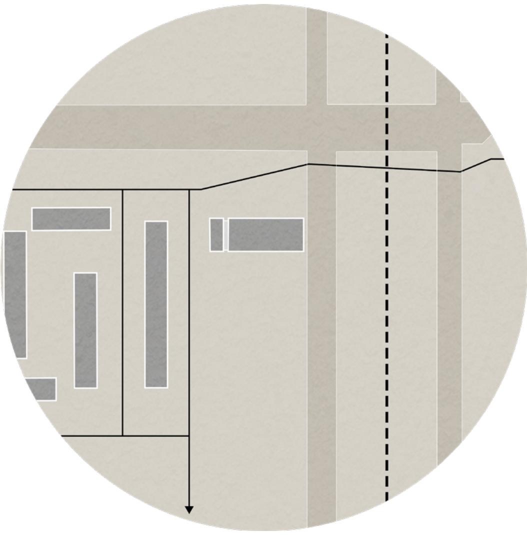
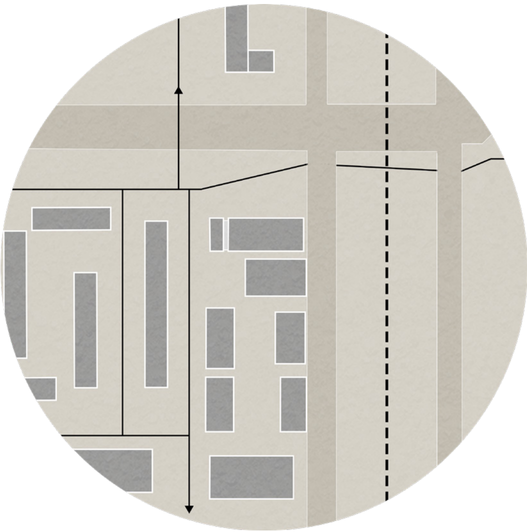


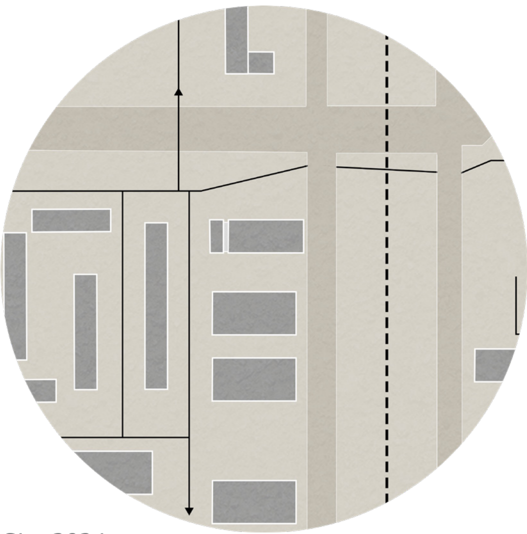
Fig 5. Machinery in the Call Center (Beeldbank Amsterdam, (1964)



Site 1960



Site 1980



Site 2024

Fig 6. Urban development (Own image, 2023)

2.1.2 Urban Developments

The building was one of the first projects realised in Slotervaart. Over the years, however, other buildings have been built around the call center, mainly including offices and housing. Immediately south of the building, several office buildings have been demolished over the past few years. Here, large residential towers and apartment complexes are now being built by FLOW development, transforming this area into Plesman Plaza. Therfore the call center somewhat obliged to go along with this renewal so that the building can be of use to its immediate surroundings.

2.1.3 Heritage values

Finally, the heritage values of the property will be revealed using the values of Tarrafa Peira da Silva & Pereira Roders (2012). Only if a value belongs to the building will it be highlighted.

Social values
Despite having no permanent function, the building currently occupies a temporary function. The ground floor of the building is now used as a boxing school and has a very positive impact on the neighborhood (J.Snijders, 2023). Many young people are involved in the boxing school, and a community has developed at the boxing school. An aspiration for my design brief could be to maintain this social value. Or it can be a starting point to improve the building to allow the social value to reach its full potential.

Historical values
Because the building's former function was as a telephone exchange, at that time it was not a requirement to receive an awful lot of daylight inside. This made experimentation of the facade possible. The facade was designed consisting of concrete facade

elements, which leave a large part of the facade closed. Frames were placed in a few places. Nonetheless, in a sense, this reflects a narrative that emphasizes the temporary significance of the building's function.

Aesthetic values
The facade, so to speak, consists of several concrete facade elements. The basic shape of the element is rectangular, however, the edges of the volume protrude prominently. The consistent repetition of the concrete façade elements creates a significant grid. The grid is interrupted by an entrance and a connecting volume. This creates a contrast that divides the building in two. A solution for this should be sought in the design phase. In addition to the façade elements, the building has a unique 25-meter-high chimney that serves as a visual attraction from a distance.

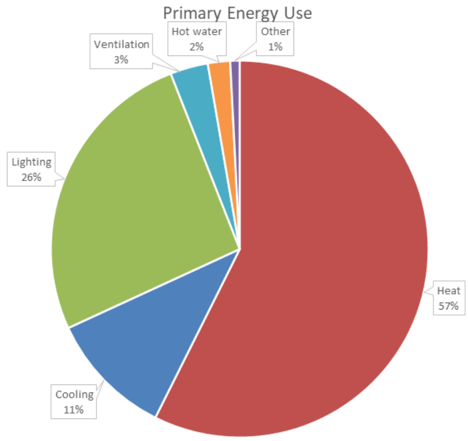
Age values
The building was built in 1960, making it more than 60 years old. Especially the application of the concrete facade is an essential value. The fact that the facade is still in use after all these years attests to the quality of the material used

Fig 7. The Call Center in 1960 (beeldbank Amsterdam, 1960)

2.2 Operational Energy

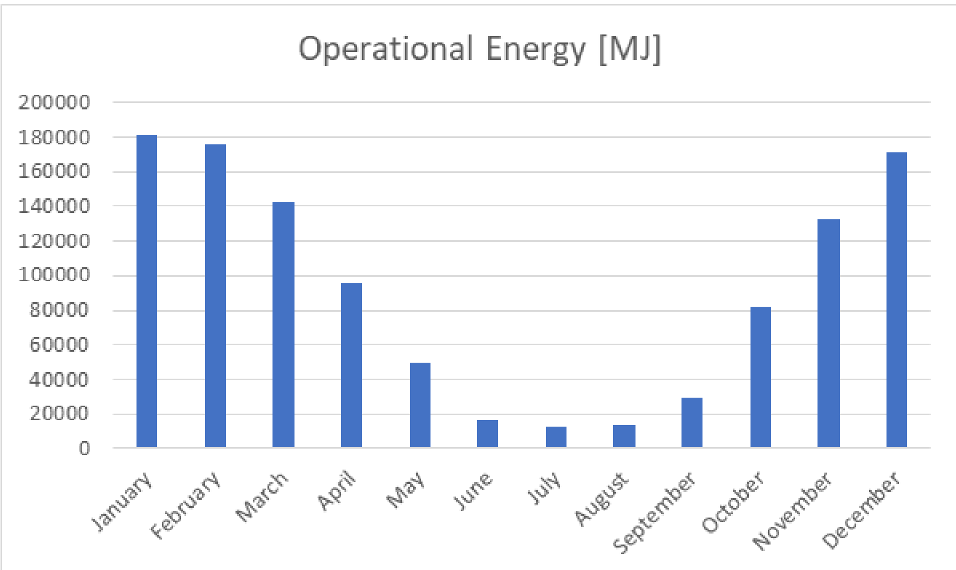
By entering various values, related to the case study, into Climatestudio program, a simulation is made of the operational energy in the building in its current state. The building physics values are determined by analysing archive drawings and notes from the construction of the Call Center. Some values, such as lighting power output, are estimated as realistically as possible.

By then placing these values in a Excel graph (per month), the operational energy becomes visually clear. The results show that currently most energy is needed for heating and cooling the building, mainly due to the low insulation in the buildings envelope and the low U-values of the windows. It was found that the energy consumption is currently 253 kWh/m², which is insufficient and means that the building has an energy label of D. The total operational energy per square meters would then be 889.2 MJ/year/m², which leads to a total of 1.978.470 MJ/year. Chapter 3.5 will determine what strategy can be applied to improve the operational energy of the building.



Graph 1. (Primary Energy use of Call center (Own image, 2023)

As we can see, the operational energy consumption of the property is currently too high. This makes sense, as shown in the study by Van Krugten et al. (2016), which shows that historical properties before 1970 generally have lower energy efficiency than properties after 1970. The aspiration could be, to be able to achieve an energy label A for the property. This would require a maximum energy consumption of 100 kWh/m² per year (Ministry of General Affairs, 2022).

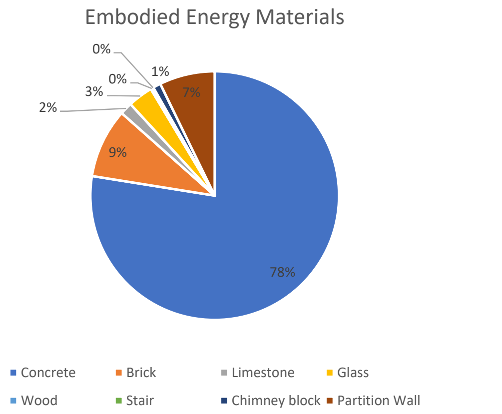


Graph 2. Operational energy per year of Call Center (Own image)

2.3. Embodied Energy

Besides analyzing the property's heritage values, this study also looks at how we can make the listed building energy efficient in total. This requires also an analysis of the embodied energy stored within the building. Therefroe, in this section, we focus on the embodied energy in the design case. For the calculations of this analysis, it is first of all important to model the building in 3D in a CAD program. By using archive materials, this can be done very precisely. Ending up with a one on one model of the building with the right properties. This allows us to use calculations to determine the different amounts of energy (Lidelöw et al., 2019) (Al-Sakkaf et al., 2021). By structurally modeling the building, we can distinguish the different types of materials used in the building. This is useful as each material has its properties.

After the building has been modeled in CAD, the Grasshopper (see appendix) script can be started. This script separates the different materials and calculates the volumes of each type of material. In doing so, it comes to the conclusion which materials are present in greater quantity, compared to others.
By then multiplying the volumes of the materials with the Embodied Energy [MJ/m^3] number belonging to the material, the total amount of Embodied Energy [MJ] can be calculated. The first number has been derived from the



Graph 3. Ratio of EE in Call Center (own image,2023)

NIBE database. It contains a sum of the embodied energy of the material's life cycle. This means from the production phase (A1) to the end-of-life phase (C3) (NIBE Milieuclassificatie Bouwproducten, 2021).
The results of the calculations are visible in the pie chart. It turns out that concrete is not only the most commonly used material within the building, but it also has the highest total amount of embodied energy. Especially the concrete floor slabs take in a prominent amount of embodied energy. Because of this high amount of embodied energy, it is more plausible to try to preserve or reuse these materials (Guidetti & Ferrara, 2023).

Materials such as limestone, glass, and the wood of the window frames contain much less embodied energy. Therefore, should a strategy for replacing these materials be chosen, the amount of embodied energy does not prevent this operation from being carried out.

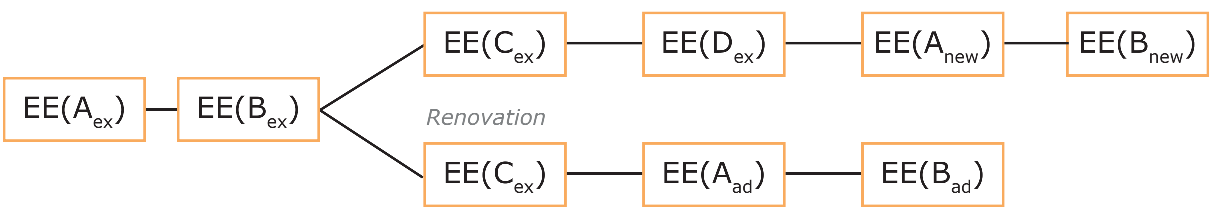
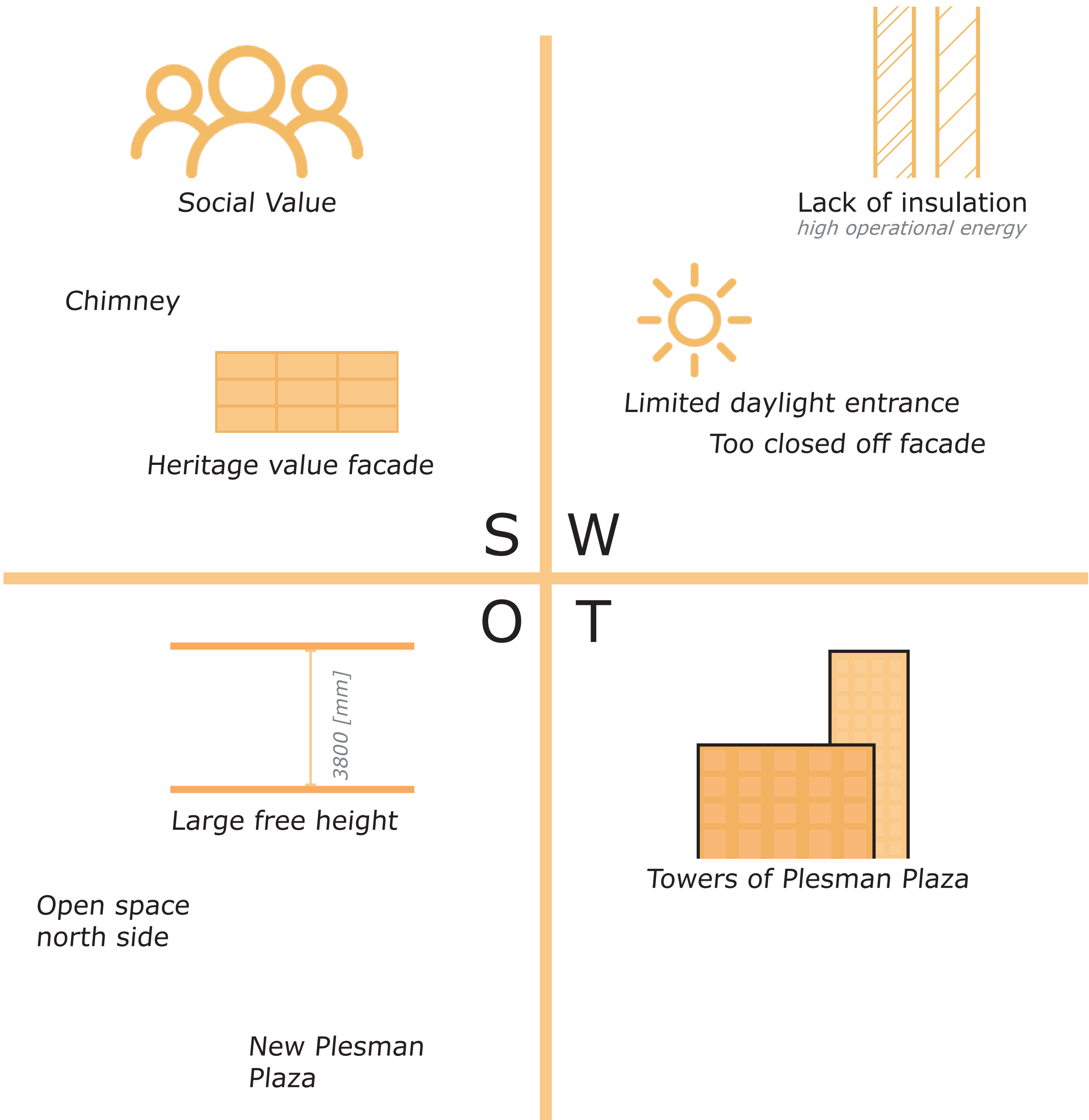


Fig 8. Impact of different scenarios on the Embodied Enrgy (own image, 2024)

In a subsequent chapter, different scenarios will be calculated. By doing this, a statement can be made about which plan is the most sustainable looking at embodied energy.

2.4. SWOT Diagram

The SWOT diagram, that can be seen below this text, shows the strengths, weaknesses, opportunities and threats related to the design case. It can be seen as an conclusion for the analysis of the case study.



3. Research

3.1 Heritage vs Common

Concerning redevelopment initiatives, there are distinct challenges associated with enhancing operational energy efficiency, applicable to both heritage buildings and structures related to more conventional architectural norms. However, it is important to acknowledge that these challenges diverge significantly from one another (Webb, 2017). Heritage buildings, as expounded by Tarrafa Pereira Da Silva and Pereira Roders (2012), are characterized by multifaceted attributes such as social, economic, political, historical, aesthetic, scientific, ecological, and age-related values. In contrast, more common buildings are typified by their facade construction and support structure, as highlighted by Webb (2017).

The difference between the two categories of buildings concerning energy retrofits manifests in the intricate nature of heritage buildings. The characteristic features inherent to heritage structures pose challenges in the application of interventions that may be readily suitable for traditional buildings. Noteworthy complications include the potential absence of insulation or irregular geometry within heritage buildings (Webb, 2017; Fatorić & Egberts, 2020). Furthermore, heritage buildings are guided by conservation principles, aiming to safeguard the historical significance of the structure; however, these principles simultaneously impose limitations on interventions that could optimize operational energy efficiency within the building.

While energy retrofits in traditional buildings often exhibit replicable patterns, the same cannot be said for heritage buildings, where such endeavors are notably less prevalent. Nevertheless, it remains crucial to explore and comprehend how interventions can enhance energy efficiency in these culturally significant structures. Webb (2017) provides a comprehensive set of assessment methods that can be employed in this context.

One such method is building analysis, wherein the monitoring of climate conditions within the structure allows for a nuanced understanding of its current state. This analysis unveils not only existing issues but also sheds light on future potential problems, and opportunities for improvement, as well as the inherent strengths and weaknesses of the heritage building.

Another valuable approach is Building Performance Simulation, which involves utilizing the existing conditions of the building as a reference point and then simulating various scenarios to determine the most effective course of action through comparative analysis. It is important to note, however, that Webb (2017) highlights certain limitations in this process, particularly regarding the appropriateness of standard modeling assumptions. Additionally, the availability of data may pose constraints, emphasizing the need for caution and consideration of potential limitations in the pursuit of energy-efficient interventions in heritage buildings.

3.2 Types of heritage interventions

There is a gradation of interventions that can be made to a heritage building. These range from preservation to demolition of a property (Bertolin & Loli, 2018), progressing from the most passive actions to the most radical actions. The explanation of the following concepts is based on the literature of Bertolin & Loli (2018).

1. Preservation - interventions required to preserve the existing materials and integrity of the property. It can be seen as part of the standard maintenance done at a property. This also includes acts such as examining and assessing material changes.

2. Conservation - These are acts that are directly applied to the building to extend the life of the building.

3. Maintenance - These are routine actions that are not deconstructive, applied to maintain the desired state of a building to actively assign a function to it. Maintenance includes preventive actions as well as actions linked to the preservation of the building.

4. Reparation - Acts aimed at restoring the functionality or appearance of a building. Some forms of repair can be seen as maintenance. If new materials are applied to complete repair, the material should match the original.

5. Refurbishment - These operations change the existing building, with the aim that the building will end up in an improved (and acceptable) condition. Refurbishment includes, for example, the following actions: giving a facelift to a façade or energy retrofitting a building so that it meets current standards. This involves looking at the existing and respecting the building's historical construction, materials, and authenticity.

6. Replacement - These interventions involve making structural changes to a building that result in a change in a character-defining part of a building. This action is mainly applied when the level of decay of the existing material is too great and therefore needs to be replaced.

7. Rehabilitation - Creating new use of an existing property, this can include modernisation of the property but also structural changes. It should apply a contemporary function within the heritage character of the property, making minimal changes to the elements that provide this heritage character.

8. Renovation - This involves renewing elements and systems of a building because of the law. Actions included here are stabilization and improving energy efficiency. The aim is thus to comply with contemporary law.

9. Restoration - The purpose of restoration is to return the existing building to its original state/condition. It may result in the removal of certain elements that have historical value, this in turn comes at the expense of the heritage value of the property.

10. Demolition - the existing parts of a building are demolished, or even completely. It changes the physical form of a building in its complicity. It should not be encouraged to demolish heritage properties.

3.3 Exploration of strategies

3.3.1 Strategies to limit the embodied energy

Material selection
The initial choice of materials is a crucial factor when it comes to the embodied energy of a building. Indeed, each material represents a different amount of embodied energy, mainly influenced by variations in production, transportation, and use (Guidetti & Ferrara, 2023). By making strategic decisions regarding the materials used, the total embodied energy can be significantly reduced (Dixit, 2017). In next chapter 3.4, a comprehensive analysis is done on the embodied energy of different types of materials. In addition to material choices, architectural choices also directly affect the embodied energy of a building. This can include minimizing the use of structural materials, emphasizing flexible and efficient spaces, and incorporating materials that are dismountable and reusable (Guidetti & Ferrara, 2023).

Reusing materials
Reusing materials significantly reduces the amount of embodied energy (Dixit, 2017). Reusing materials involves using the material for the same purpose without compromising the integrity of the material (Thormark, 2002). This approach not only helps reduce ecological impact but also ensures that the already existing resources are utilized efficiently.
In addition, there is the possibility of recycling materials, which is also a sustainable practice (Thormakr, 2202). Recycling involves breaking down the material and adding it again in the production of a new product. Using this method not only extends the life of a material but also reduces the need to use new raw materials(Thormark, 2002).

Adaptive Reuse
When heritage properties are at risk of becoming vacant or even considered for demolition, a good solution may be to give the property a new function (Lidelöw et al., 2019). The entry of a new function increases the likelihood that the property increases in economic value, urban valuation, and energy efficiency (Aigwi et al., 2023). As the building gains a new function and is reused, the probability of demolition is lower, this results in no increase in embodied energy. In addition, the probability of making the traditional building more sustainable (e.g. through insulation) is increased by integrating a new function. This in turn affects operational energy consumption, which is reduced by these measures (Aigwi et al., 2023) (Ibn-Mohammed et al., 2013). Therefore adaptive reuse can be considered a sustainable method to reduce both operational and embodied energy

Fig 9. Caixaforum Madrid (Herzog & de Meuron, 2008) Succesfull adaptive reuse project in Spain.

3.3.2 Strategies to decrease the operatinal energy

Adding Insulation
As explained already in the text, the revitalization of heritage buildings poses a unique challenge as it requires a balance between preserving historical significance and incorporating more modern sustainability practices to improve the operational energy efficiency. Nevertheless, this chapter looks at how sustainable interventions are made to improve the operational energy of a building.

As we discussed, the choice of material has a certain impact on the operational energy and the embodied energy. However we shift our focus now on the strategy in which an insulation material can be applied to the building. For example, roofs, floors, and facades can all be insulated. Here, different methods of insulation can be used for each component. For now, we focus on insulating the facade. This can be done in several ways. Firstly, insulation materials can be placed on the outside of the façade. By doing this, there is a change a heritage building loses some aesthetic & age-related values (Pereira Da Silva and Pereira Roders, 2012). This becomes clear in the study of by Havinga et al. (2020). The study shows that this method has often been applied in post-war neighbourhoods a A conclusion was that the insulation did cover up the masonry of the original facade. Therefore this strategy was assessed as a negative strategy to reduce the operational energy since it decreased the heritage value of the buildings.

Fig 10. Different buildings where insulation is applied on the outside of the facade, losing the sight of the masonry (Havinga et al., 2020)

An alternative method, for applying insulation, is to apply it on the inside of the building envelope. This is illustrated in the 'De Koningsvrouwen van Landslust' project in Amsterdam, implemented by the architectural firm Archivolt (Loussos et al., 2015). The details show how this approach was implemented. By adding two additional layers of insulation, 50 mm rock wool and 60 mm PIR, the Rc value of the facade was increased to 4.1 m²K/W. Space was deliberately left between the existing wall and the new insulation to avoid moisture problems. In addition to the facade insulation, insulation was also installed around the window frames to avoid cold bridges.

Details also show improvements to the floors and the walls separating dwellings, both in terms of thermal insulation and sound insulation
Compared to the previous strategy, fewer heritage values are affected by insulating the inside of the building envelope. Indeed, the age, aesthetic, and historical value of the façade are not affected, this would have been the case when insulating on the outside of the façade.

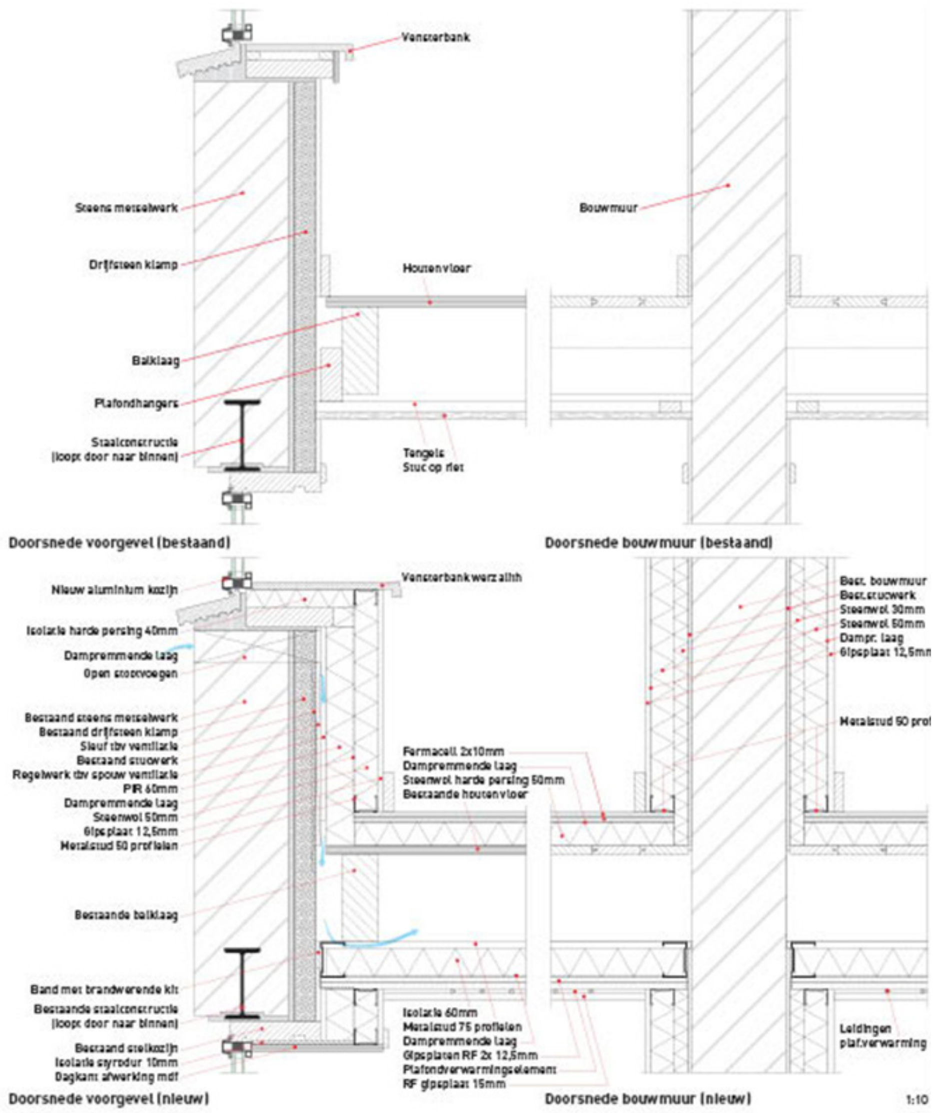


Fig 11. Details of project 'Koningsvrouwen van Landslust' (Wind, 2011)

Window Replacement

Heritage buildings frequently contain single-pane windows that offer limited insulation, this results in an increased energy consumption for heating and cooling. Addressing this concern leads to interventions aimed at enhancing the U-value of the windows. Among the various approaches available, the replacement of windows and frames emerges as a viable solution. Notably, studies such as Lidelöw et al. (2019) assert that this intervention can be executed without substantially losing the heritage value of a property.

However, caution is warranted in the execution of such interventions, as evidenced by the findings of Havinga et al. (2020). Their academic report delves into the heritage attributes of post-war housing estates in Amsterdam, revealing a notable loss of value associated with window frame replacements. The study identifies the replacement of window frames as one of the most negatively perceived interventions. In many instances, fenestration was inadequately considered, leading to suboptimal outcomes.

A critical observation from Havinga et al.'s (2020) report emphasizes that, in some projects, the choice of window frames often prioritizes cost considerations over the architectural value inherent in these elements. This oversight diminishes the aesthetic and historical integrity of heritage structures .

The latter was also the case with the 'De Koningsvrouwen van Landslust' project; the original building dates from 1938 and was characterized, among other things, by its steel window frames. These were replaced by white aluminum window frames in 1980. However, this affected the historical and aesthetic values of the facade. In the more recent renovations in 2011, the facade was restored to the millimeter (Wind, 2011). New aluminum window frames are now similar in aesthetic appearance to the original steel window frames

Fig 12. Replacement of window frames without considering the heritage value of the former frames (Havinga et al., 2020)

Fig 13. Change of window frames at the project 'Koningsvrouwen van Landlust'

Smart services
To get the operational energy of a heritage property to a lower amount, only improving the insulation in the buildings envelope and replacing its windows are not enough (Lidelöw et al., 2019). Smart systems should also be added in the property. Indeed, HVAC systems(heating, ventilating, and conditioning) are important for thermal comfort in the building. Despite the potential importance of these services, efforts should be made to minimise dependence on HVAC systems (Kuipers & De Jonge, 2017). This is because the systems take up a lot of space and you don't want them in view, because of their appearance and noise, so they will have a lot of impact upon your interior (Kuipers & De Jonge, 2017). In terms of lighting systems, historical lighting systems are often replaced, because they do not meet the requirement of our time. It is more sustainable to switch to LED lighting (Kuipers & De Jonge, 2017), as they are more energy efficient.

Renewable energy integration
Finally, we look at the use of renewable energy sources. The most effective form of renewable energy is solar energy, using PV panels and solar heating systems (Lucchi, 2023). Integrating these systems significantly reduces the operational energy of a historic building. Nevertheless, the use of PV panels also has a downside. These panels are preferably not visible, and can emphatically affect the heritage value of a property if they are (Kuipers & De Jonge, 2017) (Lucchi, 2023). Lucchi's (2023) diagram shows how, the more visible the panels, the higher the resistance to the application of PV panels. It may therefore be important to map the visibility of the panels through analysis. That way, it can become clear whether the panels are visible or not. If they are not, the application of PV panels can be considered. This may ultimately make the property more sustainable as renewable energy reduces operational energy. On the renovation project of 'The King's Wives of Landslust', PV panels have also been installed on the roof, they are not visible. The panels power the collective installations and are one of the reasons why the property went from energy label G to A.

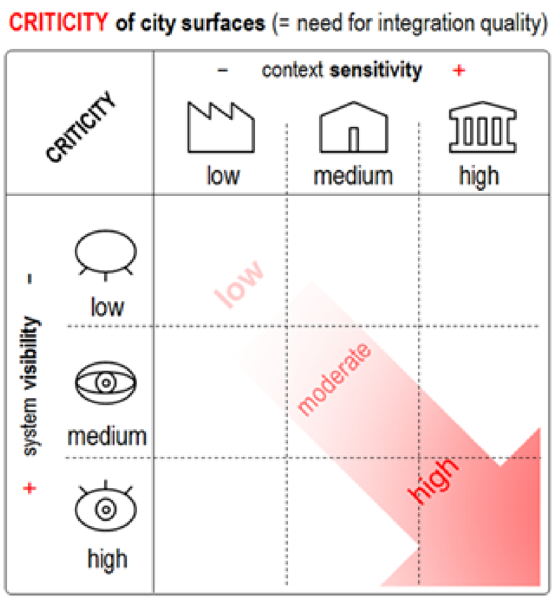


Fig 14. Estimation of critics for use of PV-Panels based upon the visibility of them and the context sensitvity (Lucchi, 2023)

3.4 An analysis of construction materials

By delving into diverse design strategies, the selection of materials emerged as a pivotal factor. Therefore it is important to investigate the embodied energy associated with each type of material. This is the key focus of this chapter.

Temporal elements & Embodied Energy
The exploration starts with a precise dissection of materials, categorized by their application in facade fragments, roof elements, and floor components. In order to measure the sustainability of these materials, consideration is attended to their service life and the amount of embodied energy these materials hold. The temporal dimension becomes important, as the lifespan of materials directly impacts the embodied energy associated with them (Loussos et al., 2015). As materials reach the end of their service life, their embodied energy increases. In the context of this study, the material demonstrating the least amount of embodied energy over time is the most sustainable option.
Thus, the assessment of materials extends beyond their immediate attributes, delving into the interplay between their inherent properties and the temporal dimension. By comparing different materials based on this context, materials can be chosen based on sustainability.

Building Elements
This study focuses on the sustainable redevelopment of heritage buildings. During the analysis, it became evident that materials associated with the supporting structure and foundations possess a substantial amount of embodied energy. Consequently, these materials have been excluded from the analysis due to need to preserve them. Therefore this chapter limits itself to the assessment of the following categories:

- Façade insulation [Façade interventions]
- Glass[Façade interventions]
- Window framing [Façade interventions]
- Cladding materials [Façade interventions]
- Roof insulation [Roof interventions]
- Floor insulation [Floor interventions]
- Floor finishing [Floor interventions]
- Partition walls [Addition of elements]

Each material possesses a unique quantity of embodied energy, denoted in megajoules per cubic meter (MJ/m³). By illustrating this relationship in conjunction with the product's lifespan, one can derive insights into the sustainability profile of the material in question (Loussos et al., 2015). Every category will assess different types of materials related to their category. Thereby providing a comprehensive perspective on their ecological impact over time.

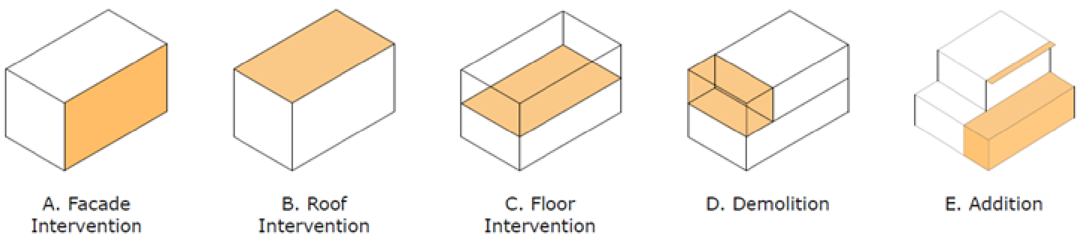


Fig 15. Division of different building elements (Own image, 2023)

3.4.1 Facade insulation materials

By properly insulating an existing building, you can drastically reduce the operational energy required by a building. In fact, insulation is crucial for delaying the heat flow and improving thermal comfort in a building. Insulation can be applied to facades, floors, roofs and foundation (van de Kraats, 2023) (Rijksdienst voor het Cultureel Erfgoed, 2022).

Thermal conductivity

The primary essential characteristic of thermal building insulation materials lies in their thermal conductivity. The typical objective is to attain the lowest possible thermal conductivity (Jelle, 2011). A reduced thermal conductivity, measured in W/(mK), allows for the use of comparatively thin building envelopes with elevated thermal resistance (m^2K/W) and a diminished thermal transmittance U-value ($W/(m^2K)$) (Jelle, 2011) This then also affects the embodied energy of the material. Because insulation materials with lower thermal conductivity requires less volume, therefore this will also reduce the amount of embodied energy [MJ]. Therefore it is important to make a thoughtful choice of the type of insulation material to be applied.

Isolation Material Facade	Thermal conductivity λ (W/mK)	Thickness [mm] needed for Rc 4,7 m2K/W
Cellulose ©	0,04	188
EPS plates (i)	0,035	164,5
EPS Plates (o)	0,035	164,5
Flax/Hemp (i)	0,035	164,5
Glass wool (i)	0,035	164,5
PUR plates (i)	0,025	117,5
Rockwool (i)	0,035	164,5
Straw Bale	0,05	235
Sheep Wool (i)	0,035	164,5
Wood fibers (i)	0,038	178,6
XPS Plates (i)	0,035	164,5
XPS Plates (o)	0,035	164,5

Fig 16. Values of different insulation material (NIBE Milieuclassificatie Bouwproducten, 2021)

Frequently used insulation materials are cork, rock wool, and mineral wool. These materials have proven to be effective insulation materials that improve the thermal performance of the building. Although these materials have proven from practical experience to be effective insulation materials, the insulation materials are inorganic and derived from minerals (Grazieschi et al., 2021). There are also developments concerning the application of more sustainable materials (Van Dam & Van Den Oever, 2019). These include insulation materials that are organic plants and are derived from animals/nature, (Grazieschi et al., 2021). Lastly there are organic fossil materials that are derived from fuel.

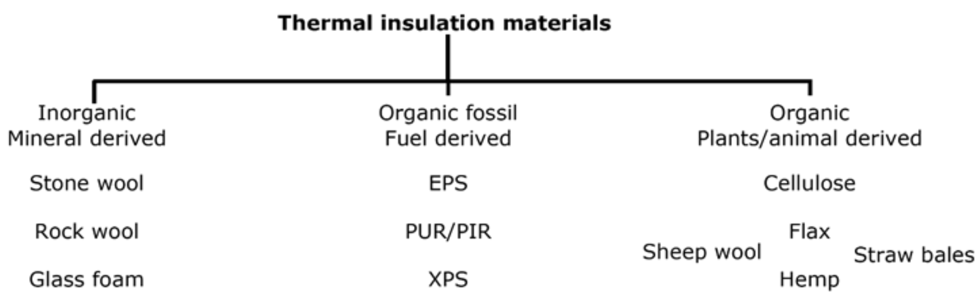


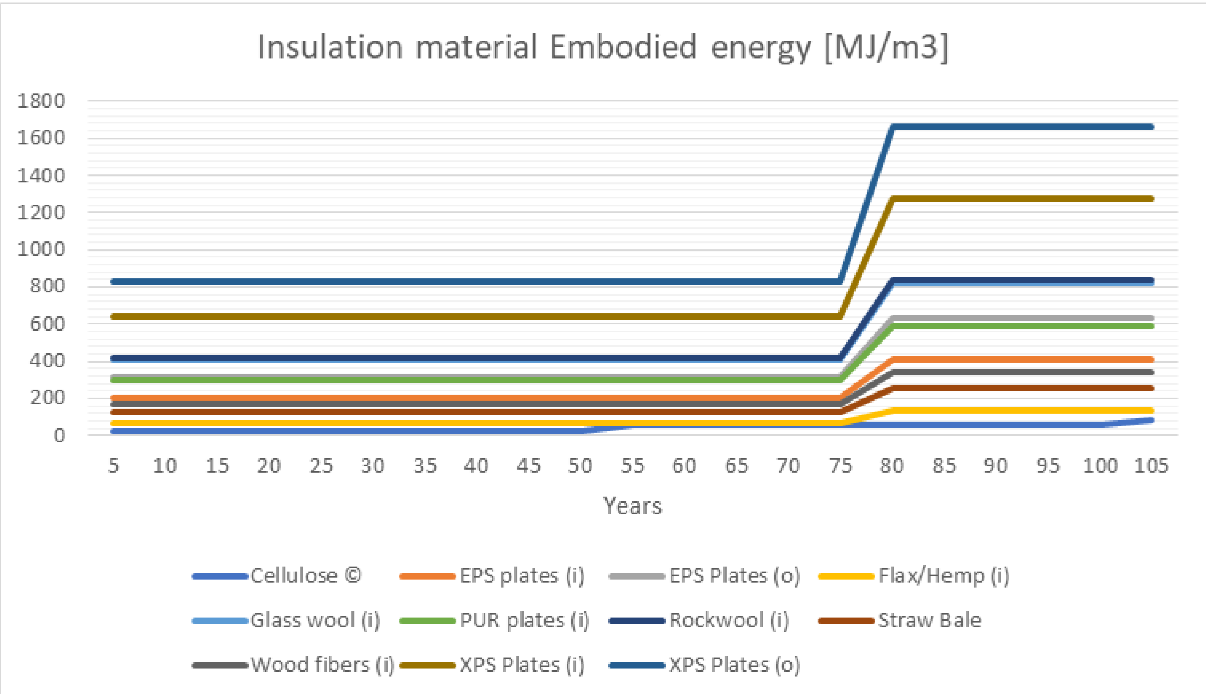
Figure 17. Different types of insulation materials Grazieschi et al., (2021)

Embodied Energy

Since we know the impact the insulation has on the operational energy, we now shift our focus to the embodied energy of different insulation materials, used in the facade. The results of the study on embodied energy of insulation materials are shown in the chart below. When choosing insulation on the inner cavity side, flax/hemp is the best material to choose, the use of straw bales and wood fiber insulation are also good alternatives. XPS is the worst-performing material with regard to this strategy of insulation.

If external wall insulation is chosen instead of internal insulation, EPS is the best choice. Again, XPS does not score well. The insulation material with by far the least amount of embodied energy per m^3 is Cellulose. It should be noted, however, that this type of material can only be used for cavity insulation, as the material is injected (NIBE Environmental Classification of Building Products, 2021).

Because the case study analysis showed that the R_c value of the building's facades are too low, they need to be improved over the entire facade. Therefore, an assumption is made that new insulation is applied across the entire façade. This leads to an area of 1660 m^2. By multiplying this with the thickness of the relevant insulation and the total embodied energy quantity, the total of embodied energy can be determined over the years. Results of these calculations can be seen in the graph in the appendix, because the classification did not change that much, compared to the graph below.

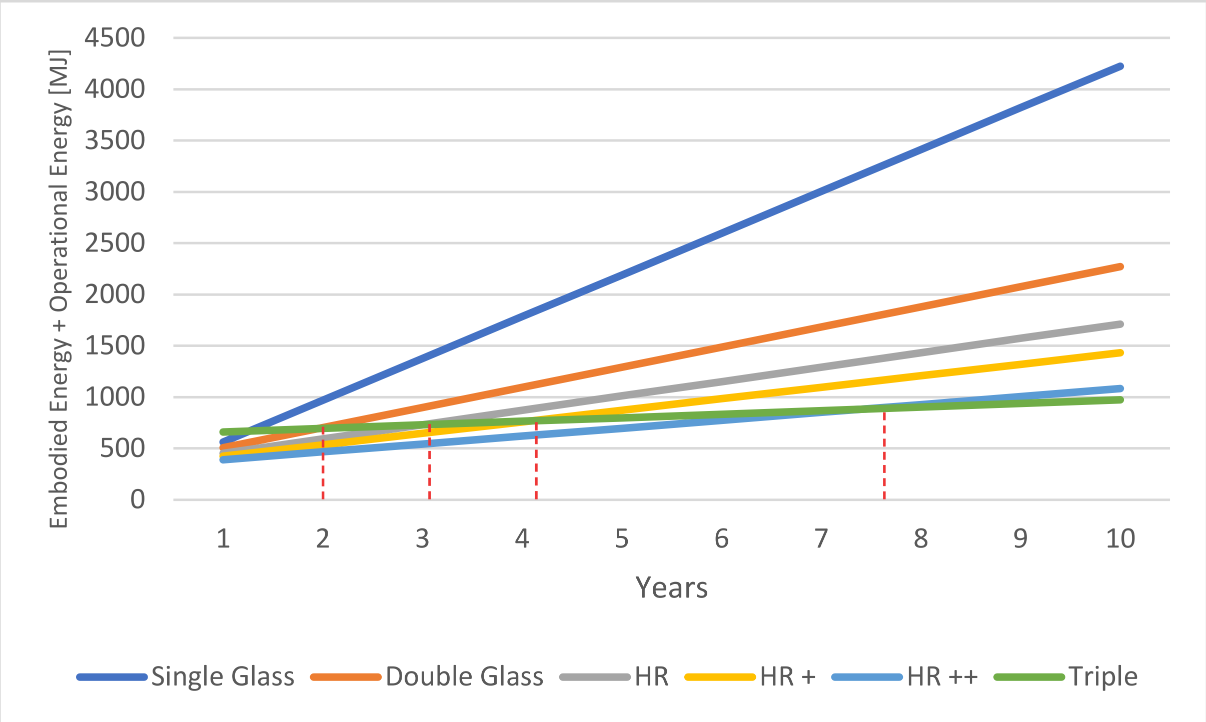


Graph 4. Embodied Energy of insulation materials

3.4.2 Glass for windows

In this sub-section, we analyze glass, a material that is not only important concerning the operational energy of a building but also contributes to the aesthetic appearance of a building. The material enables light to enter, allowing passive heat to be generated, and ambiances to be defined. Not only in terms of aesthetics does glass have an important role to play. Glass also affects the energy efficiency of a building. By choosing a type of glass with a low U value, heat loss can be minimized. In the analysis in this section, we look at the embodied energy required per type of glass per square meter, but also at the precise impact of the choice of glass on the operational energy.

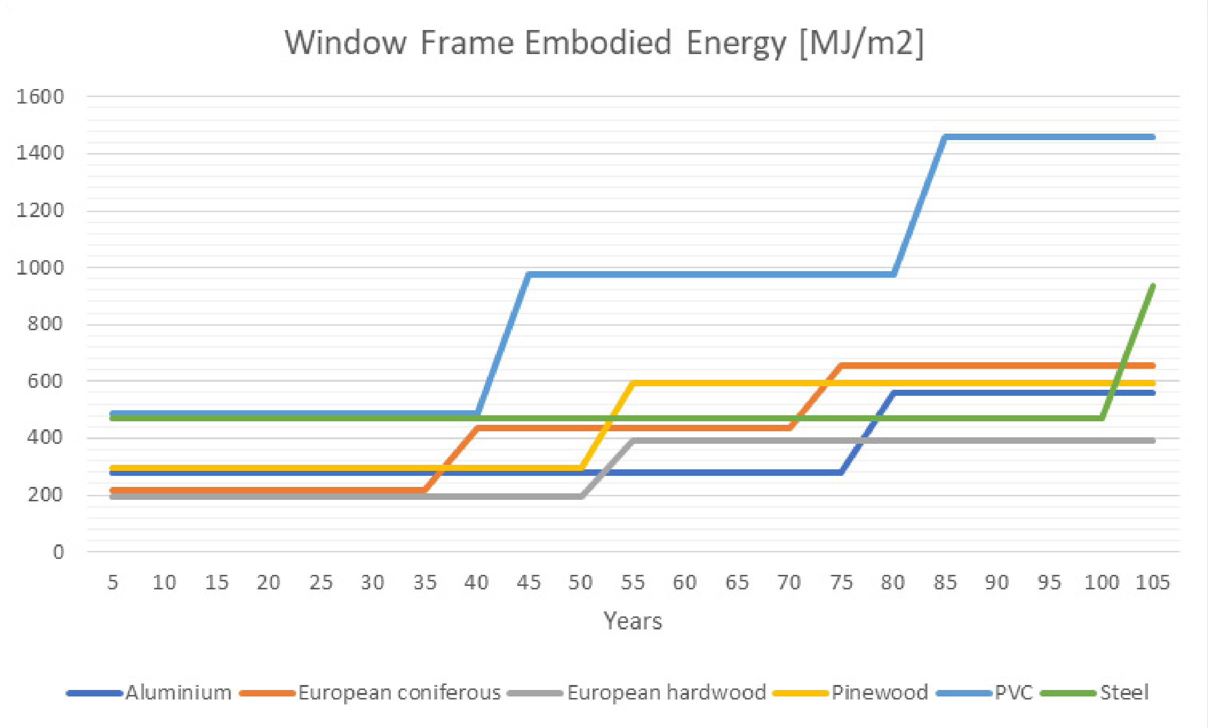
Looking at the results here, we see something significant. The glass with the lowest U-value, namely the triple glass, is a more durable option compared to the HR ++ glass, only 8 years after purchase. In addition, it is also a more sustainable option than the double-glazing only after 2 years. This analysis therefore reflects the impact of embodied energy clearly. Because the tripple glass, has a higher embodied energy quantity, it is a more sustainable choice than the other options only after a x number of years.



Graph 5 Embodied Energy + Operational Energy of different glass types

3.4.3 Window frames

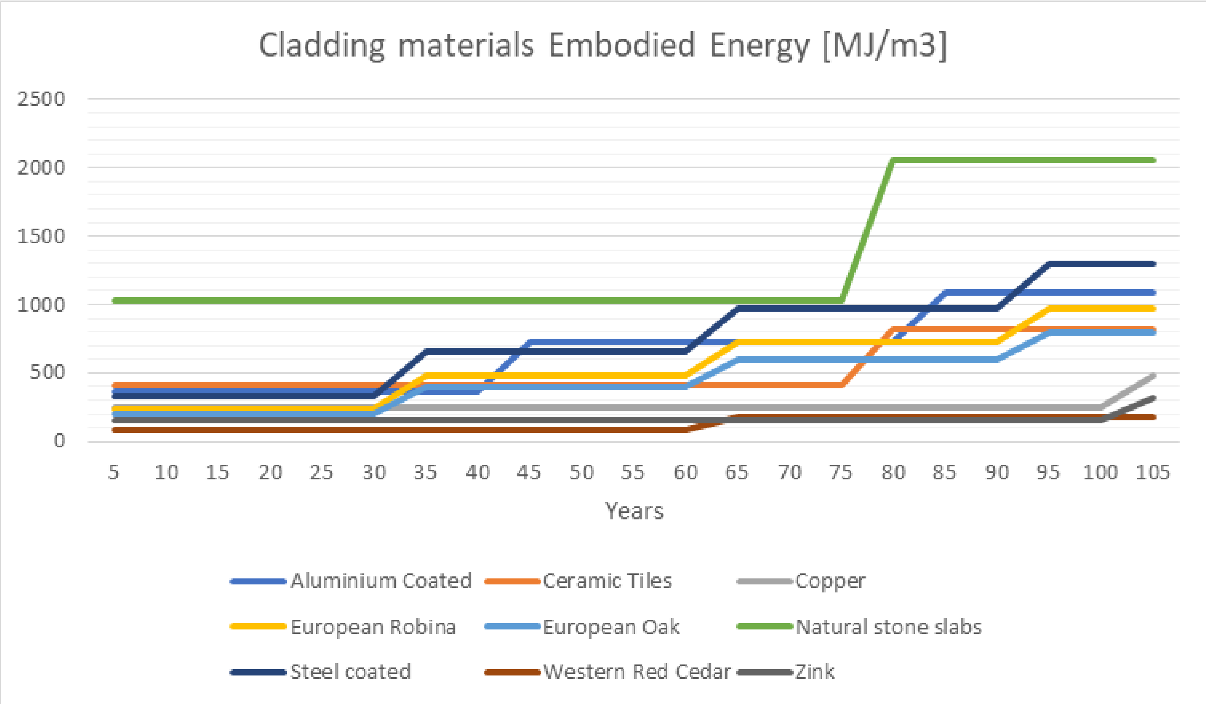
For the third materials analysis, we assess window frame materials. A distinction can be made between 4 different types of material, these are aluminum, wood, PVC, and steel (Asif et al., 2005). Here wood has 3 different variants. These are coniferous, hardwood, and pinewood. The embodied energy results are shown in the graph below. The worst choice of this study appears to be the PVC window frame. Due to the high embodied energy and the short lifespan of the material, it appears that choosing this type of material is the worst choise. In contrast, the various types of wood score a lot better, in particular, European hardwood is a window frame that has a low embodied energy amount and is, therefore, a sustainable choice.



Graph 6. Embodied energy of different window frame materials

3.4.4 Cladding materials

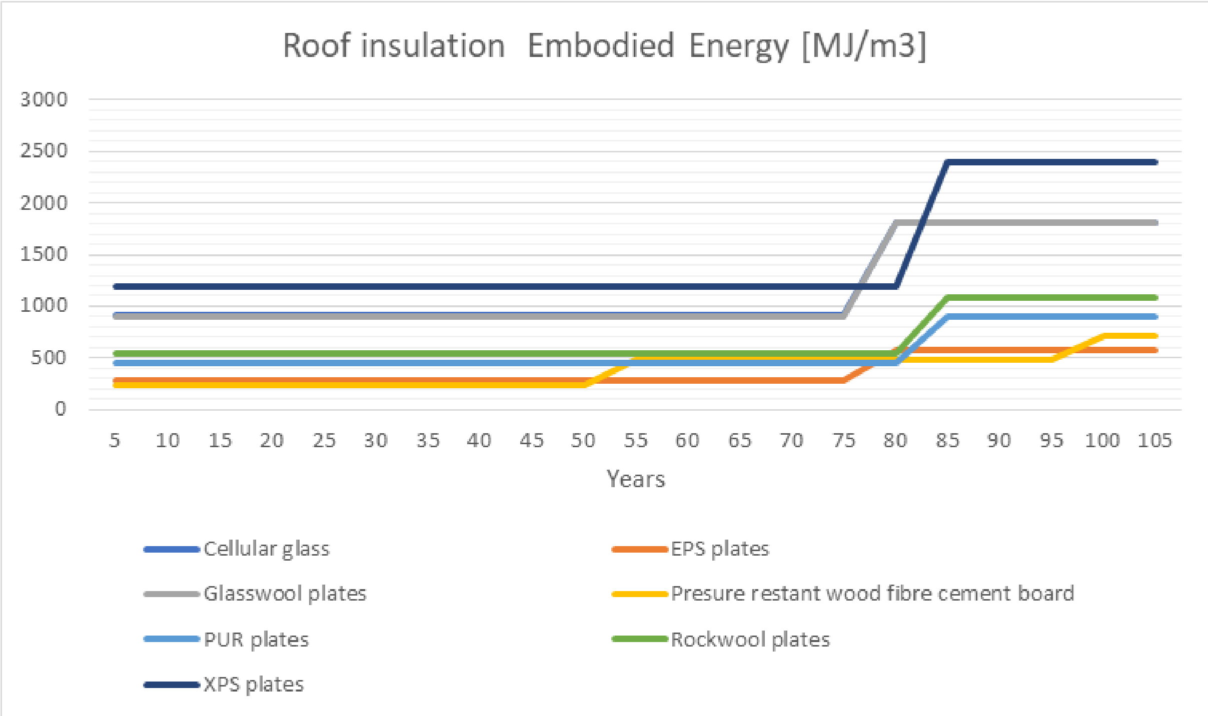
Choosing cladding material for a heritage project is complex task. Not only is it important that the material takes into account the aesthetics of the existing property, the durability of the material also needs to be considered. Therefore, embodied energy is also assessed in this chapter. The results of this are shown in the chart on the next page. It turns out that the lifetime of the materials has a major impact on the amount of embodied energy over the years. Although the initial amount of embodied energy of the various materials does not distinguish each other significantly, it is noticeable that copper, western red cedar and zinc have longer lifetimes. As a result, these materials show lower embodied energy, making them more durable compared to the other materials that need to be replaced more frequently. So this is evidence that the lifespan of materials also plays a crucial role in overall durability.



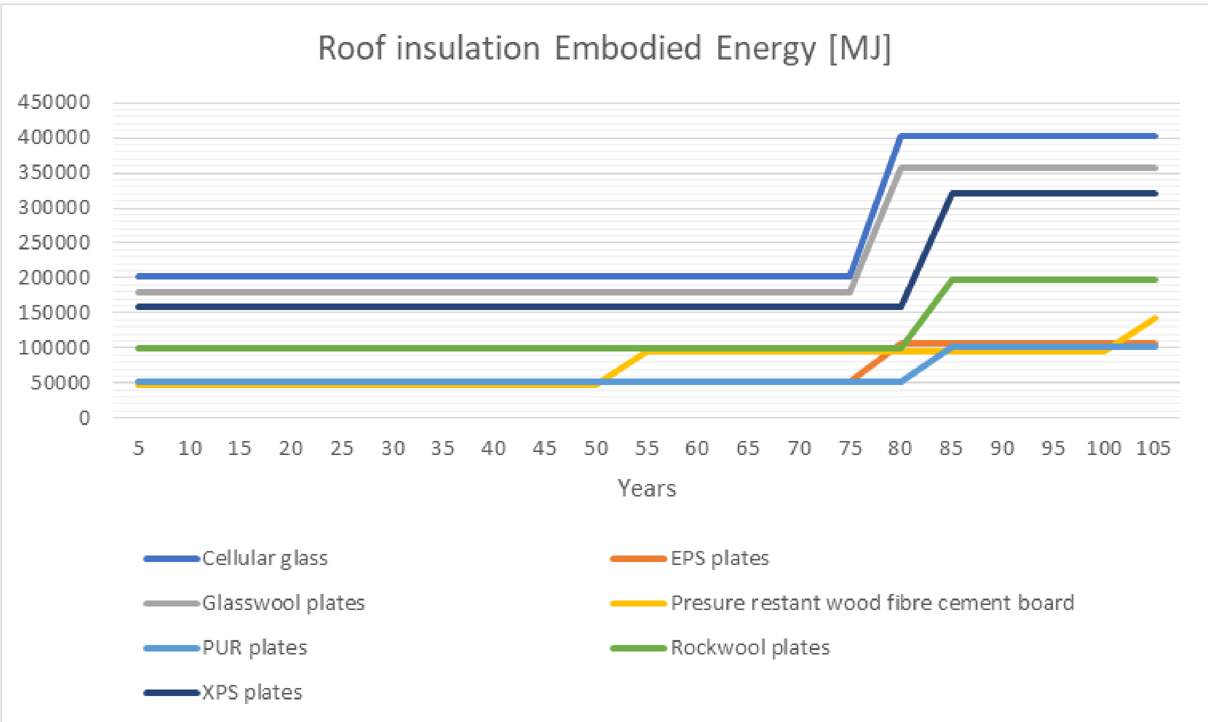
Graph 7. Embodied energy of cladding materialsA

3.4.5 Roof insulation

In addition to the facade, floors and roofs are often insufficiently insulated in heritage buildings (Akande et al., 2014) (Koezjakov et al., 2018). Furthermore, the analysis of the case study revealed that the insulation here is also inadequate for a new function. The addition of new roof insulation is therefore a requirement. For this reason, research has also been conducted on the amount of embodied energy in various roof insulation materials. The results are again shown in the graph below, which shows that two materials have significantly higher embodied energy values than the rest: XPS and glass wool boards. As a result, it can be concluded that these are less sustainable choices compared to the other materials. Indeed, all other materials show relatively low scores in terms of their embodied energy. However, when we look at the thermal conductivity of the materials and calculate how much volume of the material is actually needed to achieve an acceptable Rc value in the design case, it appears that cellular glass seems to be the least responsible choice. This calculation also shows that EPS boards and the pressure-resistant wood fibreboard are the most durable materials, followed by PUR boards.



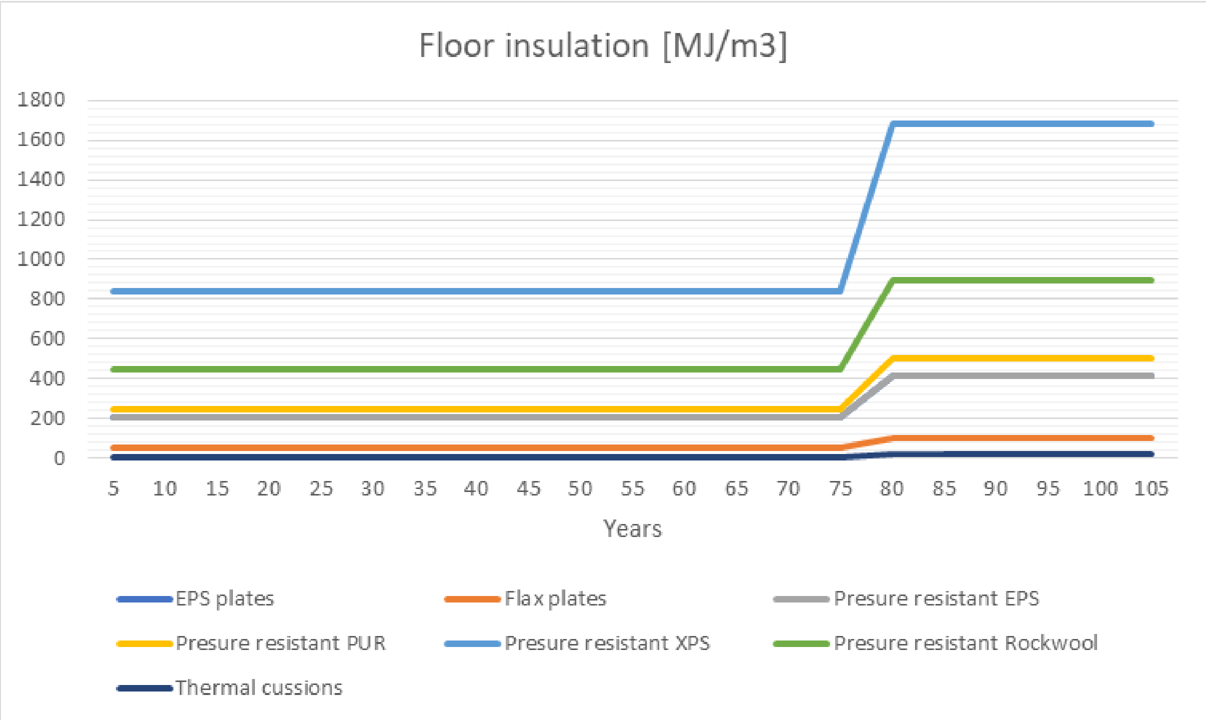
Graph 8. Embodied energy of insulation materials used for the roof



Graph 8. Embodied enrergy amount of roof insulation related to the case study

3.4.6 Floor insulation

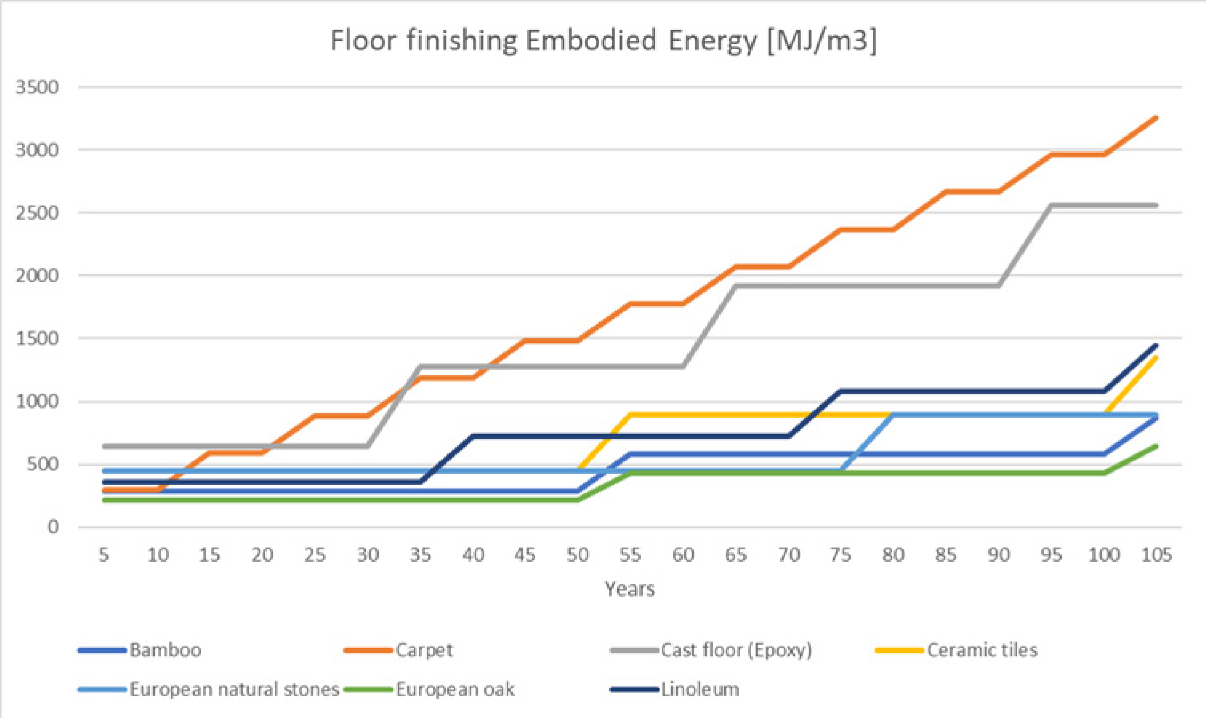
As indicated earlier, the importance of floor insulation is significant. It can bring about significant reductions in the building's operational energy costs. The results of the calculations are shown below. The material that performs remarkably well is the use of thermal cushions. This insulation cushion reduces heat loss through the floors. It is applied under the floors and can achieve an Rc value of 5.5 m²K/W already with an air layer of 25 centimeters. Due to the thin profile and the use of recycled polyester, these cushions score significantly better than other insulation materials (NIBE Environmental Classification of Building Products, 2021). Nevertheless, the cushions are not always suitable for floor insulation, as space under the floors is required to apply the thermal cushions. In cases where pressure-resistant insulation is required, it is advisable to choose pressure-resistant PUR or EPS insulation



Graph 9. Embodied energy of insulation materials used for the floor

3.4.7 Floor finishing

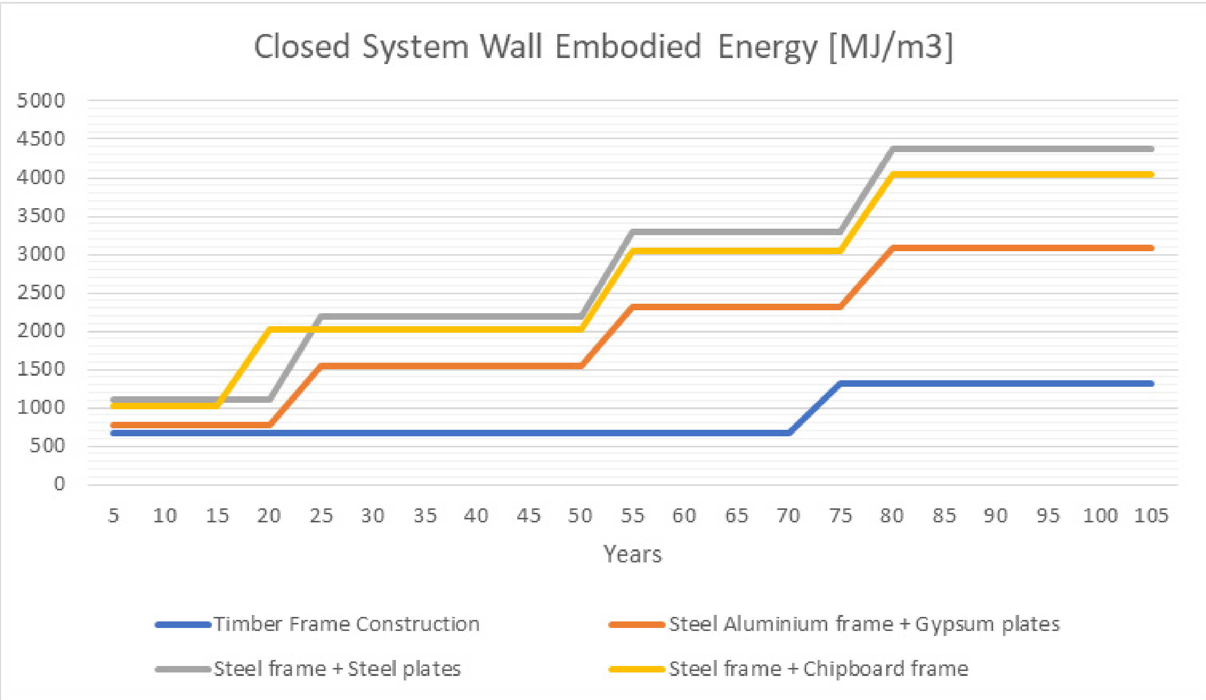
Besides the insulation of the floor, its finish also has a significant impact on the amount of embodied energy, this becomes clear from the chart of results. It appears that choosing carpet as a floor finish has a significant impact on embodied energy in the long term, as this material has a limited lifespan and needs to be replaced every 20 years. On the other hand, using oak flooring is a significantly more sustainable choice, due to the longer lifespan of the material and the initial amount of embodied energy



Graph 10. Embodied energy of floor finishing materials

3.4.8 Partition walls

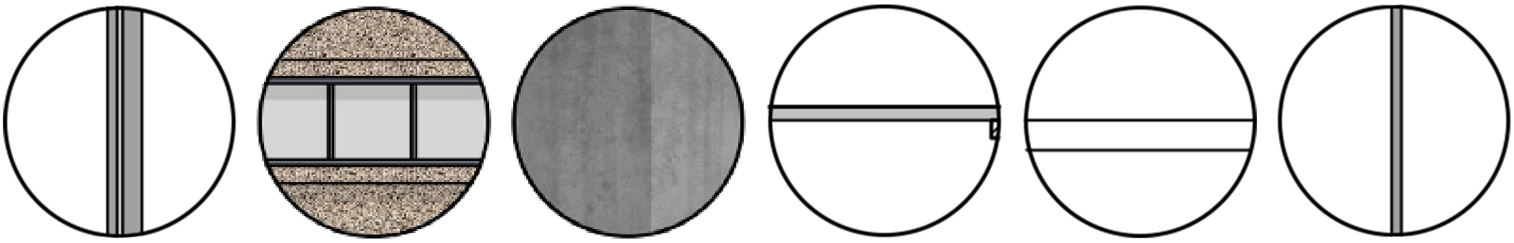
Finally, this material analysis focuses on internal walls. Here, a distinction is made between two different typologies. Firstly, closed system walls are considered, and secondly, solid, non-load-bearing internal walls. The results of both analyses are shown in the corresponding graphs. These show that timber frame construction is by far the most durable system wall. In terms of solid internal walls, it is noticeable that sand-lime brick, CLT and gypsum blocks are little inferior to each other (see appendix).



Graph 11. Embodied energy of partition walls

3.4.9 Results

Concluding the material analysis an overview of materials can be found on the next page. Showing for each category what type of material is the most sustainable in terms of embodied energy. For insulation materials, the thermal conductivity coefficient has also been included in the calculation. The amount of material required to achieve an Rc value that meets the relevant location of where the insulation material is applied was considered. By calculating this, the impact on the operational energy of the materials also becomes clear. The better the thermal conductivity coefficient of the material is, the less volume of the material is required. As a result, the amount of embodied energy may be more limited than initially assumed. The final ranking can be found below.



A. Facade

Ranking

1. Cellulose
2. Flax
3. Wood fibres

B. Windows

Glass Ranking

1. Triple
2. HR ++
3. HR +

Frame Ranking

1. European Hardwood
2. Aluminium
3. Pinewood

C. Cladding

Ranking

1. Red Cedar
2. Zinc
3. Copper

D. Roof

Insulation Ranking

1. EPS plates
2. PUR
3. Wood fibre cement plate

E. Floor

Insulation Ranking

1. Thermal cussion
2. Flax plates
3. Presure resistant EPS

Finishing Ranking

1. Red Cedar
2. Zinc
3. Copper

F. Partition wall

Ranking

1. Timber frame
2. Steel frame

Solid wall Ranking

1. Red Cedar
2. Zinc
3. Copper

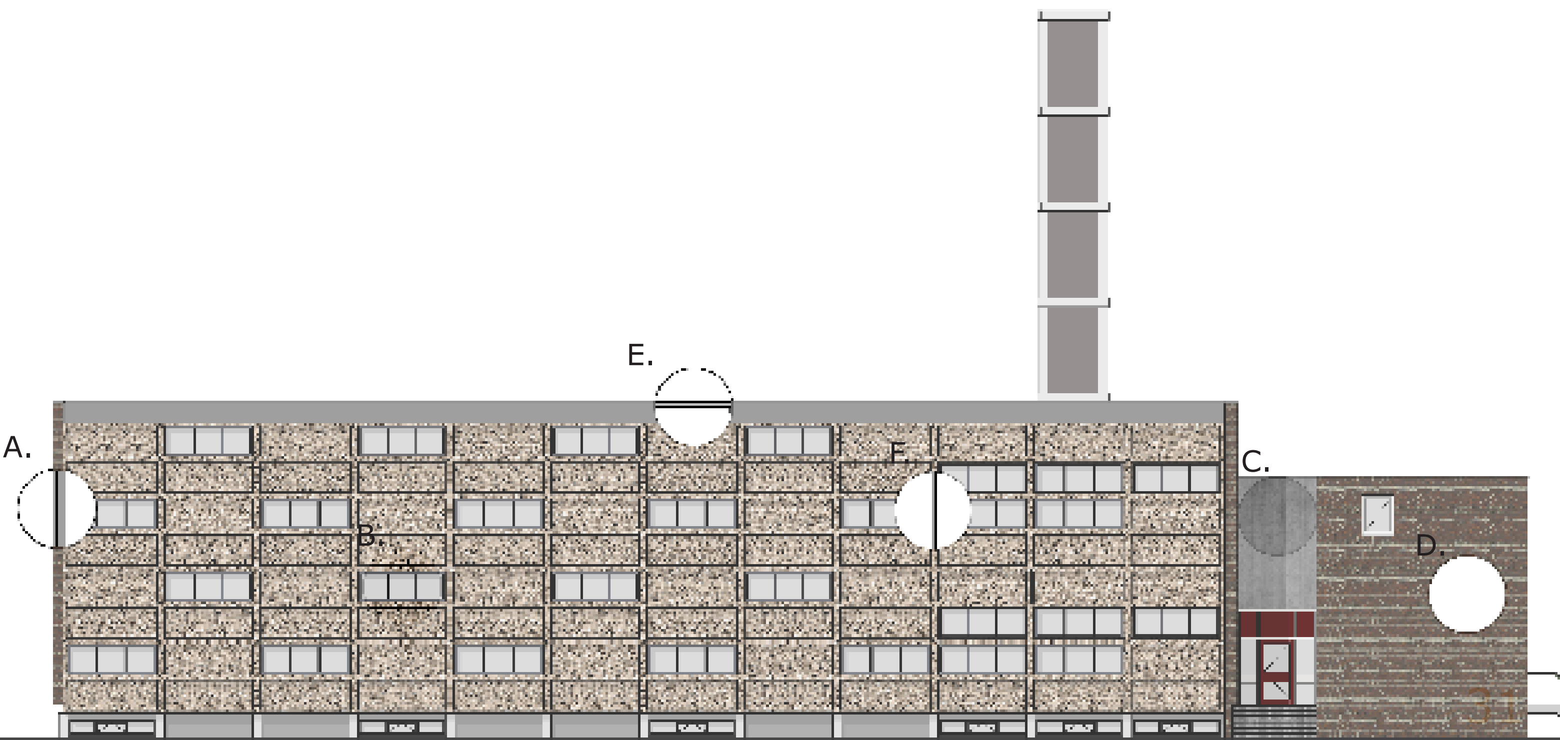


Fig 18. Results of material analysis

3.5 Strategy comparison

3.5.1 Facade scenario

In this chapter, we will use different scenarios to examine how certain choices affect the heritage value, the operational energy, and the embodied energy. First, we will focus on four strategies related to the facade of the design case. The baseline against which we compare the four scenarios is the current state of the design case. Because we assessed the case in chapter 2, we know the embodied energy and the operational energy of the building.

The four scenarios we will focus on are the following:
1. Replacing the facade completely.
2. Upgrading the façade on the outside of the existing façade with insulation.
3. .
Add insulation material to the inner wall of the existing façade (box-in-box principle).
4. Second skin strategy, add a glass facade in front of the building.

This analysis will be done at the most distinctive location of the property, which is the longitudinal facade. Because this facade contains the recognizable concrete elements which, as could be read in the heritage analysis, contribute to the overall heritage value of the property. The facade is constructed quite simply and consists of the concrete elements, an 'insulating' layer of bimsconcrete (pumice) and a thin sheet material, which type of material this exactly is, is unkown.

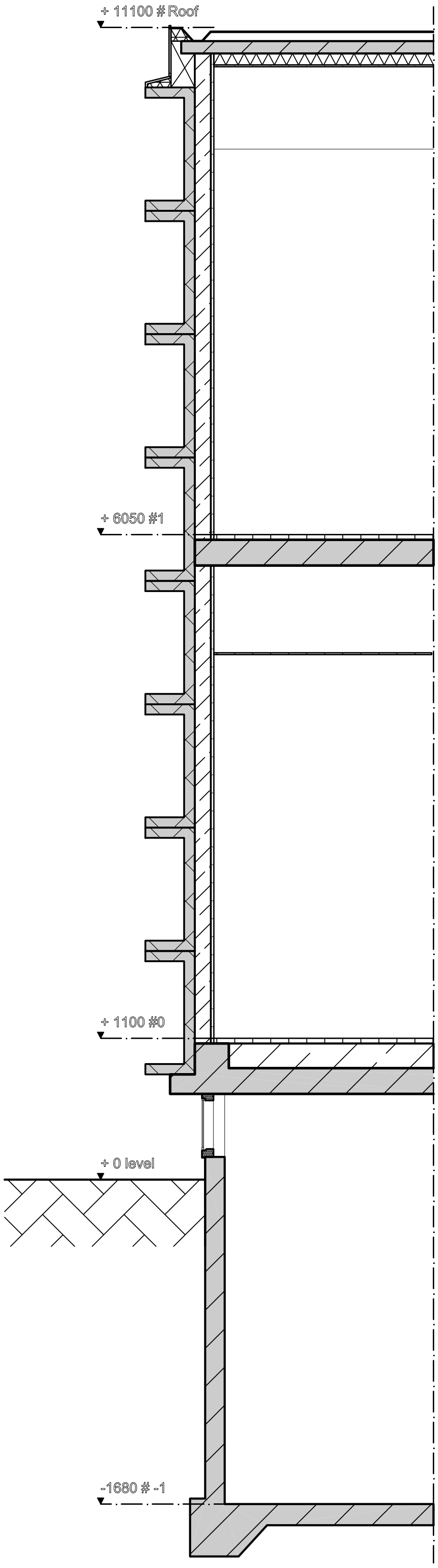


Fig 19. Section of existing facade

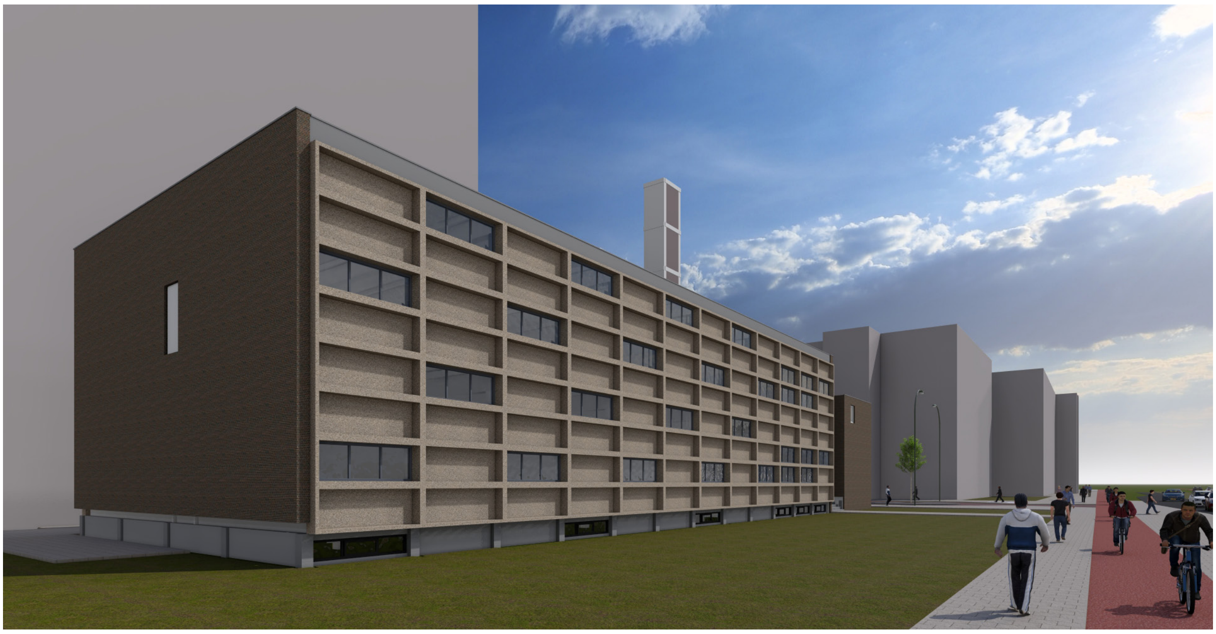
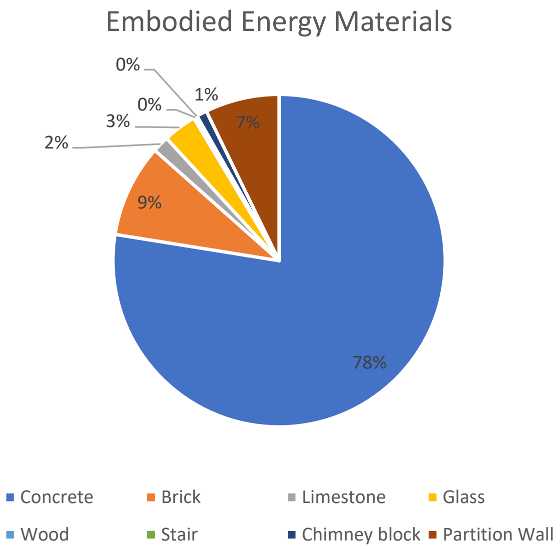
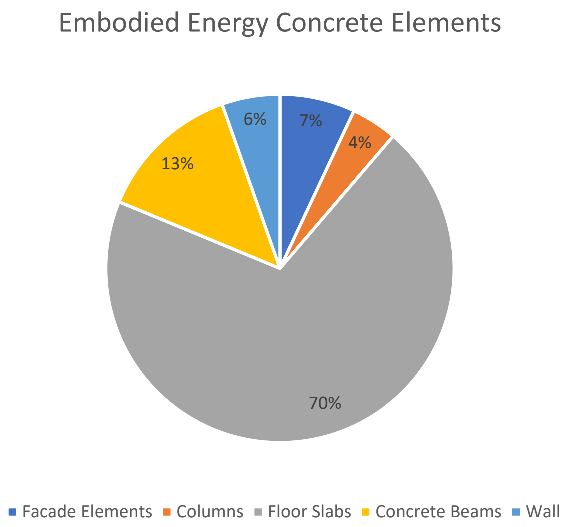


Fig 20. Render of existing facade



Graph 12. Embodied energy in case



Graph 13. Embodied energy of concrete elements in case

Facade replacement

In the first scenario, the entire facade of the Call Center is demolished, after which a completely new facade is added to the building. The new facade consists of brick, flax insulation, as it emerged from the analysis as the most sustainable insulation material, and a gypsum board to cover the insulation. In this approach, the concrete façade elements are not reused in the new design, so this scenario can be considered as an extreme scenario. This extremism is reflected in the graphs, where can be seen that an significant amount of concrete is demolished. Resulting in a significant loss of 'embodied energy'.

Not only is this strategy extreme in terms of the environmental impact, but it also has serious implications for the heritage value of the property. Several values are lost when the distinctive façade is demolished. The property loses a significant part of its historical value by removing the distinctive panels, thus removing the temporal significance of the building. In addition, this strategy negates the age value by replacing the façade with a more contemporary design. The heritage value of the building is therefore given a score of 1. Because significant changes have irreparably damaged the heritage value of the building.

Nevertheless, this strategy does lead to improvements in operational energy. The Rc values of the entire façade are increased to a value of 4.7 m^2K/W, resulting in a reduction in the heating and cooling required for the property and therefore also in operational energy.

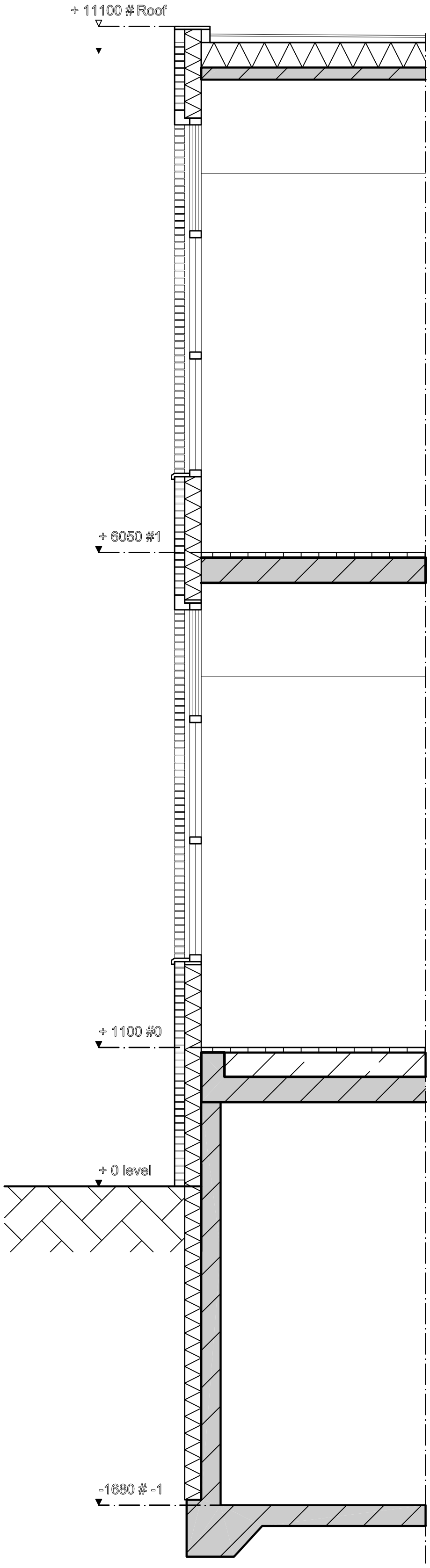
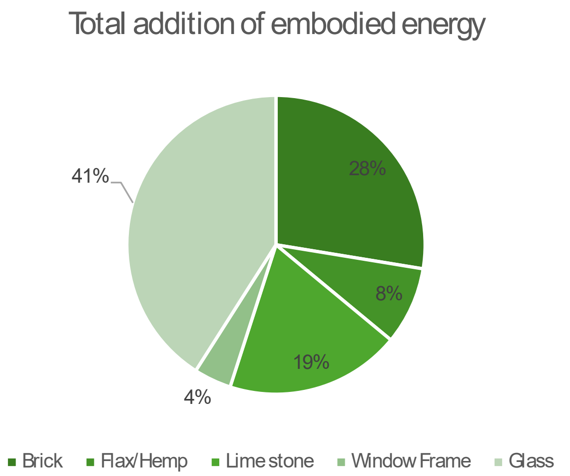
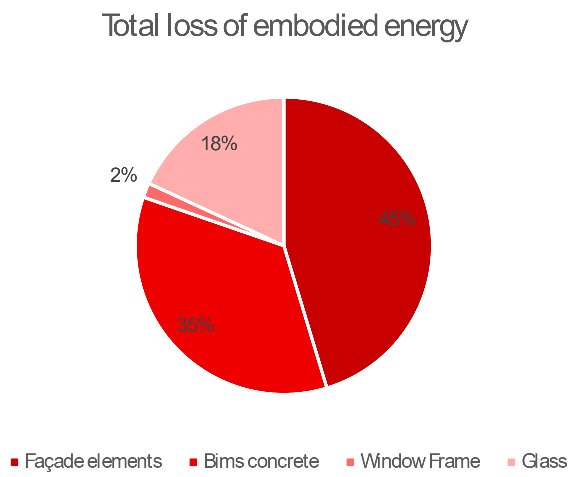


Fig 21. Section of scenario 1

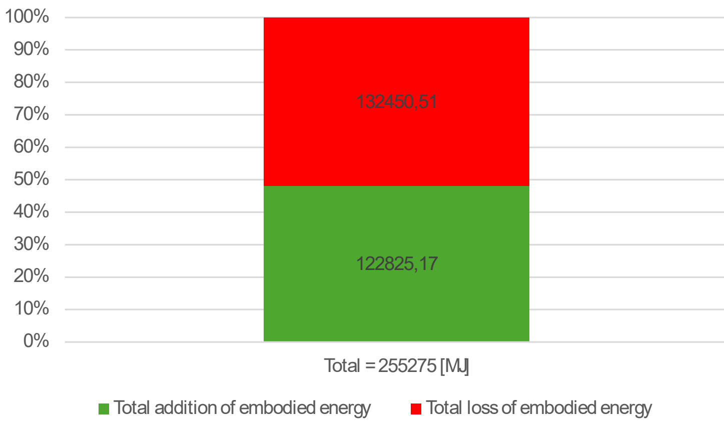
Fig 22. Render of facade in scenario 1.



Graph 14. Total addition of Embodied Energy



Graph 15. Total loss of Embodied Energy



Graph 16. Total amount of Embodied energy in scenario 1

4,7 [m²K/W]

R_c Value

1

Heritage Score

Exterior Upgrade

As explained in Chapter 3, façade insulation is a strategy that can be applied to reduce the operational energy of a building. As the material analysis showcased that EPS boards are the most sustainable option for this strategy, EPS is chosen. In addition, stucco is chosen as the finishing material layer, to mimic the former façade.

Adding the required EPS insulation gives the façade an Rc value of 4.7 m²K/W. Therefore the operational energy is limited. In terms of embodied energy, low losses can be observed since almost no materials are demolished. Besides that few materials are added, which leads to a minimal addition of embodied energy. As a result, it can be said that this strategy is a very effective way to reduce operational energy, while also keeping embodied energy low.

However in terms of heritage value we see that the building loses value by covering the existing façade. As described earlier in this chapter and in the literature by Havinga et al. (2020), adding stucco to an existing façade decreases the heritage value. This is because, age- and aesthetic-related values are lost through this strategy. Because the façade of the property and its form are largely preserved, this strategy receives a heritage score of 2.

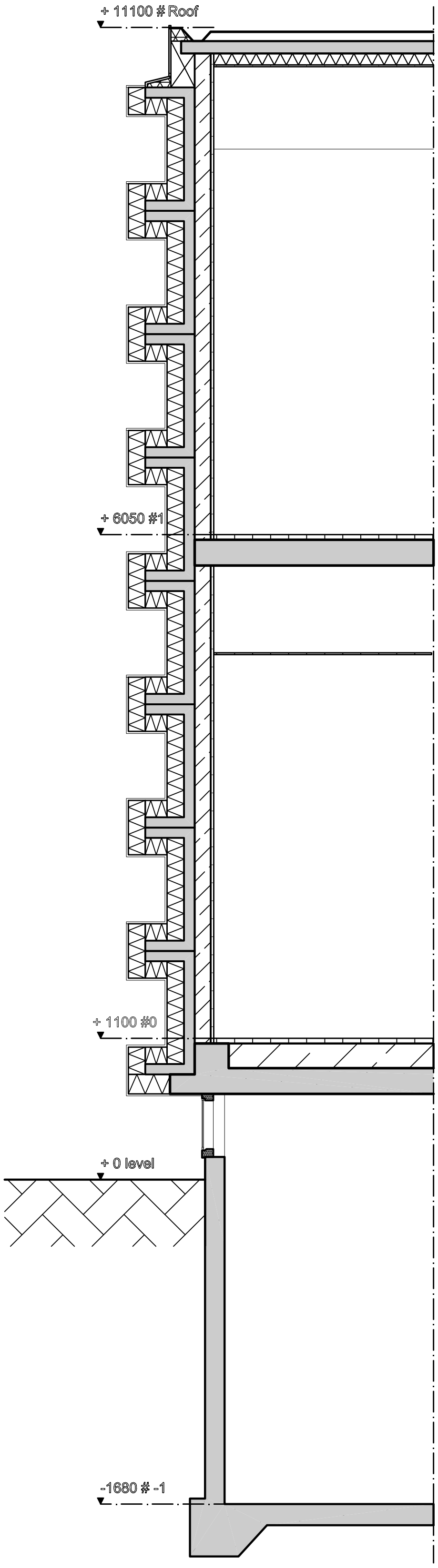
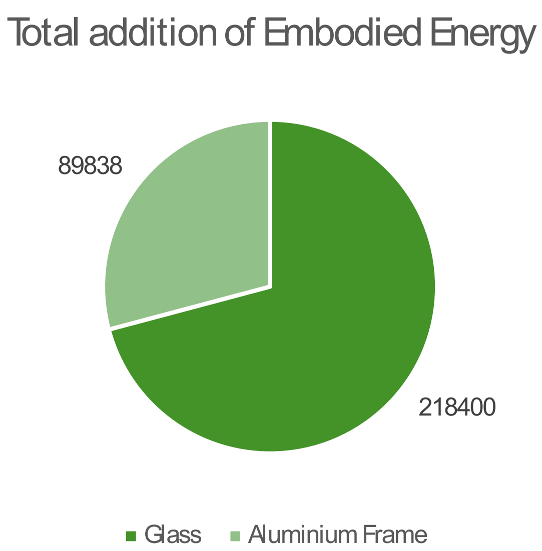
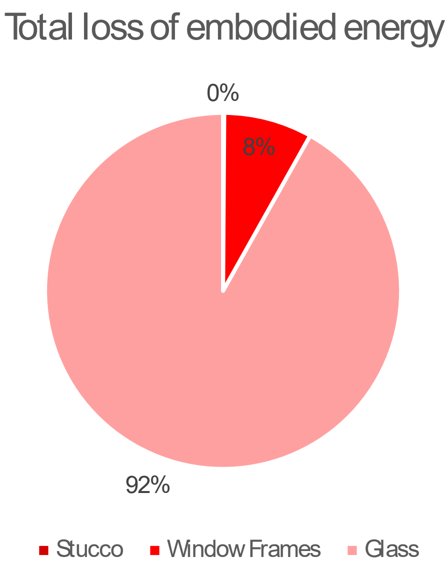


Fig 23. Section of scenario 2

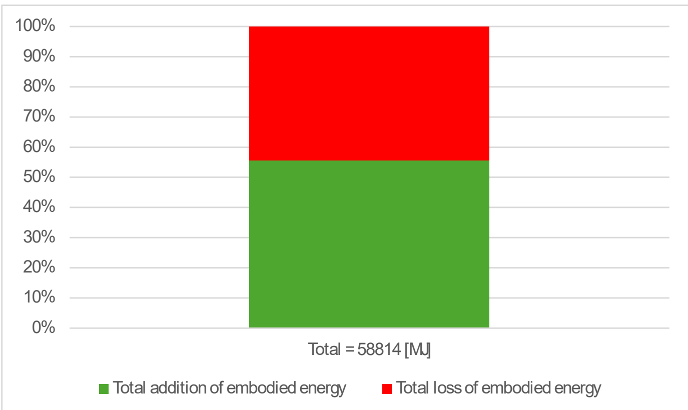
Fig 24. Render of scenario 2



Graph 17. Total addition of Embodied Energy



Graph 18. Total loss of Embodied Energy



Graph 19. Total amount of Embodied energy in scenario 2

4,7 [m²K/W]

R_c Value

2

Heritage Score

Interior Upgrade

The third scenario, tested in this chapter, focuses on the box-in-box principle. As in the case study 'Koningsvrouwen van Landlust' discussed earlier, this scenario focuses on insulating the inside of the building.

Just like the last scenario, avoiding large-scale demolition of concrete elements ensures that the embodied energy of these materials is retained. Moreover, it appears that the embodied energy added in this scenario is aslo significantly low. This can be attributed to thoughtful material selection and limited use of materials. In terms of operational energy this strategy proves to be effective aswell. The facade improves to get a Rc value of 4.7 m²K/W.

Finally, if we look at the property's heritage value, we see that it remains unchanged. By preserving the facade on the inside, the building's distinctive facade is not affected. In addition, the building has no heritage value in its interior cavity wall. Therefore, this is an intervention that proves to be appropriate in all areas(embodied & operational energy quantity and heritage value). This is why this project receives a heritage score of 5. Since the building has been virtually unchanged

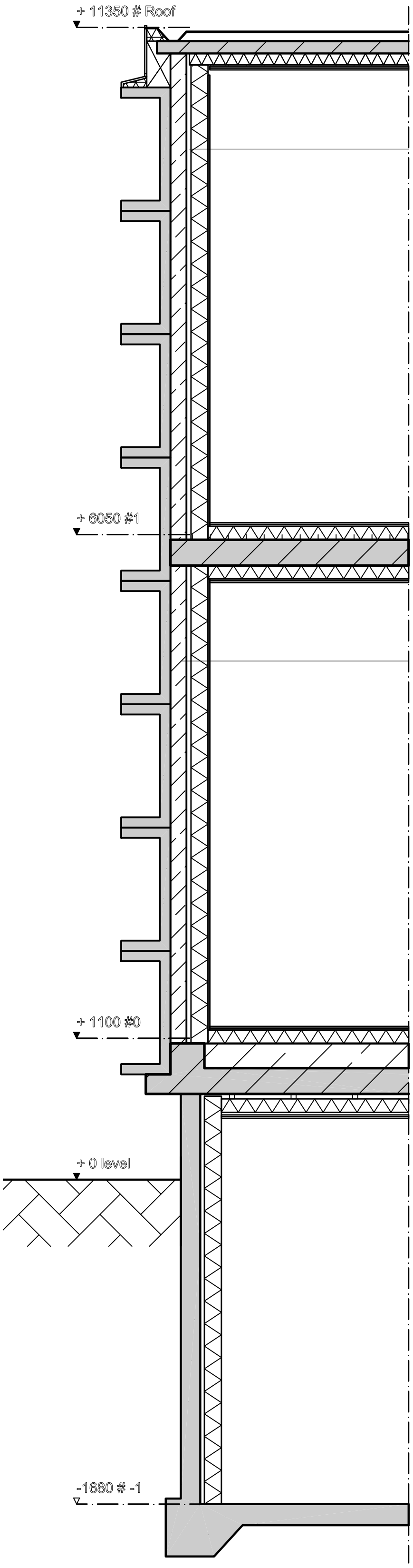


Fig 25. Section of scenario 3

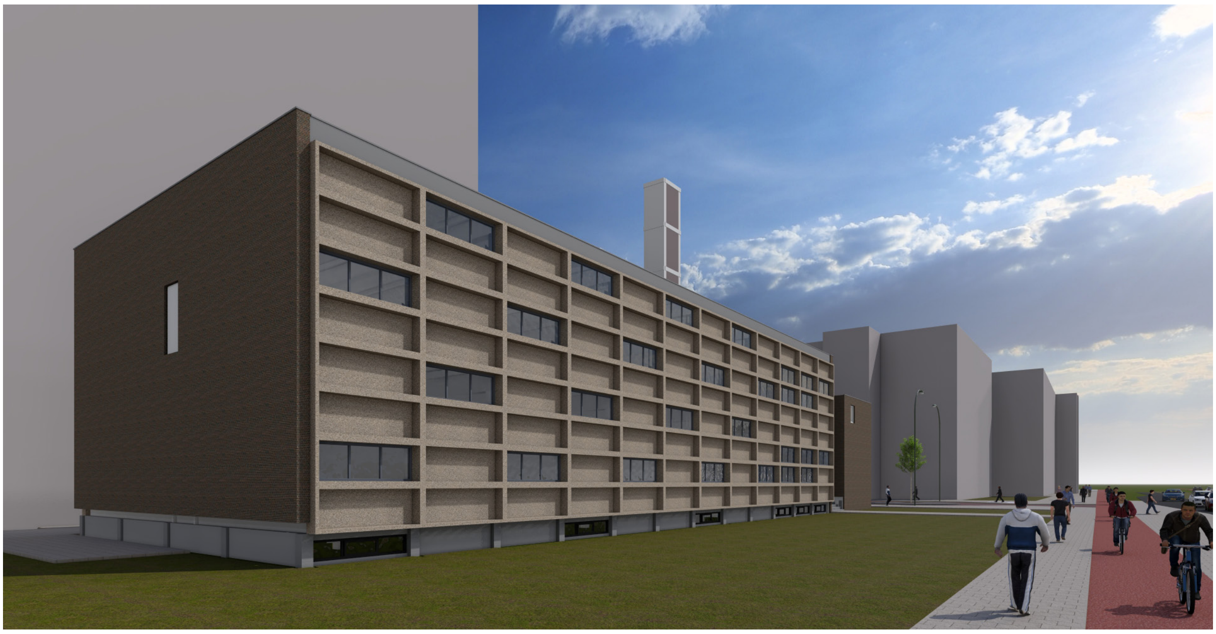
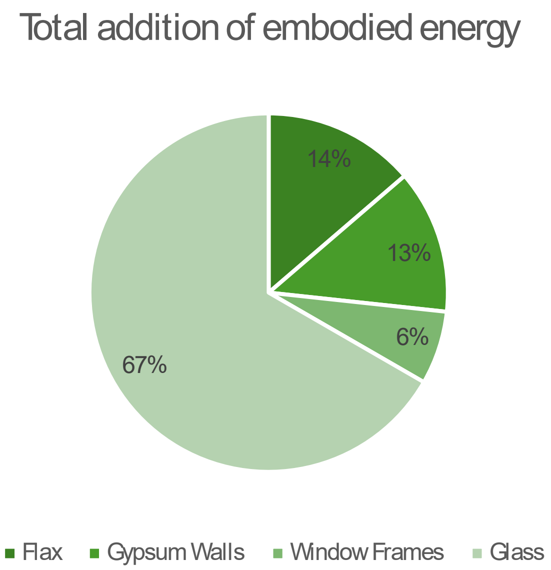
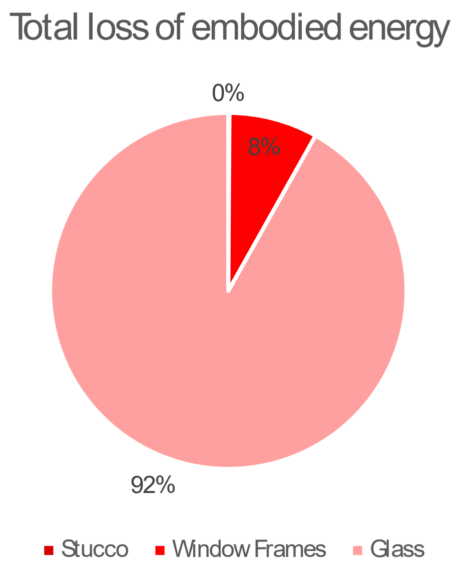


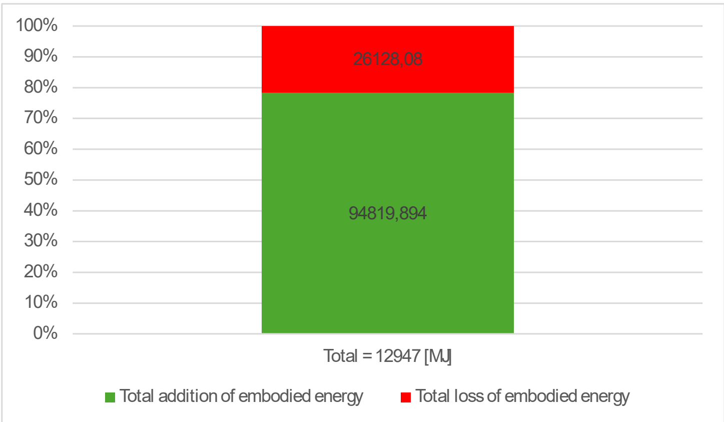
Fig 26. Render of scenario 3



Graph 20. Total addition of Embodied Energy



Graph 21. Total loss of Embodied Energy



Graph 22. Total amount of Embodied energy in scenario 3

4,7 [m²K/W]

R_c Value

5

Heritage Score

Second Skin

An additional, second, glass facade is the latest strategy analyzed in this chapter. A double-skin facade consists of two layers of glass and most commonly used a aluminum frame, fixed to the existing facade (Souza, 2023). This creates a buffer of air that, improves the energy efficiency of the building (Souza, 2023). In this case we create a buffer of 30 centimeters. The operational energy of the building is thus reduced through this strategy. Besides thermal insulation, this strategy also improves the acoustic insulation of the building, reducing noise pollution from the surrounding area (Souza, 2023).

However when we look at the caluclations that have been done in terms of the embodied energy, we can see that the choise of this strategy has a huge impact upon the embodied energy of the facade. The reason for this is that the glass has alot of embodied energy. Simultaniously, the material is extensively used along the whole facade.

The second skin also has its effect on certain values related to the heritage. It negates the value of the façade in terms of history and aesthetics. The concrete is shielded with a transparent material. Nevertheless, this does affect the appearance of the monumental facade. Reflections can certainly limit the view of the monumental facade. Because of al these reasons the building receives a heritage rating of 2.

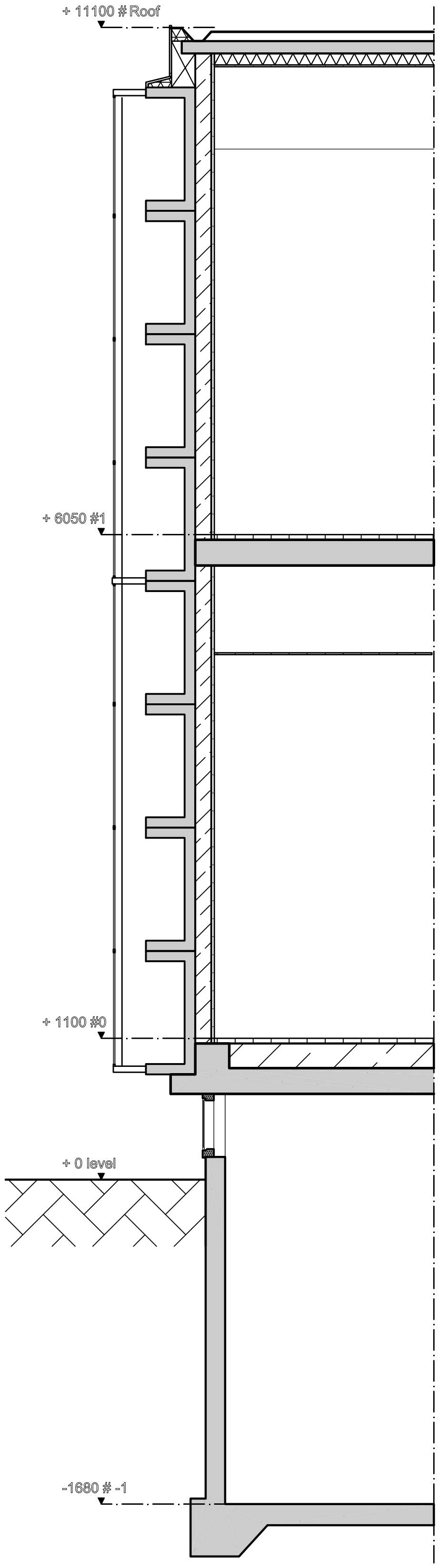
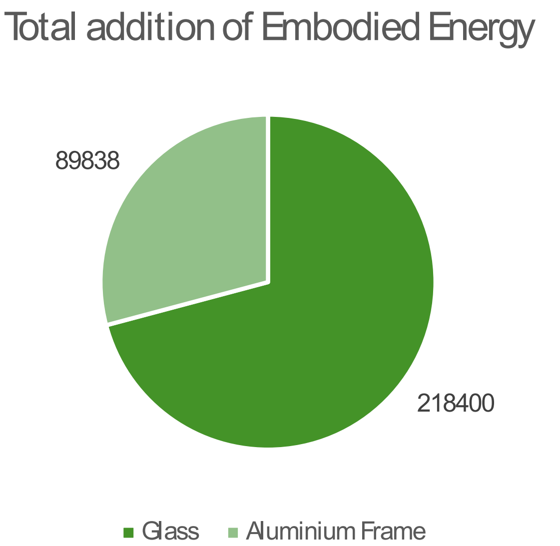


Fig 27. Section of scenario 4

Fig 28. Render of scenario 4



Graph 23. Total addition of Embodied Energy

4,7 [m²K/W]

R_c Value

2

Heritage Score

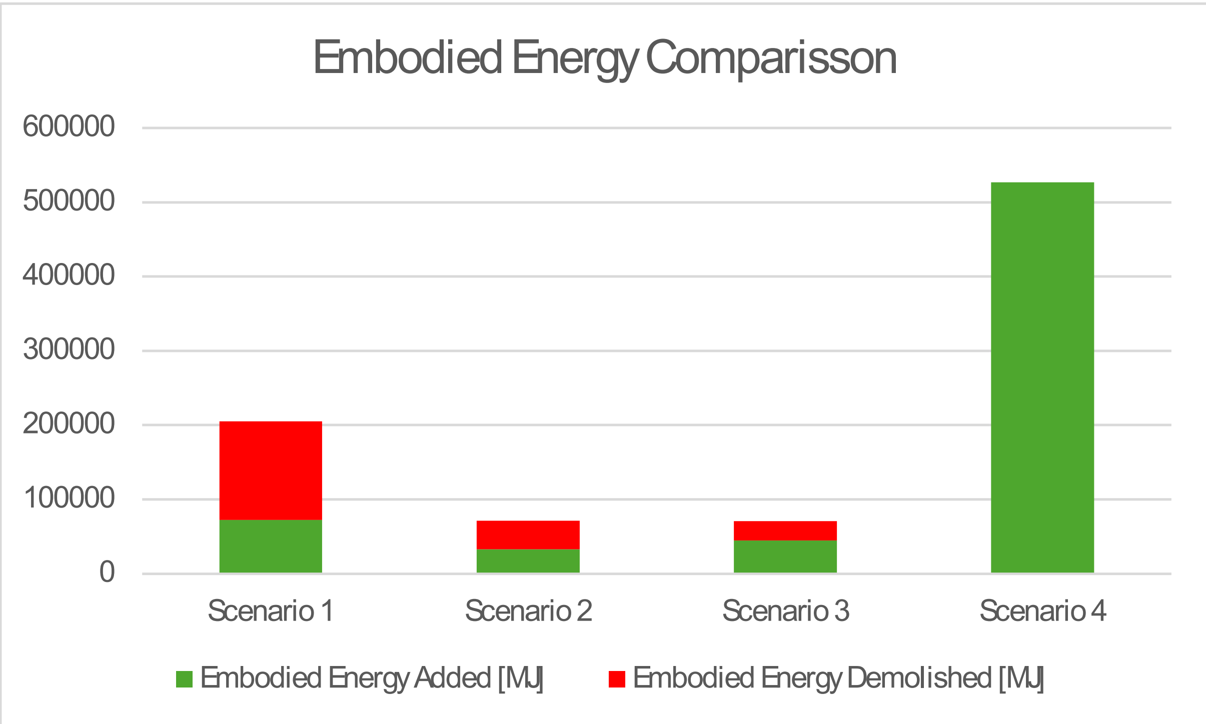
Facade scenario conclusion

Reflecting on the results related to the different scenarios, we can draw several conclusions. First, it is noticeable that only a minimal difference can be observed between the four different scenarios concerning operational energy. Scenarios 1, 2, and 3 all achieve the required Rc value, limiting operational energy. Scenario 4 does reduce operational energy, but the exact gain of this has not been calculated.

In terms of embodied energy, we see clear differences between the four scenarios. Scenario 4, with the double façade, has by far the highest embodied energy, mainly because of the high energy consumption of glass and the frequent use of this material in this method. Thus, this scenario is not recommended based on this observation. In addition, this scenario has a heritage score of 2, meaning that this strategy is unsuitable for the application to the facades of heritage buildings.

This leaves scenarios 1 to 3. Scenario 1 performs as least well here, due to the demolition of the existing façade. This leads to a significant loss of embodied energy and also has a major impact on the heritage value of the property. It loses aesthetic, historical, and age-related values. Therefore, this scenario is also not recommended.

This leaves Scenarios 2 and 3 performing similarly in terms of both operational energy and embodied energy. However, in terms of heritage score, a difference is noticeable. Scenario 2 loses the heritage value of the façade by covering it. Unlike scenario 3, where this is not the case. Therefore, it can be concluded that scenario 3 is the most suitable scenario for the redevelopment of the façade.



Graph 24.The Embodied Energy comparisson of the different scenarios

3.5.2 Roof scenario

In the second scenario comparison, our attention shifts towards interventions concerning the roof. Within this context, we shall delve into two different scenarios, evaluating and contrasting each not only with one another but also against the backdrop of the current condition.

Scenario 1 places its emphasis on improving the existing roof structure through insulation. Meanwhile, scenario 2 unfolds a transformation with the realization of a green roof on top of the existing structure. Both scenarios will undergo a comprehensive examination, considering their effects on embodied energy, operational energy, and the heritage value inherent in the structure.

Addition of insulation

First, we examine the possibilities of improving the existing situation through insulation. Three possible strategies are available. The insulation can be placed under the existing structural concrete slab, resulting in a cold roof structure. In addition, it is possible to place the insulation material on top of the existing insulation and roofing, resulting in an inverted roof (de Vree, 2023).

Finally, it is possible to choose to remove both the existing insulation and roofing material and install a completely new structure, known as a warm roof structure (de Vree, 2023).

In this particular scenario, we decided to use a warm roof construction to avoid potential condensation problems. As an insulation material, we choose EPS, since this material emerged as the most durable in the material analysis. The standard thickness of an EPS board is 120 [mm]. Including 2 sheets in this roof package creates a total thickness of 240 [mm], which is more than the required thickness of 233 mm to achieve an Rc value of 6.3. The existing roofing and insulation are removed subsequently a new vapor control layer is applied to the existing concrete slab, to which the EPS layers are then attached. These are covered with an insulating slope plate and a new roof covering (EPDM).

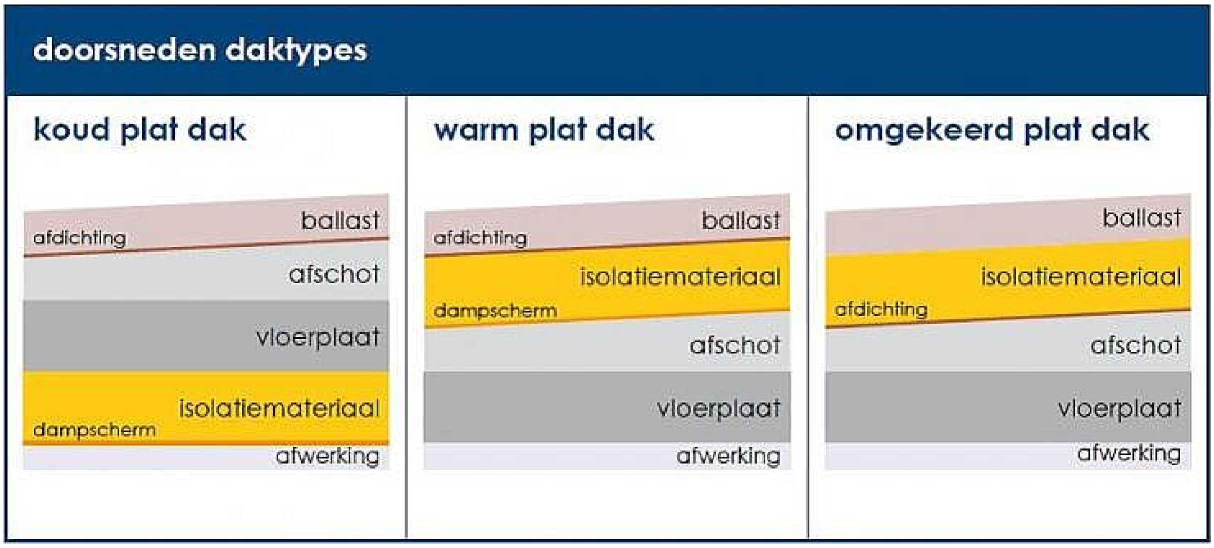


Fig 29. Types of flat roofs

A green roof
We then analyze the structure of a possible green roof for the design case. There are different types of green roofs. On the one hand, you have extensive green roofs, which mainly consist of various types of grass, moss, and small plants. On the other hand, you have intensive green roofs, which instead have a wide variety of plants, shrubs, and so on. The difference between the types is mainly in the heaviness of the construction and the thickness of the substrate. Several options exist between these extremes.

A green roof consists of several layers, each with its structural properties. The substrate forms the top layer of a green roof package and determines, among other things, which types of plants can grow on the roof. The thicker the substrate, the bigger the plants can be on the roof since there is more space for the roots of the plants to grow.
For our case study, we chose an extensive roof, which means that the substrate and construction will not be too heavy. On the other hand, this does mean that the biodiversity on the roof will be more moderate.

Besides the substrate, a green roof package also contains other layers that are important for proper functioning (Bezuijen, 2019). These include the structural layer on which the roof package rests, various moisture control layers, insulation, and drainage.

For this scenario, we maintain the structural concrete structure of the building, but demolish the already existing insulation and roofing. In addition, we again choose the EPS plates as insulation material. The remaining construction of the roof deck is based on the literature of Bezuijen (2019), who has researched the most sustainable composition of materials.

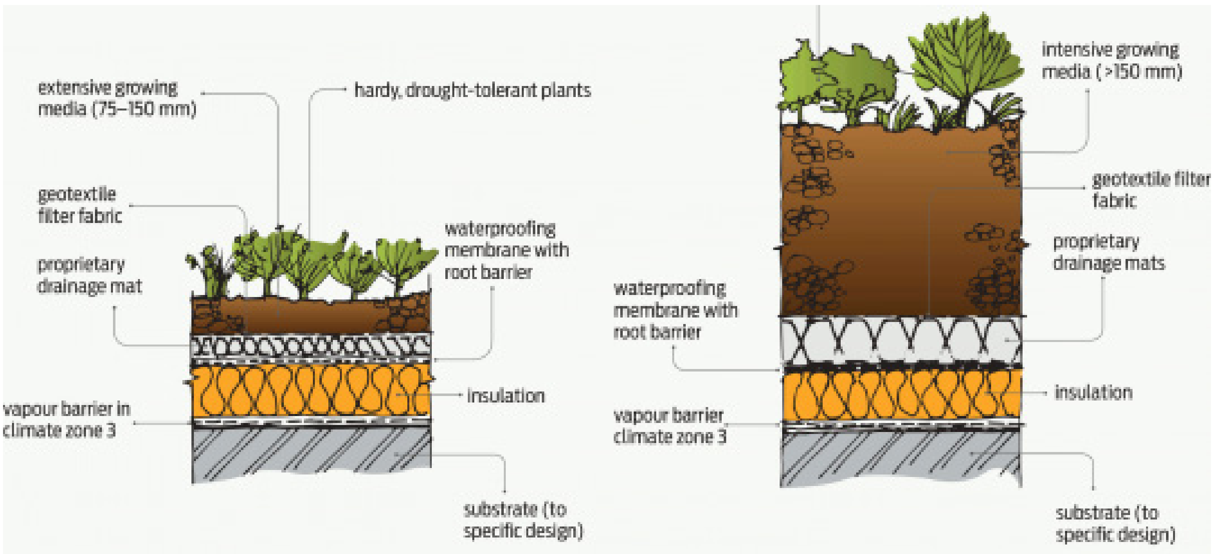


Fig 30. Difference between extensive and intensive roofs (Elkink, 2017)

Results

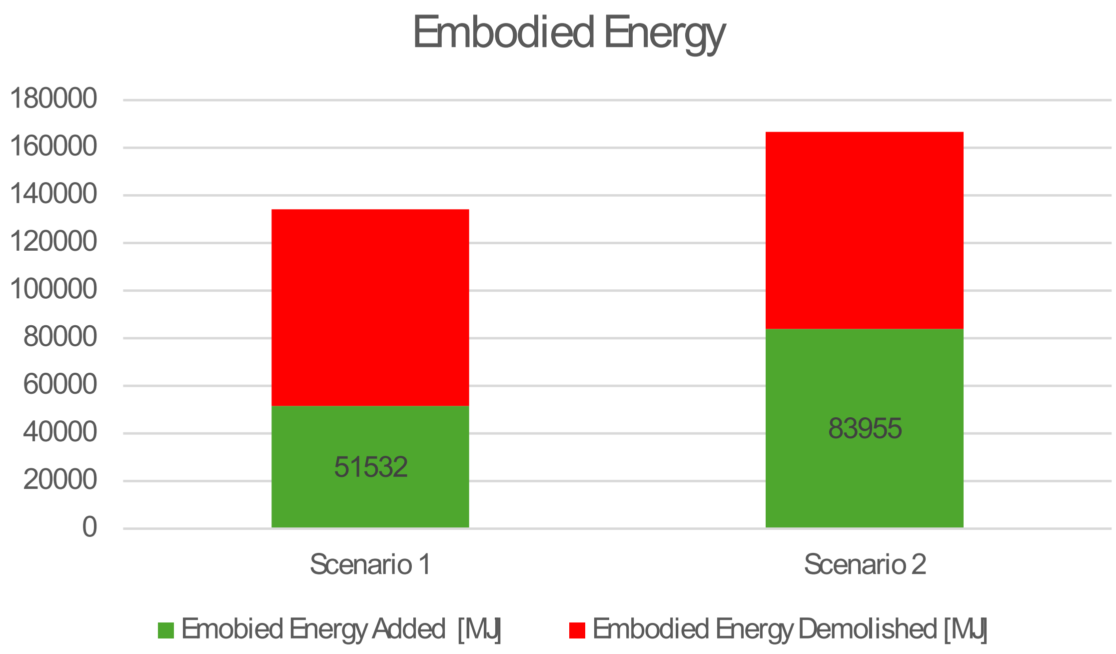
Finally, as in the previous section, the two scenarios are compared. First it is save to say that both strategies improve in comparrison with the current situation.

Second, there is a difference in the amount of embodied energy between the two scenarios. This difference lies in the embodied energy that is added, as more material is used in the construction of a green roof, resulting in a difference of 40,000 [MJ].

In terms of operational energy, we see that both roof structures achieve the required Rc value of 6.3 [m^2K/W] due to the use of sufficient insulation material. Nevertheless, the top layer of the green roof, the planting, does reduce the required cooling of the property in the spring and summer (Bevilacqua, 2021). This is mainly due to the evaporation of water, which provides cooling and reduces the temperature of the roof. As a result, we can conclude that scenario 2 has a better impact on reducing the operational energy than scenario 1.

Finally, the heritage value of the building. This changes little to nothing in scenario 1. The roof is refurbished to meet contemporary building requirements, it is replaced and improved without changing its appearance. Therefore it receives a heritage score of 5.

Scenario 2, however, replaces not only the current roof in terms of materials but also its appearance, affecting the heritage value of the property. The green roof contributes to a more pleasing appearance of the heritage building, therefore improving its aesthetic value. In addition, the implementation of various plants on the green roof leads to an increase in biodiversity. This creates a better connection between the building and its surroundings, giving the building an increase in ecological value. In conclusion, the improvement of the two values increases the heritage value of the property (Tarrafa Pereira Da Silva & Pereira Roders, 2012). This leads to a heritage score of 3.



Graph 25.The Embodied Energy comparisson of the different scenarios

3.5.3 Whole building scenario

In the final scenario comparison, we will look at a larger scale for interventions. We will now analyse scenarios involving the entire building. These will be the following scenarios. Scenario 1; the building will be demolished, and new construction will then be built on the site of the demolished building. This new building will match the style and typology of one of developer FLOW's developed properties. Scenario 2; the property will be made more sustainable by applying different strategies and materials that emerged from the study as the most convenient. No solar panels are applied in this scenario. This is the case with scenario 3, which fulfils the same conditions as scenario 2 however, solar panels are applied

1. Demolition and new construction

Scenario 1. thus focuses on demolishing the existing building and constructing a new building. This new construction is based on the plan under development to the south of the design case (highlighted in the picture). Among other things, the dimensions and material use are adopted from the building. The building will be a three-storey high with space for six homes

Fig 31. Plesman Plaza

In terms of embodied energy, the types of materials considered to have the most impact are included. Using a simplified model, the embodied energy can then be calculated for all these materials, subsequently they will be added together. At last a calculation is made for the estimated operational energy per year for this scenario.

2. Renovation (no PV panels)

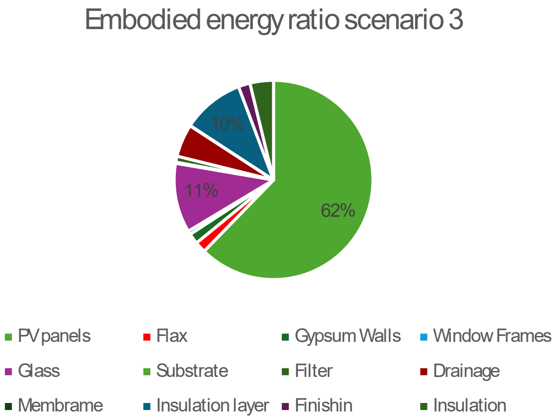
Scenario 2 focuses on retaining the existing heritage building, and renovating it. For this, the different materials and strategies from the earlier analysis are applied. So, internal insulation is applied, a green roof structure is applied and materials are used that would be the most sustainable according to the material analysis.

3. Renovation (PV panels)

This scenario can be seen as almost the same strategy as the last one, only here PV panels are applied. These will reduce operational energy, however, this also has its impact on embodied energy and the property's heritage value

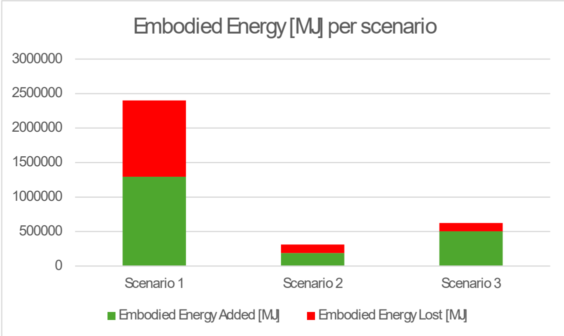
Conclusion whole building scenario

Looking at the results, we see that scenario 1 loses the most amount of embodied energy because the building is completely demolished. Also, the most amount of embodied energy is added because an entirely new building is built, which requires a lot of materials. Looking at the other two scenarios, we see that scenario 3 adds more embodied energy. This is only because of the PV panels that are implemented in this scenario. There are 40 PV panels included,resulting in a total embodied energy of 313520 [MJ], which is 62% of the total amount.



Graph 26. Embodied energy ratio of scenario 3

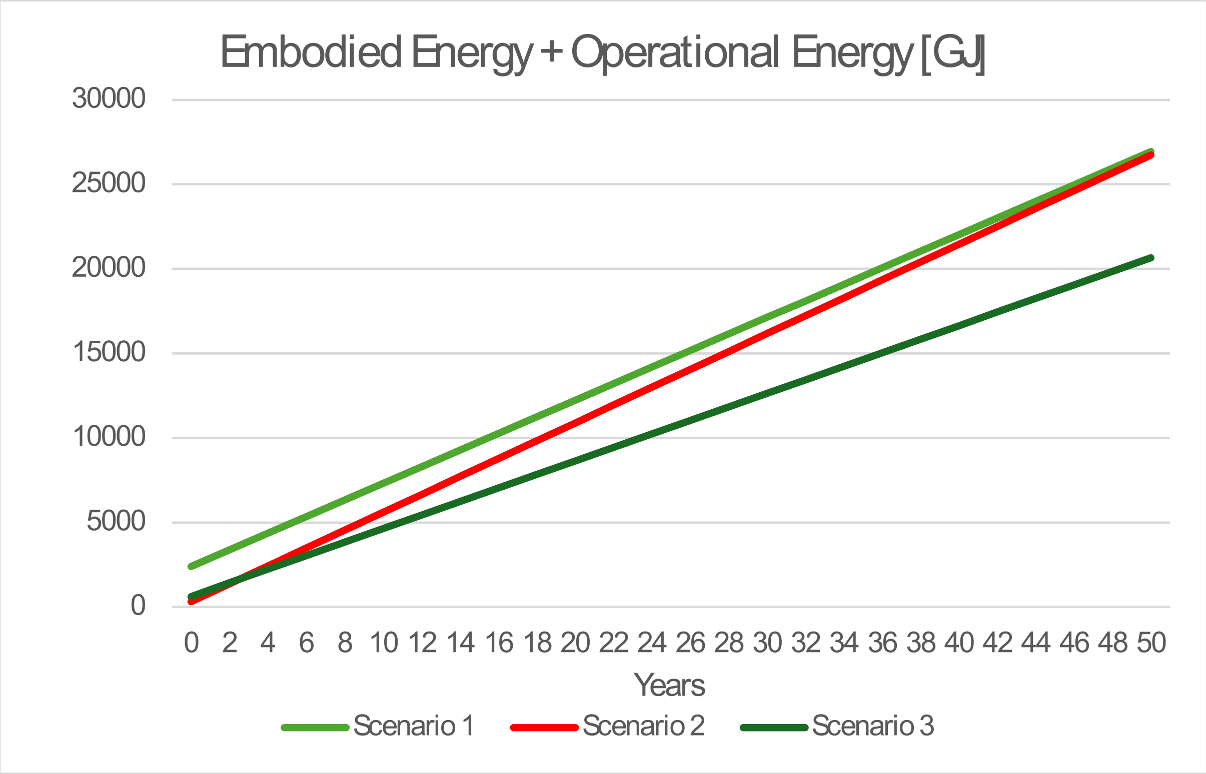
The addition of the PV panels not only impacts embodied energy but also operational energy. Whereas scenario 2 has an annual operational energy of 528660 [MJ/year], this is as much as a fifth less than scenario 3 and amounts to a quantity of 400500 [MJ/year]. The impact on the operational energy of the PV panels becomes clear here, despite the large amount of embodied energy they carry. Scenario 1 is just a little lower than scenario 3 in terms of operational energy value and needs 490806 [MJ/year]. By calculating the operational energy over 50 years and adding this to the embodied energy, it can be concluded which scenario, in terms of energy efficiency, is the most



Graph 27.The Embodied Energy comparisson of the different scenarios

sustainable. The results of this can be seen in the graph on the next page. Because scenario 3 has the lowest operational energy, but a high embodied energy amount, it will take 5 years to become the most energy efficient. Looking at the other 2 scenarios, we see that they are not much inferior to each other in terms of operational energy, but ultimately scenario 1 has a lower amount. However, because the embodied energy here was the highest, it will take 50 years for it to be more energy efficient than the other scenario.

In terms of heritage, scenarios 2 and 3 are not too far apart, provided that the PV panels in scenario 3 are not visible from street level. These two scenarios, therefore, both receive a heritage score of 3, since the roof is changed, as mentioned in the previous paragraph, but without affecting the monumental value of the building. Scenario 1 on the other hand receives a score of 1 due to the complete demolition of the heritage building. Thereby losing the heritage value completely

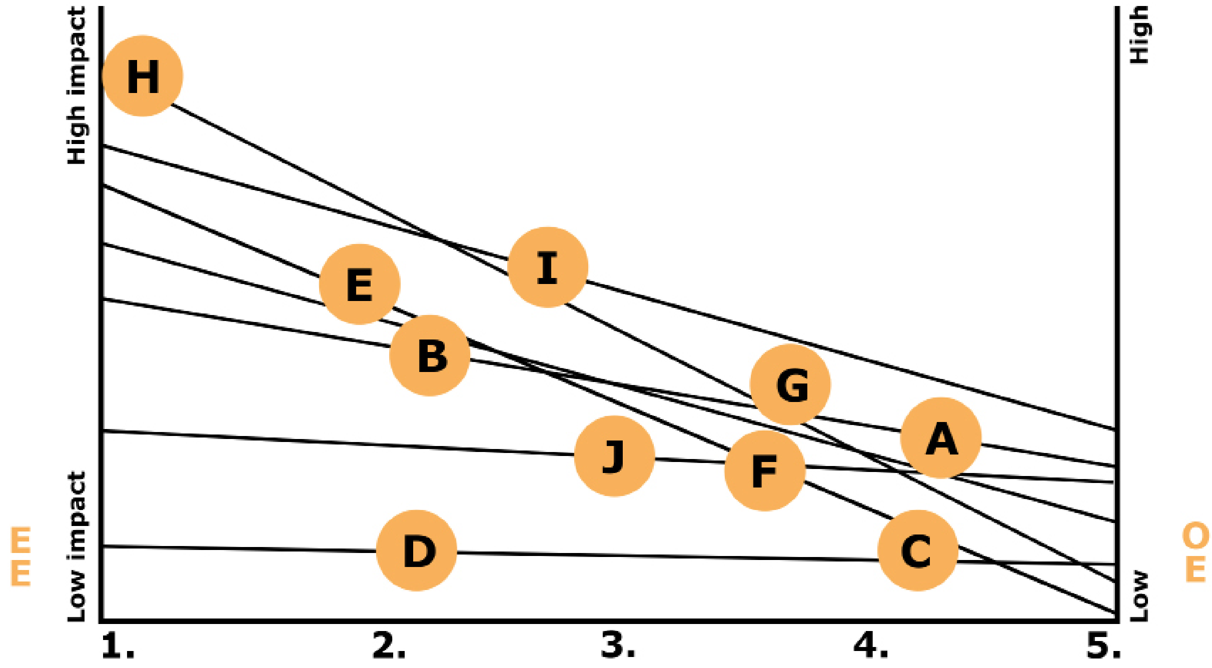


Graph 28. The Embodied Energy + the Operational Energy of the different scenarios

3.6 Results of the research

This chapter concludes with a summary illustration that allows for a comparative analysis of interventions. The illustration takes the form of a graph, with values plotted along three axes. The horizontal axis represents the impact score associated with heritage value. The two vertical axes correspond to impact scores related to energy values, with embodied energy (EE) on the left and operational energy (OE) on the right. On the EE axis, a higher starting point indicates a greater impact on the embodied energy. On the OE axis, the graph's upper end reflects higher operational energy, while the lower end signifies a lower operational energy.

For instance, if an intervention significantly affects the EE but substantially reduces the OE of the building, the graph will depict a line moving from the top-left to the bottom-right. By examining the position of a circle on this line and considering its horizontal displacement, one can determine the intervention's impact on the property's heritage value.



A. Window replacement in line with fenestration old facade
B. Window replacement without looking at the old facade
C. Adding insulation on the inside of a building
D. Adding insulation on the outside of a building
E. Addition of PV panels in sight of the public
F. Addition of PV panels out of sight of public / Collaboratively designed with existing
G. Integration of new HVAC services
H. Facade, structure demolition (without reusing)
I. Designing a double skin facade
J. Design of a green roof structure

4. Discussion

Within this research, there have been some limits to where this research could reach. For example, many calculations were done for the embodied and operational energy of different scenarios. Although these scenarios are based on valid data from the NIBE database and the program Climatestudio, these calculations are theoretical and thus have not been applied in practice. It is therefore possible that the calculated quantities in reality may differ from the theory. Nevertheless, I am convinced that the results, concerning the calculations, paint a valid picture of the various scenarios and that conclusions can certainly be drawn from them.

In addition, an important assumption was made for the calculations in the last section. This was the fact that the supporting structure of the building was strong enough for the imposition of a green roof. However, this was not calculated, therefore this could have admittedly affected the results. Should the roof have been too load-bearing, an addition or replacement of supporting structure would have been necessary. This would have had a big impact on the embodied energy of the scenario in question. Nevertheless, by choosing an extensive roof in the scenario, the risk of an excessive load was reduced. This means that the material used for realizing this roof, and thus the additional imposition, was limited.

Finally, there is a final point of discussion. As mentioned earlier in the report (Chapter 3.1), heritage buildings are special buildings. Not only because of their historical and cultural significance but also the way these properties are built. The buidling often have special ways of construction that are not all too common. Therefore, this can lead to really case-specific problems. This was also evident in my case study, the Call Center. It had its specific weaknesses, think of the limited daylight and the high operational energy, but also its specific strengths. Nevertheless, in this study, through the different scenarios, we tried to experience what impact general interventions always have on heritage cases. However, I now see that there is no one-solution-fits-all when it comes to heritage properties. This may make the outcome less validly applicable to other heritage cases. But on the other hand, the method applied in this study proves to be valid in all kinds of other cases. The method proves itself as a tool to come to insights related to different design scenarios.

In future studies, in addition to the three indicators tested in this study (heritage, operational energy, and embedded energy), a fourth indicator can be added to the analyses. For example, the cost of materials and thus the cost of different scenarios could be calculated. This would add an extra dimension to the different scenarios and bring the analysis even closer to reality. Since there is often a limited budget available for a design assignment, this could be a valuable addition to further compare the choices.

5. Conclusion

The main research question was:
How can redevelopment interventions achieve a balanced approach that enhances both operational efficiency and heritage value, while minimizing the increase in embodied energy?

Through literature review and analysis, several things can be concluded. When interventions are made in a redevelopment project, it is important that the building should be properly analyzed first. One should look at the heritage value of the property, what is the condition of the building, and also where the strengths and weaknesses lie in and around the building. Strengths should be exploited, but weaknesses should be addressed. Based on this, strategies can be formulated to make the property inhabitable again. In this process, operational energy should be reduced while embodied energy should remain as low as possible. While working out strategies, it is therefore important to always consider the energy efficiency of different interventions.

To keep embodied energy as low as possible, the most important thing is to reduce material consumption. By analyzing which building materials contain the most embodied energy, a strategy can be developed that preserves these elements. Vice versa, it is more appropriate to replace materials with lower embodied energy to achieve certain goals in a strategy. Should materials be applied in a design, it is important to gain knowledge about these materials. For example, it has been shown that a lot of energy can be saved by applying materials with a low amount of embodied energy.

Then, with a heritage building, it is important to reduce operational energy. The analyses and calculations showed that operational energy is a major contributor to the total energy consumption of a building. Limiting this through proper insulation can certainly reduce consumption. This involves looking at what type of insulation is used, with a low thermal conductivity, but also looking at how the insulation is applied. Insulating should not affect the heritage value of a property. Finally, the addition of PV panels has proven to be a sustainable means of achieving an energy-efficient building. While this again needs to be linked with the heritage value of the property.

In summary, it can be concluded that a balanced approach in redevelopment interventions is critical to optimize both operational efficiency and heritage value while minimizing the increase in embodied energy. Analyzing the building and identifying both strengths and weaknesses form the basis for strategies that lead to a sustainable and energy-efficient redevelopment. Reducing embodied energy, especially through the conscious use of materials, proves to be a key factor. In addition, reducing operational energy, primarily through thoughtful insulation and incorporating sustainable technologies such as PV panels, saves a lot of energy over the years. These conclusions underscore the need for a comprehensive approach that combines energy efficiency with respect for heritage values to achieve sustainable redevelopment.

6. Reflection

Influence of Research and Design

rom my research there were several goals set to apply to the design task of my graduation project. Of which the first was to occupy a new function that would fit into the present time and be flexible to change. This would prevent the demolition of the heritage building. As a result, not only the heritage value of the building would be preserved, but also the materials of this building, and thus the embodied energy (Guidettie & Ferrara, 2023) .

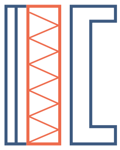
It also showed how evident it was to save on the operational energy of the building (Lidelöw et al., 2019). So to make the building functional within the current time spirit, it was therefore of great importance to reduce the operational energy of the building. My research showed that applying and testing strategies was a good way to determine which design solution would have the most impact on the operational energy. This had to be done without drastically increasing embodied energy and without affecting the heritage value of the property. Tangible goals that emerged from the study included applying internal insulation to improve the building's energy efficiency without affecting the monumental façade. It was also recommended to introduce and implement green roofs, due to their cooling effect and minimal increase in embodied energy (Bezuijen, 2019) . Finally, the use of smart systems was suggested, which can save and even generate energy through PV panels.
The research conclusions and their impact within the design are displayed in the diagram below and on the next page.

Conclusion

Desing Decision **ICON**

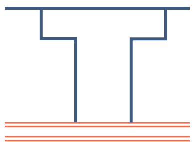
Adding internal insulation will increase the O.E. efficiency of the building without increasing the E.E. nor altering the Heritage value of the building

Adding Internal Insulation materials



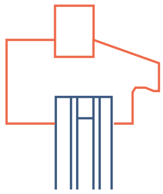
Smart services will increase the O.E. efficiency of the building without increasing the E.E . In terms of the Heritage value , installations should not interfere the Heritage.

Smart Services are not concealed are not covered by a false ceiling, leaving the concrete column/beam structure visible



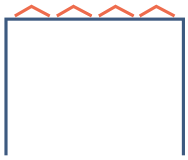
Window replacement is a very sufficient way of increasing the O.E. of a building.

The windows are replaced with new HR ++ glass. The material of the frame was chosen the same as the original window frames, hardwood.



PV panels do have an impact upon the E.E amount of a building. However it has a really big impact on the O.E. efficiency of the building as well. Additionally Pv panels should not be visible from street level view, because it has a negative impact on the heritage value of the building

The solar panels are placed on the taller towers to the east and west of the heritage property

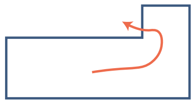


Applying natural elements cools the building during hot days, thereby increasing O.E. efficiency. The placement of greenery has no negative impact on the heritage.

Greenery is embraced in the design. Green facades and a green active roof are applied.

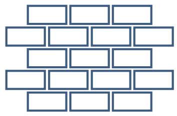
Natural ventilation, reduces the amount of O.E. , by decreasing the amount of energy for mechanical ventilation

Chimney ventilation is applied within the design, providing natural ventilation



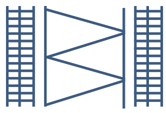
Reuse of materials gives a 2nd life to this material. Whereby E.E is not lost.

Discontinued bricks are reused as railing directly in the context of the design



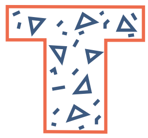
Applying flexible floor plans makes it possible to realize different programs in the future. This reduces the risk of demolition, thus preserving E.E.

No solid walls will be added to the building, only demountable light plaster walls.



By preserving materials with a high E.E content, it is not lost.

The concrete elements within the building will be retained.



Apply materials with low E.E. content. These materials are more durable in nature.

From the materials analysis, the most durable material per material will be chosen, if there is an entitlement to do so.

7. Literature

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8. Appendix

Flax/Hemp (i)	Glass wool (i)	PUR plates (i)	Rockwool (i)	Straw Bale	Wood fibers (i)	XPS Plates (i)	XPS Plates (o)
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
65,255	410,75	296,05	418,5	127,1	168,95	637,05	829,25
130,51	821,5	592,1	837	254,2	337,9	1274,1	1658,5
130,51	821,5	592,1	837	254,2	337,9	1274,1	1658,5
130,51	821,5	592,1	837	254,2	337,9	1274,1	1658,5
130,51	821,5	592,1	837	254,2	337,9	1274,1	1658,5
130,51	821,5	592,1	837	254,2	337,9	1274,1	1658,5
130,51	821,5	592,1	837	254,2	337,9	1274,1	1658,5

Embodied Energy Insulation

Flax/Hemp (i)	Glass wool (i)	PUR plates (i)	Rockwool (i)	Straw Bale	Wood fibers (i)	XPS Plates (i)	XPS Plates (o)
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
17873,3445	112504,425	57990,274	81975,78	49581,71	50089,6202	174487,995	227131,575
35746,689	225008,85	115980,548	163951,56	99163,42	100179,2404	348975,99	454263,15
35746,689	225008,85	115980,548	163951,56	99163,42	100179,2404	348975,99	454263,15
35746,689	225008,85	115980,548	163951,56	99163,42	100179,2404	348975,99	454263,15
35746,689	225008,85	115980,548	163951,56	99163,42	100179,2404	348975,99	454263,15
35746,689	225008,85	115980,548	163951,56	99163,42	100179,2404	348975,99	454263,15
35746,689	225008,85	115980,548	163951,56	99163,42	100179,2404	348975,99	454263,15

Embodied Energy Insulation

Year	Aluminium Coated	Ceramic Tiles	Copper	European Robina	European Oak	Natural stone slabs	Steel coated	Western Red Cedar	Zink	Wood fibre cement board
5	364,25	407,65	243,35	241,8	198,4	1026,1	325,5	90,52	156,6	595,2
10	364,25	407,65	243,35	241,8	198,4	1026,1	325,5	90,52	156,6	595,2
15	364,25	407,65	243,35	241,8	198,4	1026,1	325,5	90,52	156,6	595,2
20	364,25	407,65	243,35	241,8	198,4	1026,1	325,5	90,52	156,6	595,2
25	364,25	407,65	243,35	241,8	198,4	1026,1	325,5	90,52	156,6	1190,4
30	364,25	407,65	243,35	241,8	198,4	1026,1	325,5	90,52	156,6	1190,4
35	364,25	407,65	243,35	483,6	396,8	1026,1	651	90,52	156,6	1190,4
40	364,25	407,65	243,35	483,6	396,8	1026,1	651	90,52	156,6	1190,4
45	728,5	407,65	243,35	483,6	396,8	1026,1	651	90,52	156,6	1190,4
50	728,5	407,65	243,35	483,6	396,8	1026,1	651	90,52	156,6	1785,6
55	728,5	407,65	243,35	483,6	396,8	1026,1	651	90,52	156,6	1785,6
60	728,5	407,65	243,35	483,6	396,8	1026,1	651	90,52	156,6	1785,6
65	728,5	407,65	243,35	725,4	595,2	1026,1	976,5	181,04	156,6	1785,6
70	728,5	407,65	243,35	725,4	595,2	1026,1	976,5	181,04	156,6	1785,6
75	728,5	407,65	243,35	725,4	595,2	1026,1	976,5	181,04	156,6	1785,6
80	728,5	815,3	243,35	725,4	595,2	2052,2	976,5	181,04	156,6	2380,8
85	1092,75	815,3	243,35	725,4	595,2	2052,2	976,5	181,04	156,6	2380,8
90	1092,75	815,3	243,35	725,4	595,2	2052,2	976,5	181,04	156,6	2380,8
95	1092,75	815,3	243,35	967,2	793,6	2052,2	1302	181,04	156,6	2380,8
100	1092,75	815,3	243,35	967,2	793,6	2052,2	1302	181,04	156,6	2380,8
105	1092,75	815,3	486,7	967,2	793,6	2052,2	1302	181,04	313,2	2380,8

Embodied Energy Cladding

Year	Aluminium	European coniferous	European hardwood	Pinewood	PVC	Steel
5	279	218,55	196,85	297,6	486,7	468,7
10	279	218,55	196,85	297,6	486,7	468,7
15	279	218,55	196,85	297,6	486,7	468,7
20	279	218,55	196,85	297,6	486,7	468,7
25	279	218,55	196,85	297,6	486,7	468,7
30	279	218,55	196,85	297,6	486,7	468,7
35	279	218,55	196,85	297,6	486,7	468,7
40	279	437,1	196,85	297,6	486,7	468,7
45	279	437,1	196,85	297,6	973,4	468,7
50	279	437,1	196,85	297,6	973,4	468,7
55	279	437,1	393,7	595,2	973,4	468,7
60	279	437,1	393,7	595,2	973,4	468,7
65	279	437,1	393,7	595,2	973,4	468,7
70	279	437,1	393,7	595,2	973,4	468,7
75	279	655,65	393,7	595,2	973,4	468,7
80	558	655,65	393,7	595,2	973,4	468,7
85	558	655,65	393,7	595,2	1460,1	468,7
90	558	655,65	393,7	595,2	1460,1	468,7
95	558	655,65	393,7	595,2	1460,1	468,7
100	558	655,65	393,7	595,2	1460,1	468,7
105	558	655,65	393,7	595,2	1460,1	1460,1

Embodied Energy Window Frames

Year	Cellular glass	EPS plates	Glasswool plates	Presure restant wood fibre cement board	PUR plates	Rockwool plates	XPS plates
5	906,75	288,3	902,1	240,25	447,95	539,4	1198,15
10	906,75	288,3	902,1	240,25	447,95	539,4	1198,15
15	906,75	288,3	902,1	240,25	447,95	539,4	1198,15
20	906,75	288,3	902,1	240,25	447,95	539,4	1198,15
25	906,75	288,3	902,1	240,25	447,95	539,4	1198,15
30	906,75	288,3	902,1	240,25	447,95	539,4	1198,15
35	906,75	288,3	902,1	240,25	447,95	539,4	1198,15
40	906,75	288,3	902,1	240,25	447,95	539,4	1198,15
45	906,75	288,3	902,1	240,25	447,95	539,4	1198,15
50	906,75	288,3	902,1	240,25	447,95	539,4	1198,15
55	906,75	288,3	902,1	480,5	447,95	539,4	1198,15
60	906,75	288,3	902,1	480,5	447,95	539,4	1198,15
65	906,75	288,3	902,1	480,5	447,95	539,4	1198,15
70	906,75	288,3	902,1	480,5	447,95	539,4	1198,15
75	906,75	288,3	902,1	480,5	447,95	539,4	1198,15
80	1813,5	576,6	1804,2	480,5	447,95	539,4	1198,15
85	1813,5	576,6	1804,2	480,5	895,9	1078,8	2396,3
90	1813,5	576,6	1804,2	480,5	895,9	1078,8	2396,3
95	1813,5	576,6	1804,2	480,5	895,9	1078,8	2396,3
100	1813,5	576,6	1804,2	720,75	895,9	1078,8	2396,3
105	1813,5	576,6	1804,2	720,75	895,9	1078,8	2396,3

Embodied Energy Roof Insulation

Year	Cellular glass	EPS plates	Glasswool plates	Presure restant wood fibre cement board	PUR plates	Rockwool plates	XPS plates
5	201794,9456	52731,5115	178453,422	47526,255	50987,90875	98658,957	159893,118
10	201794,9456	52731,5115	178453,422	47526,255	50987,90875	98658,957	159893,118
15	201794,9456	52731,5115	178453,422	47526,255	50987,90875	98658,957	159893,118
20	201794,9456	52731,5115	178453,422	47526,255	50987,90875	98658,957	159893,118
25	201794,9456	52731,5115	178453,422	47526,255	50987,90875	98658,957	159893,118
30	201794,9456	52731,5115	178453,422	47526,255	50987,90875	98658,957	159893,118
35	201794,9456	52731,5115	178453,422	47526,255	50987,90875	98658,957	159893,118
40	201794,9456	52731,5115	178453,422	47526,255	50987,90875	98658,957	159893,118
45	201794,9456	52731,5115	178453,422	47526,255	50987,90875	98658,957	159893,118
50	201794,9456	52731,5115	178453,422	47526,255	50987,90875	98658,957	159893,118
55	201794,9456	52731,5115	178453,422	95052,51	50987,90875	98658,957	159893,118
60	201794,9456	52731,5115	178453,422	95052,51	50987,90875	98658,957	159893,118
65	201794,9456	52731,5115	178453,422	95052,51	50987,90875	98658,957	159893,118
70	201794,9456	52731,5115	178453,422	95052,51	50987,90875	98658,957	159893,118
75	201794,9456	52731,5115	178453,422	95052,51	50987,90875	98658,957	159893,118
80	403589,8913	105463,023	356906,844	95052,51	50987,90875	98658,957	159893,118
85	403589,8913	105463,023	356906,844	95052,51	101975,8175	197317,914	319786,235
90	403589,8913	105463,023	356906,844	95052,51	101975,8175	197317,914	319786,235
95	403589,8913	105463,023	356906,844	95052,51	101975,8175	197317,914	319786,235
100	403589,8913	105463,023	356906,844	95052,51	101975,8175	197317,914	319786,235
105	403589,8913	105463,023	356906,844	142578,765	101975,8175	197317,914	319786,235

Embodied Energy Roof Insulation [Total]

Year	EPS plates	Flax plates	Presure resistant EPS	Presure resistant PUR	Presure resistant XPS	Presure resistant Rockwool	Thermal cussions
5	209,25	50,685	209,25	249,55	838,55	446,4	9,19
10	209,25	50,685	209,25	249,55	838,55	446,4	9,19
15	209,25	50,685	209,25	249,55	838,55	446,4	9,19
20	209,25	50,685	209,25	249,55	838,55	446,4	9,19
25	209,25	50,685	209,25	249,55	838,55	446,4	9,19
30	209,25	50,685	209,25	249,55	838,55	446,4	9,19
35	209,25	50,685	209,25	249,55	838,55	446,4	9,19
40	209,25	50,685	209,25	249,55	838,55	446,4	9,19
45	209,25	50,685	209,25	249,55	838,55	446,4	9,19
50	209,25	50,685	209,25	249,55	838,55	446,4	9,19
55	209,25	50,685	209,25	249,55	838,55	446,4	9,19
60	209,25	50,685	209,25	249,55	838,55	446,4	9,19
65	209,25	50,685	209,25	249,55	838,55	446,4	9,19
70	209,25	50,685	209,25	249,55	838,55	446,4	9,19
75	209,25	50,685	209,25	249,55	838,55	446,4	9,19
80	418,5	101,37	418,5	499,1	1677,1	892,8	18,38
85	418,5	101,37	418,5	499,1	1677,1	892,8	18,38
90	418,5	101,37	418,5	499,1	1677,1	892,8	18,38
95	418,5	101,37	418,5	499,1	1677,1	892,8	18,38
100	418,5	101,37	418,5	499,1	1677,1	892,8	18,38
105	418,5	101,37	418,5	499,1	1677,1	892,8	18,38

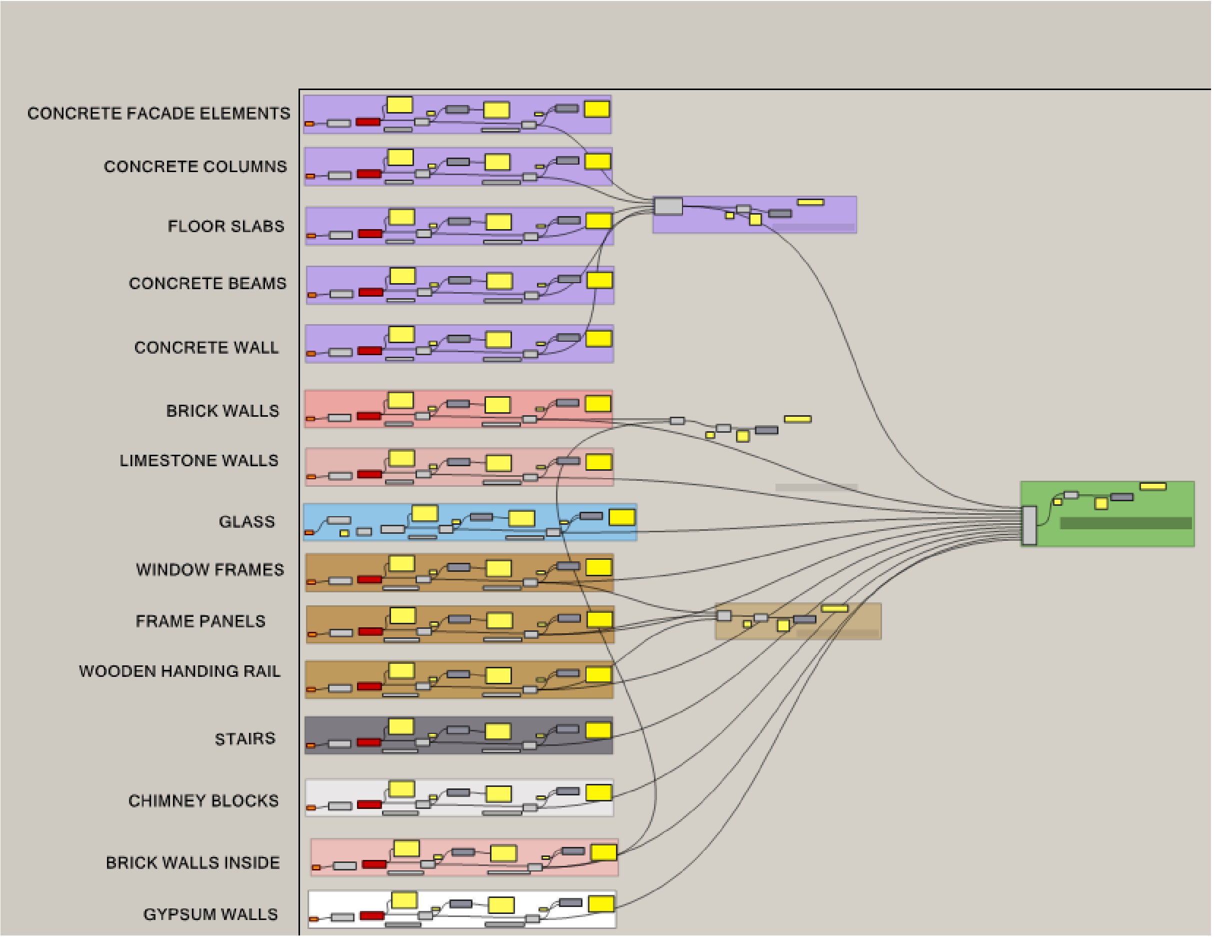
Embodied Energy Floor Insulation

Year	Bamboo	Carpet	Cast floor (Epoxy)	Ceramic tiles	European natural stones	European oak	Linoleum
5	290	296	640	448,25	444,85	214	361
10	290	296	640	448,25	444,85	214	361
15	290	592	640	448,25	444,85	214	361
20	290	592	640	448,25	444,85	214	361
25	290	888	640	448,25	444,85	214	361
30	290	888	640	448,25	444,85	214	361
35	290	1184	1280	448,25	444,85	214	361
40	290	1184	1280	448,25	444,85	214	722
45	290	1480	1280	448,25	444,85	214	722
50	290	1480	1280	448,25	444,85	214	722
55	580	1776	1280	896,5	444,85	428	722
60	580	1776	1280	896,5	444,85	428	722
65	580	2072	1920	896,5	444,85	428	722
70	580	2072	1920	896,5	444,85	428	722
75	580	2368	1920	896,5	444,85	428	1083
80	580	2368	1920	896,5	889,7	428	1083
85	580	2664	1920	896,5	889,7	428	1083
90	580	2664	1920	896,5	889,7	428	1083
95	580	2960	2560	896,5	889,7	428	1083
100	580	2960	2560	896,5	889,7	428	1083
105	870	3256	2560	1344,75	889,7	642	1444

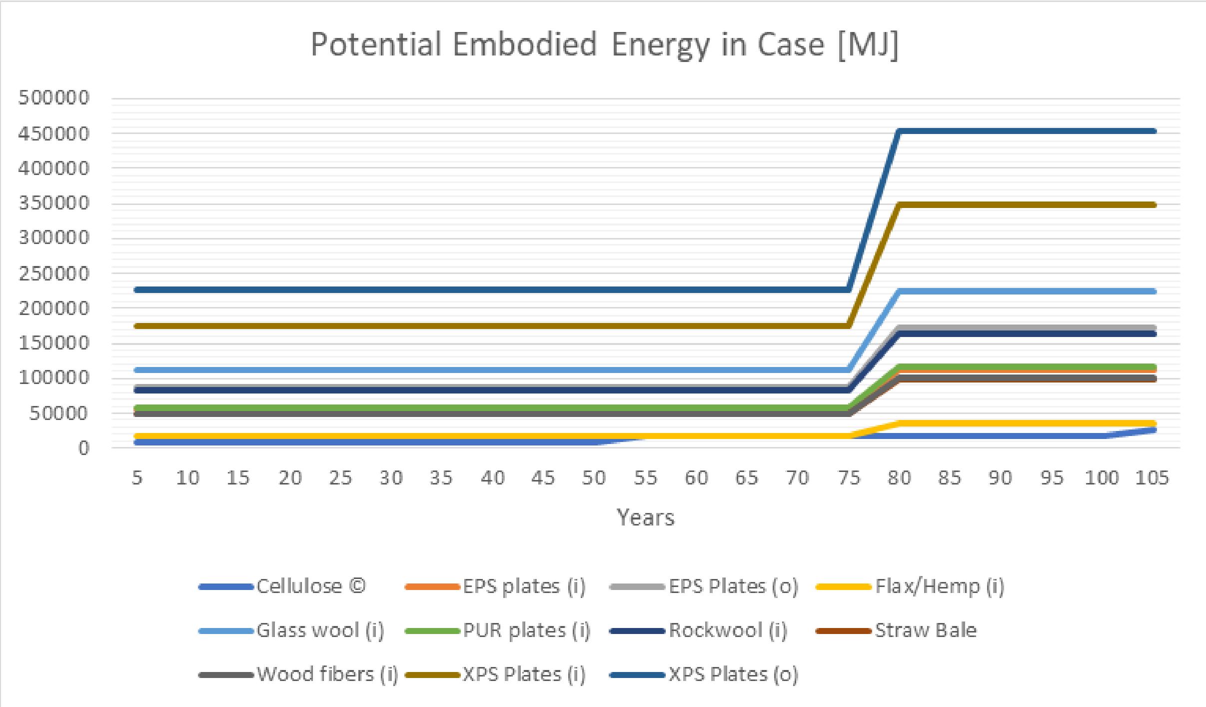
Embodied Energy Floor finishing

Years	Aerated Blocks	CLT wall	Concrete Blocks	Gypsum blocks	Lime Stone	Timber Frame Construction	Steel Aluminium frame + Gypsum pl	Steel frame + Steel plates	Steel frame + Chipboard frame
5	782,75	606,05	775	403	441,75	661,85	773,4	1095	1012
10	782,75	606,05	775	403	441,75	661,85	773,4	1095	1012
15	782,75	606,05	775	403	441,75	661,85	773,4	1095	1012
20	782,75	606,05	775	403	441,75	661,85	773,4	1095	2024
25	782,75	606,05	775	403	441,75	661,85	1546,8	2190	2024
30	782,75	606,05	775	403	441,75	661,85	1546,8	2190	2024
35	782,75	606,05	775	403	441,75	661,85	1546,8	2190	2024
40	782,75	606,05	775	403	441,75	661,85	1546,8	2190	2024
45	782,75	606,05	775	403	441,75	661,85	1546,8	2190	2024
50	782,75	606,05	775	403	441,75	661,85	1546,8	2190	2024
55	782,75	606,05	775	403	441,75	661,85	2320,2	3285	3036
60	782,75	606,05	775	403	441,75	661,85	2320,2	3285	3036
65	1565,5	606,05	775	806	441,75	661,85	2320,2	3285	3036
70	1565,5	606,05	775	806	441,75	661,85	2320,2	3285	3036
75	1565,5	606,05	775	806	441,75	1323,7	2320,2	3285	3036
80	1565,5	606,05	1550	806	883,5	1323,7	3093,6	4380	4048
85	1565,5	606,05	1550	806	883,5	1323,7	3093,6	4380	4048
90	1565,5	606,05	1550	806	883,5	1323,7	3093,6	4380	4048
95	1565,5	606,05	1550	806	883,5	1323,7	3093,6	4380	4048
100	1565,5	606,05	1550	806	883,5	1323,7	3093,6	4380	4048
105	1565,5	1212,1	1550	806	883,5	1323,7	3093,6	4380	4048

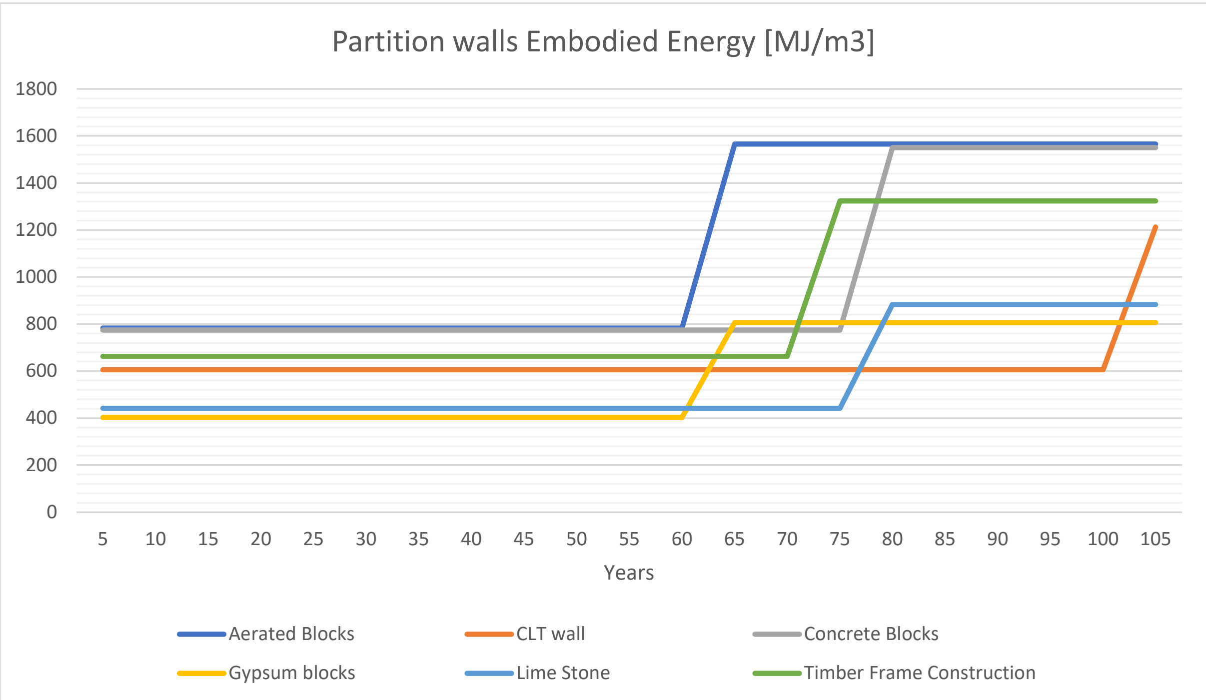
Embodied Energy Massive partition walls

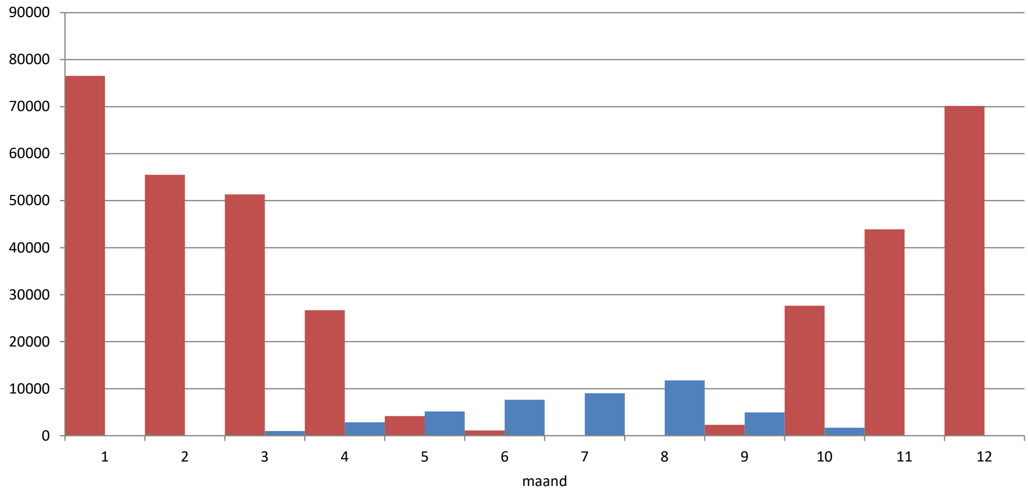


Grasshopper script that was used to calculate the Embodied energy of different materials

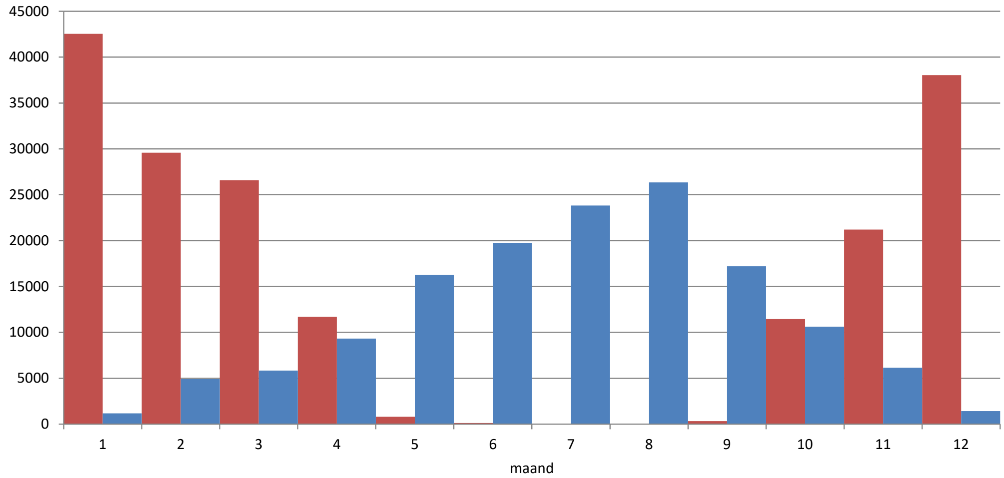


Embodied Energy Roof Insulation [Total]

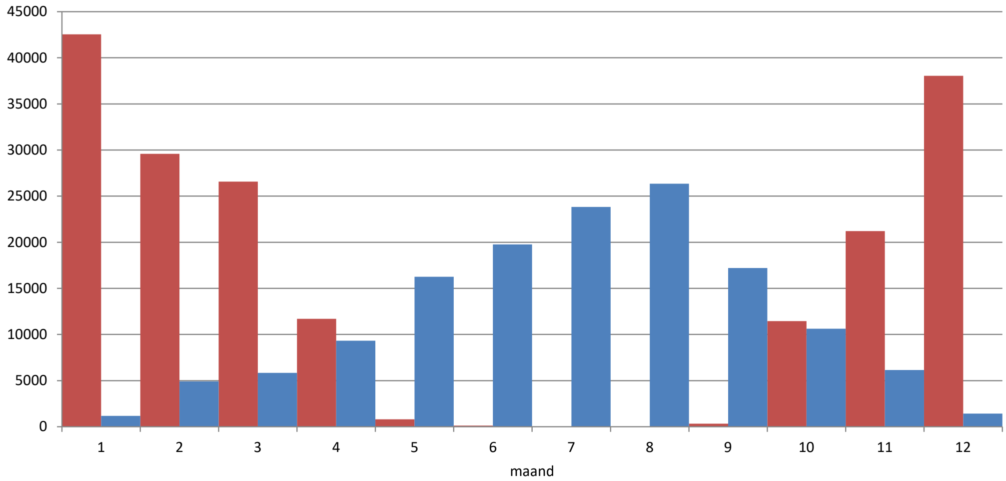




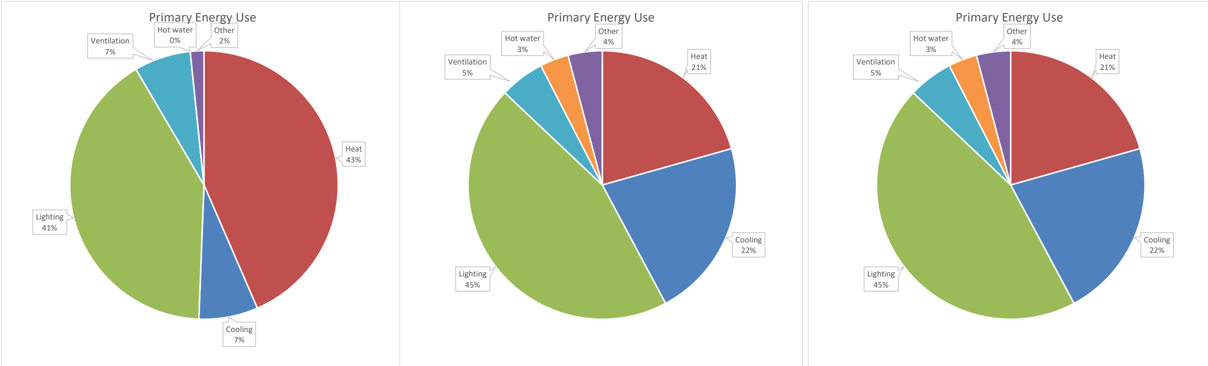
Operational energy scenario 3.1



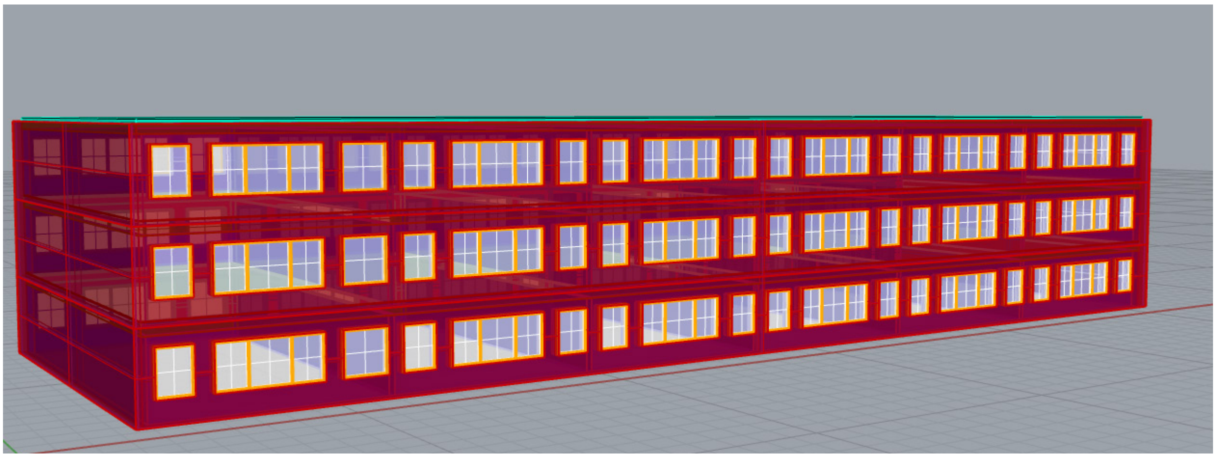
Operational energy scenario 3.2



Operational energy scenario 3.3



Operational energy ratios of scenario 3.1-3.3 (left to right)



Simplified model of the new dwelling building in scenario 3.1