

# Evaluation of the social house renovation project

*Case study of Eckart renovation project*



**Kayo Uesaraie**

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## **----- Case study of Eckart renovation project**

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### **Personal information:**

Author: Kayo Uesaraie

Student ID: 0990363

E-mail address: [k.uesaraie@student.tue.nl](mailto:k.uesaraie@student.tue.nl)

### **Graduation Committee:**

Chairman: prof. dr. ir. B. (Bauke) de Vries

Graduation supervisor: dr. D. (Dajuan) Yang

Graduation supervisor: dr. Q. (Qi) Han

Company supervisor: Marieke van den Wijngaard

### **Institute:**

University: Eindhoven University of Technology

Faculty: Faculty of the Built Environment

Department: Construction Management and Engineering

### **Company:**

Name: Woonbedrijf

Address: Wal 2, 5611 GG Eindhoven



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## Summary

Global energy problem is required to be addressed for various purposes, and it occurs due to the non-efficient way of generating and consuming energy. In order to achieve the energy goals from both EU and the Netherlands, implementing more social housing energy renovation project can be regarded as one of the sufficient methods. Therefore, this thesis mainly focuses on reducing energy consumption from social housing aspect through conducting energy efficiency renovation project. Compared to public building and office buildings, social housing sector has conducted less energy efficient renovation project. This happens since social housing has split interest. House owners (housing organizations) are required to invest for the project while tenants receive the benefits (energy bill reduction and living condition improvement) from this investment.

This lead to the following research questions: How to successfully implement social housing renovation project. The balanced methods of communication between different stakeholders that have relationships within the range of social housing are required to be discovered to further develop the renovation process. The finding is assessed by a practical renovation project in the Eindhoven to test the feasibility. These questions are mainly answered through literature review, case study, interview and Life Cycle Cost Analysis (LCCA). Literature review provides general situation of past social housing renovation project. Common problems and concerns can be found out after the research. Case study focuses on the practical situation and interviews through the inputs from both literature review and case study provide the insight of current renovation condition. LCCA at the end contain financial feasibility assessment of the project. The conclusion provides the recommendation to the following social housing renovation project regarding what they are required to consider for successfully implementing their project.

This thesis starts with literature review regarding the current situation of social housing renovation project. The impacts and benefits of energy renovation projects are first distinguished and analyzed. These lead to necessity to implement energy saving renovation project. It not only benefits the total energy consumption, CO2 emission and tenants' wellbeing of the area, but also contributes to the development of construction industry and economic growth. With the help of these impacts and benefits, social housing energy renovation projects have still not been well spread due to various lagging factors. Finance and technique are the two main barriers that affected past renovation projects. Project teams from social housing renovation projects cannot continue with other processes due to their influence. Other barriers and risks, such as organizational barriers and time risks also lag the development of social housing renovation project. Many previous projects stopped their development since they cannot overcome these factors in the early stages. Solutions for these lagging factors are also found in literatures, but project teams are still required to implement the solutions based on the situation of project area. Successful factors are found after looking for lagging factors. These factors are mentioned in the literatures that lead

previous projects to success. Many literatures have mentioned the importance of tenants' focus (focus on what tenants require for the renovation project) and stakeholder involvement (involve stakeholders from early stages to discuss and verify project's process). They are not necessarily implemented in the project, but these factors would provide the project team smooth process and feasible outcomes. Moreover, project assessment methods are found from literatures. They all have different functions and focus for evaluations. Case study, interview and Life Cycle Cost Analysis are chosen for the assessment of the project in this thesis.

The third part of the thesis contains research process and results. Case study of Eckart area is first implemented to understand the general situation of the project. This case has been chosen since the project team is implementing a unique concept of "series of one". From this experimental concept, new guideline for implementing social house renovation project might be found out. Interviews with the input questions from literature reviews and case study are conducted to gain the insight of the research questions. Interview structures are mainly divided into three parts, potential lagging factors, successful factors and judging criteria. The structure is divided based on what literatures indicate. The lagging factors are the reason current social housing organizations cannot conduct a successful renovation project, and successful factors would lead the project to success. Therefore, these are the important factors to consider for assessing a practical project and its concept to draw the conclusion at the end. Moreover, the criteria are set to double check with the finding of this thesis to provide a reliable guideline for following social housing organization at the end. After conducting interview with the project manager of housing organization, contractor and tenants, some factors are adjusted based on the Eckart case. Moreover, LCCA is implemented to test the financial feasibility for both tenants and the project team. The result indicates that tenants focus truly have good impact on the project. Tenants are willing to join the project since their requirements are considered during plan phase. However, in this specific case, this convenience for tenants leads to the extra burden for the project team for the schedule and finance plan.

Therefore, this thesis can conclude that in order to successfully implement social housing renovation project, the project team is required to be familiar with the situation in the project area to select sufficient renovation measures. Moreover, the experience from past renovation project also needs to be considered during decision making process. The project team should learn from the lagging factors and successful factors to understand how to deal with the problem in their project. The guidelines for these factors are provided based on the study from literature reviews and interview. Moreover, in order to achieve a feasible renovation outcome at the end, it is essential to find the balance between tenants interests focus and company requirement based on the project situation. This balance can ensure both controllable process and feasible outcomes.

## **Abstract**

Conducting energy efficiency renovation project especially in the social housing section is rather necessary to achieve the energy goal from both the EU and the Netherlands since reducing energy consumption in the buildings can be executed better than producing more renewable energy at current stage in the Netherlands. The slow development and spread of social housing energy efficiency renovation project is because of several lagging factors. These factors and correlated solutions are revealed and discussed in this thesis to provide general guideline for following social housing renovation project. Furthermore, common renovation measures to improve energy label in the households and successful factors from past social housing renovation project that can provide process guide for following renovation project are also provided in the general guideline for social housing energy efficiency renovation project. Besides the general guidelines, a case study related to a specific ongoing social housing renovation project is also conducted in this thesis. Moreover, Interview with the housing organization, contractors and tenants, and LCCA are implemented to obtain better insight of the project for a comprehensive project evaluation. This evaluation conducted through several interviews includes the successful factors, potential lagging factors and evaluation criteria of the case. The basic framework and content are obtained from literature review and preparation interview with the project manager. The following in-depth interview with the project manager and contractor improve the interview framework and provides detailed answers and insight for the case. Moreover, project feasibility from both aspect of the housing organization and tenants are assessed by terms of interviews with tenants and LCCA (mainly focus on financial feasibility for the company). The opinion directly from tenants regarding their satisfaction related to the all the process in the project can be obtained. The financial feasibility of the case is assessed by terms of LCCA for the period of 30 years maintenance (calculate until the next renovation project). Some recommendations and discussions for tenants approach and tenants' satisfaction can also be obtained after the comprehensive evaluation. This thesis provides insights of how to successfully conduct social housing renovation project and the results can be used to accelerate the process and development of conducting social housing energy efficient renovation project.

## List of Abbreviations/Glossary

(According to the appearance in the report)

|      |                                  |
|------|----------------------------------|
| EU   | European Union                   |
| EI   | Energy Index                     |
| EE   | Energy Efficient                 |
| ZenN | Nearly Zero energy Neighborhoods |
| POE  | Post Occupancy Evaluation        |
| LCA  | Life Cycle Assessment            |
| LCCA | Life Cycle Cost Analysis         |
| PCRS | Pearl Community Rating System    |
| LCC  | Life Cycle Costing               |
| PV   | Present Value                    |
| FV   | Future Value                     |
| WSW  | Waarborgfonds Social Woningbouw  |

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# 1. Introduction

## 1.1. Problem definition

### 1.1.1. Background information

Energy crisis nowadays is not only because of the lack of energy sources, but also because of the non-efficient (lack of innovation) way of producing and consuming energies. There is still no efficient way to address it (Rinkesh, 2009). As for the situation in EU (European Union), the final energy consumption has decreased by 11% in the EU-28 countries during the period from 2005 to 2014 (Barbu, 2016). However, as it shown in the Figure 1, the main energy consumption is still sourced from oil and gas that accounts for 37% and 22% respectively, while renewable energy only occupies 8% in the total consumption in 2015. Therefore, in tandem with supply-side policies, EU has launched a number of initiatives and policies that aim at increasing energy efficiency, reducing energy demand, and decoupling energy problem from economic growth (Consumption of energy, 2017). Paris Agreement (The Paris Agreement, 2016) also prompts this process.

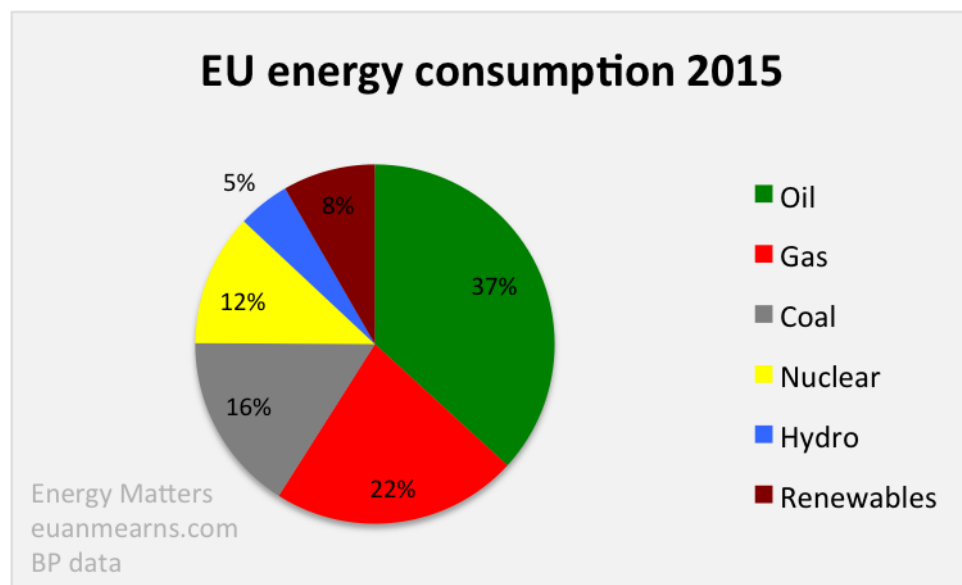


Figure 1 EU energy consumption 2015 (sited from (Mearns, 2016))

Considering the situation in the Netherland, with the annual amount of 119.60 billion kWh in energy consumption, (Energy consumption in the Netherlands, 2017) the country is capable of producing 96% of the total amount of energy. The Dutch government has determined to have a low-carbon economy by 2050, which means that almost all energy should be produced from sustainable sources (The future of fossil fuels, 2017). This is also for supporting and accomplishing the energy goals from the EU.

In order to reach the energy goals from both the Netherlands and the EU, briefly two actions can be conducted: Reduce the consumption (demand) of energy and increase the production of renewable energy (Sorrell, 2015). Despite the rich renewable sources, the development of renewable energy share is still low. The main reason can be concluded as cash cow sourced from oil and gas since the government is capable of making a great deal of money (around 7 billion per year) from the involvement in the fossil fuel industry (Avery, 2016). Therefore, the government will not discard the cash cow from oil in a short term. Consequently, the thesis will mainly focus on the aspect of reducing energy demands in housing sectors.

In order to accomplish the environmental goal from both EU and the Netherlands by 2020, reducing the energy consumption in household is essential. Over the past 30 years, average Dutch household gas consumption has reduced by nearly half mostly through high-performance boilers and better housing insulation (PBL, 2014). Therefore, the implementation of energy renovation project together with other energy saving technology can further reduce energy consumption in the household, which would contribute to the environmental goal since 40 % of total energy consumption in European Union is used in buildings (EU, 2017). Besides that, it is being estimated that people globally spend approximately 70 % of their time in buildings (Sustania, 2014).

### **1.1.2. Problem statement**

Despite the necessity of implementing energy renovation project to reduce energy consumption in the building and households, there are several problems and limitations that the renovation concepts are currently facing. Although a wealth of policies, regulations, incentives, and other interventions that have been introduced to stimulate and support the diffusions of energy efficiency measures, home owners still remained stubbornly resistant to improve their homes' energy efficiency by renovation (Wilson., 2014). There are diverse renovation projects running in Northern Europe, but those are mostly within the range of public buildings and office buildings.

35% of the total housing stocks (2.4 million houses) in the Netherlands are social housing. As it shown in Figure 2, only approximately 25% of the houses are above energy label B in 2014. Most of the houses only have an energy label that is lower than C (households energy consumption more than 160 kWh/m<sup>2</sup>/year). Although the energy label in the social houses is generally improving due to the implantation of one and two label steps renovation according to Figure 3, the low energy label problem in social housings is still serious. Even though carrying out energy renovation project is necessary and there are various benefits to implement energy renovation projects, the spread of renovation projects in social housing is still at a low level. As it shown in Figure 3, the deep energy renovation rates (at least three or more label steps) was 3.5% in total from 2010 to 2014. The trend had a steep increase in the year of 2012, but it remained stable again after 2013 (Filippidou, 2017). More social housing energy renovation projects are required to truly achieve the energy goal from both EU and the Netherlands.

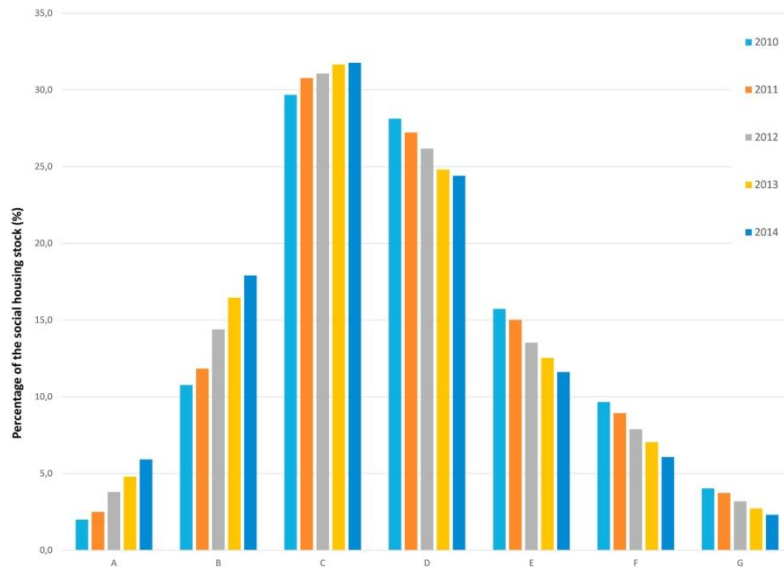


Figure 2 Energy label categories in social housings (cited from (SHAERE database, 2018))

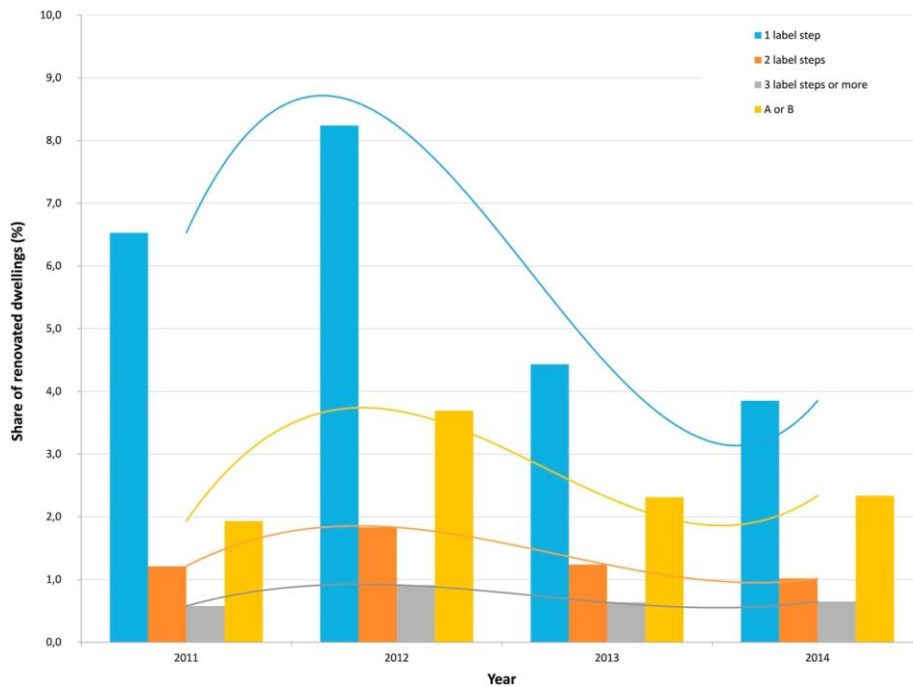


Figure 3 Energy renovation rates of the social housing sector (cited from (SHAERE database, 2018))

The most essential problem is that it is difficult to take the final joint decision during initial stage. The social housing organizations do not have enough experiences and budgets to carry out a large- scope renovation project. The residents are not sure about whether the renovations truly have the effect which was guaranteed by the company, and they are not willing to invest on a rental house. Therefore the main purpose of this

thesis is to find out what are the successful factors and potential lagging factors (the factors that might lag the process of project) for social housing renovation project, and how can this be implemented in later social housing renovation project for a successful outcome.

## **1.2. Research questions and expected results**

### **1.2.1. Research Questions**

Due to the importance and necessity of implementing social housing renovation project, the successful method and guideline for social housing organization needs to be provided to further accelerate the process of social housing energy efficiency renovation. Moreover, the questions related to case evaluation compose another part of the thesis. In order to accomplish this, two parts of analysis will be carried out as following:

#### **Part 1: Energy Renovation Project Evaluation**

Main question: How to successfully implement social housing renovation project? How is the outcome of the renovation project? What can other renovation project learn from this specific case?

In order to answer this question, literature review and a specific case study (and interview) is conducted. General situation and problem of previous renovation project and correlated solutions are found out after literature review. Case study is implemented to obtain some unique and updated information for social housing renovation project. Moreover, three sub-questions are formulated to further elaborate this main question. The sub-questions can help with the detailed understanding of each factor.

Sub questions:

1. What energy saving renovation measures are implemented in the project? Are they proper for this renovation project?
2. What are the successful factors and how do they influence the project?
3. What are the potential lagging factors? What are their effects and how to overcome them?

Both literature review and case study (interview) are implemented to answer these questions. General recommendations for social housing renovation project can be obtained after case study.

#### **Part 2: Project Feasibility Assessment**

Since the social housing company is implementing a new way to renovate social housings, the feasibility of the method needs to be assessed to find out whether it is necessary to continue with the same method.

Main question: Is this renovation project feasible for both the social housing company and their tenants?

In order to answer this main question, interview with tenants and housing organization in the specific case study is conducted. These interviews can provide the insights from both sides to understand the project feasibility in a comprehensive way. Moreover, three sub-questions are formulated to obtain the further understanding.

Sub question:

1. Is the project feasible for the company, especially from financial aspect?
2. Are tenants satisfied with the renovation concept, approach and process?
3. Is it feasible to continue renovating other possible houses with the same method?

Financial feasibility is set as one of the sub question since budget is mostly the biggest barrier for projects. These questions are formed to assess the outcome of this specific renovation project. They are answered mainly through case study and interview.

### **1.2.2. Expected results**

It is expected that social housing energy efficiency renovation project is not widely spread because of several barriers and risks that social housing organizations cannot address during decision-making process, and consequently influence the whole project. Therefore, these lagging factors should be revealed and discussed. One of the expected results of this thesis is to provide a guideline for the social housing organizations to accelerate their renovations. Furthermore, the evaluation result of a specific case study is demonstrated in the thesis. The guideline will include both specific renovation in the houses and renovation approaches for the company and their tenants.

Another expected result is the evaluation of an on-going experimental social housing renovation project. This evaluation mainly focuses on financial aspect and tenants satisfaction aspect. It is also expected that the evaluation result can provide some recommendations for the following social housing renovation projects.

### **1.3. Research Design**

The research design of this thesis is shown in Figure 4. The research begins with understanding technology background conducted from literature review. The experience and knowledge from previous projects is obtained for the input and preparation of the analysis. A specific social housing case is introduced afterwards, and the input from both literature review and case overview is implemented in interviews to obtain insight from expert to understand the case detail and current social housing renovation situation. Results of the interview are applied to both qualitative analysis and quantitative analysis. Consequently, conclusion and discussion of the report are described at the end of the thesis together with the recommendation of general social housing energy efficiency renovation project.

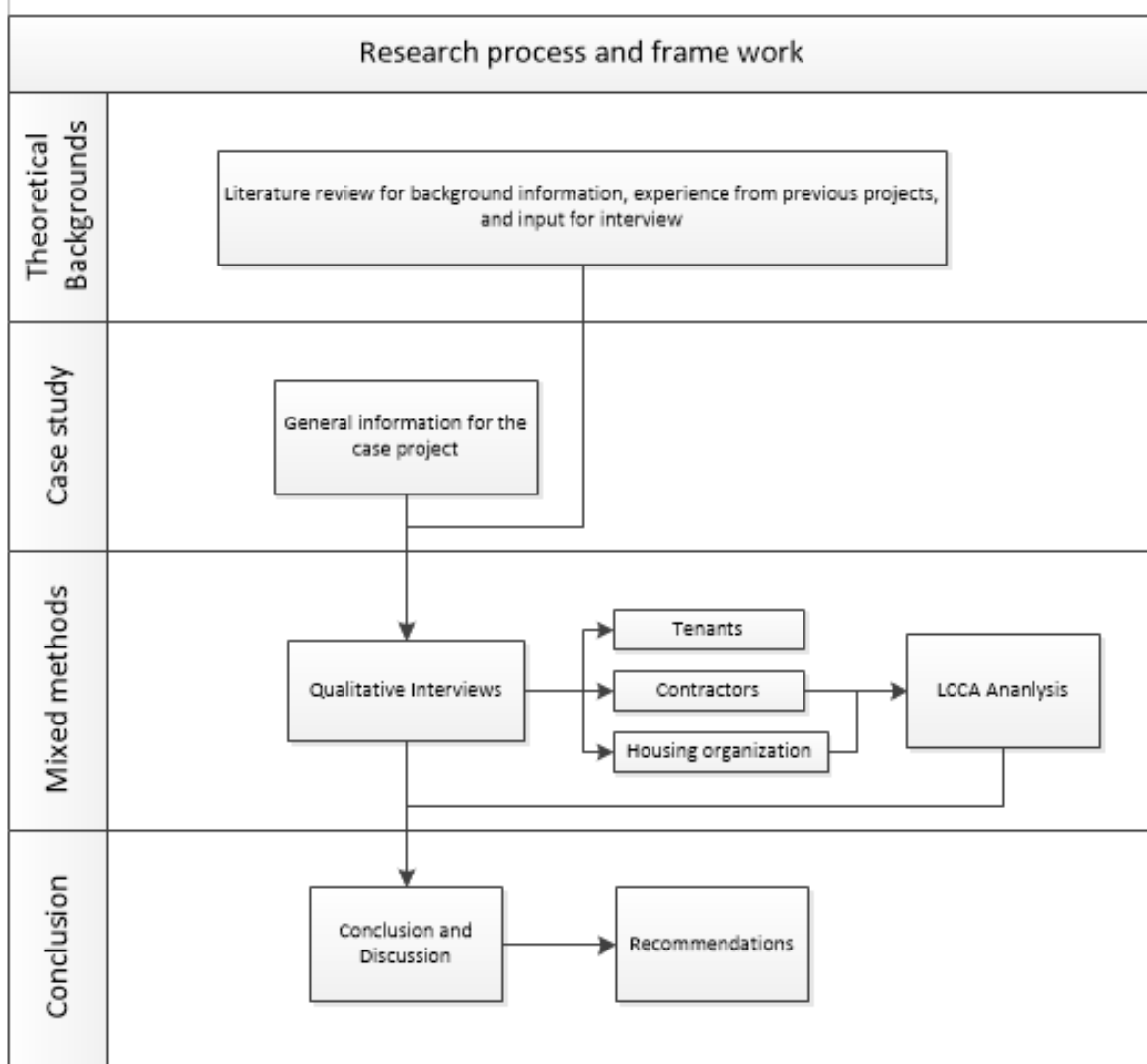


Figure 4 Research framework

## 1.4. Importance of the subject

### 1.4.1. Practical importance

From the perspective of social relevance, the subject of this thesis can contribute to accelerate and improve the social housing renovation process. Considering the fact that old and poorly insulated social housing stock accounts 35% of the total housing stock in the Netherlands, and they are all required to have an average energy label of B by the year of 2020, the importance and urgency of social housing renovation project is obvious. Therefore, the barriers and problems from previous energy renovation project should no longer hinder this process. This new way of renovating social housing can also provide a unique way for social housing organizations to choose and implement in their cases.

### **1.4.2. Social relevance**

Energy efficiency in housing sectors is the key factor for reducing energy consumption. This renovation can also improve the indoor air quality for the tenants. However, the current situation indicates that although energy renovation is a “win-win” operation, not many people are willing to follow this process. This is the consequence of bad reputation from previous renovation projects. Housing organizations and tenants have no trust in the outcome of the project. Therefore, from the social relevance, the subject of this thesis is capable of reversing this cagey circumstance to encourage people to realize and understand renovation project. Consequently, more people and companies will be willing to conduct energy renovation projects.

### **1.4.3. Scientific relevance**

From the scientific perspective, this study contributes to the existing literature regarding project evaluation methods. This thesis analyzes the existing literatures and evaluation methodologies for concluding and discussing what the best way to analyze one project is, and what aspects do the method focus on when conducting evaluation. This perspective links the scientific relevance to the thesis.

## **1.5. Reading guide**

This thesis is structured into six chapters, where the first chapter captures the introduction of the problem background. In the first chapter the problem is stated, based on which the research objective, theoretical framework and research questions are formulated. The introductive chapter also presents the importance of the thesis from practical and social aspects.

The second chapter provides an insight into the existing literature in the topic of general social housing renovation situations, as well as barriers and problems that lag this renovation process. Furthermore, the literature review provides different methodologies of assessing renovation project. Author can obtain knowledge background of what is required for this thesis from this chapter.

The third chapter introduces the research methodology of this thesis. Motivation and general structure of the methods are elaborated in this chapter. Furthermore the method and type of data collection, processing method and analysis is described. This chapter provides an understanding of required methodologies for the reliable analysis and consequently feasible outcome at the end.

The fourth chapter is the outcome of the case study and interview. Overview of the case is first described, following with the interview structure that developed for the evaluation of this project. This structure is also the guideline for the interview analysis. In this analysis, the elements that could influence the outcomes of the project, such as barriers and risks, are described and assessed. At the end of this chapter, the result of project evaluation is presented. The fifth chapter present the result of another

methodology, Life cycle cost analysis. The result of this chapter can assess the renovation project from the aspect of financial aspect.

The sixth chapter presents the conclusions of the research, based on the results and data analysis, the recommendations for the social housing company regarding energy efficiency renovation project, limitations of the research as well as future research opportunities are presented.

## 2. Literature Review

### 2.1. Introduction

The second chapter presents a review of existing academic literature on the topic of building energy renovation project and its evaluation. In order to correctly evaluate the value and achievement of a specific and innovative renovation project, the pre-knowledge of general evaluation is indispensable.

First of all, the general information including energy renovation measure categories and energy label (Energy index) description, and some renovation examples from public buildings and office buildings. Moreover, impact of energy renovation project is demonstrated, following with the barriers and incentives for social housing energy renovation projects. These three sections elaborate why the renovation project is important but difficult to implement. Furthermore, the assessment methodologies for existing academic literatures will also be revealed to elaborate what and how the evaluation process should be accomplished.

### 2.2. Energy Renovation Categories and Examples

As mentioned in the introduction, there are not many social housing renovation project carried out previously; therefore, this section mainly focus on summarizing the categories of social housing energy renovation project, and providing some examples of renovation projects from public building and office buildings. These examples are chosen since they have clear description regarding the goals, renovation measures and outcomes.

Three types of energy renovation for social housing were distinguished by Trime through his interviews with social housing organizations (Trime , 2016):

- Deep renovation: Increase the energy label to A or B in a dwelling with poor technical conditions. The tenants have to leave their house during the period of renovation in most of the case.
- 2 label step renovation: Increase the energy efficiency of the house with at lease 2 labels, while the house is occupied.
- Single measure renovation: Replace the specific component when it is needed.

The last two types are mostly implemented in the social housing renovation project since they are easier to manage and less capital is required compared to the first one.

Energy label mentioned in dividing renovation types is a common way to express EI (Energy Index) that is the official coefficient for measuring energy efficiency of an existing dwelling. The correlated relationship is shown in Table 1. EI is calculated as (Filippidou, 2017),

$$EI = \frac{Q_{\text{total}}}{155A_{\text{floor}} + 106A_{\text{loss}} + 9560}$$

In which:

|                    |  |
|--------------------|--|
| $Q_{\text{total}}$ | Yearly primary energy use of the dwelling                  |
| 155                | Correction factor for useful living area                   |
| $A_{\text{floor}}$ | Total heated floor area of the dwelling                    |
| 106                | Correction factor for transmission losses                  |
| $A_{\text{loss}}$  | Areas that are not heated in the dwelling (such as cellar) |
| 9560               | Standard amount of energy used for existing dwellings      |

*Table 1 Connection of Energy Index and Energy Label (cited from (ISSO, 2009))*

| Energy Label | Energy Index | Mean theoretical primary energy consumption (kWh/m <sup>2</sup> /year) |
|--------------|--------------|--|
| A (A+, A++)  | <1.05        | 96.8   |
| B            | 1.06 – 1.3   | 132.5  |
| C            | 1.31 – 1.6   | 161.6  |
| D            | 1.61 – 2.0   | 207.8  |
| E            | 2.01 – 2.4   | 265.0  |
| F            | 2.41 – 2.9   | 328.0  |
| G            | > 2.9        | 426.9  |

Various renovation projects for different sectors have been implemented in Europe. Although these projects are mostly focus on public building and office building, the renovation ideas are still capable of providing a reliable reference since the effect of renovation can be reflected through the outcomes. The typical and successful building renovation project examples are shown in table 2.

*Table 2 Renovation Project examples*

| Name   | Sector              | Goal   | Renovation  | Results   |
|--|---------------------|--|---|---|
| Aarhus (14-17)<br>(EUR 53.5M)<br>(European Investment Bank, 2014)      | Public buildings    | cut the CO2 emissions by 40%                   | Energy efficiency projects and PV projects  | <ul style="list-style-type: none"> <li>• Energy savings of 32,100 MWh/a</li> <li>• Renewable energy 13,700 MWh/a</li> <li>• GHG emission reduce 17,300 tCO<sub>2</sub>eq/a</li> </ul> |
| The Salopelto family (13-14) (Renzerd energy renovation project, 2014) | Single-Family House | Make the house nearly zero-energy              | Replacement of house envelope, and installation of ground-source heat system and PV panel | Renovated to energy class level A;<br>The basement and floor structure(not included in renovation) were found with leaks  |
| Sweden(16-19)<br>(Mahapatra, 2016)                                     | Detached house      | Cost effective and energy efficient renovation |   |   |

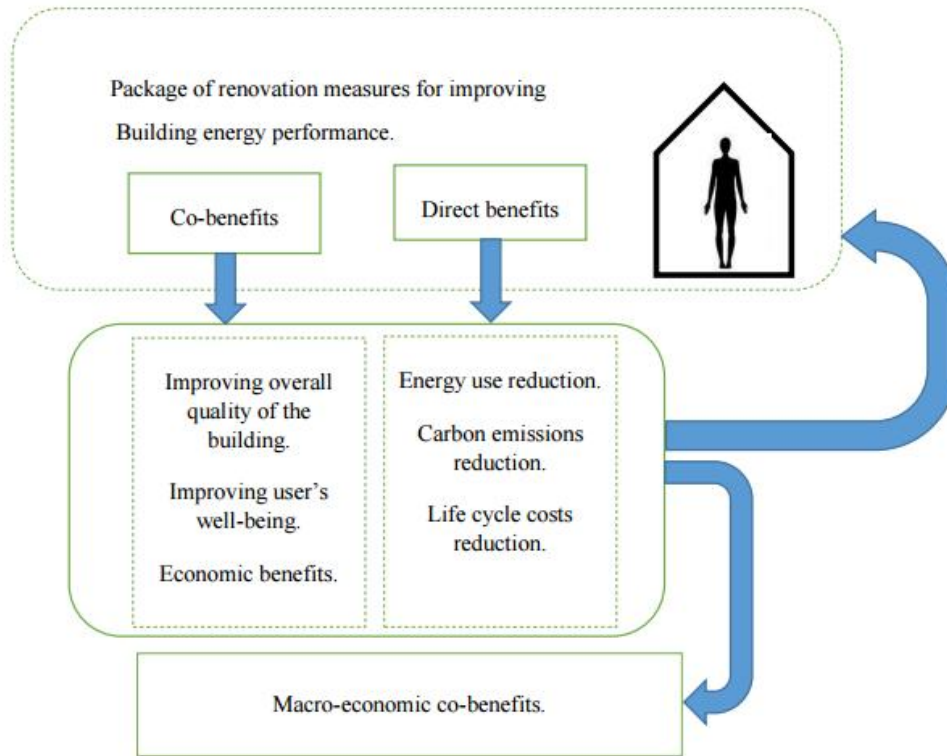
|   |                     |   |   |  |
|---|---------------------|---|---|--|
| SHERPA (16-19)<br>EUR 3,6M<br>(SHERPA , 2017)                           | Public<br>buildings | Reach the EU 20%<br>energy efficiency and<br>25% CO2 emissions<br>reduction target by<br>2020 | Reinforce the capacities of<br>public administrations at<br>regional and sub-regional<br>level to improve Energy<br>Efficiency                |  |
| Office building<br>Frankrijklei 71<br>(BUREAU<br>BOUWTECHNIEK,<br>2011) | Office<br>building  | To change a building<br>into passive building   | limiting the heat losses,<br>Sun protection, new<br>energy-efficient lighting, a<br>preferment ventilation<br>system and night<br>ventilation |  |

### 2.3. Impact and benefits of energy renovation project

There are multiple benefits in investing in energy efficient renovation project on buildings and housings. As it described in the previous chapter, 40% of total energy consumption in EU is accounted by building sector. Moreover, people spend approximately 70% of their time in the building (Jensen, 2015).

Gas is an important energy sources in the Netherlands. In the household, approximately 77.3% of energy consumption is sourced from gas and it is mainly used for house heating. As the consequence of energy efficiency renovation project, the average energy performance in the household increases and energy consumption fell steeply from 2141PJ to 2090PJ between 2000 and 2016. This trend will continue so that the energy consumption is expected to decline to 2,000 PJ in 2020, and 1,933PJ in the 2030. This decline occurs mainly because of the reduction in heating requirement due to the improvement of house insulation. Furthermore, gas consumption is also expected to fall further while renewable sources consumption increases (ECN , 2017).

Therefore, it is necessary to retrofit the buildings since retrofits also provide impact in the construction industry with business during construction and design phase, improving the energy efficiency, indoor health and comfort of their tenants, increasing the value of their homes, creating jobs by employing a wide range of workers, and helping reduce carbon emissions as it shown in Figure 5. Furthermore, since the generation and usage of energy always have some links and networks in most of the cases, although only one renovation is implemented, the benefits and impacts can be multiple. For instance, the introduction of heat recovery ventilation will result in considerable saving of heating energy, better indoor air quality and even centralized cooling (Paiho, 2015).



*Figure 5 Impact of housing renovation (sited from (Regmi, 2016))*

Consequently, energy renovation project will lead to a result of user wellbeing. As Venus described in his study, thermal comfort, indoor air quality, internal and external noise, ease of installation and reduced annoyance and natural lighting had been improved variously after renovation project (Venus, 2017). Moreover, renovation projects can also lead to cost reduction from the perspectives of both energy bills and energy assets exposed to extreme weather condition. This can increase the affordability of energy service. This co-benefit motivates tenants from social housings to request renovation measures.

From the perspective of environment, energy efficiency renovation project can contribute to reduce CO<sub>2</sub> emissions from household. Global warming caused by overuse of energy can be eased as the result of retrofitting projects. This improvement can facilitate the quality of surrounding environment, social and economy (Regmi, 2016).

Furthermore, Næss-Schmidt described that the low EE (energy efficient) scenario would have a much lower annual benefits to the society comparing to the high EE scenario, as it shown in the Figure 6. Not only the part of energy savings would increase significantly, but also the part of health benefits would grow dramatically as the result of renovation project. Moreover, a similar result can be found also in the improvements of public

finance and GDP (Næss-Schmidt, 2012). The improvement of society and economy also included the impact on the job creation (Meijer, 2012).

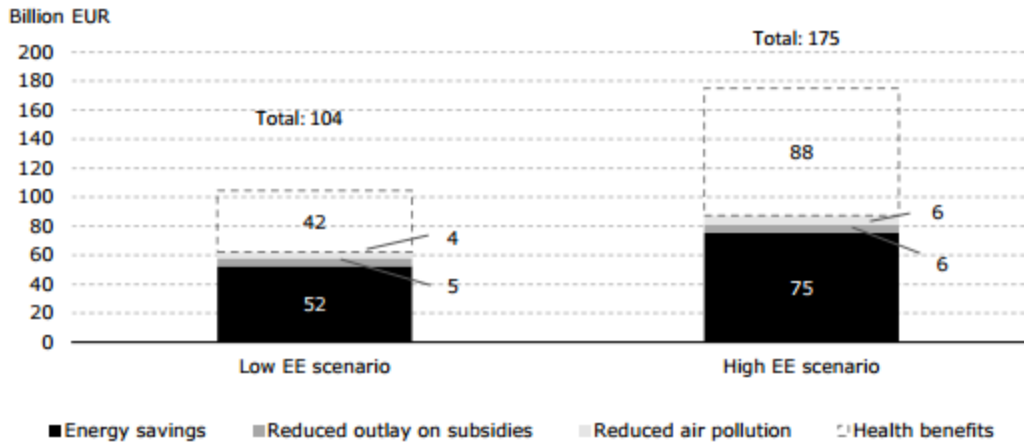


Figure 6 Annual gross benefits to society from energy efficient renovation of buildings, 2020 cited from (Næss-Schmidt, 2012)

## 2.4. Barriers and Solutions

The barriers in social housing renovations projects have been studied in several literatures, especially during the decision-making process. Paiho & Ahvenniemi demonstrated in his study that there might be lack of clarity over who is responsible for change (homeowners or governance) (Ahvenniemi, 2017). Common technical and financial barriers also lag the development of social housing renovation projects. The correlated solutions are also demonstrated following the barriers.

### 2.4.1. Technique

The lack of the knowledge and experience of many stakeholders on the building level as well as on decision-making level slowed down the process of the renovation project. The owners might not know why and how to start with the energy refurbishment, since the total and long-term picture of the energy supply system was not often understood (Levin, 2014). Lack of information and knowledge about energy-efficient and sustainable materials and products can be also conducted as one of the knowledge and technology barrier of the renovation (Palm & Reindl, 2016).

### 2.4.2. Finance

Economical and financial aspects are the greatest barrier for starting energy renovation project (Levin, 2014). The housing organizations are mostly lack of funds and capital to implement renovation project.

Karlsson described his found of barriers in technical aspect: “Existing building structure and technical system limit the choice of technical solutions that can be used but where technical solutions can be found, they are often costly and not financially viable”. Therefore, even though the necessity of the projects has been emphasized during the past few years, the social housing organizations did not have the ability to afford the

cost for a wide range of renovation. This financial problem can also be regarded as one of the technical barriers (Karlsson, 2013).

Furthermore, the organization of ZenN (Nearly Zero energy Neighborhoods) concluded that the discrepancies between predicted and actual savings are also one of the technical barriers that renovation projects are currently facing. This will lead to a result that building owners are unlikely to make return on investment, which reduce their willingness to implement energy renovation project (ZenN, 2013).

Levin also elaborated that the widespread use of simple payback method for investment evaluation is one of the serious financial barriers, since the financial timely changes (e.g. currency change and increasing energy price) were not implemented, which would lead to the underestimation of profitability and positive cash flow effects (Levin, 2014). Therefore, in order to carry out a successful energy renovation project for all the stakeholders, the financial barrier has to be addressed properly.

### **Solution**

In order to receive more funds and capitals for renovations, a funding model is required to be created for the project. It would be the best to have financial assists and funds from government (Levin, 2014). Moreover, the housing organizations can gather more capitals by means of increasing monthly rent to charge tenants for the investment. When tenants express negative opinions for rent increase, housing organizations can provide a living expenses guarantee that the increased rent will not exceed the inflation rate in a certain period for tenants (Trime , 2016).

Financial and technical barriers mentioned above regarding the difference between expectations and outcomes can be solved by gathering the experience from past projects and documents. More accurate expectation can be created in this way. Furthermore, this research helps in offering more renovation measures to the housing organization.

As for the limitation regarding housing conditions, housing organizations can combine housing renovation project together with maintenance and upgrade of the houses (Cash, 2012). Housing conditions can be upgraded and more renovation measures can be installed in the houses consequently.

When the finance problem stops housing organizations from making the decision to renovate, they need to consider the increased dwellings market value as the consequences of renovations. This change of thoughts could encourage motivations for housing organizations. (Trime , 2016)

### **2.4.3. Organizational barriers**

In the same study from Levin, he also analyzed the barrier regarding the lease relationship in social houses. In most of the case, the rent agreement was exclusive of heating and cooling, which meant that the benefits of the renovation investment went directly to the tenants instead of the property owner who made the investment. Therefore, there was less motivation for the property owners to carry out the renovation project (Levin, 2014).

The tenants also refuse to cooperate with the social housing organization because of the increase in their rent as the result of renovation, and inconvenience and disturbance during construction. The tenants have few trusts in social housing organization. They are also not familiar with the energy efficiency goal; therefore, they notice no urgent and necessity in renovation (Levin, 2014).

Besides the barriers related to the relationship, the barriers can also be seen in general organizations of social housing. The building codes mostly focus on new buildings instead of existing buildings. Therefore, the renovations need to be conducted according to the regulation of new built. It is difficult to implement the same equipment and measure in houses with the building years of 1960s to 1970s, which is the common building year of most of the social housings in Europe (related to the first technology barrier) (Levin, 2014).

### **Solution**

When the outcomes of renovation are closely related to tenants, they will be more open towards it. Therefore, one solution to encourage the motivation of tenants to renovate is demonstrating clearly the increased comfort and living condition as a consequence of energy renovation (Trime , 2016).

### **2.4.4. Other possible barriers**

Similar to the barrier of lease relationship, the split incentive is also a significant barrier for renovations. Each stakeholder has its own incentive which is vary from others. For example, the incentive for housing organization is to renovate the houses until energy label A with an economical investment, while tenants wants no increase in their rent with high energy efficient equipment and furniture. If these thoughts cannot be communicated and discussed, the renovation plan is difficult to implement (Palm & Reindl, 2016).

A bad reputation of energy renovation project also occurred as the result of the experiences of low quality and costly investments according to the study of Staniaszek and Volt. Public were skeptical about the outcome of the renovation project due to the reason mentioned in previous paragraphs (Staniaszek & Volt, 2016).

Additionally, they demonstrated that the dwellings' energy performance was viewed as less important than its investment value. Therefore, even though the energy

performance rose due to the renovation, it is still not easy to show the increased value to the tenants (Palm & Reindl, 2016).

### **Solution**

To address the barrier of split incentive, a clear renovation beneficial scheme for house owners and tenants needs to be developed. This can be done through further developing their contracts into the direction of “All inclusive leasing contract” (utility costs are not paid separately) and “green leasing contract” (concrete agreement regarding energy objects and building specific cooperate social responsibility objects). When the tenants and housing organizations share the benefits of renovation, there will be more motivation from both sides (Levin, 2014).

In order to speed up the renovation decision making process, consultants and designers should be involved early in the process. In this way, the project team has more time to develop and consider the critical elements for renovations (Cash, 2012).

### **2.5. Successful factors of past projects**

Not only the lessons from past social housing renovation projects could benefit the process of accelerating social housing renovation project, the model from successful renovation projects can also provide valuable knowledge and approaches. Therefore, this section mainly focuses on describing the models to obtain the knowledge from successful past energy renovation projects.

Staniaszek (Staniaszek, Renovation in Practice, 2015) analyzed in his report about several successful cases in social housing renovation project as following:

The case of stroomversnelling is a successful innovative retrofitting project in the Netherlands. The non-profit market development team gathered six social housing organizations and four construction companies to catch up with the social housing goals in the Netherlands. It implemented a holistic approach to accomplish the goal of zero-energy retrofits for existing social housings. In this case, the development team succeeded in providing quickly construction and no extra cost for the tenants. The successful and key factors are:

- Stakeholders: housing providers, tenants, construction companies and finance providers;
- First implement and evaluate several “prototype”, and then put to the full industrialization phase until all aspects are satisfied by all the stakeholders involved;
- The renovation of the house is achieved within 10 days;
- The amount that tenants pay for housing rent remains the same;
- An energy performance guarantee of 30 years is provided;
- A high degree of off-site industrial prefabrication is conducted to decrease costs while achieving high quality and reducing construction period in the houses;
- Tenants are offered with a comfort, livable and affordable living condition.

The case of Habiter Mieux in France tackled the problem of three quarters of houses falling into inefficient energy label (D-G) and fuel poverty. The case targeted at low-income households to improve their living quality. A comprehensive renovation including thermal insulation and heating equipment replacement was carried out in the dwellings. The successful and keys factors are:

- Stakeholders: Government, national housing coordinator, housing providers, finance providers and project engineers.
- Large-scale national program funded (a clear fund and financial scheme was made to elaborate) by public budget for low-income housing sector
- Thermal diagnosis (technical visit) before renovation
- Realization of thermal renovations was leaded by the cooperation with project engineering and financial engineering.

Another case of Bridgend in UK (Cash, 2012) indicates their successful and key factors as:

- Stakeholders: Government, housing providers, finance providers, investors, designers, tenants and project engineers.
- All the stakeholders involved from the early stage (planning and design stage)
- The owners and joint representatives were also involved in the early stage
- Project monitored by private investors and government

NeZeR described a renovation in apartment building in the case of Groningen in the Netherlands. The renovation contained 168 units with poor insulation, ventilation and indoor air quality, built from 1966. The energy consumption before renovation was 265 kWh/m<sup>2</sup> /year. The structure there was with small apartments and large loggias. The successful and key features of the case are as following (NeZeR, 2014):

- Focus on tenants satisfaction (1 on 1 tenants guide, Safety first and customer-friendly contact during process)
- Set a specific goal of zero energy consumption with Larger apartments, better indoor air quality, higher comfort level after renovation
- Short construction period and minimal building activities on site
- First renovate several demo apartments
- Fresh and modern look externals
- Affordable for tenants and housing organization

There are more successful social housing renovation project carried out until now. Some of them indeed have their unique successful factors, such as a case of an apartment building “De Wachter” in the Netherlands. This project has included a mix of commercial rent and social rent, which made it possible for the project to include high quality renovations with rents below the requirement for subsidies (Reshape, 2009). The other projects in most of the time have some common factors that lead the project to success.

Affordable and easy finance: Finance problem as the biggest barrier for the social housing company to carry out the renovation project, needs to be taken into consideration from the very beginning of the project, and needs to be tracked and monitored all the time during the project. The companies need to make sure that they have enough funds, supports or loans to support the project, and sufficient agreements with the stakeholders and tenants regarding financial distribution.

Involve stakeholders (including tenants) in the early stage: This aspect can also be described as planning everything in the early stage. Energy renovation project is relatively comprehensive; therefore, it is significant to plan everything beforehand from various aspects, such as finance, construction and design aspects. Early involvement of stakeholders leads to lower likelihood of insufficient design and higher likelihood of efficient design since they have more time to understand and consider the project. Furthermore, early involvement grants possibilities to create solutions and development of ideas (Lehto, 2011). As for the tenants, they also need to be involved in the early stages, since they are the property “owners” in the project. This involvement means the agreement on renovation project including rent adjustment and construction period agreement. Involving all the stakeholders is essential for the smooth process of the project.

Good tenants’ satisfaction: Tenants are the main beneficiaries of the renovation projects. This is also one of the major challenges in the renovation projects. The project team is required to understand what the true requests from tenants are instead of determining everything on their own. When tenants are not satisfied with what has been promoted, the project cannot be regarded as a true success (Sanderson, 2016).

Besides the factors mentioned above, demonstration project, and specific and sufficient goal seems to be other important factors that could lead the project to success. Demonstration houses are implemented to provide basis processes and products in the project. Demonstration contributes to reduce uncertainty through new information. Therefore, renovation details can be assessed during demonstration houses, and it could bring innovative idea to the construction (Koch, 2014). As for the aspect of specific goals, it provides clear outlines of the expectations and addresses realities. By doing so, the success rate can increase by up to 70% since everyone knows exactly what the priorities are. During the early stages, it is more important to agree on goal meanings instead of details, so that the project team can make full use of early stages in the project (Brandeis, 2018) (Woodruff, 2018).

On the other hand, there are also features that have high possibility to lead the projects to an insufficient result. Hoppe (Hoppe, 2012) analyzed eight renovation projects in the Netherlands to gather the lessons that renovation projects could learn from:

- Lack of financial feasibility assessment in the early stage of the renovation
- Renovation goals are over-ambitious

- Delay caused by unexpected situations
- Lack of trust from the tenants

All these elements are the contrasts of the successful elements mentioned above. Therefore, paying attention to the successful factors during implementing renovation projects is significant to the outcomes of the project.

## 2.6. Renovation (energy saving) measures

It is essential to understand some common retrofitting techniques in order to assess the renovation project from the choice of renovation measures. The common ways to improve energy efficiency are: 1) Control the usage of all energy sources, such as water and electricity, in the building; 2) Purchasing energy star products; 3) Switch off computers, and unplug battery chargers during long periods of non-use (Jamison, 2016); 4) Install solar panels; 5) Make sure the insulation of the walls and windows; 6) Improve the efficiency of the furnace and hot water system (Sachs, 2009), etc. As a conclusion of the methods mentioned above, upgrading and installing the equipments and isolations is the most important and common way to improve the energy efficiency in the buildings. The general energy saving measures in residential buildings can be seen in Figure 7.

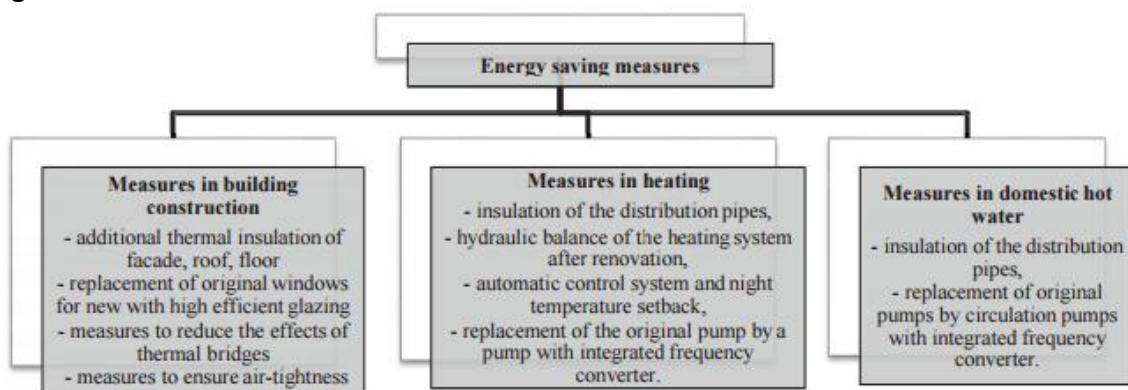


Figure 7 Energy saving measures for residential building renovation cited from (ková, 2015)

Some literatures demonstrated some specific renovation measures that were implemented in their specific cases. For example, Carreón (Carreón, 2015) summarized that of building envelope in his study as shown in Table 26 in Appendix A. In addition, Visser (Visser, 2014) indicated several renovation measures in his thesis, as shown in Table 27 in Appendix A. Palm and Reindl (Palm & Reindl, 2016) also show presented some of the renovation measures that are shown in Table 28 in Appendix A.

The renovation measures mentioned above are all currently commonly used in housing renovation project. Venus elaborated renovation measures from another aspect, which include BITS (building integrated technical systems) – measures on technical systems for heating, domestic hot water, cooling, auxiliaries, lighting, ventilation and common

appliances; Investigated energy sources for heating and domestic hot water production – energy sources that were investigated in the parametric studies (Venus, 2017).

Understanding these commonly implemented renovation measures can indicate the efficiency and value of the project from the choice of renovation. These measures are used in the later chapter to compare with the Eckart project to evaluate the project from the choice aspect.

## **2.7. Assessment Methods and Tool for evaluating renovation project**

A proper and sufficient assessment method and tool is essential in helping of developing and evaluating an energy efficient renovation project. The process of the project might show no delay or problem during and after the renovation. However, the true value and result of the renovation project need to be assessed from different aspects, such as stakeholders' interest and satisfaction, financial outcome and energy performance. In this section, the common evaluation tools for assessing and evaluating energy renovation project are studied to obtain the insights of evaluation.

### **2.7.1. Post Occupancy Evaluation (POE)**

POE is one of the oldest and most common methods to evaluate building performance; therefore, it is suitable to use this method to assess the project with the performances data before and after the renovation. The main purpose of conducting POE is to improve the ways that buildings are used to support productivity and well being. This evaluation is normally conducted with the combination of user surveys and technical measurements for indoor climate after the occupancy of the building. The POE process provides value-neutral prompts to stimulate stakeholders to make testable observations about their experiences of buildings' effect on productivity and wellbeing. The main focuses in this method are classified as generic methods, beauty, usability and technology (Preiser, 2005).

Post-Occupancy Evaluation is capable of (Bre, 2018):

- Discovering any immediate problems and situations that can be addressed and solved
- Emphasizing the gaps and barriers in communication and understanding between various stakeholders that have impact and influence on the building performance
- Providing guidelines and lessons to improve the renovation projects in the future
- Acting as a bridge between various projects for comparisons over time

Therefore, POE is a sufficient tool to assess the renovation project for improving building performance. It has also benefits for the housing organizations that have multiple renovation tasks, since they can learn the lessons from past mistakes during different processes of the renovation.

### 2.7.2. Interview

Interview is a commonly used qualitatively assessment method to obtain professional knowledge, views and experience (Mason, 2002). It is one of the best methods to collect detailed personal information from individuals. The three categories of interview are structured interview, semi-structure interview and unstructured interview. Furthermore, the main types of research interviews are brief survey, extensive survey, in-depth interviews and monologue. The primary advantage of In-depth interviews is that it provides rich information compared to what can be obtained through other data collection. People could answer spontaneous questions that they need to express themselves. However, the results obtained might be not generalisable. Semi-structured interview is a more commonly used methods since it offers considerable researcher flexibility. Moreover, the questions are partial pre-planned, so accurate answers related to research questions can be obtained (Woods, 2011).

Many literatures also conducted interviews as their methodology to gather relevant information and data. Gaitani conducted semi-structured interview in his thesis in order to gain in-depth knowledge of the involved stakeholders (including the project manager of the case, municipality, university and architecture company), and to assess the challenges of holistic approach for sustainable development. The in-depth interview helped him to better understand the selected case, and how the experience of the selected case can be implemented to a more general situation. Although the results demonstrated that the selected case was difficult to applicant in general cases, the interview approach have still provided a reliable output for the case (Gaitani, 2014).

Rahola implemented both interviews and questionnaires for energy renovation expert from EU countries to fill the knowledge gap between the project delivery methods and the potential for energy renovations. Design-build-maintain has the maximum potential to deliver energy savings because it facilitates collaboration between the various actors and promotes their commitment to achieving project goals. (Rahola, 2013)

The general approach of interview analysis starts with building themes through process of coding, and then study focus as orienting focus for the formulation of themes. The themes are required to be reduced to five and seven at the end. Coding system needs to be made in relation with the research questions, and all relevant data needs to be organized into codes.

The qualitative data analysis is iterative, and it begins with analyzing preliminary analysis during data analysis. This involves critically the reflection on the collected data to build up a knowledge regarding the emerging issues and follow-up. This process is required to be repeated until research question is answered and no new data is emerged. Afterwards, the thematic analysis is conducted to identify recurrent patterns in order to reduce data amount (Braun, 2006). The process of thematic analysis is shown in Figure 8.

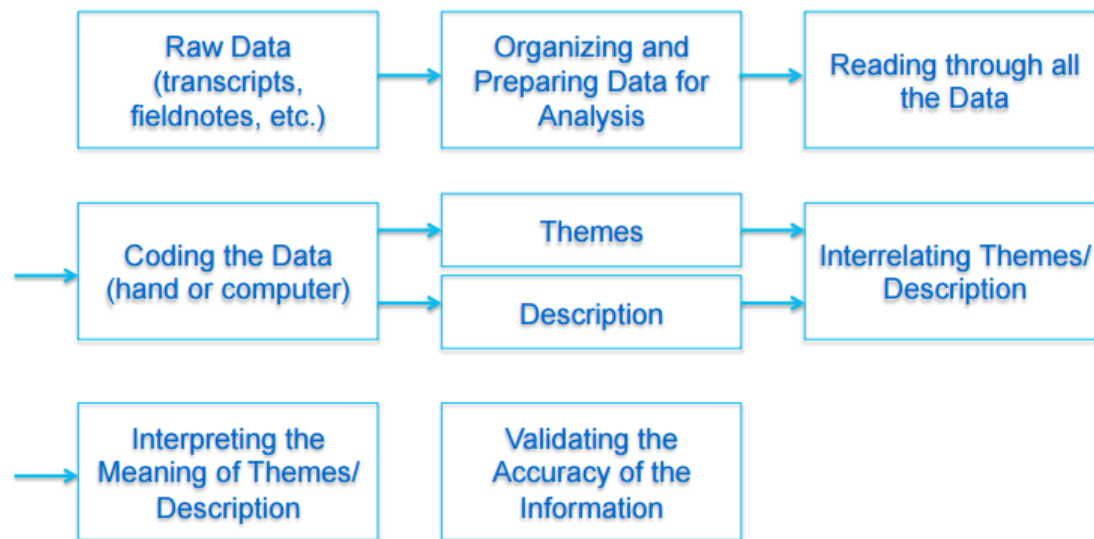


Figure 8 The process of thematic process (cited from Presentation)

The method mentioned above is commonly used for qualitative analysis that has one interview question to multiple interviewees. This coding system can be implemented to obtain the common outcome for a specific phenomenon and topic. This outcome can reflect a reliable result for the questions.

### 2.7.3. Life Cycle Assessment (LCA)

Life cycle assessment is commonly used in different fields for the assessment of sustainability. When it is implemented in renovation sector, this methodology can be used to encourage and support building owners to evaluate various renovation alternatives from the aspects of environment, economy and society (Mjörnell, 2014). Many studies have implemented LCA as their assessment tool in office buildings, such as the study from Su (Su & Zhang, 2007). The main focus of this study is to identify and quantify the energy consumption and environmental emissions during the life cycle of office buildings. It started from analyzing building energy system in life cycle, and then various energy parameters and inventories are analyzed and calculated to obtain the comprehensive understandings the relationship between building behaviors, and energy consumption and environmental emission of different materials. As the result, the most optimized scenario of material combination for office building.

Furthermore, the study from Erlandsson and Levin (Erlandsson & Levin, 2004) analyzed different renovation scenarios though calculating the difference of environmental performance between existing houses and houses after renovations by terms of life cycle analysis and case study. Various energy generation methods are assessed in terms of energy production, transportation and future forestry. Moreover, energy consumption and energy conservation measures are analyzed to assess different approach. Consequently, the case study implemented inside achieved a reduction of 70%

for heating service and 75% for wastewater system, which is similar to what has been expected from the calculations.

Therefore, LCA is an efficient and proper method to assess the building improvement from the aspects of energy consumption and environmental emissions. However, this report is mainly focus on the heuristic method for social housing decision making process. Environmental elements are indeed significant to assess, but specific expenses on the renovation is a more important aspect to assess.

#### 2.7.4. Life Cycle Cost Analysis (LCCA)

Life-cycle cost analysis (LCCA) is a method for assessing the total benefits of facility ownership from different aspects. It takes into account all the balances of acquiring, owning, and disposing of a building or building system (Fuller, 2016). It is a part of the whole life costing. The cost optimal level refers to the energy performance that leads to the lowest cost during the life cycle of the project; therefore, the purpose of an LCCA is to estimate the overall benefits of project alternatives and to select the design that ensures the facility will provide the sufficient overall benefits of ownership consistent with its quality and function. It is essential to implement LCC during the decision making process is because of the time value of the currency, and similar ratio between maintenance, operation and utility cost, and initial investment, as it shown in Figure 9. Typically, performing an LCCA study involves:

- (1) Establishing objectives for the analysis,
- (2) Determining the criteria for evaluating alternatives,
- (3) Identifying and developing design alternatives,
- (4) Gathering cost information,]]
- (5) Developing a life cycle cost for each alternative (Reidy, 2005).

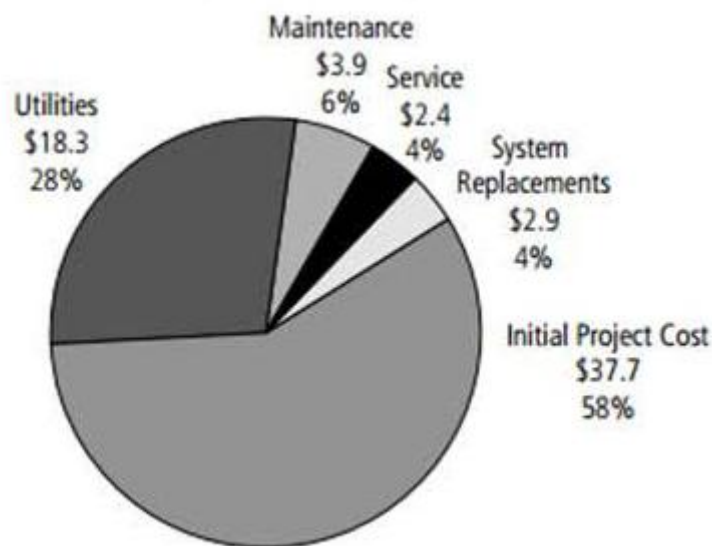


Figure 9 Building 30-year life cycle cost (million dollars) (cited from (Coban, 2018))

A widely used methodology for assessing the feasibility of the social house company Life Cycle Cost Analysis (LCCA) will be viewed. Two literatures below demonstrate the example of implementing LCCA: the case of Cattolica (Giuseppe, 2016) and a case from Portugal (Almeida & Mateus, 2017).

The case of Cattolica is a renovation project for a single-family detached house with building year of 1990. The housing organization proposed three different scenarios with one original control for the renovation that has a life cycle of 20 years. Due to the uncertainty quantification of Life Cycle cost, this study proposed to combine building simulation and LCC analysis. As a result, besides calculating LCC by the formula proposed by the author, additional LCC module software was also used in this case to transform the sample generation to UA and SA global cost to improve the accuracy of the result (Giuseppe, 2016).

As for the case in Portugal, the project mainly focused on the buildings that were built in the 1950s. There were no insulations on the envelope, no heating and cooling system, even the hot water was heated by electricity and was stored in a tank. Due to these serious conditions, several renovation scenarios were assessed by LCCA to obtain the best choice for this case. The assessment started with the calculation of energy requirements and primary energy consumption in the building for each renovation scenarios considered and the calculation of the related global costs taking into consideration of the limit of cost effectiveness. Eight scenarios were analyzed for the balance between cost efficient and energy performance, as it shown in Figure 10 (Almeida & Mateus, 2017).

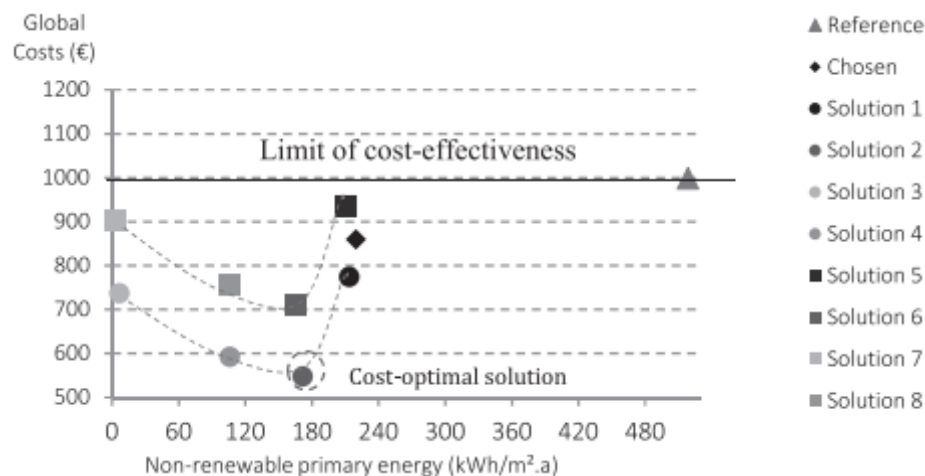


Figure 10 The result of LCCA (cited from (Almeida & Mateus, 2017))

There are more implementations of LCCA in various projects, and the two cases shown above are the commonly used method to interpret this method. In this thesis, the

interpretation of LCCA varies from its common usage. More specific information and analysis can be found in chapter 4.

### 2.7.5. Other possible assessment methods and tools

The most direct way to exam energy renovation project is to measure and compare the differences of energy consumption. Carreón summarized four techniques and tools to evaluate energy performance in heritage buildings as it shown in table 3. Due to their measurement abilities, the tools could be used in both detecting where need to be enhanced and how well the improvements performed (Carreón, 2015).

*Table 3 Techniques and tools to evaluate energy performance of heritage buildings  
(cited from (Carreón, 2015) )*

| Technique     | Description   | Tool   |
|---------------|---|--|
| Air tightness | Air permeability and location of air leakage paths  | Blower door  |
| Thermograph   | Assessment of insulation continuity and measurement of thermal irregularities                                 | IR camera  |
| Heat flux     | Derivation of an in situ “U” value for the building element   | Heat flux sensors/<br>Temperature sensors  |
| Co-heating    | Heat losses measurement resulting from both infiltration and thermal transmission through the building fabric | Electrical heaters and<br>thermostatic controller/<br>Temperature and relative<br>humidity sensors/kWh meter |

However, the improvement from data comparison can sometimes only elaborate renovation measures from energy saving aspect. In order to provide a proper evaluation, the renovation measures need to be assessed from various fields. Eriksen elaborated a method of holistic, which entails equivalent consideration of energetic, structural, economic, architectural and social aspects (Degan, 2014). The purpose of this evaluation is to provide a standardized and holistic evaluation of buildings to renovate during the prefeasibility study phase (Eriksen, 2013).

In another report, Jensen developed his own method, RENO-EVALUE, to evaluate energy efficiency renovation project through 4 case studies in Denmark. It is a tool, which covered four main categories: Stakeholders, Environment, Project organization, and Economy, for holistic assessment of sustainability in building renovation projects. It can be used in both supporting decision-making process and evaluation the renovation project, even as a tool of communication between various stakeholders and comparison between alternative renovation proposals (Jensen, 2015). The evaluation method is to illustrate a spider’s web according to the grade (1~5) of different factors among all the stakeholders. By means of the comparison between the rating before and after the renovation project, it is possible to compare the expectations with the final results (Jensen, 2015).

Additionally, there is some internationally used sustainability assessment tools also applied in measuring energy renovation projects. Ameen reviewed five widely used methods in her research: BREEAM Communities, LEED-ND, CASBEE-UD, Pearl Community Rating System (PCRS) and GSAS/QSAS (Ameen, 2015). However, the methods and tools mentioned above have a narrow environmental or energy focus. The recent trend is towards development of more holistic tools for sustainability assessment and certification including also social and economic aspects, such as the international SBTool, the Australian CASBE and the German DGNB (Jensen, 2015).

## 2.8. Conclusion

In this chapter, literature review regarding current situation of social housing renovation project is conducted. The literature concludes that the barriers from the aspects of technology, finance and organization lag the development of social housing renovation project. It is essential to overcome all these barriers that have direct and immediate effect on the project before stating the project to ensure the success of the project. Moreover, the successful factors including demonstration houses and easy financial plan could help the following social housing organizations to set a feasible and reliable plan from the beginning of the project. As for renovation measures, they can be divided into three categories, and most of the organizations mainly focus on building construction category.

Project evaluation methods and tools are also elaborated in the literature review. In order to answer the research question proposed in this thesis, the methodology regarding in-depth understanding of the case project to answer the first part research question. Moreover, the methodology that can assess financial feasibility and tenants satisfaction are required to answer the second part of research question. Therefore, interview and LCCA are chosen as the methodology of the thesis to answer the two questions.

### **3. Research Approach**

#### **3.1. Introduction**

In this chapter, the methodologies used in the thesis are elaborated and explained. In order to provide proper and sufficient outcomes, both qualitative and quantitative methodologies are implemented. They are case study, interview and LCCA. The first two methods were chosen since the evaluated project is distinct and specific. The project indeed has some similar characteristic as common ones, but its uniqueness is the main aspect that needs to be assessed. LCCA is chosen to evaluate the financial feasibility in long-term. More specific arguments are given in the following sections.

#### **3.2. Methodologies**

##### **3.2.1. Case study**

###### **3.2.1.1. Motivation to use case study**

Case study is one of the most flexible research designs; it allows the researcher to retain the holistic characteristics of real-life events while understanding a complex issue or object (Schell, 1992). Therefore, in order to understand the current situations of energy efficiency renovation projects and their problems, the method of case study can convert this abstract subject to a real-life situation that is easier to understand and observe. This research process becomes consequently concrete and constructed. The method is also necessary for the in-depth understanding of the aim of this thesis and the structure of the research.

###### **3.2.1.2. Case selection**

The case selected for this thesis is Eckart project in Eindhoven conducted by social housing corporation Woonbedrijf. This is a social housing energy efficiency renovation project and its concept is unique compared to ordinary social housing renovation. This project is also one of the projects within the range of Triangulum project; it is a highly valuable case.

##### **3.2.2. Interview**

###### **3.2.2.1. Motivation to use interview**

The purpose of conducting interviews is to gain knowledge and insight regarding this specific project. Therefore, the concrete knowledge is necessary, and the first-hand information from the closest people is the best way to obtain descriptive data on the personal experiences of the interviewee. A key feature of semi-structured interview is partially pre-planning interview questions. Therefore, new questions raised in the interview can also be answered, which leads to comprehensive outcomes that cover all the aspects (Gaitani, 2014). Semi-structured interview also provides more insight and detailed information compared to questionnaires and surveys especially for some spontaneous questions that participants need to express themselves. Therefore, semi-structured interview is implemented in this report to obtain the valuable and in-depth information from different stakeholders (Rahola, 2013).

#### **3.2.2.2. Interview data Collection**

Data was collected through semi-structured face to face interviews for the input of the case with different stakeholders from March to June 2018:

- Project manager of Eckart project, Woonbedrijf (14-03, 28-03, 18-04, 07-05)
- Project manager, Woonconnect (25-04)
- Project manager, Jansen Huybrechts Projecten BV (04-05)
- Tenants, (30-05, 05-06, 07-06)

Four interviews were conducted with the project manager of Eckart project (Woonbedrijf). The main topic of the interviews was related to various situations in Eckart project. After the background knowledge from literature review, the main interests from the author are the barriers, risks and the corresponding solutions of them. Additionally, stakeholders and tenants involvement were also discussed in the interview. Other related general questions, such as why the project was selected and how the concept was developed are also asked for in-depth understanding.

The interview with project manager of Woonconnect is to understand the basic function and duty of Woonconnect in the project, and whether it contributes to the success of the project. Other general questions such as establishing purpose and future vision are also asked for better understanding a new mode of communication. Moreover, the interview with the contractor from Jansen Huybrechts Projecten BV is conducted to obtain the knowledge regarding technology and construction of the project. Interesting and essential features that only happen during constructions can be obtained from this interview.

Interview with tenants mainly focuses on tenants satisfaction aspect in the project. This includes the perspective of project concept, living condition improvement, information exchange and construction process. Two of the tenants (indicate tenant A and tenant B) are the tenants from demonstration houses, and another one is the household that going to renovate soon (indicate tenant C).

These stakeholders were selected since they all work closely on the whole process from developing the concept to implement the final construction. These stakeholders have different duties and responsibilities in the project; therefore, separate interview questions regarding specific topics are required for comprehensive understanding of the project. There are also other stakeholders in the project, such as a third party evaluation company and research companies. However, since they both do not play a key role at current stage, and they only have little influence to the whole project, they are not involved in the interviews. All the interviews were recorded and written down on paper. The interview questions and answers can be found in Appendix B.

#### **3.2.2.3. Interview analysis method**

Qualitative data analysis is different from quantitative data analysis. There are no clear rules but guidelines on how to conduct it. Qualitative analysis also starts with

hypotheses, but developing working hypotheses and tests them during data analysis. In this thesis, since the interview object is only one specific expert questions instead of number of interviewees with different project related, using the common method mentioned above is insufficient. Therefore, the main analysis implemented in the thesis is to obtain the insight of Eckart case from the interviews and analyze the successful factors to implement them in general cases.

Therefore, hypothesis causal relationships between different elements, as shown in Figure 11, are first established, and then the interview questions will evaluate these relationships to obtain the essential criteria and elements. All these hypothesis factors and relationships are formed based on the literature review and case study.

This causal structure can be mainly divided into three parts: factors that can encourage success of the project, factors that can lag success of the project, and criteria to judge success of the project. The structure is decided since literatures indicate that the lagging factors are the reason current social housing organizations cannot conduct a successful renovation project, and successful factors would lead the project to success. Therefore, these are the important factors to consider for assessing a practical project and its concept to draw the conclusion at the end. Moreover, the criteria are set to double check with the finding of this thesis to provide a reliable guideline for following social housing organization at the end.

In the consumption barriers and risks are set as the two main factors that could lag the success of the project. These are set due to the different barriers and risks that highly influenced the project process mentioned in the literature review.

As for the factors that could encourage success of the project, they are formed in combine with some common elements, such as early stakeholders involvement and demonstration houses, and some unique elements, such as the involvement of “Woonconnect” and different implementations related to tenants’ focus. Through the assessment of these relationships, the elements that are essential for the project can be obtained, and the advices for new type of social housing renovation method can also be composed.

The criteria to judge success are the last part of the causal structure. The hypothesis part mainly focuses on the degrees of completion of the project goal. More specifically, whether the project goal is fulfilled in an ideal way is the standard for judgment. The most important element in hypothesis for this part is the cost difference between ordinary renovation project and “one at once” renovation. Project cost increases from material and times aspect when carrying out “one at once” renovation. Because Woonbedrijf assume that the project cost would be similar for project life cycle, it is essential to test it from a long term insight. Through the assessment of these relationships, the feasibility of the project can be evaluated. If the outcomes are positive, then this project is feasible from company and contractors aspect, vice versa.

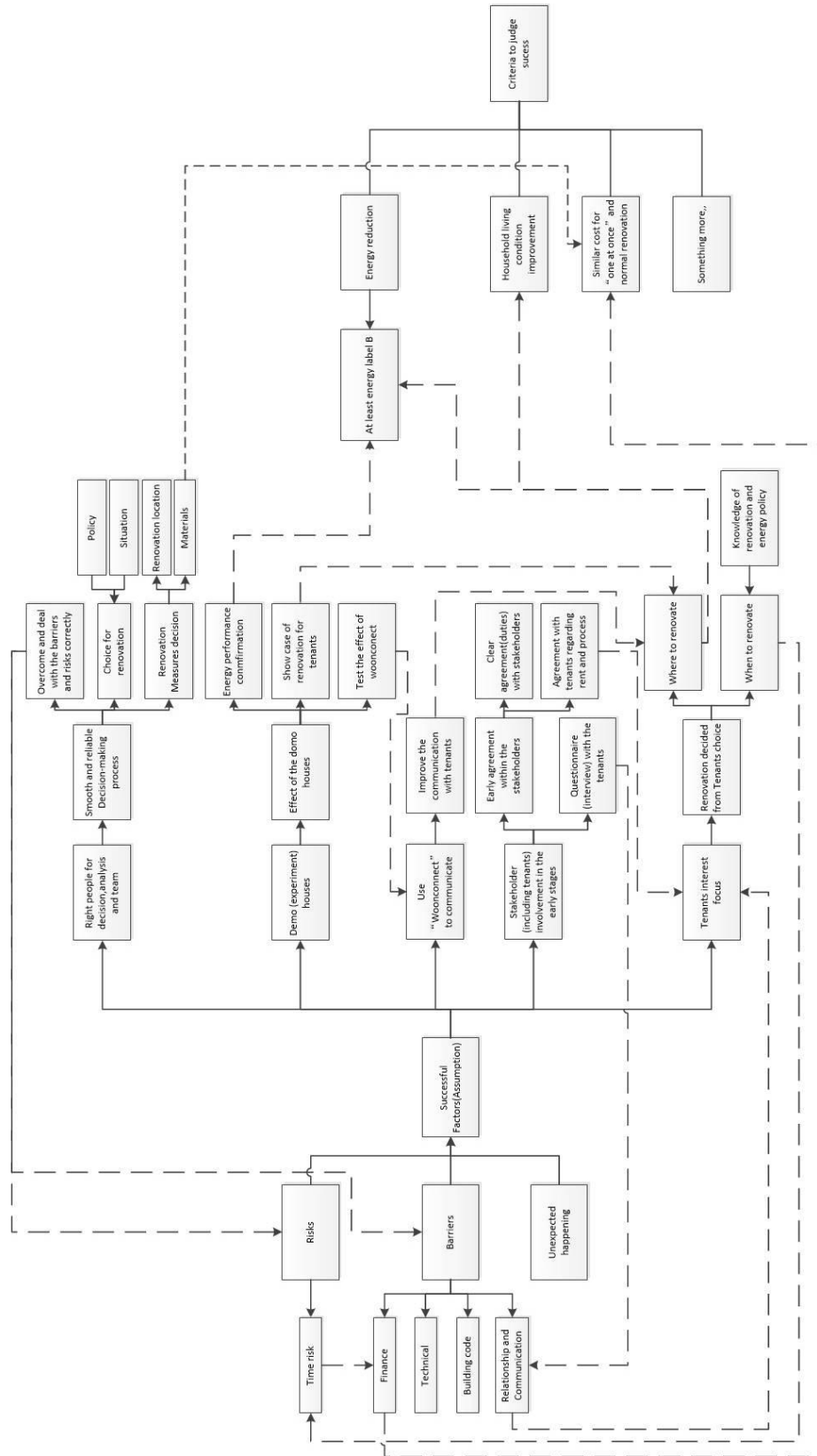


Figure 11 Hypothesis causal relationship of successful elements and factors

The semi-structured interview is formed based on these hypothesis causal relationships. After obtaining all data from different stakeholders, the coding system will first demonstrate the critical elements for the project. The outcomes can be used to modify hypothesis causal relationships into an accurate and case oriented structure. At the end, the causal relationship will indicate the essential elements that could affect the success and feasibility of the project.

### 3.2.3. LCCA

#### 3.2.3.1. Motivation to use LCCA

Life Cycle Costing (LCC) is defined in the International Organization Standardized standard as *“economic assessment considering all agreed projected significant and relevant cost flows over a period of analysis expressed in monetary value. The projected costs are those needed to achieve defined levels of performance, including reliability, safety and availability”* (ISO, 2008). Therefore, LCC is a sufficient tool to assess a real estate development from various alternatives to test a long term planning and budgeting to improve the feasibility of the project. In addition to the similar ratio between early stages and later stages in renovation project as shown in the literature review, the distribution of building life cycle stages also represents the significance of analyzing in a comprehensive aspect as it demonstrated in Figure 12. The cost for initial stages disappears after the first peak of investment, while the other costs remain at a similar level during the whole life cycle. Therefore, it would be not rigorous to only consider the costs of initial stages for estimating the whole project, and the cost from each stage need to be considered with currency value to obtain the sufficient result.

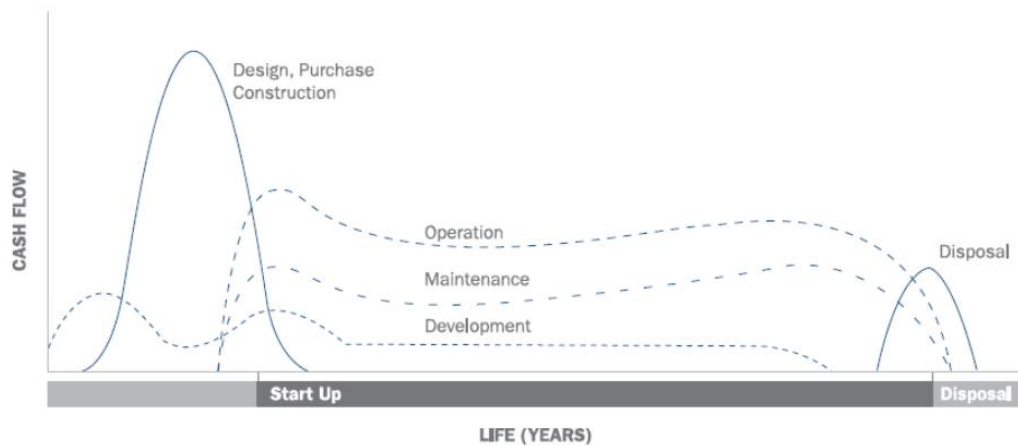


Figure 12 Building life cycle stages (cited from (Australian National Audit Office, 2001))

In this thesis, instead of choosing the optimal solution for the project, LCCA tool is mainly used for comparing the financial outcome for the specific case and ordinary cases. These certain cases includes the analysis for currant “one at once” type renovation, the analysis for hypothesis common renovation (renovate together), and hypothesis no renovation. In this chapter, the model for LCCA is first analyzed, followed with the calculation and result of LCCA to assess whether the Eckart renovation project

is feasible from financial aspect.

### 3.2.3.2. LCC Model

In order to obtain the correct and proper assessment at the end, an appropriate model needs to be implemented. The typical asset of LCC in renovating an existing building can be expressed as:

Life Cycle Cost = initial (projected) capital costs + projected life-time operating costs + projected life-time maintenance costs - projected residual value (ICMAB, 2014). The mathematic formula is shown in formula 3.1.

$$LCC = C_0 + \sum_{t=0}^T OCost + \sum_{t=0}^T MCost - RCost \quad (3.1)$$

Where

|         |                                       |
|---------|---------------------------------------|
| $C_0$   | Initial (projected) capital costs     |
| $OCost$ | Projected life-time operating costs   |
| $MCost$ | Projected life-time maintenance costs |
| $RCost$ | Projected residual value (cost)       |
| $T$     | Life cycle period (in year)           |
| $t$     | Number of Period (in year)            |

All the costs need to be standardized by annualizing the costs, which will result in having the present value of these investments in order to make the investments comparable across the schemes. This process is essential since the value of currency and other factors, such as building cost, changes over time. Initial capital costs are already present value; therefore, no change needs to be conducted. Operation costs and Maintenance costs exist through the whole life cycle; the present values are obtained through the discount from their future value as it shown in Formula 3.2 (Geltner, 2007). Residual value appears at the end of the life cycle. Its present value is also calculated based on formula 3.2.

$$PV = \frac{FV}{(1 + r)^t} \quad (3.2)$$

Where

|      |                            |
|------|----------------------------|
| $PV$ | Present Value              |
| $FV$ | Future value               |
| $r$  | Discount rate              |
| $t$  | Number of Period (in year) |

Therefore, the formula 3.1 can be written in:

$$LCC = C_0 + \left( \frac{O\text{Cost}_1}{(1+r)^1} + \frac{O\text{Cost}_2}{(1+r)^2} + \frac{O\text{Cost}_3}{(1+r)^3} + \dots + \frac{O\text{Cost}_T}{(1+r)^T} \right) + \left( \frac{M\text{Cost}_1}{(1+r)^1} + \frac{M\text{Cost}_2}{(1+r)^2} + \frac{M\text{Cost}_3}{(1+r)^3} + \dots + \frac{M\text{Cost}_T}{(1+r)^T} \right) - \text{pvf} \times \text{RCost} \quad (3.3)$$

Where

pvf Present value factor  $(1+r)^{-T}$

r Discount rate

T Life cycle period (in year)

As the components of different elements in LCC, according to ISO (ISO, 2008), typical LCC analyses are conducted based on:

1. Construction costs (initial cost) and all associated costs such as delivery, installation, commissioning and insurance;
2. Operational costs, including utility costs such as energy and water use;
3. Maintenance costs, including all costs of replacement, maintenance, repair and adaptation of the constructed asset;
4. End-of-life costs such as removal, recycling and refurbishment.

Therefore, each component is required to first be identified and then calculated separate to obtain the final result and comparison. End-of-life costs reflect the project residual value. The common and general elements for each component are shown in Table 4. The calculation is mainly conducted in a excel sheet since the project is not too complicated.

*Table 4 Common and general elements for each component in LCC (ISO, 2008),*

| Investment cost                      | Operational cost                    | Maintenance cost |
|--------------------------------------|-------------------------------------|------------------|
| Decision making cost                 | Website operating cost              | Replacement cost |
| Material cost                        | Contract cost                       | Repairmen cost   |
| Design cost                          | Re-habitat cost                     |                  |
| Website cost                         | Energy usage (Electricity, water..) |                  |
| Technical advice and information fee | Failure cost                        |                  |
| Legal and compliance fee             | Pollution cost                      |                  |
| Visit cost                           | Insurance                           |                  |
| Taxes                                |                                     |                  |

### 3.2.3.3. LCCA data collection

Finance data for analyzing Life Cycle Cost is obtained from Woonbedrijf project manager. As the project is currently at the beginning of realization phase and tenants have the decision on renovation details, many hypothetical conditions are implemented to obtain reliable outcomes. More detailed information and the LCCA results can be found in section 4.3.



## 4. Eckart case study

### 4.1. Overview of the case

#### 4.1.1. Current situation and renovation decision

The area of Eckart is located at the North part of Eindhoven. In this area, average temperature is 3.1°C in January and 17.5°C in August. It receives average global horizontal radiation of 1020 kWh/m<sup>2</sup> yr, and annual heating degree days of 2978°Cd/yr (calculated according to base temperature 16 °C). The houses there were mainly built from 1967 to 1969. The condition of house itself still remains fine. However, the energy labels of the houses are pretty low (D or E), since the roofs are not at all insulated, and there is serious problem with ventilation. The types and locations of the houses are shown in Figure 13.

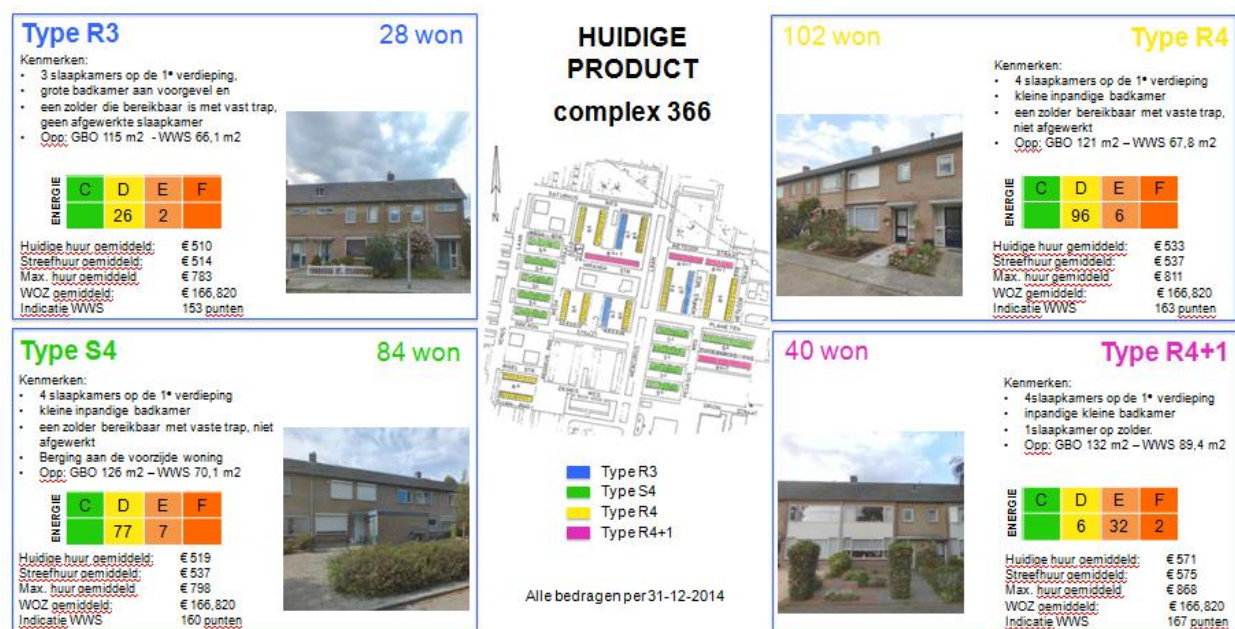


Figure 13 Types and location of renovation house (source: woonbedrijf)

Eckart area was chosen to be renovated since:

1. It is already under the requirement of maintenance;
2. The Eckart area is one of the locations within the range of “Trangulum” project, and it is the complex of dwellings that make the biggest improvement. Therefore, it is a perfect match for Eckart area;
3. All social housing corporations have the agreement to improve their houses to an average energy label B in 2021.

The Triangulum project is “one of nine European Smart Cities and Communities Lighthouse projects, set to demonstrate, disseminate and replicate solutions and frameworks for Europe’s future smart cities. The flagship cities Manchester (UK), Eindhoven (NL) and Stavanger (NO) will serve as a test bed for innovative projects

*focusing on sustainable mobility, energy, ICT and business opportunities.”* (Triangulum, 2018). In Eindhoven Eckrt-Vaarbroek is one of the project areas and the goal is to reduce CO<sub>2</sub> emission in the houses, and understand that although housing association owns that houses, but tenants are the true owners.

#### **4.1.2. Basic concept of Eckart case**

The basic concept and principle of the Eckart renovation project is to renovate social houses according to the preference of the tenants; it is called “series of one”. More specifically, *“an individual house in a block of houses can be renovated at the most convenient time of the tenant according to his or her individual choices – and not when the housing association deems it appropriate.”* (Triangulum, 2018) Since the company provides their tenants a web service called “WoonConnect” where they can visualize energy and house renovation options, the tenants are capable of choosing their own renovation options without difficulty.

Woonconnect is an online system that visualizes energy performance and renovation measures in 3D model. It is one of the experimental objects during the Eckart renovation process. The main purpose of this system is to ease the communication between tenants and Woonbedrijf regarding renovation measures and starting time. Woonconnect has been developed for six to seven years specifically for this market. People can see the consequences of their behavior and home improvement in their own house and environment. In this way, the company attempts to accomplish awareness for everyone, in this case especially for the tenants and Woonbedrijf. When using the Woonconnect Model, people can see directly what the consequences are for the cost of energy, investment for the renovation measures, influence on the environment, and influence on the bills.

In Woonconnect, tenants’ house information is already in the system; therefore, tenants can see their house condition at the interface of Woonconnect through 3D models. Tenants can also obtain their approximate household energy usage through the calculation related to family members and shower time. After the basic setting mentioned above, tenants can start to choose different renovation measures according to their house conditions and preferences. Every time when one measure is selected, correlated energy bill decrease and energy performance increase, and change of 3D model are shown at the interface. Sometimes when tenants choose luxury measures (new kitchen and new bathroom), correlated rent increase is also shown. Therefore, tenants can test and compare various combinations to obtain the most suitable result. After selecting all the renovation measures, the list with information including chosen measures, energy performance, energy bill reduction and increased rent is provided for the final check. All this information will be send to Woonbedrijf for management and administration.

This concept is decided since Woonbedrijf concentrates more on tenants' interest instead of getting benefits from them. The successful implementation of this project can lead to a new method of renovating social housings.

#### 4.1.3. Project team component

The structure of internal project team can be found in Figure 14. In this team, two project managers are both expert in renovation field. They have been conducted several renovation projects in Woonbedrijf. The external contractors are two maintenance companies, Woonconnect and one architecture company (only during design phase). Both of the maintenance companies and Architecture Company are contractors of Woonbedrijf before the renovation and they are responsible for Eckart area.

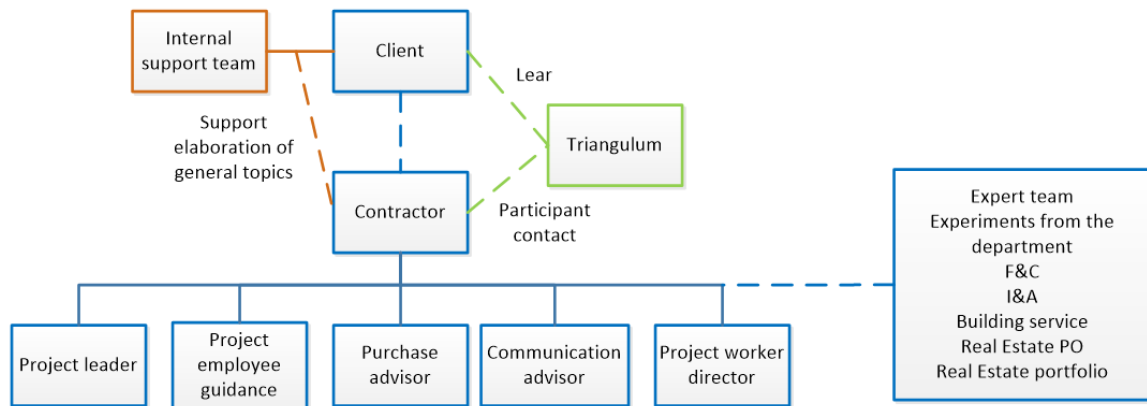


Figure 14 Internal organization (source: Woonbedrijf)

The contractors in this case take charge of the entire renovation technology situations. There are two contractors in this project; unfortunately, the author could only reach one of them. According to the contractor, since they are working in the same area, all the design and process should be the same. Therefore, information from one contractor is enough to cover the key feature of Eckart case. The two contractors are both maintenance companies that are responsible for the request from Eckart area; therefore, they are the stakeholders who truly understand the house situations there.

#### 4.1.4. Renovation measures decision

##### 4.1.4.1. Interviews and Questionnaires with the tenants

In order to response to the concept of Eckrt case, opinions from the tenants regarding renovation measures are necessary. Therefore, questionnaires were provided to the tenants by the company during the design phase of the renovation project. This questionnaire was conducted in order to obtain the overview of the current living condition, and tenants' opinions of Eckart area since Woonbedrijf communicate seldom with most of the tenants living in complex c366. Most importantly, this is also a great opportunity for Woonbedrijf to start conversation and communication with the tenants. That is why Woonbedrijf combined questionnaires with interviews; Employees asked tenants questions from questionnaire, and also seek for some qualitative insights from

tenants. The content of questionnaire includes the situation of tenants' living conditions, general opinions on improvement, neighborhood conditions, general opinions on service, help and mobility, energy awareness, district conditions, and general tenants' information. This questionnaire was implemented in Woonconnect; examples are shown in Figure 35 in Appendix C.

#### 4.1.4.2. Renovation requirement of Woonbedrijf to contractors

Combining the outcomes of tenants and experience from the contractors, contractors have the first thoughts of renovation locations and measures. These thoughts need to fulfill the requirements from Woonbedrijf as it shown in Table 5. Only the renovation measures related to energy saving are demonstrated in this thesis. Other renovation measures such as new kitchens and new bathrooms (also can be called "luxury renovation measures") are not the main focus of this thesis.

*Table 5 Requirement of renovation measures of Woonbedrijf to the contractors*

| Category | Components        | Requirement  |
|----------|-------------------|--|
| Roof     | General           | Energy performance of Rc=6; No maintenance for 50 years; Ready for the transitions of others (toilet, kitchen) |
|          | Solar panels (PV) | Ready to put PV on the roof; Need to be installed in the roof surface instead of on the tiles                  |
| Facade   | General           | Eliminate cold bridge  |
|          | Masonry           | Repairing and Cleaning   |
|          | Joints (mortar)   | Repairing (25 years of no maintenance)   |
|          | Window (Frame)    | Apply HR++ glass; Replace rotating parts; Install ventilation grilles  |
| Inside   | Ventilation       | New ventilation needs to be installed in toilet, bathroom and kitchen  |
|          | Energy component  | Repairing and replacing for further renovations  |

#### 4.1.4.3. Renovation measures

Based on the information from all the relevant parties, specific renovation measures are decided in the following sections. All these information is printed into pamphlet for tenants to ensure that tenants understand what will happen in their household during construction process.

##### **Roof**

The basic roof renovation contains five parts as shown in Figure 15:

1. Chimney: A new chimney is installed for better ventilation;
2. Skylight: Replace the old skylight with the new ones that have the same dimension;
3. Roof: Install a new insulated roof on the current roof slab together with replacing old tiles with the new ones. Lower part of the roof can be used to install solar panels since there is no roof tile there;
- A. Expand skylight with an increase of €1.05 per month;  
Extra skylight small (55 \* 78 cm) with an increase of €3.87 per month;  
Extra roof window large (78 \* 118 cm) with an increase of €4.92 per month;

- B. Solar Panel: Depending on the location of the house, an increased service fee of €12.64 per month and €21.93 per month is charged for 5 and 10 solar panels respectively.



*Figure 15 Energy efficiency renovation: Roof (source: Woonbedrijf)*

New chimneys are installed outside of the existing ones with 70mm insulation and frameworks. This measure will increase the energy efficiency in the household by terms of reducing heat loss. The prefabricated roof is insulated from outside as it shown in Figure 16. Compared to the old situation, a new renovation roof is installed in between and roof tiles are replaced. A seal coating is implemented inside of the house to reduce the damage from UV, moisture and other aging effect (Illbruck, 2016). Moreover, isolation stone wool is installed in between of two roofs (houses). Solar panels are installed for renewable energy input for the households. In order to maintain proper exterior of the roof, solar panels are installed in line with the roof tiles.

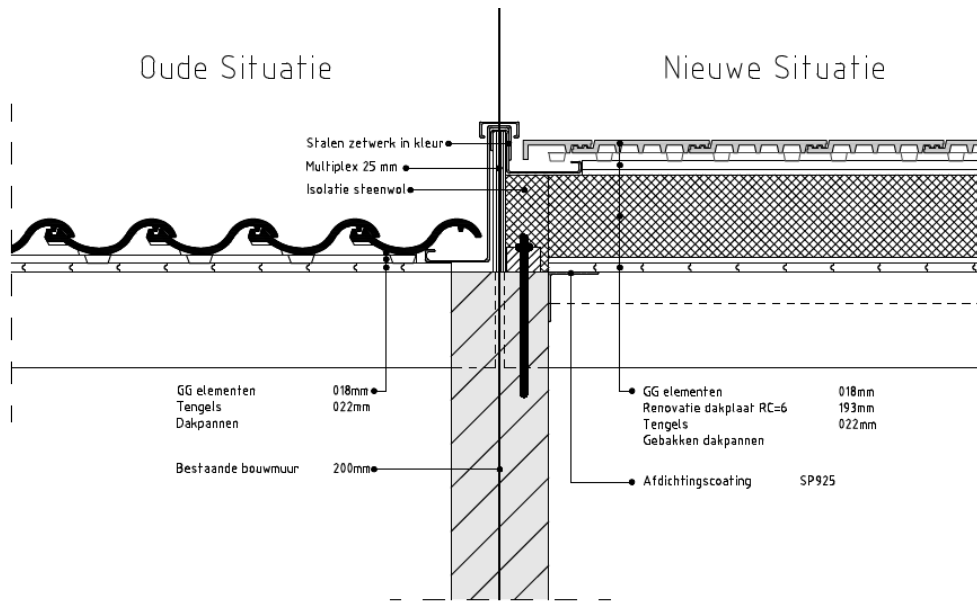


Figure 16 Roof renovation (source: Jansen Huybrechts Projecten BV)

### Façade

The basic facade renovation contains six parts as shown in Figure 17:

1. Window: HR++ glass is installed and old wood window frames will be painted;
2. Ventilation: Air ventilation is installed where it is necessary. Valve frame above the back door and in the bathroom is replaced;
3. Small fixed window: This window is replaced with an openable window;
4. Brick wall: The brick is checked and replacement is required when necessary. The insulation in the cavity is checked, and supplement is required when necessary;
5. Replacement of rain pipe;
6. Front door: Front door is replaced; it can be executed in 3 models and 3 different colors.



Figure 17 Energy efficiency renovation: Façade (source: Woonbedrijf)

### ***Inside***

New ventilation grilles are installed at a number of windows to supply enough fresh air while minimizing the loss of heat through ventilation. Mechanical ventilation is also installed in loft for adjustable ventilation. This active ventilation system can maintain the balance between intake cold air and outlet warm CO<sub>2</sub>-rich air mechanically to achieve heat recovery in the house (Yanovshtchinsky, 2013). Sensors that measure the CO<sub>2</sub> concentration in living rooms are installed to control the mechanical ventilation box located in the loft. Some extra switches to control the mechanical ventilations are installed in toilet, bathroom and kitchen. This type of CO<sub>2</sub> driven ventilation has an advantage of only taking air from outside when it is needed to ensure an adequate ventilation load (Yanovshtchinsky, 2013). In order to solve the complaints related to cold indoor temperature, the tenants can also require for an extra insulation on the inside to improve the thermal bridge. Moreover, to ensure the house is ready for the further renovation in the future, the installation for electricity, gas and water is checked for reparations and replacement.

#### **4.1.5. Demonstration houses (trials) and show room**

After all the procedure mentioned above, seven experiment housing renovations are conducted prior to renovation of all 254 houses in the area. These demo houses were conducted to assess the technical solutions (renovation measures) and risks during the real construction. When the real housing conditions affect the technology selections, the project team is still capable of modifying the solutions accordingly. Energy performance outcomes are also evaluated in demonstration houses.



*Figure 18 Show room condition*

Moreover, one show room was also built for exhibiting all the possible renovation measures and interior materials as it shown in Figure 18. Tenants are able to come to

the show room to experience the living condition and to closely observe the materials that they are going to implement in their houses. It is helpful for tenants to choose preferable renovation measures.

#### 4.1.6. Process and Time schedule

Seven steps exist in Eckart case for tenants to accomplish the renovation project as shown in Figure 19.

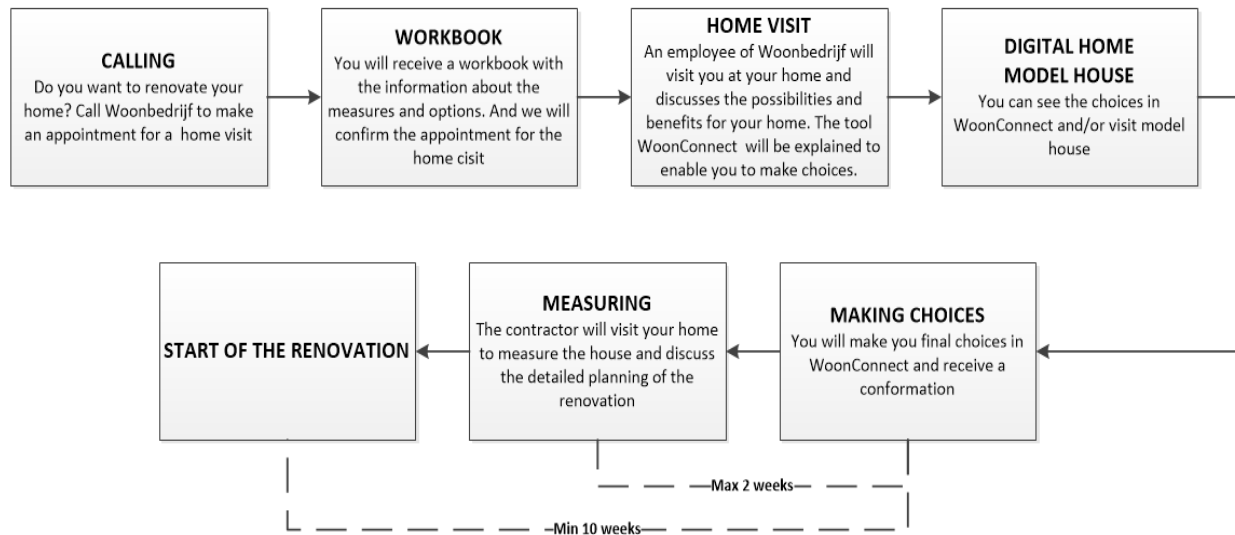


Figure 19 Renovation process from tenants perspective (Source: Woonbedrijf)

As the process demonstrated here, after sending out the invitation letters, tenants are required to take the first action to start the renovation. After selecting all the renovation options in the households, contractors start to be responsible for the process. It takes maximum 2 weeks for contractors to measure tenants house components from the moment that tenants decide their final renovation measures. Moreover, tenants can only choose to start renovation construction 10 weeks later than the moment that they decided their final renovation measures.

Time schedule of the project is demonstrated in Figure 20. The total duration of the project is 9 years, which is longer than ordinary renovation projects. All the renovation requirements were sent to Woonbedrijf at the end of 2013. They first implemented intuitive phase and performance phases to assess the feasibility of the project, following with define and design the project. Design and preparation phases were closed after they overtake the project through a seven months preparation of tender. The construction and realization phase started from 1<sup>st</sup> of July in 2017. This phase was planned for five years since tenants decide when and where to renovate their houses.

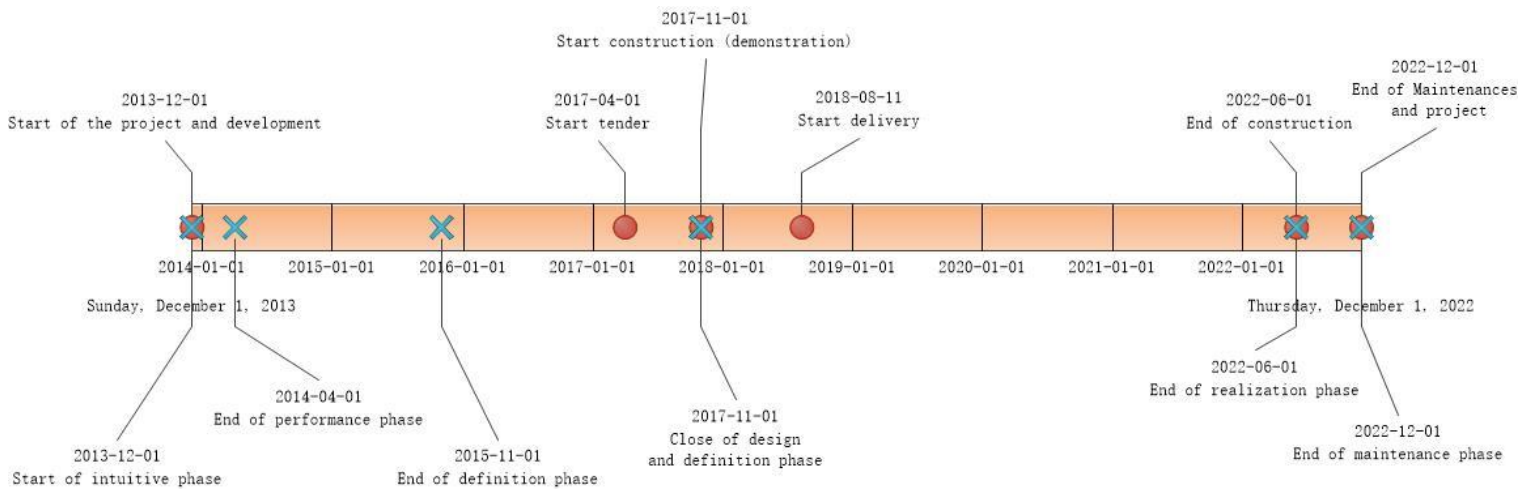


Figure 20 Time line of Eckart renovation project

#### 4.1.7. Conclusion

In this section, overview of Eckart project is presented. It includes basic information of Eckart area and specific construction process information. This information provide general insight of Eckart project. The case study and analysis are conducted in the following sections to evaluate the project.

#### 4.2. Interview analysis

In this section, interview outcomes are analyzed by terms of elaboration and comparisons based on the hypothetical interview structure. Besides direct causal connections within the same category, there are also connections across categories. Every connection is described in the sections. The comprehensive structure to judge success is shown in Figure 21. Pink blocks demonstrate the new elements and factors raised from the interviews, and green blocks demonstrate minor modification from the hypothetical structure. More specific information regarding the contents can be found in the following sections.

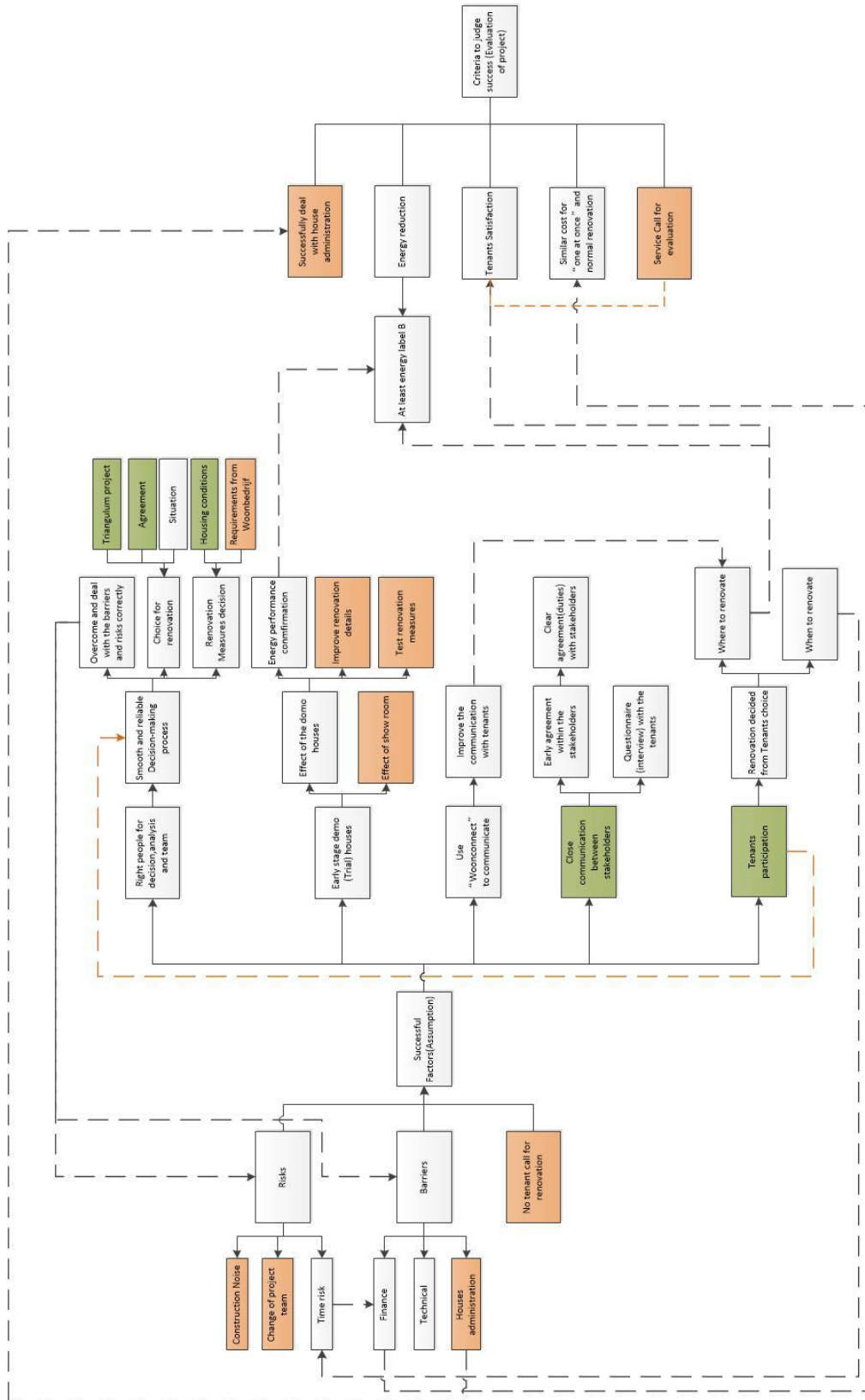


Figure 21 Causal structure after input of interview

#### 4.2.1. Successful factors during the project

Compare to hypothetical structure, some elements in substructure are modified during the interview as it shown in Figure 22. Five factors are raised for the contribution of success. Each factor and element is elaborated and analyzed in the following sections. Orange blocks indicate that the element is newly raised after interview and green blocks indicates that the element is modified slightly modified after interview.

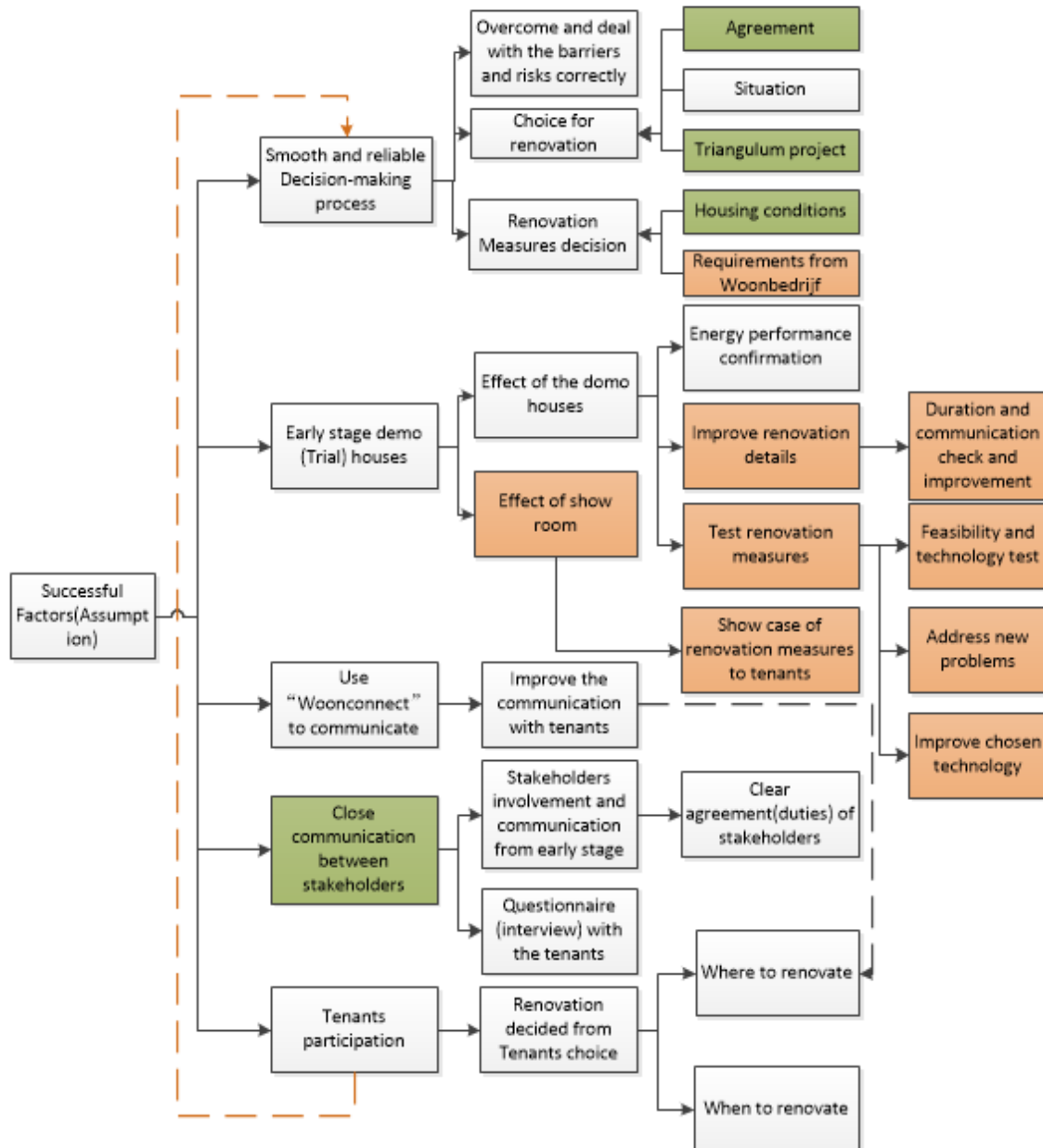


Figure 22 Successful factors

#### 4.2.1.1. Smooth and reliable decision-making process

As it mentioned in the introduction and literature review, decision-making process is a significant component in the whole project. The smooth and reliable decision-making process has a high possibility to lead the project to a successful outcome.

*“The project managers are both expert in renovation field. For me, I have worked in renovation in social housing for 20 years and I am familiar with the policies and regulations in renovation field.”*

*“The contractors are both maintenance companies in the areas; one works in the area of Eckard, and another one works in the area of Vaartbroek. Therefore, both of the companies are already quite familiar with the conditions and issues of the houses there.”*

Project Manager from Woonbedrijf

The proper choice of renovation subject provided the project an easy initial phase. The project team has a clear direction and purpose to work on. The interview with the project manager also indicates that all the members from the project team are highly experienced specially the two project leaders. Contractors are also familiar with the situation in the Eckart area since they are the contractors of Woonbedrijf that are responsible for Eckart before the renovation. Therefore, the project team is capable of addressing possible barriers and risks in the Eckart area and leading the project to the final joint decision.

*“We don’t know exactly how they think of their houses .... Since we already have some thoughts in our minds, we need to confirm it with the tenants by questionnaires.”*

*“We leave the technical part to the contractors since they know better about the area than we do. We provide them what we require at the beginning, and let them decide the details.”*

Project Manager from Woonbedrijf

As for the element of deciding renovation measures, sufficient measures also contribute to the smooth process of decision making. Since the outcomes are controlled by tenants, contractors and housing organization, the selected measures are mostly what are necessary for the households. Compared to what has been elaborated in the literature review, Eckart case implements new thermal insulation roof on the existing roof slab, installs new HR++ glass and installs new insulation for better thermal bridge for the aspect of building construction. No renovation related to heating is implemented since it was conducted few years before, and renovations related to domestic hot water is for future plan. Therefore, although the Eckart case concentrates more on the building construction aspect from general renovation frame work, this case still covers most of the common renovation measures as comparing to the three examples in appendix A.

#### 4.2.1.2. Early stage Demonstration (trial) houses

Demonstration houses are essential for the development of new concepts and technologies. In this Eckart case, it contributed from different aspect for the success of the project.

*“We tested with prefab process of the roof. Since we didn’t receive the material on time for the first two houses, we “pre” fabricated everything on site. It also went well, so we think it will be the same if we do in the factor. Since this test went well, we decided to do more prefab things.”*

*“The subsidence of the block is really serious compared to what we expected..... If only measuring one house, the roof outline will not be straight anymore. Therefore, we decided to measure the two end points of the block from the outside. With the help of 3D model, we can ensure the straight outcome.”*

Project manager from Jansen Huybregts Projecten

Demonstration process helped the contractors with development of pre-fabrication technology and discovering new problems (subsidence). The contractor indicates that demonstration houses truly helped them to improve their construction detail and process, such as the pre-fabrication technology and new problem of subsidence and construction dust. They were also more confident regarding the construction process in the realization phase.

*“It is very good that we had some trial cases. We could solve most of the bugs after tenants try the system. We improved our options and system from trial process.”*

*Woonbedrijf also ask us to combine two flows to one flow to make sure tenants will go make appointment with the contractor directly after choosing renovation measures.*

Project manager from Woonconnect

Two flows indicate that the process of choosing renovation measures and making an appointment with contractors are independent in the system. Tenants need to arrange an appointment with contractors separately after choosing renovation measures. Combining them together would reduce confusion from tenants’ side and avoid the situation that tenants only choose renovation measure but forget to make an appointment with contractors. Therefore, interview with Woonconnect also indicates that the trial process helped with the software improvement and feasibility.

*"We want to do it early in the process since we can learn a lot from the demo houses, such as technical solutions and risks."*

*"We stopped once with the demo process since we were not satisfied with long construction duration. After improving, we had some unexpected snow and storm "test" due to the weather. The contractors couldn't work in the first day because of the storm, but they still accomplished the roof work in two days. Although we can't say we can always finish the roof in two days, but it was a good sign for the project team. We also learn about the methods to communicate with tenants. If you cannot show up as the appointment, tenants need to know about that."*

Project Manager from Woonbedrijf

Woonbedrijf was also capable of assessing the construction process regarding duration and methods from contractors. Time period adjustment in demonstration houses gave them a chance to confirm and improve every step that will be realized later in the project. Moreover, this process also contributes to the decision making process of the board of Woonbedrijf since they can recognize the feasibility from the real outcomes of the demonstration houses. Therefore, from the perspective of both contractors and Woonconnect, it was really necessary and helpful to implement every theory and to observe closely at construction area before the realization phase.

#### **4.2.1.3. Use "Woonconnect" to communicate**

Woonconnect is a helpful tool for tenants to understand the current situation of their household. All the necessary information regarding select suitable renovation measures can be found in the system after logging in. Unfortunately, no interview from tenants' side related to the effect of Woonconnect was conducted. This perspective can be further elaborated in the future.

#### **4.2.1.4. Close communication between stakeholders**

As it mentioned the literature review, stakeholder involvement in the early stage has a significant effect on success of the project. This trend is also shown in the Eckart case.

*"The two contractors were chosen by the project manager and purchasing managers during the design phase. Woonconnect was already involved in the Triangulum project"*

*"The input and design of the process came from the complete team including the contractors (everyone involved)..... Sometimes we get in stuck because of the old way of thinking, so we have to let it go and start off again"*

Project Manager from Woonbedrijf

Every stakeholder in the project was involved from the design phase of the project. When stakeholders are involved from the early stage, they are capable of developing new concept together with the knowledge and opinions from various fields. All the stakeholders are clear about their duty and responsibility in the project. In this way the concept keeps increasingly growing on right track.

*"I can express what I want (a fixed window) in my house during construction phase."*

Tenant A from Eckart project

*"Woonbedrijf fulfilled my requirement of having a bigger window on the roof. I also wanted a toilet, but it was not approved since they think it is not necessary."*

Tenant B from Eckart project

*We already installed our own insulations several years ago..... We didn't agree to join the project at the beginning since we have to destroy what we already installed. Later on, we agreed upon joining since Woonbedrijf said that we don't need to destroy anymore.*

Tenant C from Eckart project

As for the communication with tenants, besides the process of deciding renovation measures, interview with tenants reflect that Woonbedrijf respond to their reasonable request during construction phases. This movement increases tenants satisfaction in the project, and tenants would be more willing to join the project. Since some tenants already lived there for 50 years, personal renovation is inevitable. It is a good movement for Woonbedrijf to communicate with the tenants to understand what they truly need to improve the outcome of the project.

#### **4.2.1.5. Tenants participation**

Tenants' participation is the main concept of Eckart project. Tenants are responsible for the renovation options and construction time of their own house.

*The concept is good.*

Tenant A & B from Eckart project

*We like it that we can choose renovation options and construction time, but we would prefer to renovate the whole street at once so that the street will be more organized.*

Tenant C from Eckart project

The interview with tenants indicates that they are appreciated about the fact that they can choose their own renovation measures and construction time. As the tenants there mostly rent the houses for a long period, they would like to decorate their house with personal preference. However, one household indicates that they would suggest constructing one street at once instead of one house at once to maintain tidy of the street. Woonbdrijf responds to this by encouraging tenants to start renovation at the same time with their neighbors.

Moreover, as the additional link added in the casual structure, Figure 16, tenants' participation also encourages the success of decision making process. As described in

the literature review, when tenants do not agree with the housing corporation regarding renovation, the renovation project can not be conducted smoothly, and the final decision of implementation will be never confirmed by the board of the housing cooperation under this situation. Therefore, involving tenants in the project process and ask for their opinions is truly a necessary factor to consider during the decision making process.

#### 4.2.2. Potential lagging factors

After analyzing the factors that can lead the project to success, the elements that could lag the success are analyzed in this section. These elements highly influence decision making process. Barriers and risks that have been considered during decision-making process are required to be addressed to receive the “pass” from the board to start realization phase. Therefore, the solution and methods mentioned in this section have significant influences on the project.

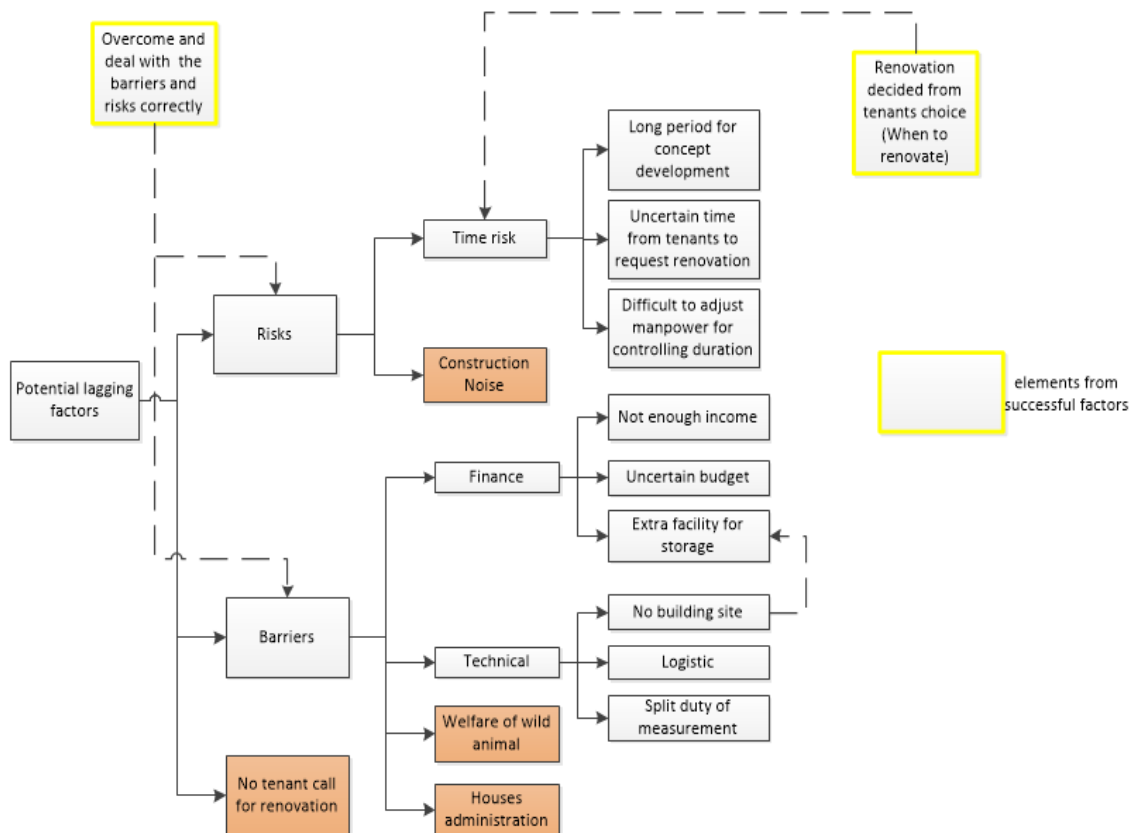


Figure 23 Potential lagging factors

##### 4.2.2.1. Barriers

Barrier is one of the factors that could lag success of the renovation project. The main barriers in this case are technologies, finance, administration of houses and different maintenance situations for the houses that have the same complex (complex means the condition, interiors and building period of the house). In this section, these three main

barriers and solutions are described and analyzed. A comparison with the common barriers and solutions are analyzed at the end of this section.

### *Technology*

The contractors take charge of all the technology of renovation measures since they are the stakeholders who understand the situations in the area the most.

*“The technologies are similar to ordinary renovations. However, since we want to reduce disturbance to tenants, we need to finish the roof construction within one day.”*

Project manager from Jansen Huybregts Projecten

According to the interview, the biggest technical problem is related to roof construction. This process is normally required to be accomplished within two days: install wood trusses, cover all the trusses with sheath (wood) and install the drip edge during the first day, and install underlayment and tiles during the second day. In order to reduce tenants disturbance, roof construction needs to be accomplished within one day.

*“There is no building site in the project. All the materials and components need to be transported in the morning for construction. If they cannot arrive on time, then we have a problem.”*

Project manager from Jansen Huybregts Projecten

Furthermore, there is no building site in Eckart area since centralized construction is not required in this project. Therefore, instead of preparing everything related to renovation at once, logistic related to material and equipments are required based on when tenants request renovations. The logistic problem needs to be addressed to fulfill the schedule requirement.

*“External measurement is also a problem, since the manufacturer wants to measure by themselves. If every manufacture does the same thing, then it will lead a huge disturbance to the tenants.”*

Project manager from Jansen Huybregts Projecten

Moreover, measurement of external components which need to be ordered from manufacturers, such as windows, is also one of the barriers. In ordinary renovation project, manufacturers send their professional measurement team with specific tools to measure the size. When any mistake related to these measurements occurs, manufacturers take the full responsibility. However, in this case, since all the stakeholders attempt to reduce the disturbance to tenants, it is not possible to let manufacturers measure at each house every time when tenants request renovations. This behavior also cost more money for the project. At the same time, if contractors measure the size for manufacturers, when mistakes occur, it is difficult to distinguish who takes the responsibility.

### **Solutions**

All these technical barriers occur because of the differences in construction methods. In order to implement the new concept of series of one, contractors used three months to develop the concept. This is not only because of the new technologies, but also because of uncooperative sub-contractors from contractors. They were less enthusiastic as the contractors when the new concept was raised. Suitable contractors and methods were found during these three months.

*"We decided to do pre-fabrication roof. We use four pre-fabrication roof slabs (6m\*3m each) so that all the process can be done in two hours."*

Project manager from Jansen Huybregts Projecten

As the contractor indicates, pre-fabrication technology is implemented to fulfill the schedule requirement and reduce tenants disturbance at the same time. There is no ideal method to address logistic barrier. The contractor would change the sequence of construction according to the site situation. Moreover, to address the split responsibility problem between contractors and manufactures, contractors proposed that they would measure everything, and take full responsibility when the components have size issues:

*"I would propose a solution that I measure and manufacturer make, then everything is my responsibility."*

Project manager from Jansen Huybregts Projecten

### **Finance**

Finance is always the most essential barrier for a project. It needs to be taken into consideration in early stages to get the permissions to carry out renovations.

*"We have a general agreement upon the renovation with contractors, but we don't know exact amount of every house because it depends on what tenants choose. We sign an individual contract with contractor every time tenant chooses."*

*"The increase in building price is enormous at the moment. So we don't have a fixed price for the next five years."*

Project Manager from Woonbedrijf

In ordinary cases, housing organizations only have one contract with their contractors. This contract contains information related to project's standard information including financial aspect, such as terms of payment and allowances (The renovation contract, 2018). The scope and complexity varies according to the scale of the project, and contractors are required to have their mission accomplished based on this contract. In this case, the main financial out flow happens also between Woonbedrijf and its contractors. However, it is impossible to cover every situation in one contract in this project due to "series of one". Woonbedrijf uses a different way to manage the financial flow. They first have price agreements upon each renovation option, and when tenants

ask for specific renovation option, the contractors will provide a unique contract together with the tenants only for this individual household. Therefore, the barrier is that there is no fixed budget for this project.

*“We are not going to buy materials separately when there is renovation request. It would be too expensive. ”*

*“When you do something new, you normally put all the risk factors inside of the finance plan, and then it would become expensive.”*

Project manager from Jansen Huybregts Projecten

From the aspect of contractors, it is also a new case to deal with. In ordinary case, they have fixed material suppliers for construction, and contractors purchase all the materials at once to store at the building site in the area for the further process. In this case, however, no building site is available to store materials for construction. If the contractors purchase one part of materials at once, the budget is not controllable. Moreover, when a new concept is raised in the project, sub-contractors normally include many risk factors for the budget. This would lead to an enormous amount. Under current circumstances of building industry, it is difficult to find a sub-contractor with ideal price.

*“We normally don’t ask for rent increase for renovation project.....We ‘gather’ money from monthly maintenance cost in the rent..... There is not fund from Municipality and €408,000 from Triangulum project.”*

Project manager from Jansen Huybregts Projecten

As for the inflow in ordinary cases, since Woonbedrijf do not ask for extra rent for basic energy efficiency renovation measures, the main inflow from tenants’ aspect is gathered only from one part from monthly rent standing for maintenance. There is no fund from municipality, but only from Triangulum project. In general Eckart case still have shortage regarding capital inflow for this renovation project.

In this project, therefore, finance is truly a big barrier to solve, since Woonbedrijf not only has little financial inflow, but it also needs to address a unique problem, uncertain budget. The company set an estimated budget based on the current situation and experience. For instance, 70% of them only choose basic renovation measures while the others also choose additional interior measures. However, if more tenants choose for large scale renovation, then the estimated budget cannot fully support the project expenditure. Furthermore, time (project duration) issue can also cause the same problem. More specific information is provided in section 4.2.2.2, Time risk.

### **Solutions**

In order to reduce the project cost to successfully implement the renovation project, the ultimate solution for company is to find efficient and innovative measures to renovate. This still needs some implementations and experiences to be achieved at the end.

At the current stage, since the main financial inflow from the tenants is from their monthly maintenance cost, one good method that has already been implemented is reducing material wastes. This can be seen from reducing wasting good materials that could still be used and focusing on long-term plan.

*"We tend to not waste the materials that are still under sufficient situation. For instance, the houses facing southeast have roofs with better condition compared to the roofs facing northwest. Then we renovate southeast roof later than northwest one.....Also window frame is always changed in renovation project, but we think the current one can still last for another 20 years. Therefore, we decide only to change the glass."*

*"We also thought of placing a new insulated wall outside of the external wall to improve the insulation of the house, since the current insulation material too thin (6cm). However, It will be a waste to destroy the external wall that is still under sufficient condition for a new one. Therefore, we decided to implement this "new wall" maybe in the future, but the new roof needs to meet the dimension of this "new wall" to reduce waste in the future. Therefore, the new roof was designed in a bigger size."*

Project Manager from Woonbedrijf

Therefore, the renovation measures are set according to the specific status of the house. Although all the houses in Eckart area is within the range of complex 366, the status of housing components still varies according to its own situation and location. Taking into consideration of all these characteristic, material wastes can be controlled to reduce expenses. Moreover, consideration for future renovations is required to "receive" money from future renovations.

*"We still need to buy a bunch of materials at once to get the ideal price. We store this material in difference places."*

*"Budget related to risk needs to be removed. When you do something new, not everything is a risk, we need to change our mindset"*

Project manager from Jansen Huybregts Projecten

As for the aspect from contractors, they still purchase all materials at once and store them in the warehouses of both companies. Moreover, contractors require sub-contractors to remove risk factors from their budget. New things are not necessarily risks; different mindset is required to deal with the budget for unique concepts.

The methods mentioned above consider mostly from long-term aspect. When there is immediate budget shortage in the project, the project team will first attempt to reduce the cost, such as asking specialist to check whether the contract provided by contractor is reasonable. Moreover, the project team also receives loans from banks with low interest. This is based on the guarantee of a private law foundation, Waarborgfonds Social Woningbouw (WSW). This foundation contributes to *“optimal financing of public housing through objective risk management”*. In this way, WSW ensures the participating corporations have the best possible financing costs and sufficient financial sources to address their financial problems (Over WSW, 2018) as shown in the interview:

*“We receive loans with low interest from bank, so that we can pay back this loan with the maintenance cost that tenants pay in the future.”*

Project Manager from Woonbedrijf

### ***Welfare of wide animals***

Welfare of wide animals is a barrier that is not mentioned in the literature review. The definition of Welfare of wide animals from the Government of the Netherlands is that *“No one may cause a wild animal to suffer unnecessarily. Some wild animals are protected by law and may not be hunted, caught or killed by humans”* (Welfare of wild animals, 2018). This policy also applies for housing renovation and maintenance.

*“We have birds and bats in Eckart neighborhood, and we need to relocate these animals before executing renovation construction. This process takes quite long time”*

Project Manager from Woonbedrijf

The relocation process requires a research related to the animals' living habits in different seasons (mainly spring, summer and autumn). More specifically, if the observation starts from summer, then it lasts until next summer; but if the observation starts from spring, then it only last until autumn in the same year. Furthermore, a license to demolish the old nest and relocate to a new one is also required for the process. Therefore, approximately 1.5 years is necessary for the whole relocation process.

*“So in this project, we start with a quick scan in the area from the early stage, and start measuring where to put the new bird houses so that no new birds can fly into our houses. But if the project scales up in the future, this might still be a problem.”*

Project Manager from Woonbedrijf

Therefore, the company starts to consider this barrier from the early stage for every potential houses in the area to make sure the relocation process. However, when the renovation project scales up to become a general renovation method, then the welfare of animals might become a serious barrier to address.

### *Administration and future maintenance of the houses*

For every house that has an address in the Woonbedrijf system, the information of house conditions and renovation perspective can be seen when you click on the house.

*“Because we renovate in “series of one”, so our own administration is a barrier”*

Project Manager from Woonbedrijf

Normally in Woonbedrijf, complex is the main subject and unit for regular renovations and maintenances. All the houses within the same complex have the same measures, and the projects are required to be finish in a certain period according to the scale of projects. In this way, every house in the same complex is under the same maintenance and renovation situation, which also leads to a simple administration process. However, in this project, since the renovations depend completely on tenants, it is difficult for Woonbedrijf to track all the process and status at house level.

*“We tried using paper for administration. In this way every house needs half an hour to administrate, which is not worthy doing. So we decided to use another method. If you want to see what has been done in the house, then you have to go to a separate excel sheet. But the ideal situation is still having everything on administrator system that we could give all the information.*

Project Manager from Woonbedrijf

As the interview indicates, the solution for now is nor ideal. Final integrated administration system still needs to be created. In the future, this barrier may intensify due to various staring times of this renovation project. The houses in the same complex are not under the same condition anymore. Consequently, the maintenance statuses are also different. This would lead to a more difficult situation for administration system in the company. Therefore, if the company continues with this new type of renovation after evaluation, an investment on administration system is required for the further development.

#### **4.2.2.2. Risk**

Risk is another factor that could lag success of the renovation project. The main risks in this case are time risk, construction noise and change of registration. In this section, these three main risks and solutions are described and analyzed. A comparison with the common risks and solutions are analyzed at the end of this section.

##### *Time risk*

Time risk in this case is mainly caused by the unique implementation method of the project. In an ordinary renovation project with similar scale, the project duration is approximately three and a half years ( $3+9+12+18=42$  months). However, in this specific case, not only the realization duration is extended to 54 months, but also the early

phases (Initial, Definition and Design) are influenced to have some extension since more time were required for every stakeholder to think differently for this project.

As it mentioned in section 4.2.2.1, Finance, the time risk also highly influences the budget of project due to the uncertainty in currency and building price fluctuation (mostly increase).

*"I made a budget regarding when I think they will choose. For example, I estimate that 50% of tenants will choose to renovate in the first year, then I make a budget according to this situation. However, at the end, only 40% choose to renovate, then the budget is not correct anymore."*

Project Manager from Woonbedrijf

This uncertainty in budget caused from time risk is difficult to address. The only thing that can be done is to make estimate accurate and encourage tenants to finish renovation fast to ensure the capital situation.

*"Normally when we do one block and there is time left, then we can already start for next house. We can also accelerate the process at the end of the project to meet the project duration requirement. However, for this project, we have to finish on the planned day. Therefore, if we have a delay, we have to scale up the workload the day after at once. This might cause some problem."*

Project manager from Jansen Huybrechts Projecten

As the interview with the contractor reveal, it is difficult to control and adjust construction under the concept of "series of one". If delay occurs in the project, contractors might need some immediate investment to balance this delay. It may cause some problem when this delay repeats several times.

## **Solutions**

*"Since the concept of this renovation project is to let tenants choose when to start, the company is not going to push tenants to choose. Maybe change the communication method with the tenants can be adjusted to help them make decision. We will wait until the tenants move out to renovate the house if they don't want to participate."*

Project Manager from Woonbedrijf

Under this circumstance, Woonbedrijf still keep the concept of tenants' choices. They would change the communication methods with tenants to convince but not urge them to determine the renovation decision in a controllable time. If some tenants are still not willing to renovate, the company will wait until the tenants stop their rent contract to renovate the house for the next tenant. As for approach of controlling the budget, the solution for now is to adjust estimated budget regarding tenants' choice trend, such as more large renovation and more renovation in year 3, the estimated budget needs to be adjusted accordingly.

### **Construction Noise**

*“There is always construction building noise in the neighborhood. People can be annoyed by that.”*

Project Manager from Woonbedrijf

There are also noises exist in ordinary project, but when the construction in the block is finished, the noise disappear. However, in the Eckart case, since tenants have the right to choose when to renovate, noises can exist in the neighborhood for longer period compared to ordinary case. This noise might cause discontent among tenants in the neighborhood. In this project, noise from roof construction has already been reduced by prefabrication. Therefore, noises are mainly sourced from replacing wall bricks, mortar, interior construction and sand wash for cleaning the bricks.

Woonbedrijf requested the contractors to control construction noise; however there is no sufficient method to control this problem at the moment.

#### **4.2.2.3. No tenants call for renovation**

This interview question is asked to obtained answer for the trigger and situation that might stop the Eckart case.

*“When the tenants don’t want this type of renovation, then the company is going to stop this experiment, and just continue with the ordinary method to renovate. The percentage is not decided yet, but this is the trigger”*

Project Manager from Woonbedrijf

Therefore, if tenants do not appreciate the renovation of “series of one”, Woonbedrijf would stop the experiment and continue implementing ordinary renovation project.

#### **4.2.3. Criteria to judge success of the project and evaluation**

Compared to the hypothetical structure showed in Figure 21, two new elements are raised during the interview with the project manager from Woonbedrijf as it shown in Figure 23. Five elements are implemented to judge and evaluate the success of the project. Therefore, the elements are described first, and following with the evaluation. Some extra evaluation criteria for general project evaluation are also implemented later to understand the project comprehensively.

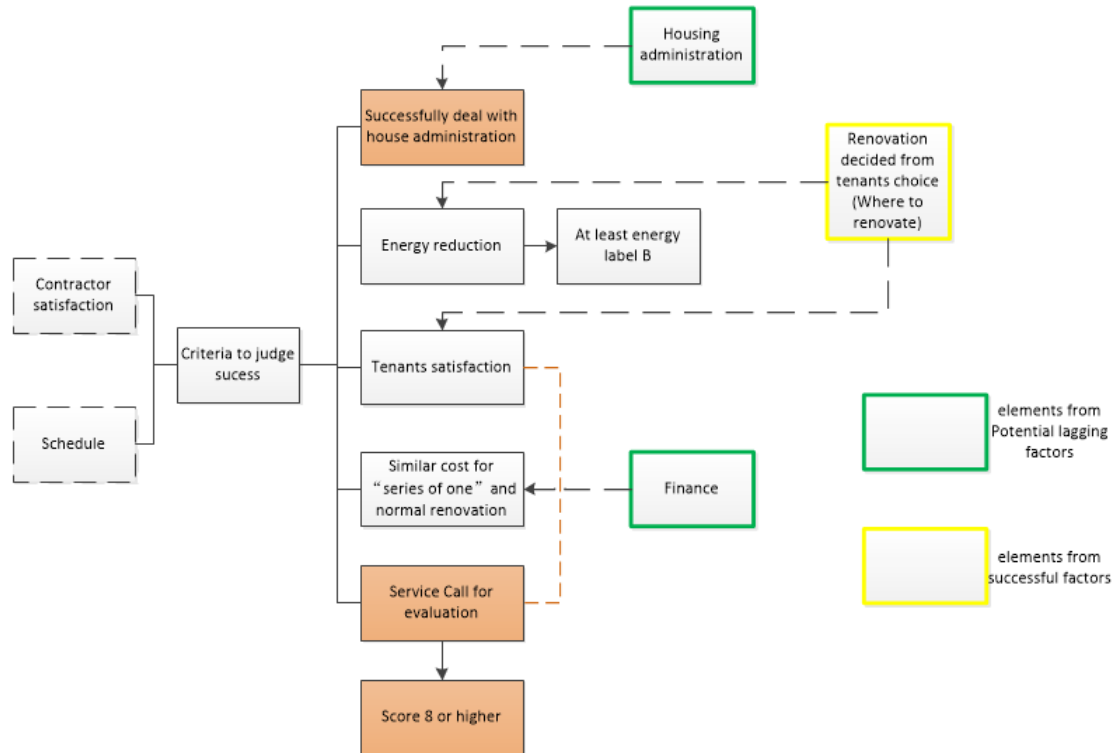


Figure 24 elements to judge success

#### 4.2.3.1. Energy reduction

In this section, energy performance improvement as the result of renovation measures is analyzed. After this quantitatively analysis from smart meter of demonstration houses, the effect of renovation measures can be assessed. This data is obtained from seven of the demonstration houses. Although the data is not comprehensive enough to demonstrate the concrete result, it still indicates reference value.

Houses' façade situation can be found in Table 6. As it shown in the table, U-value of housing façade was not sufficient before the renovation, especially in the perspective of roof, ground floor and glazing. U-value is a measure of heat transmission through building components. Lower numbers of U-value indicates better insulating conditions (Merriam, 2018). This means that these houses loss too much heat from façade, which lead to the situation of energy insufficient of households. After renovations in demonstration houses, the meters installed in the household provided the result of real outcome as it shown in the same table. Wall situation had a decline since this is the average data from the houses in this complex. As for Roof tops, the insulation material provide houses a better condition compared to what has been expected; an improvement of 93.4% is achieved. After changing from normal glass to HR++ glass, the improvement of 56% in glazing also significantly enhanced energy performance in the households. As for ground floor, normally floor renovations are implemented to increase the energy performance here. However, since all the floors in Eckart project are made of cement, it is not possible to renovate them in short time period without relocating tenants.

Table 6 Façade situation (source: Woonbedrijf)

| Components      | Existing houses (before) | Suggested result | Real outcome | Unit               |
|-----------------|--------------------------|------------------|--------------|--------------------|
| Wall            | 0.47                     | 0.56             | 0.61         | W/m <sup>2</sup> K |
| Roof            | 2.56                     | 0.81             | 0.17         | W/m <sup>2</sup> K |
| Ground floor    | 6.67                     | 4.13             | 6.67         | W/m <sup>2</sup> K |
| Glazing (glass) | 4.1                      | 2.28             | 1.8          | W/m <sup>2</sup> K |
| Ventilation     | -                        | -                | 0.55         | -                  |

Energy demand of total floor area is shown in Figure 25 and Figure 26. They are divided based on whether PV panels are installed. The main heating source in the households is gas. After improving the insulation and glazing quality in the households, an average reduction of 46.32% in gas consumption has been indicated since less heat transfer is processed in the household consequently. Ventilation implemented in the project also reduced heat loss compared to formal nature ventilation. There was no measure implemented for lighting system and the implementation of mechanical ventilation could lead to the increase in electricity usage. In general, a reduction of 49.81% in energy demand is achieved at the end of the construction according to the data from demonstration houses.

As for the situations in the households that implemented PV panels, an impressive result can be seen from the data. Besides a similar result from the perspective of ventilation and electricity, some additional value for heating can be distinguished. Energy converted from solar energy contributes to housing heating system. 5 solar panels with the capacity of 275WP contribute to approximately 12% of energy for heating.

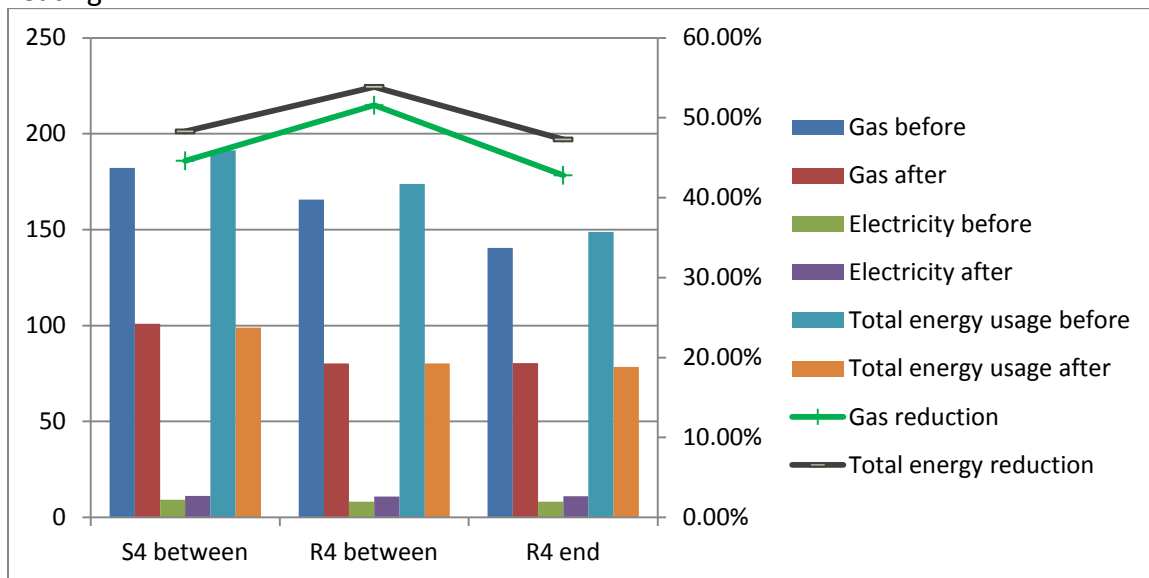


Figure 25 Energy demand reduction in household after renovation without solar panel (unit: kWh/m<sup>2</sup> yr)

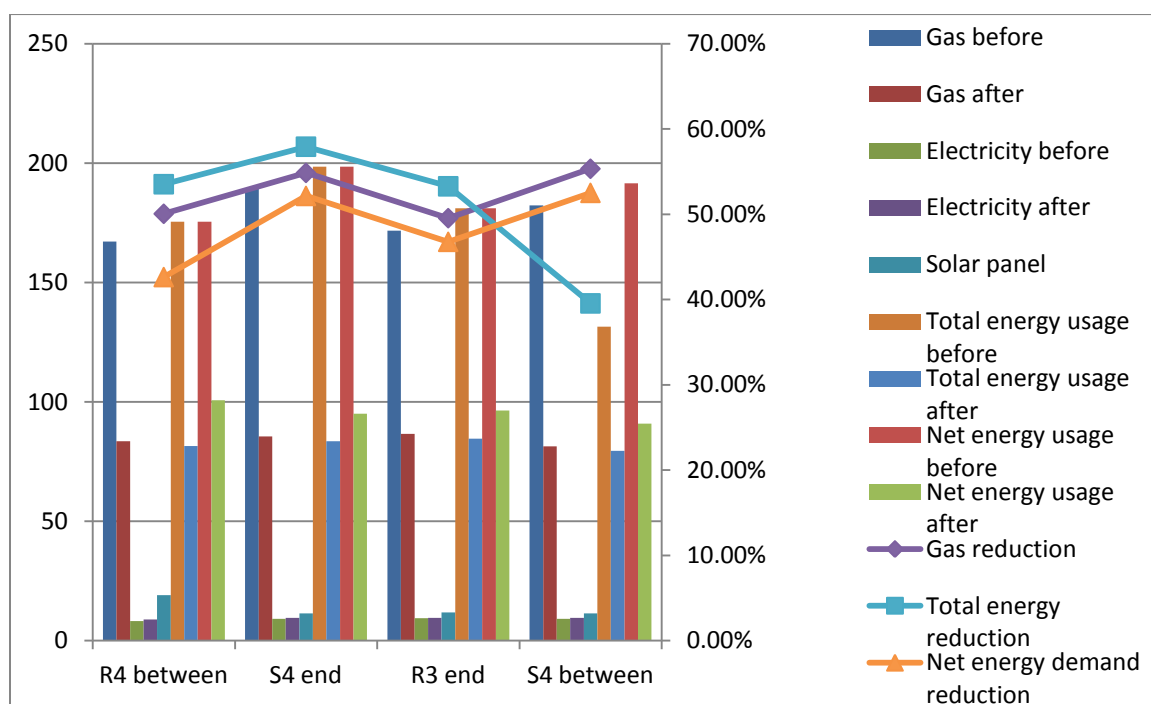


Figure 26 Energy demand reduction in household after renovation with solar panel (unit: kWh/m<sup>2</sup> yr)

Table 7 demonstrates the renovation outcomes related to cost reduction and CO<sub>2</sub> emission reduction. A significant decline of 52.8% in CO<sub>2</sub> emission is indicated after renovation. This data correlates with the energy performance increase as the result of new insulations and ventilations. Reasonable energy reduction is also shown after renovation. The goal of Woonbedrijf for this renovation project is to reach energy label of B (EI=1.06-1.3); however the result actually exceeded the expectation to energy label A (EI< 1.05). Therefore, from the aspect of energy performance improvement, the project is on the track to success.

Table 7 Renovation outcomes (source: Woonbedrijf)

|                                  | House 1          | House 2         |
|----------------------------------|------------------|-----------------|
| Solar panels                     | Yes              | No              |
| EI before renovation             | 1.82 (D)         | 1.87 (D)        |
| EI after renovation              | 0.87 (A)         | 0.95 (A)        |
| CO2 emission reduction           | 2262.28 kg       | 1865.63 kg      |
| Annual energy cost reduction     | € 720.85         | € 528.62        |
| Renovation measures related cost | € 35,341 (60 yr) | € 29,184 (44yr) |

#### 4.2.3.2. Tenants satisfaction

Tenants satisfaction is a essential criteria to judge the success of the social housing renovation project. This can be done from several perspectives. Tenants participation and tenants involvement in the decision making process are two of the perspectives. These two aspects are already presented in section 4.2.1.4 and section 4.2.1.5, and the analysis indicates good tenants satisfaction. Another perspective of tenants satisfaction can be seen as living condition improvement. This improvement includes indoor thermal comfort, CO<sub>2</sub> concentration reduction and acoustic improvement.

*The indoor temperature was not bearable at that moment. Summer is very hot and winter is very cold.....Now my house is really under a good temperature condition. The bigger roof now provides shadow into my room. But I think I didn't get the point of ventilation. I just put it on "Auto" all the time.*

Tenant A from Eckart project

*The sound prove of the house is also better now. If I want to sleep early, then I just need to close my window; this was impossible before. I'm satisfied. I don't really feel many differences from the ventilation. At the beginning I felt something, but not anymore.*

Tenant B from Eckart project

The interview with tenants (demonstration houses) indicates that they are satisfied with the indoor living condition, especially from thermal perspective. The indoor temperature has been dramatically improved and tenants are highly satisfied about this improvement. However, newly installed ventilation system seems to have less effect. Tenants reflect that they do not feel many differences related to CO<sub>2</sub> concentration difference. The ventilation switch in the house can be adjusted manually when tenants require ventilation. However, they mostly turn the switch on "Auto" since they do not understand the difference. Moreover, acoustic condition in the households is improved. Although tenants can still hear the noise from road, other sound from neighbors is dramatically reduced.

Moreover, tenants satisfaction during information exchange and construction process are another perspective that requires to be evaluated.

*"When we first receive the letters, we were not sure what would happen for renovation, it would be better if the pamphlet could come together with the invitation letter."*

*"They came to measure my windows for three times; we don't understand why."*

Tenant C from Eckart project

From the aspect of information exchange, it turns out that the sequence of information provided might need some adjustments. Tenants can only get the pamphlet that contains detailed renovation measures information after they agree upon renovation

project. However, tenants reflected that it would be clearer if the pamphlet can be sent together with the invitation letter for renovations. It is easier to make the final decision within the households in this way. The second point is mentioned in barrier section regarding split responsibility in housing measurement. This barrier has not been addressed according to the interview with tenants. The project team is required to keep alert to reduce tenants disturbance from this aspect.

*“One month was really heavy to my family from the aspect of emotion and finance.”*

Tenant B from Eckart case

From the aspect of construction process, as it has been elaborated in the overview sections, construction period exceeded what has been planned during demonstration houses construction. It was a burden for the family to have such a long construction period. This situation has been addressed by the contractors, but the project team needs to keep alert of the schedule. Tenants further elaborated the attitude of the workers during construction:

*“Workers just walk in and out; sometimes I feel that they are very rude, and I think the workers didn’t really care about the privacy in the households.”*

*“The workers sometimes even talked bad things about my family.”*

*“I really felt that these people don’t have respect to my family and house.”*

Tenant B from Eckart case

There might be some culture differences between tenants and workers, but respect during construction is essential for tenants satisfaction. More supervision from different aspects, such as workers selection and work process monitor, during construction process is required. This supervision is also essential for the reputation of Woonbedrijf since tenants might consider that all the workers are from Woonbedrijf.

#### **4.2.3.3. Similar cost between “series of one” and ordinary project**

Woonbedrijf expects that when more tenants choose to renovate in this way, the outcomes are similar compared to ordinary renovation project (renovating a block of house at once). More specific calculation and expectation can be found in section 4.3.

#### **4.2.3.4. Successfully address the administration problem**

As it described in one of the barriers, Eckart project is facing the problem of house administration in the same complex. It is not a primary problem at current stage; however, it will have big influence in later stages for housing management. Therefore, whether the project can successfully address this problem is also one key element to assess success of the project.

#### 4.2.3.5. Service call for evaluation

*“We want to add some extra questions in service calls regarding whether they are appreciated for the freedom that they can choose the moment to renovate.”*

Project Manager from Woonbedrijf

In order to assess the project success from tenants' satisfaction, Woonbedrijf request a third party service call for evaluation. The most important criterion for this evaluation is information. More specifically, whether tenants have enough information that they feel safe to decide and start renovation. Moreover, some questions regarding whether they appreciated the freedom of choosing the moment and options to renovate. Tenants will receive a service call from the evaluation company after their renovation to judge the renovation with a score from 1 to 10. If the tenants give a score higher than 8, then the project is a success from tenants' perspective. This perspective is separated from tenants satisfaction section since this assessment will be accomplished at the end of realization phase and it is for concluding of the project. The perspectives mentioned in the tenants satisfaction section focus on current situation.

#### 4.2.3.6. Contractors satisfaction

The contractors here mainly focus on maintenance companies. Although it is not one of the primary criteria for Eckart case to evaluate contractor satisfaction, this satisfaction level also influence the outcome of the project.

From the aspect of maintenance Company, although the author only conducted interview for one company, this interview could reflect a general opinion from both of the contractors since they need to negotiate everything to maintain the consistence of Eckart project.

*“I thought it was a nice concept, but the subcontractors of us were less enthusiastic as me. They think it costs more money to implement renovation in one house at once.”*

Project manager from Jansen Huybregts Projecten

Contractor reflects that they were interested in the concept of “series of one”, It was difficult for them to convince that subcontractors to join. Due to this interest, the contactor was still succeeded in providing feasible renovation measures at the end. Therefore, the contractor indicates “satisfied” to the perspective of project concept.

*“It was very important and necessary to have demonstration project before the realization phase. We could test and improve new technology.”*

Project manager from Jansen Huybregts Projecten

Moreover, the contractor indicates the importance and necessity of demonstration process in the interview. Eckart project implements many differences procedure and technology compared to ordinary project. The demonstration houses provided

contractor a chance to prove that their measures are feasible to every stakeholder including themselves. The improvement in technologies and cite understanding also brought more feasibility to the project. The contractor is appreciated to participate, and to improve the feasibility and suitability during the demonstration process.

*“Our goal is to develop the technology that lead less disturb to tenants. We mainly focus on roof in this project, and when we can accomplish the roof in one week. This can also be implemented in other projects as a new business model.”*

Project manager from Jansen Huybregts Projecten

The contractor is also satisfied from the perspective of their further development. They could develop a new business model in Eckart project. After the demonstration process, the contractors are more confident with the technologies that they developed for this renovation. As the interview with contractor reflects that they think this business model can be completed according to current renovation process. In general, the contractors are satisfied with renovation project from different perspective.

#### **4.2.3.7. Schedule**

Schedule is another essential factor for the success of a project, it reflect the management skill and process during the project period. A delayed project cannot be fully assessed as a successful project (Braimah, 2013).

In the Eckart case, although the intuitive phase and performance phase for feasibility assessment were accomplished very soon after receiving the details of project requirements, design and definition took approximately 4 years to accomplish. This development period is rather long for a renovation project and indeed exceeded what has been expected. Several delays happened during the early stages:

1. Development of the concept with all the stakeholders took longer time than what has been expected
2. Half year gap after the first two demonstration houses due to the construction technology adjustment and improvement
3. One month delay before (at) the beginning of realization phase because of Woonconnect improvement

Moreover, although the construction duration in each house was already controlled within two weeks, but the schedule during the realization phase is completely depends on the choice of tenants and there is no concrete method to truly control this process. Although the implementation of Woonconnect improved the efficiency of conducting renovation project, too many uncertain elements are included in the realization phase which makes it difficult to track the project's schedule.

Therefore, the Eckart project cannot be regarded as a feasible project from the aspect of project's schedule, since the delay and uncertainty can not only cause the complaint

from tenants but also influence the consistence of the project. Although this is an experimental project, more innovative plans are required for the further development in schedule control.

#### 4.2.4. Conclusion

In this section, case study and evaluation are conducted from the perspective of project successful factors, potential lagging factors and criteria to judge the success of the project.

From the perspective of successful factors, they all have significant influence on the project. The first factor that has been analyzed is smooth and reliable decision making process. This is achieved by the experienced team members. They are familiar with general renovation process and the Eckart area. Therefore, implementing sufficient renovation measures and addressing potential problem are possible for them.

Demonstration houses and Woonconnect trials are the experimental objects of all the decisions from both contractors and Woonbedrijf. It is not only an opportunity for Woonbedrijf to test and assess the detail of renovation methods, but also a chance for contractors to improve their technologies. Moreover, tenants are also capable of observing the outcomes from the houses in the neighborhood. This implementation provided confidence to all the stakeholders involved in this project.

Early development of concept and technology also bring success to decision-making process. Everyone was clear about their responsibility and duty for the project. Working closely together created the opportunity to develop proper technologies for the project. Furthermore, stakeholders can support each other from falling back to the fixed mindset from ordinary projects. Input from tenants provides accurate insight regarding housing situations and conditions. This can make sure that every renovation decision is determined on a right track. All these factors lead and contribute to the success of decision-making process, and eventually the whole project including realization phase.

From the perspective of lagging factors, compared to the barriers mentioned in the literature review, the biggest two barriers also exist in this project, technical barriers and financial barriers. These two barriers can be considered as temporally addressed with the solutions mentioned in the sections. From the opinion of author, the uncertainty in budget cannot be solved completely under the concept of “series of one”, but it is controllable. As for the barrier of logistic, punctuality is significant not only for contractors, but also for logistic companies. This involves the development of operational plans, and vehicle schedule. GPS can be implemented in the vehicle, together with the understanding of conditions along the route. Furthermore, communication and negotiation is also important for reducing the influence from the barrier. When logistic notices that the components cannot be transported on time, they are required to report the situation to contractors immediately. Contractors can adjust their construction plan accordingly to reduce the affects.

*"I think the relationship between us and tenants is not good and not bad. People in Eckart just live very independently. Tenants from this complex had the most positive respond to the project. They are also excited about the concept."*

*"We didn't consider much about building code since we don't change the structure and components of the houses. If we don't change, then we don't need to follow building code."*

Project Manager from Woonbedrijf

Organizational part that has been mentioned in the literature review is not a big issue for this case, since there is no increased rent required from tenants for basic energy efficiency renovation measures. Although the relationship between the company and tenants is just ordinary leasing relationship, there is no mistrust between the two groups. Moreover, the tenants were also enthusiastic about this renovation project when they first heard the information. As for the building code issues, the codes are indeed mostly for newly built houses; however, only when building components, such as columns, roofs and walls, are changed and modified, housing organizations are required to follow the building code. In this case, only some new installations are added in the households to improve the energy efficiency; therefore, Woonbedrijf do not need to follow the building code strictly.

Besides the general barriers mentioned above, this case seems to have some unique barriers related to management and administration of houses and time issue. These barriers have little influence on decision-making process but more for follow-up management process. Nevertheless, they still need to be addressed for a fully successful project.

As for the aspect of project risk, the biggest risk, time risk, also exists in this project as it is elaborated in the literature review. Time risk can be seen in this project from different aspects. Project leaders and contractors already have some methods to control it. As for construction noise, it is still a difficult task to address. The project team also attempts other washing methods with less noise, such as steam wash. However, cleanliness is low compared to sand wash. Therefore, the balance between cleanliness and noise level needs to be obtained to address this problem. After all, it is essential to consider the true request from the tenants to truly have a success outcome at the end.

From the perspective of evaluation, it is conducted based on the primary criteria provided by the project manager and two extra general points. Overall, the project is on the right direction to success. The outcomes from demonstration houses indicate that the project could have the sufficient result regarding energy performance improvement and living condition improvement at the end of realization phase. Contractors are satisfied with project from the aspects of project concept, demonstration process and company development. However, the project team still needs to pay attention to the

information exchange process and construction process to further improve tenants satisfaction. Respect and trust during construction process is truly essential for tenants satisfaction. Service call by the end of the project would reflect general tenants satisfaction at the end. Moreover, administration and schedule problem still need to be addressed and improved during the realization phase.

### 4.3. Life cycle cost analysis

In this section, the result of LCCA is demonstrated. The results include the aspects from Woonbedrijf and tenants in Eckart area. Due to the uncertainty of budget, the investment situation is set under prognosis. Therefore, different prognosis is assessed, and the most realistic situation is used at the end for evaluation. As for the aspect of tenants, the calculation is focused on whether implementing renovation project is feasible and beneficial.

#### 4.3.1. Financial feasibility from company perspective

In this section, the financial feasibility from company perspective is analyzed. As elaborated in financial barrier section, Woonbedrijf only have uncertain budget for the project due to “series of one” concept. Therefore, in this section, the prognosis scenario that Woonbedrijf uses for project analysis is first introduced, and other possible scenarios are created to further describe other possibility to reflect “series of one” concept. The comparison between ordinary scenario and “series of one” scenarios is conducted at the end of this section to assess the feasibility of Eckart project.

An overview of all the scenarios can be found in Table 8. Since LCCA is conducted to analyze the feasibility, life cycle of each scenario highly influences the outcomes. Total life cycle indicates the period until next renovation and maintenance cycle indicates the period that operation cost and maintenance cost need to be calculated. The scenario of Woonbedrijf prognosis is developed by the project manager of Eckart case. Specific calculation and explanation can be found in each separate section following.

*Table 8 Overview of all the scenarios*

| Name                    | Start (year) | End (year) | Total life cycle/Maintenance cycle(year)** | Luxury measures* proportion (%) | Implementation of Woonconnect |
|-------------------------|--------------|------------|--|---------------------------------|-------------------------------|
| Woonbedrijf prognosis   | 2014         | 2049       | 36/30 (27, 28,29,31)                       | 30%                             | Yes                           |
| Ordinary scenario       | 2014         | 2047       | 34/30                                      | 30%                             | No                            |
| Diffusion of innovation | 2014         | 2050       | 37/30 (28,29,31,32)                        | 30%                             | Yes                           |
| Projected scenario      | 2014         | 2050       | 37/30 (28,29,31,32)                        | 50%                             | Yes                           |

\*Luxury measures: Luxury measures indicate the new interiors that cost extra rent, such as new kitchen and new bathroom

\*\*Years in the blanket indicate that due to the different renovation demand of each year, houses have different maintenance years accordingly.

#### 4.3.1.1. Woonbedrijf Prognosis scenario

All the financial information, including the other three scenarios, for analyzing financial feasibility of Eckart case is based on Woonbedrijf prognosis scenario. In this prognosis, it is assumed that 50% of the households choose to renovate in the first year (month scale) since the discussion of renovation was already raised in 2012 and people are looking forward to the renovation project. Following with 30% of the households, they would choose renovation after observing their neighborhoods. The rest of the households will be difficult to start renovation, but there are still 15% of households that can be convinced by communication. It would be the best to implement the rest of the 5% renovation at the end of the realization phase as it demonstrated in Table 9. After dividing households based on month scale, the percentage is assigned to each calendar year according to the starting date of Eckart project. House amount is also assigned accordingly. Moreover, Woonbedrijf assume that 30% of the tenants choose luxury renovation, such as new kitchen and new bathroom, 40% of the tenants choose to install solar panels, and the rest will mostly only choose basic renovation. An increase of 3% per year in building cost is assumed in this prognosis.

*Table 9 Woonbedrijf prognosis scenario renovation requirement distribution  
(Source: Woonbedrijf)*

| Year           | 2018 | 2019 |      | 2020 |      | 2021 |      | 2022 |      |
|----------------|------|------|------|------|------|------|------|------|------|
| Month          | 6-12 | 1-5  | 6-12 | 1-5  | 6-12 | 1-5  | 6-12 | 1-5  | 6-12 |
| 12 month scale | 50%  |      | 30%  |      | 10%  |      | 5%   |      | 5%   |
|                | 29%  | 21%  | 17%  | 13%  | 6%   | 4%   | 3%   | 2%   | 5%   |
| Calendar year  | 29%  | 38%  |      | 18%  |      | 7%   |      | 7%   |      |
| House amount   | 79   | 96   |      | 45   |      | 17   |      | 17   |      |

Table 10 demonstrates the financial outcomes from two of the demonstration houses. House 1 requested for both luxury renovation and solar panel, which lead to total renovation cost of € 57,235.42. House 2 only request for basic renovation and no solar panel, which lead to total renovation cost of € 48,787.20.

*Table 10 Financial outcomes (architecture cost) from demonstration house  
(Source: Woonbedrijf)*

| House   | Total renovation cost | Energy saving renovation cost (Including solar panel) | Solar panel cost | Situation                           |
|---------|-----------------------|---|------------------|-------------------------------------|
| House 1 | € 57,235.42           | € 32,806  | € 2,535          | Luxury renovation and solar panel   |
| House 2 | € 48,787.20           | € 29,184  | -                | Basic renovation and no solar panel |

Based on Table 4 in section 3.2.3.2, financial data is obtained and analyzed. There are some common elements as well as unique elements exist in every component of LCC in Eckart case. The integrated yearly financial situation based on prognosis description, Table 9 and Table 10 are shown in Table 11. Architecture cost accounts for the highest proportion. It contains all the payments to contractors, such as costs for construction materials, labor and related logistics. Development cost and risk include every expense happened during concept development phases. As for direct cost, it includes every additional cost from the renovation process, such as license for wide animal relocation, research cost, contractors cost, legal and advices cost. Not recoverable cost is the cost of VAT (Value Added Tax). It is not recoverable since Eckart case is a renovation project; it is not included in the VAT recoverable construction category. The construction such as building and selling new house can receive recovered VAT. Eckart project is assumed to have 30 years life cycle after the renovation.

*Table 11 LCC elements of Eckart case and correlated yearly financial information (Woonbedrijf prognosis situation for each year expenses) (Source: Woonbedrijf)*

| Cost Activity    | Early phases | 2018        | 2019        | 2020        | 2021      | 2022      |
|------------------|--------------|-------------|-------------|-------------|-----------|-----------|
| Architecture     | -            | € 4,083,903 | € 5,134,025 | € 2,477,255 | € 968,507 | € 988,968 |
| Development cost | € 155,000    | € 107,440   | € 130,560   | € 61,200    | € 23,120  | € 23,120  |
| Development risk | € 15,000     | € 10,886    | € 13,228    | € 6,200     | € 2,343   | € 2,343   |
| Unexpected       | € 2,000      | € 61,259    | € 77,010    | € 37,159    | € 14,528  | € 14,835  |
| Direct cost      | € 248,672    | € 85,500    | € 105,231   | € 49,766    | € 17,701  | € 17,959  |
| Not recoverable  | € 54,678     | € 883,006   | € 1,109,491 | € 535,098   | € 208,816 | € 213,193 |

*Table 12 Total investment cost and yearly operation and maintenance cost (Source:Woonbedrijf)*

| Investment cost (Total cost of Table 11) |                 | Operation cost         |                 |
|--|-----------------|------------------------|-----------------|
| Cost activity                            | Amount          | Cost activity          | Amount          |
| Architecture cost                        | € 13,652,658.00 | Land lord levy         | €763/house/year |
| Development cost                         | € 500,440.00    | Insurance              | €375/house/year |
| Development risk                         | € 50,000.00     | Company operation cost | €900/house/year |
| Unexpected cost                          | € 206,790.00    | Maintenance cost       |                 |
| Direct cost                              | € 524,829.00    | Replacement cost       | €900/house/year |
| Not recoverable cost                     | € 3,004,282.00  | Repairmen cost         |                 |

Total investment cost and yearly operation and maintenance cost are demonstrated in Table 12. Operation and maintenance cost are mostly calculated based on house level. Land lord levy (Verhuurderheffing) is a financial contribution from landlord to the

government for national debt reduction. “Landlords who own more than 50 rental properties pay a levy on the WOZ value of the rented housing. This concerns rental properties of which the rent does not exceed € 710.68 per month (price level 2018). In 2018 the landlord levy is 0.591%.” (Rijksoverheid, 2018) In this case, although the landlord levy is calculated according the value of the houses, Woonbedrijf calculated every house based on the average house value from all of their house properties. Average landlord levy of each house is €763/year in this case. Insurance is calculated as €375/house/year and company operation fee is calculated as €900/house/year. As for the maintenance cost, it is also calculated based on house level; Woonbedrijf reserves €900/year for each house for maintenance, including general replacement and regular painting.

Based on all the information mentioned above, LCCA can be conducted. Total life cycle of this prognosis scenario is 36 years. Since the realization phase lasts for five years and 68% of the households are assumed to be renovated during the first two years, the maintenance cycle of 30 years will be calculated from the year 2020 as it shown in Figure 27. Different maintenance cycle is set for the houses that finish renovations in different years. For example, the houses that finish renovation in year 2018 have maintenance cycle of 31 years and houses that finish renovation in year 2021 have maintenance cycle of 28 years. The rest of the houses also follow the same trend for maintenance cycle. The residual rate of this project is 5.5% of the initial investment and discount rate is 5%. These two rates are both assumption and they are considered as the reference value for the scenarios following.

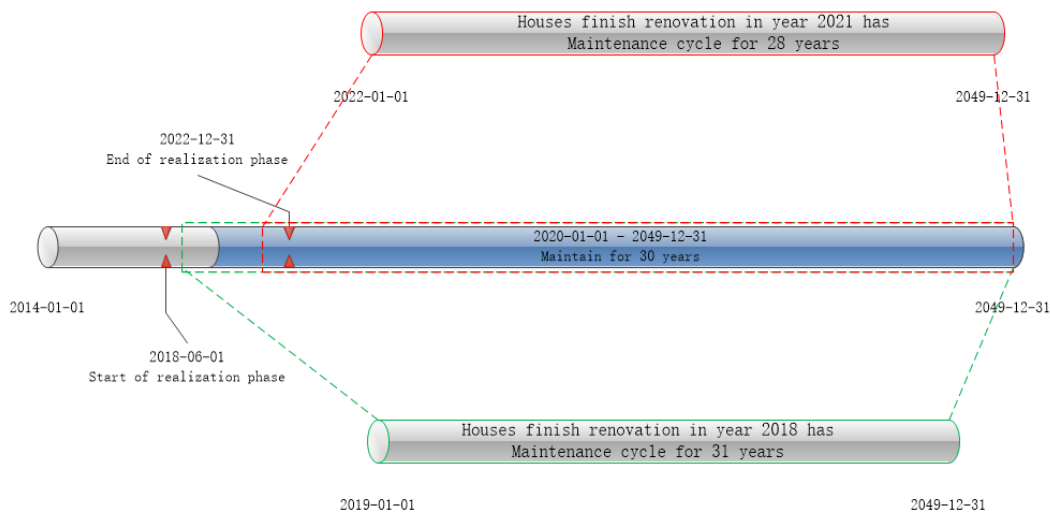


Figure 27 Life cycle of Woonbedrijf prognosis scenario

In order to implement LCC calculation, the present value of each cost activity needs to be obtained. Based on Formula 3.3 and the situation that maintenance fee and operation fee are the same every year, the equitation can be simplified as:

$$LCC = C_0 + (O\text{Cost}_1 + M\text{cost}_1) \times \frac{(1 + r)^T - 1}{r(1 + r)^T} - \text{pvf} \times R\text{Cost} \quad (5.1)$$

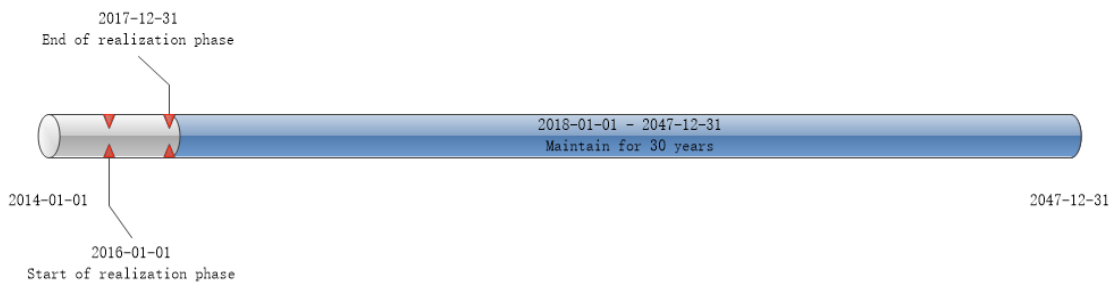
The value of pvf and  $\frac{(1 + r)^t - 1}{r(1 + r)^t}$  (pvf<sub>sum</sub>) in each year during life cycle of the project is demonstrated in Appendix D together with calculation formula. The discount rate of this scenario is assumed as 5% and residual rate of investment cost after 30 years is assumed as 5%, The result is demonstrated in Table 13.

*Table 13 Result of LCC calculation of Woonbedrijf prognosis scenario for all houses*

| Cost activity          | Amount                 |
|------------------------|------------------------|
| Architecture           | € 13,652,658.00        |
| Development            | € 500,440.00           |
| Development risk       | € 50,000.00            |
| Unexpected             | € 206,790.00           |
| Direct cost            | € 524,829.00           |
| Not recoverable        | € 3,004,282.00         |
| Land lord levy         | € 2,968,936.29         |
| Insurance              | € 1,459,175.77         |
| Company operation cost | € 3,502,021.84         |
| Maintenance cost       | € 3,502,021.84         |
| Residual value         | € 228,287.40           |
| <b>Total</b>           | <b>€ 29,142,868.33</b> |

#### 4.3.1.2. Ordinary scenario

This scenario reflects the financial situation when the renovation project in Eckart area is an ordinary project (renovate one block after another and Woonbedrijf decides where and when in the household is renovated). As it described in section time risk, definition and design phase only takes two years and realization phase takes two year in ordinary case. After all the construction, the maintenance period is 30 years. The life cycle of this scenario is demonstrated in Figure 28.



*Figure 28 Life cycle of ordinary case*

The general financial information mentioned in Table 11 is based on the prognosis scenario from Woonbedrijf in Eckart case. When calculating for the rest of the scenarios, average value of financial information of Woonbedrijf prognosis scenario is implemented to indicate the difference in renovation requirement from tenants. Moreover, some data is modified to better reflect ordinary case. Architecture cost is reduced by 5% since logistic and labor cost less when there is building site in the area and concentrated construction can be implemented. The development cost and development risk have been reduced for 5% since ordinary case do not require too many development. Moreover, the direct cost also has a reduction of €60,000 since Woonconnect is not implemented in ordinary project. The discount rate of this scenario is 5% and residual rate of investment cost after 30 years is 4%, since this scenario has longer maintenance period compared to the previous scenario (Woonbedrijf prognosis).

In ordinary scenario, construction would be implemented in the neighborhood continually with the requirement from Woonbedrijf. Therefore, when 8 houses can be renovated within 2 weeks in one year (assume 8 weeks vacation), 176 houses can be renovated in the first year, and 78 houses can be renovated in the second year. The calculation process of LCC calculation is shown in Appendix D and the result is demonstrated in Table 14.

*Table 14 Result of LCC calculation in ordinary case for all houses*

| <b>Cost activity</b>          | <b>Original scenario</b> | <b>Woonbedrijf prognosis</b> |
|-------------------------------|--------------------------|------------------------------|
| <b>Architecture</b>           | € 12,606,225.32          | € 13,652,658.00              |
| <b>Development</b>            | € 475,418.00             | € 500,440.00                 |
| <b>Development risk</b>       | € 47,500.00              | € 50,000.00                  |
| <b>Unexpected</b>             | € 200,767.47             | € 206,790.00                 |
| <b>Direct cost</b>            | € 464,829.00             | € 524,829.00                 |
| <b>Not recoverable</b>        | € 2,923,342.68           | € 3,004,282.00               |
| <b>Land lord levy</b>         | € 2,979,211.75           | € 2,968,936.29               |
| <b>Insurance</b>              | € 1,464,225.96           | € 1,459,175.77               |
| <b>Company operation cost</b> | € 3,514,142.30           | € 3,502,021.84               |
| <b>Maintenance cost</b>       | € 3,514,142.30           | € 3,502,021.84               |
| <b>Residual value</b>         | € 154,727.49             | € 228,287.40                 |
| <b>Total</b>                  | € 28,035,077.30          | € 29,142,868.33              |

The comparison between original scenario and Woonbedrijf prognosis scenario (original financial data) is also indicated in Table 14. Prognosis scenario has more investment cost compare to original scenario due to the increasing building cost in the five years. On the other hands, operation and maintenance cost indicates an opposite phenomenal since some of the houses only have maintenance period of 27 and 28 years.

#### **4.3.1.3. Diffusion of innovations model**

When a new method and innovation is raised, the diffusion of innovations model is commonly considered. The model is demonstrated in Figure 29 (Rogers, 1995). In this

case, the households from demonstration can be included in innovators. From the start of realization phase, the household that join the renovation will follow the trend of innovation diffusion for each year. The assumed amount of household joining is shown in Table 15. The financial information is assumed as the average financial value from Woonbedrijf prognosis scenario. The integrated financial information is shown in Table 16.

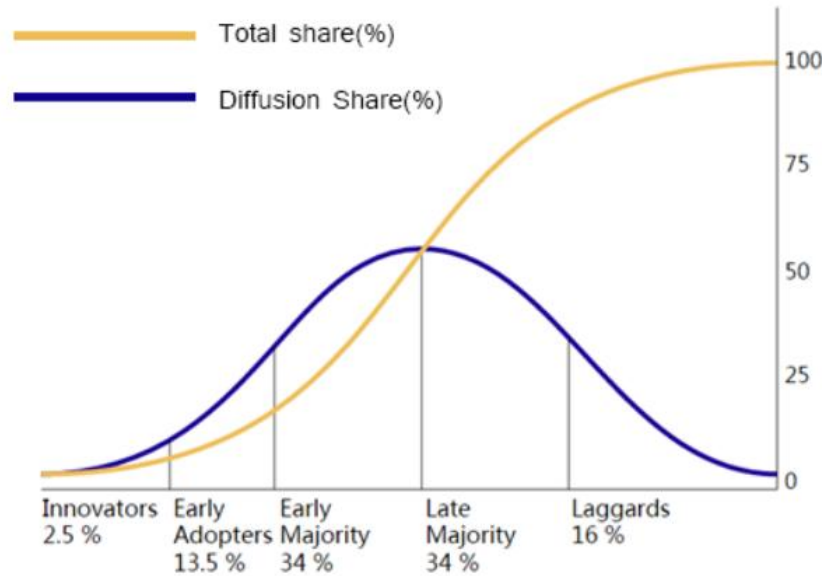


Figure 29 Diffusion of Innovation

Table 15 Innovation diffusion scenario renovation requirement distribution

| Year           | 2018 | 2019 | 2020 | 2021 | 2022 |
|----------------|------|------|------|------|------|
| Month          | 6-12 | 1-5  | 6-12 | 1-5  | 6-12 |
| 12 month scale | 16%  | 34%  | 34%  | 16%  |      |
|                | 9%   | 7%   | 20%  | 14%  | 10%  |
| Calendar year  | 9%   | 27%  | 34%  | 20%  | 10%  |
| House amount   | 23   | 68   | 87   | 51   | 25   |

Table 16 Integrated financial information for Investment cost for innovations diffusion scenario (Total amount for all the houses that require renovation in each year)

| Cost Activity    | Early phases | 2018          | 2019          | 2020          | 2021          | 2022          |
|------------------|--------------|---------------|---------------|---------------|---------------|---------------|
| Architecture     | -            | €1,188,984.42 | €3,636,601.04 | €4,789,359.67 | €2,905,521.00 | €1,454,364.71 |
| Development      | €155,000     | € 31,280.00   | € 92,480.00   | €118,320.00   | € 69,360.00   | € 34,000.00   |
| Development risk | € 15,000     | € 3,169.34    | € 9,369.83    | € 11,986.67   | € 7,029.00    | € 3,445.59    |
| Unexpected       | € 2,000      | €17,834.90    | € 54,548.75   | € 71,840.73   | € 43,584.00   | € 21,816.18   |
| Direct cost      | € 48,672     | €24,892.41    | € 74,538.63   | € 96,214.27   | €53,103.00    | € 26,410.29   |
| Not recoverable  | € 54,678     | € 257,077.70  | € 785,889.46  | 1,034,522.80  | € 626,448.00  | € 313,519.12  |

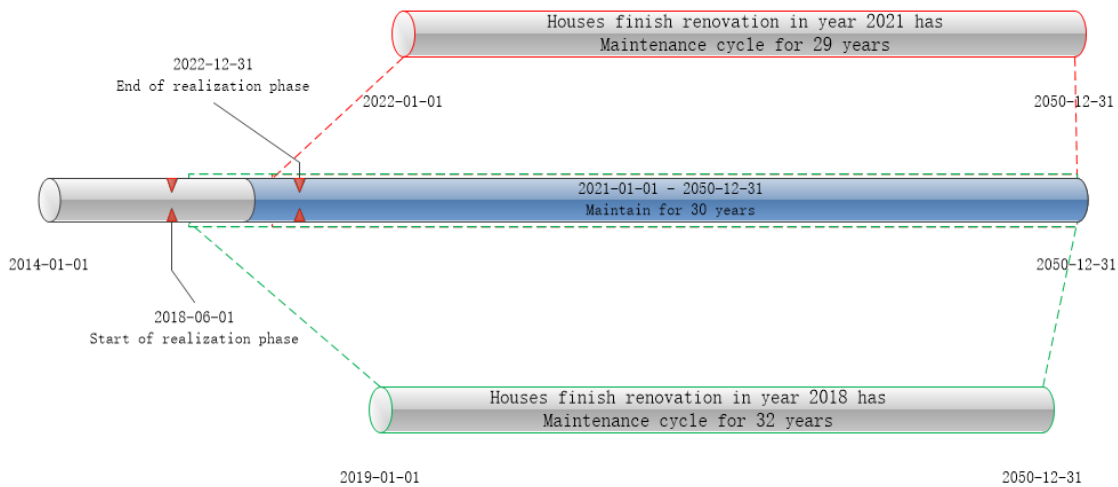


Figure 30 Life cycle of innovations diffusion

In this scenario, since the realization phase lasts for five years and 67.5% of the households are assumed to be renovated during the first three years, the life cycle of maintenance will be calculated from the year 2021 as it shown in Figure 30. It is assumed that the residual rate of the project is 5% since this scenario has shorter maintenance period compared to the two scenarios mentioned above, and discount rate is 5%. The calculation formulas are demonstrated in Appendix D, and result is demonstrated in Table 17. The comparison between innovation diffusion scenario and Woonbedrijf prognosis indicates that when implementing renovation project with long realization phase, it is essential to convince the tenants to renovation in the earlier years to further reduce the total cost.

Table 17 Result of LCC calculation of innovation diffusion scenario for all houses

| Cost activity          | Innovation diffusion | Woonbedrijf prognosis |
|------------------------|----------------------|-----------------------|
| Architecture           | € 13,974,830.83      | € 13,652,658.00       |
| Development            | € 500,440.00         | € 500,440.00          |
| Development risk       | € 50,000.43          | € 50,000.00           |
| Unexpected             | € 211,624.56         | € 206,790.00          |
| Direct cost            | € 523,830.59         | € 524,829.00          |
| Not recoverable        | € 3,072,135.07       | € 3,004,282.00        |
| Land lord levy         | € 2,980,143.60       | € 2,968,936.29        |
| Insurance              | € 1,464,683.94       | € 1,459,175.77        |
| Company operation cost | € 3,515,241.47       | € 3,502,021.84        |
| Maintenance cost       | € 3,515,241.47       | € 3,502,021.84        |
| Residual value         | € 212,090.54         | € 228,287.40          |
| Total                  | € 29,596,081.42      | € 29,142,868.33       |

#### 4.3.1.4. Projected scenario

Eckart project is currently at the beginning of realization phase when this thesis is written. It is important to assess the scenario that can be developed based on the current renovation requirement situation from tenants although this scenario can only provide a scenario with limited reliability. Table 18 demonstrates the current situation regarding how many tenants are reached and how many of them have already chosen the renovation. Tenants are required to start considering about renovation when they receive the invitation from Woonbedrijf, and they need to make the first appointment to start choosing their renovation measures. From this table, it can be assumed that tenants who live in house type R3 have high motivation to join the renovation while tenants in R4 and R4+1 do not. All the households that have chosen the renovation have been scheduled in this year. Therefore, the assumption of this scenario based on current situation is shown in Table 19. House types are here demonstrated in the first time for the distribution of renovation requirement. However, it is only used for precise requirement prediction on house level. House type difference does not affect the investment in each house.

*Table 18 current situation of tenants' choice (05-28-2018)*

| House type  | First appointment | Chose renovation | Invitation sent | Total amount |
|-------------|-------------------|------------------|-----------------|--------------|
| <b>R3</b>   | 7                 | 4                | 8               | 28           |
| <b>R4</b>   | 14                | 2                | 41              | 102          |
| <b>R4+1</b> | 3                 | 1                | 13              | 40           |
| <b>S4</b>   | 17                | 4                | 38              | 84           |

*Table 19 Projected scenario renovation requirement distribution*

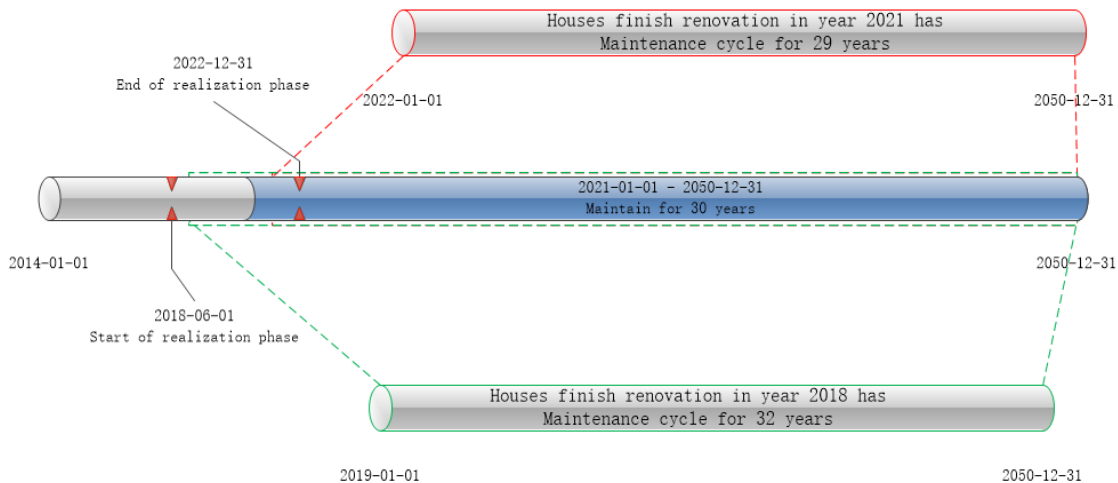
| Year         | 2018 | 2019 |      | 2020 |      | 2021 |      | 2022 | Total |
|--------------|------|------|------|------|------|------|------|------|-------|
| Month        | 6-12 | 1-5  | 6-12 | 1-5  | 6-12 | 1-5  | 6-12 | 1-12 | -     |
| <b>R3</b>    | 7    | 8    | 10   | 2    | 1    | 0    | 0    | 0    | 28    |
| <b>R4</b>    | 6    | 9    | 12   | 15   | 20   | 15   | 10   | 15   | 102   |
| <b>R4+1</b>  | 3    | 4    | 7    | 8    | 6    | 4    | 3    | 5    | 40    |
| <b>S4</b>    | 10   | 10   | 14   | 20   | 15   | 10   | 4    | 1    | 84    |
| <b>Total</b> | 26   | 31   | 43   | 45   | 42   | 29   | 17   | 21   | 254   |

Based on the average finance value from Woonbedrijf prognosis and Table 19, the integrated financial information is demonstrated in Table 20. Under current circumstance, half of the household from each type chose to install solar panel, and the rest mostly chose basic renovation.

*Table 20 Integrated financial information for Investment cost of projected scenario  
(Total amount for all the houses that require renovation)*

| Cost Activity    | Early phases | 2018          | 2019          | 2020          | 2021          | 2022          |
|------------------|--------------|---------------|---------------|---------------|---------------|---------------|
| Architecture     | -            | €1,350,660.34 | €3,976,236.60 | €4,811,414.17 | €2,632,327.00 | €1,226,989.85 |
| Development      | €155,000.00  | € 35,360.00   | €100,640.00   | €118,320.00   | €62,560.00    | €28,560.00    |
| Development risk | €15,000.00   | € 3,582.73    | €10,196.58    | €11,986.67    | €6,339.88     | €2,894.29     |
| Unexpected       | €2,000.00    | €20,161.19    | €59,361.88    | € 71,840.73   | €39,311.06    | €18,325.59    |
| Direct cost      | €248,672.00  | €28,139.24    | €81,115.56    | € 96,214.27   | €47,896.82    | €22,184.65    |
| Not recoverable  | € 54,678.00  | € 290,609.57  | € 855,232.65  | €1,034,522.80 | €565,031.53   | €263,356.06   |

In this scenario, since 74% of the households are assumed to be renovated during the first three years, the life cycle of maintenance will be calculated from the year 2021 as it shown in Figure 31. It is assumed that the residual rate of the project is 5 % and discount rate is 5%. The calculation formulas are demonstrated in Appendix D, and result is demonstrated in Table 21. The comparison indicates that the difference in solar panel requirement influence investment cost. Therefore, the project team should pay close attention to the demand change from tenants regarding solar panel and luxury renovations.



*Figure 31 Life cycle of scenario under current situation*

*Table 21 Result of LCC calculation of projected scenario for all houses*

| Cost activity    | Projected scenario | Woonbedrijf prognosis |
|------------------|--------------------|-----------------------|
| Architecture     | € 13,997,627.97    | € 13,652,658.00       |
| Development      | € 500,440.00       | € 500,440.00          |
| Development risk | € 50,000.16        | € 50,000.00           |
| Unexpected       | € 211,000.45       | € 206,790.00          |

|                               |                 |                 |
|-------------------------------|-----------------|-----------------|
| <b>Direct cost</b>            | € 524,222.54    | € 524,829.00    |
| <b>Not recoverable</b>        | € 3,063,430.60  | € 3,004,282.00  |
| <b>Land lord levy</b>         | € 2,984,467.53  | € 2,968,936.29  |
| <b>Insurance</b>              | € 1,466,809.08  | € 1,459,175.77  |
| <b>Company operation cost</b> | € 3,520,341.78  | € 3,502,021.84  |
| <b>Maintenance cost</b>       | € 3,520,341.78  | € 3,502,021.84  |
| <b>Residual value</b>         | € 212,250.88    | € 228,287.40    |
| <b>Total</b>                  | € 29,626,431.00 | € 29,142,868.33 |

#### 4.3.1.5. Comparison and discussion

As it shown in Figure 32, ordinary scenario has less investment cost and total cost at the end for the project compared to other scenarios that implement the concept of series of one. It is expected to have this result due to the additional process, such as using Woonconnect and dealing with logistics. Woonbedrijf would like to have a similar cost at the end of the project to ensure the feasibility of Eckart project from financial aspect. As the result shown in Figure 33, ordinary scenario indeed costs less than the scenarios of “series of one”, but the difference is only 3.95% in whole life cycle of the project and 7.3% in investment cost. Moreover, the three different scenarios which simulate the concept of “series of one” have similar financial outcome at the end (difference approximately 2%). Therefore, it can be concluded that Eckart renovation project is financially feasible since the cost outcome of this new concept is similar to ordinary renovation project. These tables also demonstrate that convincing tenants to participate early in the project and pay close attention to tenants demand of solar panel and luxury renovation can further control financial outcomes.

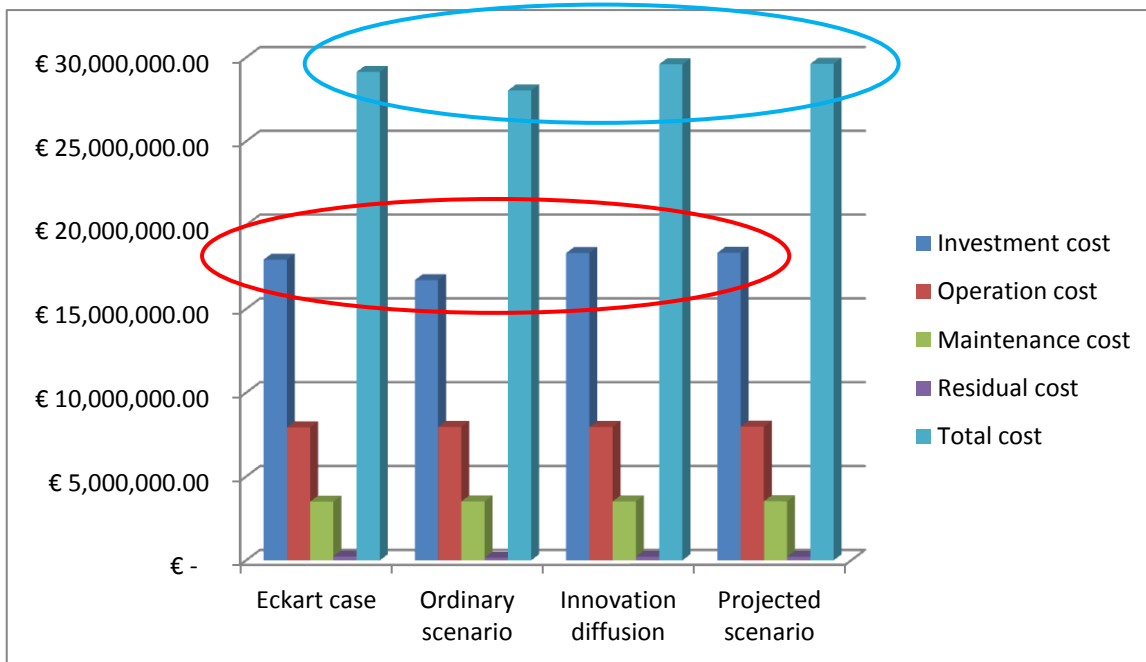


Figure 32 Cost difference of four scenarios during the entire life cycle

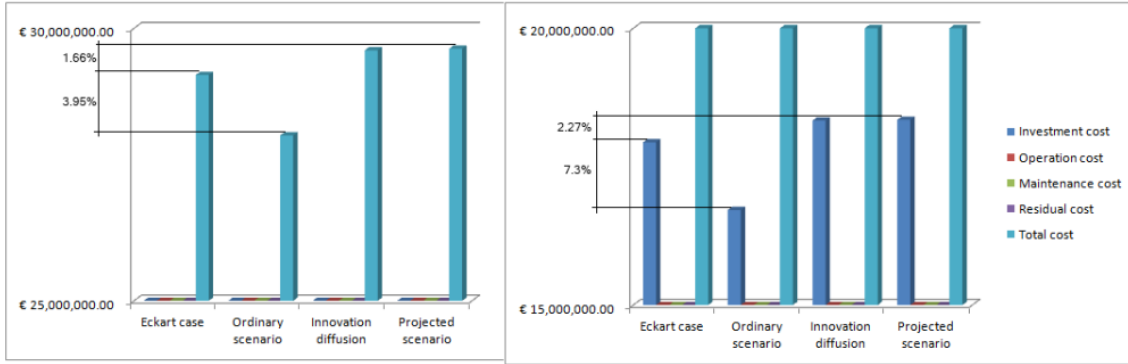


Figure 33 Amplification of information in the circles in Figure 32

#### 4.3.2. Financial feasibility from tenants perspective

In this section, the renovation benefit from tenants' aspect is analyzed. The main focus is whether it is beneficial for the household to participate in the energy renovation project. This is assessed by the data from two demonstration houses. From the aspect of tenants who chose luxury renovation, their investment in renovation includes €4/month increase in rent for luxury renovation and €12.64/month increase in service cost for solar panel. The operation cost is mainly conducted by energy usage, and maintenance cost is already included in the rent. As for the tenants who only choose basic renovation, the investment cost is only €2/month increase in rent for some basic renovation. The operation and maintenance cost is the same as the tenants who choose luxury renovation. Since the energy efficiency is the key point of this renovation, only the amount related to solar panel is included in the calculation. The process of two houses energy bill calculation (one with solar panel and one without) is shown in Appendix D and result is shown in Table 22 and Figure 34.

Table 22 Result of LCC calculation of Tenants investment and return  
(one household for 30 years)

|                        | House with solar panel | House without solar panel |
|------------------------|------------------------|---------------------------|
| <b>Investment cost</b> |                        |                           |
| Service cost           | €12.64/month           | € -                       |
| <b>Operation cost</b>  |                        |                           |
| Energy cost before     | € 1519.08/year         | € 1469.45/year            |
| Energy cost after      | € 798.23/year          | € 940.84/year             |

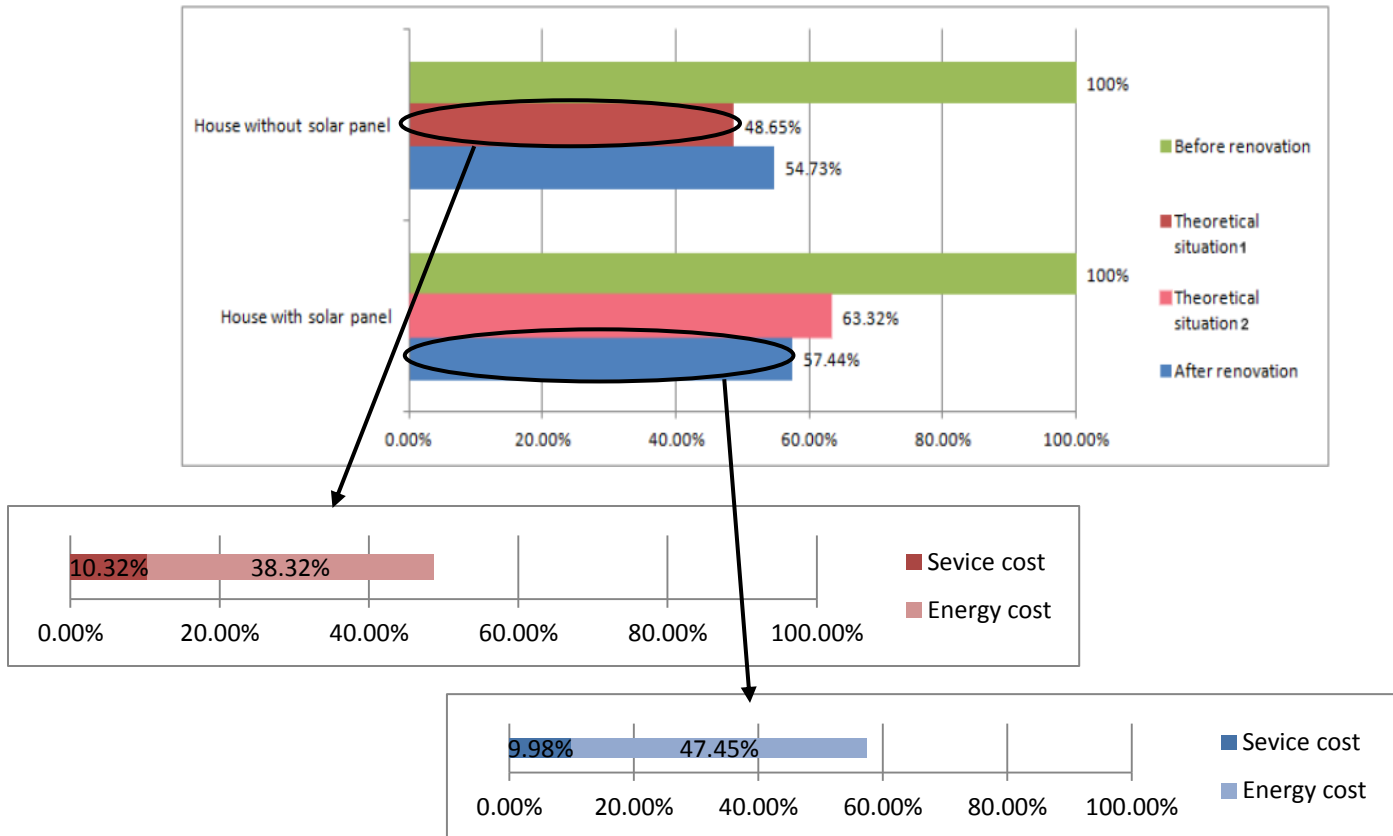


Figure 34 Energy bill proportion difference after renovation

Therefore, after renovating the house with 5 solar panels, although € 2331.69 service fee is required for solar panel, but an overall bill reduction of 42.56% is expected after renovation. Compare to the theoretical situation that no solar panels are installed in the house, 5.88% less energy bill can be expected after renovation. As for the situation of no solar panel installation, a reduction of 45.27% is also expected from no investment cost if tenants participate in the renovation project. However, if comparing with the theoretical situation that solar panels were installed in this house, 6.08% less energy bill can be expected. Therefore, it is recommended for the tenants to participate the renovation project with solar panel installation. Unfortunately, there is no data related to outcome of 10 solar panels installation, but it can be assumed that 10 solar panels would reduce energy bill even more comparing to 5 solar panel installations after renovation. It is definitely beneficial for tenants to join the renovation project with the option of installing solar panel.

#### 4.3.3. Conclusion

According to the calculation result of LCCA, the project is financially feasible for both the Housing Corporation and tenants. Tenants would receive high return if they choose to install solar panel on their roof. More energy generation options could provide tenants even higher benefits. From the aspect of company, although renovation with the

concept of “series of one” cost more compare to ordinary project, the overall expenses tend to not have a huge gap. Therefore, renovating social housing using the concept of “series of one” does not lag the project from financial aspect. Convincing tenants to participate in the early years of the renovation project and pay close attention to solar panel and luxury renovation demand can further control the financial outcome. Moreover, the expenses of followed up project after this experiment are expected to be further reduced due to the shorter development period and more mature technologies. This financial feasibility also provides the company more confidence to develop new tenants oriented option.

#### 4.4. Conclusion

In this chapter, case study of Eckart project is conducted. After reviewing the general situation of Eckart project in the first section, case analysis and evaluation are conducted for in-depth understanding of the project. After implementing all the analysis, the interview results demonstrate that the project team has implemented several successful factors mentioned in the literature review, such as involving stakeholders from early stages, tenants participation and demonstration houses. The communication between various stakeholders in the early stages and tenants’ participation ensure the smooth decision-making process that improves the quality of renovation. Tenants participation also assist Woonbedrijf to truly understand tenants demands for renovation, which responses to the concept of “series of one”. Demonstration project offers the team an opportunity to test and assess the whole renovation process for the smooth implementation in the realization phase. Furthermore, the project team has overcome immediate and essential barriers and risks that might influence the project process with the proper solutions in the early stages. This provides the project enough base and guideline to achieve success at the end. The renovation project can be expected to be success according to the proper and reasonable in every process before the realization phase.

Furthermore, the result of project evaluation demonstrates that the project is on the right track to success from the aspects of energy performance improvement, living condition improvement, contractor satisfaction. However, from the aspect of tenants’ satisfaction and schedule, more efforts are required. These two aspects have big impacts on the renovation project in the later phases, so it is essential to gradually find concrete solutions for schedule control and improve tenants’ satisfaction regarding construction process and information exchange.

As for the financial feasibility of the project, the result of LCCA demonstrates that implementing renovation project with the concept of “series of one” is feasible for both project team and tenants. From project team perspective, difference of maximum 4.6% in total cost between ordinary scenario and “series of one” scenario meet the criterion from the project team. Convincing tenants to participate in renovation project from early years and paying close attention to tenants demand of solar panel and luxury renovation could further control financial outcomes of the project team. From tenants

perspective, renovation project can lead to energy bill decrease and living condition improvement. When tenants choose to install solar panels, although they need to pay monthly extra service fee, they could receive more payback of energy bill within the life cycle of 30 years. It is feasible for tenants to participate in this energy saving renovation project especially with installation of solar panel.

## 5. Conclusion and discussion

In the last part of the report, the final conclusion, discussion and recommendation are provided after answering the research questions of the thesis.

### 5.1. Research question answers

#### Part 1: Energy Renovation Project Evaluation

Main question: How to successfully implement social housing energy renovation project?  
How is the outcome of the energy renovation project? What can other renovation project learn from this specific case?

Three sub questions are formed in order to answer the question. The answers of these three questions are integrated in the main question answer instead of being indicated respectively. The main question is answered based on literature reviews and correlated parts in case study. In order to successfully implement social housing energy renovation project, it is essential to have proper energy saving measures conducted as it shown in Table 23. With the combination of these measures, energy efficiency in the households can be improved. It is not necessary to implement everything at once; the decision needs to be made according to the housing and budget conditions.

*Table 23 Common and proper energy saving renovation measures in social housings*

| Energy saving categories |   | Examples   |
|--------------------------|---|--|
| Building construction    | Additional thermal insulation                 | Install rood and wall insulation                         |
|                          | Replacement of window                         | Install new HR++ or HR+++ glass                          |
|                          | Reduce thermal bridge                         | Adjust the materials accordingly                         |
|                          | Ensure air-tightness                          | Add materials on gaps                                    |
| Heating                  | Improve pipe insulation                       |  |
|                          | Automatic control system                      | Install new automatic control system                     |
|                          | Replacement of pump with integrated converter | Install new boilers in individual and collective system. |
|                          | Insulation of distribution pipes              |  |
| Domestic hot water       | Replacement of pump with integrated converter | Install new boilers in individual and collective system. |
|                          | Insulation of distribution pipes              |  |
| Self energy generation   | Renewable energy                              | Solar panels   |

Moreover, understanding and learning from the factors that lead the previous social housing energy efficiency renovation project to success is necessary for properly implement the following projects. Table 24 demonstrates the successful factors and correlated influence to the project. There are also some unique successful factors from special cases. Therefore, besides comparing to the table, housing organizations are required to understand their project comprehensively to seek hidden opportunities.

*Table 24 Common successful factors from previous social housing energy efficiency renovation project and correlated influence*

| Perspective          | Factor  | Influence   |
|----------------------|---|---|
| Stakeholders         | Involve stakeholders in the early stages of the project | A comprehensive plan that considers all the possible outcomes and interest can be proposed and developed from the early stages.                           |
| Financial            | Easy finance plan by fund/loans/pre-fabrication...      | Make the finance easy for the project provides housing organizations opportunity to implement the project with more renovation options without concern.   |
| Construction         | Implement demo project before realization phase         | Demo project provides contractors and house owners an opportunity to assess the feasibility of the project from comprehensive perspectives.               |
|                      | Short construction period                               | Short construction period reduce the disturbance to tenants regarding construction noise and inconvenience.   |
| Tenants satisfaction | No/little rent increase                                 | Tenants are more willing to join since they lose nothing  |
|                      | Energy performance guarantee                            | This guarantee provides tenants confident that they will get benefit from the renovation project even if the energy saving measures do not work properly. |
| Others               | Set a specific goal                                     | It is more feasible for housing organizations to develop their concept at the beginning, and evaluate at the end.   |

Furthermore, overcoming the lagging factors throughout the life cycle of the project, especially during decision making process is necessary for success of the project. Table 25 demonstrates the common lagging factors, and correlated solutions. Unique lagging factors also exist in different project. Longer development period in the early stages of the project is required for addressing its unique problem.

*Table 25 Common lagging factors, and correlated solutions in social housing energy efficiency renovation project*

| Category           | Factor  | solutions   |
|--------------------|---|---|
| Technical barriers | Lack of knowledge and experience related to renovations                                   | Involve all the stakeholders from the early stage to study and develop the concept according to the project condition from past experience. |
| Financial barriers | Few financial feasible measures for existing housings due to their structures and systems | Combine energy efficiency renovation with maintenance and upgrade of the houses.  |
|                    | Project outcomes do not match the investment  | Gather and study experience from previous projects and reports  |
|                    | Lack of fund and capital to implement renovations   | Create proper funding model to receive financial assist. Consider the increased dwelling value after renovations                            |
|                    | Simple payback method for investment evaluation that                                      | Implementing time related investment evaluation methods such as LCCA.   |

|                         |   |  |
|-------------------------|---|--|
|                         | underestimate the project profit                                      |  |
| Organizational barriers | Lease relationship in social houses                                   | Demonstrate clearly the increased comfort and living condition as the consequence of renovations.  |
|                         | Limitation due to building code                                       | Avoid modifying the structure of the houses or make a complete change to meet the building code requirement.   |
| Time risks              | Lack of time for development  | Start to consider the project and involve different stakeholders as early as possible.   |
|                         | Long project period   | Make a concrete plan for the whole life cycle of the project and evaluate the process regularly to keep track of the progress.                             |
| Other barriers          | Split incentive   | Create a clear renovation beneficial scheme for stakeholders. This can also be done through “all inclusive leasing contract” and “green leasing contract”. |
|                         | Tenants do not see the value of energy efficiency renovation measures | More communication together with the real outcomes with tenants is required to fully demonstrate the incentives for tenants.                               |
|                         | Lack of trust from tenants  | Housing organizations should develop and maintain the relationship with their tenants from daily communication.  |

Therefore, in order to successfully implement social housing energy renovation project, the in-depth consideration from the perspectives of energy saving renovation measures, successful factors and lagging factors according to the specific situation of the project is required. The comparison needs to be implemented during the early stages of the project to future develop their unique concept.

As for the evaluation of Eckart project, the project manager considered all the perspective mentioned before in combine with the specific situation in Eckart area. From the perspective of energy saving renovation measures, Eckart project implemented measures related to building construction (new roof insulation, new HR++ glass and ventilation system) and self energy generation (solar panels). No heating related measure is implemented in Eckart project since the housing organization already installed them previously. The housing organization distinguished a specific goal from this aspect, which is to reach energy label of B from D and F after renovations. According to the data from demonstration houses, this goal is achieved with better result of energy label A; CO<sub>2</sub> emission also reached a decline of 52.8%.

From the aspect of learning from successful factors of previous renovation project, Eckart project involves stakeholders from early stage (design phase) since their unique concept requires long time to develop. The concept is not difficult for experienced employees from the project, but the change of perspective needs deep consideration in

combine with their experience. Although the project only receives a little fund from the Triangulum project, the project team manages to apply for loan with little interest. Therefore, they are able to arrange the project investment from the rent (maintenance part) before and afterwards. Besides implementing demonstration houses, the project also constructed show room for tenants to visit. The project team is able to assess the construction process and improve construction details. The technology of pre-fabrication is used in Eckart case to reduce budget and shorten project duration (The whole process takes around 2 weeks). From the project concept of “series of one”, the housing organization already focuses on tenants’ satisfaction in this project. There is no rent increase for basic energy saving measures, but no energy performance guarantee is provided also due to the same reason. Lastly, the project also has specific goals to achieve: energy goal as mentioned before; assess the possibility and feasibility of implementing the concept of “series of one” in the following energy saving renovation from both sides of housing organization and tenants.

As for the aspect of overcoming lagging factors, the experienced project team work together to address possible problem. The technical problem occurred in this project from both the side of Woonconnect and construction process. Since Woonconnect is a new technology for renovation project, it learns from the housing organization and contractors what they require to match the Eckart project. Moreover, the technical problem revealed from demonstration project of subsidence is also addressed by 3D modeling scanning based the knowledge from contractors. The financial barrier of the project is currently addressed by receiving loans with low interest, so that the project team can cover the expenses by terms of “borrowing” future rent from tenants. Pre-fabrication technology from contractors also eases the financial problem and time risk related to construction duration for the project. Although the project team is using simple payback investment evaluation at this moment, the LCCA from this thesis can still provide a better insight. Although the problem related to finance, project duration and administration are not completely addressed yet, the project is still on the right track since the essential parts are all addressed. However, according to the interview with tenants, there are still complains related to construction process and communication process. The project team needs to pay more attention for this aspect since tenants satisfaction has huge influence on the success of the project.

Based on the current situation, besides the excellent outcome from energy performance improvement, contractor satisfaction and living condition improvement also indicates that the Exckart project is on the right track to success. Based on the information from previous paragraph, more attentions are required to improve tenants satisfaction during communication and information exchange process.

Therefore, based on the experience from Eckart case, the following social housing energy saving renovation projects should also compare their plan with the three tables above to check whether they covered what is essential for the success of the project. The project team needs to choose the energy saving measures that suits the condition

of the houses. It is essential to remember that considering their own housing condition is as important as learning from previous renovation experiences for the success of the project. The successful factors are rather significant for the whole project especially the factors that are mentioned in Table 24. The following project is required to pay attention to all the factors to lead the project to a real success. As for overcoming lagging factors, an experienced team is rather important for the process. When there is no experienced member in the team, an external consultant is essential for the success. Moreover, it is recommended to not start realization phase but develop the concept more although it might postpone the project process when there are essential lagging factors that have not been overcome.

## Part 2: Project Feasibility Assessment

Main question: Is this renovation project feasible for both the social housing company and their tenants?

This main question is answered based on case study and interviews though the three sub questions:

1. Is the project feasible for the company, especially from financial aspect?

From financial aspect of the project, the result of LCCA demonstrates that the Eckart project is financially feasible for the housing organization. Although renovation with the concept of “series of one” cost more compare to ordinary project, the overall expenses only lead to a maximum difference of 4.6% in total cost and 9.57% in investment cost. Moreover, the expenses of followed up project after this experiment are expected to be further reduced due to the shorter development period and more mature technologies. Therefore, the Eckart case is feasible from company aspect.

2. Are tenants satisfied with the renovation concept, approach and process?

According to the interviews with tenants, tenants are pleased with the concept of choosing their own measures to renovate their houses at preferred time. However, it seems that tenants still prefer to renovate one block at the same time instead of renovating one house at once. As for the aspect of approaching method, tenants are satisfied with patient from the housing organization to explain them regarding the details of renovations. However, the tenants also reflect that it would be better if the organization could have sent the pamphlet together with the invitation letter, so the tenants can have more insight regarding what they can choose and what they can expect when they make the final decision of participating in the renovation project. Moreover, the information regarding renovation measures can also be improved. Some tenants especially reflect that the function and usage of new ventilation system is unclear.

As for the aspect of renovation process, there are many complaints regarding time schedule, construction noise and workers. There are indeed schedules set for construction process, but tenants require a more precise and concrete schedule to fully prepare themselves for the construction especially in a family. Moreover, the housing

organization is required to supervise the construction process from different aspects for better satisfaction during construction process.

In general, the tenants are satisfied with the concept and outcome of the project (based on the feedback from tenants in demonstration houses), and the project is also feasible for the tenants. However, the housing organization still needs to pay more attention on how to approach the tenants and how to monitor and arrange construction process to improve the tenants satisfaction.

3. Is it feasible to continue renovating other possible houses with the same method?

From financial aspect, the project cost is expected to be reduced due to the shorter development period and more mature technology as it mentioned in the first sub question in part two. Therefore, continuing with the same concept to renovate the rest of the houses is financially feasible for the housing organization. However, as the method requires houses under similar structure and composition, only the houses from 60s and 70s are suitable for this method (They were built during the period that requires many houses; therefore, the houses from that period have similar structure and composition). It is difficult to implement the same methods to other houses that were not built in that time period. Moreover, the house management and administration part needs to be improved to truly reach the success of the project.

Therefore, to answer the main question, the project is feasible for both company and tenants, but the company still needs to put more effort on improving tenants satisfaction regarding their approach and construction process.

## **5.2. Social relevance**

As it mentioned in the chapter of introduction and literature review, it is necessary to implement energy saving renovation project from both aspect of energy saving and indoor living environment. It is a “win-win” strategy for both the government and citizens. However, the burden and lagging factors of energy saving project still exist to postpone the development of it. After reviewing the relevant literature and combining the knowledge with case study of the Eckart case, a reliable guideline for social housing energy saving renovation project is provided as it shown in the answer of Part 1. The author hopes to contribute in accelerating the process of implementing energy saving renovation project in social housings through the guideline from this thesis for social housing organizations.

## **5.3. Limitation of the research**

Although the evaluation of the Eckart case is accomplished through literature review, case study and interviews, there are still some limitation in the research that could influence the result of the evaluation.

- 1) Due to the language barrier of the author, although obtaining reliable data and information from the housing organization is possible, it is difficult to require the

same accuracy when it comes to the aspect of tenants. Therefore, the help from Dutch speaker is needed for the reliability of tenants' interview. This process could lead to misunderstanding and incomplete information exchange.

- 2) The most reliable way to discover the energy performance of the households is reading the meters. However, since there is not many data available at this moment, the result from this data might be inaccurate.
- 3) Since the project is still at the beginning of realization phase, the financial situation is still a prognosis. The budget spend in every house might also differ. Therefore, the financial result might be inaccurate.
- 4) Effect of the new communication technology "Woonconnt" should also be assessed in this thesis; however, since it is difficult for the author to have a short interview with the tenants in the show room, no evaluation is conducted in this thesis.

#### **5.4. Discussion and Further research**

In this thesis, essential factors from both literatures and case study that lead to the success of social housing energy saving renovation project are elaborated and discussed. Referencing and comparing these factors during decision making process would contribute to the acceleration of following social housing renovation project. Eckart case as another part of the thesis is a challenging project to analyze and evaluate. Although "series of one" is only an experimental concept, the project team put many efforts in development to increase tenants satisfaction during energy saving renovation project. In order to achieve complete success at the end of Eckart project, it is essential to address all the long term barriers and risks, and further develop and supervise tenants satisfaction of the project. From the perspective of feasibility, many uncertainties still exist in financial aspect and tenants participation. The project team has to keep close attention to related circumstances and feedbacks.

After comparing the past projects and Eckart case, the importance of tenants' interest focus is further elaborated. Since tenants are the "true owner", they are more willing to join renovation project when they can make their own decisions. This consideration can be seen from understanding of tenants' requirement and involving them in the decision making process. However, comparing to the past projects, Eckart case considered too much for the tenants. Providing tenants opportunities to select when and where to renovate is obliging from the perspective of social housing organizations. However, some controls for schedule is required. A final renovation deadline can be provided by the project team to have an ultimate control.

From the perspective of social housing renovation project, this thesis mainly focuses on existing situations and options. A followed up topic regarding future options could be recommended, such as possible renewable energy source in social housing neighborhood. As the development of energy related policies, renovation measures should be more innovative. From the perspective of Eckart project, since it is currently at the beginning of realization phase, there will be more valuable information in the

following years. Followed up researches regarding financial situation, tenants satisfaction, technology development and construction process improvement is rather necessary for the overall evaluation of Eckart project. Moreover, evaluations towards tenants aspect, such as Woonconnect evaluation and assessment, instead of housing organization and contractor aspect can be conducted for the project to further understand tenants' demands in social housing renovation project.

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## Appendix A Literature review

*Table 26 Retrofitting techniques regarding the building envelope of heritage buildings (cited from (Carreón, 2015))*

| Element             | Most adopted solutions  |
|---------------------|---|
| Windows             | Secondary glazing - a second window installed internally next to the original window reducing both radiated heat loss and air leakage.                |
| Draught proofing    | Gunned mastic material in gaps between the floorboards or skirting.   |
| Suspended floors    | From below the floor: with woodfibre, compressed hemp, wool of sheep.<br>From above the floor: with semi-rigid batts, boards or loose fill cellulose. |
| Solid floors        | Replacing carpets with wooden floors or tiles   |
| Internal insulation | Apply new internal to the timber structure to control vapor and careful isolate from sources of dampness  |
| External insulation | Use materials including hemp-lime composites, wool of sheep and mineral wool as a protective render.  |
| Pitched roofs       | Install ventilation and moisture control materials, such as mineral fiber and wools above the top floor ceiling between the ceiling joists.           |
| Flat roofs          | Use vapor permeable as insulation materials.  |

*Table 27 Renovation Measures (cited from (Visser, 2014))*

| Element        | Renovation Measures  |
|----------------|--|
| Insulation     | Insulation for floors, flat roofs, pitched roofs, indoor and outdoor wall, panels, doors and cavity wall panels.   |
| Window         | HR++ glazing for single glazing or glazing with $U > 1.75$ ; Triple glazing for all other types of glazing or glazing with $U > 0.5$ . Replace all windows |
| Heating system | HR107 boilers in individual and collective systems; Heat pump electric in all individual systems, outside air, auxiliary gas HR107                         |
| Ventilation    | Mechanical exhaust, CO <sub>2</sub> -controlled individual ventilation, DC (Direct Current)  |
| PV panels      | 12~27 PV-panels  |

*Table 28 Renovation Measures (cited from (Palm & Reindl, 2016) )*

| Element        | Renovation Measures   |
|----------------|---|
| Ventilation    | HRV ventilation, mechanical exhaust air system  |
| insulation     | Attic (floor)/loft supplementary insulation with 300/400 mm of mineral wool   |
| Window         | 3-glazing and fitted with interior blinds. U-value: $1.1 \text{ W/m}^2\text{K}$ . Windows with balcony, U-values: $0.9$ and $1.1 \text{ W/m}^2\text{K}$ |
| Entrance       | Exterior doors and entrances. Insulation values, $U_{\text{max}} = 0.8$ and $1.1 \text{ W/m}^2\text{ }^\circ\text{C}$                                   |
| External Walls | Exterior walls supplementary insulation with 100 mm mineral wool  |
| Appliances     | energy class A++  |

## **Appendix B Methodology**

### **Interview with project manager from Woobedrijf**

**14-03**

#### ***How did the company first come up with the idea of renovation?***

The client (Ingrid) first brought the assignment of renovating 250 social housings that has the feature of freedom for tenants to choose, to the board of Woonbedrijf.

#### ***How were the renovation team chosen?***

The team was chosen by the real estate department of Woonbedrijf. They chose them based on the availability and suitability according to previous renovation experience.

#### ***Do you have anyone in the team who is expert in energy renovation field?***

Yes, the project managers are both expert in renovation field. For Marieke, she has worked in renovation in social housing for 20 years, and conducts the experiment in renovation. Furthermore, she is familiar with the policies and regulations in renovation field.

#### ***When were the partners (contractors) chosen? and how did the company decide who (which field and which company) to choose? How did your contractors think of the renovation project?***

The two contractors were chosen by the project manager and purchasing managers during the design phase. They are both maintenance companies; one works in the area of Eckard, and another one works in the area of Vaartbroek. Therefore, both of the companies are already quite familiar with the conditions and issues of the social housing there.

They are both really interested in the project, but they both felt confused about the concept of the “series of one” renovation style. This issue has been solved after face to face communication.

There used to be one architecture contractor as well, but they mainly worked during design phases for the outlook of all the renovation measures.

#### ***Do you receive any fund or loan from any organizations? If yes, how did you choose who to cooperate?***

The company does not receive funds. One part of the investment is collected from the rent of the tenants. There is one part of the rent standing for maintenance. The other part comes from the loan from a bank (can be a normal bank); the company can pay lower interest due to the guarantee of the WSW.

#### ***How did you make the final joint decision? Was there any difficulty for making the decision?***

There was some misunderstanding at the beginning, but it was solved by several face to face communications. The final renovation measure decision was made together with

the contractors. Contractors first proposed the measures and the Woonbedrijf and Architects gave the feedback and comments.

***How did Woonconnect first come up to the table? (Whose idea to implement? And how was the final decision made?)***

There was no official decision at the beginning, but it was already in the “TRIANGULUM” project.

***Why do you want to improve sustainability of the current social housing portfolio? And what were the top three reasons?***

- 1) The houses in Eckart area are already under the requirement of maintenance; therefore, it is a match also with the energy renovation process.
- 2) The Eckart area is one of the locations within the range of Triangulum, and it is the complex of dwellings that can make the biggest improvement.
- 3) All social housing corporation have the agreement to improve their houses to an average energy label B in 2021

***What information has helped you to make the decision to increase the sustainability of the current houses?***

The choices were made with the help of technical information on maintenance according to the initial maintenance plan. The important feature to consider during renovation is to not waste materials; therefore, the sustainability renovation choices were finally made based on the consideration of what is the best option to conduct maintenance and sustainability renovation at the same time.

The decisions were also made based on the experiences of the project manager and the advisor in sustainability area. Furthermore, an energy performance matrix of different renovation combinations was also conducted to help with making the final sustainability decision.

***How have you defined what neighbourhoods/house types were most applicable for renovation?***

Basically all the social housings that have a building year from 1960s to 1970s are applicable to the renovation. The reason why Eckart was chosen was mainly because of the combination with Triangulum project.

***What measure(s)/KPI's have you used to define renovation potential? Do you have data about the potential reductions in energy usage, the costs of the renovation, the increase in rent price for the tenants and the expected savings?***

I will look at the documents that you sent me.

***What do you see as the main benefits of implementing sustainable renovations? What are these benefits for the housing corporation and what are the benefits for the tenants?***

We would like the tenants to have more influence on their own house. They can decide when, where and how they want to renovate their house. In a long term, we would like to make this “series of one” renovation style as another option of renovating social housing.

For tenants: They can make their own decision for their house.

For company: Provide another way to renovate social housing. There are still 32,000 social housing in woonbedrijf that can be renovated in the future, so the more options, the better. We assume that the total cost after renovating all the houses one by one, should be the same as renovating the whole housing block at once. This “series of one” renovation style can also renovate houses according to their specific features, which will reduce the waste of good materials. (e.g. the roof of the house facing southeast remains a better condition than that facing northwest, then the roof of the first house can be renovated 3 years later than the roof of the second house)

***What are the barriers for you to decide to implement sustainable renovations?***

There were very few barriers, but the main one can be seen as the different way of thinking. Welstand (Architecture Company) tested the visual part of the project. They thought that it would be less beautiful if the house was renovated one by one, since the color of the roof would be different in one housing block. This barrier was solved after communication. Furthermore, our own organization was also a barrier because of the different ways of thinking for the project.

***How do you determine return on investments and do you communicate it with the tenants?***

The return on investments was tested based on the calculation method in the company, and the board of the company needed to agree to the result of the calculation. We did not communicate the return with the tenants.

***What were the criteria for you to decide on the different types of renovations the tenants could choose for?***

Some renovations were already decided based on the experience of the project manager and advisors, and some came from the result of the questionnaire to the tenants. The criteria are: Feasible for the housing condition; No waste of the materials (combination of maintenance and renovation); Need to have the biggest improvement on energy performance; Price feasible.

***What other options for renovation have you considered? What are the reasons why you did not incorporate these renovation options?***

One is to place a new insulated wall outside of the external wall to improve the insulation of the house, since the current insulation material between internal and external wall is still too thin (6cm). However, since the performance of external walls is still fine, it will be a waste to destroy that wall to replace a new one. Therefore, this new insulation wall will be implemented maybe in the future.

***Renovation design phase:***

1. How was the process of renovation made?

***Who are involved in the process making process?***

One company "ideate" made the process document at the end, but the input and design of the process came from the complete team including the contractors (everyone involved).

***How did they come up with the process? Was there any difficulty in certain part of the process agreement? If yes, where? And how did they solve the problem and got the final agreement (Who involved)?***

Not really, as the whole project, it is a different state of thinking about how you manage your project like this. Normally we begin with a raw house and we begin on the date we chose. For this project, the tenants can choose when they want to start their project. Make of this plan helped and developed our different ways of thinking. Everything we do takes more time than what we do regularly because we have to think differently. Sometimes we get in stuck because of the old way of thinking, and we have to let it go and start off again.

***How is it different from the previous renovations (if available) by your company?***

The processes are basically the same, just need to think differently for the process

***Do you think the difference makes the planning and design phase difficult? (besides the misunderstanding part, such as material choices)***

It is difficult for the contractors to negotiate with their suppliers. The suppliers are mad at the beginning since instead of buying, the contractor is going to reserve the materials for 250 houses. I don't know how they completely manage it now, but I think they made the warehouse for all the stuff. I don't know it for sure because it is not my problem to solve.

2. How was the questionnaire to tenants contributed to the decision-making process

***Who came up with the idea of having a questionnaire?***

The former client

***Why did you decide to implement questionnaire before the renovation?***

We don't speak with most of the tenants in this complex. They pay rent, they sometimes call for small maintenance request, but we don't see them that much. Some people rent the house 45 years before, and they still live there. They rent the house from the first start of the contractor. But I don't think many people live that long in the house anymore. In the neighborhood you see the anniversary for 50 years. But if you pay the rent and don't make any hazards, then, it may be a bit strange, we don't know

exactly how they think of their houses. The house is also not that bad and it is not falling apart. So we already have some thoughts in our mind, and we need to confirm.

Before the questionnaire, we first made a brief document and the most important thing is to start the conversation with the tenants. During the conversation you fill in the questionnaire. One of the best examples is that one of my colleges went to a 85-year-old woman. The only thing she wants is actually death. He just closed the laptop and drank a cup of coffee and chatted about the old days. So there is no interview result, but it is still a success since we had a conversation. He still got some information such as how she likes to live there, what could be improved. Still the conversation is the most important. That's why sometimes we don't get the perfect result for the questionnaire because in the end we say we had a conversation that provides some qualitative insights.

***Who designed the questionnaire for the tenants?***

Input from the municipality about the surrounding of the neighborhood, Woonbedrijf regarding housing situation, questions about inter sustainability from TU/e.

***How were the questions and options formed? What factors did she/he consider during the questionnaire making process?***

Every couple of years, we scan our homes to know maintenance condition. So we know from that scan part of what is necessary to have a house with good maintenance. We know also from the few contacts in the neighborhood about other problem, such as draft and contact noise. With this information, we started to decide renovation measures questionnaires and the outcome of the questionnaire tells us that we are on the right track and these are the good measures. We also want to reach at least energy label B, so we try to combine the maintenance and necessary measures to reach B.

***Who analyzed the result of the questionnaire?***

One of the colleges who has an expertise in analyzing the questionnaire in Woonbedrijf, and Dujuan for another part. Both parts are used for Triangulum project. The biggest issue from the questionnaire is related to draft. We have to do something about that.

***Did the project team satisfy with the outcome of the questionnaire?***

Yes, because the outcome was what Woonbedrijf expected. If the outcome was completely different from what Woonbedrijf expected, they would be satisfied as well, because the tenants would answer which part is different. The part that Woonbedrijf did not satisfy is that we made such a long questionnaire with the input from municipality, so the quality of the questionnaire can be improved massively just by kicking off half of the questions. Our own questions also need to be improved. The questions can be more specific. Even we felt it was weird to answer some of the questions.

**3. How was the renovation measures decided?**

***On which sustainability aspects did you focus more when giving the comments to the proposed measures that contractors provided (any uncovered part)? Did you have any specific environmental criteria for the material used during the renovation?***

The biggest focus is to reduce the energy usage, and the second focus is environmental ideal material usage according to natural respect, but sometimes it is hard since it is difficult to always have ideal material for both energy reduction and environmental friendly; therefore, Woonbedrijf needs to incorporate these two aspects. For instance in the roof, the insulation material is mostly made from PIR, which is really chemical and not environmental friendly; therefore, Woonbedrijf is considering to change it with flax, which is a natural product for insulation. If you can change it from chemical ones to natural ones, that is also a sustainability improvement. We also decided something that we are not going to do. If the roof or frame of the glass is still fine for the next 25 years, then we are not going to replace it. So it was able to put in HR++ glass but not triple because we also need to change the wooden construction and you have to throw away good materials that still can last for decades.

***What do you expect from these measures? (energy performance improvement) (Energy label B?)***

Woonbedrijf expected the energy label B as the performance demand, but it ends up with energy label A.

***Do you provide some renovation packages to let tenants choose as well?***

No, only let the tenants choose one by one.

## **Interview with project manager from Woobedrijf 28-04**

### **4. Barriers**

#### **1) Communication and relationship with tenants**

***How do you think is the relationship between the company and tenants?***

I think it is not good and not bad. People in Eckart live very independent, so most of them, we don't hear anything. That's why I say our relationship is not really bad but not close. If we are close, then most of the time we have something that can help the tenants.

***How was the reaction from the tenants when they heard of the renovation?***

We first sent out the letter in the first week of April. We sent the start letter from invitation to 31 houses in a block and we sent an updated newsletter to the rest of the 220 houses. We need to do a home visit before starting the project, so we started with a smaller part. If we start with everyone, when everyone in the project team is ready, maybe some of the tenants already waited for 3 months, which could make people get annoyed. We made a plan in the map; there are three different house types in block one, which might not be the smartest way to start. Here are the people with the most

positive opinions regarding renovations and they are also the most promising part. From 4<sup>th</sup> of April till this afternoon (18<sup>th</sup> of April), we got the appointment for interviews. It was not as many as I thought, but if you see the people who are calling, although they already received letters on 4<sup>th</sup> of April, they are still calling for that until now. When they first received the letter, they just put it aside and wait for later. Therefore, we already sent the invitation for the second block, and the third block at the end of this week. We want the first invitation as soon as possible, so that they can really make the decision on when. Otherwise, the process will be too long. There are already two houses used Woonconnect to choose their renovation in June.

***Did you feel any resistance from the tenants? If yes, How did you solve this resistance?***

There was only one small resistance related to the extra installation (blinds) outside of the house. If you want to do the renovation and the maintenance of the houses, then you need to get off your blinds by yourself. We got one email that said that costs a lot of money. We know but it is not fair that you have the blinds and we have to invest on it, so you need to it yourself. In the current roof construction, it is hard to put them back on the top of the windows because there is no enough room any more. So that is the first small barriers that we created ourselves. We don't install blinds for the livability of the street. Part of the social control is that you see what is happening on the street, and also the other way around. It is safety from both sides, but people in the house want them since it is dark and it is cooler. I can understand but it is their investment.

***Do you have any contract or agreement with tenants? (For example, energy performance guarantee, reduced cost guarantee)***

No, we don't have a contract of guarantee of anything because the tenants don't need to pay much for the renovation. We have one contract for the solar panels that it is an add-on for the light contract, but there is no guarantee on it. The tenants also need to pay for the solar panels. We have contract regarding the output of Woonconnect.

2) Technical

***Do you find any barrier in technology part?***

We leave the technical part to the contractors since they know better about the area than we do. We provide them what we require at the beginning, and let them decide the details.

3) Finance

***How does the finance loop work in this project?***

We have a big agreement on the renovation and what is it about, but we don't know about exact amount of every house because it depends on what people choose. We have a cost agreement that we agreed upon at lease for this year. Every time tenant chooses, we know what exact price will be, and get an individual contract with the amount for that house.

***Do you get any fund from municipality or Triangulum project?***

No funds from municipality and a small amount from Triangulum project (€418,000). It is a huge amount, but compare to the energy reduction investment (€18,000,000). And the rest we finance the renovation by ourselves. The houses are now 50 years old, and it can still easier go on for another 30 years. So every year we got the rent from tenants, which is a part of investments. Now we take loan to make this investment, and later on tenants need to pay it back.

***Do you think you have enough budgets for your renovation?***

No, it may sounds a bit silly, but the increase in building price is enormous at the moment. So we don't have a fixed price for the next five years. And I don't think it is realistic, because what cost in five years will be different. If you pay now, what we think will be the average in five years; you may actually pay too much. This is because the trend of building cost increase start to slow down again. We made a plan that the price will increase by 3% every year. That's why we made a contract decision for now, and we still want to innovate in those years, so that we can reduce the cost again. Maybe even lower than the initial building price. And I made a budget regarding what I think they will choose. I think 70% will choose for this, and 30% will choose for that. But I don't know how many kitchen and how many solar panels, so I made an estimate. We set down the estimate; if we don't make it then we can go to the board. For example, if we see now that we have 30 houses, and we have 25 solar panels, then we know that we don't have that much money for this amount, because now we only estimate that 40% will take solar panels. Every year we make an estimate according to the experience of last year or even last month. So I have budget, but it is not really steady. That is more because we don't know when they choose and what they choose.

The budget was originally (at the beginning of 2015) 3 million lower. And this budget is to estimate what will cost now. 2015 was still the year to start to get out from the crisis, so the building price started to increase by then. Especially in last, the building price increased for 10%. So we went to the board to ask for more money. We were not the only project to do so, so the board also understands and no one can foresee for this situation.

***Do you have some specific ways to reduce the cost? (For example, pre-fabricated component)***

The reduction of the cost will more come from more efficient process and innovation in a more efficient and smarter way using different materials. But we still need to think of these. So this year we have a budget for the first houses, and we will see the improvement.

***How do you deal with your finance problem?***

Go to the board, but we will first try to decrease the cost again. You try to negotiate and make the renovation measures more efficient. I also ask a specialist on renovation cost to check the cost of measures that the contractors provide for us. If they say the price is normal and fair for the marker, then we pay it. If you really want to reduce the cost,

then we have to do fewer measures at the moment. We have an ambition to reduce the energy consumption in the houses by renovation.

#### 4) Building code

##### ***What building code (regulation) do you base on for the renovation?***

There are some building codes, but not so many for renovations. Because we keep most of the houses in test, it has to be safe and it has to be well ventilated. We didn't consider much about building code since we don't change the structure and components of the houses. If we don't change, then we don't need to follow building code. For example, since we are not taking out the complete roof, we only put the insulations on the top of the roof, so we don't have to follow the building code which requires RC6. But regarding the regrets that we mentioned before, we want to have the roof with RC6. Because we only change the glazing, the building codes do not say anything about it.

##### ***Are they mostly for New built?***

The building codes are indeed mostly for newly built. Some are for renew for parts of the old building. Not for maintenance and renovation.

#### 5) Other barriers

What is it and how do you solve it?

##### ***a. Welfare of wild animals***

You know that you have to follow that law. The only barrier is when you start it too late. If you start in time with the preparation for that, you take measures into your construction, and then it is not really a barrier. They have to observe the animals for couples of time a year in different seasons and you need to build bird houses somewhere else so that the birds can live there. Then you have to get the license that you are going to demolish it. You normally observe these animals in spring, autumn, and summer, if the observation starts from summer, then it lasts until next summer; but if the observation starts from spring, then it only last until autumn in the same year. Furthermore, a license to demolish the old nest and relocate to a new one is also required for the process. Therefore, approximately 1.5 years is necessary for the whole relocation process (best estimate in 1 year). If we already start research from the definition period, then you have enough time until realization period to finish the research. That's what we learned from other projects since we always stuck there. So in this project, we start with a quick scan in the area, and start measuring where to put the new bird houses so that no new birds can fly into our houses.

##### ***b. Administration of the houses***

Because we renovate in the series of 1, so our own administration is a barrier. We normally work in the complex and do almost the same thing at every house. We said to the contractors that we have the fixed price, and you do the 150 houses; we pay you by terms. However, we don't know when they are going to be renovated, what exactly they

are going to do; do they do at once or in two times. For every house that has an address in our system, you can see which part was renovated when you click on that house. But it is not possible for this case. We had paper, and we could hang paper on the administrative program. In this way every house needs half an hour to administrate, which is not worthy doing. Project leader will be more an administration worker than an project leader. So now we decide to so house contractor; we do that at house level. But if you want to see what he has done for the house, then you have to go to a separate paper for now in an excel sheet. And you can see what he has done. We had a plan B, but the ideal situation is still having everything on administrator system that we could give all the information.

***c. Different maintenance situation for the houses within the same house complex***

In the future, the maintenance situations in the houses start to be different. The first house is painted in year 1, and the last one we painted in year 5 since we paint every seven years at the same time, while the last house was just painted two years ago. That's why we also wanted the information on house level, but this is the first project that we work like this. If we want to continue after evaluations, then we have to invest in the system for administration and measures.

**5. Risk Management Time issue**

***How long will the whole project last?***

$3+9+12+54=78$  months This project also takes longer for the previous phases since they need more time to develop and think for the process.

***How long would it normally take if it is a common (all renovate together) project with the similar scale?***

$3+9+12+18=42$  months Start 4 houses a week, and each house lasts for 2 weeks.

***How does time issue affect the project? (What is the risk, why is it a risk)***

The renovations in houses take too long. We chose to renovate over years, this is not a risk but our choice. You know what the consequences are.

We know the price now, and we know the price is going to increase. We are not intending to decrease price now. If there are not a lot of people choose to renovation this year, but more for next year, then we already know the expenses will be much more expensive because of the current increase. You don't predict that, maybe it even cost the same price because the building price go up and down again. The main part is to measure it in time whether it is correct or not. If you see that more people choose for large scale renovation, then you can explain that why this gap happens. And you can make an estimate that people will choose more things. But also some measures that related to rent increase will cost more investment from us, but our income will also increase.

***Do you think the project is currently on the track?***

Not from the original plan. We should have started the second quartile of 2017. Development of the plan, system and concept for this project took more time than expected. I had no client for half a year and it didn't help. For now, we started since we sent the first invitations, and we are going to officially start after around 10 weeks. During the process, my project team also changed a couple of times. It takes time to get everyone back to speed.

***Do you have methods to make sure that the project will be on track?***

No, since the concept of this renovation project is to let tenants choose when to start, the company is not going to push tenants to choose. Maybe change the communication method with the tenants can be adjusted to help them make decision.

If some tenants do not want to renovate, then the company is going to wait until the tenants stop their rent contract and the company renovate the house for the next tenant. Since you don't have a complete full schedule, you can't say the program is on track or not on track.

6. Other risks

***a. Construction noise***

There is always construction building noise in the neighborhood. People can be annoyed by that. In the normal project you have a lot of noise, but you know this will last for the block, and it will finish. You know the time, you know the plan. We try now to let our contractors to reduce the noise as much as possible. We are now getting out the bricks, you cannot do without noise.

***b. Change in the project team***

I am the last woman standing, everytime when it changes, there are lots of knowledge and communication exchange in between. Because we know the houses, so we didn't see many changes in the houses, but for our own registration and project team, there are a lot of internal.

***The trigger to stop company from renovation***

When the tenants (50%) don't want this type of renovation, then the company is going to stop this experiment, and just continue with the ordinary method to renovate.

***What are the criteria for you to judge the success of this renovation project?***

The most important criterion is information. More specifically, whether tenants have enough information that they feel safe to decide and start renovation. And the second one is whether the contractors and Woonbedrijf implement what they agreed upon (Do everything that you agreed on time).

The company helped with customer journey will go into depth of the process with some of the tenants. Tenants will get a service call from the evaluation company after their renovation to judge the renovation with a score from 1 to 10. If the tenants give a score higher than 8, then the project is a success.

7. What is the goal of renovation?

***What is the goal of renovation from tenant's aspect? (What are the Criteria?)***

We would like to let them to take the ownership of their own home. In this case, they can plan the moment and choice for certain components of the renovation. Therefore, the criteria are 1. We really see that people choose a period that tenants think it is really suitable for them. For example, there is one tenant who chooses three weeks later from the earliest available period. 2. We want to add some extra questions in service calls regarding whether they appreciated for the freedom that they can choose the moment to renovate. We don't have KPI yet for the satisfaction and feasibility. It is hard to set a goal for now.

***What elements do you think will encourage the success of this project? (e.g. Demo houses, Use Woonconnect to communicate, Includes stakeholders from early stage, Tenants interest focus)***

1. The tenants' appreciation. 2. At the end it is not really more expensive than the normal renovation. We hope with the innovation and more houses to divide the cost, we will have similar financial outcome. 3. Our organization change, maybe it is a success, but it is maybe too much for the organization. Our company is tenants' driven organization. 4. We know how to deal with our own administration. It should be more program and process driven for the renovation.

***Pre Renovation phase:***

1. Effect the demo houses (or is it just the first ones that want to be renovated?)

***Why did you decide to include demo houses in your renovation process? What is the goal of including demo houses (e.g. Energy performance, test the effect of woonconnect, and help for tenants' choice)?***

Normally, we always make one demo house and show room for visit later. But we normally implement it just before the real renovation. Now we want to do it early in the process since you can learn a lot from the demo houses, such as technical solutions and risks. You can't learn everything from paper; sometimes you just have to do it. We chose eight since we have four types of houses, and we want to make sure that in-between houses and corner houses are all covered, although we only had seven and it were not all covered. This is because that the tenants were not available for that. Normally, I would do demo houses in an empty house, but it was not available this time.

***How is this demo project different from the demo from other renovation project?***

Eight houses, so that we can already test the process of real project.

***How did you choose which houses to renovate as demo? (Tenants choice?)***

The tenants' manager contacted the tenants if there are people that want to be a part of the demo project, and they are also critical enough to give us feedback. The tenants need to be aware that this is demo project, so it might be more unexpected situation. For example, the first two demo houses took more than 3 weeks only for the outside.

***Do you provide some "incentives" for these demo houses? (e.g. Discounts?)***

No incentives, but the demo houses had longer insulated roof for longer period to save the energy.

***Did you find some additional problem or barriers during demo renovation? Did you already find reliable ways to tackle these problems?***

The first two demos we weren't satisfied with them, so we stopped the demo process. It was because that the process took too long compared to what was expected. Therefore, there was a four months gap between the first two demos and the third one. We also had some unexpected snow and storm "test" due to the weather. The contractors couldn't work in the first day because of the storm, but they still accomplished the roof work in two days. Although we can't say we can always finish the roof in two days, but it was a good sign for the project team. We also learn about the methods to communicate with tenants. If you cannot show up as the appointment, tenants need to know about that.

***Do you think the demo renovation achieved the goal that you expected? (From the aspects of the effect of demo houses and general renovation goal)***

Yes, it achieved the goal for the first part, but it is not more the end goal. There are still things that can be improved, such as materials. The insulation material is still not very sustainable, so we are looking for other innovative idea in the near future. Furthermore, the process can still be improved to have a smaller construction team. People that are working in the house can be reduced; it is more comfortable and trustful for the tenants. The most important goal is that we learned that the first prototype was not what we wanted, and we made a good choice to start earlier. Now, we can still say that to the tenants that we had delay.

## **Interview with project manager from Woonconnect 25-04**

### ***Why did you decide to join the Triangulum project?***

Already cooperated for 2~3 years. It was described in the Triangulum, one of the task is citizen participation. There are two tasks described in the Triangulum project, one is renovate to reduce CO2 emission, one is citizens participation.

For Woonconnect, it is an opportunity to develop the software and program for the tenants together with knowhow and registration of the contractors. For us, it is learning, and developing our program. We continue learn from each other and for evaluations.

### ***What is your team component for this project?***

We supply the software program, and site that Woonbedrijf can go to the tenants to let them make choices for renovations and communicate with them including contractors. We are supplying the infrastructures.

### ***Why and how did you come up with the concept of using digital information to help tenants to visualize their renovation options?***

Our company develops software, and we are originally architecture and building engineer company. About 25 and 30 years ago, we decided to inject in software industry to make life happier and easier for architects and contractors. That's why it has been growing and growing. For about 6 or 7 years, we developed Woonconnect specific for this market. Our goal is to not only support tenants but also house owners. People can see the consequences of their behavior and home improvement in their own house and environment. They see the house that they are living. In that way, we are trying to accomplish awareness for everyone, in this case especially for the tenants and Woonbedrijf. When using the Woonconnect Model, people can see directly what the consequences are for the cost of energy, investment for the renovation measures, the influence on the environment, and the influence on your bills.

Our directors continually develop some new programs; they see this can be something useful for the market related to buildings and construction. So this was a idea which begins very small, but eventually big. We also developed software before Woonconnect, it is a library regarding all the building materials for 15 and 20 years. It is still developing.

### ***What is your duty and responsibility in this project?***

#### ***- Which part and what process do you need to contribute during the project?***

We are involved in all the preparation for actual customer contact. We have been working together very closely until a few weeks ago. Woonbedrijf is now in contact with tenants, so we supply software, and now the only thing we have is for the aftercare. Answering questions and solving problems. When software is developed and it goes live, there bugs in it. We have to fix them. That's our role at the moment.

- ***How do you communicate with Woonbedrijf?***

We have weekly meetings once in two weeks also with all the contractors. So the concept is growing and growing. We had some test houses at the beginning, after that we evaluated and changed what we find in those houses. There are some questions and improvements for the next 250 houses. So we try first at small, look at it, evaluate and then improve it.

- ***How do you communicate with contractors?***

Weekly meetings

- ***How do you communicate with tenants?***

We don't have direct contact with tenants. That's all for Woonbedrijf. Questions for the software are only online, and we also have question desk when tenants are having problems regarding the software. Choices that they made go to Woonbedrijf. And of course the college from Woonbedrijf who works over there also helps. They will call us as soon as possible when there is problem.

- ***What is the main focus point of your duty in this project? (e.g. Communication between stakeholders, Technical reliability.... )***

The main focus for me is to translate the wishes of Woonbedrijf, and measures from contractors. Also the wishes from other contractors to translate it into the program together with my colleges to make sure they make what they want. Moreover, I need to direct my colleges that I just mentioned. In our company, I am the one to control and manage the process and communicate with stakeholders.

***Have you ever participate in other ordinary renovation project before?***

Not that different for Woonconnect, but more for contractors.

***Did this difference make it difficult for you to accomplish your task in this project?***

This is our first time to do things in this way, and we did everything together with Woonbedrijf and the contractors. Every discussion is made together.

They installed a new function in Woonconnect for tenants to contact the contractors to come. (This is the point that causes delay) We decided together on how it should be and what the functions should be. And I need to go back to the programmers to explain how it should work. We implemented it eventually in the site, which is special for this project. In ordinary project, people don't need to plan their renovation completely on their own, so they don't need to contact the contractors to come. For tenants, the concept is very unique, especially that they can choose their own outlook of the houses.

***Do you find anything that you think you could improve after the choice of first two houses?***

The choices are good, we couldn't do anything any better. It is very good that we had some few test cases, and we can still improve our options from that.

For Woonconnect, our development still needs to continue for a while. We want to continue improve and learn and the process is going on. I hear something that there were some bugs and we tried to solve them very quickly.

There is one point mentioned from Woonbedrijf that there are two flows currently for the choices that tenants. More specifically, the renovation measures that tenants chose, and making an appointment with contractors are independent. This will cause a problem that tenants think choosing all the measures is the last step, and they are not going to make an appointment with the contractors. Therefore, it is the best to combine these two flows into one, and we are currently working on it. There are two ways to solve it, first one is that since Woonbedrijf is not receiving the notification whether the tenants made the appointment or not, they can first receive notifications when tenants make an appointment. The second one is the ideal situation, which is the one mentioned above.

***How do you think you accomplished your job for the first two houses?***

We have done pretty well as a team performance. Each party has input, also the contractors involved and they had a lot of patient.

***What does Woonbedrijf expect from Woonconnect in this project?***

It's a tool that tenants can make the relevant decisions. They can see the consequences on energy use, energy cost, rent and whether they are well informed. So Woonconnect can provide a complete communication regarding strategy and making choices. It is a important part, otherwise we have to it with pen and paper. The pro of Woonconnect is that it has the energy consumption part related to the family. So you can have an input of your family that comes as close as possible to the reality instead of having a general energy consumption in the neighborhoods or block like other program. The interesting part is whether the tenants also use that part.

## Interview with project manager from Jansen Huybregts Projecten 04-05

### ***Renovation design phase:***

#### 1. Decision for joining

##### ***How did you feel at the first place when you heard of this renovation project?***

Woonbedrijf ask us to do the project, they did not have a good feeling for the previous contractor. That's why they asked us to step in and overview the situation. Woonbedrijf thinks it is possible to implement this "series of one" project. We started to develop the concept for one year.

##### ***I heard that you used three monthes to communicate with Woonbedrijf regarding this project, why and how did you decide to join at the end?***

I thought it was a nice concept, but the subcontractors of us were less enthusiastic as me. Still, different sub-contractor thinks it costs more money to implement one house at once. You don't have a building site in the area to store materials.

#### 2. Renovation process decision

##### ***Is the process of this renovation different from what you used to do? From which aspect? Do you feel this difference make it hard for the process? If yes, which parts?***

There is no building site in the project, normally when you do one block and you have time left, then you can already start for next house. We can also accacelarate the process at the end of the project to meet the project duration requirement. However, for this project, we have to finish on the planned day. Therefore, if we have a delay, we have to scale up the workload the day after at once. This might cause some problem.

We do a lot of prefab. You want to start and finish as soon as possible, otherwise there is too much noise for the tenants. Therefore, if you so much in less time period, then the tenants will be happier. Normally when you do isolation of roof, you have standard place to put on roof. Now we use pre-fab roof slab(6m\*3m), we prepare four slabs and all the process can be done in two hours. Normally, when you renovate roof, you first put on wood during the first day, and the day after, you put tiles on. Everything you do, you need lots of transport to move materials. If we do it in two days, then it is also a burden for tenants, so everything needs to be done in one day.

##### ***How did you decide where to renovation? Did the input from tenants help for the decision?***

We followd the points mentioned by Woonbedrijf that is what should the measures be if there will be no renovatons in the next 20 years. We looked at the frame of glass to see whether it needs to be replaced. The result showed that with the paint jobs, the frame can still last for 20 years. We also looked at wall bricks, and the cement (joint) between bricks is too bad to last for another 20 years, so we decided to replace it. This process was implemented to every house components. The input from tenatns also helped. They had some compalins reagarding thermal bridge and cracks on the wall, so we also had renovation for them.

***How did you decide what kind of renovation measures (technology) you are going to use for the project?***

The measures are similar to ordinary renovations.

### 3. Barriers

#### 1) Communication

***What do you think is the relationship between your company and Woonbedrijf?***

I think it is good, we already cooperated for 7, 8 years.

***Do you think you can always express and communicate with woonbedrijf well? Do you have any complain about that ? Do you find any difficult part?***

Yes, you can express your feeling most of the time. Since Woonbedrijf is a big company, it takes longer time for them to decide and execute.

***How about the communication with the other contractor?***

Yes, we also need to decide things together...

***Does Woonconnect help with this process?***

Woonconnect is pure for the tenants.

#### 2) Technology

***Do you use the same technology for this renovation compare to your previous renovation?***

Mostly similar

***Do you find any technical difficulty and problem when designing the renovation measures for "one at once" renovation style? How do you solve these problems?***

Roof is the biggest technical problem. However, since we want to reduce disturbance to tenants, we need to finish the roof construction within one day. There is no building site in the area; the slabs have to come in the morning by truck. However, we will have a serious problem if the truck stuck in traffic.

External measurement is also a problem, since the manufacturer wants measure by themselves. We understand that they have special tools and specialists to measure, but if every manufacturer want to measure by themselves, then it is a huge disturb for the tenants. This happens also because of the split responsibility. If the contractors measure and manufactory make, it is difficult to tell who takes responsibility for mistakes. I would propose a solution that I measure and you make, then everything is my responsibility.

#### 3) Finance

***Do you have a regular material partner for renovation and maintenance?***

Yes, but for this project, we have to go for other suppliers, since we have some new materials for this project. We chose it because it can last for 20 years. Moreover, since the material is easy to bend, it makes the outlook of houses more beautiful.

***How is it different to purchase material in this project compare to others? Is it a problem? How do you solve this problem?***

We still need to buy a bunch of materials at once. We have to buy a lot to get the ideal price. Otherwise it is too expensive. We store this material in difference places.

***How “series of one” type of renovation influence the financial plan compared to what you do before?***

When you do something new, you normally put all the risk factors inside of the finance plan, and then it would become expensive. Therefore, all the risk money needs to be out of the budget. When you do something new, not everything is a risk, we need to change our mindset a little bit.

***How do you control your budget?***

The budget of demo houses was not so good, which is normal since the first houses you do, it normally takes more money. You have to put extra people, and you need to measure twice as normal. In the future, after people start to get used to the process, we can have less expenditure. This situation is suitable for every project. Prefab will control some of the budget.

***Do you have any financial problem until now? How are you going to solve it?***

It is difficult to get proper subcontractors with an ideal price.

***Do you have any other barriers for the renovation?***

The logistic is a big barrier.

We also need to discuss every detail with another subcontractor since we need to have the exact same outcomes.

#### 4. The goal of the renovation

***What is the goal of this renovation from your company’s aspect? (What are the criteria?)***

The goal is to develop the technology that lead less bother to tenants. We mainly focus on roof in this project, and when we can accomplish the roof in one week. This can also be implemented in other project as a new business model.

Criteria: 1. Everything fits perfectly for the prefab. 2. Everyone is happy with the results 3. We keep having development in the process.

***How do you make sure that the goal can be fulfilled?***

We scan the house with digital outcomes; some walls already start to subside. When we measure the houses from inside, we also compare the result of the digital tool. So that we know exactly what is happening in this house.

***Pre Renovation phase:***

1. Effect the demo houses (or is it just the first ones that want to be renovated?)

***What is your goal during demo renovation? What do you expect from demo renovations?***

We tested with prefab process of the roof. Since we didn't receive the material on time for the first two houses, we "pre" fabricated everything on site. It also went well, so we think it will be the same if we do in the factor. Since this test went well, we decided to do more prefab things.

***Did you find some additional problem or barriers during demo renovation? Did you already find reliable ways to tackle these problems? (Technical, finance, communication...)***

The subsidence of the block is really serious compared to what we expected. The walls and roofs are not straight anymore. When only measuring one house, the roof outline will not be straight anymore. If this trend continues, the outline of a block is not straight anymore. The outlook of the block will be terrible, and it will also cause the problem of installing other roofs which is next to it.

Therefore, we decided to measure the two end points of the block from the outside. With the help of digital measurements, we can have the straight outcomes at the end.

***Do you think the demo renovation achieved the goal that you expected?***

Yes, it was very important and necessary to have demo house before the realization phase. We could test and improve new technology.

***Renovation (Construction) phase:***

***How do you communicate with tenants during the construction phase?***

We have our own application, after we go in to the house and measure, the decision that we make in the house, we put it down in the tablet. Later, we send all the measurement via email to the tenants for them to sign. Every communication is on email.

***How are you going to reduce construction noise?***

The noises are mainly caused by the process of taking out the bricks with hammer. It is not possible to reduce that noise. The only thing that we can do is reduce the time of construction.

Another noise is from sand washing the bricks. It is not a necessary process, but architects want it to make the outlook of the house cleaner. We set up scaffolding with cloth around the wall to reduce the noise and sand blowing in the air. The effect is not significant and more feasible and effective solution is required.

***What elements (criteria) do you think that can influence the success of the renovation project?***

Prefab, logistic, reducing construction noise, reducing the budget.

## **Interview with Tenant A 30-05**

### ***Hoe voel je je over je huidige levensomstandigheden? Heb je daarover geklaagd?***

I was already happy about my living condition before the renovation, but the indoor temperature was not bearable at that moment. Summer is very hot and winter is very cold. Therefore, after renovation I am even happier.

### ***Hoe denk je over de relatie tussen jou en het bedrijf? (Goede relatie? Gewoon bedrijf en huurders?) Vertrouw je op Woonbedrijf voor de informatie die zij verstrekken?***

The relationship is good; they provide me every reasonable thing that I need. I trust the information from Woonbedrijf.

### ***Had u al enige kennis over het energieprobleem en de doelen in Nederland of de EU?***

I know some of the policy, such as you should put one degree lower for your heater. The Government is trying to implement the policy, but it is difficult to be fulfilled.

### ***Hoe voelde u zich toen u de informatie over de renovatie voor het eerst ontving?***

I first receive a letter including what they are going to do from Woonbedrijf. I think it is a good idea when I first receive it, since I want to change the temperature condition in my house.

### ***Waarom heb je besloten om mee te doen aan het demonstratiehuisproject?***

Because I had the schedule that I will not be at work during that period, and I was interested in the renovation.

### ***Hoe heb je het aanbod van het bedrijf begrepen? (Vond u het moeilijk om te begrijpen wat zij leveren?) Heeft woonbdrijf u een duidelijke uitleg gegeven voor het project (waarom het nodig is, wat u kunt doen, hoe het bedrijf het project gaat uitvoeren ....)?***

I completely understood what Woonbedrijf provides me from the information they sent.

### ***Hoe vond je het renovatieconcept en wat verwachtte je van de renovatie? (De verbetering van de levensomstandigheden? Verminderde energierekening?)***

I like the renovation concept, and my expectation is to change the temperature in the house. The renovation project fulfilled my requirement completely. My house is now cool in summer and warm in winter.

### ***Vond u het moeilijk om uw mening te geven over het renovatieproject? (Zoals vragen stellen, informatie opvragen)***

No, I could express what I want to Woonbedrijf. For example, they provided my one option that I need to change the closed window to an openable one. However, I didn't want it since people from outside can also open the window, so I refused.

***Had u weerstand tijdens de besluitvorming binnen het huishouden? En hoe overtuig je het huishouden?***

I live alone, and I decided everything.

***Hoe lang duurde het om de definitieve beslissing te nemen vanaf het moment dat u hoorde van een renovatie?***

I made the decision immediately since I really liked it.

***Heb je geklaagd over het proces tijdens de renovatie? (Zoals je altijd thuis moet blijven, bouwgeruis)***

The plan was to renovate in two weeks, but the implementation actually took 5 weeks. This delay is caused by the lack of materials. I can understand them, and it was fine for me since I live alone. My neighbor had the same problem and since they are with a big family, they complained a lot about it. I trust the construction team and then also trust me. I allowed them to leave their equipments in my garden, and I don't mind giving them my home key. However, I couldn't bear the noise from renovating mortar (2 days). If I knew that it would be this noisy, I might not choose the renovation.

***Hoe voel je je nu na de renovatie? Heeft het echt de leefomstandigheden verbeterd (van het aspect van thermisch comfort, zichtcomfort, akoestisch comfort en een goede luchtkwaliteit binnenshuis) en energiebesparing (uit het oogpunt van energiebesparing)? Heeft het bereikt wat je verwachtte? Ben je tevreden?***

Now my house is really under a good temperature condition. The bigger roof now provides shadow into my room, so the living condition is even better. There is one small hall on my roof, and there are bats living inside, I also like it. I can also see that my meter is going back for 100kWh in the last 5 weeks because of the solar panels. So my energy is free now and I suppose that I can get money back in winter. I can use this extra money to go for travel.

***Wat zijn de tevreden delen van de renovatie? (Inclusief zowel renovatieobjecten als de aanpak van het woonbedrijf)***

Everything is good.

***Denkt u dat het hele renovatieproces haalbaar was voor u en het huishouden? (bouwlawaai, verbetering van de leefomstandigheden ...)***

The construction noise was horrible, other things during construction was fine. There is one thing that I think they didn't clean well after the renovation. My house was very dirty with cement.

***Voelt u enige spijt tot over uw renovaties? (Ik had moeten kiezen, ik had niet moeten kiezen ...)***

Only the construction noise was not good. I also wanted more solar panels but it was not possible for my house.

## **Interview with Tenant B 05-06**

***How do you feel about your current living condition? Did you have any complain about that?***

Not very happy. When it is in winter, the window will be wet when the glass was single glass. The house is warmer; I don't need to put heater on every time now. We also had complains regarding mold especially in the toilet.

***How do you think of the relationship between you and the company? (Good relationship? Just company and tenants?) Do you trust Woonbedrijf for the information that they provide?***

Very nice, I have a really good relationship with the company. I already rent houses from them for 23 years. I trust the information that Woonbedrijf provides me.

***Did you already have some knowledge about the energy problem and goals in the Netherlands or EU? Do you have a gas meter at home?***

No.

***How did you feel when you first receive the information related to the renovation?***

I was happy and I asked to be the first ones. But I didn't expect that it would be this hard for me.

***Why did you decided to join demonstration house project?***

When I first heard it, I felt that I need to take it.

***How did you understand from the offer from the company? (Did you find it difficult to understand what they provide?) Did woonbdrijf give you a clear explanation for the project (why it is necessary, what you can do, how the company is going to implement the project....)?***

Yes, they provide a lot of information; they also came to my house to do interview with me to explain.

***How did you like the renovation concept, and what did you expect from the renovation? (The improvement of living condition? Reduced energy bill?)***

The concept is good, I wanted my indoor living condition becomes better. Also because I have a big family, our energy bill is huge. I want to reduce it.

***Did you feel it difficult to express your opinion on the renovation project? (Such as asking questions, ask for information)***

No it was not difficult. I wanted a bigger window on the roof, and Woonbedrijf fulfilled my requirement. However, Woonbedrijf didn't approve the requirement from me of changing toilet since Woonbedrijf thinks that it was not necessary.

***Did you have some resistances during the decision making within the household? And how did you convince the household?***

Everyone was excited about the renovation. However, along with the renovation construction process, I felt that my family was under stress about the construction.

***How long did it take to make the final decision from the moment that you heard of renovation?***

Immediately

***Did you have any complain about the process during the renovation construction? (Such as you have to always stay at home; construction noise) Do you think the whole renovation process was feasible for you and the household? (construction noise, living condition improvement...)***

To be honest, sometimes yes. One month was really heavy to my family from the aspect of emotion and finance. We were really stressed, and our family had to go out to eat in the restaurant since we don't want to see them and hear from them.

Workers just walk in and out; sometimes I feel that they are very rude, and I think the workers didn't really care about the privacy in the households. I have twin girls, but the workers just walked in their bedroom. Once my son was taking shower, the workers still just walked into the bathroom. The workers sometimes even talked bad things about my family. We always respect the workers; we cook for them and bring them drinks, but the workers didn't show enough respect to us. Sometimes people don't need to talk, but you feel the judgment from them. I really felt that these people don't have respect to my family and house. We also have boxes on the loft, and when the workers need to take the rood off, I almost went crazy. I understand that it is their job, but sometimes it was too much.

I also wanted some compromises from Woonbedrijf, such as you don't need to pay for the rent for the month of renovation, because that month was hell for me; my house was not my house anymore. I was really stressed, and I even needed to take pill to keep down. When I heard the bell in the morning at 7.30, I was almost crying. Sometimes they didn't come in the morning, so I thought that I will have a day off. Then you hear the door knock..... They really need to make a precise plan for even a plug on the door. Sometimes I really had to run away from my house. However, I didn't hear anything from Woonbedrijf anymore, and I didn't even have a thank note or anything from Woonbedrijf. It was a bit upset about it.

When you implement construction in a house with a big family, it is different from constructing in a small family. We need to plan a lot for that. The construction noise was really terrible; I sometimes even felt that I can hear it in the evening. Moreover, the workers don't clean after the construction. I was really tired of cleaning everything up for that.

Many neighbors went to me and ask what was going on. I just told them that I am not information desk and they need to go to Woonbedrijf to ask for information. I think that Woonbedrijf didn't realize how this renovation had impact on me. I lost 12kg during this one month since I couldn't eat.

***How do you feel now after the renovation? Did it really improved the living condition (from the aspect of thermal comfort, vision comfort, acoustic comfort and good indoor air quality) and energy saving (from the aspect of energy bill saving)? Did it achieve what you expected? Are you satisfied?***

Yes, the room is warmer now, and I even got 200 euro back from the energy company. The sound prove of the house is also better now. I really like my new kitchen sine I like cooking. If I want to sleep early, then I just need to close my window; this was impossible before. I'm satisfied in general.

I still have complains regarding molds and circulation. I don't really feel many differences from the ventilation. At the beginning I felt something, but not anymore now.

***Do you have other things that you want to express?***

I feel that Woonbedrijf should move the family out to do the renovation or talk with the people and provide some support. The tenants need to know what is really coming so that they can prepare for that. Woonbedrijf really need to check the family when they do renovation inside. When my children are under stress, my house is not my house anymore. Woonbedrijf needs to watch and monitor these companies because they are not always nice, and people might think that everyone is from Woonbedrijf. A concrete and fixed plan for the household is really necessary. The plan needs to be precise to what is going to be renovated at what time by whom, so that people can prepare for that. There are also people who cant speak Dutch well, so this information is really necessary.

## **Interview with Tenant C 07-06**

***Hoe voel je je over je huidige levensomstandigheden? Heb je daarover geklaagd?***

Excellent. No complain at all.

***Hoe denk je over de relatie tussen jou en het bedrijf? (Goede relatie? Gewoon bedrijf en huurders?) Vertrouw je Woonbedrijf op de informatie die ze verstrekken?***

It is good, but there is miscommunication especially with the renovation process. For example, they measured the window size for three times, glass manufacture, renovation management and some else that we don't know. We don't understand why. If we don't trust the information, we will ask immediately.

***Had u al enige kennis over het energieprobleem en de doelen in Nederland of de EU?***

No, we don't know much about policies. But I think the process is too quick, and I feel like it is getting money from us. And we also know that old cars cannot go into city center anymore.

***Hoe voelde u zich toen u de informatie over de renovatie voor het eerst ontving?***

We don't think it is a good idea. We are here for 50 years, and we already did what they are planning to do (we already installed insulation by ourselves). We have to destroy what we have done to join this renovation, so we didn't agree at the beginning. Since Woonbedrijf agree that we don't need to destroy what we have already done, we agreed upon the renovation.

***Waarom heb je besloten om het renovatieproject te starten?***

Woonbedrijf wanted to make the street look the same.

***Hoe vond je het concept van 'series van een'? Vond je het leuk dat je zelf je renovatie- en tijdsloot kunt bepalen? Waarom?***

We didn't like this concept. Because it is difficult to make it organized,,,,, It is better to renovate the whole street at once so that the street will be more organized. Choosing my own time to construct is a good concept. The thing that we can choose where to renovate is also good since things can be personalized. I wanted a red door, but we could only get green ones, so we were not so happy about that. It is also good that we can choose to join or not join center ventilation.

***Wat verwachtte u van de renovatie? (De verbetering van de levensomstandigheden? Verminderde energierekening?)***

It is troublesome for us to take out every personal things for renovation. His roof, satellite, and blind. People might just decide to not join the renovation because of this. When you are old, it is difficult to join the renovation. If you put something at one place for long time, when you take it down, it might destroy the thing.

We don't trust solar panel. We don't trust the energy company, and the house direction is not so good. We don't think that we can get enough profit from solar panel. But it is good that if we still want to put it on, it is still possible. We don't want smart meter, since it might sense my private such as when I go to bathroom and toilet. Did you feel it difficult to express your opinion on the renovation project? (Such as asking questions, ask for information)

***Vond u het moeilijk om uw mening te geven over het renovatieproject? (Zoals vragen stellen, informatie opvragen)***

No, we just always ask when we have questions. Sometimes, we can find them on the street, and we just ask immediately.

***Had u weerstand tijdens de besluitvorming binnen het huishouden? En hoe overtuig je het huishouden?***

There is no resistance, and the household always have similar opinions. Woonbedrijf is good with dealing problem; they will come to the house and solve the problem. It was not good before in the perspective of communication, but it becomes better now. The whole process of renovation only takes 12 days.

***Waar in het huis heb je gerenoveerd?***

We already renovated ourselves a lot, so we are only going to put a new roof.

***Hoe heb je gekozen waar je wilt renoveren? Waarom en waarom niet? Was het moeilijk voor jou om te beslissen?***

Did you go and check the show room? If yes, do you think the show room helped you to choose where you would like to renovate? Did the showroom also help you with other decisions?

***Ben je de showroom gaan bekijken? Zo ja, denkt u dat de showroom u heeft geholpen te kiezen waar u wilt renoveren? Heeft de showroom je ook geholpen met andere beslissingen?***

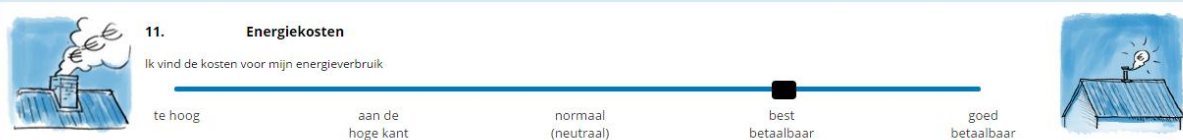
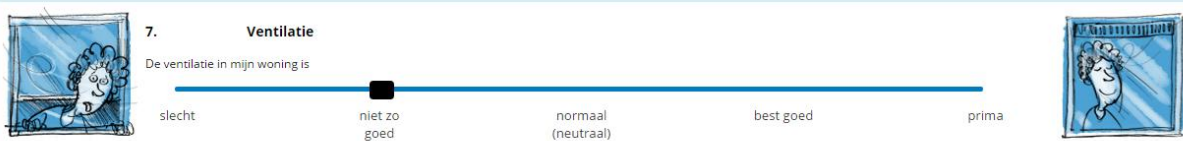
Show room is very helpful for the renovation choice. They didn't understand door shorten at the beginning, and they figured out in the show room regarding that option.

***Heb je andere klachten?***

When we first receive the letters, we were not sure what would happen for renovation, it would be better if the pamphlet could come earlier. We called them for renovation, but they forgot that we asked for renovation.

## Appendix C Interview analysis

### 1 Mijn woning



### 3 Mijn buurt



#### 7. VeiligheidsBuurt

Het is in mijn buurt:

crimineel      onveilig      normaal  
(goed zoals het is)

redelijk veilig      erg veilig



#### 8. Behulpzaamheid

De mensen in mijn buurt zijn:

zeer onbehelpzaam      onbehelpzaam

normaal  
(goed zoals het is)

behelpzaam

zeer behulpzaam



#### 9. Schoon of vies

De straten en groenstroken zijn:

vies

niet zo netjes

normaal  
(goed zoals het is)

redelijk netjes

schoon



De geluiden in mijn buurt kun je omschrijven als:

herrie

druk

normaal  
(goed zoals het is)

rustig

stille



#### 11. Overzichtelijkheid

De indeling van mijn buurt is:

een warboel

niet overzichtelijk

normaal  
(goed zoals het is)

best overzichtelijk

duidelijk geordend



#### 12. Ligging

De ligging van mijn buurt is:

slecht

niet zo best

normaal  
(goed zoals het is)

redelijk

goed



## 6 Hulp en mobiliteit

### Welke aanvullende hulp zou u graag ontvangen?

- |   |   |  |
|---|---|--|
| <input checked="" type="checkbox"/> Geen          | <input type="checkbox"/> Administratief | <input type="checkbox"/> Boodschappen      |
| <input type="checkbox"/> Zorg voor huisdier(en)   | <input type="checkbox"/> Afvallen       | <input type="checkbox"/> Huishoudelijk     |
| <input type="checkbox"/> Tuinieren                | <input type="checkbox"/> Kinderoppas    | <input type="checkbox"/> Klus in huis      |
| <input type="checkbox"/> Vervoer                  | <input type="checkbox"/> Hond uitlaten  | <input type="checkbox"/> Psychische zorg   |
| <input type="checkbox"/> Solliciteren/baan zoeken | <input type="checkbox"/> Maaltijd       | <input type="checkbox"/> Medische zorg     |
| <input type="checkbox"/> Hulp bij opvoeding       | <input type="checkbox"/> Gezelschap     | <input type="checkbox"/> Stoppen met roken |
| <input type="checkbox"/> Lichamelijke verzorging  |   |  |

### Anders namelijk:

### Kent u Wijleindhoven?

- ☐ Ja ☒ Nee

### Wijleindhoven

Sinds enkele jaren is in uw buurt een team van Wijleindhoven actief.

Het WIL-team bemiddelt als bewoners ondersteuning nodig hebben. Bijvoorbeeld op het gebied van werk, wonen, onderwijs, financiën, opvoeding, problemen

**Mogen zij contact met u opnemen?** Daarbij wordt samen gekeken wat bewoners zelf kunnen en hoe bewoners elkaar kunnen helpen

- ☐ Ja ☒ Nee

Als u vragen of ideeën heeft, of als u iets wil doen om andere mensen in uw buurt te helpen, dan komen de medewerkers van Wijleindhoven graag met u in contact.

### Zo ja, hoe?

- ☐ per e-mail  
☐ telefonisch  
☐ via een huisbezoek

Figure 35 Examples of tenants' questionnaires in Woonconnect (source: Woonbedrijf)

## Appendix D LCCA

*Table 29 Value of pvf and pvf<sub>sum</sub> for each year*

|    | PV $((1+5\%)^{-t})$ | $\text{pvf}_{\text{sum}} \left( \frac{(1+5\%)^t - 1}{r(1+5\%)^t} \right)$ |
|----|---------------------|---|
| 1  | 0.952381            | 0.952381  |
| 2  | 0.907029            | 1.85941   |
| 3  | 0.863838            | 2.723248  |
| 4  | 0.822702            | 3.545951  |
| 5  | 0.783526            | 4.329477  |
| 6  | 0.746215            | 5.075692  |
| 7  | 0.710681            | 5.786373  |
| 8  | 0.676839            | 6.463213  |
| 9  | 0.644609            | 7.107822  |
| 10 | 0.613913            | 7.721735  |
| 11 | 0.584679            | 8.306414  |
| 12 | 0.556837            | 8.863252  |
| 13 | 0.530321            | 9.393573  |
| 14 | 0.505068            | 9.898641  |
| 15 | 0.481017            | 10.37966  |
| 16 | 0.458112            | 10.83777  |
| 17 | 0.436297            | 11.27407  |
| 18 | 0.415521            | 11.68959  |
| 19 | 0.395734            | 12.08532  |
| 20 | 0.376889            | 12.46221  |
| 21 | 0.358942            | 12.82115  |
| 22 | 0.34185             | 13.163  |
| 23 | 0.325571            | 13.48857  |
| 24 | 0.310068            | 13.79864  |
| 25 | 0.295303            | 14.09394  |
| 26 | 0.281241            | 14.37519  |
| 27 | 0.267848            | 14.64303  |
| 28 | 0.255094            | 14.89813  |
| 29 | 0.242946            | 15.14107  |
| 30 | 0.231377            | 15.37245  |
| 31 | 0.220359            | 15.59281  |
| 32 | 0.209866            | 15.80268  |

**Woonbedrijf prognosis:***Investment cost €:*

Architecture cost:  $4083903 + 5134025 + 2477255 + 968507 + 988968 = \text{€ } 13652658$

Development cost:  $155000 + 107440 + 130560 + 61200 + 23120 + 23120 = \text{€ } 500440$

Development risk:  $15000 + 10886 + 13228 + 6200 + 2343 + 2343 = \text{€ } 50000$

Unexpected cost:  $2000 + 61259 + 77010 + 37159 + 14528 + 14835 = \text{€ } 206791$

Direct cost:  $248672 + 85500 + 105231 + 49766 + 17701 + 17959 = \text{€ } 524829$

*Not recoverable cost:*

$54678 + 883006 + 1109491 + 535098 + 208816 + 213193 = \text{€ } 3004282$

Subtotal: **€17,939,000.00**

*Operation cost €:**Land lord levy:*

$763 \times (79 \times 15.5928 + 96 \times 15.3725 + 45 \times 15.1411 + 17 \times 14.8981 + 17 \times 14.643)$   
**= € 2968936.29**

*Insurance:*

$375 \times (79 \times 15.5928 + 96 \times 15.3725 + 45 \times 15.1411 + 17 \times 14.8981 + 17 \times 14.643)$   
**= € 1459175.77**

*Company operation fee:*

$900 \times (79 \times 15.5928 + 96 \times 15.3725 + 45 \times 15.1411 + 17 \times 14.8981 + 17 \times 14.643)$   
**= € 3502021.84**

Subtotal: **€7,930,133.89**

*Maintenance cost €:**Replacement and repairment cost:*

$900 \times (79 \times 15.5928 + 96 \times 15.3725 + 45 \times 15.1411 + 17 \times 14.8981 + 17 \times 14.643)$   
**= € 3502021.84**

*Residual cost €:*

$17939000 \times 5.5\% \times 0.23138 = \text{€ } 228287.4$

*Total €:*

$17939000 + 7930133.89 + 3502021.84 - 228287.4 = \text{€ } 29,142,868.33$

**Original scenario:**

*Investment cost €:*

Architecture cost:  $95\% \times (176 \times 51694.97 + 78 \times 53479.43) = \text{€ } 12606225.32$

Development cost:  $95\% \times 500440 = \text{€ } 475418$

Development risk:  $95\% \times 50000 = \text{€ } 47500$

Unexpected cost:  $176 \times 775.43 + 78 \times 802.19 + 2000 = \text{€ } 200767.47$

Direct cost:  $176 \times 1082.28 + 78 \times 1096.16 + 248672 - 60000 = \text{€ } 464829$

Not recoverable cost:

$176 \times 11177.29 + 78 \times 11557.2 + 54678 = \text{€ } 2923342.68$

Subtotal: **€16,718,082.47**

*Operation cost €:*

Land lord levy:  $763 \times 254 \times 15.3725 = \text{€ } 2979211.75$

Insurance:  $375 \times 254 \times 15.3725 = \text{€ } 1464225.96$

Company operation fee:  $900 \times 254 \times 15.3725 = \text{€ } 3514142.30$

Subtotal: **€7,957,580.02**

*Maintenance cost €:*

Replacement and repairment cost:  $900 \times 254 \times 15.3725 = \text{€ } 3514142.30$

Residual cost €:  $16718082.47 \times 4\% \times 0.23138 = \text{€ } 154727.49$

*Total €:*

$16718082.47 + 7957580.02 + 3514142.30 - 154727.49 = \text{€ } 28,035,077.30$

**Innovation diffusion scenario:**

*Investment cost €:*

Architecture cost:

$$23 \times 51694.97 + 68 \times 53479.43 + 87 \times 55050.11 + 51 \times 56971 + 25 \times 58174.59 \\ = \text{€ } 13974830.83$$

Development cost:

$$155000 + 23 \times 1360 + 68 \times 1360 + 87 \times 1360 + 51 \times 1360 + 25 \times 1360 \\ = \text{€ } 500440$$

Development risk:

$$15000 + 23 \times 137.8 + 68 \times 137.79 + 87 \times 137.78 + 51 \times 137.82 + 25 \times 137.82 \\ = \text{€ } 50000$$

Unexpected cost:

$$2000 + 23 \times 775.43 + 68 \times 802.19 + 87 \times 825.76 + 51 \times 854.59 + 25 \times 872.65 \\ = \text{€ } 211624.56$$

Direct cost:

$$248672 + 23 \times 1082.28 + 68 \times 1096.16 + 87 \times 1105.91 + 51 \times 1041.24 + 25 \times 1056.41 \\ = \text{€ } 523830.59$$

Not recoverable cost:

$$54678 + 23 \times 11177.29 + 68 \times 11557.20 + 87 \times 11891.07 \\ + 51 \times 12283.29 + 25 \times 12540.76 = \text{€ } 3072135.07$$

Subtotal: **€18,332,861.48**

*Operation cost €:*

Land lord levy:

$$763 \times (23 \times 15.8027 + 68 \times 15.5928 + 87 \times 15.3724 + 51 \times 15.1411 + 25 \times 14.8981) \\ = \text{€ } 2980143.60$$

Insurance:

$$375 \times (23 \times 15.8027 + 68 \times 15.5928 + 87 \times 15.3724 + 51 \times 15.1411 + 25 \times 14.8981) \\ = \text{€ } 1464683.94$$

Company operation fee:

$$900 \times (23 \times 15.8027 + 68 \times 15.5928 + 87 \times 15.3724 + 51 \times 15.1411 + 25 \times 14.8981) \\ = \text{€ } 3515241.47$$

Subtotal: **€7,960,069.01**

*Maintenance cost €:*

*Replacement and repairment cost:*

$$900 \times (23 \times 15.8027 + 68 \times 15.5928 + 87 \times 15.3724 + 51 \times 15.1411 + 25 \times 14.8981) \\ = \text{€ } 3515241.47$$

*Residual cost €:*

$$18332861.48 \times 5\% \times 0.23138 = \text{€ } 212090.54$$

*Total €:*

$$18332961.48 + 7960069.01 + 3515241.47 - 121090.54 = \text{€ } 29,596,081.42$$

**Projected scenario:**

*Investment cost €:*

Architecture cost:

$$26 \times 51694.97 + 74 \times 53479.43 + 87 \times 55050.11 + 46 \times 56971 + 21 \times 58174.59 \\ = \text{€ } 13997627.97$$

Development cost:

$$155000 + 26 \times 1360 + 74 \times 1360 + 87 \times 1360 + 46 \times 1360 + 21 \times 1360 \\ = \text{€ } 500440$$

Development risk:

$$15000 + 26 \times 137.8 + 74 \times 137.79 + 87 \times 137.78 + 46 \times 137.82 + 21 \times 137.82 \\ = \text{€ } 50000$$

Unexpected cost:

$$2000 + 26 \times 775.43 + 74 \times 802.19 + 87 \times 825.76 + 46 \times 854.59 + 21 \times 872.65 \\ = \text{€ } 211000.45$$

Direct cost:

$$248672 + 26 \times 1082.28 + 74 \times 1096.16 + 87 \times 1105.91 + 46 \times 1041.24 + 21 \times 1056.41 \\ = \text{€ } 524222.54$$

Not recoverable cost:

$$54678 + 26 \times 11177.29 + 74 \times 11557.20 + 87 \times 11891.07 \\ + 46 \times 12283.29 + 21 \times 12540.76 = \text{€ } 3063430.60$$

Subtotal: **€18,346,721.72**

*Operation cost €:*

Land lord levy:

$$763 \times (26 \times 15.8027 + 74 \times 15.5928 + 87 \times 15.3724 + 46 \times 15.1411 + 21 \times 14.8981) \\ = \text{€ } 2984467.53$$

Insurance:

$$375 \times (26 \times 15.8027 + 74 \times 15.5928 + 87 \times 15.3724 + 46 \times 15.1411 + 21 \times 14.8981) \\ = \text{€ } 1466809.08$$

Company operation fee:

$$900 \times (26 \times 15.8027 + 74 \times 15.5928 + 87 \times 15.3724 + 46 \times 15.1411 + 21 \times 14.8981) \\ = \text{€ } 3520341.78$$

Subtotal: **€7,971,618.39**

*Maintenance cost €:*

*Replacement and repairment cost:*

$$900 \times (26 \times 15.8027 + 74 \times 15.5928 + 87 \times 15.3724 + 46 \times 15.1411 + 21 \times 14.8981) \\ = \text{€ } 3520341.78$$

*Residual cost €:*

$$18346721.72 \times 5\% \times 0.23138 = \text{€ } 212250.88$$

*Total €:*

$$18346721.72 + 7971618.39 + 3520341.78 - 212250.88 = \text{€ } 29,626,431.00$$

**Tenants with solar panel outcomes:**

*Investment cost €:*  $12 \times 12.64 \times 15.3724 = \text{€ } 2331.69$

*Operation cost before renovation €:*  $1519.08 \times 15.3724 = \text{€ } 23351.98$

*Operation cost after renovation €:*  $798 \times 15.3724 = \text{€ } 12270.75$

**Tenants with solar panel outcomes:**

*Operation cost before renovation €:*  $1469.45 \times 15.3724 = \text{€ } 22589.05$

*Operation cost after renovation €:*  $940.84 \times 15.3724 = \text{€ } 14463.02$