Improve the future, Renovate the past

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A research on improving the balance between cultural value, sustainability, and costs in industrial heritage renovation projects.

Colophon

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This report is together with the Excel file: Decision-support model p5

Preface

This thesis for my graduation is within the domain Adaptive reuse of the master track Management of the Built Environment at the University of Technology in Delft.
This report contains a research into the complexity of industrial heritage renovation projects. To lower the threshold, a decision-support model will be created that will find a balance between cultural value, sustainability, and costs.
This report is written from my passion for embracing our cultural heritage and for working on a sustainable future. The idea to write about this subject was inspired by my parents. They own a beautiful old house which they wanted to renovate and asked me for advice. I gave them some options, such as applying insulation and changing the windows. However, with every option, they disagreed because it would impact the aesthetics of their house. Ultimately, with the later in mind, only the expensive options were left. Through this experience, I realized that there was an iron triangle with tension between cultural value, sustainability, and costs. After this had happened, I found my motivation to find a solution to these kinds of problems. I wanted to create a tool for people just like my parents that would help them find a perfect solution for their home without sacrificing the much beloved cultural values. It is for this reason, I would like to thank my parents Evaly van Dijk and Peter Bodewes for being my inspiration.
I also would like to thank my mentors Hilde Remoy and Hielkje Zijlstra for supporting me and being critical to my work. Also, I would like to thank Rosi de Kok from ABT for giving an excellent opportunity to work on this project with an inspiring company.

Rosaly Bodewes

Summary

Nowadays, a significant part of the building stock consists of industrial heritage buildings. To ensure the continuous use of these buildings, it is essential to renovate them according to the contemporary sustainability standards. To ensure the viability of these renovations, costs must be kept in mind as it determines the decision to renovate. However, these buildings embed cultural values that express in the historical building characteristics. Renovations can result in extensive alterations to these historical building characteristics, which can impair the cultural values. Preserving these characteristics can cause tension with the sustainability enhancement and viability of the project.

The main assumption of this report is that the tension between these three aspects, cultural value, sustainability, and costs, form an iron triangle (see figure 1). Meaning that in a project there is a trade-off between the three aspects and only two can be met. Realizing a feasible project, preserve the cultural values, and enhance sustainability can be considered as complicated. The one thing that connects the three aspects are measures (such as applying insulation). Measures affect the increase of the sustainability of a building, can interfere with cultural values and bring costs.

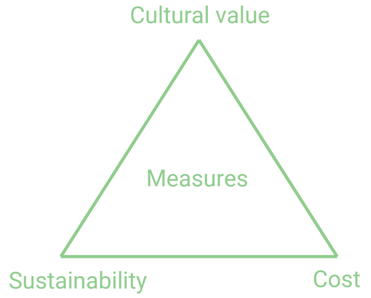

Figure 1 . Iron triangle (own image)

The goal of this research is to develop a model to find the right balance between cultural value, sustainability, and costs by comparing available measures. The outcome of this model supports a conscious decision. This leads to the research question: 'How can a decision-support model be created that analyses renovation measures to improve the balance between cultural value, sustainability, and costs in industrial heritage renovation projects?' To converge this research, the focus is on the façade since the most tension between sustainability, cultural value, and costs is situated there.

Since the aspects cultural value, sustainability, and costs are quite comprehensive, a literature research is executed to gain background knowledge on these aspects. This literature study provides more precise definitions of cultural value, sustainability, and costs, to be applied in this research. Cultural value is defined as the characteristics of the specific building parts that together determine architectural-historical & building-historical meaning of the building. The building parts focused on in this research, exterior finishes, interior finishes, frames, and glass, derived from other cultural value measure models. Literature shows that sustainability is an umbrella term for numerous definitions. This research concentrates on energy performance, and for this reason, only the thermal resistance of the facade in the form of R and U value is considered. The literature research into cost leads to multiple types of costs (e.g., building costs, additional costs, taxes). For this research, cost is identified as the direct building costs price in euro per square meter.

After narrowing down the specific criteria to test the impact of measures, the next step is to extract the types of measures from case studies. The three cases studies conducted on Gusto MSC, Cruise terminal, and Tricot indicated some applied measures and their risks. The analysis shows three significant measures: applying insulation (interior and exterior), replacing the glass and changing the frames. Each of these measures has building cost price, R or U value, and impact on the characteristics of a building part and façade as a whole.

The operational research contains the development of the 'decision-support model'. The input for this model is the criteria extracted from the literature study and the measures extracted from the case studies. This model compares multiple measures with the three aforementioned criteria and ambition for cultural value, sustainability, and costs. For this reason, the foundation of the first part of the decision-support model is a trade-off matrix. This trade-off matrix indicates which measures are best to fit the ambitions in order to achieve the right balance between cultural value, sustainability, and costs.

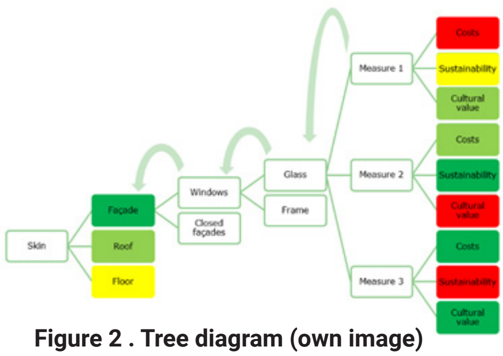

Figure 2 . Tree diagram (own image)

The second part of the decision-support model is a tree diagram (see figure 2) whereas the trade of matrix compares the types of measures within their category (exterior insulation, interior insulation, frames, and glass), the tree diagram compares the categories to each other taking into account their current condition and the number of square meters that they occupy in the building. This will give the assessor an overview of what building part has the best potential for renovation.

This research concludes that the decision-support model implements the project properties together with the ambitions and shows which measures fit the best to those properties and ambitions. In this way, it supports the decision for the right combination of measures that will provide the balance between cultural value, sustainability, and costs that fits the ambition (see Figure 3). This model can support the decision making for developers and owners. Further research and the addition of more parameters can result in a more elaborate model in the future. For instance, there is a possibility to include additional building parts and measures to this model. Also, the criterion sustainability can be more comprehensive and can include aspects such as embedded energy, durability, health, safety, etcetera. The cultural value guidelines can be tested in practice on usability. Costs can also contain indirect costs or revenues. This can lead to a detailed model that, eventually, will help to improve the future by renovating the past.

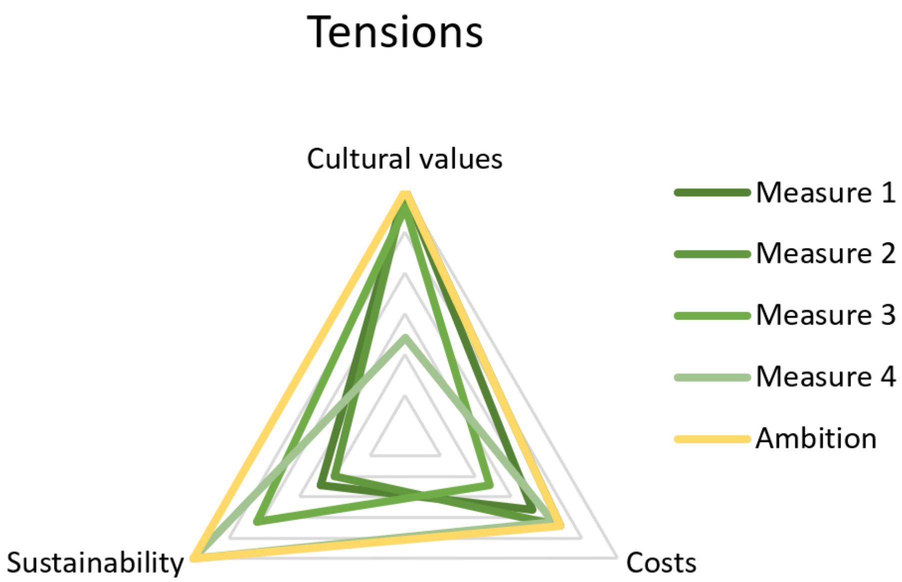

Figure 3 . Combinations of the right measures find the balance between cultural value, sustainability, and costs that fits the ambition. Cultural values and sustainability are on a positive axis and cost on a negative axis, meaning that when the costs are low, the value is further from the center.

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Terminology

Term	Definition
Measure	A certain act in a building project, such as applying insulation, changing the glass, etcetera.
Iron triangle	The Iron triangle is a common aspect of Project management (Atkinson, 1999). The iron triangle visualizes a trilemma between aspect. Where only two of the three can be achieved during a project. The commonly used trilemma is between time quality and scope.
Cultural values	For this research, cultural value is defined as the characteristics of the specific building parts that together determine architectural-historical & building-historical meaning of the building.
Sustainability	For this thesis, sustainability means the enhancement of the energy performance of the building, which is affected by the R-value and U value of building materials
R-Value	R-value is a measure of how well layer, such as insulation, resists the conductive flow of heat. The greater the R-value, the better the thermal insulating properties.R-value is expressed in m2K/W
U-Value	U-value is the rate of transfer of heat through a structure. The lower the U-value, the better-insulated a structure is.U-value is expressed in W/m2K.
Costs	For this research, cost is identified as the direct building costs price in euro per square meter.

1. Introduction

As a result of climate change, the European council aims to reduce the CO2 emission by 80-95%, compared to the levels of 1990, by 2050. This means that changes are needed to achieve this goal. The built environment contributes a significant part to that emission. Around 42% of the energy consumption and 35% of the greenhouse gas emission can be reduced with better usage of the buildings (European Council, 2011; Visscher, Meijer, Majcen, & Itard, 2016). In a reaction to this agreement, the New Dutch Housing act introduces a goal to make all the buildings Nearly Zero energy by 2035 (Visscher et al., 2016; Westrhenen & Cramer, 2018). Because about 75% of the building stock in 2050 is already built (Visscher et al., 2016), it is vital to renovate the existing stock. A part of the existing stock has a monumental status; at the moment there are 61.927 registered monuments in the Netherlands (CBS, 2018).

In addition, in the early 1900's, industrial buildings were positioned outside of cities in the Netherlands. Over time, the number of inhabitants in great cities increased and so the city expanded. Where the industrial buildings first were active and outside of the city, they now are inactive and near the city center. This results in vacant industrial buildings near the city center. These vacant buildings can establish an undesirable image for the surroundings. Renovating these buildings ensures that people will use them and will influence their surroundings positively (Cramer & Breitling, 2007; Niu, Lau, Shen, & Lau, 2018).

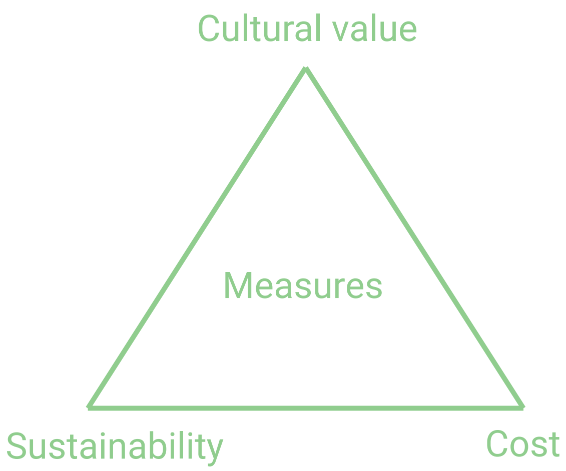

Figure 4 . Iron triangle Renovations (own image based on Atkinson (1999)

A substantial amount of these industrial buildings is now listed as cultural heritage. Renovating a listed cultural heritage building is considered as more complex due to heritage laws that comprise certain restrictions. (Bouw, Vanhellemont, & Dubois, 2017). Heritage laws obstruct changes to specific building component that are regarded as valuable. During a project, it is common that a developer deals with several aspects, such as cultural value, sustainability, and costs; a developer wants to achieve a feasible project that has high cultural values and is sustainable (Yung & Chan, 2012). Nevertheless in most cases only two of those three aspects can be achieved, which increases complexity of a project. (Bouw et al., 2017) (see Figure 4).
Measures, such as applying insulation, impact perceived cultural values of a building, contribute to the sustainability of a building and have costs. For this reason, measures connect the aspects cultural value, sustainability, and cost (see Figure 4). To lower the threshold of industrial heritage renovation projects, it is necessary to investigate these four aspects and find a method to reduce their complexity. This research will create a model that analyzes the impact of various measures on the aspects cultural value, sustainability, and costs, which will result in an overview of which measures are best to use in an industrial heritage renovation project to find a balance between cultural value, sustainability, and costs.

1.1 Problem statement

Right now, there is a certain gap in knowledge. There is not yet a decision-support model that shows what the impact is of different renovation measures on the aspects, cultural value, sustainability, and costs. At the moment, building experts try to find the balance between the aspects in a complex iterative process during the design phase. The result of this process is still not optimal and not visualized for non-experts. There is much research done about industrial heritage renovation projects but not about the specific measures that can be used for it, such as applying insulation and replacing the glass. These measures are used, but the exact impact on costs, sustainability, and especially cultural value is not clear. When this is clear, a decision-support model can be created that will help designers, developers and other people that renovate industrial heritage by showing which measure will be best to apply during that specific project.

1.2 Research goal

The goal of this research is to create a decision-support model that will improve the process of industrial heritage renovation projects by looking at the impact of measures on the aspects: cultural value, sustainability, and costs. This will not only benefit the national sustainability goals, but it will also attribute to the close surrounding of industrial heritage by preserving its cultural values. During an internship at ABT, this research looks at past projects and analyses the impact of the used measures on the aspects of cultural value, sustainability, and costs. When this data is collected, it can then be implemented in a decision-support model. This model will create an overview of what measures are suitable to apply during a project to find the right balance between cultural value, sustainability, and costs.

1.3 Scientific relevance

In the academic world, some researchers have investigated the renovation of heritage. Many researchers stress the need for preserving heritage and making heritage sustainable. One of them is Janssen (2014), in his thesis, he stresses the importance of preserving heritage in the Netherlands. This paper urges the need for creativity to maintain the quality of heritage preservation and renewal. Yung & Chan (2012) acknowledged the challenges and difficulties that arise during the sustainable renovation of heritage. The recommendation for further research in this paper states that more research must be done on viewing the sustainable framework more holistically by integrating more aspects as, social, economic, environmental and political policies.

There is also a paper written by the ICOMOS International Scientific Committee for Twentieth Century Heritage (ISC 20C) that stresses the need to preserve twentieth-century heritage. (ICOMOS, 2011a) This paper concluded that there is indeed a need for preserving industrial heritage. Moreover, to do so, renovations are needed to ensure usability and decrease vacancy, which is a crucial factor for preserving heritage according to Yung and Chan (2012). Niu et al. (2018) stress that adaptive reuse of buildings is a form of sustainable urban regeneration because it extends de buildings life and avoids demolition waste. Besides the technical aspects, they also explain that renovations also provide significant social and economic benefits to society.

Rogic (2009) explored the conservation of the design guidelines for the conversion of industrial buildings. She investigated how aesthetic integrity can be understood concerning industrial buildings that are considered as being without architectural value. She gives arguments on why industrial buildings are worthwhile to preserve and why they are of architectural and historical importance.
WTA ("Wetenschappelijk-Technische groep voor Aanbevelingen inzake") (Bouw et al., 2017, p 1 -3) confirms that there is an issue in heritage renovation projects. They acknowledge that there is a tension between different aspects of industrial heritage renovation projects, but they state that there is an iron triangle between heritage-energy-comfort. Return on investment plays a significant role in these projects because it decides whether a project is viable or not. (Bouw et al., 2017) From this research can be drawn that there is indeed an iron triangle. Energy and comfort can both be considered as sustainability, and they confirm that costs are indeed an issue when renovating heritage.

To conclude, ICOMOS (2011b), Janssen (2014), Niu et al. (2018) and Rogic (2009) acknowledge that there is a need to renovate industrial heritage buildings, wherein Bouw et al. (2017) and Yung & Chan (2012) stress the need for more research in these renovations to find a holistic approach that integrates multiple aspects of industrial heritage renovation projects and create a balance between social, economic, environmental and political aspects. From this literature overview there is a particular gap in knowledge, right now there is not yet a decision-support model that shows for each renovation project which measures are best to use for finding the right balance between costs, sustainability, and cultural value. Because there is a need to renovate buildings closing this gap will encourage people to renovate buildings more efficiently and holistically.

1.4 Societal relevance

The research in sustainable heritage renovation projects has a societal relevance that consists of two main reasons. First of all, when research is done in this field, the renovation of industrial heritage in a sustainable way will be less complicated and challenging. This might stimulate people to transform heritage and make it sustainable. When there is an increasing number of sustainable buildings, there will be a decrease in energy consumption and greenhouse gas emission. Also, with an increasing number of sustainable buildings, an area has a better change to be successful (Adams & Tiesdell, 2012). This means that researching sustainable renovation projects of heritage, will eventually benefit the climate change we are currently dealing with. Secondly, this research focuses on preserving cultural values while renovating industrial heritage. Meaning that when this research is completed, developers and other stakeholders gain more insight into preserving cultural values. This is important because cultural values have a lot of positive externalities to society (Niu et al., 2018; Stratton, 2000). Heritage influences the surrounding area by giving it more character (Bloszies, 2012; Cramer & Breitling, 2007). When an area has more character, it has more change to be successful (Adams & Tiesdell, 2012). This makes an area more attractive which results to an increase of inhabitants and tourist. This leads to more income for that area and so heritage can indirectly contribute to the economic growth of a city (Adams & Tiesdell, 2012; Cramer & Breitling, 2007; Niu et al., 2018), which makes this research relevant for society.

Not only the cultural values and sustainability are reasons to renovate buildings. In some cases, the building materials and physics of the industrial buildings are deteriorating (e.g. reducing drought, rotting wood and strengthening the construction). To facilitate housing in the building it is important to ensure the building safety (Cramer & Breitling, 2007; ICOMOS, 2011b).

1.5 Applicability

When this research is completed, a decision-support model is created that weighs different renovation measures. This model then indicates the impact that a particular measure, such as changing the glass, has on the building. This is divided into the three aspects cultural value, sustainability, and cost. When this is done a set of measures with their impact properties can be shaped. In practice, when a renovation project starts a developer or designer can consider using this data. An overview shows which measures are available and which ones are better to use and fit the ambition of the person that takes the initiative. In this way, a better balance between costs, sustainability and cultural value can then be found, because it is clear for each decision how much impact it has on cultural value, sustainability, and costs. When the impact is clear, decisions can be made to enhance the most optimum combination of measures that will make sure that the most of the cultural values are preserved, the best sustainability can be achieved, with the best cost efficiency.

1.6 Main research question

This research is focused on the technical aspects of industrial heritage renovation projects. Renovation measures mostly influence the result of a renovation project on the aspects, cost, sustainability, and cultural value. To make sure a developer or designer finds a suitable balance between these aspects it is vital to research the impact of renovation measures on industrial heritage renovation projects. With this research, the main question is:

How can a decision-support model be created that analyses renovation measures to improve the balance between cultural value, sustainability, and costs in industrial heritage renovation projects?

1.7 Research sub questions

The main research question is based on several subquestions. By answering the subquestions, the main question is answered. The subquestions of this research are formulated as followed:

Heritage guidelines and recommendations are significant for industrial heritage renovation projects, and so it is vital to understand the guidelines and recommendations and observe if it is possible to implement them.
What guidelines and recommendations are there for industrial heritage renovation projects?

Cultural value is a broad concept. To explore the body of knowledge and define a specific definition for this research, the questions below must be answered briefly.
What are cultural values?
How can cultural values be measured?

Sustainability is an umbrella term and so must be explained in this research. For this research, it is crucial to investigate what defines sustainability and how this can be measured.
What defines the sustainability of a building?
How can these aspects be measured?

Costs are essential during any project because it indicates at specific points of a project whether it should proceed or not. To investigate the following question must be answered:
What are the different costs in a renovation project?

Research must be done on different case studies on what measures, such as applying insulation or changing the glass, were used and how they influence the projects.
What are the key issues to be solved in renovation projects?
What measures were used for these issues?
To what extent do the measures contribute to the cultural value, sustainability, and costs of a building?

1.8 Conceptual research model

The first part of the model shows the building life cycle (Wamelink, 2009) (see Figure 5). Such as any building, industrial heritage has 4 phases, use initiative, design, and build. The only difference is that the initiative phase consists of extensive research of the existing building. (Hendriks & Hoeve, 2009; Kuipers & Jonge, 2017).

As described in the introduction, Bouw et al. (2017) stated that there is indeed a trilemma between the aspects: cultural value, sustainability, and costs. In the model, these are at every corner of the iron triangle. (Atkinson, 1999). This triangle shows a trilemma, within heritage projects it is common that only two of the three aspects can perform well in a project. This means that if a project developer wants to excel in cultural values and sustainability, the costs will probably be high. The conceptual idea is that with the proper combination of measures a balance can be found between cultural value, sustainability, and costs that fits the ambitions of the project.

All of these aspects will be integrated into a decision-support model. This decision-support model can then be used by developers during the research, design and build phase of a heritage project. The goal of this decision-support model is to improve the balance between costs, sustainability and cultural value during these phases because it creates an overview of the options an initiator of industrial heritage renovation projects has.

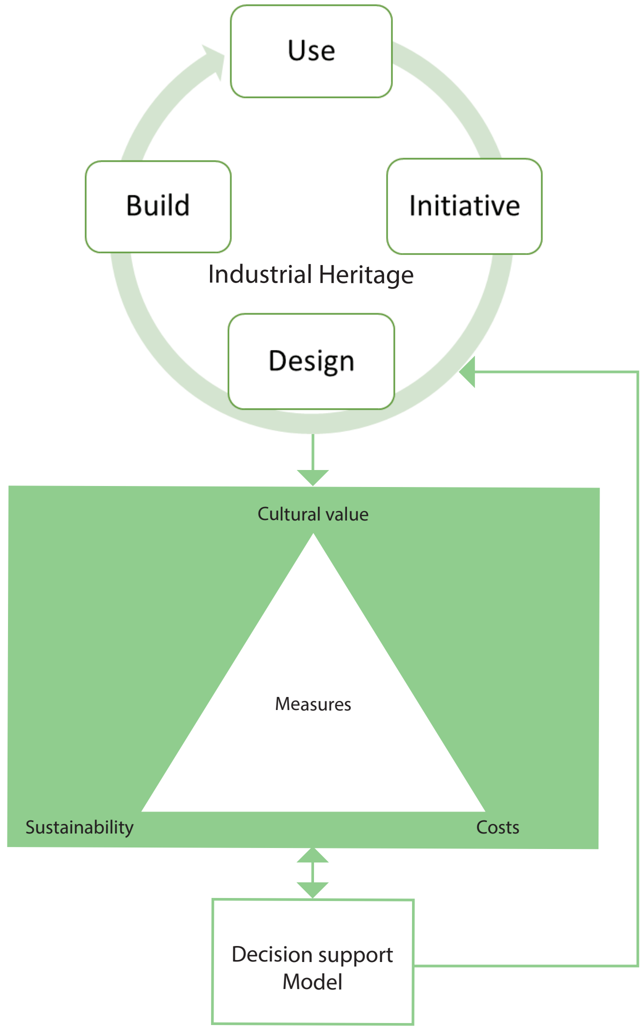

Figure 5 . Conceptual model (own image)

2. Research method

This research will be a combination of literature, empirical and operational research. First, the literature study will narrow down the definitions of cultural value, sustainability, and costs. The empirical research will extract applied measures. The criteria and measures will be used to create the decision-support model in the operational research. (Figure 6)

2.1 Literature research

The literature study will examine heritage legislation, cultural values, sustainability, and costs. These aspects are comprehensive; the goal of this literature study is to review the terms and specify the limitations of this research. Chapter 3.1 Heritage policies, gives background information on how the government regulates industrial heritage projects which is vital knowledge when creating a decision-support model. Cultural values (chapter 3.2) are difficult to define, which makes it challenging to insert in a decision-support model. Previous research attempted to quantify cultural heritage. After researching these calculation models, one or two models can be selected and applied in the decision-support model. Chapter 3.3 provides criteria that can be used to test measures on their impact on sustainability. Chapter 3.4 explores the different kind of costs that occur during a renovation project and will specify the definition of costs for this research. The literature research ends in a conclusion that shows the specified definitions of cultural value, sustainability, and costs, alongside the criteria.

2.2 Empirical research

The empirical research will extract the measures from case studies. The case studies will be conducted during an internship at ABT (see chapter 2.4). First, the research method will be adapted to make sure it will fit into the ambitions of ABT and to make sure that the data drawn from the case studies will attribute to an efficient conclusion. In table 1 are the main aspects that are going to be studied. The data which is retrieved will be treated with respect and will only be used for educational purposes. Most of the data is drawn from the internal drives of ABT and informal meetings with involved people that elaborated upon questions that arose during the research. From this research, two main things will be extracted: applied measures and criteria that are important to incorporate into the model.

2.3 Operational research

With the definitions and criteria from the literature research and the measures and criteria from the empirical research, a first draft of the decision-support model can be created. First, an appropriate basis of a model will be selected. After that, the used measures of the case studies and some alternatives will be implemented. They will be analysed with the criteria that are extracted from the literature research and empirical research. Next, the decision-support model will be validated, and faults will be corrected to create a final version of the decision-support model. The model will include instruction for the model to enhance the usability for users. Finally, the conclusion of the thesis will be made; the conclusion will contain the answer to the research question. Also, some reflections and recommendations will be made for further research.

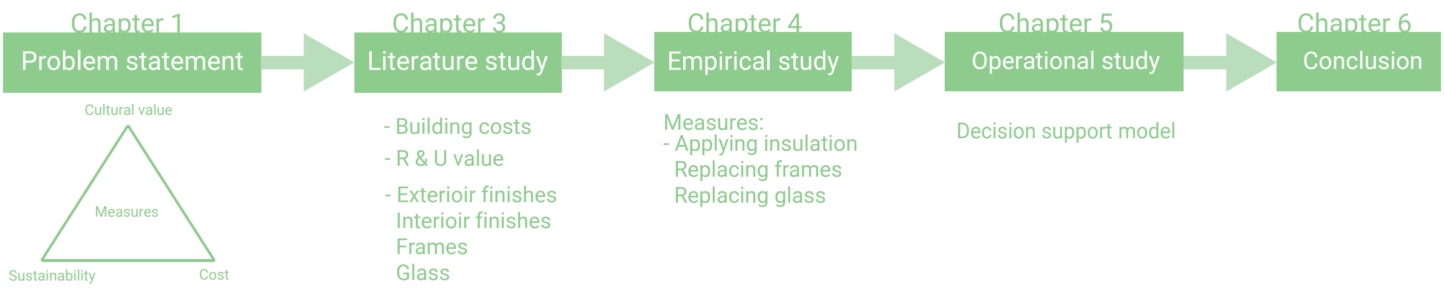

Figure 6 . Research design (own image)

Table 1. Case study method

Case study
Location
Year of built
Original function
Current function
Goal of renovation
Year or renovation
Client
Architect
Project size
Time durance of project
People involved from ABT
Existing situation
The first part describes some general information and the existing problems (e.g. poor comfort and condensation). The existing problems are investigated because they indicate which measures are used to solve them. This will answer the sub question given in chapter 1.8: What are the main issues to be solved in renovation projects?
Cultural value
The description of the cultural values gives the history of the building and gives the possible cultural values of the different building parts as described in the previous chapter. These building part while be visualized in the figures, inspired by the analytical mapping method of Kuipers & Jonge (2017) in chapter 3.2.2. Leading to a list of building parts that are valuable to take into account for this specific building.
Sustainability
Because in this research sustainability is only considered as the energy performance of the façade (chapter 3.3), this step shows the requirements for the comfort and energy performance of the building. This leads to the decisions of why certain measures were taken considered the existing situation, cultural values, and sustainability. This chapter will answer the sub-question given in chapter 1.8 What measures were used for these issues?
Costs
This part of the analyses are the costs that were involved in the project. This part will indicate the costs that are known for each case study. It depends for each case study how much costs are known at ABT.
Overview
Lastly an overview with a list of all the essential building parts, the issues, and used measures with their R or U value, costs and risks are given. This answers the sub-question in chapter 1.8 To what extent do the measures contribute to the costs, cultural value, and sustainability of a building?
Conclusion
The conclusion shows what connects the three case studies and defines the common issues that must be solved during renovations of industrial heritage. This will then result in a list with the used measures and their alternatives with their impact on costs, sustainability and cultural value, and the possible risks that they bring with. This will provide input for the decision-support model that will be created during the operational research.

2.4 Graduation internship

ABT is a construction engineer company that has the ambition to create integrated solutions. This company has executed many different projects, including industrial heritage renovations. Next, to that, ABT developed the ABT quick scan (van der Voordt, Geraedts, Remoy, & Oudijk, 2007), this quick scan is developed for everybody that is involved with development, design and managing real estate. The scan indicates three steps (inspect, check and value), five building parts (Installations, skin, construction, access, and stuff) and the location. Each of these aspects is checked with the use of function analyses, to see which function fits best on that location (van der Voordt et al., 2007). The experience that ABT has in creating decision-support models and in renovating industrial heritage is valuable for this research.

To converge the scope of the research, it is vital to select building with similar aesthetics in the Netherlands. In this research buildings in the era between 1900 and 1940 will be analysed. From these case studies, the measures that will be used in the model will be extracted. During this internship these three case studies will be used for the research (ABT, n.d.-a):

Gusto Msc Schiedam

Project: Timmerfabriek Schiedam
Year of built: 1948
Original architect: Vermeer and van Herwaarden
Client: GustoMSC
Architect: JHK Architecten
Location: Schiedam, the Netherlands
Completion time: 2014 - ongoing

Figure 7 . Gusto MSc Schiedam. (Source Architectenweb)

Cruise terminal Rotterdam

Project: Rotterdam Cruise Terminal
Year of built: 1949
Original architect: Brinkman, J.H. van den Broek and J.B. Bakema
Client: Port of Rotterdam Authority
Architect: TomDavid Architects
Location: Rotterdam
Completion time: 2013 - 2015

Figure 8 . Cruise terminal Rotterdam (Source: NRP gulden feniks)

Tricotfabriek Winterswijk

Project: Tricotfabriek
Year of built: 1912
Original architect: Arend Beltman
Client: De woonplaats
Architect: Frits van Dongen
Location: Winterswijk
Completion time: 2008

Figure 9 . Tricot fabriek winterswijk (Source: Wikimedia)

2.5 Deliverables

A deliverable of this thesis is a decision-support model, created in Excel, with instructions (chapter 5). This model will eventually improve industrial heritage renovation projects and so contribute to a more sustainable future. For this research, it is crucial to find a building part that has the most tension between costs, sustainability, and cultural value and where renovation measures can be applied. The skin is, within the industrial heritage, an important part that has the most tension between costs, sustainability and cultural value, the roof and the facade are the building parts where most of the thermal loss occurs (Dobbelsteen & Huijbers, 2012) and so is an important part for the sustainability. Also, the façade is a essential building part that contributes to the cultural value since the features of the building such as material and windows are exposed. Therefore, the facade is further analysed in the model.

When this model is used, the multiple measures (such as insulation, HR+ glass etcetera) are tested against the three aspects, cultural value, sustainability, and costs. The colour of the score shows what impact the measure has on the renovation. Red is negative, yellow is neutral, and green is positive. The exact definitions and how the measures are tested are elaborated upon and concluded in chapter 5. When a developer or designer inserts the ambitions and project propertie,s to the model, it will form a clear overview in colours which measures are better to use during a renovation project to fit the ambitions.

2.6 Audience

The audience that can use this model can consist of project developers and designers that are working on industrial heritage projects. Next to project developers, owners of heritage buildings that are interested in renovating their industrial property and want to know what the options are to do so might use this model.

Academics can also be interested in this research. It will inspire them to do more research on this topic. They can add more measures to the data set, or they can add more properties to the decision-support model, like safety, social influence etcetera.

3. Literature research

3.1 Heritage policies

For this research it is essential to know what the heritage guidelines are and if this research can implement this into the model. Heritage policies restrict a developer to renovate a monumental building. They protect the cultural value of heritage buildings. For this chapter, the main question is:

3.1.1 *What guidelines and recommendations are there for industrial heritage renovation projects?*

Heritage guidelines and recommendations can be divided into two levels, international and national. Three important international organizations focus on protecting heritage. First, there is the United Nations Educational, Scientific and Cultural Organization (UNESCO). They mention that any work done to a heritage building must be preceded and accompanied by thorough studies and should be carried out in co-operation with specialists of this field (United Nations Educational Scientific and Cultural Organization, 1972). The second international organization is the International Council On Monuments and Sites (ICOMOS) (ICOMOS, 2011b). One of the principles is that the use of the building is the most frequent and sustainable way to ensure the conservation of the building (Douet, 2015; ICOMOS, 2011b). The third organization is the Council of Europe, adopted a strategy to promote industrial heritage (Shift-X Project, 2014). This document focuses on how a government can promote industrial heritage by financing and coordinating re-utilizing industrial heritage projects.

On the national level, in 2016 the Heritage act was created, based on the previous Monument act of 1988. This Act protects everything that is considered as cultural heritage, including monuments (Cultural heritage agency, 2016). A monument can have a monumental status on national, provincial, and municipal level. Each administrative body can elect a building as a monument, and each body can interpret rules differently.

In 2010 the WABO went into effect. This act is called the environmental code, and it combines the 25 permits that existed into one permit, the environmental permit. This act applies to every building in the built environment, including monuments. The environmental code makes sure that a project obeys to the policies, first are the standard building requirements, such as climate, fire safety, sustainability etcetera. (Rijksoverheid, n.d.). Secondly, whenever a renovation project is initiated, it must obey to the criteria specified for monuments. This means that the building first has to undergo a historical building research. This research will map the cultural-historical aspects of the building that are of value. These reports give a review framework for suggested alterations of the monument. The building archeologic research guidelines (Richtlijnen Bouwhistorisch onderzoek) are created by the 'Monumentenzorg'. (Hendriks & Hoeve, 2009). A building historian executes the assessment. This assessment decides which buildings parts are essential to conserve. More in-depth details about this assessment is done in chapter 3.2.

3.1.2 *Conclusion heritage policies*

There are many guidelines and recommendations about industrial heritage on a national and international level. There is certainly a common ground about how people should interact with industrial heritage. The only thing is that the interpretation of the guidelines and recommendations differs in each project because it depends on the person who executes the assessment and to what administrative body the monument status belongs. This indicates that the guidelines are more discussion issues rather then strict rules. This makes it difficult to find the exact criteria that can be implemented in the model. The aspect of making renovations reversible is a criterion that can be used in the model. When a certain renovation measure is reversible, it could get a higher score on cultural value because it then conserves the building parts because it can be removed.

3.2 Cultural value

Cultural value is a broad concept. It consists of different qualitative aspects. To understand cultural value assessments and to try to make it fit in a decision-support model it is crucial to do a literature review on this. The questions that are answered in this chapter are:

What are cultural values?
How can cultural values be measured?

3.2.1 *What are cultural values?*

There is not one definition of cultural value. To understand the aspect of cultural value, different definitions are explored, and a connection between those definitions and this research is stated. In this research, it is considered that heritage contains cultural values.

The English dictionary says that heritage contains qualities, traditions, and features which has been passed on to multiple generations. (Collins English Language Dictionary 1987 (ed.) 1993) These qualities, tradition, and features can perhaps be defined as cultural values. The definition of the Dutch government (Cultural heritage agency, 2016) is close to the definition of the English dictionary only it includes term tangible and intangible.

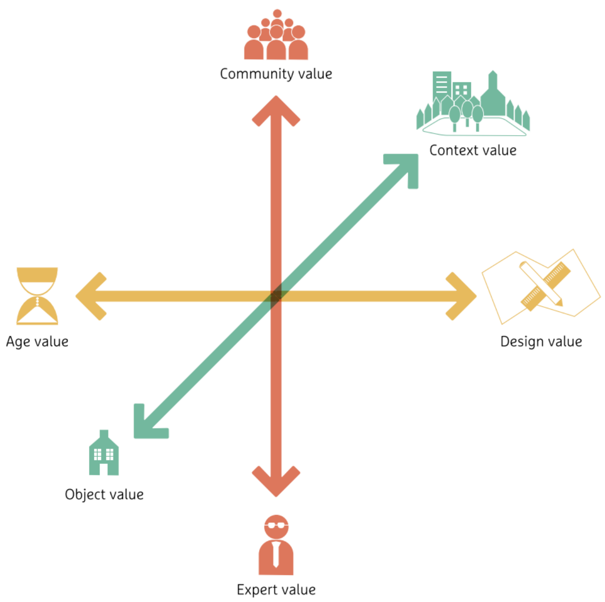

Figure 10 The dimensions of cultural value. (Meurs, 2016)

This means that cultural values can be tangible and intangible. Halberstma & Kuipers (2014) give a differentiation between tangible and intangible. Tangible heritage consists of everything that can be 'touched' it is a thing, a product, it is fixed, unchanging, something to save and protect. Intangible heritage is 'non-material' it is an event, a process, it is fleeting, changeable, it happens, something to cherish (De Jonge, 2018; Halberstma & Kuipers, 2014).

Nusselder (2008) says that the tangible cultural values of a building are represented by the different materials (such as bricks, mortar, and wooden beams) of the building parts (frames, glass, finishes).

Wilkinson, Remøy, & Langston (2014) explain that there are buildings that no longer have cultural values due to poor building quality; this supports the statement that cultural values are embedded in building materials. If they are of inadequate quality, the cultural values diminish.

A building can also consist of intangible values. This means that the building can remind people of a certain event or memory (Cramer & Breitling, 2007; Nusselder, Ven, Haas, & Dulski, 2008). Meurs (2016) states that there are multiple dimensions, community value versus expert value, context value versus object value and age value versus design value (see figure 10) (Meurs, 2016). There are also sources that divide the intangible values in economic and non-economic. The economic values relate to the price and utility of a certain building whereas non-economic refers to good or bad characteristics (Persoon, 2019).

Figure 11 shows the classification of the different definitions of cultural value as explored in this research. There are many more definitions of cultural values and from that can be concluded that cultural value can be interpreted in diverse ways. This means that the cultural value of a building is not one definition and that it will depend on the perspective of the person who observes the building. For this research, it is necessary to select a definition of cultural value to make sure it can be implemented in a decision-support model. For this reason, cultural value in this research consists of the aesthetics of the charecteristic building parts that together give the building architectural-historical & building-historical meaning as described by Nusselder (2008). Figure 11 shows the definitions extracted during the researcg and shows the focus of the research. By using this definition, the impact of a certain measure can be expressed in the way it interferes with the aesthetics of the material of a building part. This will be further elaborated in chapter 5.

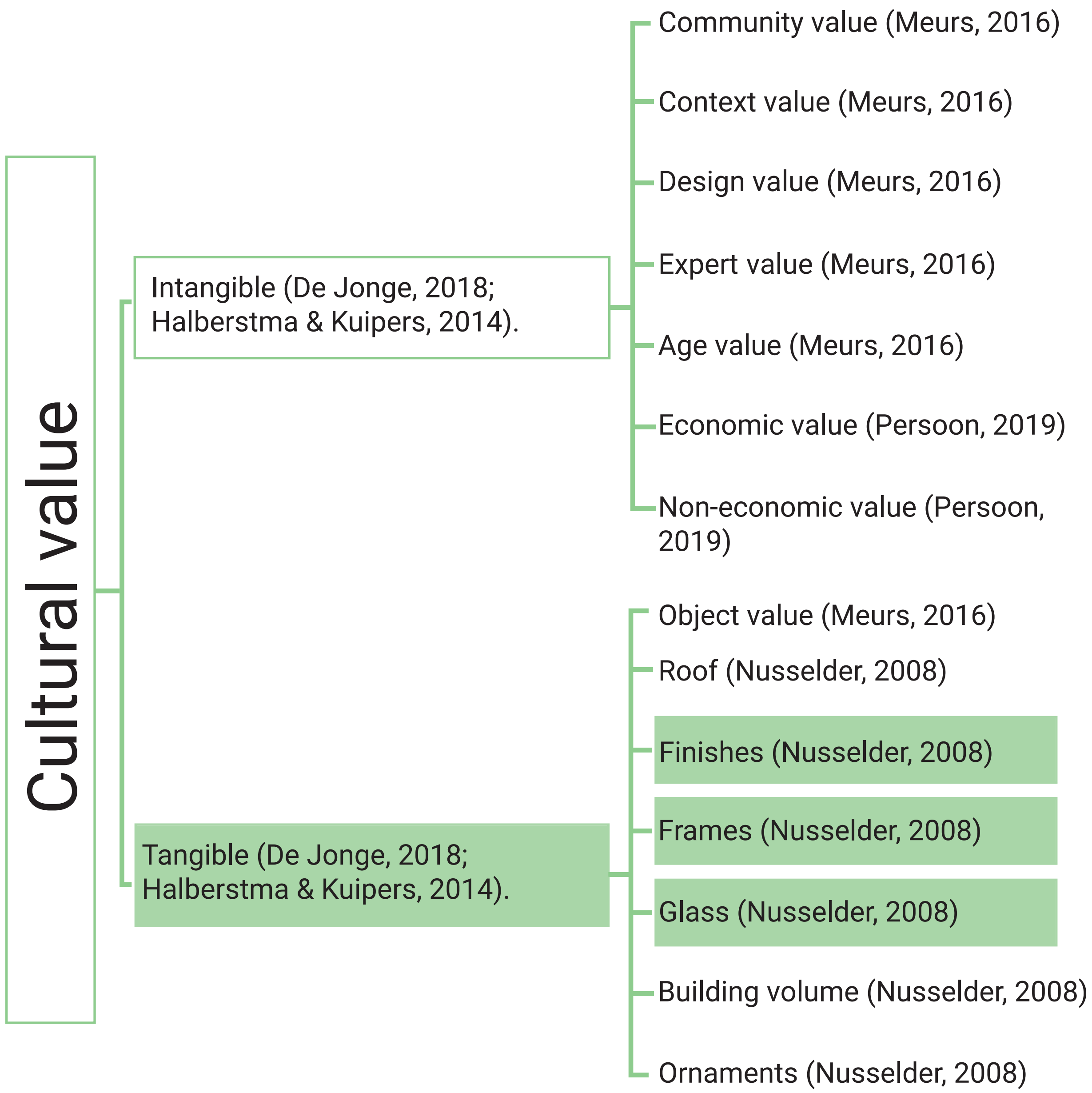

Figure 11 Focus breakdown of cultural value definitions for this research

3.2.2 *How can cultural values be measured?*

Now that the definition of cultural value for this research is set, multiple existing methods for cultural value assessments are reviewed to find way to implement cultural value in a decision-support model.

Building Archeologic Research

The Cultural Heritage Agency (RCE) developed guidelines for building archeologic research, as described in chapter 3.1.1 (BAR). This model analyses tangible and intangible cultural values of a building. (Hendriks & van der Hoeve, 2009) The cultural value assessment is based on the authenticity and the rarity of an individual building compared to other buildings. The value assessment is divided into five subcategories. For each part are the most critical focus points explained to create some guidelines for the building historian that usually does the assessment, see Appendix A (Hendriks & Hoeve, 2009)

The BAR method also consists of a system to visualize the tangible cultural value in blueprints. (figure 12) Within these images, building parts are categorized to their cultural value. The categories are (Hendriks & Hoeve, 2009):

- Great cultural value (blue): these are of crucial importance for the structure or the meaning of the building.
- Positive cultural value (green): these are important for the structure or the meaning of the building.
- Indifference cultural value (yellow): these are of little importance for the structure or the meaning of the building.

To conclude, the guidelines of the BAR method (see Appendix A) can be used as handles to help indicate the cultural importance of the building. The guidelines described in Appendix A can be implemented for the cultural value assessment in the decision-support model. The colour system also has the potential to be implemented in this research. Because the research is narrowed down to the façade (see chapter 2.5) only the guidelines are selected that can be applied to the façade visible in table 2.

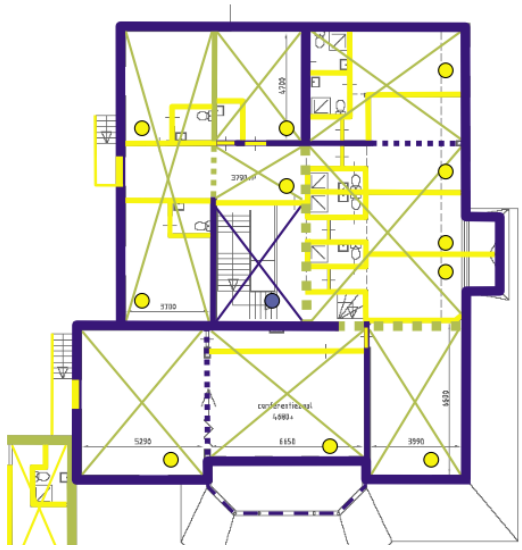

Figure 12 cultural value blueprint. (Hendriks & Hoeve, 2009)

'DuMo' calculation model

This model has the goal to weigh cultural value up against sustainability and with this creates a balance between conserving cultural value and enhancing sustainability (Nusselder et al., 2008). The cultural value here is described as the 'Mo-coefficient' and sustainability as the 'Du-index'. These values are multiplied to get the final DuMo score. This means that when a building with a high 'Mo-coefficient' needs less sustainable interventions than a building with lower 'Mo-coefficient' to get to the same DuMo score. To retrieve this 'Mo-coefficient', this model makes use of a worksheet that must be filled in by building historians (see appendix B). They must compare with other projects to define the cultural value of the building (Nusselder et al., 2008). The criteria in this model are based on the guidelines for building archeologic research. See Appendix A (Hendriks & Hoeve, 2009).

Because the 'DuMo' method focusses on the ability of a building to find a good balance between cultural value and sustainability it only focusses on the building parts where sustainability measures can be used upon, such as building envelope, ground floor, façade, windows, and roof. This means that it only assesses the 'tangible' cultural value.

From this model, the aspect of focussing on the building parts (exterior/interior finishes, frames, and glass) solely and the criteria from the worksheet (Appendix B) can be used for this research. The criteria that can be used (Nusselder et al., 2008) are visible in table 2.

Cultural Historical Value assesment

In the book 'Transformatie van kantoorgebouwen', van der Voordt et al. (2007) illustrate the instrument of Beers (2004). Beers tried to transform the relatively abstract criteria of the BAR method (Hendriks & van der Hoeve, 2009) to more specific formulated criteria. With this, a quick overview can be given about the cultural value of the industrial building(part(s)) (Geraedts & van der Voordt, 2005). Beers used five categories to define cultural value: history, urbanism, socio-cultural, architecture, and landscape. Within these categories are multiple components which the building historians must grade with a number from 0-4. This is then weighted with 1,2 or 3 based on the importance. The grade will be multiplied with a completeness and rarity factor (see Appendix C) to get to a cultural value. (Beers, 2004; van der Voordt et al., 2007).

In the second part, Beers assigns cultural value to each component of an industrial building. This is done in the interaction matrix. This matrix shows the relation between building parts and cultural value explicitly. In the matrix, the total value of the component is multiplied with a relation factor. This results in a clear overview of which component has a higher cultural value and is more critical to preserve (see Appendix C) (Beers, 2004; van der Voordt et al., 2007).

In this way, Beers quantified the cultural value of a building. The weighting factor is subjective, and it depends on who executes the value assessment. This means that when this is used in the decision-support model, the perspective of the person that does the assessment must stay constant to assure that values can be compared. Beers also incorporates different building parts and their cultural value which can be very useful for this research. The building parts (that are only applicable to the façade, see chapter 2.5) that can be brought with from this model are visible in table 2.

Analytical mapping

Kuipers & Jonge (2017) state that it is essential that not only specialists in cultural history and building archaeology, but also designers can analyse heritage and their cultural values. For that reason, they created a step by step plan (Kuipers & Jonge, 2017):

- Chrono-mapping: Compile the construction history of a heritage site.
- Value mapping: identify and classify site-specific heritage features.
- Differentiate the identified features on three levels of significance.
- Distill a position statement.

This method contains questions on how to assess a building. These questions (such as What are typical features of fabric, form, (former-) functions, spaces, volumes, sizes, colours, views, waters and/or greenery (Kuipers & Jonge, 2017)) can be quite useful while doing the case studies.

Cultural Value Factor

Another instrument described by van der Voordt et al. (2007) is the method developed by Schrieken (2000) in collaboration with the experts of the government department cultural heritage (RCE). Schrieken developed a cultural value assessment for the transformation of churches (CHW-meter). Just as with the method of Beers (2004), the 17 criteria are rated from 0-4, multiplied with an integrality factor and weight with a fixed importance factor (see Appendix D). The score is then compared to the maximum score of 132, which creates a final percentage that can be used in comparison to other churches. (Schrieken, 2000; van der Voordt et al., 2007)

When the cultural value of the building is assessed the conservation score can then be applied. The conservations score indicates the amount of cultural value that remained after a transformation of a building to another function. This is done by testing the impact of different design options on their preservation of cultural value. (Schrieken, 2000; van der Voordt et al., 2007)

The criteria of Schrieken (2000) (see Appendix D) is perhaps outdated, but the method is still significant for this research. The principle of the conservation factor is something that can be used in this research. Instead of giving each design a certain score on conservation, every measure used on the building could get a conservation score. This will show the impact of a measure in the cultural value of a building.

3.2.3 *Conclusion cultural value*

The conclusion which can be drawn from the literature research is that cultural value is subjective to the perspective from which the assessment has been conducted. Still, there are ways to calculate cultural value. These calculation methods try to quantify cultural value and use this to compare and make transformation decisions. All the methods enhance similar criteria and mention that it is subjective and that the numbers are just a way to facilitate comparison and decisions. It is important to keep in mind that the perspective from which the assessment of cultural value of a building is taken from stays constant to ensure good comparison. Also, in the model that will be created during this research, the method of Beers (2004) can be of great use because he focused especially on industrial heritage and he incorporated a way to give each building part a different cultural value. For this model the principle of the conservation factor of Schrieken (2000) can be used to give every measure a conservation factor to describe the impact on cultural value.

Table 2 shows the guidelines from each calculation model (see appendices A, B, C &D) that can be used in the decision support model. These guidelines are selected based on the criteria that they should be applicable to the façade, because this research will only focus on this building part, as described in chapter 2.5.

Table 2. Overview lessons learned cultural value (own table)

Method	Extracted guidelines and tools
Building archeologic research	The guidelines from this method are useful as handles to make an indication of cultural value. The handles: • Importance of the building due to the ornamentation; • Importance of the building due to the interior & exterior finish • Importance of the building for the history of building technology; • Importance of the building due to the readability of the building history (historical layering); • Importance of the building due to the use of materials.
DuMo calculation model	From this model, the aspect of only focussing on the building parts (finishes, frames glass) can be used in this research. The criteria for the cultural value that can be incorporated are: • Quality of building type (rare or common) • Execution quality (rare or common) • Amount of historical remaining • Technical state
Cultural-historical value assessment	From this method, the assessment of giving a score to each building part and multiply it with an integrality factor can be used in this research. The different building part definitions that can be used: • Form • Construction • Ornament and detail • Measurements and grid • Use of material
Analytical mapping	From this method, the structure of doing the research can be used while doing case studies. First collecting the construction history and then value mapping the building parts that can be considered as necessary.
Cultural value Factor	The principle of the conservation factor can be used to give every measure a conservation factor to describe the impact on cultural value. Also, the implementation of a weighting factor into the calculation model is useful for this research.

3.3 Sustainability

This chapter will define sustainability for this research and will show the criteria for answering the following questions:

What defines the sustainability of a building?
How can sustainability aspects be measured?

3.3.1 *What defines the sustainability of a building?*

Sustainability is an umbrella term; it consists of the four pillars, economic viability, social responsiveness and respect for the environment (Blagojević & Tufegdžić, 2016). For a building, it is comfort, energy, thermic comfort, air quality, light, acoustics, electricity, greenery, water and materials (Dobbelsteen & Huijbers, 2012). There are multiple methods, (Agentschap NL, 2011; Vreenegoor, Hensen, & De Vries, 2008) that define sustainability (see table 3). Defining the sustainability of new buildings is different than for used buildings, or monuments. Not every calculation model applies to heritage; see table 3 (Nusselder et al., 2008). For this reason, there are calculation models created explicitly for monuments.

The DuMo-method is one of these methods. The calculation model for this is based on the GreenCalc+ method. This method is commissioned by the government and expresses sustainability in one number (Milieu index gebouw). The sustainability themes are divided into energy, water, and material (Nusselder et al., 2008).

Another calculation model is the Building Research Establishment Environmental Assessment Method (BREEAM). BREEAM-NL has two main calculation models, one for new construction and one for renovation, BREEAM-RVO (BREGlobal, 2015). The latter can also be used for heritage buildings, because the model incorporates important aspects, such as maintaining cultural values (Tuerlings & Provincie Noord Brabant, 2017). BREEAM international RFO defines management, health, and wellbeing, energy, transport, water (waste), materials, land use & ecology, pollution and innovation as aspects of sustainability (BREGlobal, 2015)

GPR-Gebouw is a digital instrument that identifies the sustainability of a building based on the aspects energy, environment, health, users quality and future value. This calculation model applies to new and existing buildings. (Agentschap NL, 2011) To conclude, there are many aspects (see figure 13) that define the sustainability of a building. In figure 13 there is a tree diagram visible that shows the large variety in definitions of sustainability that is explored in this literature study. For implementing the term sustainability in the decision-support model, it is important to know with what parameters they measure the sustainability of the building. The criteria used by BREEAM-NL and DUMO can be implemented in the decision-support model. To converge the scope of the research, the focus is only laid on the thermal resistance because this aspect is important for the sustainability indication of a façade (Dobbelsteen & Huijbers, 2012).

Table 3. Calculation methods (Agentschap NL, 2011)

Calculation methods methods	Location	Building	Monument
DPL (DuurzaamheidsProfiel van een Locatie)	X		
EPL (EnergiePrestatie op Locatie)	X		
GPR-gebouw		X	
GreenCalc+	X	X	X
EPU (NEN 2916)		X	
EPW (NEN 5128)			X
BREEAM-NL		X	X
Afwegingskader locaties	X		
EPCheck			X
LEED	X	X	
OEI (Optimale Energie Infrastructuur)		X	
BouwTransparant		X	

3.3.2 *How can sustainability aspects be measured?*

Now that there are two models found that define sustainability and are applicable on heritage buildings, the next step is to find criteria that they use to assess the sustainability and research whether they can be implemented in a decision-support model.

GREENCALC+

The GreenCalc+ tool makes use of the 'Milieu Index Gebouw' (Nusselder et al., 2008). The height of this index indicates what kind of label the building has. This calculation model is a computer program (Vreenegoor et al., 2008). For this computer program, multiple parameters must be filled in to assess the 'sustainability' of a building. The parameters that focus on the façade and the thermal resistance of the façades are:

- U-Value [W/m2K] (used for frames and glass)
- R-Value [m2K/W] (used for insulation)
- ZTA – value (used for glass)

BREEAM-RFO

As described before, BREEAM-RFO is a pervasive measuring tool. To extract useful criteria for sustainability, the focus is laid on the aspects material. When searching for criteria, the report of BREGlobal, BREEAM International Non-Domestic Refurbishment 2015, is used. In this report, they elaborate on the methodology for calculating the elemental energy score of buildings. For the facade, they look at the thermal resistance and infiltration. The parameters that they use to assess sustainability are (BREGlobal, 2015):

- U-value [W/m2K] (used for frames and glass)
- Infiltration rate [mm/h] (used for frames)
- Glazing area [m2] (used for glass)

3.3.3 *Conclusion sustainability*

Many aspects make a building sustainable (see figure 13). From now on, for this research, sustainability is the thermal resistance of a façade expressed in the units R and U value. This will test the sustainability effect of a measure. A measure with better thermal resistance will have a positive impact on sustainability. This will be further elaborated in chapter 5.2.1.

Figure 13 Focus breakdown of sustainability definitions for this research

3.4 Costs

Previous chapters analysed the definition of sustainability, and cultural value, the last aspect of the iron triangle that needs defining is cost. Cost is such as sustainability and cultural value a broad concept. During industrial renovation projects, there are different kind of costs in different kind of phases. The sub-question that will be answered in this chapter is:

3.4.1 *What are the different costs in a renovation project?*

According to NEN 2699 (Koninklijk Nederlands Normalisatie, 2017), there are two main types of costs; operating costs of property and investment costs. Investment costs are all the costs required for realizing a building (building cost), including all consultancy fees such as design and engineering (additional costs) and acquiring the plot (land costs). Operating costs relate to the of use the building, including profits and benefits such as rent. Operational costs and investment costs should be in balance to have a financially feasible project. As part of the operational costs, a subcategory can be defined as life cycle costs. These costs are for maintaining the building over its full lifespan, consisting of elements like technical maintenance, cleaning of interior and exterior, energy costs (gas, water electricity) etcetera. Investment including life-cycle costs is also known as total costs of ownership of a building. (Koninklijk Nederlands Normalisatie, 2017)

Because this research does not focus on the operational phase (see conceptual model, chapter 1.9) only the investment costs are considered, moreover the building costs in specific. Investment costs consist of multiple other costs as defined by NEN 2669. In figure 14 there is a scheme visible that breaks down all the costs that belong to investment costs. The focus
of this research is on the façade (chapter 1.8), for this reason, the scheme breaks down to the costs that are involved with the façade, exterior wall

Table 4. Breakdown indirect costs (own table)

Direct costs		**€ 100,00**
Indirect costs	29%	
Further detail	5%	€ 105,00
Construction site costs	10%	€ 115,50
Overheads	7%	€ 123,59
Profit and risks	3%	€ 127,29
Commutation	1%	€ 128,57
Insurance	1%	€ 129,21
Building costs	**excl taxes**	**€ 129,21**
Additional costs	25%	€ 161,51
Unforeseen	10%	€ 177,66
Investment costs	**excl taxes**	**€ 177,66**
incl. Taxes	**21%**	**€ 214,97**

constructions, exterior wall openings, and exterior wall finishes. These costs are expressed in €/m2. Within the building costs shown in figure 14, there are two types of costs, direct and indirect costs. Direct costs are costs that can be directly attributed to a product or service when calculating the cost price (Koninklijk Nederlands Normalisatie, 2017). Indirect costs are not directly attributable to a single product or service but must be incurred as a general contingency to realize the preconditions for the production or delivery of a service. Examples of these time-based costs are construction crane, site management, container park but also insurances, overhead costs and profits or risks for the main contractor.

The direct costs of measures, such as glazing or frames, can be extracted from multiple sources. For this research Vakmedianet BouwCommunities B.V.,(2019) and a costs expert at ABT (Wouter Blondeel) has been consulted to gain the right information on the direct costs of the measures (chapter 5). The most commonly used parameters in costs analyses are the building costs price per square meter.
The indirect costs are more challenging to make as tangible as direct costs because in advance of the project the indirect costs are mostly indicated with a percentage of the direct costs. Table 4 shows how the indirect costs relate to the direct costs.

3.4.2 *Conclusion costs*

To conclude this part of the literature study, it is noticeable that the term costs is quite broad and that it consists of multiple types of costs. To converge this research, only the direct building costs price per square meters for a measure will be considered because this is commonly used in calculation models.

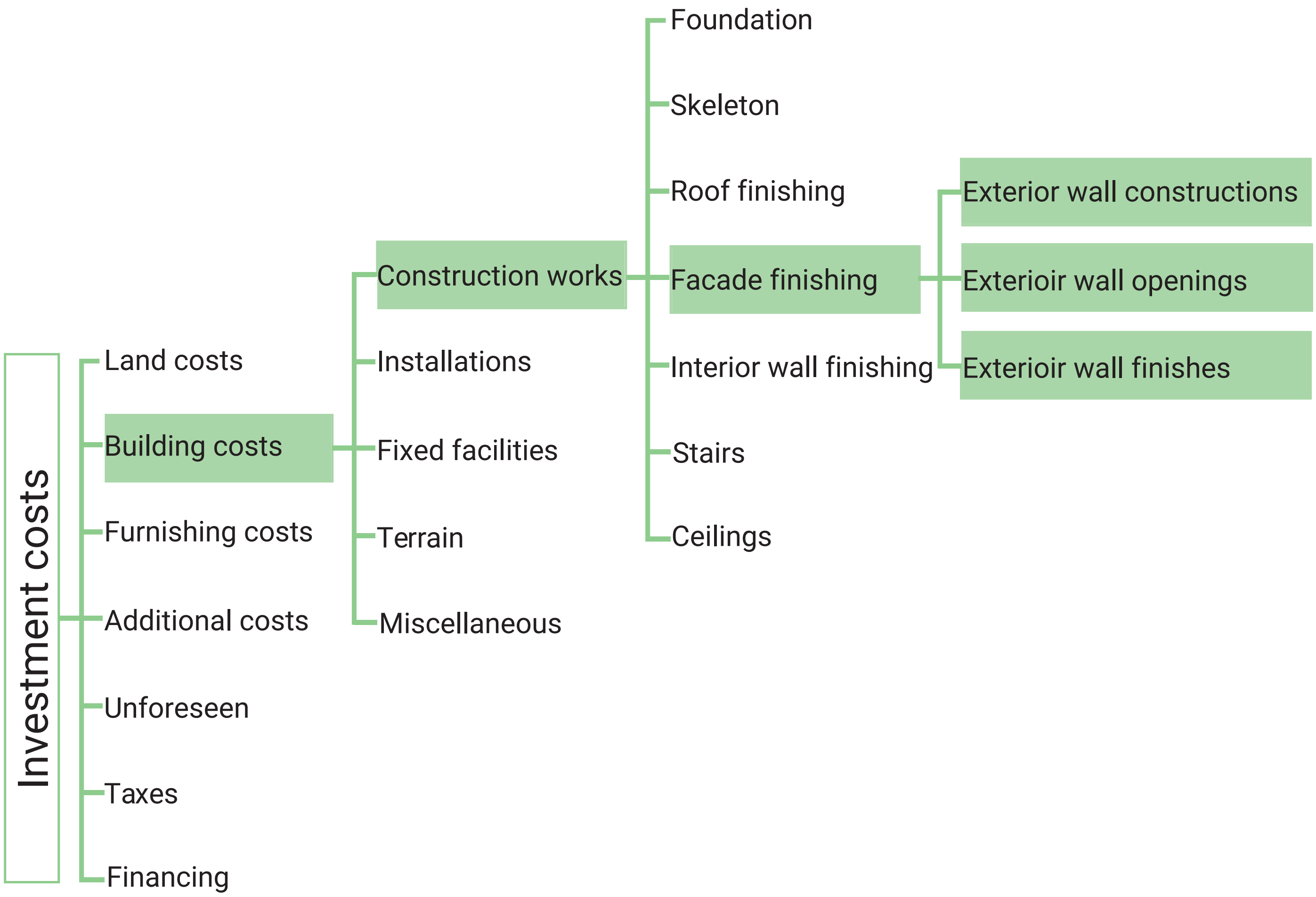

Figure 14 Focus breakdown of costs definitions for this research

3.5 Conclusion literature research

Table 5 shows all the lessons learned from the literature research and the precise definitions of cultural value, sustainability, and costs that will be used during this research.

3.5.1 *Heritage policies*

Heritage policies is critical to keep in mind because this decides whether a project can get a permit and can proceed. Also, the assessment of whether certain building parts are essential to preserve is done by the 'monumentenzorg', with the use of the guidelines of Hendriks and van der Hoeve (2009). These guidelines can be used to assess the cultural value of building parts and if measures impact these values.

3.5.2 *Cultural value*

The cultural value methods analysed in this literature review contain criteria that derive from Hendriks and van der Hoeve (2009). This means that for this decision-support model the guidelines of Hendriks and van der Hoeve (2009) are used (See appendix B and table 5). These guidelines are selected based on the criteria that they should be applicable to the façade, because this research will only focus on this building part, as described in chapter 2.5.

This research shows that the perception of cultural values is subjective which means that it is vital to make sure that the assessment is done from one perspective. Also, it is important to ensure that an expert assesses the cultural value of certain building parts, because the architectural-historical values must be kept in mind during the use of a decision support model. When this model is used by non-experts it can be difficult to assess cultural values. For this reason, the guidelines are critical to use.

Furthermore, from the research of Schrieken (2000) and Beers (2004) the importance arose that a modelling technique is needed that analyses each building part separately and weighs the importance of the criteria.

3.5.3 *Sustainability*

This researched showed that sustainability is a broad definition. There are many aspects that can define the sustainability of a building. For this research it is important to narrow down the aspect to ensure quality of the research. It became clear in the literature research that one of the most common aspect for defining the sustainability of a building is thermal resistance of the skin. The parameters used for assessing the thermal resistance in a façade were the U and R-value. This means that the U and R-value are important to keep in mind to indicate the impact on the sustainability of measures.

3.5.4 *Costs*

The literature research for costs was less extensive then the other due to the fact that costs is a more practical definition and less complex to grasp. This research showed that there are multiple types of cost and how they are calculated during a project. After this research it became clear that the costs for this research will only contain the direct building cost price per square meters.

3.5.5 *Decision-support model*

All the information extracted from the literature (table 5) will eventually be used to create a decision support model. The guidelines from the cultural values will be used to assess the impact of measures on the aesthetics of characteristic building parts. The parameters extracted from the sustainability research will be used to define the impact of measures on the thermal resistance. The definition of costs indicates the costs of the measures. Besides constructing the decision support model. These definitions will be useful during the empirical research to extract the right information.

Table 5. Lesson learned literature study (own table)

Theme	Lesson learned
Heritage policies	The interpretation of the rules differs in each project because it depends on the person who executes the assessment and to what administrative body the monument status falls under.
Cultural value	Cultural value of a building is not one definition and depends on the perspective of the person who assesses the building. Also, for this research a modelling technique is needed that can test each building part to a criterion and incorporates the importance of that certain criteria. Criteria: • Importance of the building due to ornamentation • Importance of the building due to the interior & exterior finish • Importance of the building for the history of the building technology • Importance of the building due to the readability of the building history • Importance of the building due to the use of materials • Quality of building type (rare/common) • Execution quality (rare/common) • Amount of historical remaining • Technical state • Form • Construction • Measurements and grids
Sustainability	U and R-value
Cost	Direct building cost price in €/m2

4. Empirical research

4.1 Introduction

The literature study gave more precise definitions of cultural value, sustainability, and cost. The empirical study will provide a research in measures, with the help of these definitions. The method for the empirical research consists of an analysis of the used measures during the renovation of the buildings and their impact on cultural value, sustainability, and costs. To achieve this, three case studies conducted during an internship at ABT, Gusto MSC, Cruise terminal and Tricot. Every building has a certain industrial aesthetic and has undergone a renovation. Each project used other measures to achieve its sustainability goals. ABT provided access to this information during the internship. Which means that specific sources and data are extracted from internal drives of the company and from colleagues that informally provided some information. The structure divides this research into steps (see chapter 2.2); each step describes the building parts: building volume, structure, roof, skin, closed façades, and open façades.

4.2 Gusto MSC

3.2.1 *Existing situation*

The former woodwork factory in Schiedam was built in 1948 by the architects Vermeer and van Herwaarden. Later, a construction company Herbach became the owner and made some adaptions, such as replacing the windows. Now it is the head office of Gusto MSC. The renovation was done in 2015 to change the function of the factory to an office building. Three architecture firms gave their vision of the accommodation requirements for the tender. Eventually, JHK architects were granted the order. The vision of the architect was to create a combination of open and closed offices and meeting rooms with a central gathering area in the light atrium. All the rooms are positioned around the Atrium; in this way, the atrium is given the attention it deserves. (ABT, n.d.-c)

Building volume: The building volume has a rectangular floorplan with formerly three high elevations with a ground floor of 6 meters and two elevations 4 meters. The building has a floor area of 9,500 m2.

Structure: A robust reinforced concrete skeleton structure supports the concrete floors and roof. The columns were placed in a grid of 6124 x 6124 mm (See Figure 17) with a profile of 520 by 650 mm. The concrete structure in the façade was in good condition.

Roof: The roof consists of four concrete curved shell structures that are perpendicular to the main façade. The roof comprises of segmented concrete elements with a grid of small openings made from glass bricks, through which a light-friendly curved roof has been constructed that facilitates light for the atrium.

Skin: The façades comprise of load-bearing concrete columns, glass surfaces in aluminium frames and masonry with plaster. The concrete skeleton structure that is visible in the façades gives the façade a rhythm. All four façades have large open surfaces to provide daylight far into the building. There is a hierarchy between the façades. The façade with the head entrance has the largest glass surfaces (figure 19), the longitude façades have a less prominent rhythm in the façade (figure 20) and half of the back façade is blind.

Closed façades: The closed façades of the building consist of masonry cavity walls that are 330mm thick. The parapets are also constructed of masonry but are covered with plaster. On the second floor, the façades were completely blind. Before the renovation, the owner created holes in the wall to make sure windows could be placed and more light could enter the upper floor.

Open façades: The windows have a rectangular grid made of aluminium window frames. In the façades at the head ends, the windows are 2026 by 3890 mm with a grid of 635 by 748 mm (figure 21). In the longitude façades, the windows have more width, 2692 by 3890 mm with the same measurements in the grid but with 4 by 5 glass panels instead of 3 by 5 (figure 22). The frames have a thickness of 30 mm. Most of the windows are directly connected to the concrete columns so that there is a maximum light interval for the interior.

Table 6. General information Gusto MSC ((ABT, n.d.-c)

Case study	
Location	Schiedam
Year of built	1948
Architect	Vermeer and van Herwaarden
Original function	Woodwork factory
Current function	office
Year or renovation	2015
Client	Gusto MSC
Architect	JHK architects
Project size	9500
Time durance of project	Two years
People involved from ABT	ir. Gyuszi Florian| ing. Hans Mecking

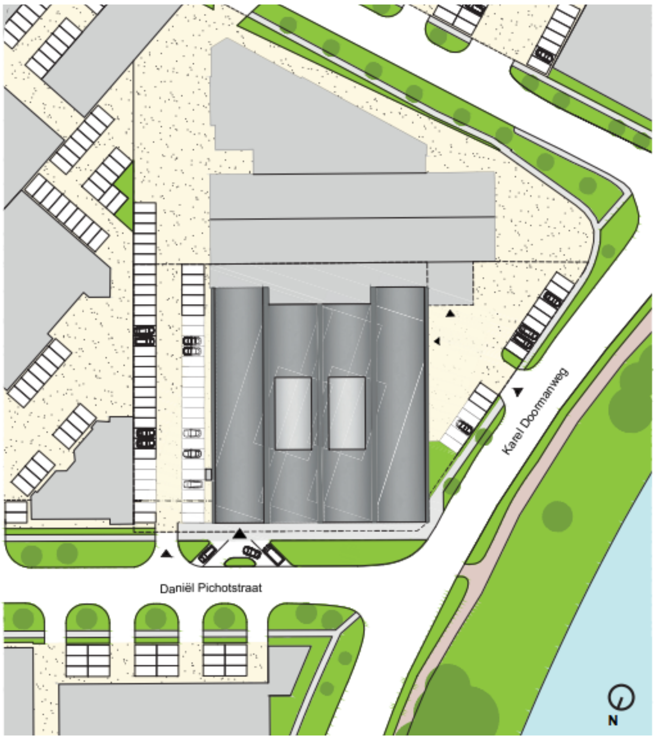

Figure 15 Situation GustoMSC (ABT, n.d.-c)

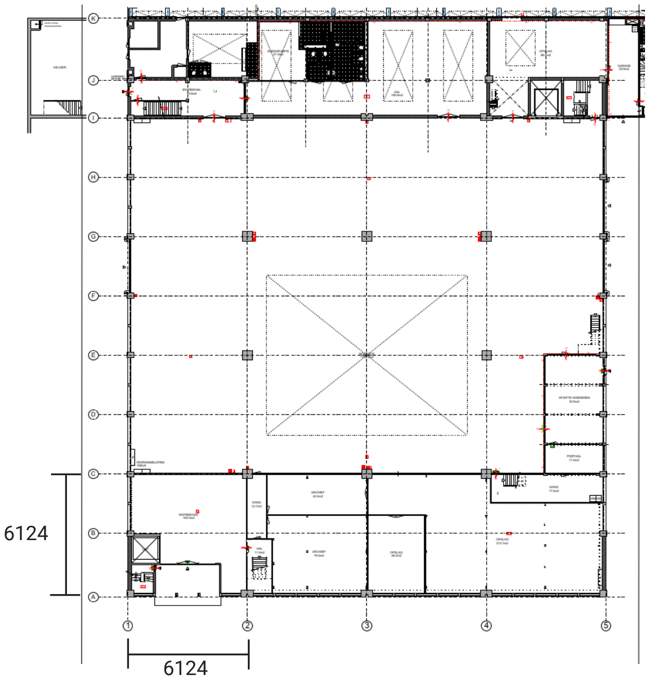

Figure 16 Ground floor plan (before renovation) (ABT, n.d.-c)

Figure 17 Gusto Msc Schiedam (ABT, n.d.-c)

4.2.2 *Cultural value*

The building dates from 1948 and is located at the former shipyard Wilton Feijenoord in Schiedam. The architects Vermeer and van Herwaarden designed the building with a concrete skeleton structure with a concrete curved shell roof. Due to the large glass surfaces, a large amount of daylight enters the interior. The original building housed a woodwork company. In 1998 the building underwent a renovation to make sure the new company, Herbach a steel production company, could house there. Due to the adaption, the interior and open façades were no longer original. Most of the concrete structure, roof and façades were kept intact. The building is not listed as a monument but has monumental values that were kept intact during the renovation. (ABT, n.d.-c)

Building volume: The rectangular floorplan and the high elevation are significant for a building like this because it indicates the original industrial function.

Structure: The concrete skeleton structure with the large elevation height and grid measurements is typical for this building, together with the atrium in the middle of the building. The internal concrete skeleton structure is significant for the cultural values.

Roof: The concrete curved shell structure as a roof is a significant feature. In the heart of the roof, the structure consists of glass bricks. This is an essential element that is considered valuable such as the cassette ceiling of the roof.

Skin: The skin consists of multiple building parts, concrete columns, large open windows, and closed façades. Together they are organised in a rhythm that symbolizes a certain hierarchy. This hierarchy and rhythm to the façade is characteristic for industrial buildings (see figures, 19 & 20).

Closed façades: The exterior finishes of the concrete and the masonry are somewhat significant because it reflects industrial aesthetics.

Open façades: As a result of the previous renovation, the original windows were replaced with HR glass and aluminium frames. The original grid was kept intact but the materials were not. This means that the characteristics of the grid is still significant for the aesthetics but the materials of the frame and glass are no longer essential to preserve. (ABT, n.d.-c)

To conclude, for this building the characteristic building parts in the façade, and the relation between those building parts, that give this building its identity and cultural values are:

- Exposed concrete columns
- Hierarchy & rhythm between columns
- Large glass surfaces with grid frame
- The curved concrete shell structure
- Glass brick structure of the roof.
- Masonry with plaster

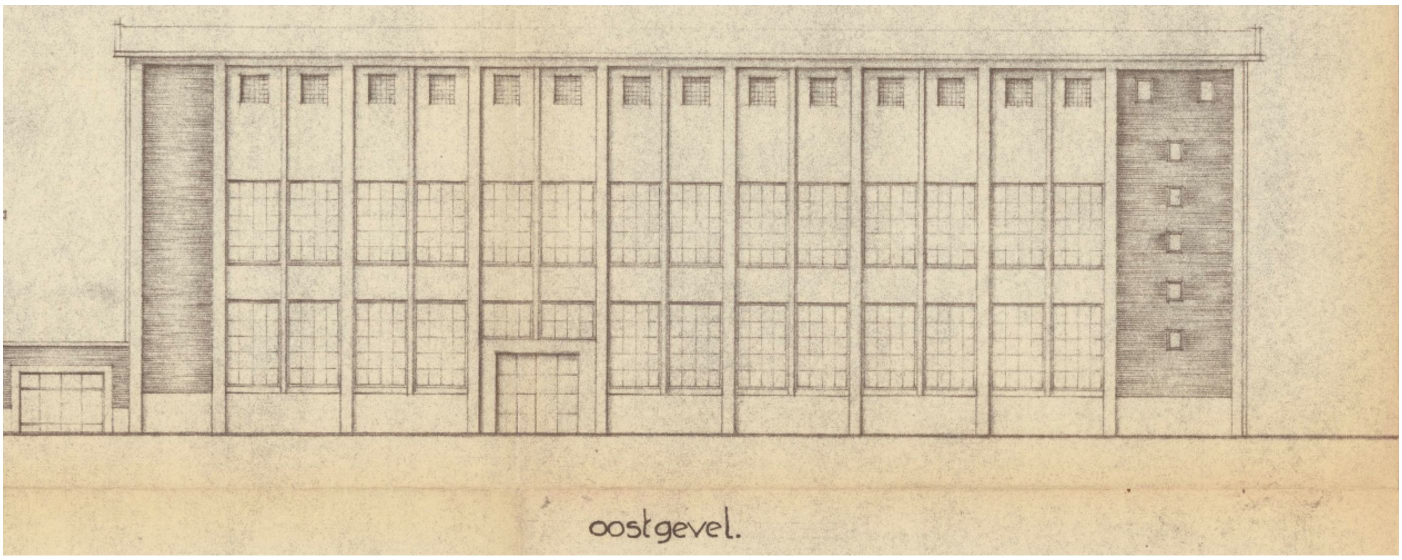

Figure 18 Old facade drawing (ABT, n.d.-c)

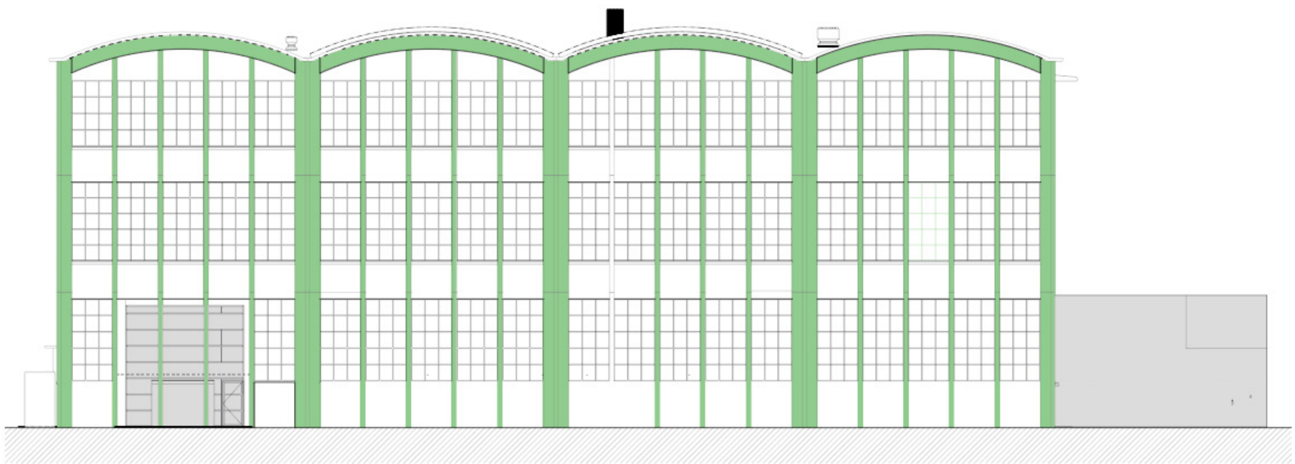

Figure 19 Head Facade Gusto MSC. Column structure highlighted in green

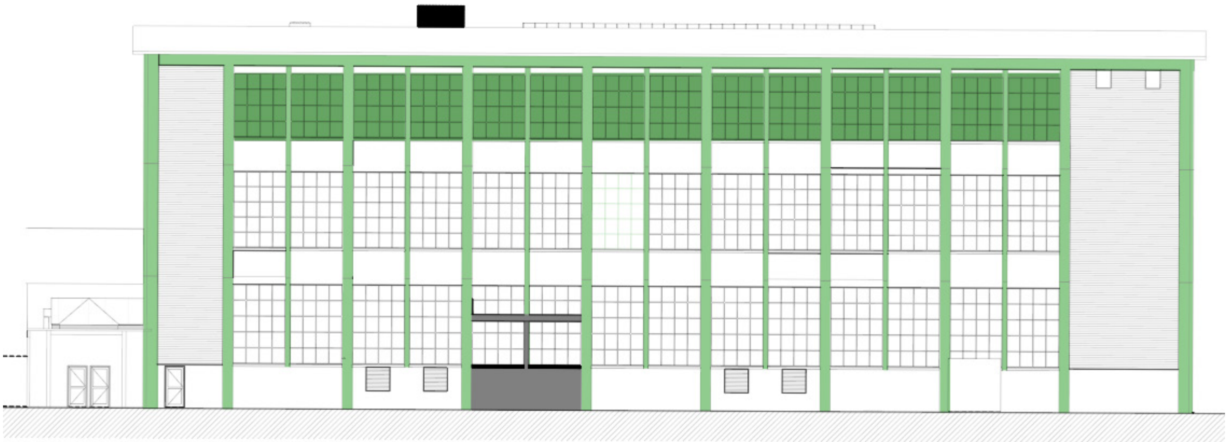

Figure 20 Side Facade Gusto MSC. Column structure and new windows highlighted in green

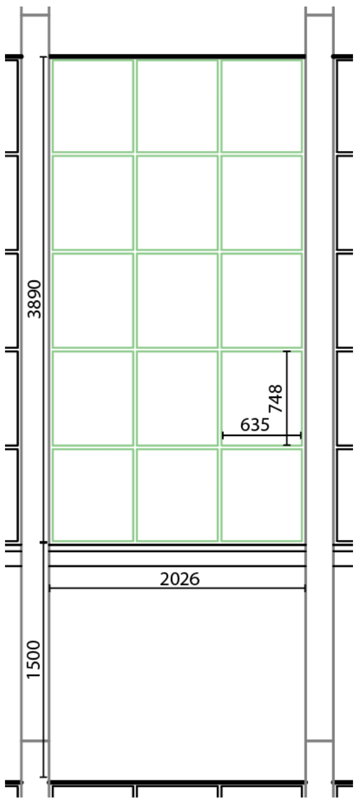

Figure 21 Windows head facade. Frame structure highlighted in green.

Figure 22 Windows side facade. Frame structure highlighted in green

4.2.3 *Sustainability*

The sustainability goals of this building were to increase the comfort and the EPC label of H to C. (ABT, n.d.-c) This is accomplished with changing the installations of the building (e.g., mechanical ventilation) and applying insulation on the façade and roof.

Building volume: More parking spaces were needed; therefore, they created a new constructive mezzanine floor, within the building volume. This was possible due to the height of the first floor.

Structure: The strength of the load-bearing structure could not support the new function. To ascertain the strength and preserve the appearance of the concrete structure; carbon adhesive reinforcement was applied.

Installations were applied in a raised floor instead of a lowered ceiling to minimize the visual impact on the concrete structure.

Roof: To meet requirements for the heat resistance of the roof was 2,5 m2K/W (Mecking, 2014), 70 mm of PIR with an R-value of 2,51 m2K/W is applicated on the roof. (Verkaart Groep, 2015) The insulation was placed on top of the roof to preserve the ceiling that represents the cultural values of the building. The thickness of the insulation on the roof was limited since it could rise above the eaves and be visible in the façade. This interferes with the exterior appearance of the building, consequently with the cultural values. The glass bricks in the roof were kept intact due to perceived cultural values. They deliberately compromised sustainability to preserve cultural values.

Skin: The requirements for the heat resistance of the façades is at least 1,3 m2K/W.

Closed façades: The closed façades and concrete columns were uninsulated. The masonry cavity wall had an R-value of 1,3 m2K/W (Mecking, 2014). The exterior appearance of the building was significant for the cultural values of the building. For this reason, high-quality insulation with an R-value of 2,5 m2K/W is applied on the inside of the concrete columns, closed façade, and the parapets. (Verkaart Groep, 2015) Placing the insulation on the exterior would have led to the interference of the thickness differences of the columns and parapets and consequently the cultural values (see figure 23).

Because the windows are connected to the columns, there is a restriction on the thickness of the insulation. Since the insulation wraps the column, the thickness of the window frame limits the thickness of the insulation. Otherwise, the insulation will interfere with the exterior look of the façade (see figure 23).

Open façades: Due to a previous renovation, the windows of the first two stories had double glazing and aluminium frames with a U-value of 3,2W/m2K. On the second floor, there were no windows, which lead to the opportunity to place new windows with a U-value of 1,1 W/m2K. The windows had to have similar size, grid, and aesthetic of the surrounding windows to preserve the cultural values of the building,

Insulation foils were applied on the ground floor and the first floor to minimize heat accumulation caused by daylight. This led to a U-value of 2,8 W/m2K and a ZTA value of 0,39. On the places where the sunlight is more than 300 W/m2, blinds with a light colour were installed on the inside (ABT, 2014). The colour of the insulation foil was selected so it would have the least impact on the cultural values. (Mecking, 2014)

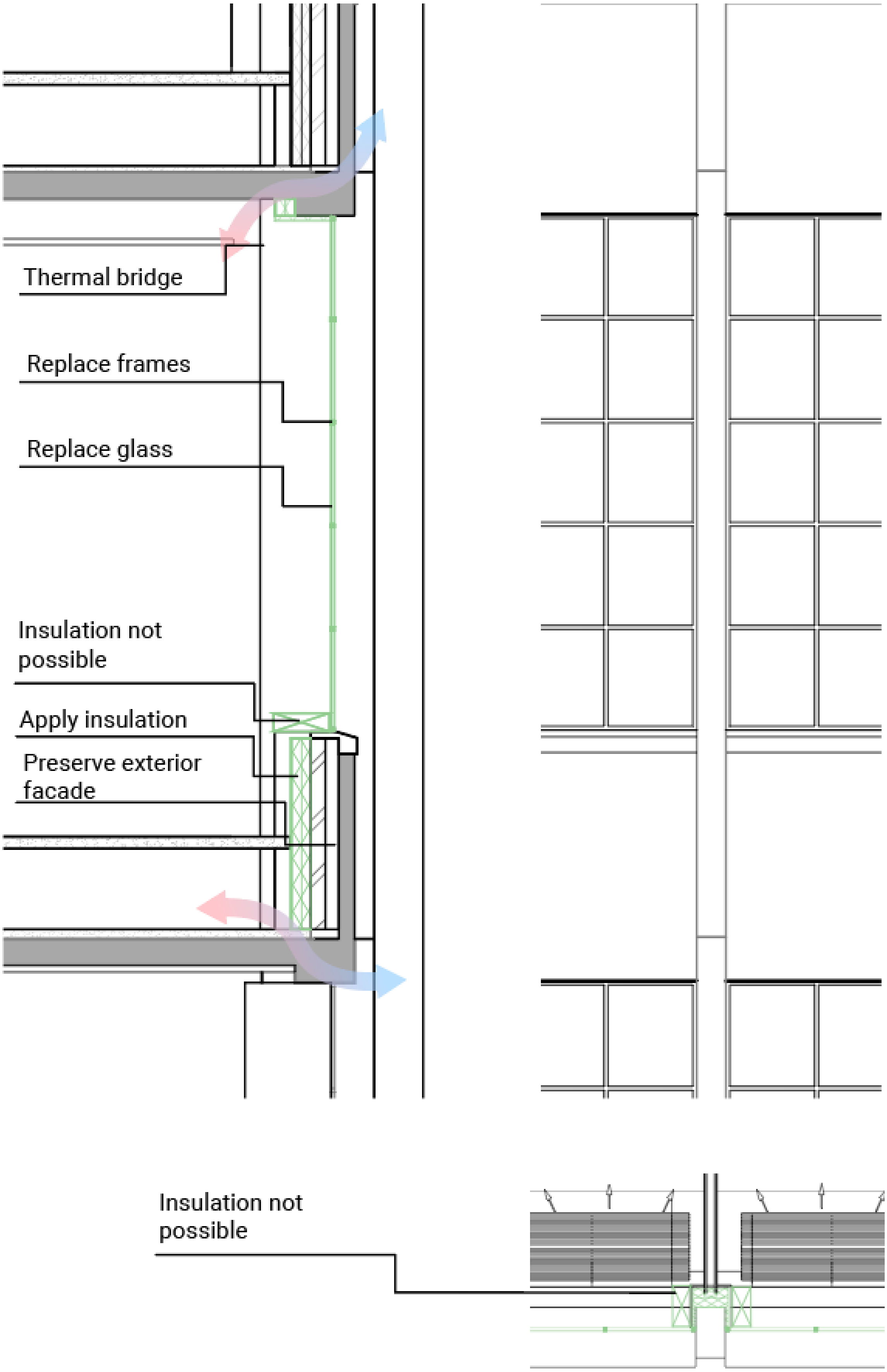

Figure 23 Facade section with new adaptions in green (own image)

4.2.4 *Costs*

The characteristic building parts for cultural value, the sustainability goals and the measures used to reach those sustainability goals are identified. The last part of the analyses are the costs that were involved in the project. The total building costs for this project was €9.000.000 (ABT, n.d.-c)

Building volume: The new floor supported by a steel construction cost 126.36 €/m2. , with a total square meter of 2.144m2, this led to a total cost of €270.907. (Matijssen, 2014) This is around 3% of the total building costs.

Structure: The costs for the carbon adhesive reinforcement could not be found.

Roof: The insulation that was placed on the roof was 70 mm of PIR with an R-value of 2,51 m2K/W and had a total cost of €192.000.

Skin

Closed façades: The interior insulation systems installed had an R-value of 2,51 m2K/W. The costs of the interior insulation systems were approximately 50 €/m2. Because there was a total of 1796 m2 insulation to be applied in the building the total costs for the interior insulation systems was €89.781. (Matijssen, 2014)

Open façades: For the upper floor new aluminium frames with HR++ glass were installed. Since the glass was already placed in the factory, the price of the frames and glass are combined. The price for the windows was 450 €/m2, with 22 m2 of placed windows this leads to a total cost of €9.900. During the renovation, they considered changing all the glass. However, this would have cost them €500,000. The time of the return on investment was too excessive, so they decided to keep the current windows. (Mecking, 2014)

Instead of changing all the windows they applied insulation foil, this foil was 41,67 €/m2 with a total of 1200 m2 this leads to a total cost of €50.000. This is 10% of the option to change all the glass. (Matijssen, 2014)

4.2.5 *Overview*

This case study showed some of the tensions that occurred during this project between cultural value, sustainability, and costs. In figure 24 the priority of each aspect is visualized; this shows which aspect had the most priority in the project.

- The appearance of the concrete structure is preserved through investing additional money into an alternative measure, carbon adhesive reinforcement.
- The decision to not insulate a significant part of the roof because of the glass bricks showed that the cultural values were more important than the heat resistance of the roof. To compensate this insulation was applied on top of the roof, to preserve the aesthetics of the cassette ceiling.
  The thickness of the insulation on the roof was limited due to the height of the eaves, and it would interfere with the exterior aesthetics. The decision to not invest in an expensive thin insulation with a high R-value shows that the priority for sustainability is lower than cost and cultural value.
- The heat resistance of the façade had to be improved because they valued the exterior façade more than the interior due to the visible concrete columns; they decided to do the insulation on the interior façade.
  It was not possible to wrap the column with the optimal thickness for insulation since the windows were directly connected to the columns. The decision to not invest in an expensive thin insulation with a high R-value shows that the priority for sustainability is lower than cost and cultural value.

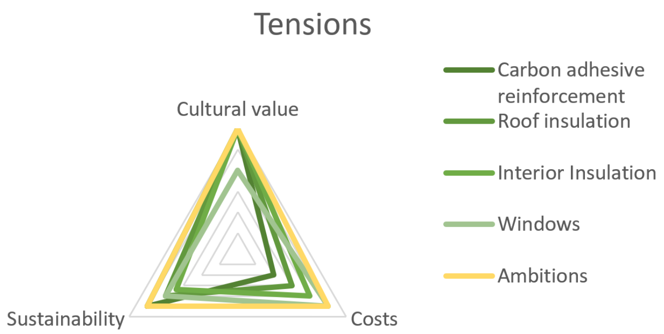

Figure 24 Balance measures Gusto MSC. Cultural values and sustainability are on a positive axis and cost on a negative axis, meaning that when the costs are low, the value is further from the center. (own image)

∆ The windows were already replaced before the renovation. The new windows matched the surrounding windows, to enhance the cultural values. The new windows fitted in the façade quite nicely and it did not interfere that much with the cultural values.
The option to change all the glass to achieve a higher thermal resistance would lead to higher costs. Eventually, the economical option was chosen since the impact on the thermal resistance would not be that high to pay ten times more money. The decision to use insulation foil instead of replacing the glass shows that cost had a higher priority than sustainability.

This project has realized the new accommodation for GustoMSC in a magnificent way, although the building is not listed as a monument, the focused maintained on the cultural values while increasing the sustainability of the building. The measures and their impact as described in table 7 can be applied in the operational research.

Table 7. Overview measures Gusto MSC (own table)

Building part	Technical State	Measures used	Sustainability impact	Costs	Risks
Building volume		Extra floor	-	€270.907	
Structure	Reinforced Concrete Skeleton	Carbon adhesive reinforcement		-	
Roof	Concrete shell structure. 2208 m2	Insulation applied on top.	70 mm PIR 2,51 m2K/W.	€192.000	The height of the eaves limits the thickness of the insulation.
	Glass bricks. 4,10 W/m2K	Kept intact	-	-	Thermal bridge
Skin					
Closed facade	Masonry cavity wall 1,3 m2K/W. 330mm	Applied insulation system inside	Insulation 2,51 m2K/W.	50 €/m2.	Thermal bridges where floors connect façade.
	Concrete columns 520 x 650 mm 220 x 380 mm Not insulated	Applied system insulation inside	Insulation 2,51 m2K/W	50 €/m2	Thickness insulation is restricted by thickness frame
Open façades	Aluminum frames GF & 1st Floor 1,3 m2K/W 30 mm	Kept intact			Thickness frame restricts thickness insulation on the column
	No frames 2nd Floor	Placed	Aluminum frames 1,3 m2K/W 30 mm	450 €/m2	Thickness frame restricts thickness insulation on the column
	Façade North Double Glass 2,8 W/m2K	Kept intact	-	-	
	Façade E, S&W GF & 1st Floor Double Glass	Sun reflecting foil	ZTA 0,39	41,67 €/m2	Colour of insulation foil may interfere with the exterior look.
	Façade E & W 2nd Floor	Glass placed	HR ++ 1,1 W/m2K	450 €/m2	

4.3 Cruise terminal Rotterdam

4.3.1 *Existing situation*

The Cruise terminal is located at the Wilhelminakade in Rotterdam. The goal of the renovation was to improve the current comfort and energy performance of the building. The renovation was called 'a quick fix' since the renovation was only to improve the crucial points such as of the glass façades and the acoustic insulation. The scope of the building was limited to the upper floor and roof. TomDavid architects executed the renovation in 2013.

Building volume: The building volume has a rectangular shape and consists of two floors. The elevation height is 6 meters, the length of the building is 38 meters and the width are 9.4 meter.

Structure: The structure of the building consists of a skeleton structure of reinforced concrete and steel. At the waterside on the ground floor of the building, the construction had been altered when they changed the frames to aluminium frames. The skeleton concrete structure has an irregular grid with a constant distance of 9 meters and a changing distance between 5, 10 and 12.6 meters. The condition of the structure is good.

Roof: The building has a roof that consists of 6 curved shell structures which are perpendicular to the longitudinal walls. The roof is made of 70 to 90mm thick concrete. The roof has eaves of 300 mm high. The acoustic and thermal insulation of the roof is poorly.

Skin: The street façade of the building is divided in two. On the ground floor, the majority of the glass façades are replaced. Only the three fronts on the right side are original (see figure 31). The upper façade rests on columns and has an overhang of 10 meters over the ground floor. This façade exists of large glass panels that rest on the parapet. On the water side, the majority is still original compared to the ground floor. This side is also completely glass, the glass runs from the balcony to the bottom of the curved roof. Whereas the front façade has the concrete structure visible (see figure 28).

Table 8. General information Cruiseterminal (ABT, n.d.-b)

Case study	
Location	Rotterdam
Year of built	1949
Architect	Brinkman, J.H. van den Broek and J.B. Bakema
Original function	Terminal
Current function	Terminal / eventhall
Year or renovation	2013
Client	Havenbedrijf Rotterdam N.V.
Architect	TomDavid rchitects
Project size	6655 m2
Time durance of project	2 years
People involved from ABT	ir. Sander Dorleijn ir. Wouter Blondeel ir. Jeroen Weijers ir. Christa Droleng ing. Rowan van Wely

Closed façades: The façades on the head ends are completely blind with a visible structure (see figures 30 and 31). The walls used to be partly indoors before the demolition of 'Norfolk' and 'Baltimore' (chapter 4.3.2). On the east side there is another building built which makes a part of that façade indoor. Also, there are some signs painted on that side. The closed façades are uninsulated.

Open façades: The street upper facade with the large glass area consists of 6 large sets of windows. These windows are curved and have a width of 16159 mm and a maximum height of 7424 mm. The frames consist of steel with a thickness of 40 mm and have a grid of glass panels of 864 x 965 mm (see figure 33).

The water façade has windows with a width of 17885 mm and a maximum height of 8204 mm. The glass panels are 1009 x 925 mm with a steel frame thickness of 55 mm. In this side, every part of the façades has a sliding double door that is still original.

The glass in the façades is replaced in 1997 with double glazing. Only this glass was too heavy for the frames and so the condition of the original frame worsened, the metal frames deformed and started to rust.

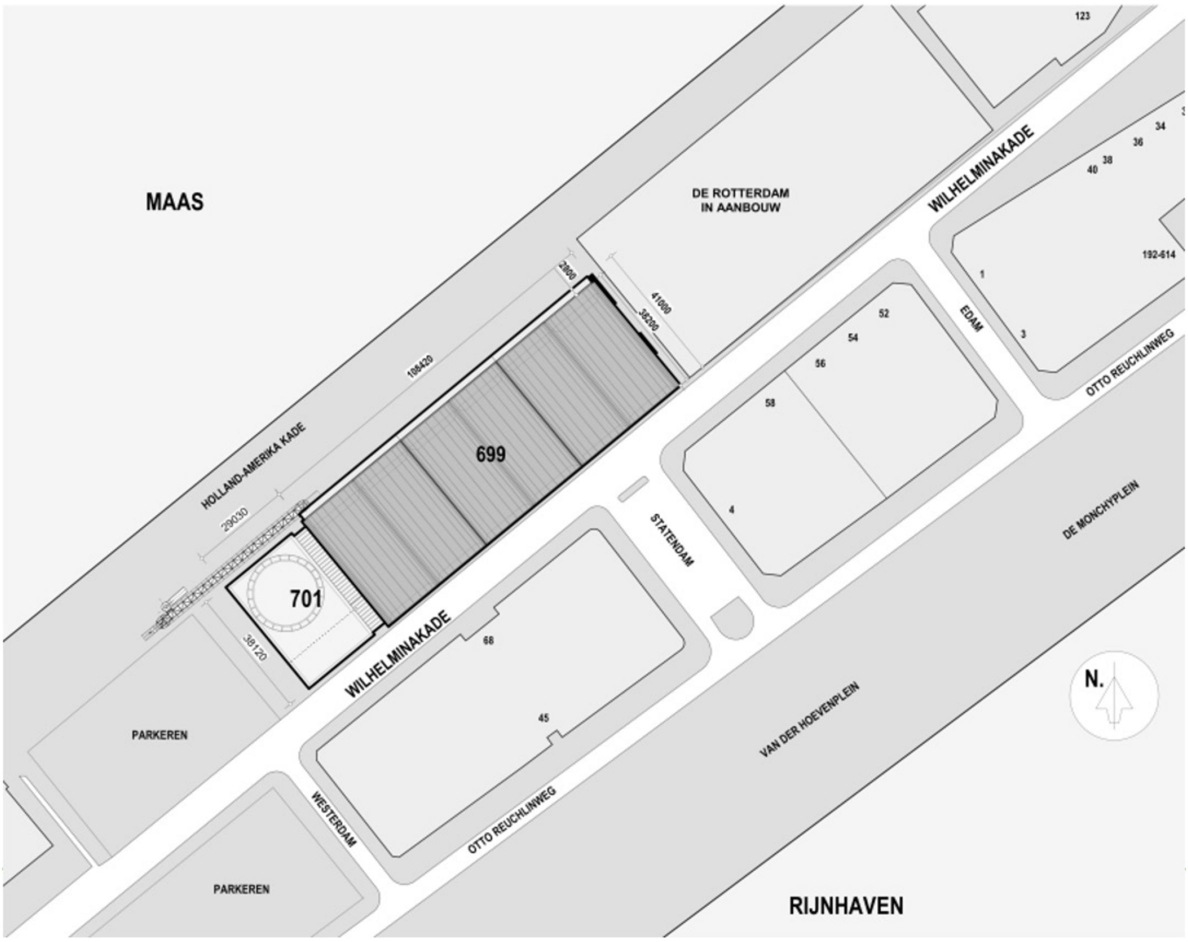

Figure 25 Situation Cruise terminal (ABT, n.d.-b)

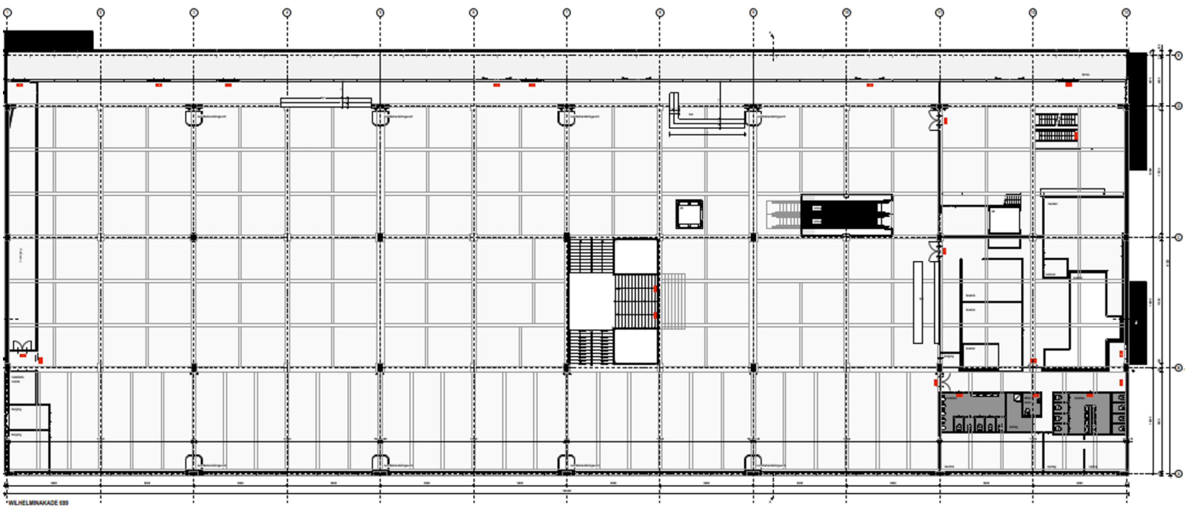

Figure 26 First floor (ABT, n.d.-b)

4.3.2 *Cultural value*

In the second half of the nineteenth century, the Prinsessekade facilitated cargo transport and emigrants to America. The origin of the building comes from the Plate, Reuchlin & Co company, which from 1873 established itself as a Dutch-American Steamship Company on this quay. The shipping company rented parts of this quay with different warehouses with a total length of 700 meters. From 1891 the quay was named after Princess Wilhelmina. In 1896, Holland-America Line was added to the name of the shipping company. In 1901, the company built a recognizable office building at the head of the Wilhelminapier, the current Hotel New York.

Due to the bombing of Rotterdam on 14 May 1940, numerous buildings on the Wilhelminapier had been destroyed. Immediately after the occupation, new warehouses erected here. Between 1946 and 1949 a total of five buildings were built, all named after different port cities (Philadelphia, Norfolk, Baltimore, New York and Rotterdam). The only one left is on the north of the quay and is named ‘Rotterdam’, the arrival and departure hall. (Monumenten.nl, n.d.-a)

The ‘Rotterdam’ was constructed in New Objectivity Style in 1949 by the architects J.A. Brinkman, J.H. van den Broek and J.B. Bakema.

In 1972, due to competition with the rising airline business, the company discontinued its services. The arrival and departure hall has been in use since 1988 as a space for exhibitions, fairs, congresses and events. Since 1999 the name of the restored arrival hall has been ‘Cruise terminal’ and houses, among other things, ‘café Rotterdam’. Since 2000, progressively more cruise ships have come to visit Rotterdam, so that the quay ‘relives’ its former glory. (Monumenten.nl, n.d.-a)

Figure 27 Cruise terminal (ABT, n.d. -b)

The building has a national monument status because the cruise terminal is important on the urbanism, architectural and cultural historic level.

Building volume: The building was designed in a New Objectivity style by the architects J.A. Brinkman, J.H. van den Broek and J.B. Bakema which gives this building architectural historical value.

Structure: The building has a concrete skeleton construction of two stories high and is closed at the top by six cylindrical shell roofs with a span of 18 meters. The manner of this construction contributes to its architectural historical value.

Roof: The cylindrical shell structured roof was the first one in the Netherlands and for that reason, carries great architectural historical values. Also, the way that the roof protrudes obliquely, at the short façades is important to preserve.

Skin: A majority of the skin exist of open façades which contributes to its character.

Closed façades: The visible concrete structure in the façade is a significant feature, the form of the structure must be preserved to maintain the industrial characteristics

Open façades: The open façades consisting the steel frames with the grid structure is considered as important.

The interior and the annex buildings are less important because they are not original. To conclude, for this building the characteristic building parts in the façade that gives this building its identity and cultural values are:

- The curved concrete shell structure
- Exposed exterior concrete columns
- Large glass surfaces with grid frame
- Concrete parapets

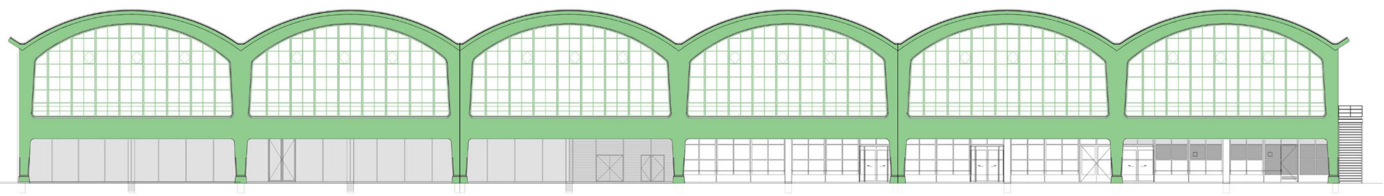

Figure 28 Street facade (own image)

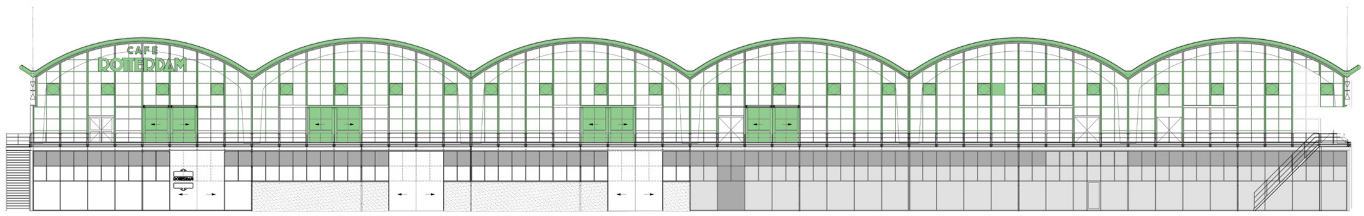

Figure 29 Water facade (own image)

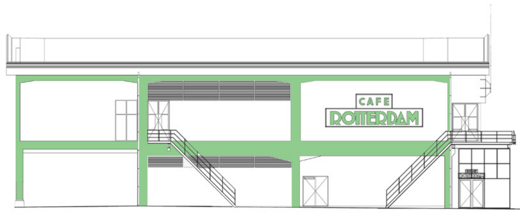

Figure 30 West end facade (own image)

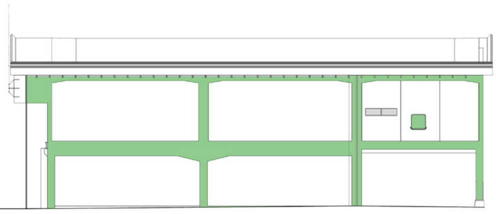

Figure 31 East end facade (own image)

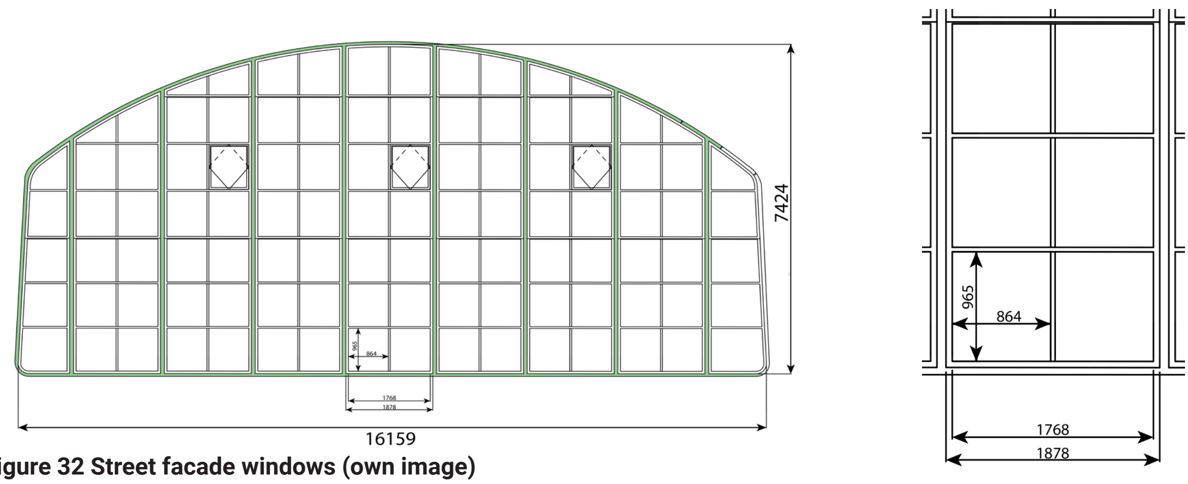

Figure 32 Street facade windows (own image)

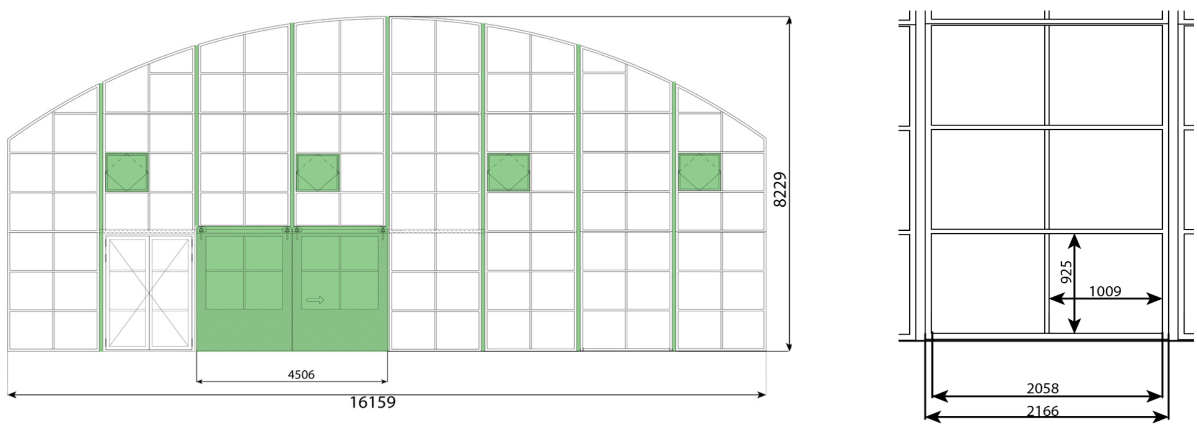

Figure 33 Street facade windows (own image)

4.3.3 *Sustainability*

The goal of this renovation was to ensure that the current function could remain. The building could no longer facilitate the function of arrival and event hall due to the poor acoustic insulation and the poor condition of the façade. Also, the people of the larger cruise ships could no longer board at the terminal because the entrance was too low for the gangway. (ABT, n.d.-b)

Building volume

Structure: The concrete structure was in good condition. The columns were repaired and painted white to enhance the aesthetics of the exterior façade.

Roof: An insulation layer is applied on the roof see figure 34. The thickness of the insulation was not limited by the height of the eaves, as they are 330mm high. Now there is a 100 mm thick insulation with an R-value of 2,5 m2K/W. (Hartman, 2014)

Skin: Because the ground floor façade has been adapted and few original elements remained, the struggle to keep cultural values is less important than in the upper façades. On the ground floor, some light maintenance on the existing façades is executed. The focus of the renovation was predominantly on the upper façades and the roof. (Hartman, 2014)

Closed façades: The concrete structure that is visible in the façade is lightly repaired and not insulated. Which can lead to thermal bridges at the columns and closed façade. But as most of the square meters in the façade is made from glass, it was more valuable to focus on replacing the glass instead of investing in insulation on the closed façades. (Hartman, 2014)

Open façades: The glass façade is replaced to increase the comfort, acoustic insulation, and the poor condition of the façade. The plan before the renovation was to preserve as much of the original material as possible, however during the execution, the frames appeared to be in such a bad condition that they had to be replaced (figure 34). For the new frames, the architectural quality commission demanded that the thickness of those frames had to be the same as the original to keep the cultural values of the façade intact. This meant investing more money in new custom made steel renovation frames with a thickness of 40 mm. (Hartman, 2014)

The placed glass in the frames, attribute to the acoustic insulation and the thermal resistance of the building. The thickness of the frames also limits the thickness of the glass, this meant the glass that is installed is monumental double 4-6-4 clear glass and has a U-value of 2.5 W/m2K. Other glass types can provide a lower U-value to increase the sustainability, but because of the restrictions that the cultural values in the façade bring this was not possible. (Hartman, 2014)

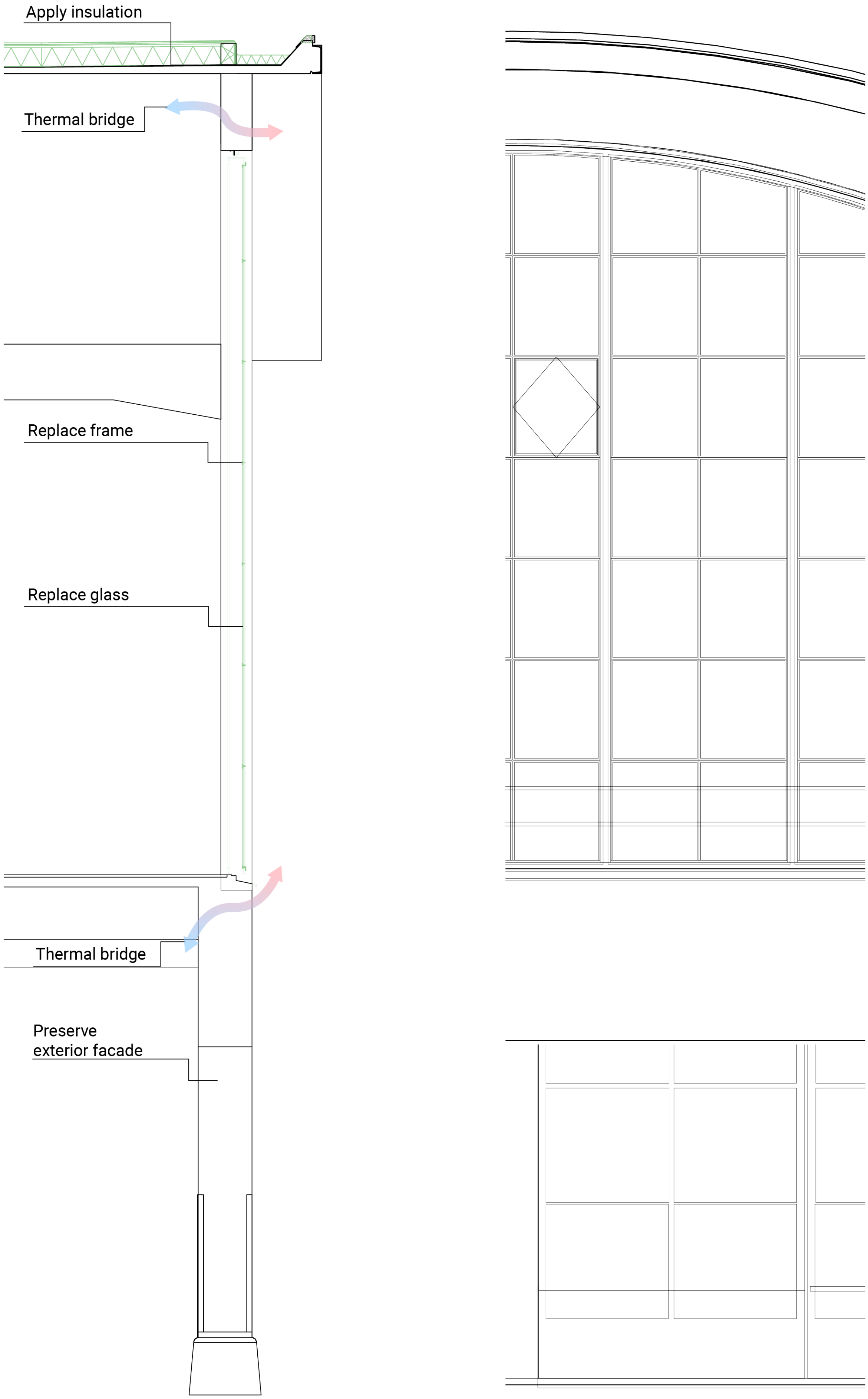

Figure 34 Facade section with new adaptions in green (own image)

4.3.4 *Costs*

The last part of the analyses are the costs that where involved in the project. The total building costs for this project was around 3.500.000 whereas around 82% of the costs was spend on the skin. (ABT, n.d.-b)

Building volume

Structure: The structure of the building did not need any insulation and underwent light repair, this costed 32,37€/m2, with a total square meter of 444,5 m2 this results in a total cost of € 14.388. (Boks, 2014)

Roof: On the roof the insulation was improved. The costs of improving the roof was 96,64 €/m2, a total square meter of 4650m2 this results in a total cost of € 449.385. (Boks, 2014)

Skin

Closed façades: There was no insulation applied on the closed façades. To enhance the aesthetics, paint has been applied on the façade. The costs of painting the closed façade was 25 €/m2, with a total square meter of 1201 m2 this results in a total cost of € 30.032. (Boks, 2014)

Open façades: The original plan for the open façade was to restore the original frames. This would have costs around 150 €/m2 and because there is a total of 799 m2 it would have costs €119.917 in total. But because during the execution the frames turned out to be in a severer condition than expected, renovation profiles were placed. Because this happened during the execution, there are no files about the exact costs of the new profiles. But according to the people involved, it eventually costed more than initiated. Moreover, the architectural quality commission demanded thinner profiles to ensure the cultural values of the cruise terminal, which directed to additional expenses for installing thinner profiles.

The new glass costed around 210 €/m2, because there is a total of 799 m2, the costs were €167.883 in total. The aluminium façades on the ground floor got a small repair that costed around 25 €/m2, with a total square meter of 258 m2, this results in a total cost of 6.457. (Boks, 2014)

4.3.5 *Overview*

For this project, the tension between costs, sustainability, and cultural values where mainly in the glass façade:

- The architectural quality committee valued the aesthetics of the glass façade as important and while renovating the demand to keep the thickness of the frames gave a limit of the sustainability that the project could achieve. This led to uninsulated thin frames that could only enclose thin glass with a lower u value. In addition, the costs for the new frames were more than calculated for. This means that the cultural value preservation of the architectural quality committee resulted in a higher u value and increase of costs (see figure 35).
- The glass in the frames could not be too thick due to the architectural quality committee and here sustainability had to be traded off to preserve cultural values.
- Roof insulation could be applied without interfering with the cultural values due to the height of the eaves.

In this case study it becomes clear that the square meters of the closed and open façades matter for the decision-making process. If the majority of the façade is open, the potential to alter this building part increases. In this case study the decision to concentrate on the open façades is noticeable. This

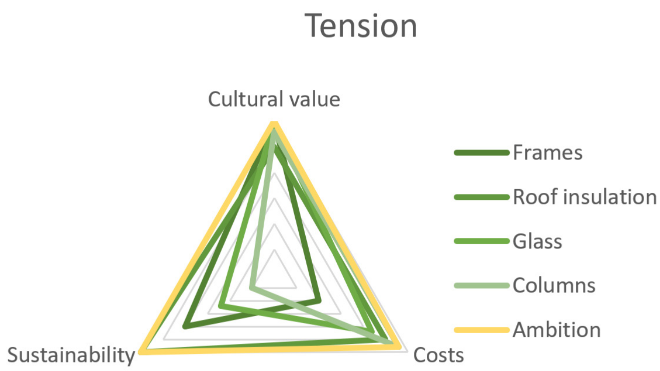

Figure 35 Balance measures Cruise terminal Cultural values and sustainability are on a positive axis and cost on a negative axis, meaning that when the costs are low, the value is further from the center. (own image)

was due the poor condition of the windows and the fact that the majority of the façade was open. It was more efficient to focus on this part.

Besides the number of square meters, it became apparent that the condition of a building part could also influence the decision-making process. When a certain glass already has a good u value, it is unnecessary to focus on changing the glass. For this situation, the ground floor façade was already renovated and was therefore not in the scope of the project.

Overall this project has upgraded the Cruise terminal in a quick way to ensure that the current function could maintain. The following can be applied in the operational research:

- Measures and their impact as described in table 9
- The fact that square meters of a building part are important for the decision of which measure should be used.
- The rate of the condition of a building part is important when deciding what measure should be used.

Table 9. Overwiew measures Cruise terminal (own image)

Building part	Technical State	Measures used	Sustainability impact	Costs	Risks
Building volume					
Structure	Concrete columns in fair condition Not insulated	Repaired where necessary, cleaned and painted	Concrete columns in good condition Not insulated	-	Low insulation Thermal bridges
Roof	Concrete 70 – 90 mm 100 mm cork	Insulation applied	Concrete 70 – 90 mm 100 mm PIR 2,50 m2K/W.	96,64 €/m2	The height of the eaves limits the thickness of the insulation
Skin					
Closed façade	Good condition Not insulated	Painted	-	25 €/m2	Low insulation Thermal bridges
Open façade	40 mm metal frames Not strong enough for the glass, so rusted and sagged.	Replaced	Steel uninsulated renovation frames 40 mm	25 €/m2	Condensation To preserve cultural values the frames & glass can't be too thick. This means that insulated frames are not possible.
	Aluminium frames on ground floor are in good condition	Clean up and maintenance	Aluminium frames are in good condition	25 €/m2	
	Double glass	New glass	monumental double 4-6-4 clear glass 2.5 W/m2K	210 €/m2	

4.4 Tricot

4.4.1 *Existing situation*

The former textile factory 'Tricot' is situated in Winterswijk. The first building was completed in 1890 and the company closed in 1978. This case study will analyse one building of this complex; the dye house. In 2008 a housing corporation 'De woonplaats' developed a new program for the building. The renovation realized apartments, exhibition space and a sunken car park, by the architect Frits van Dongen. (Roorda, R., Kegge, B., & Backaert, 2016; Stenvert, 1995)

Building volume: The dye house has a rectangular floorplan and partially 4 stories with a height of 4 meters. The fourth building layer has a lighter construction in comparison to the rest. The concrete structure is in good condition.

Structure: The load-bearing structure consists of a white painted concrete skeleton structure constructed after the Hennebique system. It consists of columns in three bays of approximately 6.6 meters (see figure 37), a length of almost 52.7 meters and a depth of 20.0 meters which allows housing a variety of functions.

Roof: The building has a flat roof that comprises out of wood. The design of the roof ensured the possibility to construct an additional building layer after the construction. The roof is not insulated.

Skin: The façade is a constructive part of the structure, it contains the load-bearing columns with the glass panels in between which ensures a transparent character. The façade has a certain rhythm and hierarchy in it. The vertical articulation of the first three floors consists of twice a narrow, once a wide column on the separation of the window shafts. The columns finish on the third floor enclosed by the mainframe. The columns and frames contain ornaments and mouldings (see figure 43).

Table 10. General information Tricot (ABT, n.d.-d)

Case study	
Location	Winterswijk
Year of built	1912
Architect	Arend Beltman
Original function	Factory
Current function	Residential
Year or renovation	2005
Client	De Woonplaats Groenlo
Architect	De Architekten Cie
Project size	8.400
Time durance of project	8 years
People involved from ABT	ing. Hans van Vliet, ing. Jos Wolters

The north and south façades are subdivided into seven bays, consisting of three window axes and one bay with two window axes. The east façade was connected to a former part of the industrial complex but was torn down. The west façade is subdivided in tree bays with the same window grid as the north and south façades (Monumenten.nl, n.d.-b)

Closed façades: The wide columns are 800 by 400 mm; the narrow columns are 400 mm by 400 mm. Next to the columns, the closed façade consists of concrete parapets. The concrete structure in the façade is in good condition but not insulated

Open façades: On the first three floors, the windows are 1636 by 2740 mm with a divided twelve-square (3x4) grid (see figure 42). The glass panels are 498 by 636,5 mm. The windows on the fourth floor separate from the others with two eight-square (2x4) grid instead of one twelve-square (3x4) grid, and a decorative 'bloktand' as molding (see figure 43). The window frames are made of cast iron and have a thickness of 38 mm. The window frames are directly connected to the columns. These frames were still in good condition to preserve, the single glass in the frame was for the most part broken or missing.(ABT, 2002)

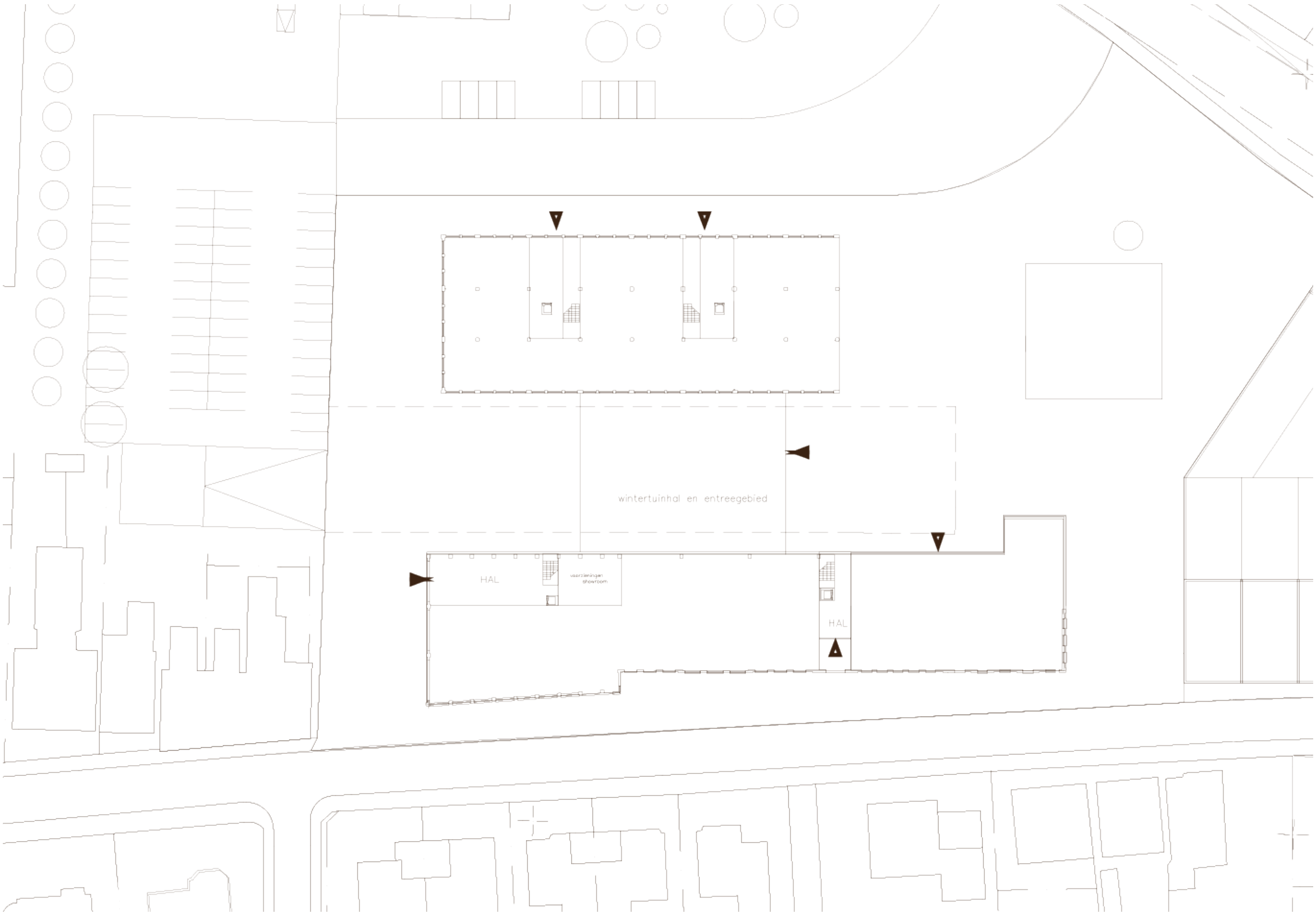

Figure 36 Situation Tricot (ABT,2002)

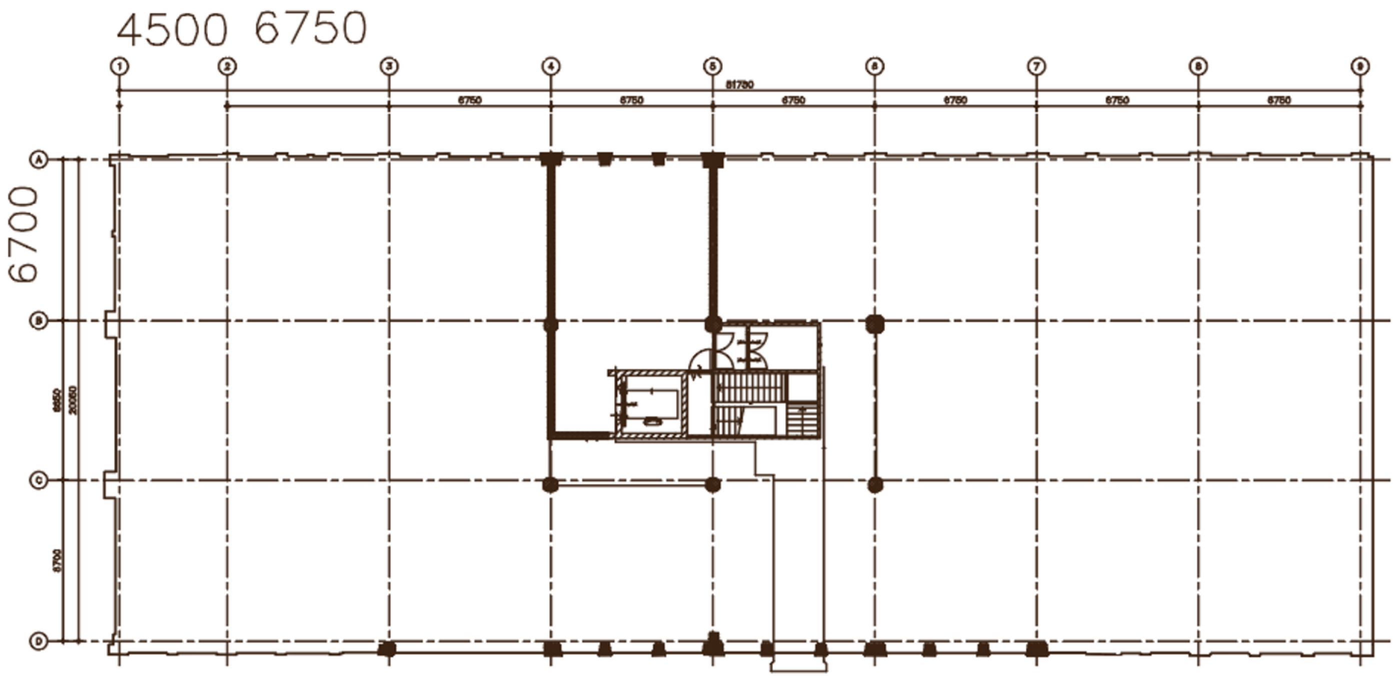

Figure 37 Floorplan (ABT,2002)

4.4.2 *Cultural value*

The dye house is constructed in 1912 as a part of the complex of the 'NV Tricotfabriek G.J. Willink' by the architect Arend Beltman in cooperation with the constructor Marten Jan Brouwer. The dye house is centrally located on a triangular terrain, enclosed by three roads in Winterswijk (see figure 36). The detached dye house is constructed in three phases. This building was designed to ensure flexibility for extensions. The east part of the building exists of three building layers and is realized in 1912. In 1915, the dye house is extended to the west with one building layer. The concrete construction had the strength to ensure an addition of an extra building layer, in 1922. This was also possible because the architect did not use a curved or pitched roof and made use of a flat wooden roof which was dismountable.

Building volume: Over time the company expanded, which resulted in 75 extensions in the whole complex. These extensions create a noticeable historical layering which is considered as important for the cultural values. (Monumenten.nl, n.d.-b)

Structure: The concrete skeleton structure reflects flexible architecture in an early stage of the 20th century that was unique and is one of the reasons why this building has a high cultural value. The dye house is an early, good, and well-documented example of a concrete skeleton structure according to the Hennebique system.

Roof: The flat roof is in line with the concept of a flexible structure. For this reason, the roof contributes to the perceived cultural values.

Skin: The early use of the concrete (skeleton) structure is visible in the façade of the dye house. The façade shows a certain character, it shows the practical support structure (see figure 39) with large glass surfaces. But also, the secondary columns that are included in a rhythmic grid with extra refinements in the form of capitals and mouldings (see figure 42). (Roorda, R., Kegge, B., & Backaert, 2016; Stenvert, 1995)

Closed façades: Concrete columns in the façade indicate the important concrete structure and so the material and form are vital to preserve. The ornaments (highlighted in figure 42) and the concrete parapets are also a feature that gives the building its character.

Open façades: The glass surfaces are significant, especially the cast iron window frames that are still original, these are highlighted green in figure 42.

To conclude, the architecture of this building is of great importance since it is designed by Beltman and it contains a high quality in architecture because of the innovative, flexible construction and Hennibique system. Therefore, the building gained a national monumental status. The exterior façade must be preserved and especially the cast iron frames, the concrete structure and the ornaments that are visible in them. To conclude, for this building the characteristic building parts in the façade that gives this building its identity and cultural values are:

- Concrete columns by the Hennibique system
- Large glass surfaces with grid frame
- Concrete parapets
- Ornaments in exterior facade

Figure 38 Dye house original state (de ArchitektenCie, 2003)

Figure 39 Longitude facade with column structure in green (own image)

Figure 40 West facade with column structure in green (own image)

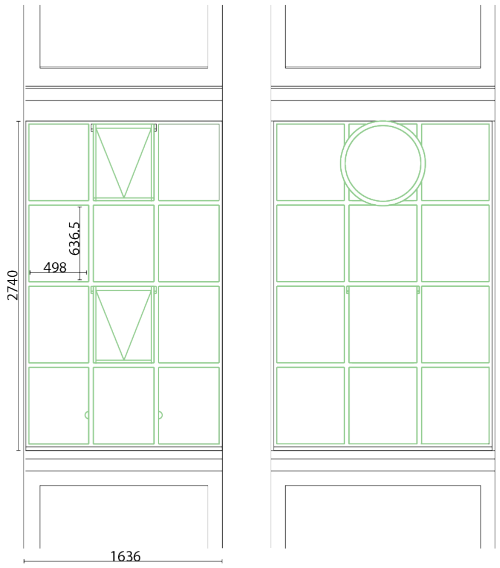

Figure 41 Windows with grid structure in green (own image)

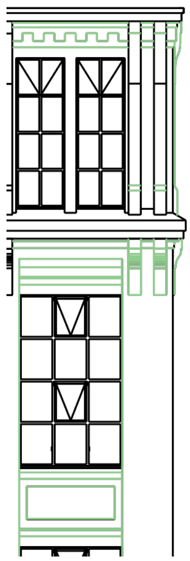

Figure 42 Ornaments in green (own image)

4.4.3 *Sustainability*

The goal of this renovation was to transform the former dye house into apartments. This meant that the heat resistance of the façade had to be improved to increase comfort.

Building volume

Structure: The main structure of the building was in a fair condition and did not need any alterations to improve the overall sustainability.

Roof: The wooden roof is replaced with a new concrete roof supported by a steel construction. An insulation layer of rock wool is applied with an R-value of 2,5 m2K/W. (de ArchitektenCie, 2003)

Skin: Before the renovation, the east façade was torn down, which gave the developers the opportunity to build a completely new façade. The east side of the façade, except for the load-bearing concrete columns, is completely new, leading to a façade that can achieve a higher energy performance than the others. The majority of the east façade comprises of windows enclosing glass that has a u-value of 1,1. (de ArchitektenCie, 2003)

Closed façades: Due to the cultural values that the exterior façades contain, an interior insulation system was applied on the interior façade. The insulation is applied on the parapets below the windows and has a thickness of 50mm. The columns are not insulated, and this can interfere with the comfort in the building. The concrete columns were considered as important and so could not be wrapped in insulation. Another reason for only insulating the parapets is due to the radiators underneath the windows. When the façade near the radiators is insulated less heat will be lost through the façade.

The fact that the windowsills are original, withheld the developers of applying insulation on the window sills. This can result in a thermal bridge (see figure 43).(de ArchitektenCie, 2003)

Open façades: The cast iron frames contain cultural values and for this reason were restored. Keeping uninsulated metal frames means that there is a chance on condensation.

Because most of the glass was gone before the renovation began, new glass panels where installed. The new glass panels must fit in the original frames which meant that the maximum thickness of the glass had to be 10 mm with a U-value of 1.4 or lower. This limited the thermal resistance of the building because to receive a lower u-value glass it needs to be thicker. (de ArchitektenCie, 2003)

4.4.4 *Costs*

The total building costs for this project was €2.800.000. From this project there are no costs calculations available, for this reason the estimated costs per square meter is described according to Vakmedianet BouwCommunities B.V., (n.d.)

Building volume

Structure

Roof:A new concrete roof with steel construction is around 70 €/m2. The application of rock wool is around 14,85 €/m2.

Skin

Closed façades: On the closed façade there is an interior insulation system applied on the concrete parapets with a R value of 2.5 m2K/W. This costs around 92,55 €/m2.

Open façades: The costs for placing glass with a U value of 1.4 W/m2K and a thickness of 10 mm costs around 40 €/m2, the repair of the cast iron frames is more difficult to trace the costs because it is not a standard procedure. But this procedure is close to the original plan of the cruise terminal. This means that the costs are approximately 150 €/m2.

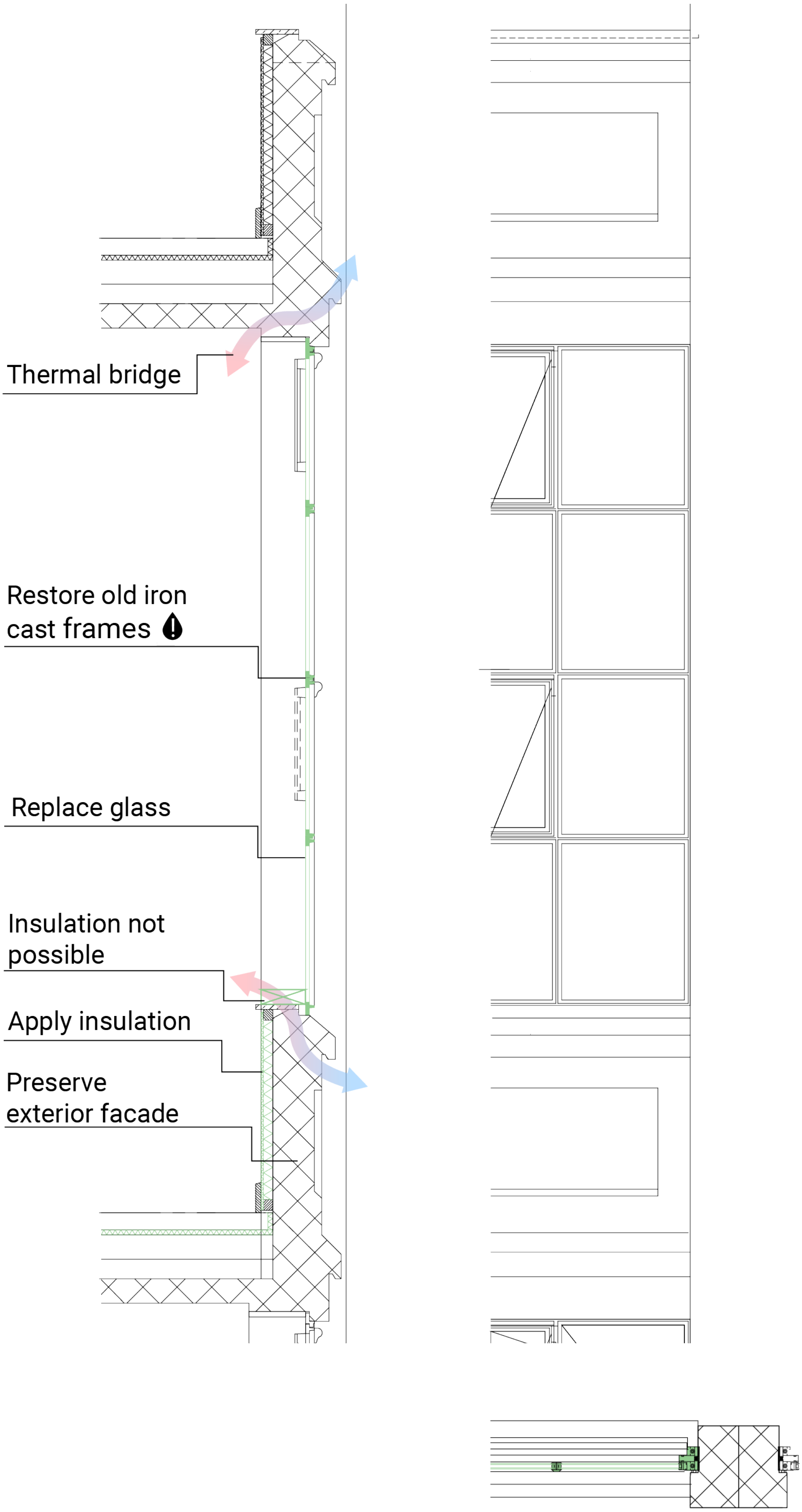

Figure 43 Facade section Tricot (own image)

4.4.5 *Overview*

The tension between cost, cultural value, and sustainability in this case study were:

- Keeping cast iron frames means that the cultural values that those iron cast frames bring, stay intact. The disadvantage of keeping those frames is that the thermal resistance of the façade does not reach its full potential.
- Keeping the original thin frames, means that the glass in the frames also must be thin, which leads to additional investments to reach a proper U-value with thin glass. This shows that the cultural values of the frames had more priority than sustainability and costs.
- The decision to not insulate the columns in the façade to preserve certain cultural values, shows that cultural value has the priority. The columns show the use of the Hennebique technique and when these columns are insulated the cultural values will be diminished.

A lesson learned from this case study is that condition of certain building parts has an influence on the decision making. In this case study, the east façade and the glass were no longer present. This led to the logic decision to replace them completely. Overall the Tricot project was a successful transformation from a vacant old building to an

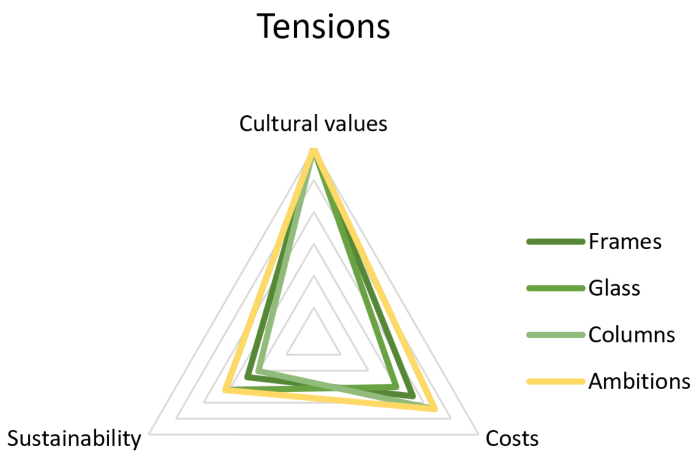

Figure 44 Balance measures Tricot Cultural values and sustainability are on a positive axis and cost on a negative axis, meaning that when the costs are low, the value is further from the center. (own image)

Table 11. Overview measures Tricot (own table)

Building part	**Technical State**	**Measures used**	**Sustainability impact**	**Costs**	**Risks**
Building volume					
Structure					
Roof	Wooden roof.	Replaced	Concrete roof with steel construction. Rock wool 2,5 m2K/W	14,85 €/ m2.	Had to be flat to preserve cultural values.
Skin	East façade: Demolished	Completely new	Glass façade: U-value 1,1 ZTA-value 0,32		Only possible if this façade does not contain cultural values and has a bad condition.
Closed façade	Concrete columns Not insulated	Repaired	Concrete Not insulated		Thermal bridge because of no insulation
	Concrete parapets 170 mm Good condition	Interior Insulation System applied	50 mm thick 2.5 m2K/W	92,55 €/ m2	Not possible to insulate windowsill. Thermal bridges where floor connects facade
	Concrete capitals and moldings Small damage	Repaired	Concrete capitals and moldings repaired and painted		Can't insulate the exterior façade due to the great loss of cultural value
Open façade	Cast iron frames 38 mm thick.	Restored	Cast iron 38 mm thick with 2 layers of coating	150 €/m2	Restricts glass thickness Condensation
	Single glass Poor condition	Replaced	U value 1.4 W/m2K Thickness 10 mm	40 €/m2	Can't be too thick due to the preserved frame.

apartment complex that can contribute to the surroundings with its cultural values. From this case study we can use the following:

- Measures and their impact as described in table 11
- The fact that there is a possibility that a part of the façade is missing or in a poor condition that it should be reconstructed.

4.5 Conclusion empirical research

The empirical research shows that even though the three case studies had similar industrial aesthetics, each renovation had a different approach. The approach of the renovation depended on multiple aspects, such as ambitions and current state of the building.

4.5.1 *Building volume and structure*

All the buildings had a rectangular floorplan with high floor elevations constructed with a reinforced concrete skeleton structure. In all the case studies the concrete skeleton structure was important to preserve because it is a characteristic feature for this typology. Only at the GustoMSC it was necessary to reinforce the structure to secure its strength. This is done in such a way that the construction is still visible.

4.5.2 *Closed facade*

In every case study the concrete structure was exposed in the façades, none of the case studies insulated the exterior façade because it would interfere with the aesthetics of the concrete columns. The number of square meters of interior façade in the building defined the decision to apply insulation. During the renovation of the cruise terminal it was not necessary to apply insulation as the large part contained open façades. The decision to apply insulation also depended on the importance of preservation of the cultural values of the structure. This means that for the decision support model, it is important to implement the number of square meters and the importance of the cultural value, as these aspects influenced the decisions during the case studies.

4.5.3 *Open facade*

All the buildings had a considerable number of open façades, which led to the fact that all the projects focused on changing the glass and frames in the building. Where it was possible to keep the original frames, the original frames were kept, reinsuring the cultural values of the building, even though this led to a less ideal U-value. When the frames were in a bad condition, they decided to replace the frames but restore the original grid structure. All the buildings had a similar grid structure in the windows. The frames in this grid consist of a small thickness, to keep the exterior aesthetics of those windows it was important, when changing the frames, to keep the thickness of the frame, even though this could lead to a less ideal U-value and higher costs.

4.5.4 *Typology analysis*

The typology analysis of the three case studies visible on the next page, shows the similar building characteristics and problems that occur in each project mentioned in the empirical research. This table gives a quick overview of what aspects are important to look at while constructing a decision-support model. The characteristics can be used for the cultural value assessment. The measures are a basis for the list of measures that will be analysed in the model. And the risks that arose will be mentioned in the model to ensure that a well-informed decision can be made with the use of the decision-support model.

Table 12 shows a quick sum up of all the lessons learned together with the tensions between cultural value, sustainability, and costs. Overall it was evident that the tension between, cultural value, sustainability and costs was visible in the renovation of the façades. The tension triangles show that for each project the focused laid on the cultural values and that the combination of measures aids in finding a balance between cultural value, sustainability and costs.

The next chapter, operational research will start with a comparison between the used measures in the case studies and gives some of the alternatives. This list will provide the impact on sustainability, cultural value, and the costs per square meters.

Table 12. Lessons learned empitical research

<table>
<tr><th>Lessons learned</th><th>Tensions</th></tr>
<tr><td>

Gusto MSC

The condition of certain building parts has impact on the decision-making process. In this case study some windows where already in a good condition and therefore where not necessary to replace.

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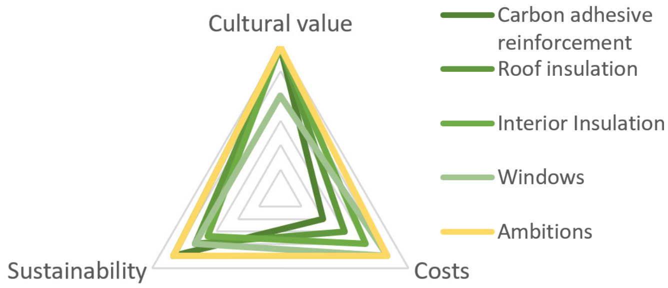

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Cruise terminal

Next to the condition, square meters of each building part have impact on the decision-making process. In this project the number of open facades was more than the closed facades and for this reason, the focus was on the open facades. The decision-support model can implement this by indicating which measure would have more impact depending on the percentage of the square meters where that certain measure can be applied.

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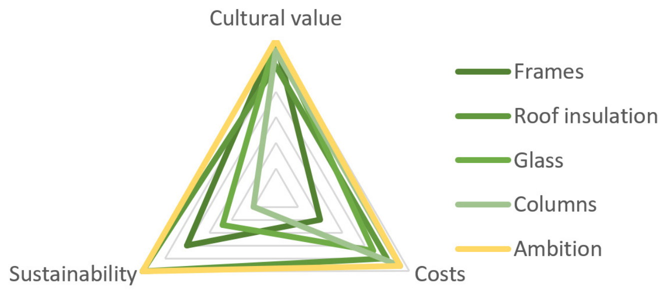

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Tricot

There must be some sort of degree of how important certain cultural values are in building parts according to the person who does the renovation. The possibility that a complete building part could be missing and that it can be built completely new. This means that in the model there could be a part where someone enters the square meters of closed façade, open façade, but also the percentage or amount that is subject to change, be completely new or stay intact. In this project the focus was laid on maintaining the cultural values instead of increasing the sustainability.

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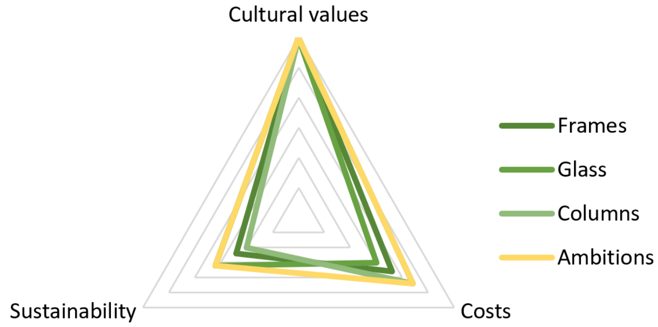

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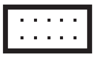
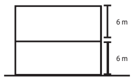
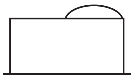
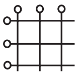
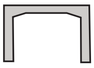
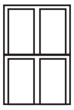
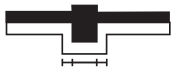
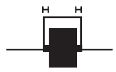
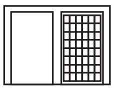
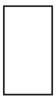
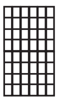
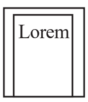
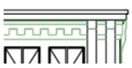
</table>

Typology analyses of the three case studies

Characteristics	Technical	Existing problem	Measures	Risks
Rectangular Floorplan 				
Large floor heights 	Floor heights between 4 and 6.	Large volume to keep warm and control acoustics	Extra installations	Loss in floor height.
Flat or curved roof 	Concrete structure with steel not insulated	Bad insulation	Apply extra insulation Inside or outside	Over heating Thermal bridges Inside: Internal details lost Outside: Thickness of insulation restricted by height of eaves.
Open grid 	Average measurements: 8 m x 8 m			
Skeleton structure 	Reinforced concrete columns	Unknown strength concrete rot	Carbon adhesive reinforcement	Drill centre to know, but is destructive.
Rhytmic column structure visible in facade 	Concrete thickness columns	Bad insulation	Apply extra insulation Inside or outside	When insulation is applied it means that on the outside facade the 'columns' are thicker.  IF column is connected to window ->Thickness insulation depends on thickness frame. 
Skin 	In between columns, either completely closed or large open surfaces.	Bad insulation	Increase R-value or U-value	Measure depends on m2 ratio open and blind facade.
Closed facade 	Concrete or masonry	Bad insulation	Apply extra insulation Inside or outside	Inside: Condensation Trapped moisture Thermal bridges Internal details lost Outside: Trapped moisture Thermal bridges External details lost
Open facade 	Windows with thin metal frames and grid structure Ratio of 5:6	Bad insulation Condensation	Change glazing Change frame Secondary glazing	Better insulating glass leads to more thickness and that means that the frames must be changed. This interferes with the grid and the ratio between glass and frame Or thinner glass to fit in thin frames, but that interferes with U-value
Ornaments  	Company name painted on facade or sign. Moldings	If painted: Can't interfere with exterior facade. If Sign: removeable		Insulation must be done on the inside. Which means that there is a loss in space.

5. Operational research

5.1 Introduction

The operational research of this thesis consists of creating a decision-support model that will improve the balance between cultural value, sustainability, and costs during industrial heritage renovation. The input for this model comes from the literature study and the empirical study. The literature study gave more precise definitions of cultural value, sustainability and costs and some criteria arose during this research. From the empirical research different measures and their restrictions and risks.

In chapter 5.2 the basis models of the decision-support model will be elaborated. Next the criteria for these models will be explained in 5.2.1. The measures that will be tested are visible in 5.2.2. These measures will be explained more thoroughly, and some alternative measures will be given. This will lead to a list with all the measures and their impact on costs, sustainability and cultural values. This list will be input for the model. This input must be supported with all the restrictions and risk that arise while using certain measures.

In chapter 5.3 the model will be explained and how it works. Starting with properties input. The project properties is the input that the assessor of the model needs to fill in in order for the model to work, for example, amount of square meter of closed and open façade, requirements for U-value and R-value, preservation importance of certain building parts, etcetera. Chapter 5.4 shows the validation of the model. The model will be tested by inserting a case study and see if it will produce useful results.

5.2 Decision-support model

To start the operational research, it is important to decide what the basis is of the model. There are different kind of models that can be used in a decision-support model. In chapter 3.2 it became clear that it was important to find a model that tests different kind of options (measures) against different kind of criteria (costs, sustainability, and cultural values). The trade of matrix (Technology Evaluation Center, 2019) is one of the models that incorporates that. This matrix is also visible in the literature study. Beers (2004) and Schrieken (2000) created a version of the trade of matrix. Also, the company ABT developed some decision tools that were based on a trade of matrix. Because ABT already has experience in working with such a matrix, it would benefit this research.

The trade of matrix makes use of the COWS method (Technology Evaluation Center, 2019). This method consists of 4 aspects, Criteria, Options, Weights and Scores. For this research, the criteria are categorized in the three aspects of the iron triangle, costs, cultural value, and sustainability. Options are the different kind of measure that can be used during an industrial heritage renovation. These are categorized in the building parts that are extracted from the empirical research. Because this research can be broad, the focus of the research is only laid on several aspects for now. Later when the model works, it will be possible to add more categories to make the model larger and more precise. The same counts for the criteria. But for now, the categories are closed façades, which is split in interior insulation and exterior insulation, and open façades, which is split into glass and frames.

In the trade of matrix, weight is also implemented. Weight crucial for a decision-support model like this because the importance of the criteria can differ. There is a possibility that the assessor does care more about the costs than about the sustainability and the cultural value. For moments like this the weights are introduced. Eventually the rating is multiplied with the weight and leads to a score. This gives a score of each criterion; all these scores are summed up to a total score that shows the height of the score compared to other measures within the category in colour. To explain this part of the model more in detail the criteria and options are further explained.

Now that all the measures have a certain score and are compared within the categories (interior insulation, exterior insulation, frames, and glass). The categories can be compared between each other. This part will be visible with a tree diagram (see figure 45 & chapter 5.2.5). This part will incorporate the number of square meters and will show which building part has the most potential for renovation.

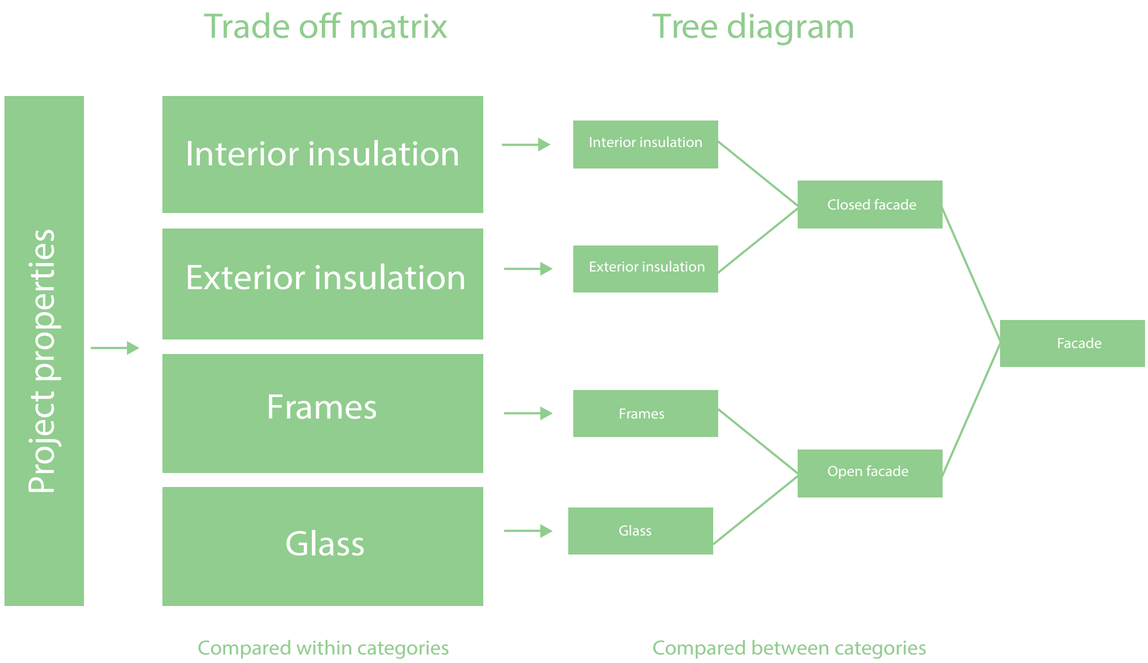


Figure 45 Concept decision-support model (own image)

5.2.1 *Criteria*

The criteria exist of three categories costs, cultural value and sustainability. Each criterion receives a certain rating. The rating of each category depends on multiple criteria.

Sustainability

Sustainability is a broad concept, this means that for this subject many criteria can be thought of next to thermal resistance (chapter 3.3). This research narrows it down to only heat resistance to make sure the model will function on time. Later more criteria can be added to the model. As described in chapter 3.3, sustainability in this research depends on the thermal resistance of the measure, R-value (insulation) or U Value (glass and frame).

For now, the rating depends on the thermal resistance. To make sure the trade-off model works it is vital to make sure that each rating has the same scale. For this model, the scale is between 1-5. To make sure the thermal resistance fits in such a scale calculation where made shown in table 13.

For U value, the lower the number, the better the thermal resistance. For R-value, the lower the number the worse the thermal resistance. For this reason, two different tables are shown.

The intention of this model is to make it flexible, the model can be amplified, and more measures can be added. For this reason, there is no fixed maximum of minimum R-value. The maximum and minimum depend on the measures that are inserted into the Excel file.

Eventually, you get a list of values where the sustainability can be compared with and that will lead to the rating of the sustainability.

The weight of the sustainability can be entered in the project properties (see excel and chapter 5.2.3) by the person who does the assessment.

The goal of the project is also very important. For this reason, an extra feature will be implemented in the model. In the project properties the question will be asked whether only the measure that meet the sustainability goals should be visible in the result (see chapter 5.3.1). When this is the case, the result of the measures that do not meet the sustainability goals will not be visible in the decision-support model.

Cultural value

For cultural value, the rating is more sensitive. As concluded in the literature review (chapter 3.2), cultural values lay in the materials of the building parts that together form the architectural-historical and building-historical meaning of the building. This means that the impact of a certain measure depends on the aesthetic of the materials that deviates from the original. This impact is expressed in a scale from 1 to 5, wherein 5 means that it interferes a lot with the original aesthetics and 1 means that it preserves the original materials.

Table 13. Scale calculations U and R-value (own table)

Scale	U value	e.g
1	Max	7,0 – 5,8
2	Max-1*((Max-Min)/4)	5,9 – 4,6
3	Max-2*((Max-Min)/4)	4,7 – 3,5
4	Max-3*((Max-Min)/4)	3,6- 2,3
5	Min	2,4

Scale	R-value	e.g
1	Min	1,4
2	Min-1*((Min-Max)/4)	2,0
3	Min-2*((Min-Max)/4)	2,6
4	Min-3*((Min-Max)/4)	3,2
5	Max	3,8

Costs

Costs is defined as the direct building costs per square meter of the applied measure (chapter 3.4). This is also fitted into a scale of 1-5. The calculations are the same as the U value because the higher the costs the worse the score needs to be. The calculations are shown in the table below.
Costs are also an aspect that can be amplified. In this model, it is possible to add extra costs or revenues that a certain measure brings with, such as indirect costs and maintenance costs. As discussed in chapter 3.4, the costs now only include the direct building costs price.

In the excel the standardized direct buildings costs are visible, these costs are extracted from bouwkostenonline.nl and are verified by a cost expert of ABT. Bouwkostenonline.nl gives an indication of the costs of all the common measures that are used in a built. In these costs calculations the labour costs are included. This means that the costs per square meter includes delivery and placement. For the different types of glass, it is a little different due to the fact that the glass is already placed in the factory itself. This means that the glass prices are just the delivery costs (see table 14 in chapter 5.2.2). It is important to note that the costs given in the model are just an indication and can not be used to make an exact cost estimate.
Regarding the budget, the same feature is implemented as done with the sustainability goal (see 5.2.1 Sustainability). When the cost of a measure, multiplied with the amount of square meter that it should be applied on is over budget, it will not be shown in the decision-support model.

Table 14. Scale calculation costs (own table)

Scale	Costs	e.g
1	Max	300
2	Max-1*((Max-Min)/4)	243
3	Max-2*((Max-Min)/4)	186
4	Max-3*((Max-Min)/4)	129
5	Min	72

5.2.2 *Options*

For this model, the options are the different measures that can be used during an industrial heritage renovation project. For these measures, the used measures extracted from the empirical research is implemented in the model and its alternatives. The measures are categorized in insulation (interior and exterior facade) frames and glass. For every category, the used materials and the alternatives are given. In the Excel you will find a list with all the materials and their impact on costs, sustainability and cultural value.

Insulation

Regarding insulation there are two options that can be used. The type of insulation, such as PIR and Cork or the application of the insulation system with different R values (see Table 15). For this research, the latter is chosen, this is due to the fact that the types of insulation give a range of other questions and difficulties, e.g. some insulation cannot be applied on the exterior façade or need a large amount of thickness to be effective.

The measures (table 15) are divided into exterior, interior, wall and cavity wall. This means that it depends whether a project has cavity walls, which measure should be used. These dependencies will be listed in the project properties (see 5.3 Project properties). Now when a project has no cavity wall, no outcome will be shown in the result for the cavity wall measures. The same is for when a project only cavity walls has, no results will be shown for the wall measures.

Cultural value

The impact on cultural value (CV) for insulation is quite easy to substantiate. The measures, 'keep existing wall' and 'apply cavity wall insulation' don't interfere with the exterior or interior look. So, these will have a positive impact of 1 (scale 1-5). The interior insulation systems will have an impact of 4 on the interior look and the exterior insulation systems an impact of 4 on the exterior look. This is because when these measures have used the look on the original façade will completely disappear, but the original material is still preserved and can be brought back. Compared to the measure 'demolish the outer sheet, apply the insulation and remodel' here the original material will be demolished and will have a more negative impact on the cultural value since the original look cannot be 'brought back'. For this reason, this measure gets an impact 5.

Sustainability
The sustainability is either the existing R-value or 1,3 2,5 and 3,5 m2K/W. This gives a certain diversity in options.

Costs
For the measures in table 15, the costs are extracted from feasibility studies from former projects of ABT and verified by the cost expert Wouter Blondeel from ABT. The costs of insulation system depend on whether it is applied to the exterior or interior. This is since for the exterior, scaffoldings are needed.

Risks
To make sure that the decision is well-considered, it is important to inform the assessor of the risks that certain measures have. Below common risks are given that can be implemented in the decision-support model.

The common risks of cavity wall insulation are (May, 2012):
- Thermal bridges
- Surface condensation
- Liquid moisture penetration

The common risks of interior insulation systems (Changeworks, 2012):
- Surface condensation
- Trapped moisture
- Thermal bridges
- Liquid moisture penetration
- Overheating

The common risks of exterior insulation systems (Changeworks, 2012; Hopper, Littlewood, & Geens, 2012):
- Trapped moisture
- Thermal bridges
- Liquid moisture penetration
- Overheating
- You need a planning consent of the Architectural quality commission.

Table 15. Insulation measures (own table)

			Measures	Sustainability		Costs		CV
Closed façade	Interior	Wall	Keep existing wall	-	m2K/W		m2	1
			Apply Interior insulation system	1,30	m2K/W	€ 94,00	m2	4
			Apply Interior insulation system	2,50	m2K/W	€ 99,00	m2	4
		Cavity wall	Keep existing wall	-	m2K/W		m2	1
			Apply Interior insulation system	1,30	m2K/W	€ 88,00	m2	4
			Apply Interior insulation system	2,50	m2K/W	€ 93,00	m2	4
			Apply cavity wall insulation	1,30	m2K/W	€ 44,00	m2	1
			..					
Closed façade	Exterior	Wall	Apply exterior insulation system	1,30	m2K/W	€ 125,00	m2	4
			Apply exterior insulation system	2,50	m2K/W	€ 130,00	m2	4
			Apply exterior insulation system	3,50	m2K/W	€ 140,00	m2	4
		Cavity wall	Apply exterior insulation system	1,3	m2K/W	€ 50,00	m2	4
			Apply exterior insulation system	2,50	m2K/W	€ 55,00	m2	4
			Apply exterior insulation system	3,50	m2K/W	€ 60,00	m2	4
			demolish the outer sheet, apply the insulation and remodel	2,50	m2K/W	€ 172,00	m2	5
			demolish the outer sheet, apply the insulation and remodel	3,50	m2K/W	€ 182,00	m2	5
			..					

Frames

In table 16 shows the different types of frames that can be used during a renovation project.

Cultural value

From the case studies is learned that the type of building mostly has uninsulated metal frames. The Gusto MSC only had aluminium frames due to an earlier renovation. The Cruise terminal used new uninsulated renovation metal frames. And the Tricot preserved their uninsulated metal frames. From this we can extract that the uninsulated metal frame would have the best positive impact on the cultural value and gets an impact of 1. The insulated metal frames have the 'original material' look but these are thicker then uninsulated frames, for this reason it has an impact of 3. The aluminium and plastic are considered as the ones with the least positive impact, these frames are considered quite 'new' and so have an impact of 5.

Sustainability

The sustainability of the frames differs from 7 W/m2K and 2.4 W/m2K, see table 16.

Costs

The costs are extracted from Bouwkosten.nl and verified by the cost expert Wouter Blondeel form ABT. The costs of the frames include the labour costs, placement costs and material costs. The costs on bouwkosten.nl for the frames is inclusive of the glass. Because this research sees frames and glass as two different entities, the costs of the glass in extracted from the total costs.

Table 16. Scale calculation costs (own table)

	Measure	Sustainability		Costs	
GustoMSC	Metal uninsulated	7	W/m2K	€ 705,00	m2
Cruise terminal	Metal insulated	3,8	W/m2K	€ 905,00	m2
Tricot	Aluminium	3,8	W/m2K	€ 320,00	m2
Alternative	Wood	2,4	W/m2K	€ 360,00	m2
	Plastic	2,4	W/m2K	€ 231,00	m2

Risks

The common risks for replacing the frames: (Changeworks, 2012; Hopper et al., 2012):

- Glass must be replaced.
- Sufficient ventilation
- Overheating
- You need a planning consent of the Architectural quality commission.

Glass

The types of glass that were used and some alternatives are shown in table 17.

Cultural value

Single glass was a common glass type that was used for the original designs of the case studies. In that time period single glass is typically used. Single glass has certain aesthetics, such as reflection colour thickness and clearness. For this reason, single glass gets a positive impact of 1 on cultural value. The measures monumental glass and single glass with coating also get a high positive impact (2). This is due to the fact that these measures come close to the aesthetics of single glass, monumental glass is double glass that is very thin and single glass only has a coating for a lower u value but has the same thickness and reflection as single glass. The other glass types get a higher impact as they have a larger thickness and different reflection. The double glass, HR and HR+. have impact 4. As where triple glass and HR++ have impact 5.

Sustainability

The U value depends on the company that makes the glass and frames. But for this research, the minimum is brought in consideration, except for HR++ glass because this has a large range in u values. For this measure the minimum middle and maximum are selected from the tables of Siemens, (2005).

Costs

The cost for the glass is derived from bouwkosten.nl, JML and verified by the cost expert Wouter Blondeel from ABT. For the costs of glass 'normal' measurements (1,2 m by 1,80m) for the glass is taken in consideration. This is due to the fact that

when the glass measurements are larger than these measurements, the costs increase exponentially. This is because the production of glass is limited, and when the measurements increase, the difficulty of production increases to.
The costs of the glass are just the material costs. This is due to the fact that the placement is most of the time already done in the factory.

The common risks for replacing the glass:
- The weight of the new glass can be too heavy for the original frame. This will lead to sagging and rusting of the frames (see chapter 4.4.1)
- The thickness of the glass and frame. New glass can only be replaced if the frame is thick enough.

In table 17 you see several types of glass with their u value.

5.2.3 *Weight*

The third aspect of the trade of matrix is weight. In this research weight stands for importance. The assessor can give to each aspect, cultural value, sustainability and costs, an overall importance, this reflects the ambition of the project. When importance is interpreted in a model like this the person who does the assessment can steer the outcome more to the ambitions of the project. For now, the importance of the sustainability and the costs can be inserted in the project properties with a scale from 1-5.

For cultural value it is a little bit different and more complex. The importance for cultural value is subdivided in the building parts used for this research, interior finishes, exterior finishes, frame and glass (see chapter 3.2). The importance of each building part will be measured with a series of questions. These questions are extracted from the guidelines of (Nusselder et al., 2008)(see table 2, chapter 3.2.3). The guidelines given are transformed to yes and no questions (chapter 5.3.1). The importance for the cultural value of that specific building parts will be expressed in the amount of questions answered with 'Yes'.

Table 17. Measures: glass (own table)

	Measures	Sustainability		Costs		CV
	Single glass	5,8	W/m2K	45,00	€/m2	1
	Double glass	2,8	W/m2K	65,00	€/m2	3
	Triple glass	1,2	W/m2K	125,00	€/m2	4
	HR glass	2	W/m2K	35,00	€/m2	3
Tricot	HR + glass	1,6	W/m2K	45,00	€/m2	4
GustoMSC	HR ++ glass min	1,1	W/m2K	55,00	€/m2	5
	HR ++ glass mid	0,9	W/m2K	65,00	€/m2	5
	HR ++ glass max	0,5	W/m2K	75,00	€/m2	5
	Single with coating	3,8	W/m2K	100,00	€/m2	2
Cruise terminal	Monuglass	2	W/m2K	150,00	€/m2	2

The guidelines used for this are:

- Importance of the building due to ornamentation
- Importance of the building due to the interior & exterior finish
- Importance of the building for the history of the building technology
- Importance of the building due to the readability of the building history
- Importance of the building due to the use of materials
- Execution quality (rare/common)
- Amount of historical remaining
- Technical state
- Measurements and grids

5.2.4 *Score*

The last stage of the trade of matrix is score. This stage combines the discussed criteria, options and weight. Each measure (option) is given a rate for the criteria sustainability, cultural value and costs, this rate is multiplied with the weight, which in this research is called importance. This leads to a score for each criterion. The total impact of a certain measure is equal to the total sum of the three scores (see figure 46). It is important to note that cultural value is added as a negative aspect. This is done because when a measure has a lot of impact on the cultural values and the building part has a high importance, the measure should receive a lower rating. For this reason, the score of the cultural value will be extracted from the total score. In the model the scores will be visible with a colour. The colours range from red to green. Where in green is positive and red is negative. This will support a quick visibility of which measures are better to use then others.

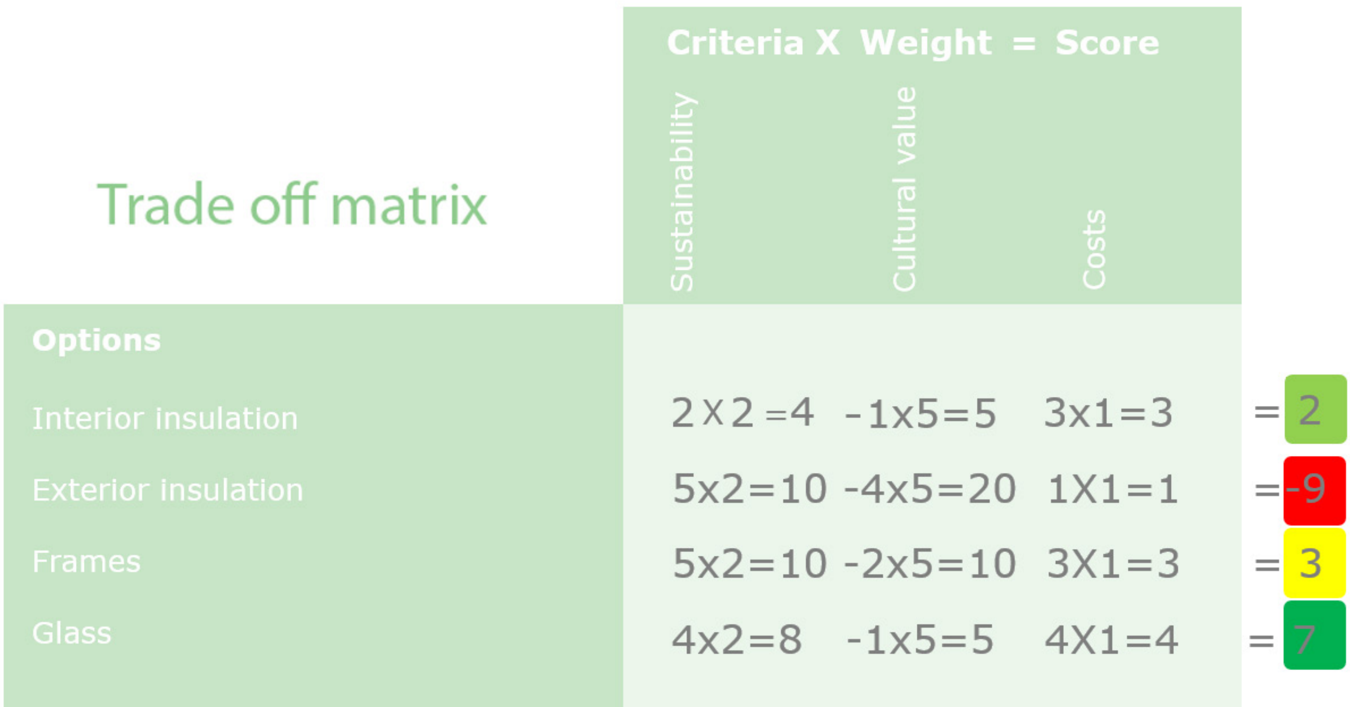


Figure 46 Concept of trade of matrix (own image)

5.2.5 *Tree diagram*

The second part of the decision-support model is the tree diagram. Whereas the trade of matrix compared the types of measures within their category (exterior insulation, interior insulation, frames and glass) the three diagram compares the categories to each other with the use of the amount square meter that they have in the building. This will give the assessor an idea on what building part has the best potential to renovate.

This part will incorporate the square meters of the building parts. The case studies show that the number of square meters is important in the decision making during a renovation project (see chapter 4.6). For example, when changing the glass and applying insulation has the same overall impact per square meters but there is more glass than closed façade (such as cruise terminal, chapter 4.4.4) it is better to focus on changing the glass because you would achieve more by doing so, but it also is more expensive than applying the insulation. Next to the amount of square meter, the condition of a building part also has an impact on the decision making (see chapter 4.4.4 & 4.5.4). When a building part has a poor condition, it is better to focus on that part instead of the building part that already is in a good condition. The tree diagram will show which building part would have the best potential to renovate by multiplying the average of the score of all the measures with the percentage of square meters of that particular building part and the condition in percentage (see figure 47).

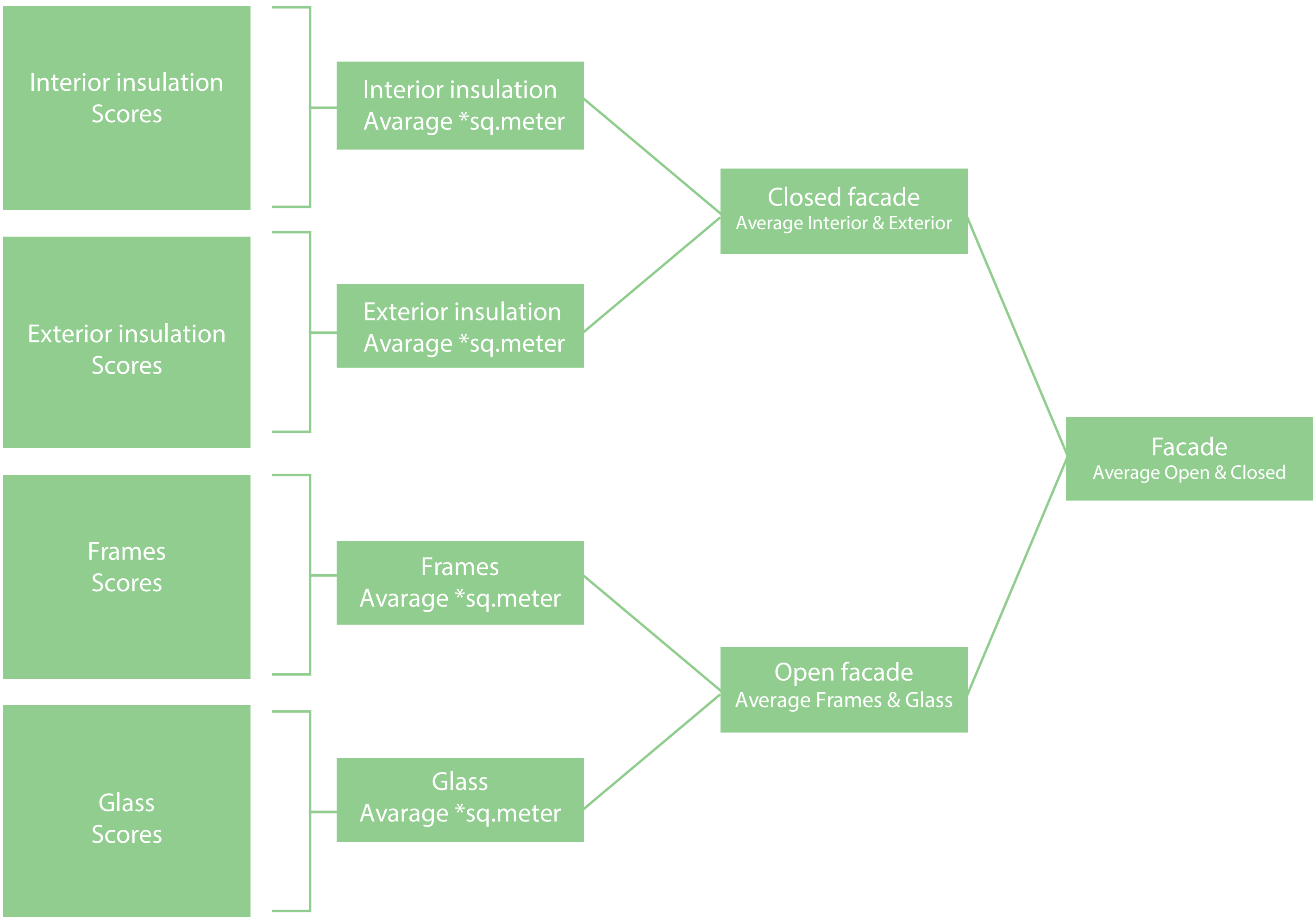


Figure 47 Concept of tree diagram (own image)

5.3 Excel model step by step

In this chapter explains how the excel model works step by step.

5.3.1 *Project properties*

Now that the main idea of the decision-support model is constructed. The next step is to construct the first sheet in the excel, the project properties. This sheet will be filled in by the assessor. This page must be easy to use and must contain instructions on how to use the excel model.

The data that must be filled in is subdivided in technical, sustainability, cultural value and costs. First is technical (see figure 48). Here the assessor must fill in the number of square meters and the condition of it to make sure that the tree diagram (chapter 5.2.5) will work correctly. Also, here is the question stated whether the façades have cavity walls. This is a yes or no question. This is implemented to make sure that only the measures applicable on a (non)cavity wall will appear in the model (see chapter 5.2.2 insulation)

Technical		
Closed façade		m2
Good condition		%
Open façade		m2
Good condition		%
Does the closed façade exist of a cavity wall?	Yes/No	

Figure 48 Technical input

For sustainability, the existing situation is requested, these values are needed to establish the change in sustainability and to assess the option to not change

Sustainability existing		
R value façade		m².K/W
U value Frames		W/m².K
U value Glass		W/m².K
Sustainability Goals		
R Value Closed façade		m².K/W
U value Frames		W/m².K
U value Glass		W/m².K
Show only measures that meet sustainability goal?	Yes/No	
Sustainability Importance 1-5		

Figure 49 Sustainability input

that particular building part. The sustainability goals are requested to ensure the option to only show the measures that meet the sustainability goal (chapter 5.2.1 sustainability). The final requested input (figure 49) is the sustainability importance as discusses in chapter 5.2.3.

The cultural value part is explained in chapter 5.2.3. The yes and no questions that will indicate the cultural value importance are visible in the first sheet of the excel file, see figure 50.

Cultural value	
Is the material of the exterior finishes still original?	Yes
Is the technical state of the material still good?	Yes
Is the building important due to the exterior finish?	Yes
Is the construction technology or ornamentation visible in the exterior façade?	Yes
Is the readability of the building history visible in the exterior finish?	Yes
Exterior finishes	5
Is the material of the interior finishes still original?	No
Is the technical state of the material still good?	No
Is the building important due to the interior finish?	No
Is the construction technology visible in the interior façade?	Yes
Is the readability of the building history visible in the interior finish?	Yes
Interior finishes	2
Is the material of the frames still original?	Yes
Is the technical state of the material still good?	No
Is the building important due to the frames?	Yes
Are the measurements and grid in the frames original?	Yes
Is the execution quality of the frame rare?	No
Frames	3
Is the glass still original?	Yes
Is the technical state of the glass still good?	No
Is the building important due to the glass?	No
Are the measurements of the glass original?	Yes
Is the execution quality of the glass rare?	No
Glass	2

Figure 50 Cultural value input

The last part is costs. Her only the costs importance (chapter 5.2.3) will be asked and the budget (see figure 51). The budget is requested to ensure the option to only show the measures that are possible in the budget. This is indicated with the direct building costs price of the measure multiplied with the square meters.

Costs	
Budget	
Show only measures that meet budget?	Yes/No
Overall importance 1-5	

Figure 51 Costs input

To make sure that the sheet is easy to fill in, some extras have been inserted in the excel sheets. First, it is important to make sure that the assessor fills in the right values. For this reason, a feature is implemented in the adjacent cell that when the filled in value exceeds the maximum number, it will turn red. This will indicate that the form is not filled in correctly. See figure 52.

Technical			
Closed façade	2400	m2	
Good condition	145	%	
Open façade	1600	m2	
Good condition	25	%	
Does the closed façade exist of a cavity wall?	Yes		

Figure 52

Secondly, some instructions of the model are given in the first sheet, see figure 535 This will enhance the usability of the Excel model.

Technical		
Closed façade	2400	m2
Good condition	90	%
Open façade	1600	m2
Good condition	25	%
Does the closed façade exist of a cavity wall?	Yes	
Sustainability existing		
R value façade	0,8	m
U value Frames	7	W

A cavity wall is a type of wall that has a hollow center. They can be described as consisting of two "skins" separated by a hollow space.

Figure 53 Comment in cell

As is explained in the instruction in figure 55. The risk of certain measures will be explained with the use of a comment added to a cell. When somebody goes over a cell with the cursor, a comment will appear (see figure 54). In this way, more information can be provided to the user.

Instructions

In this sheet the properties of the building must be inserted. First fill in the right values in the orange cells. If there is a value entered that is not possible, a red warning square will appear.
For the questions please select an option in the drop-down menu.
The red squares in the corner of the cells indicate a comment. This comment will clarify the question.

In the sheet 'result' the result is visible of you project. Underneath 'Overall score' the colors indicate the best options for your specific project. The colors range from green (positive) to red (negative). The tree diagram indicate which building parts are better to focus on. When the path is green, this indicates that when these building parts are altered they have a more positive impact then the other building parts.

When the best measure are clear, please note the red squares in the corner of the cells where the measure is described. These cells have notes that will explain some of the risks that must considered during the renovation. Please advise these notes before considering applying a measure on your project.

The sheet measures show the different applicable measures. This is background information for the decision support model, you do not have to change anything here.

If there are any questions please contact:
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Figure 55 Instructions Excel model

Closed façade	Exterior façade	Wall	Apply exterior insulation system low
			Apply exterior insulation system mid
			Apply exterior insulation system high
		Wall	Apply exterior insulation system low
			Apply exterior insulation system mid
			Apply exterior insulation system high

Common risks:
- Trapped moisture
- Thermal bridges
- Liquid moisture penetration
- Overheating
- You need a planning consent of the Architectural quality commission.

Figure 54 Risks explained in Excel model

5.3.2 *Result*

Appendix F and figure 56 show the decision-support model sheet. This excel sheet shows the result of the model. Next to each measure the score is visible for each criteria. The overall score shows the summed score and colour indication. As described earlier (chapter 5.2.4) the colours range from green to red. Whereas green is positive and red is negative. This will give a quick overview of the result to the assessor. The assessor also can trace back why certain measures received a good or bad score. Also, in this part the risks that each measure has are implemented in a comment inserted in a cell (see figure 53 and 54). Next to the trade-off matrix the tree diagram is visible. This tree diagram indicates which building part has the most potential to renovate (see chapter 5.2.5). This is visible with the colours red and green wherein green indicates high potential and red low.

5.3.3 *Measures*

Appendix G shows the measures sheet. This excel sheet contains all the measures that are tested in this model. In this list measure can be assed or changed. For the person who does the assessment this sheet is not important and will show no results. When a person wants to know more about a particular measure they are able to do so in this sheet. In this sheet, more criteria can be added when further research is done. By adding more criteria to this sheet, the model can be more specific.

Decision support model

Building part			Measures	Sustainability	Weight	Score	Cultural value	Weight	Score	Costs	Weight	Score	Overal score
Closed façade	Interior Façade	Wall	Keep existing wall	1	3	3	1	2	2	5	3	15	
			Apply Interior insulation system low	2	3	6	4	2	8	2	3	6	
			Apply Interior insulation system high	3	3	9	4	2	8	2	3	6	
		Cavity wall	Keep existing wall	1	3	3	1	2	2	5	3	15	
			Apply Interior insulation system low	2	3	6	4	2	8	3	3	9	7
			Apply Interior insulation system high	3	3	9	4	2	8	2	3	6	7
			Apply cavity wall insulation	2	3	6	1	2	2	4	3	12	16
Closed façade	Exterior façade	Wall	Apply exterior insulation system low	2	3	6	4	5	20	2	3	6	
			Apply exterior insulation system mid	3	3	9	4	5	20	2	3	6	
			Apply exterior insulation system high	5	3	15	4	5	20	1	3	3	
		Cavity wall	Apply exterior insulation system low	2	3	6	4	5	20	3	3	9	-5
			Apply exterior insulation system mid	3	3	9	4	5	20	3	3	9	-2
			Apply exterior insulation system high	5	3	15	4	5	20	3	3	9	4
			demolish the outer sheet, apply the insulation and remodel low	3	3	9	5	5	25	1	3	3	-13
			demolish the outer sheet, apply the insulation and remodel high	5	3	15	5	5	25	1	3	3	-7
			..										
Open façade	Frame		Metal uninsulated	1	3	3	1	3	3	2	3	6	
			Metal insulated	3	3	9	3	3	9	1	3	3	3
			Aluminium	3	3	9	5	3	15	4	3	12	6
			Wood	5	3	15	4	3	12	4	3	12	15
			Plastic	5	3	15	5	3	15	5	3	15	15
			...										
	Glass		Single glass	1	3	3	1	2	2	4	3	12	
			Double glazing	3	3	9	3	2	6	3	3	9	
			Triple glazing	4	3	12	4	2	8	1	3	3	7
			HR glass	3	3	9	3	2	6	5	3	15	
			HR + glass	4	3	12	4	2	8	4	3	12	16
			HR ++ glass min	4	3	12	5	2	10	4	3	12	14
			HR ++ glass mid	4	3	12	5	2	10	3	3	9	11
			HR ++ glass max	5	3	15	5	2	10	3	3	9	14
			Single w/ coating (Ruysdael)	2	3	6	2	2	4	2	3	6	
			Monuglass	3	3	9	2	2	4	1	3	3	
			...										

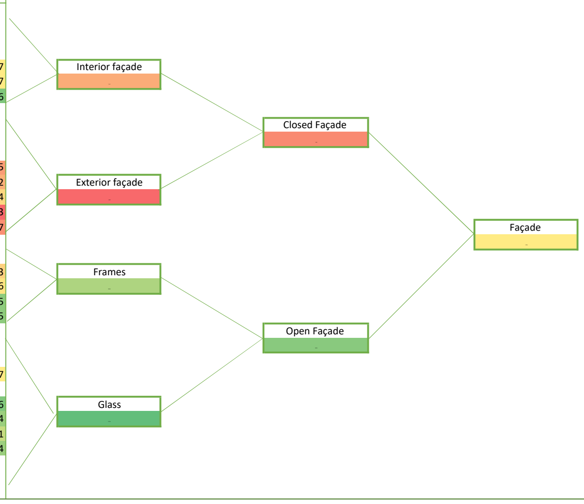

Figure 56 Result Decision-support model Excel

5.4 Validation

The excel model will be tested with the use of a case study. This case study is not yet analysed during the process of this thesis. This will give a good opportunity to see if the model can be applicable to other projects. The structure of this validation will follow the structure of the excel model

5.4.1 *Ringers complex*

The project is called Ringers complex and is initiated by the owner Rabo Real Estate together with Stichting BOEi, the municipality of Alkmaar, and chocolate producer Dobla. The ringers complex is an old chocolate factory situated in Alkmaar that is constructed in 1920.(Stichting Boei, n.d.; Veghel, 2018) For this project there is not yet a final execution plan and has not been renovated, for this reason the precise ambition of the project is not known. ABT conducted an analysis on this building and so can provide the information that is needed for this model. This project is selected due to the fact that the era and aesthetics of the building are similar to the projects that are analysed in chapter 4.

Figure 57 Ringers complex (Veghel, 2018)

Technical

The building consists of 5 floors wherein the closed façade has a total of 2400 square meters, the open façades has around 1600 square meters, which brings at total of 4000 square meter façade. All the façades are constructed from uninsulated massive masonry walls. The masonry is in between concrete columns. During the visual inspection was stated that there was indeed a cavity wall. It was unclear whether all the façades had a cavity wall. The condition of the building is not strongly degraded since it has been in use for a long time. The open façades are quite large and consist of steel frames with single glass. The condition of the glass is moderate to poor (Veghel, 2018)

Technical		
Closed façade	2400	m2
Good condition	90	%
Open façade	1600	m2
Good condition	25	%
Does the closed façade exist of a cavity wall?	Yes	

Figure 58 Technical input Ringers

Sustainability

The R-value of the massive masonry is 0,3 m2K/W together with the cavity wall of 0,5 m2K/W it has a total of 0,8 m2K/W. The glass has a U value of 5,6 W/m2K. The U value of the frames is 7 W/m2K. There are also better insulated windows with secondary glazing with a U value 3,5 W/m2K. But for this analysis these are not brought in consideration because they cannot be separately inserted in the model. (Veghel, 2018) The sustainability goals of the renovation are in line with the Dutch building code. According to the Dutch building code there is no need to insulate the façade with a renovation if the façade is not altered during. If the façade is going to be altered, then a minimum R value of 1,3 m2K/W is needed. When the open façade is replaced it needs to have a maximum U value of 3,8 W/m2K for the frame and 1,8 W/m2K for the glass. The developer of the building did not yet set any goals for the sustainability at this point. For now, only the goals of the Dutch building code is used. As the building should comply with the Dutch Building code, only the measures that meet the requirements are shown in the result. (Veghel, 2018)

Sustainability existing		
R value façade	0,8	m².K/W
U value Frames	7	W/m².K
U value Glass	5,6	W/m².K
Sustainability Goals		
R Value Closed façade	1,3	m².K/W
U value Frames	3,8	W/m².K
U value Glass	1,8	W/m².K
Show only measures that meet sustainability goal?	Yes	
Sustainability Importance 1-5	3	

Figure 59 Sustainability input Ringers

Cultural value

In 2016 the building got a monumental status. The architectural quality and monumental commission of Alkmaar analysed the building and stated some of the important aspects of the building that contribute to the cultural values of this building. (Gemeente Alkmaar, 2016; Stichting Boei, n.d.; Werf, 2016)

One of these aspects is the original façade of the building, this contained characteristic masonry and decorative tiling, the aesthetics of these materials are considered as important. In a previous renovation in 1982 the building was wrapped with plastic panels, to give it a more modern look. Because the aesthetic of the exterior finish was so important, the plastic panels were removed in 2016 to make sure the original material was visible again. Next to removing the plastic panels, With the help of crowdfunding, BOEi successfully restored the letters on the façade, as this ornamentation was considered as important. (Stichting Boei, n.d.)

Another aspect is the visible historical layering. The building is with a clear vision constructed in different phases. Each part of the building has a different construction that they value. (Gemeente Alkmaar, 2016)

When answering the questions according to this information the exterior finish gets an importance 5, which seems very logical as they did a lot of effort in restoring the original exterior look.

In the interior the aesthetics on the construction is still original and somewhat important. But the commission values the exterior and the contribution of the exterior to the urban surrounding as the most important aspect. When answering the questions according to this information the interior finish gets an importance of 2.

The architectural quality and monumental commission of Alkmaar mentions the large windows with steel frames, which indicates importance to the material and the measurements. The frames are still original but according to Veghel (2018), are in a poor condition. When answering the questions according to this information the interior finish gets an importance of 3. The glass in the windows is according to van Veghel in a poor condition. The architectural quality and monumental commission of Alkmaar does not mention the single glass and only states that the large measurements are characteristic. When answering the questions according to this information the interior finish gets an importance of 2.

Costs

In the document of van Veghel there is no indication on the importance for costs. For this reason, the importance is set on 3 as this is average. There is also no budget indicated so this part is not filled in.

Cultural value	
Is the material of the exterior finishes still original?	Yes
Is the technical state of the material still good?	Yes
Is the building important due to the exterior finish?	Yes
Is the construction technology or ornamentation visible in the exterior façade?	Yes
Is the readability of the building history visible in the exterior finish?	Yes
Exterior finishes	5
Is the material of the interior finishes still original?	No
Is the technical state of the material still good?	No
Is the building important due to the interior finish?	No
Is the construction technology visible in the interior façade?	Yes
Is the readability of the building history visible in the interior finish?	Yes
Interior finishes	2
Is the material of the frames still original?	Yes
Is the technical state of the material still good?	No
Is the building important due to the frames?	Yes
Are the measurements and grid in the frames original?	Yes
Is the execution quality of the frame rare?	No
Frames	3
Is the glass still original?	Yes
Is the technical state of the glass still good?	No
Is the building important due to the glass?	No
Are the measurements of the glass original?	Yes
Is the execution quality of the glass rare?	No
Glass	2

Figure 60 Cultural value input ringers

Costs	
Budget	
Show only measures that meet budget?	Yes/No
Overall importance 1-5	

Figure 61 Costs input Ringers

5.4.2 *Result*

Because the ambitions for this project are not known for this research and this model partially depends on the ambitions of a project, several results will be elaborated. Three results will have equal ambitions, high (5) middle (3), and low (1). The other three results will have one aspect (cultural value, sustainability, or costs) high, while the other two are low. All the scenarios will be visualized with a graph (note that cost is placed on a negative scale, meaning that the most cost-efficient measure is further from the center). For each result, the tree diagram indicates that the closed façade has less potential to be renovated compared to the open façade. This is because the open façade has the highest number of square meters and the worst condition. It is more than reasonable to focus on this building part.

Equal ambitions

Appendix F shows the result of the scenario with all the ambitions low. For the cultural value, all the questions (figure 50) must be answered with 'no' in order to gain a low ambition for cultural value. Because the ambitions are low and there is no restriction for the sustainability goals and budget, more measures are visible in this result. This result shows that the best options are to change the frames to wood and insert HR glazing while keeping the existing wall. Figure 62 shows that the applied measures are quite equally distributed and all the measures are the less expensive options.

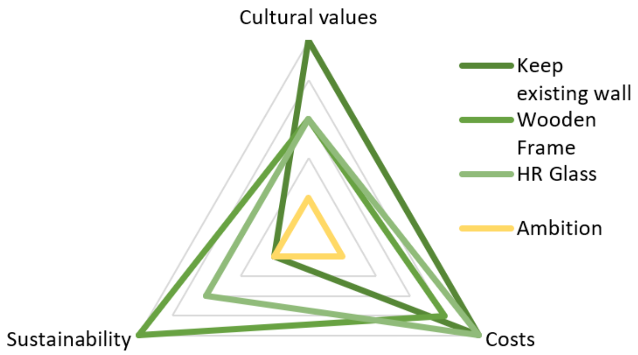

Figure 62 Low equal ambitions

Appendix H shows the result for the Ringers project when the ambition for all the aspects is valued with 3. In this scenario, the option to only show the measures that meet the sustainability goal is selected. The result shows that the best option for the closed façade is to apply cavity wall insulation. This is because the exterior of the façade is essential to preserve. For the open façade, a wooden or plastic frame with HR+ glass contains a higher score since the cultural value of the windows is less critical (see 5.4.1). In figure 63, it is visible that there is slightly more weight to sustainability. The best measures are performing the best on sustainability impact.

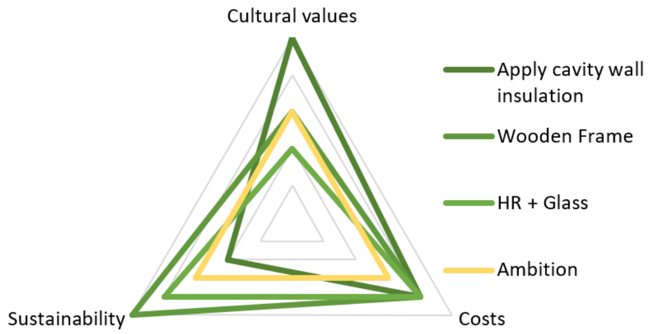

Figure 63 Medium equal ambitions

Appendix I shows the results when all the ambitions are very high. For the cultural value, the questions all must be answered with 'Yes' in order to gain a high ambition for cultural value. In this scenario, the option to only show the measures that meet the sustainability goal is selected. Figure 64 shows that the best measures for this situation are quite equal to the previous ones, which means that the three measures that are the best in every scenario, are the measures that have similar scores for each aspect.

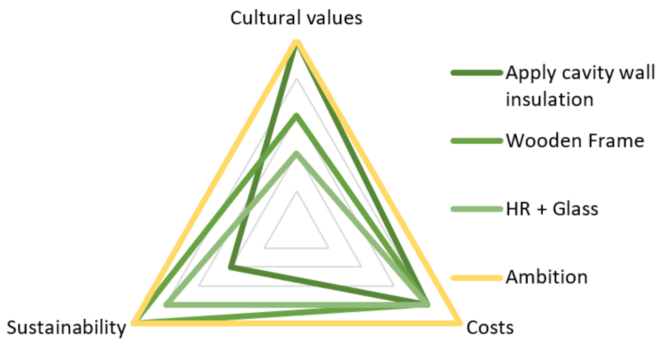

Figure 64 High equal ambitions

Different ambitions

Appendix J shows the result of the scenario where sustainability is considered as important. For this result, the option to only show the measures that meet the sustainability goal (figure 49) is selected because sustainability is important in this scenario. The results show that applying the highest insulation system on the exterior, applying frames of wood and HR++ glass with the highest U value are the best options because they have the best impact on sustainability. Figure 65 shows the measures and a visualization of the ambition. This figure shows that the weight of the measures is indeed at the sustainability corner because the measures with the best impact on sustainability are selected. It is also visible that these were also less expensive options and that they have a negative impact on cultural value.

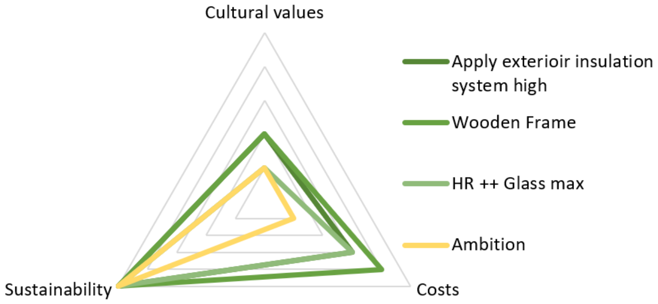

Figure 65 High Sustainability ambition

Appendix K shows the result where only cultural value is important. This scenario shows that the best options are: keeping the existing wall, applying the uninsulated metal frames and applying the single glass. This result is quite apparent. For preserving the cultural values, it is logical that the measures that do not interfere with the current situation are considered as the best. For this situation, it is noticeable that this scenario shifts the tree diagram and suggest focusing on the closed façade instead of the open façade. This is because when focusing on the cultural value, the most significant feature of the building (the one with the highest number square meters, open façade) should be preserved. Figure 66 shows the options suggested. What is notable is that this figure shows that when preserving the most cultural values, this would also benefit the cost. This is due to the fact that with not applying

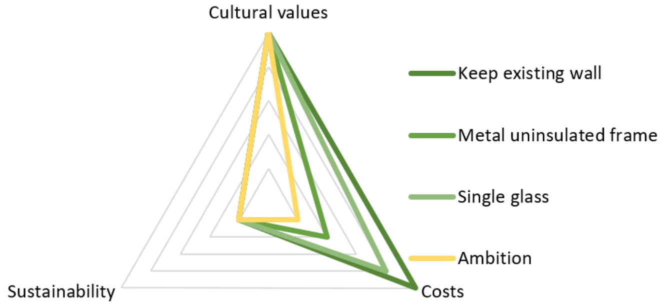

Figure 66 High Cultural value ambition

insulation, no extra direct building costs occur. In reality, this is different because the maintenance costs and other aspects must be considered.

Appendix L shows the result of the scenario when only costs are important. In the scenario keeping the existing wall, applying plastic frames, and applying HR glass are the best measures since these measures contain the lowest costs. Figure 67 shows that this scenario is the most equally distributed compared to figure 65 and 66 since keeping the existing wall is inexpensive and good for the cultural values. As mentioned before, not all the costs and revenues are considered in this model. Meaning that this result is only focused on the direct building costs and can not yet be a representative result for practice.

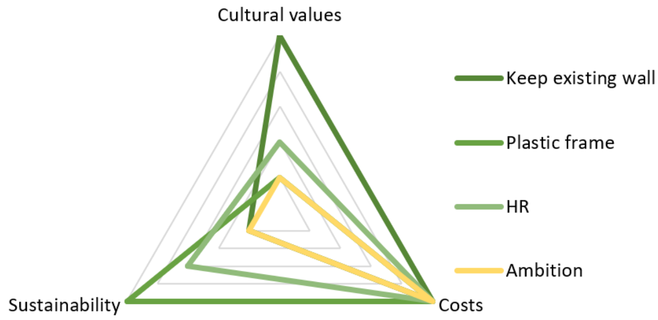

Figure 67 High Costs ambition

5.4.3 *Conclusion*

The recommendations in the report of (Veghel, 2018) consisted of applying exterior insulation and replacing the windows with thicker frames and glass which is similar as the result in appendix J. This is due to the fact that for this report, the focus was mainly on the energy performance of the building and not the preservation of cultural value. Considering cultural value, Veghel (2018) did recommend applying interior insulation, cavity wall insulation and windows with similar aesthetics as the original ones which is similar as the result in appendix K. To conclude, the model does give a proper outcome that is comparable with the solutions given by the expert of ABT.

Comparing the solution given by the expert and the study with different scenarios, shows that decisions such as these will always depend on the ambition of the person who does the assessment. If a building physicist inserted the data, he would give more priority to sustainability, and the result will be different compared to the investor that gives more priority to costs.

The scenario study also shows that there is still a lot to research on this matter. It indicates what measures are best to used and the suggested combinations can be substantiated. At the moment these decisions are made by experts. But this model can support the decision making for other people, such as developers or owners, by creating a clear overview.

The validation emphasizes a couple of considerations for further research:

- To create a more specific model, the quantity of a cavity wall is an option to implement in the model. This project showed that there is a possibility that not all the façades consist of a cavity wall and this can influence the result.
- At the moment, the model does not have the opportunity to enter different types of windows. Right now, only an average of all the windows can be inserted. To extend the model, an option to insert multiple types of existing windows can be implemented.
- It becomes clear that in practice, glass and frames are considered as one building part. For this reason, it is common to give a total U value for the window and not to the glass and frame separately. This model separates the window to glass and frame; for further research, it might be useful to enhance connection to practice and consider windows as one entity.
- The questions for the cultural value can be formulated differently. Now the questions only ask if certain aspects are present, not if they are important. It is plausible that there is indeed a construction visible in the façade, but not valued as important. It can be better to insert questions that indicate whether an aspect is important or not.

6. Conclusion

Improving sustainability and preserving the cultural values while maintaining a viable project is a complex process. The goal of this research was to create a decision-support model that will support industrial heritage renovation projects with finding the balance between cultural value, sustainability, and costs.
The literature review provided answers to the following sub-questions:

What guidelines and recommendations are there for industrial heritage renovation projects?

There is a wide range of rules and recommendations concerning industrial heritage on different scales, international, national, provincial and municipal. To receive a building permit, it is necessary to obey to the value assessment of the monuments committee. The main rules and recommendations that are used by the monument committee are the 'Guidelines for building archeological research.' Other value assessment methods use these guidelines as a foundation for their approach.

What are cultural values?

Cultural values are subjective, meaning there is not one definition for it. Many researchers agree that cultural values can be divided into tangible and intangible values. Where the tangible values are represented by materials contrary are the intangible values, most of it is considered as non-material. For this research, the cultural value consists of the tangible characteristics of the building parts wherein the relation between those building parts give the building architectural-historical & building-historical meaning.

How can cultural values be measured?

There are several methods that indicate the cultural values of a building and several measures that strive to quantify cultural values. The majority of these methods use the 'Guidelines for building archeological research' as a foundation to indicate the cultural values of a building. These guidelines are not created to quantify cultural values, but methods, such as DuMo, CHV and CVF (chapter 3.2.2), transformed these guidelines to do so. Even though cultural value assessments always depend on the person who does the assessment, the 'Guidelines for building archeological research' is a good approach to measure cultural values.

What defines the sustainability of a building?

Sustainability is an umbrella term, but for a building, the main aspects that are defined are comfort, energy, thermic comfort, air quality, light, acoustics, electricity, greenery, water, and materials. To converge this research, only the aspect material and the thermal resistance of a material are taken into account.

How can these aspects be measured?

The thermal resistance of the materials in a façade can be measured with the use of the U-value is expressed in W/m2K, and R-value is expressed in m2K/W.

What are the different costs in a renovation project?

Costs can be divided into operating costs and investment costs. Investment costs contain building costs, additional costs, and land costs. The building costs are direct costs that can be attributed to a product or service. For this research, the costs of a measure are considered as the direct building costs price per square meter.

The empirical research provided the answers to the following sub-questions:

What are the key issues to be solved in renovation projects?

The key issues that arose during the case studies were poor insulation of the closed façade and roof uninsulated metal frames with single glass that caused condensation and thermal bridges.

What measures were used for these issues?

The used measures are applying interior insulation systems, exterior insulation systems, cavity wall insulation, replacing the frames and replacing the glass.

To what extent do the measures contribute to the cultural value, sustainability, and costs of a building?

In appendix G a list of the used measures and the alternatives is given. For each measure, the R or U value indicates the impact on sustainability, the building costs price per square meter indicates the impact on costs and the amount of interference with characteristics of the building part indicates the impact on cultural value.

The operational research combines the sub-questions and answers the main research question:

How can a decision-support model that analyses renovation measures improve the balance between cultural value, sustainability, and costs in industrial heritage renovation projects?

The decision-support model implements the project properties together with the given ambitions for cultural value, sustainability, and costs. With this information it tests the measures whether they match with the given project properties and ambitions. The measures that fit the best have a higher rate than the others, the higher rates turn green, and the lower rates turn red. In this way, the model shows a clear overview which measures fit the best to those properties and ambitions. This supports the decision-making process for developers and owners to find the right combinations of measures to ensure the balance between cultural value, sustainability, and costs (figure 68). Next to giving the right measures, the decision-support model also incorporates the condition and square meters to show which building parts have more potential to renovate compared to others. To ensure well-informed decision making, the risks for the measures are given in the model.

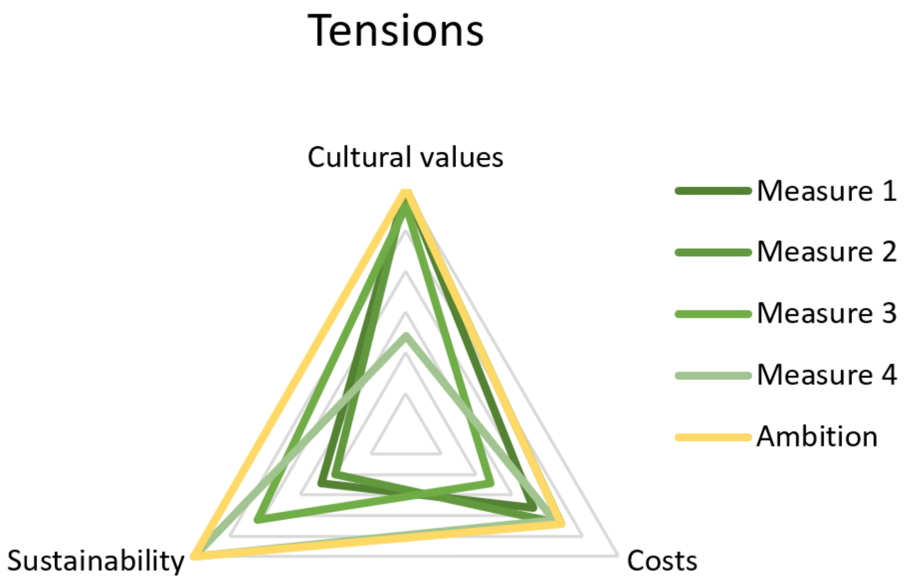

Figure 68 . Combinations of the right measures find the balance between cultural value, sustainability, and costs that fits the ambition. Cultural values and sustainability are on a positive axis and cost on a negative axis, meaning that when the costs are low, the value is further from the center.

7. Epilogue

7.1 Discussion

This chapter discusses the research methodology and results.

7.1.1 *Literature research*

The literature research consists of four chapters, heritage policies, cultural value, sustainability, and costs. The chapter about heritage policies facilitated background information for this research but also gave a first insight on the 'Guidelines of building archeologic research'. This chapter gives information on international and national guidelines and recommendations. As the national policies is partially based on international policies, it was not necessary to go more in depth at the international level. Likewise, since the 'Guidelines of building archeological research' would be elaborated in the following chapter, it was unnecessary to go in depth in the chapter heritage policies.

Compared to the other criteria, sustainability and costs, the chapter about cultural value contains the most information and research. This is because cultural value is subjective, which makes it challenging to comprehend. Exploring various cultural value assessment methods contributed to finding a precise definition for this research. The majority of the methods used the 'Guidelines for building archeological research' as a foundation for their method, and for that reason, this research also used these guidelines for defining cultural value. The methods also indicated how to structure the decision-support model.

The literature research into sustainability resulted in the statement that sustainability is a very comprehensive term and needed a more specific definition for this research. This research only observed two sustainability measure methods. This can be considered as a small sample. However, from the twelve calculations methods, only GreenCalc+ and Breeam consider monuments.

The research into costs showed that various types of costs could be used in this research, but the direct building costs price per square meter is eventually applied. The depth of the literature research is disputable; however, considering the time and efficiency, it would be redundant to do so.

7.1.2 *Empirical research*

The empirical research was executed during an internship at ABT. For this research, only three case studies were selected, which can be considered as a small sample. From these case studies, the assumption is drawn that several measures are commonly used. This can be biased because all of the case studies where executed by ABT. There is a possibility that the commonly used measures concluded from the case studies only apply to ABT and that other companies prefer using other measures.

During the case studies, not all the information needed could be found. For each case study, the role of ABT differs. The detail of information depended on the level of involvement from ABT during the renovation. For this reason, there was no information about the building costs for Tricot. Besides the information that is provided by ABT is interpreted by one person. For this reason, bias could occur. To enhance the reliability of this research, more then one person should have implemented the data.

The majority of the data for the case study is extracted from internal drives and therefore is not publicly accessible. This interferes with the reliability of this research since the data and conclusion cannot be adequately verified.

7.1.3 *Operational research*

The operational research is based on the information of the literature and empirical research. The model which is created in this research is developed in Microsoft Excel. This is done because this software is very accessible; there is a possibility that another software would have fitted better to this research but was not considered.

Also, the method of how the impact on cultural value is assessed in chapter 5.2.2 is roughly executed. The assessment is done by observing the interference with aesthetics without a research structure.

In the model, glass and frame are viewed as two separate building parts. However, in practice, it is common to view frames and glass as one building part, window. For this reason, it is common to give a total U-value for the window and not to the glass and frame separately. This can mean that the model is perhaps not as applicable to practice as it could be. For further research, it might be beneficial to enhance the connection to practice and consider windows as one entity.

7.2 Limitations

- The decision support model contains some limitations:
- This model can only support decisions and cannot make them. Risk must be kept in mind.
- This model only focuses on the façade.
- The list of measures is limited.
- The model is constructed with 3 case studies and tested with one case study and for this reason may not work well on other case studies.
- The model is not tested on accessibility for non-experts.
- The model has limited criteria for cultural value, sustainability, and costs.
- The model is only tested for industrial heritage.

There are some risks to be considered while using this model. This model only supports decisions. People can mistake this model for a decision-making model and follow the advice without assessing it themselves. It is important to implement the risks, such as trapped moisture, before making a decision. A risk of using this model can comprehend that users do not take the risks of measure into account and make a non-informed decision. Also, the costs used in this model are standardized costs and are not precise enough to make a cost estimate. Another risk of using this model is that people may use this model as a cost estimation and take non-informed decisions.

7.3 Recommendations

7.3.1 *Further research*

An important conclusion of this research is that it is possible to extend this model. This research is the first step and creates a foundation of the model. Further research into this model is necessary to be able to use this in practice. For each aspect, cultural value, sustainability, costs, and measures, there are possibilities to extend the model.

Cultural value

The method to indicate the importance of cultural value can be made more extensive (chapter 5.2.2). There is a possibility to create more questions to make the model more precise. The accessibility of the model can be improved by giving the assessor examples of aesthetics of building parts that are considered valuable. This gives the assessor the possibility to compare the project to the examples and can then asses whether it is valuable or not.
Next to the importance assessment, the impact assessment can also be more precise (chapter 5.2.3). Now the assessment is done by observing the interference with aesthetics roughly. Further research can enhance this by creating a checklist that indicates how much a measure interferes with the aesthetics.

Sustainability

This model only implements the thermal resistance of the façade. As chapter 3.3.1 describes, there are many definitions of sustainability. Further research can extend this model by implementing more aspects such as comfort, energy, thermic comfort, air quality, light, acoustics, electricity, greenery, and water. Nowadays, the importance of the origin of the used materials and the ecological footprint is increasing. These aspects can be implemented in the model.

Costs

Next to the direct building costs price, more aspects can be brought into consideration such as indirect costs and revenues. Instead of only costs, there is a possibility to insert the revenues that can be gained over the years due to the improvement of the energy performance.

It is also possible to implement maintenance costs of the measures. It is possible that some measures require more maintenance than others, that can have an impact on the overall life-cycle costs.

Measures

Next to more criteria, further research can also enhance the list of measures that will be tested in the decision-support model. This model only has four types of measures that apply to the façade. This model is flexible to increase the number of measures. Likewise, it is possible to not only look at the façade but at other building parts as well, such as roof, installations, floors etcetera. This then will create a good overview of which building part has the most potential to renovate.

Model

Further research can be done on the model itself. It can be transformed into better software to make it more accessible. The calculations can be made more precise.

At the moment, the condition of building parts is not supported by literature. For further research, the condition of the building parts can be supported by the NEN 2767 that provides a list of scores of conditions

As described in chapter 5.4, it is only possible to enter one insert one type of window. In the project, it is possible that over time more types of windows are constructed, with further research the model can be specified with the option to implement the fact that more types of windows can be replaced.

To specify the model, the quantity of cavity wall is an option to implement in the model. This project showed that there is a possibility that not all the façades consist of a cavity wall and this can influence the result.

7.3.2 *Practice*

Further research can investigate how this model will eventually work in practice, and if it indeed lowers the threshold to renovate industrial buildings. It can observe in what context this model is best to use. This model can be applied within companies but can also be helpful for homeowners.

7.4 Reflection

7.4.1 *Choice of subject*

The relationship between my graduation and the subject 'adaptive reuse' is visible. Adaptive reuse as a research subject is seen as a sustainable real estate strategy. The goal is to transform buildings to reduce the vacancy and increase sustainability. This graduation connects to this as the research goal is to renovate industrial heritage to ensure use of the building and sustainability.

As mentioned in the preface, I have a passion for heritage. To combine this passion with management helped me to stay motivated for this thesis. At the beginning of my graduation, I already knew what I wanted to do. I wanted to find a way to help people find the right balance between cultural value, sustainability, and costs. The struggle was on how I wanted to research this. I knew I wanted to make model or program that could facilitate that. While exploring my graduation topic, I noticed that more people did research in my field, but nobody made the link between cultural value, sustainability, costs, and the measures used during a renovation. To explore the field, I did some informal interviews with experts to ask whether it would be a promising idea to research this subject and I received positive replies, which motivated me to continue in this path. The fact that experts outside of the academic field were interested in this model shows the transferability of my graduation to the wider professional framework.

7.4.2 *Research proposal*

Close to my P2, I had the struggle to find the right methodology to do my research and especially in what form my decision-support model would be. With the help from my mentors at the faculty and my mentor at ABT, I came closer to a final structure for my model. The feedback that I received from my mentors was for that reason helpful. Sometimes I struggled with the feedback because I did not agree, and I could not handle the criticism if it did not come along with compliments. However, over time, I learned how to learn from the criticism, and it helped me develop my report.

The research consists of a literature study to gain background knowledge about the subject. In advance, I did not know enough about industrial heritage renovation, and so a literature study was needed to ensure background knowledge. The literature study also provided more specific definitions for the otherwise broad terms of cultural value, sustainability, and costs. The empirical research contained case studies to extracted common issues and measures. This also helped me to gain overall knowledge about renovations and to know why certain measures where used. Initially, the empirical research included interviews with experts. During the research, it became clear that this was an unnecessary method that would take to much time since most of the information that I needed was provided in the internal drives of ABT. Interviews are only needed if you need to extract intangible aspects such as communications flaws. For this research only, substantial data was needed. To create a model, operational research is done. This last method was an obvious approach since a model needed to be created. For this research only one case study is used to validate the model. This can be considered as a low sample, but it does not interfere with the scientific relevance because the model was constructed with three other case studies to ensure applicability.

7.4.3 *Data collection*

The data collection for the empirical research was done at ABT. From this part, I learned the most from my research. As a management student, I did not have enough knowledge of heritage and building engineering to understand why certain measures are applied. I knew some aspects due to my bachelor architecture, but that was not enough to grasp the essence of some façade sections. Because I did my internship at a building engineer company, I had enough people to help me figure it out. My mentor Rosi encouraged me to try and understand the issues that arise during an internship. I liked to learn more about heritage renovation, and it motivated me even more to finish this research.

During the data collections, an ethical consideration arose. Different companies and not just ABT formed the extracted data. This means that there is a certain sensitivity needed when using this data, such as referencing to the company. Also, the experts that helped during the research participated voluntarily and gave consent for the use of the data.

7.4.4 *Data analysis*

Transforming the collected data into conclusions helped to form the result. During the analysis, the conclusion arose that the condition and the square meters of a certain building part is an important aspect that must be implemented in the decision support model. This conclusion transformed the result.

During the literature and empirical research, I already thought about how to make the decision support model. For this reason, the creation of the model went quite smoothly. The important part was to select the proper program as a foundation of the model. Eventually, Microsoft Excel was selected as this was the most accessible program. This was a right decision and it supported the research enough.

7.4.5 *Outcome*

The assumption I made at the beginning of my thesis does not differ much from the final conclusion, meaning that I did not compromise my ideas and motivation while doing this research.

Initially, the model should show the impact of the measures on cultural value, sustainability, and costs. Eventually, the goal extended, and the model also shows which building part has the most potential to renovate by implementing the number of square meters, and the condition. Therefore, the outcome of this research was more than expected. The result of my graduation thesis is a first stepping stone to a decision-support model that has the potential to be transferred in a wider social, professional, and scientific framework. In the end, this model has the potential to benefit the social environment because it stimulates professionals to renovate more industrial heritage and trigger academics to use this model as a foundation for their research. This will result in less vacant buildings and a better sustainable future. This supports to the ethical consideration of attributing to the society in a positive way.

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9. Appendices

Appendix A: Value assessment of Hendriks & van der Hoeve (2009)

Appendix B: DuMo worksheet of Nusselder et al. (2008)

Appendix C: Value assessment of Beers (2004)

Appendix D: Value assessment of Schrieken (2000)

Appendix E: Project properties

Appendix F: Result Low equal ambitions

Appendix G: Measures

Appendix H: Result medium equal ambitions

Appendix I: Result High equal ambitions

Appendix J: Result High Sustainable ambitions

Appendix K: Result High Cultural value ambitions

Appendix L: Result High Costs ambitions

Appendix A
Value assessment of Hendriks & van der Hoeve (2009)

General historical values (related to social developments)
- Relation with cultural, socio-economic and / or spiritual developments ;
- Relation with geographical, landscape or administrative developments ;
- Relation with technical or typological developments ;
- Importance of the building due to innovative value or pioneering character.

Ensemble and urban values
- Importance of the building as an essential part of a larger whole that is cultural-historical, architectural-historical and urban-planning of (inter) national significance;
- Importance of the building due to the situation, connected with the development / expansion of a region, city or district;
- Importance of the building due to the method of subdivision / layout / facilities;
- Importance of the building for the appearance of a region, city, village or district;
- Importance of the building due to the high quality of the buildings and the historical-spatial relationship with green areas, roads, water and / or soil conditions.

Architectural-historical values
- Importance of the building for the history of architecture;
- Importance of the building for the oeuvre of a master builder or architect;
- Importance of the building due to the high-quality aesthetic qualities of the design;
- Importance of the building due to the ornamentation;
- Importance of the building due to the interior finish (in connection with the exterior).

Building historical values
- Importance of the building for the history of building technology;
- Importance of the building due to the readability of the building history (historical layering);
- Importance of the building due to the use of materials.

Values from the usage history (related to the object of research)
- Importance due to the organization, coherence or layout of buildings or spaces, appropriate to a (historical) function, use or production in the object / complex;
- Importance due to a (historical) function, use or production in the object / complex;
- Importance of the building as a reminder of a historical event or prominent occupant / user / client.

Appendix B

DuMo worksheet of Nusselder et al. (2008)
(P: Very positive, Q: Positive, R: Mediocre, S: Negative) (Nusselder et al., 2008)

Work sheet cultural value					
Question	Item	Score P	Score Q	Score R	Score S
Architectural-historic value					
321	Quality of building type				
	1 if rare or				
	2 if common				
322	Quality architecture				
	1 if rare or				
	2 if common				
323	Execution quality				
	1 if rare or				
	2 if common				
324	Meaning of building in oeuvre of the architect				
Cultural-historic values					
331	Importance concerning historical themes				
332	Importance concerning local historic developments				
333	Relation with historic person or event				
Contextual values					
341	Meaning of surroundings to building				
342	Meaning of building to surrounding				
Completeness					
351	Amount of historical remaining				
352	Technical state				
Total					
Category (A, B, C, Xa, Xb or Xc					
Number of Cultural value					

Appendix C

Value assessment of Beers (2004)

Assessment components Cultural Value	Score	Weight	Integrality	Rarity	Total	Total %
Part 1: Landscape						
1.1 Morphologic underground						
1.2 Culture landscape						
1.3 Natural landscape						
1.4 Architectural landscape						
1.5 Trade routes, water ways						
Part 2: Urbanism						
2.1 Relation green, water, public space						
2.2 Urban concept						
2.3 Scale						
2.4 Allotment type						
2.5 Unity buildings & public space						
2.6 Framework of the city						
2.7 Urban fabric						
2.8 Public structure						
2.9 Quality public space						
2.10 Composition						
2.11 Transformation Urban fabric						
Part 3 Architecture						
3.1 Typology						
3.2 Construction						
3.3 Unity use and function						
3.4 form and Construction						
3.5 Harmony and proportion						
3.6 Ornament and details						
3.7 Measurement and grids						
3.8 Use of material						
3.9 Concept						
3.10 Composition						
Part 4: Social/Cultural						
4.1 Status by the public						
4.2 Status of the building						
4.3 Relation with historic event						
4.4 Visual recognizability						
4.5 Social-cultural service						
4.6 Status architect						
4.7 Oeuvre Architect/Urban planner						
4.8 Recognizability						
Part 5: History						
5.1 Innovative techniques						
5.2 Innovative materials						
5.3 Style period						
5.4 Building period						
5.5 Age						
Maximum value						
Value object in relation to total						

Properties input

Technical		
Closed façade	2400	m2
Good condition	90	%
Open façade	1600	m2
Good condition	25	%
Does the closed façade exist of a cavity wall?	Yes	
Sustainability existing		
R value façade	0,8	m².K/W
U value Frames	7	W/m².K
U value Glass	5,6	W/m².K
Sustainability Goals		
R Value Closed façade	1,3	m².K/W
U value Frames	3,8	W/m².K
U value Glass	1,8	W/m².K
Show only measures that meet sustainability goal?	Yes	
Sustainability Importance 1-5	3	
Cultural value		
Is the material of the exterior finishes still original?	Yes	
Is the technical state of the material still good?	Yes	
Is the building important due to the exterior finish?	Yes	
Is the construction technology or ornamentation visible in the exterior façade?	Yes	
Is the readability of the building history visible in the exterior finish?	Yes	
Exterior finishes	0	
Is the material of the interior finishes still original?	No	
Is the technical state of the material still good?	No	
Is the building important due to the interior finish?	No	
Is the construction technology visible in the interior façade?	Yes	
Is the readability of the building history visible in the interior finish?	Yes	
Interior finishes	3	
Is the material of the frames still original?	Yes	
Is the technical state of the material still good?	No	
Is the building important due to the frames?	Yes	
Are the measurements and grid in the frames original?	Yes	
Is the execution quality of the frame rare?	No	
Frames	2	
Is the glass still original?	Yes	
Is the technical state of the glass still good?	No	
Is the building important due to the glass?	No	
Are the measurements of the glass original?	Yes	
Is the execution quality of the glass rare?	No	
Glass	3	
Costs		
Budget		
Show only measures that meet budget?	No	
Overall importance 1-5	3	

Instructions

In this sheet the properties of the building must be inserted. First fill in the right values in the orange cells. If there is a value entered that is not possible, a red warning square will appear.
For the questions please select an option in the drop-down menu.
The red squares in the corner of the cells indicate a comment. This comment will clarify the question.

In the sheet 'result' the result is visible of you project. Underneath 'Overall score' the colors indicate the best options for your specific project. The colors range from green (positive) to red (negative). The tree diagram indicate which building parts are better to focus on. When the path is green, this indicates that when these building parts are altered they have a more positive impact then the other building parts.

When the best measure are clear, please note the red squares in the corner of the cells where the measure is described. These cells have notes that will explain some of the risks that must considered during the renovation. Please advise these notes before considering applying a measure on your project.

The sheet measures show the different applicable measures. This is background information for the decision support model, you do not have to change anything here.

If there are any questions please contact:
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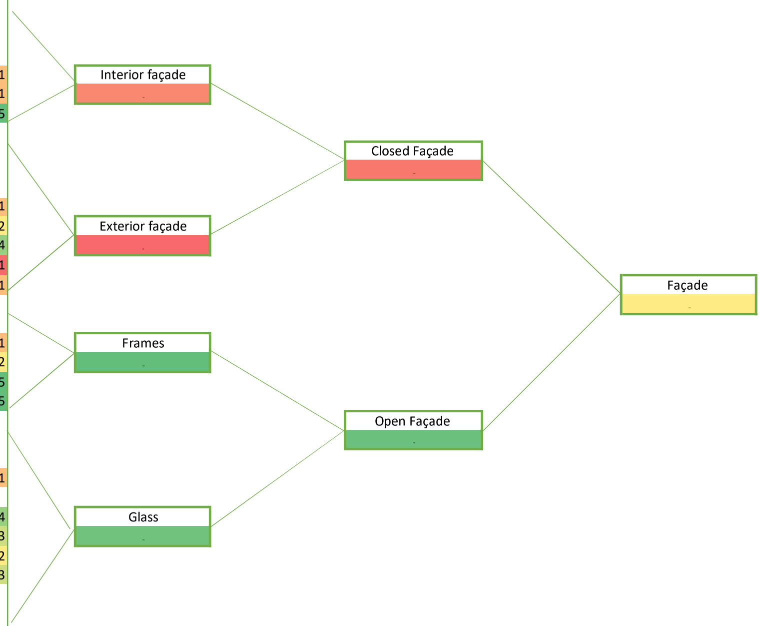
Appendix F

Decision support model

Building part			Measures	Sustainability	Weight	Score	Cultural value	Weight	Score	Costs	Weight	Score	Overal score
Closed façade	Interior Façade	Wall	Keep existing wall	1	1	1	1	1	1	5	1	5	
			Apply Interior insulation system low	2	1	2	4	1	4	2	1	2	
			Apply Interior insulation system high	3	1	3	4	1	4	2	1	2	
		Cavity wall	Keep existing wall	1	1	1	1	1	1	5	1	5	
			Apply Interior insulation system low	2	1	2	4	1	4	3	1	3	1
			Apply Interior insulation system high	3	1	3	4	1	4	2	1	2	1
			Apply cavity wall insulation	2	1	2	1	1	1	4	1	4	5
Closed façade	Exterior façade	Wall	Apply exterior insulation system low	2	1	2	4	1	4	2	1	2	
			Apply exterior insulation system mid	3	1	3	4	1	4	2	1	2	
			Apply exterior insulation system high	5	1	5	4	1	4	1	1	1	
		Cavity wall	Apply exterior insulation system low	2	1	2	4	1	4	3	1	3	1
			Apply exterior insulation system mid	3	1	3	4	1	4	3	1	3	2
			Apply exterior insulation system high	5	1	5	4	1	4	3	1	3	4
			demolish the outer sheet, apply the insulation and remodel low	3	1	3	5	1	5	1	1	1	-1
			demolish the outer sheet, apply the insulation and remodel high	5	1	5	5	1	5	1	1	1	1
			..										
Open façade	Frame		Metal uninsulated	1	1	1	1	1	1	2	1	2	
			Metal insulated	3	1	3	3	1	3	1	1	1	1
			Aluminium	3	1	3	5	1	5	4	1	4	2
			Wood	5	1	5	4	1	4	4	1	4	5
			Plastic	5	1	5	5	1	5	5	1	5	5
			...										
	Glass		Single glass	1	1	1	1	1	1	4	1	4	
			Double glazing	3	1	3	3	1	3	3	1	3	
			Triple glazing	4	1	4	4	1	4	1	1	1	1
			HR glass	3	1	3	3	1	3	5	1	5	
			HR + glass	4	1	4	4	1	4	4	1	4	4
			HR ++ glass min	4	1	4	5	1	5	4	1	4	3
			HR ++ glass mid	4	1	4	5	1	5	3	1	3	2
			HR ++ glass max	5	1	5	5	1	5	3	1	3	3
			Single w/ coating (Ruysdael)	2	1	2	2	1	2	2	1	2	
			Monuglass	3	1	3	2	1	2	1	1	1	
			...										



Appendix G

Building part			Measures	Sustainability	S	Impact 1-5	Goal	Costs	S	Impact 1-5	Under budget	Cultural value	Impact 1-5	Risks	AQC	Other
Closed façade	Interior	Wall	Keep existing wall	0,80 m2K/W	6	1	0	0 €/m2	6	5	1	Exterior finishes	5		Yes	
			Apply Interior insulation system low	1,30 m2K/W	6	1	1	€ 93,08 €/m2	6	2	0	Exterior finishes	2	1,2,3,4,5	Yes	
			Apply Interior insulation system high	2,50 m2K/W	6	3	1	€ 98,46 €/m2	6	2	0	Exterior finishes	2	1,2,3,4,5	Yes	
		Cavity wall	Keep existing wall	0,80 m2K/W	6	1	0	0 €/m2	6	5	1	Exterior finishes	5		Yes	
			Apply Interior insulation system low	1,30 m2K/W	6	1	1	€ 87,18 €/m2	6	3	0	Interior finishes	2	1,2,3,4,5	No	
			Apply Interior insulation system high	2,50 m2K/W	6	3	1	€ 92,55 €/m2	6	2	0	Interior finishes	2	1,2,3,4,5	No	
			Apply cavity wall insulation	1,30 m2K/W	6	1	1	€ 43,12 €/m2	6	4	0	Interior finishes	5	1,2,3	No	
											1					
Closed façade	Exterior	Wall	Apply exterior insulation system low	1,30 m2K/W	6	1	1	€ 125,21 €/m2	6	2	0	Exterior finishes	2	1,3,4,5,6	Yes	
			Apply exterior insulation system mid	2,50 m2K/W	6	3	1	€ 130,21 €/m2	6	2	0	Exterior finishes	2	1,3,4,5,6	Yes	
			Apply exterior insulation system high	3,50 m2K/W	6	5	1	€ 140,21 €/m2	6	1	0	Exterior finishes	2	1,3,4,5,6	Yes	
		Cavity wall	Apply exterior insulation system low	1,3 m2K/W	6	1	1	€ 50,00 €/m2	6	3	0	Interior finishes	2	1,3,4,5,6	No	
			Apply exterior insulation system mid	2,50 m2K/W	6	3	1	€ 55,00 €/m2	6	3	0	Interior finishes	2	1,3,4,5,6	No	
			Apply exterior insulation system high	3,50 m2K/W	6	5	1	€ 60,00 €/m2	6	3	0	Interior finishes	2	1,3,4,5,6	No	
			demolish the outer sheet, apply the insulation a	2,50 m2K/W	6	3	1	€ 172,21 €/m2	6	1	0	Interior finishes	1		No	
			demolish the outer sheet, apply the insulation a	3,50 m2K/W	6	5	1	€ 182,21 €/m2	6	1	0	Interior finishes	1		No	
Open façade	Frame		Metal uninsulated	7 W/m2K	2	1	0	€ 705,00 €/m2	7	2	0	Frames	5	2	No	
			Metal insulated	3,8 W/m2K	2	3	1	€ 905,00 €/m2	7	1	0	Frames	3		Yes	
			Aluminium	3,8 W/m2K	2	3	1	€ 320,00 €/m2	7	4	0	Frames	1		Yes	
			Wood	2,4 W/m2K	2	5	1	€ 360,00 €/m2	1	4	0	Frames	3		Yes	
			Plastic	2,4 W/m2K	2	5	1	€ 231,00 €/m2	1	5	0	Frames	1		Yes	
			…													
	Glass		Single glass	5,8 W/m2K	2	1	0	€ 45,00 €/m2	8,9	4	0	Glass	5		No	
			Double glazing	2,8 W/m2K	2	3	0	€ 65,00 €/m2	8,9	3	0	Glass	3	7	Yes	
			Triple glazing	1,2 W/m2K	1	4	1	€ 125,00 €/m2	8,9	1	0	Glass	2	7	Yes	
			HR glass	2 W/m2K	2	3	0	€ 35,00 €/m2	8,9	5	0	Glass	3	7	Yes	
			HR + glass	1,6 W/m2K	2	4	1	€ 45,00 €/m2	8,9	4	0	Glass	2	7	Yes	
			HR ++ glass min	1,1 W/m2K	1	4	1	€ 55,00 €/m2	8,9	4	0	Glass	1	7	Yes	
			HR ++ glass mid	0,9 W/m2K	2	4	1	€ 65,00 €/m2	8,9	3	0	Glass	1	7	Yes	
			HR ++ glass max	0,5 W/m2K	2	5	1	€ 75,00 €/m2	8,9	3	0	Glass	1	7	Yes	
			Single w/ coating (Ruysdael)	3,8 W/m2K	5	2	0	€ 100,00 €/m2	8,9	2	0	Glass	4		No	
			Monuglass	2 W/m2K	5	3	0	€ 150,00 €/m2	8,9	1	0	Glass	4	9	Yes	
			…													

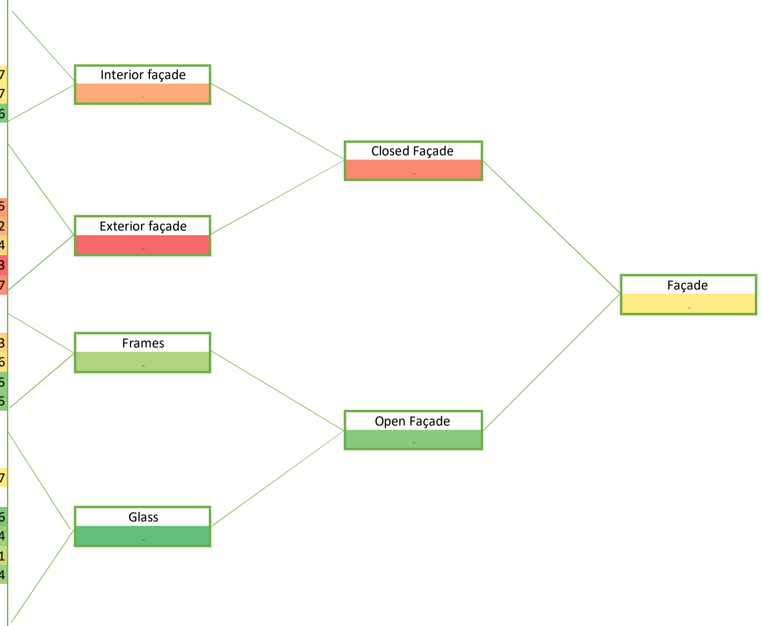
Source
1 181107_16492_LST_haalbaarheidsstudie_v1_CON
2 http://www.bouwvraagstuk.nl/bouwfysica/tabellen/tabellarium.pdf
3 https://www.lambda.be/nl/energietips/lambda-waarde-van-alle-materialen
4 EPBD
5 190212_15322_RAP_scenario-advies-buitenkozijnen_v1_DEF
6 20120502_Energiebesparingkostenmodel_v01_wsj
7 Bouwkosten.nl
8 jml.nl
9 Wouter Blondeel

Risks
1 Thermal bridges
2 Surface condensation
3 Liquid moisture penetration
4 Trapped moisture
5 Overheating
6 You need a planning consent of the Architectural quality commission.
7 Change frame
8 Heavier than single glass, frames should be calculated to this.
9 Color & reflection changes slightly with right coating

Appendix H

Decision support model

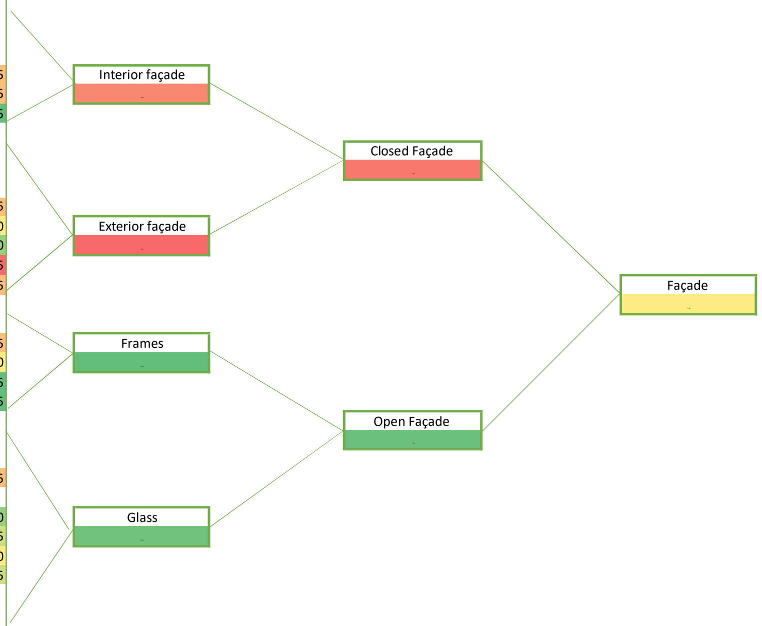
Building part			Measures	Sustainability	Weight	Score	Cultural value	Weight	Score	Costs	Weight	Score	Overal score
Closed façade	Interior Façade	Wall	Keep existing wall	1	3	3	1	2	2	5	3	15	
			Apply Interior insulation system low	2	3	6	4	2	8	2	3	6	
			Apply Interior insulation system high	3	3	9	4	2	8	2	3	6	
		Cavity wall	Keep existing wall	1	3	3	1	2	2	5	3	15	
			Apply Interior insulation system low	2	3	6	4	2	8	3	3	9	7
			Apply Interior insulation system high	3	3	9	4	2	8	2	3	6	7
			Apply cavity wall insulation	2	3	6	1	2	2	4	3	12	16
Closed façade	Exterior façade	Wall	Apply exterior insulation system low	2	3	6	4	5	20	2	3	6	
			Apply exterior insulation system mid	3	3	9	4	5	20	2	3	6	
			Apply exterior insulation system high	5	3	15	4	5	20	1	3	3	
		Cavity wall	Apply exterior insulation system low	2	3	6	4	5	20	3	3	9	-5
			Apply exterior insulation system mid	3	3	9	4	5	20	3	3	9	-2
			Apply exterior insulation system high	5	3	15	4	5	20	3	3	9	4
			demolish the outer sheet, apply the insulation and remodel low	3	3	9	5	5	25	1	3	3	-13
			demolish the outer sheet, apply the insulation and remodel high	5	3	15	5	5	25	1	3	3	-7
			..										
Open façade	Frame		Metal uninsulated	1	3	3	1	3	3	2	3	6	
			Metal insulated	3	3	9	3	3	9	1	3	3	3
			Aluminium	3	3	9	5	3	15	4	3	12	6
			Wood	5	3	15	4	3	12	4	3	12	15
			Plastic	5	3	15	5	3	15	5	3	15	15
			...										
	Glass		Single glass	1	3	3	1	2	2	4	3	12	
			Double glazing	3	3	9	3	2	6	3	3	9	
			Triple glazing	4	3	12	4	2	8	1	3	3	7
			HR glass	3	3	9	3	2	6	5	3	15	
			HR + glass	4	3	12	4	2	8	4	3	12	16
			HR ++ glass min	4	3	12	5	2	10	4	3	12	14
			HR ++ glass mid	4	3	12	5	2	10	3	3	9	11
			HR ++ glass max	5	3	15	5	2	10	3	3	9	14
			Single w/ coating (Ruysdael)	2	3	6	2	2	4	2	3	6	
			Monuglass	3	3	9	2	2	4	1	3	3	
			...										



Appendix I

Decision support model

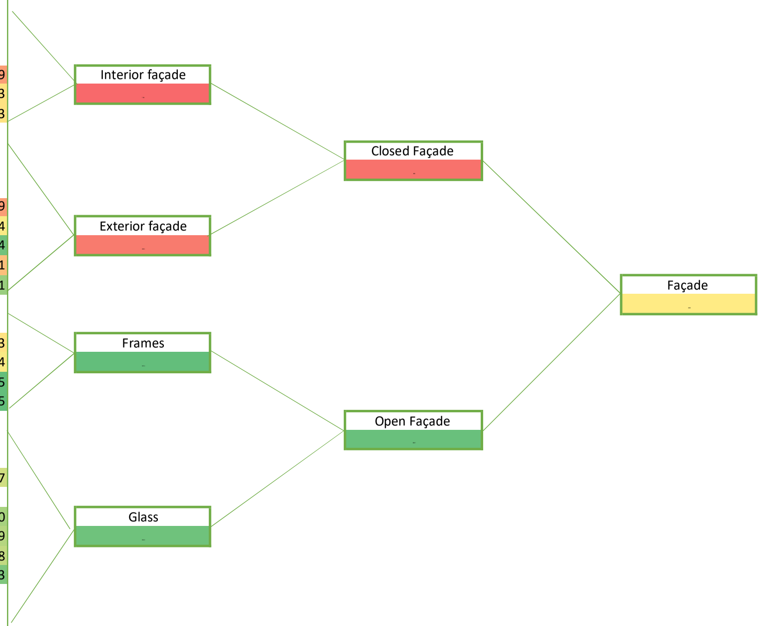
Building part			Measures	Sustainability	Weight	Score	Cultural value	Weight	Score	Costs	Weight	Score	Overal score
Closed façade	Interior Façade	Wall	Keep existing wall	1	5	5	1	5	5	5	5	25	
			Apply Interior insulation system low	2	5	10	4	5	20	2	5	10	
			Apply Interior insulation system high	3	5	15	4	5	20	2	5	10	
		Cavity wall	Keep existing wall	1	5	5	1	5	5	5	5	25	
			Apply Interior insulation system low	2	5	10	4	5	20	3	5	15	5
			Apply Interior insulation system high	3	5	15	4	5	20	2	5	10	5
			Apply cavity wall insulation	2	5	10	1	5	5	4	5	20	25
Closed façade	Exterior façade	Wall	Apply exterior insulation system low	2	5	10	4	5	20	2	5	10	
			Apply exterior insulation system mid	3	5	15	4	5	20	2	5	10	
			Apply exterior insulation system high	5	5	25	4	5	20	1	5	5	
		Cavity wall	Apply exterior insulation system low	2	5	10	4	5	20	3	5	15	5
			Apply exterior insulation system mid	3	5	15	4	5	20	3	5	15	10
			Apply exterior insulation system high	5	5	25	4	5	20	3	5	15	20
			demolish the outer sheet, apply the insulation and remodel low	3	5	15	5	5	25	1	5	5	-5
			demolish the outer sheet, apply the insulation and remodel high	5	5	25	5	5	25	1	5	5	5
			..										
Open façade	Frame		Metal uninsulated	1	5	5	1	5	5	2	5	10	
			Metal insulated	3	5	15	3	5	15	1	5	5	5
			Aluminium	3	5	15	5	5	25	4	5	20	10
			Wood	5	5	25	4	5	20	4	5	20	25
			Plastic	5	5	25	5	5	25	5	5	25	25
			...										
	Glass		Single glass	1	5	5	1	5	5	4	5	20	
			Double glazing	3	5	15	3	5	15	3	5	15	
			Triple glazing	4	5	20	4	5	20	1	5	5	5
			HR glass	3	5	15	3	5	15	5	5	25	
			HR + glass	4	5	20	4	5	20	4	5	20	20
			HR ++ glass min	4	5	20	5	5	25	4	5	20	15
			HR ++ glass mid	4	5	20	5	5	25	3	5	15	10
			HR ++ glass max	5	5	25	5	5	25	3	5	15	15
			Single w/ coating (Ruysdael)	2	5	10	2	5	10	2	5	10	
			Monuglass	3	5	15	2	5	10	1	5	5	
			...										



Appendix J

Decision support model

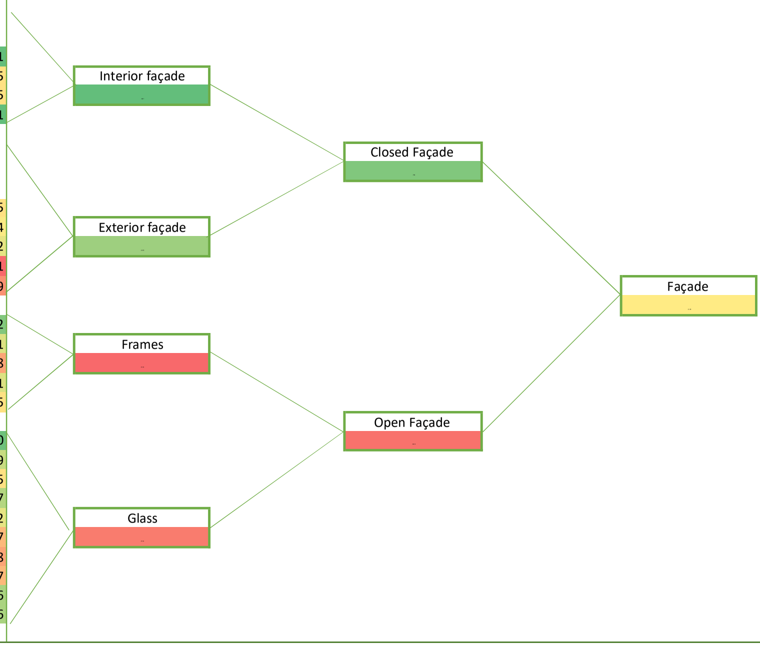
Building part			Measures	Sustainability	Weight	Score	Cultural value	Weight	Score	Costs	Weight	Score	Overal score
Closed façade	Interior Façade	Wall	Keep existing wall	1	5	5	1	1	1	5	1	5	
			Apply Interior insulation system low	2	5	10	4	1	4	2	1	2	
			Apply Interior insulation system high	3	5	15	4	1	4	2	1	2	
		Cavity wall	Keep existing wall	1	5	5	1	1	1	5	1	5	
			Apply Interior insulation system low	2	5	10	4	1	4	3	1	3	9
			Apply Interior insulation system high	3	5	15	4	1	4	2	1	2	13
			Apply cavity wall insulation	2	5	10	1	1	1	4	1	4	13
Closed façade	Exterior façade	Wall	Apply exterior insulation system low	2	5	10	4	1	4	2	1	2	
			Apply exterior insulation system mid	3	5	15	4	1	4	2	1	2	
			Apply exterior insulation system high	5	5	25	4	1	4	1	1	1	
		Cavity wall	Apply exterior insulation system low	2	5	10	4	1	4	3	1	3	9
			Apply exterior insulation system mid	3	5	15	4	1	4	3	1	3	14
			Apply exterior insulation system high	5	5	25	4	1	4	3	1	3	24
			demolish the outer sheet, apply the insulation and remodel low	3	5	15	5	1	5	1	1	1	11
			demolish the outer sheet, apply the insulation and remodel high	5	5	25	5	1	5	1	1	1	21
			..										
Open façade	Frame		Metal uninsulated	1	5	5	1	1	1	2	1	2	
			Metal insulated	3	5	15	3	1	3	1	1	1	13
			Aluminium	3	5	15	5	1	5	4	1	4	14
			Wood	5	5	25	4	1	4	4	1	4	25
			Plastic	5	5	25	5	1	5	5	1	5	25
			...										
	Glass		Single glass	1	5	5	1	1	1	4	1	4	
			Double glazing	3	5	15	3	1	3	3	1	3	
			Triple glazing	4	5	20	4	1	4	1	1	1	17
			HR glass	3	5	15	3	1	3	5	1	5	
			HR + glass	4	5	20	4	1	4	4	1	4	20
			HR ++ glass min	4	5	20	5	1	5	4	1	4	19
			HR ++ glass mid	4	5	20	5	1	5	3	1	3	18
			HR ++ glass max	5	5	25	5	1	5	3	1	3	23
			Single w/ coating (Ruysdael)	2	5	10	2	1	2	2	1	2	
			Monuglass	3	5	15	2	1	2	1	1	1	
			...										



Appendix K

Decision support model

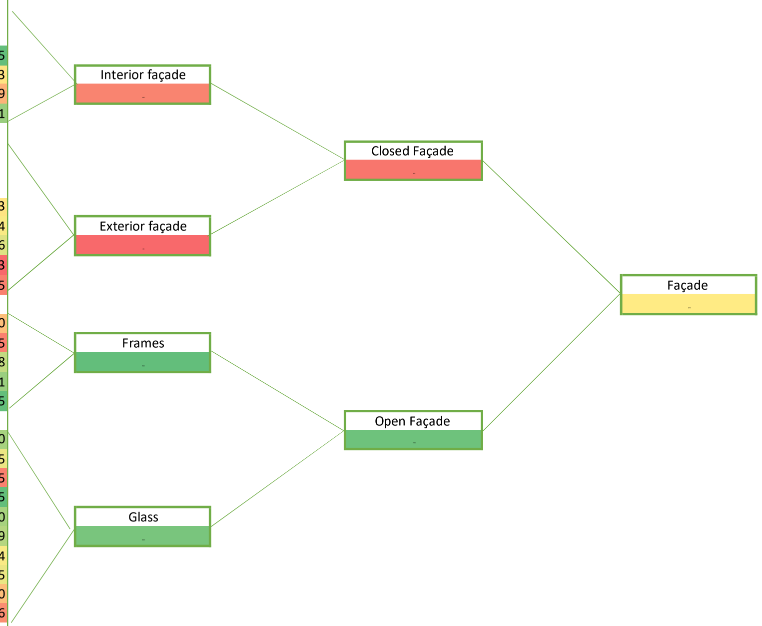
Building part			Measures	Sustainability	Weight	Score	Cultural value	Weight	Score	Costs	Weight	Score	Overal score
Closed façade	Interior Façade	Wall	Keep existing wall	1	1	1	1	5	5	5	1	5	
			Apply Interior insulation system low	2	1	2	4	5	20	2	1	2	
			Apply Interior insulation system high	3	1	3	4	5	20	2	1	2	
		Cavity wall	Keep existing wall	1	1	1	1	5	5	5	1	5	1
			Apply Interior insulation system low	2	1	2	4	5	20	3	1	3	-15
			Apply Interior insulation system high	3	1	3	4	5	20	2	1	2	-15
			Apply cavity wall insulation	2	1	2	1	5	5	4	1	4	1
Closed façade	Exterior façade	Wall	Apply exterior insulation system low	2	1	2	4	5	20	2	1	2	
			Apply exterior insulation system mid	3	1	3	4	5	20	2	1	2	
			Apply exterior insulation system high	5	1	5	4	5	20	1	1	1	
		Cavity wall	Apply exterior insulation system low	2	1	2	4	5	20	3	1	3	-15
			Apply exterior insulation system mid	3	1	3	4	5	20	3	1	3	-14
			Apply exterior insulation system high	5	1	5	4	5	20	3	1	3	-12
			demolish the outer sheet, apply the insulation and remodel low	3	1	3	5	5	25	1	1	1	-21
			demolish the outer sheet, apply the insulation and remodel high	5	1	5	5	5	25	1	1	1	-19
			..										
Open façade	Frame		Metal uninsulated	1	1	1	1	5	5	2	1	2	-2
			Metal insulated	3	1	3	3	5	15	1	1	1	-11
			Aluminium	3	1	3	5	5	25	4	1	4	-18
			Wood	5	1	5	4	5	20	4	1	4	-11
			Plastic	5	1	5	5	5	25	5	1	5	-15
			...										
	Glass		Single glass	1	1	1	1	5	5	4	1	4	0
			Double glazing	3	1	3	3	5	15	3	1	3	-9
			Triple glazing	4	1	4	4	5	20	1	1	1	-15
			HR glass	3	1	3	3	5	15	5	1	5	-7
			HR + glass	4	1	4	4	5	20	4	1	4	-12
			HR ++ glass min	4	1	4	5	5	25	4	1	4	-17
			HR ++ glass mid	4	1	4	5	5	25	3	1	3	-18
			HR ++ glass max	5	1	5	5	5	25	3	1	3	-17
			Single w/ coating (Ruysdael)	2	1	2	2	5	10	2	1	2	-6
			Monuglass	3	1	3	2	5	10	1	1	1	-6
			...										



Appendix L

Decision support model

Building part			Measures	Sustainability	Weight	Score	Cultural value	Weight	Score	Costs	Weight	Score	Overal score
Closed façade	Interior Façade	Wall	Keep existing wall	1	1	1	1	1	1	5	5	25	
			Apply Interior insulation system low	2	1	2	4	1	4	2	5	10	
			Apply Interior insulation system high	3	1	3	4	1	4	2	5	10	
		Cavity wall	Keep existing wall	1	1	1	1	1	1	5	5	25	25
			Apply Interior insulation system low	2	1	2	4	1	4	3	5	15	13
			Apply Interior insulation system high	3	1	3	4	1	4	2	5	10	9
			Apply cavity wall insulation	2	1	2	1	1	1	4	5	20	21
Closed façade	Exterior façade	Wall	Apply exterior insulation system low	2	1	2	4	1	4	2	5	10	
			Apply exterior insulation system mid	3	1	3	4	1	4	2	5	10	
			Apply exterior insulation system high	5	1	5	4	1	4	1	5	5	
		Cavity wall	Apply exterior insulation system low	2	1	2	4	1	4	3	5	15	13
			Apply exterior insulation system mid	3	1	3	4	1	4	3	5	15	14
			Apply exterior insulation system high	5	1	5	4	1	4	3	5	15	16
			demolish the outer sheet, apply the insulation and remodel low	3	1	3	5	1	5	1	5	5	3
			demolish the outer sheet, apply the insulation and remodel high	5	1	5	5	1	5	1	5	5	5
			..										
Open façade	Frame		Metal uninsulated	1	1	1	1	1	1	2	5	10	10
			Metal insulated	3	1	3	3	1	3	1	5	5	5
			Aluminium	3	1	3	5	1	5	4	5	20	18
			Wood	5	1	5	4	1	4	4	5	20	21
			Plastic	5	1	5	5	1	5	5	5	25	25
			...										
	Glass		Single glass	1	1	1	1	1	1	4	5	20	20
			Double glazing	3	1	3	3	1	3	3	5	15	15
			Triple glazing	4	1	4	4	1	4	1	5	5	5
			HR glass	3	1	3	3	1	3	5	5	25	25
			HR + glass	4	1	4	4	1	4	4	5	20	20
			HR ++ glass min	4	1	4	5	1	5	4	5	20	19
			HR ++ glass mid	4	1	4	5	1	5	3	5	15	14
			HR ++ glass max	5	1	5	5	1	5	3	5	15	15
			Single w/ coating (Ruysdael)	2	1	2	2	1	2	2	5	10	10
			Monuglass	3	1	3	2	1	2	1	5	5	6
			...										



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