Future proof buildings

Sustainable refurbishment of 1960's high rise residential flats.

Jordy de Rouw

April 2018

Master thesis

Future proof buildings
Sustainable refurbishment of 1960's high rise residential flats.

Jordy Martin de Rouw
1534378

Building Technology
April 17th, 2018

First mentor: Eric van den Ham
Second mentor: Arie Bergsma

Faculty of Architecture & the Built Environment
Julianalaan 134
2628 BL Delft

TU Delft

Abstract

The built environment has an important role to play in sustainable development. The Dutch government estimates that the build environment is responsible for 50% of resources used, 40% energy use, 30% of water use, 35% of CO_2 production and 40% of the total waste production in the Netherlands. Because of these relatively high numbers, changes in the build environment can have large impact on the sustainability of our society.

At this moment about a hundred thousand dwellings built during the 1960 -1970 are reaching the age of 50 each year making more than 50% of the Dutch building stock older than 50 years. In the current Dutch building stock, only a small portion of new buildings is added every year. At the current rate of 0.4% it would take 250 years before all buildings would be renewed. The average lifetime of a residential building is 50 years. This can be extended another 50 years with the right intervention. It is therefore very important to have a solid strategy to deal with existing buildings as this can play an important role in maintaining a high-quality building stock while working towards sustainable goals.

This thesis looks at the challenges of high rise residential flats built in the post- WW2 era of the 1960’s in order to develop a refurbishment method that can help to upgrade and maintain these types of buildings in a sustainable way. By keeping the buildings instead of demolishing or replacing them resources and energy can be spared and by refurbishing them a more sustainable building stock can be achieved.

The chosen refurbishment method is an add-on strategy as this deals with many challenges the flats are facing. Using the parameters from the case study project the Leeuwerik flat in the Poptahof, add-on variants have been designed with big emphasis on flexibility, demount ability and durability. The Add-ons aim to improve the physical building qualities by providing better thermal performance. They improve the spatial qualities by providing extra space and they improve the social quality of a building by provide a new and more diversified look.

The three main add-on variants are categorised by material namely wood, concrete and FRP. The add-ons have been detailed to be completely prefabricated and to be quickly mounted on the building. The performance of each of the addons has been assessed in order to compare them and to find out what the influence is of the material choice on add-on dimensions, the thermal performance the and the environmental performance.

Overall it can be concluded that using a demountable add-on strategy is a feasible way to quickly refurbish a building. It offers a way to deal with existing building physical problems and can improve the architectural and spatial qualities of an existing building. Different add-on types and construction materials and are possible. This leaves a lot of space for designers that want to use the demountable add-on strategy while working on a refurbishment project of a high rise residential building to make their own choices depending on the focus of the project, giving each building a unique appearance. This will lead to a higher quality and more sustainable building stock in the long run.

Contents

Introduction 8

Problem definition 8
Problem statement 8
Research question 8
Objectives 9
Scope of the research 9
Approach and methodology 9
Outline of design task 10
Final products 10

Background research 12

History of the high rise residential flats 12
Description of high rise flats 13
Challenges of 1960's high rise residential flats 16
Technical problems 17
Spatial problems 17
Environmental problems 17
Social problems 18
Financial problems 18
SWOT analysis 19
Assessing the state of a high rise flat 19
Site 20
Structure 20
Skin 20
Services 21
Space plan 21
Stuff 21
Possible approaches 21
Nothing 21
Maintenance 21
Renovation 22
Refurbishment 22
Demolition 22
Replacement 22
5. Sustainable building improvement strategies 22
Social sustainability 22
Environmental sustainability 23
Financial sustainability 26
Technical sustainability 26
Spatial sustainability 27
Choice for refurbishment 29
Refurbishment approach 29
Toolbox 31

7. Façade refurbishment techniques ... 32
Façade replacement ... 32
Add-in ... 32
Cover-it ... 32
Wrapping the old façade ... 33
Addon ... 33
Interior rearrangement ... 33
Choice for add-on ... 33
Design goals ... 34
Design goals for the building ... 34
Technical quality ... 34
Social quality ... 34
Environmental quality ... 34
Spatial quality ... 34
Financial quality ... 35
Sustainable design goals add-on ... 35
Addon options ... 37
Addon types ... 37
The hanging addon ... 37
The half-supported addon ... 37
The self-supporting addon ... 38
Choice self-supporting addon ... 39
Addon built-up ... 39
Small element built up ... 39
Large element built up ... 40
Unitized built up ... 41
Choice unitized built up ... 42
Structural options ... 42
Stacking of the units ... 42
Units in frame construction ... 42
Conclusion structural options ... 42
Unit built up ... 43
Frame unit ... 43
Shell unit ... 44
Conclusion unit built up ... 44
Material choice load bearing structure ... 45
Conclusion material choice for frame structure ... 47
Material choice add-on units ... 47
Concrete/high performance concrete ... 47
Cross laminated timber ... 48
Fiber reinforced polymer sandwich panel (FRP's) ... 50
Isolation materials ... 51
Window frames ... 53
Case study Research ... 56

Background information 56
Site analysis 56
History of the Poptahof 56
Current situation 58
Urban context 59
Pictures chosen flat 60
Original drawings Delft archive 62
Visualisation original building 3d model 66
Building analysis 68
Typology and dimensions 68
MUWI building system 69
Façade system 71
Climate installations 72
Addon design 74
Existing single apartment unit 74
Existing structural dimensions 76
Addon placement 77
Addon depth 78
Detailing options 80
Add-on insulation options 80
Frame insulation 81
Structural performance options 82
Place of window frame 83
Façade panel finish 84
Revised climate system 86
Details 88
Vertical section wooden add-on 1:10 89
Vertical section concrete add-on 1:10 90
Vertical section GRP add-on 1:10 91
Horizontal section concrete add-on 1:10 92
Frontal section concrete add-on 1:10 93
Side section concrete add-on 1:10 94
Addon built-up 95
Performance 97
Thermal performance addons 97
Environmental impact add-on 97
Wood add-on 98
GRP add-on 98
Concrete (HPC) add-on 99
Steel structure 99
Case study building redesign 101

Visualizations variant 1 ... 102
Visualizations variant 2 ... 103
Gallery side solution ... 104
Conclusions ... 105
Recommendations ... 108
Reflection ... 109
References ... 110
Appendix A ... 118
Spatial Design Options ... 118
Appendix B ... 120
Building streams ... 120
Options sustainable building systems ... 122
Potential yield of chosen systems for gallery flats ... 127
Appendix C ... 145
Interview: Woonbron ... 145
Interview Molenaar & co architects ... 147

Introduction

Problem definition

One of the main goals of the building industry is to provide fitting, good quality housing for every family at an affordable price. At the same time every period has its own challenges to meet this goal (Brouwers & Heeswijk, 2013, p. 10).

Over the past decades' sustainable development has become an important topic on the agenda of the Dutch and European governments. The goal of sustainable development is to maintain the current living standards of our society without jeopardising the ability of future generations to meet their needs (European Comission, 2016).

The built environment has an important role to play in sustainable development. The Dutch government estimates that the build environment is responsible for 50% of resources used, 40% energy use, 30% of water use, 35% of CO_2 production and 40% of the total waste production in the Netherlands (Ministerie van Infrastructuur en Milieu, 2016, p. 60). Because of these relatively high numbers, changes in the build environment can have large impact on the sustainability of our society. It is therefore a logical step to address the built environment when trying to achieve sustainability goals.

At this moment about a hundred thousand dwellings built during the 1960 -1970 are reaching the age of 50 each year making more than 50% of the Dutch building stock older than 50 years (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2016). In the current Dutch building stock, only a small portion of new buildings is added every year. At the current rate of 0.4% it would take 250 years before all buildings would be renewed (TNO, 2015, p. 3). The average lifetime of a residential building is 50 years (TNO, 2015, p. 8). This can be extended another 50 years with the right intervention (Brouwers & Heeswijk, 2013, p. 7). It is therefore very important to have a solid strategy to deal with existing buildings as this can play an important role in maintaining a good building stock while working towards sustainable goals.

Problem statement

A large part of the buildings in the Dutch building stock are nearing the end of their life and will reach an age of 50 years or more over the coming years. To maintain a healthy building stock and to meet the future sustainable requirements it is important to find a good solution for these buildings.

Research question

What type of approach can ensure that post world war 2 high-rise residential buildings can keep providing a high-quality living space for their inhabitants while at the same time meet the sustainability goals for environmental, technical, spatial, social and financial viability?

Objectives

- Have a clear overview of the advantages and disadvantages of post WW2 high-rise residential buildings in the Netherlands.

- Find out what is necessary to transform the high rise residential buildings into more sustainable buildings.

- Give an overview of the possibilities and technologies that are being used to improve post WW2 high-rise residential buildings in the Netherlands and the effect these have on the sustainability of the buildings.

- Come up with new design possibilities that can help achieve the goal of transforming the high-rise post war flats into high quality sustainable buildings.

- Implement the design in a case study project to get an estimation of how effective the solutions can be in reaching the environmental, social, technical, spatial and financial sustainability goals.

Scope of the research

The focus of this report will be on the sustainable transformation of high-rise residential buildings in the Netherlands, in particular the buildings made in the post WW2 era between 1960-1970.

The goal is not come up with one generic solution that will work on every residential high-rise building but to show that it is possible to transform an existing building while keeping into account environmental, technical, social, spatial and financial sustainability.

The design will provide a range of options with varying performances to choose from depending on the preference of the designer and for each individual building the best fitting solutions will have to be determined.

Approach and methodology

The methods that are going to be used are:

- literature review
- reference project analysis
- research by design

Literature review

The literature review is done for the following purposes:

- To have an overview of the pros and cons of current high-rise residential buildings
- To find out what are the important aspects for a high-quality building
- To find out what the sustainable building goals are and how they can be met

- To find out the effects of spatial organisation
- To map the different streams that enter and exit a high-rise residential building
- To get an overview of (climate) systems that can be used to reach a more sustainable building
- To gain insight into refurbishment techniques and building skin options
- To find out what materials can be used and how to apply them in as sustainable way
- To find information about the case study project

Reference project analysis
The reference project analysis will be used to get a better understanding of what has already been done within the field of refurbishment and sustainable design by analysing existing projects. This will also give insight into the state of the art techniques that are being used and how they affect the performance of the building. Along the graduation process more relevant examples will be added and analysed.

Research by design
Research by design will be used to come up with a new design solution and will be implemented on the case study project. By using the findings of the literature and reference studies as a base, certain requirements can be set, and these can be used to make design choices in order to get a good result. By continually measuring the design against the pre-set goals it becomes clear how well the design performs and what could be altered or added to improve upon it.

Outline of design task

Design research: sustainable building transformation
Combine the results of the literature study and the analysis of reference projects into a design that can be used to improve the state of high rise residential buildings in a sustainable way.

Case study
The design assignment consists of a 1960's high-rise residential building located in the neighbourhood Poptahof in Delft and the goal is to use it to get an estimation of how well the new design approach functions with regards to the sustainability and overall quality of the building.

Final products

Report containing
- The main challenges for high rise residential buildings.
- Strategies for approaching high rise residential building in a sustainable way.
- Case study research
- Proposed design
- Design implemented on the case study project.
- The results and performance of the design

Design products

Site plans
Floorplans building
Floorplans apartments
Sections building 1:100
Section apartment 1:50 / 1:20
Facades building 1:100
Façade apartment 1:50 / 1:20
Digital 3d model building

Design solution 1:20
Design solution details 1:5

Climate schemes building
Climate schemes apartment

- Energy
- Heating / Cooling
- Ventilation air

Performance of the apartments EPC score (Uniec 2)
Thermal performance (Therm)
Life cycle analysis in the form of, embodied energy, CO2 emissions and shadow costs.

Render visualizations exterior

- Facades
- Building in Surroundings
- Built-up in steps

Background research

History of the high rise residential flats

In the period between 1960 and 1975 high rise residential flats were constructed on a large scale throughout the Netherlands. There are two main reasons why this type of flat was so popular at that time.

The first reason is that in the period after World War 2 The Netherlands like many European countries faced housing shortages. Reasons for these shortages were: the destruction of buildings and the building stop due to the war, the baby boom after the war, a shortage of skilled builders, a shortage of materials and the continuation of urbanisation that came as a result of industrialisation. In many countries housing shortages became the number one tread to society after the second world war (Turkington, et al., 2004, pp. 5-6). A high demand for housing could lead to higher housing prices which in turn could lead to demands for higher wages which would lead to higher prices for goods and services disrupting the fragile recuperating post-war economy (Mustard, et al., 2009, pp. 5-7).
To protect the economy the government decided to freeze the housing prizes. To deal with the housing shortages the government came with subsidies and ordered housing associations to build the houses. The building industry was stimulated to come up with new building methods and they developed rationalized, industrial building systems like the prefab concrete construction. These systems required less workers, less scarce materials and had shorter built times. This resulted in mass construction of standardized dwellings of about $55m^2$ with strictly regulated dimensions. In many cases quantity was more important than quality, the exact location, the impact on the urban landscape and the appearance of the flats was of lesser importance as long as they could quickly be build (Pflug, 2015). The area around the buildings was often times filled with parking spaces and low maintenance green areas. This resulted in many neighbourhoods lacking their own character and monotonous, poorly looking housing.

The second reason many of the additions to the building stock after the war consisted of high rise residential buildings is due to the modernist views on architecture (CIAM) in that time period (Mustard, et al., 2009, pp. 8-9) (Turkington, et al., 2004, p. 7) (Straub & Vijverberg, 2015, p. 12). The most important aspects of a modern city according to the CIAM group are air, light, vision and space. This was in contrast with the existing densely built cities of that time. The new modern city had to be a functional city with a clear separation of functions. Living, working, traffic, recreation and nature all had to have their own space within an urban plan (Somer, 2007). Most of the high-rise housing was built for low to middle income households. At that time, the high-rise housing was new, more spacious and better equipped compared to other similar priced housing. Add to that the large green spaces surrounding the buildings and it is no wonder that many of the estates were very popular in that time.

Description of high rise flats

A flat is considered to be high rise building when it has at least 5 or more storeys making a lift a necessity (Roeloffzen, et al., 2004, p. 7). The neighbourhoods where the flats were built were located on the outskirts of the cities and they usually consisted of multiple rows of uniform flats placed in a repeating pattern (Roeloffzen, et al., 2004, p. 10)

About 6.7% of the current housing stock consists of high rise buildings. About 60% of these buildings were built during the nineteen sixties and seventies. Most of the high-rise flats, 62% are built and owned by housing associations. Common high-rise apartments have three to four rooms are occupied for 90% by one or two people and have a floor area of 60 to 100m^2. In the Netherlands, high rise housing is the most popular with older people, young people and students. Many of them use the high-rise apartments as transitional housing during a couple of years. There are relatively more ethnic minorities living in high-rise flats and about sixty percent of the residents have an income that is modal or low (Roeloffzen, et al., 2004, pp. 5, 15-17).

High rise flats all share common spaces like the entrance hall, rubbish disposal, staircases and the lift. To make sure that the common facilities are managed and cleaned all residents pay a monthly fee and this fee is ether managed by the landlord in most cases a housing association or an owners' association managed by the residents of which both have the possibility to install a caretaker that manages these tasks (Roeloffzen, et al., 2004, p. 22).

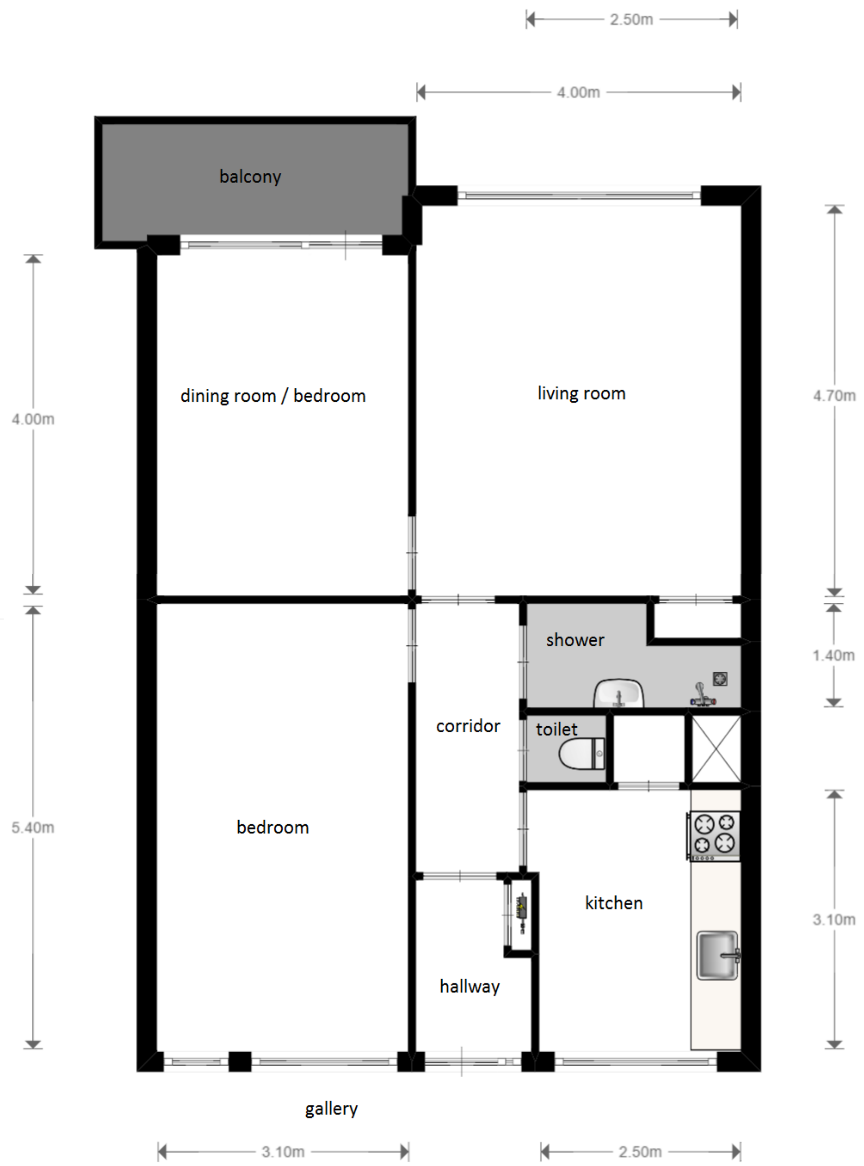
Most of the high rise residential buildings were made using concrete prefab construction methods developed after the war. The most common type of flat made during this era was the gallery flat with two to three bedrooms. (Roeloffzen, et al., 2004, p. 10). There are also other types of high rise flats like the hallway-access and the corridor-access flats, but the focus of this report will be on the gallery type flats. About 2% of the total building stock in the Netherlands consists of gallery access flats which account for 125.000 flats. Of these flats 65% is social rented housing 20% is private rented housing and 15% private owned housing. The most common type of households in these flats accounting for 40% are single person households (Roeloffzen, et al., 2004, p. 108).

Gallery access flats are usually easily recognisable. They are usually nine to fourteen floors tall and the front facades have open gallery's running horizontally along the façade functioning as elevated streets by which people can reach their doors. The back façade usually has balconies. The balconies can look similar to the gallery running along the entire façade with the exception that they are separated by baffles to allow for some privacy or they can be interrupted balconies only partially covering the façade usually placed in front of the bedroom. Other notable aspects are the lack of dwellings on the ground floor due to storage boxes making the plinth very closed (Brouwers & Heeswijk, 2013). The main entrance located on the ground floor leads to the stairs and elevators which can be ether incorporated into the building or on the outside with a very visible elevator shaft.

Example gallery flat (Funda, 2016)

The dwellings in a gallery flat are usually located on a single floor. The average floorplan of the gallery access flat consists of a rectangular floorplan that is often times divided by walls along the horizontal and vertical middle axis. The compartments can have the same width but in many cases the compartment containing the living room is wider. On the gallery side, there is always a main entrance and a hallway and usually the kitchen and one or two bedrooms are also located on this side. The other side of the floorplan contains the living room and in most cases a second bedroom with balcony. Sanitary functions are usually located in the middle part of the floorplan as these rooms do not require daylight. Most rooms can be accessed through the hallway or the corridor but in some cases the entrance to a room goes through another room. What is often seen is that one of the bedrooms can only be accessed through the living room and sometimes the shower access is located in the kitchen.

The walls along the mid axis can be loadbearing depending on the construction type. This can play an important role in the flexibility of the floorplan as these walls cannot be easily moved or changed. There are three main construction methods for the post-war flats and they all utilize concrete. It is important to know what construction type is used when there is the intention to adjust the flats, as it effects how easy the flats can be restructured. Things like loadbearing walls, the floor type, the type of façade and compartment sizes have direct influence on how easy it is to change the floorplans, make replacements and possibly adjust the building organisation. Therefore, a short description will be given of the three main systems. The first one is the stack type construction the second is the in-situ method and the third is large prefab elements construction.



Example floorplan gallery flat (Funda, 2016)

The stack type method was invented to reduce the need for construction machines and educated builders. By making use of lightweight prefabricated concrete blocks about twenty times the size of a traditional brick the building process could progress a lot quicker. All the blocks would be lifetable by hand by one or two persons. Available existing floor systems could be used in combination with this system, but sometimes custom designed floor systems would be applied. The most common know systems of this type are Tramonta, Airey, MuWi, Pronto and Bakker. (Andeweg, 2013, p. 2) (Battum, 2002, p. 12) (Roeloffzen, et al., 2004, pp. 43, 102)

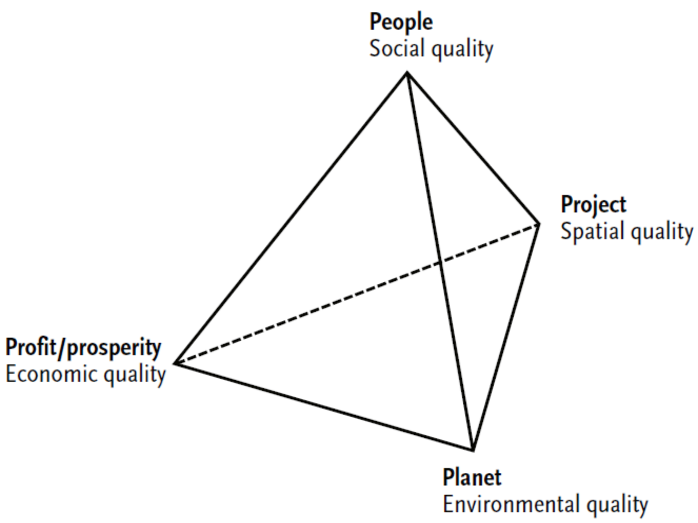
The in-situ method uses tunnel or floor and wall formwork. These can be made of timber or steel elements. The system requires a large amount of repetition to be effective. This method is mostly used for high-rise buildings due to the good stability it offers. The façade is added in separately from the floor and walls and is therefore easy replaceable at a later stage. An advantage of buildings made in this system is that the compartments have a royal width. A disadvantage is that there can be thermal bridges and acoustic leaks due to the in situ poured concrete. The most common known systems of this type are ERA, Korrelbeton, Welschen and RBM (Andeweg, 2013, pp. 5-6) (Battum, 2002, p. 14) (Roeloffzen, et al., 2004, pp. 43,103).

The large prefab elements method is characterized by load bearing walls and floors pre-made in the factory. The quality of the elements is good, but it relies on heavy road transport and for construction a crane is a necessity. Due to the scale of the elements the construction speed is high. This system is not very suitable for high rise as stability issues occur when adding layers. The compartments are made with a royal width making it easy to reorganise the floorplans. The most common knows systems of these type are Rottinghuis, BMB and Dura-Coignet (Andeweg, 2013, p. 4) (Battum, 2002, p. 16) (Roeloffzen, et al., 2004, pp. 44,104).

Challenges of 1960's high rise residential flats

The popularity of the post WW2 high rise residential buildings did not last long. Even though the flats where perceived as spacious at the time of construction, in the following years families who could afford it often times moved away to more attractive larger housing elsewhere in the city leaving the flats to inhabitants that did not have this option for economic reasons (Mustard, et al., 2009, p. 11) (Turkington, et al., 2004, pp. 11,132). In current times, many of the post WW2 high-rise residential buildings gained the attention of governments and urban planners because they are characterized by a variety of problems.

The problems can be divided into four main categories. These are People, Planet, Prosperity and Project (Elkington, 1997) (Duijvestein, 1997). People, focuses on the social and psychological needs of inhabitants like social cohesion, safety, health and residential stability. Planet, focuses on the environmental aspects like resource efficiency and sustainable cycles for energy, water and building materials. Prosperity is mainly about the economic perspective, with focus on the market position, affordability and overall value. Project is about the technical perspective with focus on the spatial quality, functionality, esthetics and durability of the building (Gruis, et al., 2006, pp. 2, 153).

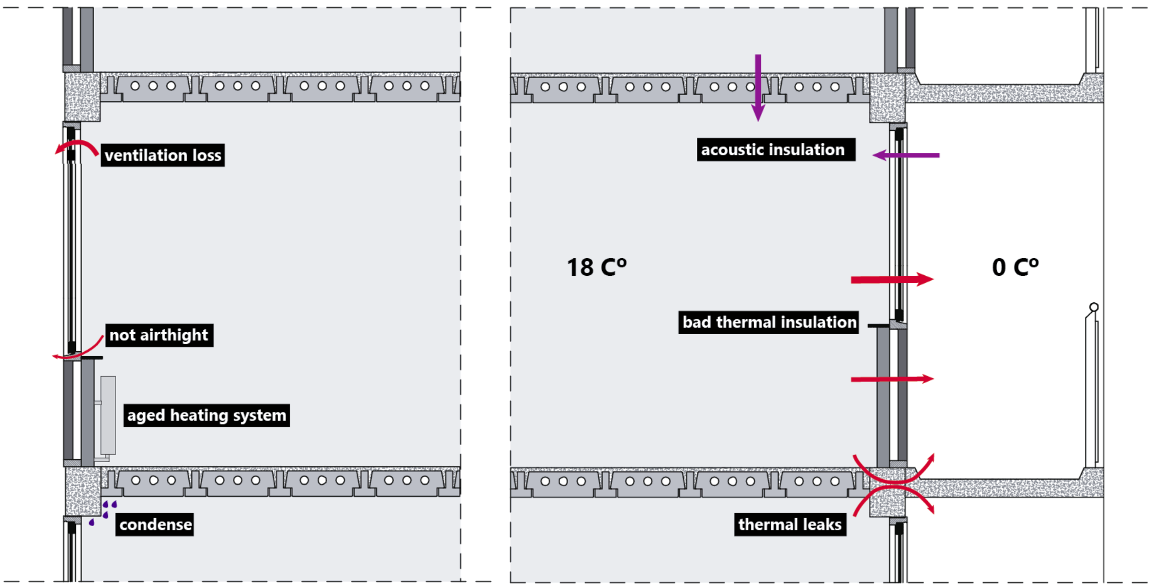


Four P's approach (Duijvestein & Dorst, 2004)

The technical, spatial, environmental, social and financial problems as described by (Mustard, et al., 2009, p. 11) (Turkington, et al., 2004, pp. 11-12, 132,136, 139) (Straub & Vijverberg, 2015, pp. 8-9, 13) (Roeloffzen, et al., 2004, pp. 24-26) (Brouwers & Heeswijk, 2013) are the following:

Technical problems

- Structural problems due to new construction methods and the use of poor materials.
- The use of materials that are polluted by for example asbestos, have bad sound insulation or have a negative effect on the indoor climate causing dampness, condensation and draughts.
- The absence or shortage of services like lifts, intercom systems and communal facilities.
- Urban design problems like high building density, noise pollution by traffic, poor location and monotony due to the repetitiveness, death plinth and uniformity of the building blocks.
- Bad accessibility for elderly and disabled people.



Technical problems (own image)

Spatial problems

- Internal design problems like small rooms, too little storage, insufficient external space
- Lack of privacy at the gallery side.

Environmental problems

- Outdated inefficient services often still relying on fossil fuels. (central heating, kitchen equipment, sanitary and electronic equipment)
- Poor thermal insulation and thermal bridges causing high energy consumption leading to higher levels of CO_2 emissions.
- Waste water and materials.

Social problems

- A lack of identity of the building and the neighbourhood due to the large anonymous buildings, having a negative impact on the bond between residents and their homes.
- Internal social problems due high housing density, like dirty or noisy neighbours.
- Increased crime rates and a low feeling of safety due to absence of watching eyes.
- A high variety of different cultures with sometimes clashing habits.
- Anti-social behaviour like leaving trash around or vandalising the shared spaces and amenities.
- The use of the buildings as temporary housing when nothing else is available can lead to indifference and cause conflict with long term inhabitants.
- Wider social problems like high unemployment rates, a lack of schooling, drug abuse, criminal activities and intensification of these problems when households in similar circumstances are concentrated together.

Monotony of flat and vandalized building

Financial problems

- Relatively high rents for tenant's due to service charges, and high maintenance costs.
- Dependency on subsidies for lower incomes to be able to afford the housing.
- High vacancies rates leading to large operating losses for the landlord.
- Competition problems due to poor image and the low market position of the estates.
- Vague ownership of flats and blocks and the space around them leading to a lack of responsibility causing deterioration and devaluation of the property.

In places where multiple of these problems coincide a cycle of decline can set in. Technical, social and economic decline enhance each other causing a downward cycle (Turkington, et al., 2004, p. 139). An example of this are places where bad urban and architectural design causes lack of social control leading to safety issues like lack of security and vandalism. This affects the competitive position of the building. Because households with a choice decide to leave the area, only households with little choice end op staying causing even bigger problems.

It might seem like post WW2 high-rise residential buildings are very problematic places to live but this is not always the case. Even though most of the flats show some form of technical problems due to aging they are not always accompanied by social and economic problems. Some flats located in favourable locations for example close to amenities and the city centre maintain their popularity. Also, the modernist design principles of light, air, vision and space are still appreciated in places where they are well applied (Turkington, et al., 2004, p. 130).

SWOT analysis

The SWOT analysis describes the current strengths, weaknesses, opportunities and threads of post WW2 high-rise residential buildings in order to get a better idea of what is important when trying to improve them.

Strengths
Lots of daylight
Affordable apartments
View
Provides many living spaces
Shared utilities
Decent structure
Convenient dimensions
Design freedom
Open green space

Opportunities
New image
Bigger apartments
Improved spatial quality
Improved outdoor space
Use of roof surface
Connect to surrounding trough plinth
Diversification of housing types and prices
Personal preference
Use of passive climate systems

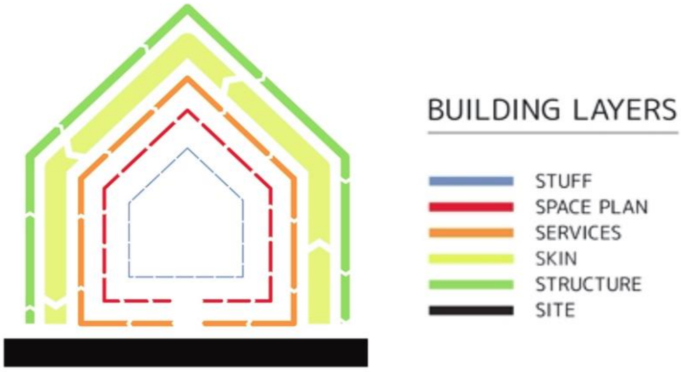
Weaknesses
Bad building skin conditions
Insufficient ventilation
Bad acoustic performance
Outdated building systems
Insufficient Isolation
Dead plinth
Lack of privacy gallery side
Small rooms
Lack of outdoor space
Thermal bridges

Threads
Monotony / Uniformity No sense of identity
Unattractive to mid and high income classes
High concentration of disadvantaged households (low income)
High density
No social cohesion
Low social security, susceptible to vandalism and criminality
Technical, social and financial decline
Dependant on collective behaviour

Assessing the state of a high rise flat

To find out how a building can be improved the state of the building has to be assessed. Depending on the problems the building is facing, the right strategy can be applied. Even though many high-rise flats look similar they are also unique. Each building has its own characteristics, history, building period, location, surroundings, residents and type of construction, position in the housing market judgements by inhabitants and outsiders and future prospects (Brouwers & Heeswijk, 2013) (Mustard, et al., 2009, p. 1). This is the reason that a building specific approach needs to be established for every project.

When designing or when improving an existing building a good approach to assess the state of the building is to look at the different building layers. The layers are the site, structure, skin, services, space plan, stuff. By separating the building into layers, the lifespan and quality of each layer can be determined. This helps to determine which approach would be suitable for the building.



Building layers (Brand, 1994)

Site

For the site a few aspects are important. The first has to do with the demand in the area of the gallery type flats. Is the building in an area with growing or declining population? Does the flat have a low or a high vacancy? What is the average income of the people looking for houses and what type of houses are they looking for. Depending on these variables the right decision can be chosen.
The second aspect is if the building close to amenities. These include public transport, shopping centre, green areas and parks, schools, parking places easy access to highways. The more amenities the more popular a location will be.
The third aspect is how good is the building connected to its surroundings. Is there social control on the ground floor or are there only storage boxes. Is it in a lively neighbourhood with a lot of social interaction that gives a feeling of safety or is the opposite the case.

Structure

For the structure of the building the most important aspects are: First, how good is the current quality of the structure and how long can it still last. The durability of the structure determines if it is worth investing in a building or not.
Second, how flexible is the structure and how easy can it be adjusted. Can it handle extra weight and can easily be adapted to offer a larger variety of dwellings and functions?
Third, how easy is it to reuse parts of the construction, is it demountable and can certain parts be recycled. This will contribute to find the most sustainable option for the building.

Skin

For the building skin there are also a few important points. The first one is how well does it fulfil its function. This means does it protect against water, wind, UV radiation and noise. Does it allow sunlight to enter, is it possible to ventilate the building and does it give privacy. Does it insulate for heat and cold and does it deal with vapour diffusion?
Second, in some cases the skin has a structural (loadbearing or scaffolding) function. This is not the case for most gallery flats but if, so it has to be taken into account as this has an impact on the ease by which the façade can be changed ore replaced.

The third aspect is the appearance of the building. Because the skin determines the appearance of the building it very important that it stays in good conditions. Nobody likes to live in a building that looks neglected, so it has to be well maintained. The façade can also contribute to a more personal appearance for the building and for each dwelling increasing overall appreciation.

Services

The services are electricity, water, heating and cooling, ventilation, sewage system. For these systems it is important that they are up to date to current sustainability requirements. This means that they have to be as efficient as possible in order to avoid wasting energy or water. The easier it is to upgrade or change these systems the better it is for the future as new improved technologies keep being developed. (see Appendix B for more information)

Space plan

For the space plan there are two important issues. The first one is if the space plan is spacious enough. This means that all the access ways, the dwellings and rooms inside the dwellings need to be big fulfill their functions.
The second one is if the space plan is flexible enough to accommodate different type of dwellings or functions and if the internal spaces can easily be adjusted to the wishes of the residents.

Stuff

The stuff includes the furniture of a house. So, this is more based on the wishes of the resident and a developer or designer does not have much say in this matter. However, giving out good information the residents might help them to make more sustainable choices. Think about efficient fridges, laundry machine, led lights.

Possible approaches

As waiting for the 1960's flats to further deteriorate is not a wise strategy, it is important to choose the right approach when trying to improve the post WW2 high rise residential buildings. There are a few options to consider when dealing with the aged buildings. The options are nothing, maintenance, renovation, refurbishment, demolition and replacement.

Nothing

Doing nothing can be an option in an area where the apartments are always rented out at reasonable market prices. The social composition works and there is a good atmosphere in the building and the neighbourhood. People happily live in the flat they feel safe and vandalism and crime is low. Of course, existing technical issues that are often there, like lack of acoustic and thermal insulation will have to be dealt with. So, at a certain point the building will have to be upgraded if it needs to conform to modern sustainable standards.

Maintenance

If the flat is in a reasonably good state like in the first example or if it is already certain the flat is going to be demolished in the short term <10 years, the maintenance strategy can be an option. This would include things like replacing old or broken elements, painting the façade, installing a new intercom system and switching to led lights. Still existing thermal and spatial issues may remain, and this is definitely not a very long-term solution as the flats continue to age.

Renovation

Renovation is most often used for buildings with a monumental status as the goal is the get the building as close to the original state as possible. Small improvements can be made, and parts replaced but the overall appearance, layout and functions of the flat stay the same.

Refurbishment

Refurbishment implies that not only will different parts will be upgraded or replaced but also the appearance, functions and layout of the building can be changed. A good refurbishment tries to maintain the good qualities of the building while improving the parts that are lacking in quality.

Demolition

Demolition of the flat would be the best option if it is in a very bad location and there is no demand for the types of apartments that the building can offer or if the condition of the flat is very bad like complete degradation of the concrete construction. In this case there is no reason to extend the life of the building.

Replacement

Replacing the building can be done if another type of building is desired or if the technical quality of the existing building is so bad that there is no way to reuse what is left of the old building. The big advantage of replacement is that the new building can be fully built up to current sustainable standard without being restrained by the legacy of an older building.

5. Sustainable building improvement strategies

To find out which approach to choose in what situation and how each one impacts the sustainability of the building it is good to look at sustainable strategies. Each approach from doing nothing, maintenance, renovation, refurbishment, demolition and replacement will have an impact on the quality and sustainability of the building.

Social sustainability

To deal with social challenges the following strategies are often applied:

In many cases differentiation is the key when addressing the housing estates. One of the most common ways to deal with social challenges is to try to achieve a different social mix in a neighbourhood by offering dwellings for low, medium and high-income households. This ensures that there are different types of families in the area maintaining a healthy social mix. On the scale of a building differentiation can be done by adapting and upgrading the apartments providing different sizes and meet the needs of different types of residents. The upgrading can be done by combining apartments or adding new buildings or extensions to the flats.

Increasing the level of homeownership in an area can also have a positive effect on the flat and on the neighbourhood. People who buy a house are more inclined to take good care of the building and the area as they are invested in it for the long term. This creates more involvement in and responsibility for the building and neighbourhood.

To deal with monotony and lack of identity the best strategy is improving the appearance of the building and the separate dwellings by diversification. This is done by compartmentalisation of the building, dividing the gallery into smaller parts, using colours or numbers and different materials, layering the façade, building cut-outs, multiple elevators for shorter routes to front door.

Improving the urban integration of a building. This is mainly done by opening up the plinth and adding functions that ensure more social activity during the day to increase the social control in order to improve the feeling of safety and to reduce vandalism.

Disclaimer
Even though some of the social problems might be a result from the architectural style of the buildings combined with the aged appearance, not all social problems can be solved through architecture. It is important not to forget that it might be also necessary to further address other challenges concerning the buildings. Upgrading the surrounding areas, dealing with the lack of amenities and provide activities to increase social cohesion. Other possibilities for tackling the social problems are: by providing schooling, language programmes and social programmes for the youth, foreigners and the elderly. For a good final result all these points should also be included in a restructuring project (Turkington, et al., 2004, p. 144).

Environmental sustainability

When taking into account that building regulations to reduce the energy consumption were only introduced in the 1970's after the energy crisis it is clear that many of the 1960's buildings are far behind on current sustainability standards. Many of them have insufficient thermal and acoustic insulation and technical installations like boilers are also often times outdated with a lower thermal performance than current day units. To reach the climate goals set in the Kyoto treaty it is important to deal with these issues on a short term to reduce CO^2 production and lower the resource and energy consumption (Gruis, et al., 2006, p. 1).

A well-known approach to deal with the challenges surrounding environmental sustainability is inspired by the book Cradle to Cradle (McDonough & Braungart, 2002). It consists of four steps.

1) Reduce the demand.
2) Reuse residual flows.
3) Solve remaining demand in a sustainable way.
4) Waste equals food.

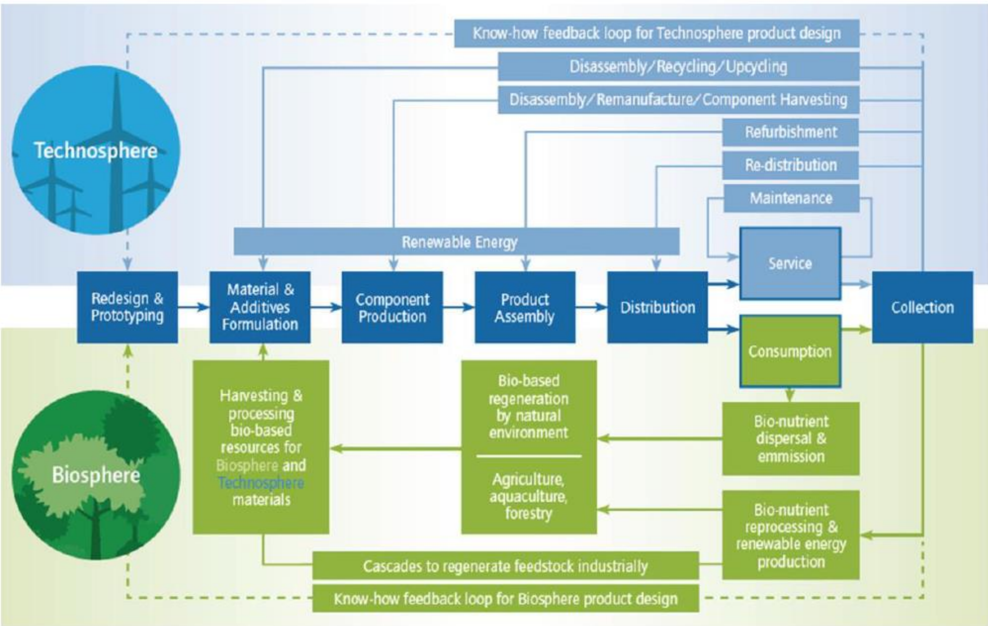
Reducing the demand is mostly about smart design for reducing energy demand making use of building orientation, dwelling organisation, thermal isolation, building mass, natural ventilation, and passive climate design to optimize sustainable building performance.

The reuse of residual flows is important for heat, for water and waste cycles. The goal is to keep using energy and resources for as long as possible within the building lowering the need for more external input.

Solving the remaining demand in a sustainable way is about using renewable energy sources like solar and wind energy but also about using high efficiency systems and getting the maximum out of the consumed resources.

Finally, the waste should not burden the environment but if possible contribute to it. This is especially the case for waste heat that cannot be reused and leaves the building (Dobbelsteen, et al., 2013, p. 45).

For materials a slightly different approach is required. The material cycles have been further elaborated in the report Towards the Circular economy (Ellen Macarthur Foundation, 2012). In this report material flows are described and separated into two categories: the biosphere and the techno sphere. The model is based on a cascading system. Biological nutrients get used and ultimately go back into the biosphere (nature). While for the technical nutrients the goal is to extend the lifetime as much as possible by good maintenance, reuse, refurbish, recycle and eventually extract the raw material to use them again. If well implemented this approach could lead to closed loops for all materials.



Circular economy material flows (EPEA & Returnity Partners, 2015)

A good way to achieve these loops for materials and components of a building is by separating parts with a longer lifespan and parts with a shorter lifespan to maximize the lifetime of each component (Geldermans & Rosen-Jacobsen, 2015, p. 9).

The components with a longer lifespan can be more static while the shorter lifespan components should allow for easy disassembly for when they need to be replaced. Also, material choice can be based on the estimated lifetime of a certain layer and what happens to the parts at the end of their lifetime should already be determined during the design stages. To facilitate the separation of components with a different lifespan distinction is made between the Base Building and the Fit Out. The base building being the load bearing structure and the fit out the interior filling (Geldermans & Rosen-Jacobsen, 2015, p. 10).

	BASE BUILDING	FIT OUT
MAIN CHARACTERISTIC	Long lifespan, Fixed, Architecturally strong	Short lifespan, Variable, Demountable
SCOPE	Main structure, Collective spaces	Partitioning walls Kitchen, bathroom, MEP services (and possibly façade elements)
MAIN INFLUENCE	Owner, Architect, Contractor	Occupant, (Interior) architect, Maintenance services, Fit-out industry
LINK WITH CIRCULARITY	Long lifespan, stable or increasing returns on investment	Adapts to change, Less waste, Facilitates circular reuse

Separation of Base and Fit Out (Geldermans & Rosen-Jacobsen, 2015, p. 10)

Both the base building and the Fit Out require a certain level of flexibility. The base building with the long lifespan consisting of mainly the construction should be designed in such a way that it can be easily changed over time thus avoiding load bearing walls that can limit the internal organization can be a pro. For the Fit Out consisting of the skin, services and space plan, flexibility is even more important as it allows for the building to change over time and adapt to new requirements. By focussing on flexibility of the building during the design stage the building will not only be financially attractive due to the functional adaptability and long-life span, but it will also be socially attractive due to the customization possibilities it offers the users (Geldermans, 2016, p. 304).

This table offers a list per building layer to help maximize the sustainability.

STRUCTURE	Dimensioning system: modular coordination
	Dimensioning system: facade-grid
	Extension/Reuse of stairs and elevators
	Load bearing capacity of floors
	Load bearing floor systems
	Self bearing facade
	Geometry of Columns
	Use of fontanel constructions
	Fire resistance of load bearing structure
	Interruptions in structure
	Connection detailing of foundation en ground bound installations
	Building technology of load bearing structure
	Thermal and acoustic quality of floor insulation
SKIN	Demountable facades
	Reuse windows
	Daylight entry
	Thermal and acoustic quality of façade insulation
	Connection detailing of facade components
SERVICES	Over dimensioning shafts
	Over dimensioning the capacity of installations
	Over dimensioning the capacity of facilities
	The way installation components can be disassembled
SPACE PLAN	Inter-changeability of fit out components
	Movable separation walls
	Connection detailing of partition walls
	Individual fit out / finishing

Flexibility of layers (Geldermans & Rosen-Jacobsen, 2015, p. 11)

When dealing with a transformation projects there is the extra challenge of having to deal with the existing building. Environmentally and circularity wise it would be best to use the existing components for as long as possible while socially, financially and technically this might not be the best approach. The challenge is then to find an approach that makes it possible to deal with the social, financial and technical problems while keeping in mind the environmental goals. In most cases this will lead to parts of the building being demolished and parts being added. These processes produce waste and are by themselves not very environmentally friendly but if they lead to parts of the building being reused over longer time they are in most cases better for the environment than complete demolition and replacing the building. In many cases this approach consists of saving and adapting the base building, while the fit out will be more thoroughly replaced.

Financial sustainability

In many cases the gallery flat apartments are socially rented. Because of this rent prizes are quite low. In a situation where the residents are staying in the apartments after the upgrade it can be hard to get the finances necessary to make the transformation happen. In this case diversification is an option. By adding new buildings as part of the project or by enlarging existing apartments and selling them it can help to achieve a financially viable solution. It also helps to keep the area attractive for different types of residents maintaining the market value.

Not having to relocate current residents because they can stay in their home during the transformation or because they can return in relative short time after the transformation can be financially beneficial as this saves costs.

Because of the large number of dwellings in a building there are benefits of scale for the design. More money can be invested in developing a good product if it is going to be used for many dwellings as the developing costs can be spread (Brouwers & Heeswijk, 2013).

Many of the post war flats are currently owned by housing associations. Because high investments are needed to improve quality and the liveability of the buildings, current strategies of restructuring still focus mostly on small improvements through maintenance to increase lifespan or demolition and building replacement. This is partly due to housing associations trying to minimize risks and partly due to diminished subsidies for building renewal (Straub & Vijverberg, 2015, p. 7). This goes against the advantages that a real transformation can provide. If the buildings are thoroughly improved current deterioration can be halted and a higher value of the building in the long run can be ensured.

Technical sustainability

To keep the building in a good condition for another fifty years it is important that existing structural problems are dealt with. This can be done by maintenance and by replacing parts that are aged before they become a liability. In the case of polluted materials, it is important that they are removed in a safe way and are replaced by materials that do not have negative effects on the health of the residents.

Adding sound insulation can provide better conditions as noise from neighbouring apartments becomes less of an issue. This reducing the chance of nuisance and leads to a better social climate in the flat.

Good thermal insulation, vapour thigh sealings and a well working ventilation system is necessary to ensure that the apartments are well ventilated and to avoid condense that can lead to water damage and fungi that can cause health damage.

To ensure that the routing through the building is good, new lifts might need to be added especially as in some cases the lifts do not stop on every floor requiring the resident to also take the stairs which is not anymore to current standards and bad for elderly and disabled people.

Intercoms can be installed to improve safety by more selectively allowing people to enter the building, which also improves the privacy of the flats.

Spatial sustainability

Given the minimal spatial requirements many post war flats do not live up to current day standards (see Appendix A for the spatial requirements). As mentioned before in a lot of cases differentiation is the key to improve a building it is therefore advantageous if the building can house different resident composition. To deal with the lack of space of the current apartments during a refurbishment project a few strategies can be deployed.

The first strategy is rearrangement within a single dwelling. Separation walls in between dwellings remain standing while interior walls are rearranged to provide a better space division. Main advantages of this strategy are that the number of dwellings stay the same and the dwellings can be renovated separately from each other avoiding large scale rehousing. An exception to this is when the pipes are being replaced in that case an entire vertical row of dwellings need to be refurbished at the same time. A downside of this method is that the overall size of the dwelling remains the same.

The second strategy is horizontally combining dwellings. This is usually done by adding a compartment of the neighbouring dwelling to the refurbished apartment. Two challenges that occur are the fact that in most cases parts of a loadbearing wall needs to be demolished to make passage ways and interior walls suddenly need to become a separation walls in between dwellings. To meet acoustic and fire safety requirements an extra intervention is then necessary. An advantage of horizontal combining is that all floors can have the same floorplan making it easier to lay out the piping. Another advantage is that all rooms stay on one level making the houses stay viable for elderly and people in wheelchairs. A downside can be that the housing density will decrease as result of this intervention, so it remains to be seen if the costs can be covered (Battum, 2002, p. 69) .

The third strategy is vertically combining dwellings. For vertically combining dwellings it is in most cases necessary to demolish part of the floor. Because many of the floors are made out of hollow lightweight concrete elements it can be risky to demolish them partly without disrupting the construction. For this reason, it is not a very popular option during refurbishment projects. The stairs that are required for vertical combining also take up space that could otherwise have been used as living area and there will also be a loss in housing density due to vertical combining of dwellings. On the other side, vertical combining can lead to a large variety of dwellings depending on how they are combined. It can also lead to a larger percentage of ground-based dwellings. This is attractive for families requiring gardens and can lead to higher levels of social control at ground level improving the overall safety in the neighbourhood. Other advantages can be having only one gallery every second floor leading to more privacy for family members. There is also the possibility of have separated workspace and living area in the same house. The vertical intervention can result in big apartments making it out of the price range for social housing but can be beneficial for differentiation in the building.

The fourth strategy is to enlarge the building by adding an extension. This can be done by enlarging the plinth and transforming storage rooms into dwellings, building extra layers on top of the building or by putting addons against or hanging them on the building. The big advantage of this is that more space can be created without sacrificing housing density.
When it is chosen to enlarge the plinth, there is the possibility to do this over multiple layers to spread the costs. The new plinth does require a new foundation to support the extra weight. It also offers the possibility of a new look for the facade and a chance to transform available storage space on the ground floor into new dwellings or shops. The main advantage is that all dwellings can get some extra space leading to more flexibility in the floorplans (Battum, 2002, p. 117).
Adding dwellings on top of a building is also a possibility, there is however the issue of the added weight on the existing construction and foundation and research shows that an increase of about 10% in the total weight is often time the max. It can also help to improve the conditions of the roof and finance other parts of the refurbishment. It is important to note that the flat needs to have a life expectancy that is close the that of the newly built layer to make it worthwhile (Battum, 2002, p. 120) . A limitation is that the extra layer can only help to enlarge the dwellings in the layer below but does not have much impact on the rest of the dwellings in the building.
Placing an addon against the building or hanging one against the building is also an option. Often times addons are placed on the blind facades of the flats making it possible to ether extend existing dwellings or add complete new dwellings. A high variety of dwelling diversification can be achieved this way. It can improve the overall image of the building provide more vision around the flat improving social security (Battum, 2002, p. 168). Again, foundation measurements need to be taken. The possibility to hang an addon on the building is mostly dependant on the current construction and if it is able to handle the extra weight and stress. With the old post war buildings, the construction usually lacks the required strength and extra structural measures need to be taken to enable this kind of intervention making it an expensive option.

Choice for refurbishment

While maintenance and renovation are in some cases good options to deal with a deteriorating flat they have their limitations. They lack the ability to deal with spatial shortcomings of floorplans like small apartments and rooms and do not offer a chance to alter the buildings sometimes monotonous appearance.

Refurbishment however does have the benefit that there is the possibility to change the image of the buildings and diversify the dwellings leading to a changed resident composition which can have positive impact on the social situation in the neighbourhood and when carried out well a refurbishment project can be much cheaper than demolition and replacement strategy at about half to one third the cost (Poel, et al., 2007, p. 394).

All these points speak in favour of refurbishment and already more projects favour refurbishment to extend the life of the current building stock. Of course, a case specific approach is still necessary, and refurbishment only makes sense when the buildings are located in an attractive location and there are long-term prospects (Turkington, et al., 2004, p. 144). If there is no market demand for the specific type of dwelling being made it is of no use to refurbish the building. It is also important not to forget the environment of the buildings while doing the refurbishment as this can have great impact on the result.

Refurbishment approach

When the choice has been made to refurbish the building, it is important that it happens in a good way. If only the appearance of the building is enhanced many opportunities are missed (Hermelink & Müller, 2011). The refurbishment should be used to make the buildings sustainable with respect to the future. Only by choosing the right refurbishment approach, by implementing the right systems and by looking at the complete lifecycle of the building the best results can be achieved. When doing a refurbishment there is the option to do it following the limit approach or with a drastic approach. The limit approach focusses mostly on energy efficiency and maintenance while the drastic approach is more focussed on adding functions and differentiation.

Examples of limit approach interventions are (Roeloffzen, et al., 2004, pp. 58-59):

- Glass membrane façade for the galleries
- Double glazing to replace single glazing
- Façade insulation
- Interior wall insulation
- Roof insulation
- Water saving showerhead
- Toilets with water saving flush
- Energy saving lights in the common area's
- Replacing central heaters with high efficiency heating boilers
- Replacing radiators with low temperature heating systems
- Drought exclusion along windows and doors
- Self-regulating natural ventilation

- Replace materials with harmful emissions (paints, asbestos)

The big advantage of this approach that it is low risk and relatively cheap. The residents can remain in their house while the rent stays at the same level. The downside is that there is no change in the social composition of the building so existing social problems stay. And no real change is applied to the floorplan organisation in cases where these are outdated. The financial gain is minimal and if the ambition level is low it could be that the flats still run empty after a while because they cannot compete with newer dwellings (Roeloffzen, et al., 2004, p. 59).

Examples of drastic approach interventions are (Roeloffzen, et al., 2004, pp. 54, 61):

- Stripping the shell and removing building components.
- Complete façade replacement
- Installing thermal and acoustic insulation
- Installing new piping, cabling, lighting, hot water and heating systems
- Use of collective energy installations like photovoltaic panels or solar collectors
- Modifying nature and the environment for example to capture and clean water
- Adding new stories to a building
- Combining or adding dwellings
- Replacing storage rooms at ground level with homes or shops
- Adding extensions to the building
- Adding new buildings to a district
- Improving the access to the dwellings by installing (extra) lifts, staircases and widening the gallery.
- Enlarging and upgrading balconies.
- Replacing functions like kitchen, bathroom and toilet.
- Partial demolition of a block or removal of unwanted buildings.

The big advantage of this approach is that it is possible to make major adaptations to the buildings enabling possibilities to deal with social, financial, technical and environmental problems. A disadvantage can be that most of these interventions are quite expensive and it is therefore important that the result is of a comparable quality with newly built apartments to ensure they will be rented out or sold.

Toolbox

The refurbishment toolbox offers more detail about what can be improved during a refurbishment project from low to higher impact (Konstantinou, 2014, p. 200).

	Building envelope					Building Systems	
	Exterior wall	Window	Balcony	Roof	Ground floor	Ventilation	Heat source
Existing construction	Masonry/ cavity wall no insulation	Single glazing	Continuous slab, no insulation	Pitched roof, timber rafters no insulation/ occupied loft	Slab on ground, no insulation	Natural ventilation	Gas stove
	Lightweight concrete/ hollow brick, no insulation	Early, double-glazing	Separate slab no/ little insulation	Pitched roof, timber rafters no insulation/ unheated loft	Basement unheated. Concrete slab, no insulation		Fossil fuel boiler in each dwelling
	Little/outdated insulation			Concrete slab, no/ little/ outdated insulation	Little/ outdated insulation	Trickle ventilation	Fossil fuel boiler per block
Retrofitting measures	Cavity insulation	Upgrade windows	Insulate balcony slab	Pitched roof, no insulation/ unheated loft	Insulation on top of ground/ first floor slab	Natural inlet/ mechanical exhaust	Replace existing boiler in each dwelling, high efficiency
	Internal insulation	Secondary glazing single	Cut off balcony	Pitch roof insulation	Insulation under existing floor	Mechanical inlet/ natural exhaust	Replace existing boiler per block, high efficiency
	Exterior Insulation and Finishing Systems (EIFS)	Secondary glazing double	Balcony cladding - Single glazing	Insulation of top floor slab		Mechanical ventilation	CHP installation
	Ventilated façade		Balcony cladding - Double glazing	Flat roof		Ventilation system with heat recovery (HR)	Heat pump
	Timber-frame wall	Replace windows (Double pane)		Green roof			
	Second Façade/ Single glazing	Replace windows (Triple pane)					
	Second Façade/ Double glazing	Shading adjustable					Biomass boiler
RES	BIPV's			Photovoltaic			Solar collectors
spatial Interventions	Additional space/ Second façade integrated	Shading fixed	Integrated balcony				Geothermy
	Lift addition	Enlarged windows	New balcony	Additional floor/ occupied loft	Additional floor/ occupied basement		District/ community heating

Refurbishment toolbox matrix (Konstantinou, 2014, p. 200)

The top part of the toolbox matrix shows existing conditions of exterior walls, windows, balconies, roofs, ground floor, ventilation system and heat source in post WW 2 multi-family residential flats. The bottom part shows different options to improve in each category. The farther down in the table the more drastic the level of intervention and effort.

7. Façade refurbishment techniques

A good way deal with an aged façade is by using the refurbishment strategies from (Konstantinou, 2014). As can be seen in the table below where an overview of different strategies with their benefits and limitations is given.

	Replace	Add-in	Wrap-it	Add-on	Cover-it
Description	Old façade elements removed and replaced with new ones	Upgrade from the inside	'Wrapping' the building in a second layer	New structure is "added on" to the existing building	Cover parts or entire internal and external courtyards and atria
Intervention-variation	Replace the entire façade Replace parts	Internal insulation Cavity insulation Box window	External insulation, Cladding of the balconies Second skin façade	Small intervention, such as adding new balconies New building as an extension Additional floor	Cover parts or entire Heated or unheated space
Benefits	New components with better performance Eliminate the physical problems	Adequate for monu-mental status Increase the thermal resistance	Solve thermal bridges Increase the thermal resistance Different cladding possibilities Little disturbance	Out-dated façade no longer exterior New façade with performance Increase space Functional benefits	Create thermal buffer Enhance natural ventilation with stack effect Out-dated façade no longer exterior Additional space
Limitations	Great impact on users Higher costs	Critical connection thermal bridging need attention Big disturbance for users	Not applicable to mo-numental buildings Possible space limi-tation	Needs to be com-bined with other strategies for facades non-adjacent to new structure Structural limitation	Not applicable to all cases Depending on layout and function of the building Overheating risk

Refurbishment strategies (Konstantinou, 2014, p. 128)

Façade replacement

Façade replacement can deal with technical issues while maintaining the old building structure. Placing a new façade can however also provide the opportunity to diversify the façade providing bigger windows and better integrated ventilation systems. There is also the possibility to expand the apartments by adding gallery or balcony space to the dwellings. Still the adaptations are only within the limits of the existing building

Add-in

The add- in does not solve all the physical problems and can be a disturbance for the users. As the post war flats do not have a monumental status it is not worth using this method especially since adjusting the floorplan of apartments is not possible and cramped living spaces might be further reduced.

Cover-it

The cover-it method is simply not suitable because in most cases there is nothing to cover. Most high-rise flats are not built so near to each other that it is possible to add a roof spanning the distance.

Wrapping the old façade

By wrapping the old façade in a new one existing thermal and acoustic issues can be dealt with. This is a good option for a building where the apartments are still highly appreciated and are being sold or rented out at a market price. The big advantage of this strategy is that the existing building can stay, and thermal issues can be dealt with while at the same time improving the façade. Big disadvantage is that it is not possible to deal with spatial issues within the apartments and diversify floorplans.

Addon

By adding an addition to the building, the apartments can be improved on a spatial and technical level while maintaining a high residential density. Also, it offers the opportunity to diversify the look of the building more and to more easily combine apartments in a horizontal or vertical way. If the addon is made demountable it can allow for easy upgrading but also for parts to be reused if it is decided in a later stage that the original building will be demolished. The addon can be used as part of a new building or can be used as addon on a different flat.

Interior rearrangement

Interior rearrangement can be necessary to deal with spatial issues that the building and apartments are facing. To achieve the best result, it probably has to be coupled with either the warping, façade replacement or the addons strategy as these can provide solutions to technical problems that the interior rearrangement does not deal with. It is important to note that the existing construction and existing shafts and ducts must be taken into account as much as possible to avoid weakening the structure of the building high costs.

Choice for add-on

When applying the different strategies on high rise post-war residential flats the most viable solutions seem to be: replace and wrap-it and add-on. The big advantage of the replacement strategy is that all physical problems can be solved and at the same time there is the possibility to change the appearance of the apartments. The wrap-it strategy on the other hand is cheaper, takes, less time and does not require the inhabitants to move but does not give the option to adjust the façade layout. The add-on is a good option as it deals with all the challenges that the first two deal with and can also address spatial shortcomings and give the flat a more diverse and personal appearance. Downside is that more material is required and because it only covers part of the façade it will have to be in combination with either replace or wrap-it strategies to address the entire building. The add-in strategy and the cover-it strategy do not seem very applicable for the high rise residential buildings.

As the goal of this research is to develop an architectural product that can deal with as many of the challenges as possible, the add-on seems the best option and the remainder of the research will therefore focus on the addon solution. Main problems that can be solved by the addon are:

- Solve technical issues
- Enable extension of living areas
- Option to add a new more versatile façade (dwelling+ building image)
- Enable apartments diversity

Design goals

Design goals for the building

For the design part of the project the goal is to improve the building with its existing issues by developing a product that serves as a design solution. To come to the right product different choices, need to be taken. This chapter sets the goals for the final product and shows the decision making behind the different choices towards the development of the product.

Technical quality

The building will have to comply with building physical requirements for acoustic insulation, fire safety and thermal insulation and have enough place for ducts and climate systems. Adaptations to the current construction of the building should be made in a way to maintain the structural integrity of the building.

- Thermal insulation
- Acoustic insulation
- Space for shafts and ducts
- Fire safety
- Maintain structural integrity

Social quality

Differentiation is important. If possible, the building should contain multiple apartment types and sizes and should accommodate low, middle and high-income residents to achieve a healthy social mix. The flat will require a new personal image. This can be done by using a new materialisation for the building skin and by differentiating the façades of the apartments on the outside. In this way the monotony of the complex can be broken giving the flat and the apartments a more personal identity.

- Differentiation of apartments and residents
- More unique image for building and dwellings

Environmental quality

The building should have a high level of environmental sustainability, solving the physical problems and make use of as many sustainable systems as possible.

- Sustainable climate systems
- Demountable elements
- Reuse / Recycle of building components and materials
- Choose materials based on good lifecycle scores

Spatial quality

The apartments should be spacious and have a more flexible organisation.

- Flexible floorplan
- Different floorplan types and sizes
- Minimum required square meters per function
- Minimum height of ceiling

Financial quality

The existing construction should remain intact as much as possible to avoid high project cost due to damage to the building and to maximize the use of already present material.
The time needed to refurbish the building should be kept as short as possible to avoid high projects costs and to make the apartments rentable of sellable as quick as possible.

- Save money by reusing existing parts
- Short transformation period
- Affordable dwellings at market prices

Sustainable design goals add-on

Most of the existing constructions of the buildings are old and not dimensioned to handle extra weight. Therefore, the addons should not put heavy loads on the existing construction. So, they should either be lightweight or carry their own load.

- Minimal weight on existing construction
- Lightweight or separate foundation

The addons should be installed with the as little montage and on-site work as possible. It is important to be able to quickly do the renovation as this allows the apartments to be re-rented or resold within the shortest amount of time. Short build times also reduces nuisance and saves on labour costs. It also makes it possible for current residents to keep their homes without having to move.

- Fast mounting time of about 1 week
- No scaffolding, only use of crane
- Minimum on site work
- As much prefabricated as possible

The addon should be completely (>95%) demountable. There should be the possibility to quickly demount it and use it on another building. But it should also be possible to take it apart in parts and reuse them.

- No welding of elements
- No use of adhesives
- No concrete connections

The addons should be prefabricated in the factory as much as possible. This to ensure that they meet the high precision requirements to be easily mounted on the existing structure

- Less waste during production
- High precision and accuracy

- Easy to test for airtightness and thermal capability and fire safety
- Not weather dependent
- High grade finished product

The components and the complete units should have a good LCA score to ensure the lowest possible impact on the environment and all parts should be reusable or recyclable.

- Materials with a good LCA score should be used
- Units, elements and parts should be reusable/recyclable
- The EPC (energy performance coefficient) value of the apartments should be less than 0.4 (BRIS bouwbesluit online, 2012)

The addon should have an Rc (thermal resistance) value of 4.5 m^2K/W or higher and an U(heat transfer coefficient) value of 1.65 W/m^2K or lower (BRIS bouwbesluit online, 2012). These are the norms that are set for new buildings to comply to environmental laws.

- $Rc > 4.5\ m^2K/W$
- $U < 1.65\ W/m^2K$

The connection of the addon with the main building should be airtight and water tight and it should be possible to do the seals on the inside. With the seals on the inside it is not necessary to use scaffolding to do the work from the outside.

Repelling rainwater should be an integrated part of the addon, so it is not necessary to use a special element for addons with a roof surface. In this way the addon can freely be placed with maximum flexibility.

The floor to ceiling height of the addon should be at least 2.1m preferably close to 2.6m. With a higher ceiling the room will be perceived more comfortable and it will also allow more daylight and sun deeper into the house. Preferably the addons floor level should be on the same level as the existing floor making them an integral part of the rooms to which they are connected and making them wheelchair friendly.

The addons should be durable with minimal required maintenance. Because the addons are not so assessable maintenance can be difficult and expensive. Therefore, it is important to choose materials that require little maintenance and are very durable. Life expectancy of at least 50 years.

Addon components should be transportable by road transport. For standard transport this means staying within the dimensions of 13.4m length, 2.6m with and 2.7m height.

Addon options

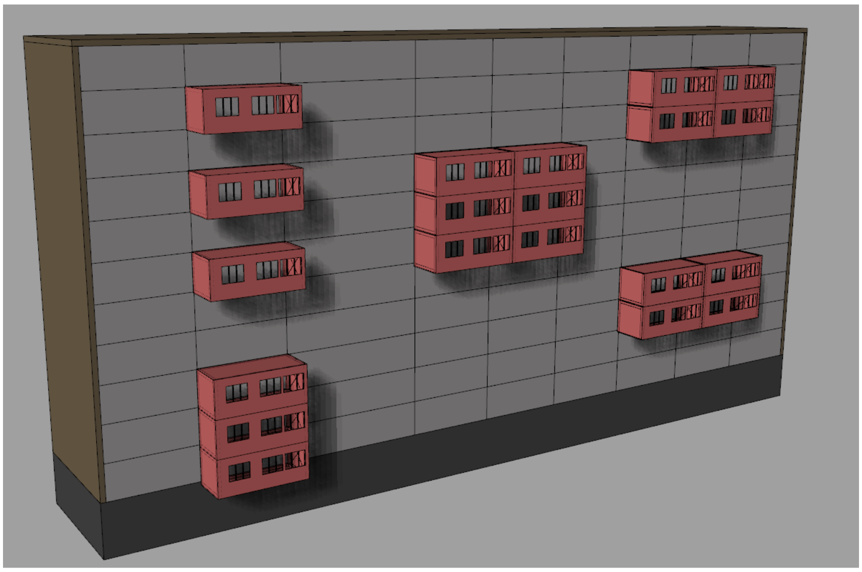
Addon types

Three main addon types will be distinguished.

- The hanging addon
- The integrated addon
- The self-supporting addon

The hanging addon

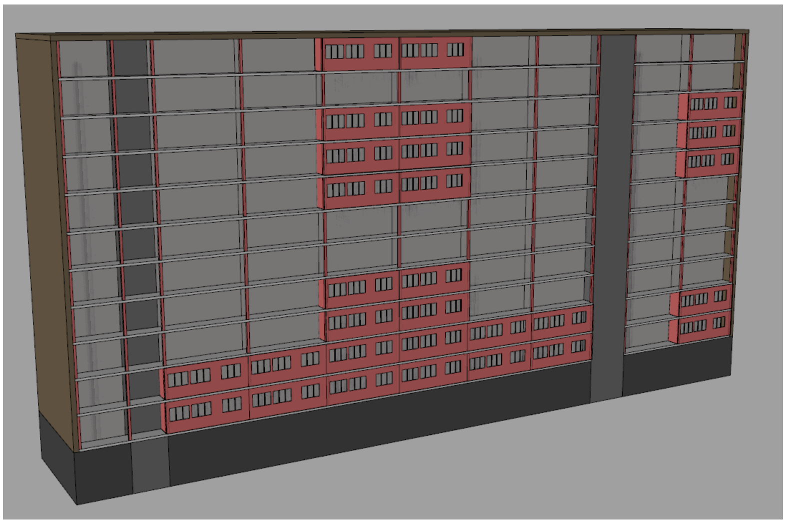
The first variant is the hanging addon. This addon distinguishes itself because it is hanged to the existing construction and can therefore be placed on different parts of the façade without requiring a separate construction. The addon will be attached to the loadbearing walls and therefore the size of the addon will be equal to the compartment size being either 4.1m for the large compartment or 2.95m for the small compartment or 7.05m for the full façade of an apartment. Because the existing construction is in most cases not dimensioned to carry extra weight the hanging addon should be as light weight as possible. The addon needs to be constructed with a rigid frame enabling it to carry its own load allowing it to be mounted on the existing building in one piece. This will save time during the construction and will allow the addon to be produced in a factory under controlled conditions ensuring a high quality. The addon should be built up from demountable parts that can be easily disassembled to allow for easy reuse.



Hanging addon (own image)

The half-supported addon

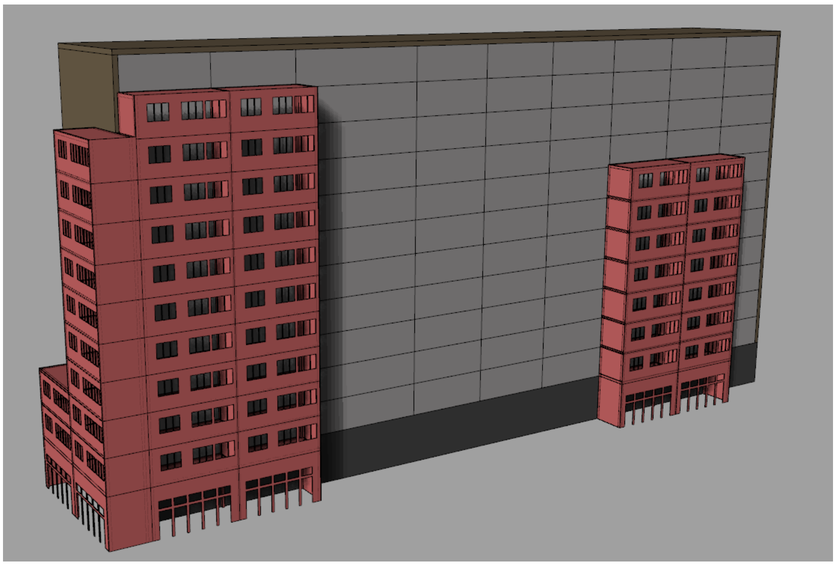
The second variant is the half supported addon. In this variant, the addon is supported by the building and by new columns This can be done for the partial or full building. Because of the new columns the add-on will be able to carry part of its own weight giving more opportunity to use heavier materials however the add-ons still rest on the existing building, so it is still better to keep them relatively lightweight as the existing construction is in many cases not capable to handle much extra weight. For the montage, the columns will have to be placed first and after the add-ons can be attached to them and to the building. The façade can be assembled in a factory and the full elements can be mounted relatively quickly on the building.



Integrated addon (own image)

The self-supporting addon

The third variant is the self-supporting addon. For this variant, a separate construction will be build adjacent to the building. Because of the self-supporting structure this variant can be very flexible in size and weight allowing for a wide range of materials to be used. An extra piece of foundation will have to be added however making it a more expensive alternative. The construction will be made out of demountable columns and beams with a cover of façade cladding. Because the structure is attached to the main construction it can use stability components of the existing construction to support itself. Assembly of the construction parts will most likely be done on site while for the façade, larger factory assembled elements can be used to speed up the construction process.



Self-supporting addon (own image)

Choice self-supporting addon

The self-supporting addon is chosen as this seems to have the most potential. It is able to carry its own weight and thus allows for a more drastic approach with more possibilities giving the most freedom in adapting the building and therefore it seems interesting to find out its potential.
The hanging addon was not chosen because due to the limited weight and also the options to adapt the façade are much more restricted giving less freedom to achieve a substantial change in image of the building. Also, the constructions of the flats are in most cases not capable of handling extra weight.
The option of the integrated support addon will not be chosen as this option is primarily viable on the gallery side and it also very limited to the size of the current gallery. Furthermore, it could cause spatial issues like accessibility of the apartments. It is also a more commonly used approach, so the results might be less interesting than that of the self-supporting addon.

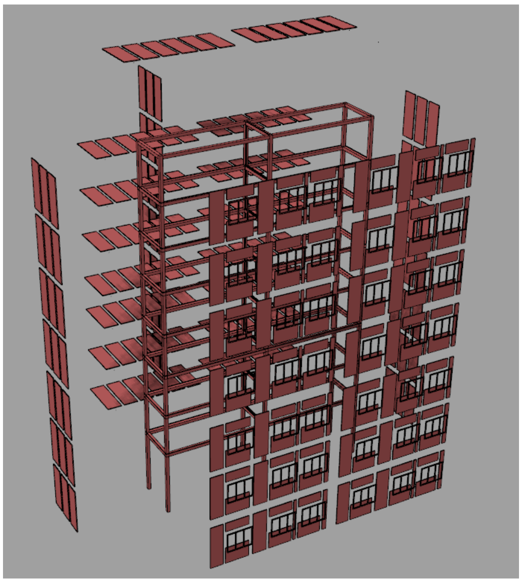
Addon built-up

There are a few basic ways to build up the addon.

- Small element built up
- Large element built up
- Unitized built up

Small element built up

The small element built up is the more traditional method. A skeleton frame is built and the beams are used to support the floors. The floors can either be made out of small elements, but it can also be made out of poured concrete on site or from timber beams and lattices. Once the floors are in place they are used to attach the façade. The facades can also be made out of small elements. These include walls, the parapet, window frames all to be mounted on site. Also, facade walls that are hand-stacked with bricks are included in this type of system.



Small element built up (own image)

The main advantages are

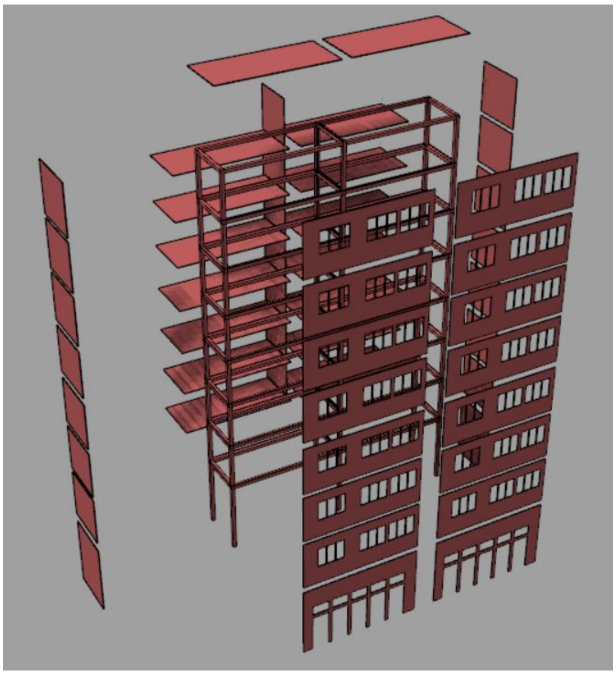
- High level of customization
- Easy to adapt to onsite circumstances
- Elements can be transported with elevators instead of cranes
- Easy transportation
- Flexible

The main disadvantages are.

- Very labour intensive
- Dependant on weather conditions
- Requires scaffolding to place all the elements
- Long building times
- Large amount of waste on site
- Not very precise in finish
- More difficult to do validation tests on site

Large element built up

The large element built up can either use a structure of columns and beams for the structure, but it is also possible to make use of a load bearing façade. The floors are made of large spanning materials like prefab concrete or wood elements, but also with this system there is the possibility to make them on site. The façade is either added later if there is a structure or in case it is load bearing it is added first to support the floors.



Large element built up (own image)

Main advantages

- Quick built times

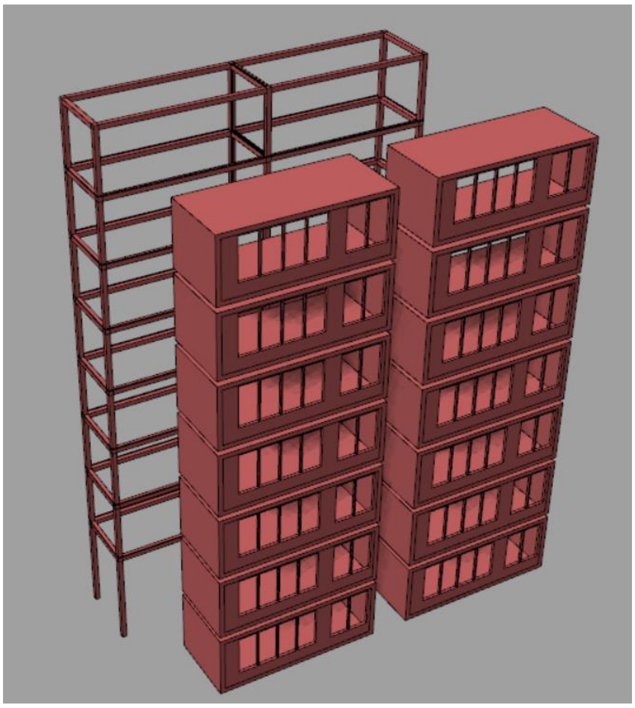
- Not so labor intensive on site
- Elements made with high accuracy in factory
- Partly tested in the factory

Main disadvantages

- Requires a crane to lift the elements
- Requires scaffolding to finish the façade from the outside
- Validation tests have to be done on site
- Weather dependent
- Harder to transport because of size and weight

Unitized built up

The unitized built up makes use of fully finished addon units. These units are prefabricated in the factory and come fully finished to the building site. Once the units arrive they only need to be placed and connected to the main structure. Because everything is done in the factory the units can have a very high accuracy and level of finish.



Unit built up (own image)

Main advantages

- Very short built times
- Not at all labor intensive on site
- No scaffolding needed
- Testing in factory
- High finish due to build up in factory
- Little waste on site
- Demountable / reusable in one piece

Main disadvantages

- Double walls, roof and floor surfaces when stacking
- Huge elements more difficult to transport
- Requires a large crane
- Unit must have structural integrity on its own
- Not very flexible
- Hard to adapt on site

Choice unitized built up

To comply with the addon demands the unitized built up is chosen as the best fit. This is because the larger the elements and the less work on site the higher the build speed enabling a quick renovation allowing residents to stay in the apartments, minimizing nuisance and saving costs for onsite labour and equipment. Also, a very high level of finish can be achieved using by the unitized system as the complete addon is factory made. Thermal, acoustic, airtightness, fire safety and structural test are done in the factory so the units all have the best performances.

Structural options

When choosing for the unitized built up there are two main options to make the extension to the building. The first is by directly stacking the units on top of each other and the second is by making a frame that can be filled in with the units.

Stacking of the units

If a stacking system is used the buildup has to be start from the ground. Because the units are stacked on top of each other each unit needs to have loadbearing capabilities. The units on the bottom will therefore have to be dimensioned bigger to be capable of carrying the load of the units on top. This means that for the assembly each unit has to be placed in a specific order. It is also not possible to leave one unit out or to take one unit out at a later stage without also demounting the units on top of it. The biggest advantage is that there is no separate construction needed and this could save built time, money, space and materials.

Units in frame construction

The second option is building a frame and hang the units in this frame. The main advantage is that because the frame is the loadbearing structure the units can all be made the same and can be placed at any desired place in the frame. There is also the possibility to leave open spots and to take units out at a later point without having to demount all the units on top first. Because the units are all similar it is easier to produce them and to reuse them.

Conclusion structural options

Because of the large array of options and flexibility the units in a frame construction are chosen to further develop. Also, the fact that the units can be standardized and are interchangeable seems a big advantage.

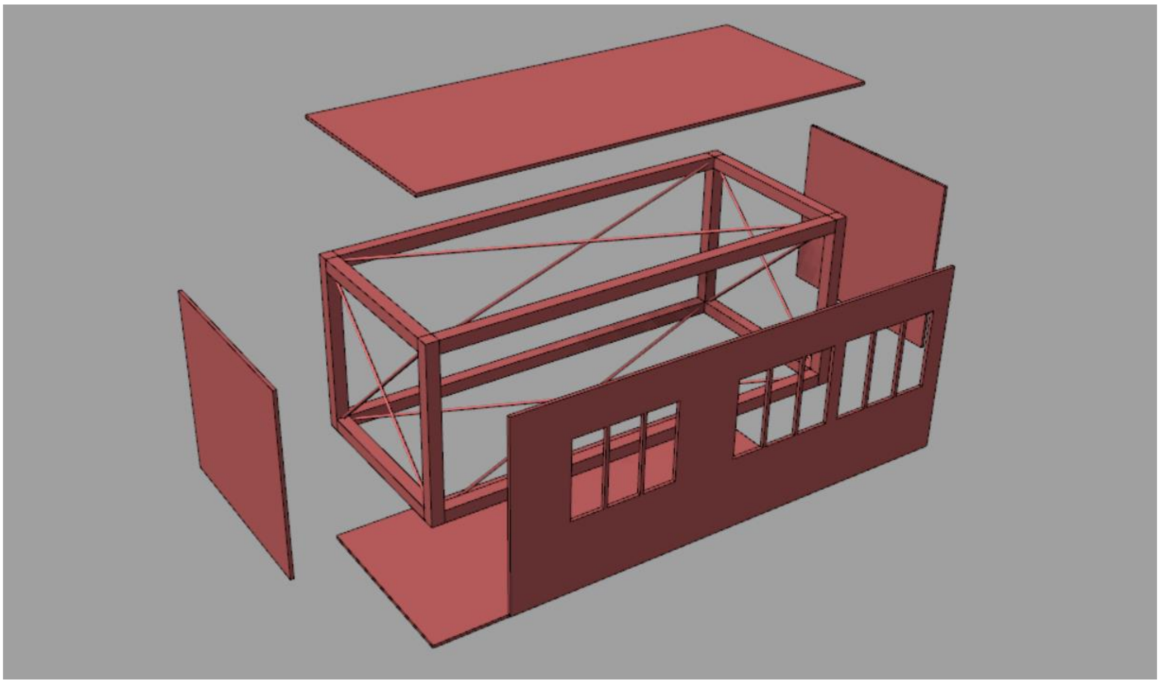
Unit built up

The unit itself needs to have a structure as well. This because it need to be transported and lifted up with a crane into the frame without losing its structural integrity. Also, if the units are stiff enough they can contribute to the stability of the frame structure that they are placed in. There are two main unit types that can be distinguished:

- frame unit
- shell unit

Frame unit

The frame unit makes use of a frame as a structural element. The frame gives the unit its integrity, so it can be lifted up by a construction crane in one piece to be attached to the building. To complete the addon the frame will be covered by the floor, the roof and the façade elements. These elements can be used to make the frame ridged in which case they have to be quite stiff. But there is also the possibility to use cross braces for the stability in which case the façade and floors can be dimensioned smaller as they have to handle less forces. Because a frame is used openings can be made on all different sides by adjusting the frame and the braces. In combination with the right floor type there will be space for ducts and piping.



Addon with frame construction (own image)

Main advantages

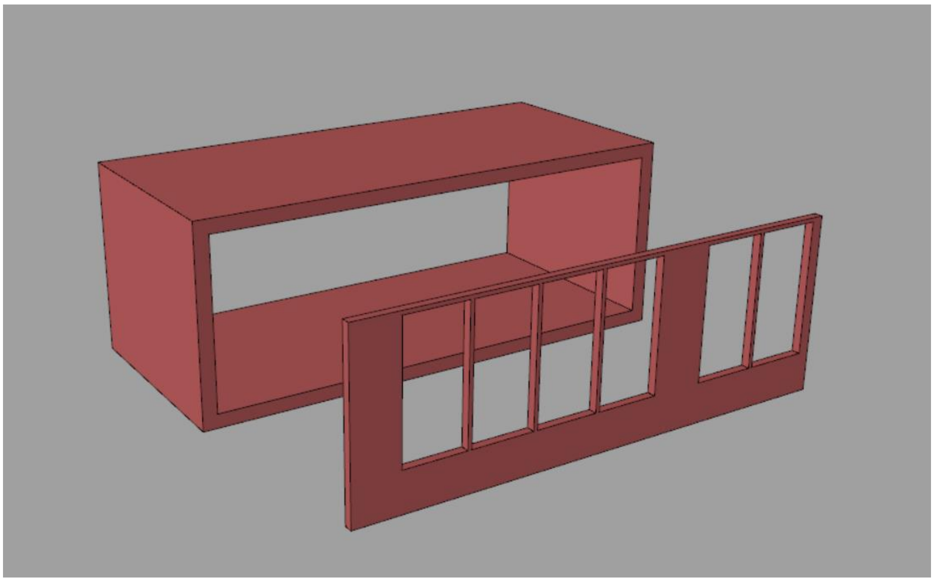
- Demountable into small elements
- Quite flexible
- Room for ducts and pipes

Main disadvantages

- Minimal height determined by construction of frame
- Extra parts are needed due to the separation of structure and façade

Shell unit

The shell unit is a unit made of one rigid shell that serves as structural as roof and floor and as façade elements. By having at least 4 stiff plates the structure has structural integrity and can be lifted as a hole by a construction crane. The stiff shell can consist of elements that are connected in such a way that they do not allow for movement. This variant is less flexible that the frame construction as it is harder to make openings in the ridged frame without causing the unit to weaken. There is also less place for pipes and ducts unless this has been added during the construction of the shell element. The big advantage of this system is that it can be made slimmer than the frame structure as the façade, roof, floor, the braces and the structure are combined into one element this saves valuable space.



Addon with shell construction (own image)

Main advantages

- Minimal height/thickness due to combination of elements into one shell
- Demountable into large elements
- Structure and façade are integrated within one shell

Main disadvantages

- Not very flexible as shell must remain intact
- Little room for ducts and pipes

Conclusion unit built up

The choice that is made is to go for the shell unit. This because it better integrates the rigidness, structural strength and façade elements into one component. As the available space to place the unit is limited the shell structure will most likely be more space efficient.

Material choice load bearing structure

The demands of the frame loadbearing structure are as follows:

- carry its own weight and up to eleven addon units
- resist wind loads and be water and fire resistant
- take up little space in order not to block the façade and the façade openings and to leave enough space for the addon units
- the frame should also be demountable to comply with environmental demands

Possible materials are wood, concrete, steel.

Materials	Density kg/m^3	Young's modulus GPa	Embodied energy MJ/kg	CO2 production kg CO2 / kg	Thermal conductivity λ in W/mK
glulam	450	12-14	12	0.84	0.13
concrete (reinforced)	2400	100-140	1.125	0.1	2.0
steel	7800	200-215	20.1	1.37	50

Wood (laminated timber) is a good option because if it is treated in the right way it is biodegradable and environmentally friendly. Wood can handle compression and tensile strength making it strong enough to carry the addons if dimensioned correctly. Wood also has a good fire resistance and is quite a good isolator which can help to avoid thermal leaks. The downside is that wood is not very good versus water and it should be treated and detailed correctly to avoid rot and degradation. Good maintenance is therefore important. As the frame elements might be hard to reach this can be a challenge. Also, as wood is the least strong from the three materials it will take up the most space which is not very favorable. If wood needs to be demountable it is also most likely that steel connections will be needed to connect the wooden beams and columns together.

Laminated timber frame structure

Concrete (reinforced) columns and beams or sheet is a good option because it is very durable and requires little maintenance. It also has relatively good fire and water resistance. The big disadvantage is that concrete on its own can only handle compressive strength, so it needs a reinforcement to handle the tensile strength. In most cases this will be steel. Because the steel is poured into the concrete the columns and beams will be harder to recycle. To make the concrete parts demountable also requires them to have metal connection parts because connections in concrete will be much harder to separate without causing damage to the components. The concrete elements can be relatively thin.

Concrete frame structure for balconies

Steel is a good option because it can handle tensile and compressive strength on its own while still being slim. Steel however should be covered to protect it from corrosion, to make it fire resistance and to avoid thermal leaks. Steel is quite easy to make demountable using steel connecting components. And it is also relatively easy to reuse or recycle the steel parts. Also, if installed right steel can be very durable and last long with little maintenance.


Steel frame structure for adding balconies

Conclusion material choice for frame structure

The chosen material for the frame structure is the steel. This because it can handle the tensile and compression forces on its own and can be dimensioned quite slim compared to the other two alternatives. Also, it does not require any other materials to make connections while still being demountable. The lifespan is very long, and it does not require any maintenance. Steel is reusable and especially if it is made demountable it can be reused multiple times.

The downside to choosing steel is that it has to be protected from fire, water and thermal leaks. For water and fire resistance a coating can be applied to the steel to protect it. For thermal performance there are two options. The first is to decouple the steel from the existing construction and isolate in between to avoid thermal bridges. The second option is to wrap the complete steel structure in isolation material. In this case the first alternative seems the most reasonable as it requires less material, less work on site and less maintenance over time.

Material choice add-on units

As determined before the addon units should consist of a rigid shell structure. The best materials to make this kind of structure are concrete/high performance concrete, cross laminated timber and Fiber reinforced polymers (FRP’s).

Concrete/high performance concrete

The main advantages of the concrete/ high performance concrete are that because of the strength the elements can be made relatively thin. This has a lot of advantages as it is easier to place the addons in such a way that the floor height matches that of the current building. Also, the functional height can be higher. There is more place for insulation layers and thicker layers of insulation can be used making the insulation cheaper and easier to handle. The concrete

itself is water and fire resistant and is very durable requiring no maintenance over long periods of time.
The typical composition of the ultra-high-performance concrete consists of cement, water, superplasticizer, steel fibers, silica fume, quartz powder and sand. The first two table shows the possible compositions of an ultra-high-performance concrete in percentages (Abbas, et al., 2016). The second table shows an example of a possible mix with the CO_2 output and embodied energy (Vergoossen, 2016) (Hammond & Jones, 2011).

UHPC constituents	Range %
Cement	27-40
Water	4-10
Superplasticizer	0.5-3
Steel fiber	0-8
Silica fume	6-12
Quartz powder	7-14
Sand	35-45

UHPC constituents	Kg / m^3 UHPC	%	Kg CO_2 eq / m^3	%	Embodied energy MJ /kg /m^3	%
Cement	925	33	600	44.4	5.5*925= 5087.5	50.7
Water	180	6.4	1	0.1	-	-
Superplasticizer	30	1.1	35	2.6	-	-
Steel fiber	240	8.6	650	48.2	20.1*240= 4824	48.1
Aggregate	1425	50.9	64	4.7	0.083*1425= 118.275	1.2
Total	2800		1350		10030	
Per kg	1		0.48		3.58	

Cross laminated timber

The cross laminated timber shell is a good option because timber is a very moldable and customizable material to work with. If it has received the right treatment it is also biodegradable which makes it the most environmentally friendly of the three options. Because it is less strong than the concrete the elements will most likely be thicker. This means that there will be less space available for insulation and a lower functional height. A good thing of the wood is though that it is quite a good thermal insulator so thermal leaks are less likely to occur. Also, it has quite a good fire resistance due to the carbonization of its outer layers. A big weakness of the material is its water resistance. To avoid deterioration of the material by molding or rotting the wood will have to be covered very well from water and it should be able to dry in case it gets wet. Because of this weakness the wood will have to be checked regularly and maintenance should be done more often. Because the elements might not be very well assessable this can be a disadvantage.

Materials	Density kg/m^3	Young's modulus GPa	Embodied energy MJ/kg	CO2 production kg CO2 / kg	Thermal conductivity λ in W/mK
Glulam	450	12-14	12	0.84	0.13

Because wood needs to be protected against water influences an extra material needs to be added that can function as covering. The first choice to make is how will it be attached mechanically or glued. Mechanically requires more parts but the big advantage is that the cover can be detached and the addon stays demountable into different materials. The benefit of gluing is that less material is required but this is only smart if the material has about the same lifespan and can also be burned with the wood at the end of the lifecycle. The two tables below show values for different materials obtained from the NIBE an ICOv2 databases (NIBE database, 2018) (Hammond & Jones, 2011).

Materials for cover Mechanical fixation	Density kg/m^2	Shadow costs in € / kg	Embodied energy MJ/kg	CO_2 production kg CO_2	Lifespan years
POCB	3.16	1.54	100	14	30
EPDM	1.727	1.81	91	17.9	50
Galvanized steel	9.677	2.08	29	26.4	15
Plant based membrane	3.77	2.43	-	13.7	35
TPO	1.64	3.59	94	31.4	30
PVC	2.21	3.81	77.2	25.4	30
Zinc	6.91	7.77	53.1	25.2	75
Bitumen	1.2	10.17	51	100	20-30

Materials for cover Glued	Density kg/m^2	Shadow costs in € / kg	Embodied energy MJ/kg	CO_2 production kg CO_2	Lifespan years
EPDM	1.4	1.24	91	13.8	50
Plant based membrane	3.77	1.52	-	10.3	35
POCB	3.5	1.95	100	20.2	30
PVC	1.78	2.56	77.2	19.5	30
SBS Bitumen	8.2	9.22	51	96.3	30
Epoxide resin 5mm	6	-	137	34.2	30

From this list the POCB, EPDM and the Plant based membrane seem like the best options as they are the most environmentally friendly and have a long lifespan. To further determine which one to choose the end of life fate of each material is shown.

Mechanical fixation	Dump %	Burn %	Recycle %	Reuse %
POCB	0.1	5.9	94.0	0.1
EPDM	8.6	77.8	12.5	1.1
Plant based membrane	5.3	5.6	89.0	0.1
Glued	Dump %	Burn %	Recycle %	Reuse %
POCB	0	41.3	58.7	0
EPDM	9.5	85.7	4.8	0
Plant based membrane	4.8	3.6	91.6	0

Based on the low shadow cost, the lifespan and the good recyclability the glued Plant based membrane seems to be the best option. The EPDM and the POCB still use elements from fossil fuels (petrol) while the Plant-based membrane is organic which makes it fit well with the wood that is also an organic material. The lifespan of 35 years is also similar to that of the wooden unit and the wooden window frames which means that maintenance or recycling of the elements can happen at the same time.

The specific plant-based membrane that will be used is called Derbipure (Derbigum, 2018). It is a fully recyclable plant-based roofing system. The material consists of vegetal oils for 20-40% and liquid pine resin for 20-40% reinforced with glass fibers 170 g/m^2 and colored with acrylic paint 350 g/m^2. A roll is 10m long 1m in with and the total thickness of a layer is 3mm with a weight of 34kg. The density is therefore of 3.4 kg/m^2. Because the material is pH neutral it does not affect rain water and the acrylic paint gives it a high reflectivity (81%) which protects the underlaying material against sunlight and overheating. The lifetime is around 30-45 years and can be extended by adding an extra layer on top of the existing one.

Derbipure roofing (Derbigum, 2018)

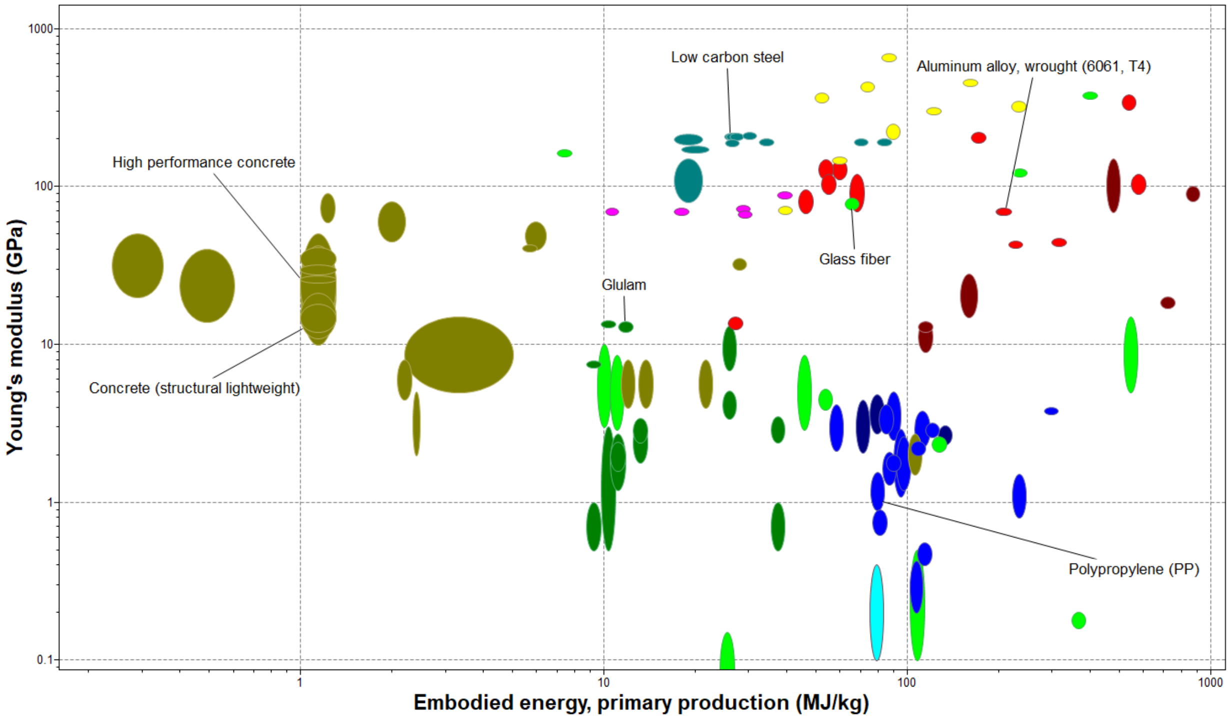
Fiber reinforced polymer sandwich panel (FRP's)

Fiber reinforced polymers are usually made out of glass fiber and in case more strength is required carbon fiber and aramid fiber (Kevlar). Materials often used for the core are polyurethane, polyethylene and polystyrene.
Fiber reinforced polymer sandwich panels are a good option because from the three options they are the most lightweight, and they have integrated insulation avoiding thermal leaks. The strength is less than that of the high-performance concrete therefore the elements will be thicker closer to the thickness of the wood elements, but as the insulation is integrated they will probably require less space. Because of the way the FRP sandwich panels are made it is easy to mold them into each desired form. They are also water resistant and can be quite durable with the right UV protection. The downside of using FRP is that the fire resistance might be an issue, but the biggest disadvantage is that currently most of the polymers used in the FRP's are made using fossil fuels like oil (petrol) which makes the material preform worse on a sustainability and environmental scale.

Materials	Density kg/m^3	Young's modulus GPa	Embodied energy MJ/kg	CO2 production kg CO2 / kg	Thermal conductivity λ in W/mK
GRP	1750	72-85	100	8.1	0.32

Materials	Density kg/m^3	Embodied energy MJ/kg	CO2 production kg CO2 / kg
Carbon fibre	1800	475	34
Glass fibre	2500	28	1.54
Epoxide Resin	1200	137	5.7
Polyester Resin	1170	115	3.93

The table below shows an overview of different materials their strength and embodied energy.



CES graph, embodied energy primary production versus Youngs modulus (CES edupack , 2017)

Isolation materials

When choosing a material to insulate the addon there are a few things to keep into consideration. The first one is the required heat resistance value of 4.5 m^{2}K/W. The second one is the available space for insulation material in the design. The third one is the thermal conductivity of a material and the corresponding thickness. The fourth is the environmental impact of the chosen material.

The table below shows information for different insulating materials. This makes it possible to compare them. A heat resistance value (Rc) of 4.5 m^{2}K/W is used to determine the thickness of each panel. Table sources: (NIBE database, 2018) (Konstantinou, 2014) (Hammond & Jones, 2011)

Isolation materials	Thermal conductivity λ in W/mK	Thickness of panels in mm	Density kg/m3	Embodied energy MJ/kg	CO2 production kg CO2 eq	Shadow costs in € / kg	Life span years
Sheep wool	0.035	158	26	20.9	88.90	7.86	75
Cellulose	0.039	176	70	2.1	22.70	2.63	30
Flax	0.035	158	31	39.5	17.6	2.40	40
Cork	0.040	180	120	4	32.10	4.66	75
Wood fibres	0.038	171	55	17	19.30	2.11	40
Glass wool	0.035	158	25	28	6.41	0.93	75
Rock wool	0.035	158	48	16.8	8.01	0.81	75
Aerogel	0.013	59	135	53	-	-	75
XPS	0.038	171	33	109.2	59.20	3.76	75
EPS	0.040	180	15	88.6	15.80	1.79	75
PIR / PUR	0.023	104	33	101.5	21.90	1.84	75
Phenolic foam	0.021	95	36	88	17.10	1.88	75
Vacuum panel	0.007	32	195	81.9	-	-	75

As it is very unlikely that there will be more than 150mm available for insulation due to restrictions in flooring for the addon to fit, the most promising materials are PIR/PUR, Phenolic foma (Resol), Aerogel and vacuum panels.

PIR/PUR insulation requires the most thickness to achieve the required insulation value of Rc 4.5 m^2K/W at 104mm. Of the chosen materials they perform the worst performing when it comes to environmental costs namely 101.5 MJ/kg embodied energy and 29.9kg CO_2 eq. The upside is that the material it is easy to use and that it is relatively cheap compared to the other chosen materials. This option seems the most compatible with the FRP add-on module as PIR/PUR can also serve as a filling for the sandwich panel while providing thermal insulation.

Phenolic foam (Resol) made from bakelite (phenol formaldehyde resin) requires a thickness of 95mm to achieve an Rc of 4.5 m^2K/W. The environmental costs are a bit better than the first option at 88 MJ/kg embodied energy and 17.10kg CO_2 eq. The material is more expensive than the PUR/PIR isolation but is still relatively cheap and is easy to install and easy in use.

This would be a good option for the wooden and concrete add-on as long as there is enough available space.

Aerogel is a material that uses nanotechnology and has micropores allowing it to be 95% air and is therefore super lightweight. Aerogel comes from the space industry where it is used as super thin weight saving insulation material. Aerogel achieves an Rc of 4.5 m^2K/W at only 59mm thickness. The base material used for aerogels is silica the same base material used for glass making the aerogel panels semi-transparent. The embodied energy needed to make the gel is low 53 MJ/kg but the aerogel needs to be protected from pressure and other influences to maintain its properties therefore the cover should also be added to the material cost. Because of the advanced technology and the newness of the product it is still very expensive to use. The upside is that it requires very little material to reach high insulation values. This is a good option is there is a very limited amount of space and especially when dealing with more complicated shapes.

Vacuum panels consist of microporous material in a vacuum envelope. The material is to withstand the pressure in order to avoid the envelope from collapsing. Vacuum panels have the highest performance for the lowest thickness, they reach an insulation value of Rc 4.5 m^2K/W at 32mm. Even though this seems ideal the vacuum panels are about 10 times as expensive as other foam panels. It is also very important when using these panels that the detailing is perfect because a hole in one of the envelopes could lead to a thermal leak and a plummeting Rc value. This material is best suited if there is almost no space for insulation available but because of the price this should be used as a last resort.

Window frames

Another important part of the add-ons are the window frames. The window frames can be designed as a part of the add-on, but they can also be added separately. The benefits of designing the frames as a part of the addon is that they can fulfil a structural function strengthening the shell. The downside is that they will be custom made with a specific fixation limiting the possible options and making them more difficult to replace them with different alternatives over time. If the frames are made as separate parts and the fixation can be more neutral allowing for a change of window frame type over time and a broader range of frame materials to choose from.

The most commonly used materials are wood, aluminium, steel, PVC and GRP and in some cases a combination of two of these materials. When comparing window frames, it is important to note that even though some of the materials have a much better thermal resistance than others this does not necessarily mean that the window frame performs worse. The design of the frame is more important in this case then the conductivity of the material. What determines the performance is the amount of air chambers used and the type of spacers this is especially the case for steel and aluminium that would have almost no thermal resistivity otherwise. The only way to truly compare window frames is by choosing specific types and comparing their performance. Because the importance of the design it is very difficult to make assumptions about the thermal performance based on the material used.

This table shows five different window frames with possible U values (NIBE database, 2018).

Window frames	Density kg/m3	U value W/m2K	embodied energy MJ/kg	CO2 production kg CO2 eq / m2	Shadow costs in € / kg	Life span years
Wood (spruce)	450	2.4	12	12.7	1.61	35
Aluminium	2700	1.3	154	17.5	2.4	75
Steel	7800	2.8	20.1	31.8	2.79	100
PVC	1400	1.2	77.2	36.5	5.8	40
GRP	1750	0.8	100	37.5	-	50

The easiest way to make a choice is by choosing the same material for the addon as for the window frames. This means that the properties will be the same with a similar lifespan and easier integration but there are however some other aspects that are important when choosing the right material for a window frame. Things to take into account are: weight, strength, acoustic performance, environmental impact, durability, maintenance, air and water tightness, fire resistance, product cost, architectural appearance.

Wooden frames are usually the bulkiest ones as wood is the least strong of the five materials and requires more material to have the same strength. Wooden frames are easy to customize making them handy in situations with a lot of unknown margins. Wood is a renewable resource so environmentally it is a good choice; however, it has the highest maintenance requirement and some parts have to be protected by other materials to prevent deterioration from water and moisture. Wood is not very expensive, and it has a warm architectural appearance.

Aluminium frames are a good option because it is very lightweight, because of the high strength the profiles can be relatively thin. Aluminium is water and corrosion resistant, is easy to clean and requires almost no maintenance. Environmentally aluminium is not classified so well due to the high environmental impact when mining for the virgin resource. However, aluminium is very durable with a long-life span and it can potentially be reused or recycled. Aluminium frames do require thermal breaks to achieve good U values as the thermal conductivity of the material itself is very high. The costs of aluminium are not very high, and the appearance is very modern.

Steel frames are on the heavy side due to the high density of steel. But because steel is very strong the profile dimensions can be very thin. Steel frames can also help with a loadbearing functions due to their high strength. Steel (coated) is water resistant, requires almost no maintenance and is easy to clean. Steel is a non-renewable resource, but it can easily be reused due to its long lifespan or recycled. Steel like aluminium requires thermal breaks to achieve a good U value. Steel frames a relatively high production cost. Their architectural appearance is modern.

PVC frames are a good option when it comes to thermal resistance as it has a very low thermal conductivity. It is light weight, scratch and water resistant, easy to clean and it requires little maintenance. It can be made in complex shapes but due to its low stiffness it requires reinforcement usually aluminium or steel profiles. Environmentally it is not a very good option as PVC is a non-renewable resource and usually gets burned at the end of its life span. PVC has a bad fire resistance, needs to be protected from UV light, is quite difficult to repair if damaged and deformations can occur due to large thermal expansion. PVC is cheap compared to the other materials. Can have a cheap appearance.

GRP frames are made out of glass fibre reinforced polymers. The have a very good stiffness and are very lightweight. Profiles can be very complex due to the way they are manufactured. GRP has very good thermal performance, is water and corrosion resistance, require almost no maintenance. Environmentally the GRP does not score so well. The material has a high embodied energy and it is also not likely to be recycled. The cost of GRP frames is still very high due to it being a relatively new material and the manufacturing process being complicated. The appearance is very slim and modern.

Case study Research

Background information

Site analysis

The chosen location for the design task is the neighbourhood Poptahof in Delft. This location is chosen because I currently live in the Poptahof and I see the post war flats of this neighbourhood daily while passing by or looking outside the window. It seems interesting to find out something about their history and to find a sustainable way to renovate them.

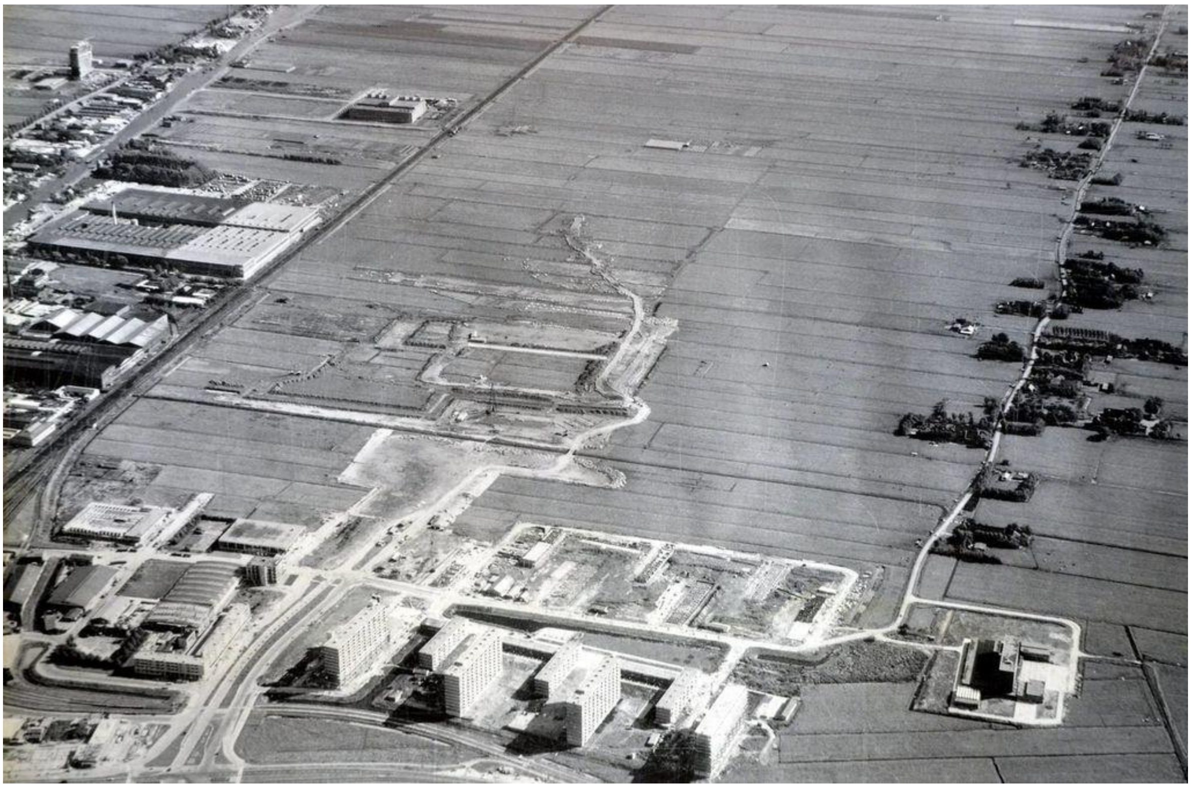
History of the Poptahof

The Poptahof was the first location in Delft where high-rise flats were being build. As many other cities, Delft was faced with a severe housing shortage after the second world war. To deal with the housing shortages it was decided to make a new neighbourhood on the outskirts of the city in what was until then a polder mainly used for agriculture. The new neighbourhood would contain more than a thousand homes and was designed by the architect S.J. van Embden. The project was commissioned by the Dutch housing association for public housing which meant that the homes would be social housing for working class people. Between 1960 and 1966 the flats were build and expectations were high as they were introducing a new way of living according to the modernist vision with lots of light, space and air (Vlis, 2005, p. 6).

At that time, the new flats were seen as luxurious places to live as they were spacious and equipped with central heating, chutes and elevators. But soon after the completion the first problems arose. The central heating could not always provide enough heat for the entire building and the heating pipes transferred sound throughout the building. The rate of vandalism and pollution in the common areas was high as inhabitants did not feel responsible for the shared spaces. Also, on the top apartments the glass was so loosely montaged in the window frames that there was severe leakage during storms. It was also difficult to keep the windows clean as window cleaners did not want to climb the building unless they could wash all the windows (Wiki Delft, 2017) (Vlis, 2005, pp. 23-27).

In the beginning the neighbourhood did not have many services. Over the years, the residents managed to get schools, playgrounds, elderly homes, a health centre and also a shopping centre. Even though the first inhabitants of the flats were very enthusiastic, for many of them the flats did not live up to the expectations. As time progressed and prosperity increased many of the initial residents decided to move to newly build single family houses on the outskirts of the city (Vlis, 2005, pp. 34-35).

Even though rent for the flats was initially on the high side, their unattractiveness made them experience a price drop and at the beginning of the seventies many low-income families from guest workers entered the neighbourhood. In the beginning, these were mainly Turkish and Moroccan families and later they were joined by families from former colonies like Suriname, Indonesia. In the nineties also refugees from Iran, Afghanistan, Irak and Somalia settled in the Poptahof. At the end of the nineties more than half the residents of the Poptahof were from ethnic minorities and the Poptahof had become a multicultural neighbourhood with more than 30 nationalities. This enhanced the effect of native families moving out as some of them did not feel at home anymore in the neighbourhood (Vlis, 2005, pp. 36-37).



Construction of the Poptahof (Aviodrome, air photography, 1963)

Poptahof after completion (Aviodrome air photography, 1965 -1970)

The deteriorating flats in combination with a high residential density of non-naturalized lower income families and social problems due to cultural differences lead to the area entering a downward spiral. Only forty years after the flats were build mayor restructuring of the neighbourhood was necessary (Vlis, 2005, p. 67). In 1984, already a big maintenance project had taken place and in the nineties the housing association did research and realised that a small-scale approach would not work. So, around the turn of the century more drastic measures were going to be used to prevent the neighbourhood from further deteriorating. A project group was installed with the goal of restructuring the neighbourhood and addressing the problems but also to find out how the monotonous housing offered could be turned into a more diverse and contemporary one. The main idea was that a wide variety of housing types would attract different types of residents improving the area (Vlis, 2005, pp. 69-70).

In 2003, the urban master plan was ready after having consulted urbanists, architects but also sociologist and the residents themselves. In the plan, the eight high-rise flats would remain while the lower flats and houses would be broken down to be replaced by different housing types and to make the neighbourhood more spacious again. By maintaining the high-rise flats, the image of the neighbourhood would remain and also for the plans level of sustainability it was advantageous to keep the buildings and avoid big waste streams. By breaking down the low-rise buildings there would be space to make different types of housing attracting a broader range of people to the area and also to finance the project by selling some of the newly built houses. In the end, the renovated high-rise flats together with the new houses would form eight courtyards with each its own identity. Also the green area in the neighbourhood would be improved by adding a park and by adding more watercourses (Vlis, 2005, pp. 70-72) (Turkington, et al., 2004, pp. 140-141) (Hekkenberg, 2011, p. 46).

In 2005, the first high-rise flat was renovated, and courtyard was made. Because of technical difficulties this part of the project ended up costing much more than expected and taking a lot more time. For the second flat, it was therefore decided to tear everything down and to build the ensemble from scratch. Even though this was less sustainable in terms of material use it ended up being more efficient at the financial side of the project. As the economic crisis hit in 2008 the plans for the restructuring stopped leaving the remaining six flats untouched until the housing market would recover (Hekkenberg, 2011, p. 50).

Current situation

Now in 2017, more than 50 years after the flats were completed the last six ensembles are still in need to be restructured. Because the flats were intended to be demolished or renovated maintenance got deferred for many years. Now that the buildings remain standing the owner, Woonbron has come up with a plan to keep the flats functioning. Four of the flats will receive small maintenance to make them function for a couple more years, while two of the flats, the ones closer to the shopping centre will receive a thorough renovation. However, the renovation is not as impactful as the one from the first renovated flat as architectonically nothing will be changed on the two buildings. Instead the interior will be renewed, and the façade will be improved while the overall composition of the flat stays the same. For the for remaining flats the idea is to sell them over time to a project developer so that they can also be renovated or replaced (Poptahof, 2017). Since the restructuring of the first two flats the social composition in the neighbourhood has changed. Where at first all the existing housing was the same type of low-income housing, the new renewed ensembles also included different housing types and also private owned housing. This had the effect that more middle class and higher income families have moved into the neighbourhood. Still about 70% of the neighbourhood is from ethnic minorities and also many students have moved in. There is a relatively high level of circulation as many residents move in and out within five years (Hekkenberg, 2011, p. 45). Also, the many social programs initiated by residents and Woonbron made the social cohesion in the neighbourhood much better. However, the suboptimal condition of the remaining un-renovated flats still poses a threat to the neighbourhood and to completely give the Poptahof a new start they will have to be dealt with over time.

Current state of the Poptahof (Google maps, 2017)

Urban context

The Poptahof is located in the northern part of the neighbourhood Voorhof. As mentioned before the Poptahof consists of eight ensembles of high rise and low-rise housing placed around a central park (Hekkenberg, 2011, p. 45). There are about 1000 dwellings of which 80% is social rented (Turkington, et al., 2004, pp. 140-141). The flats are oriented around the north-south axis which makes the apartments have an east-west orientation. The borders of the neighbourhood consist of four main roads the Papsouselaan, Martinus Nijhofflaan, Prinses Beatrixlaan and the Westlandseweg. On the south-eastern part of the border there is the shopping centre: De Hoven. On the eastern part of the neighbourhood there is a big public transport hub which takes you to Delft central station and the city centre in less than five minutes. This makes the Poptahof an easy assessable location close to the city centre with many services and thus a very attractive location to live.

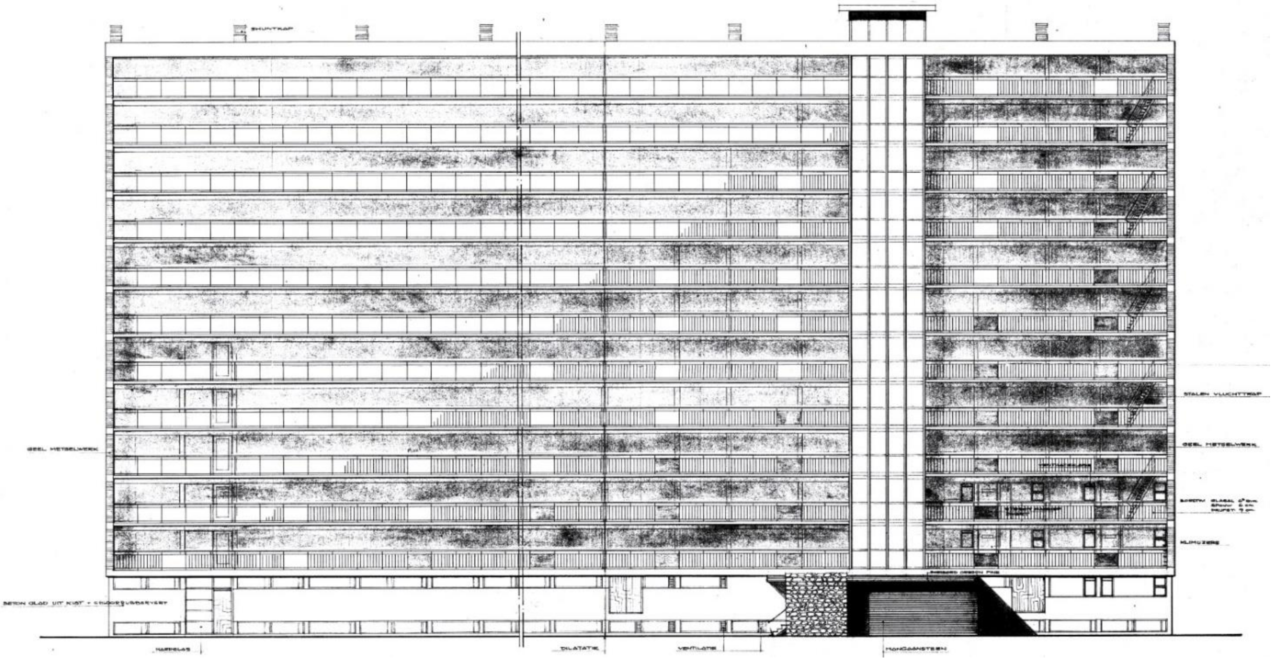
Pictures chosen flat

Current state Leeuwerik apartment side (own image)

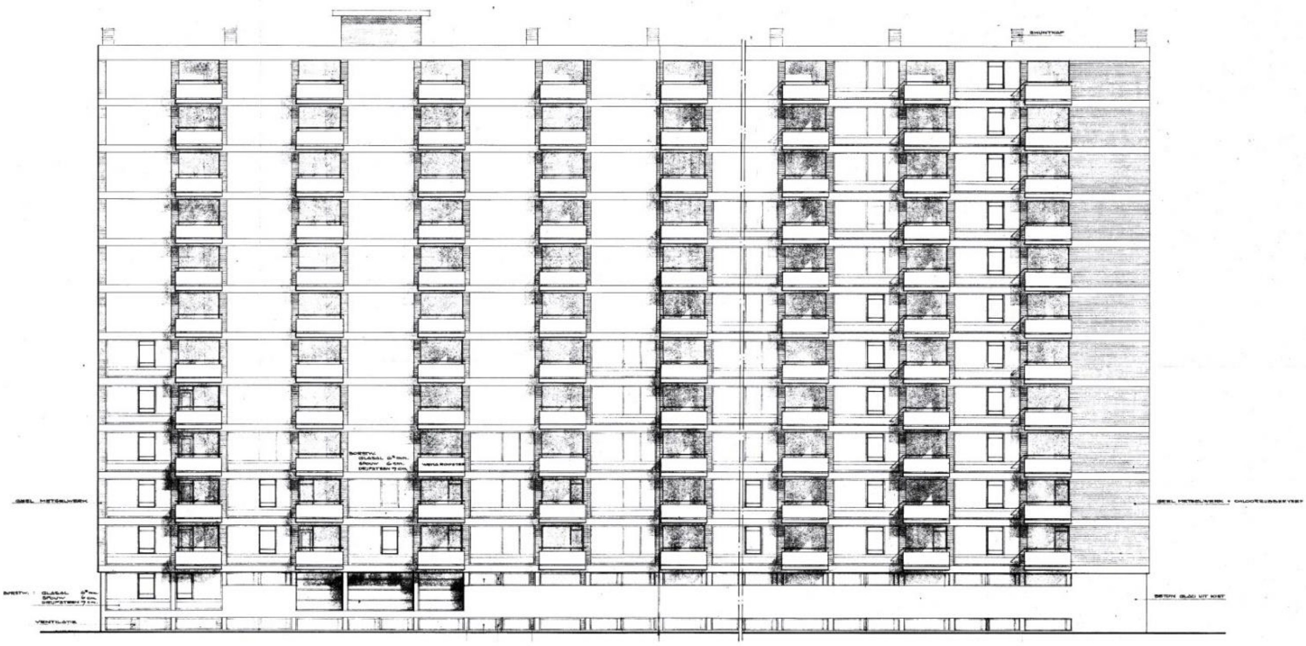
Current state Leeuwerik gallery side (own image)

Original drawings Delft archive

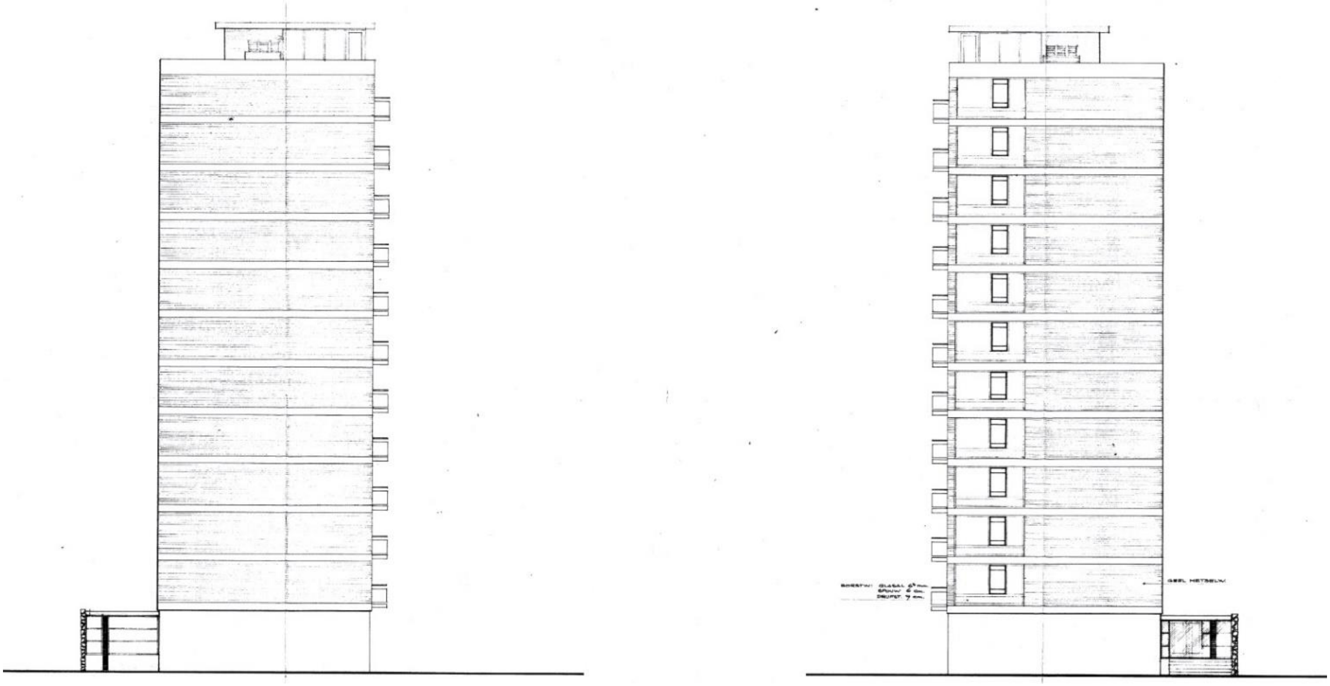
Flat name: De Leeuwerik



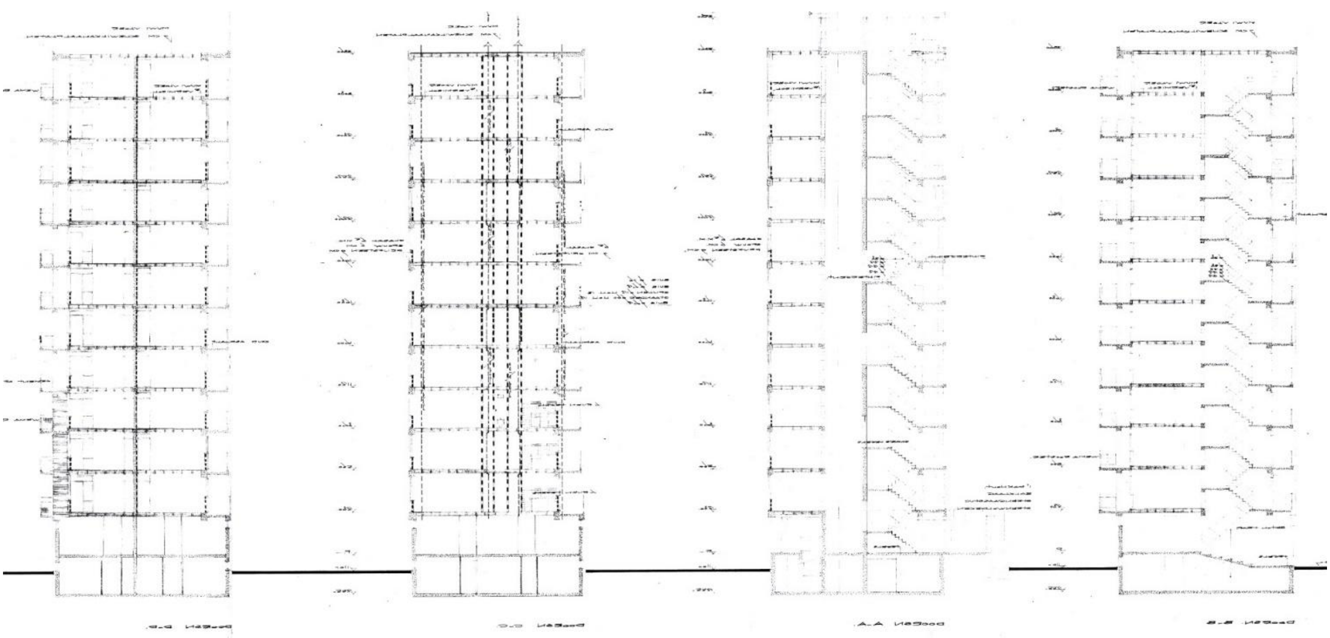
East façade



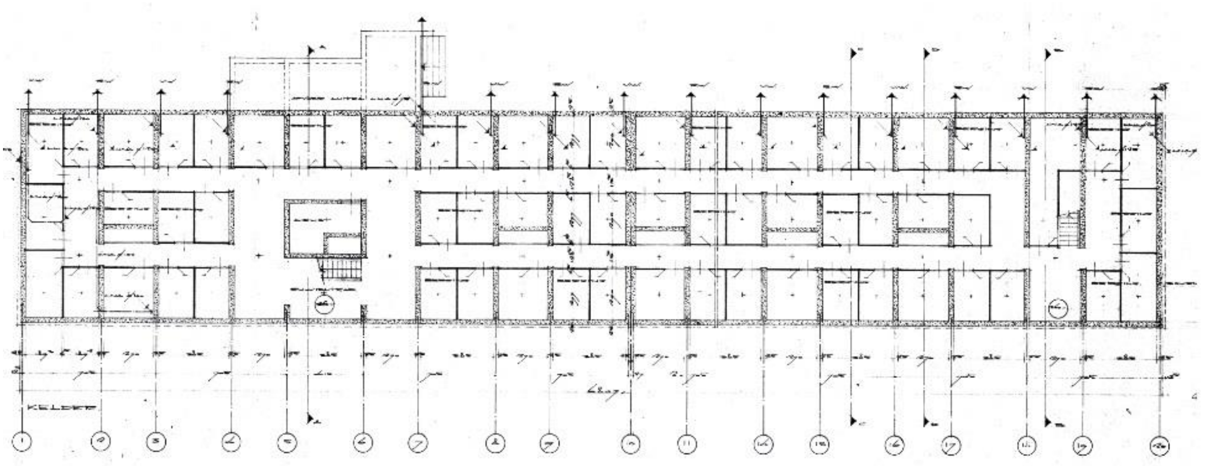
West façade



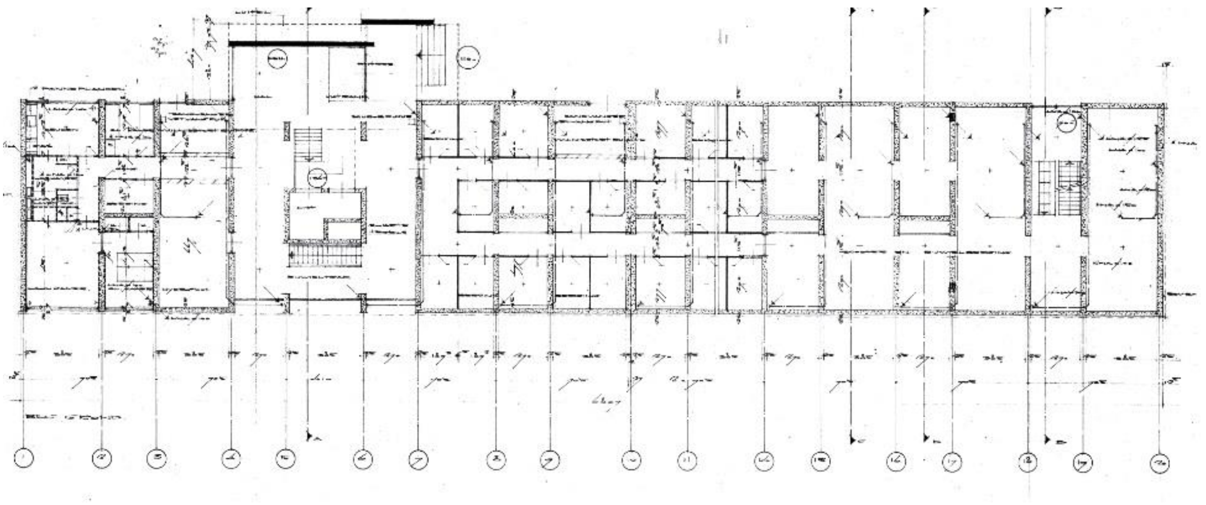
North and South façade



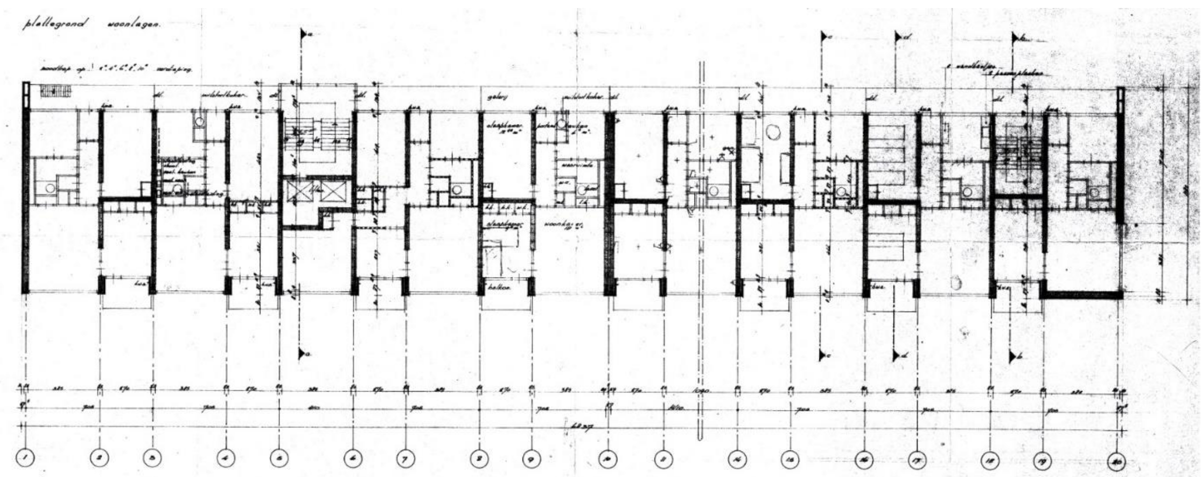
Sections



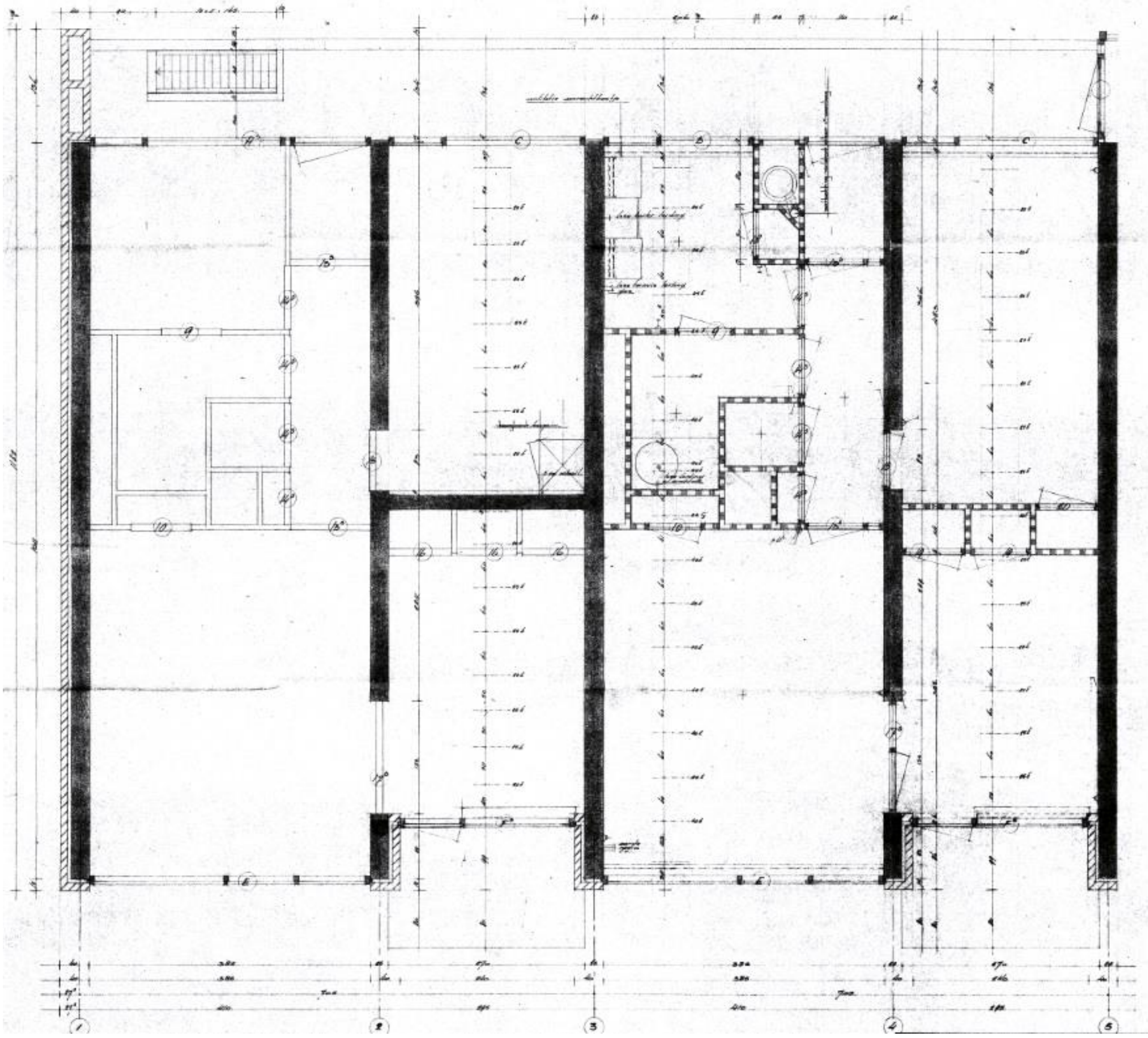
Floorplans Cellar



Floorplans ground floor

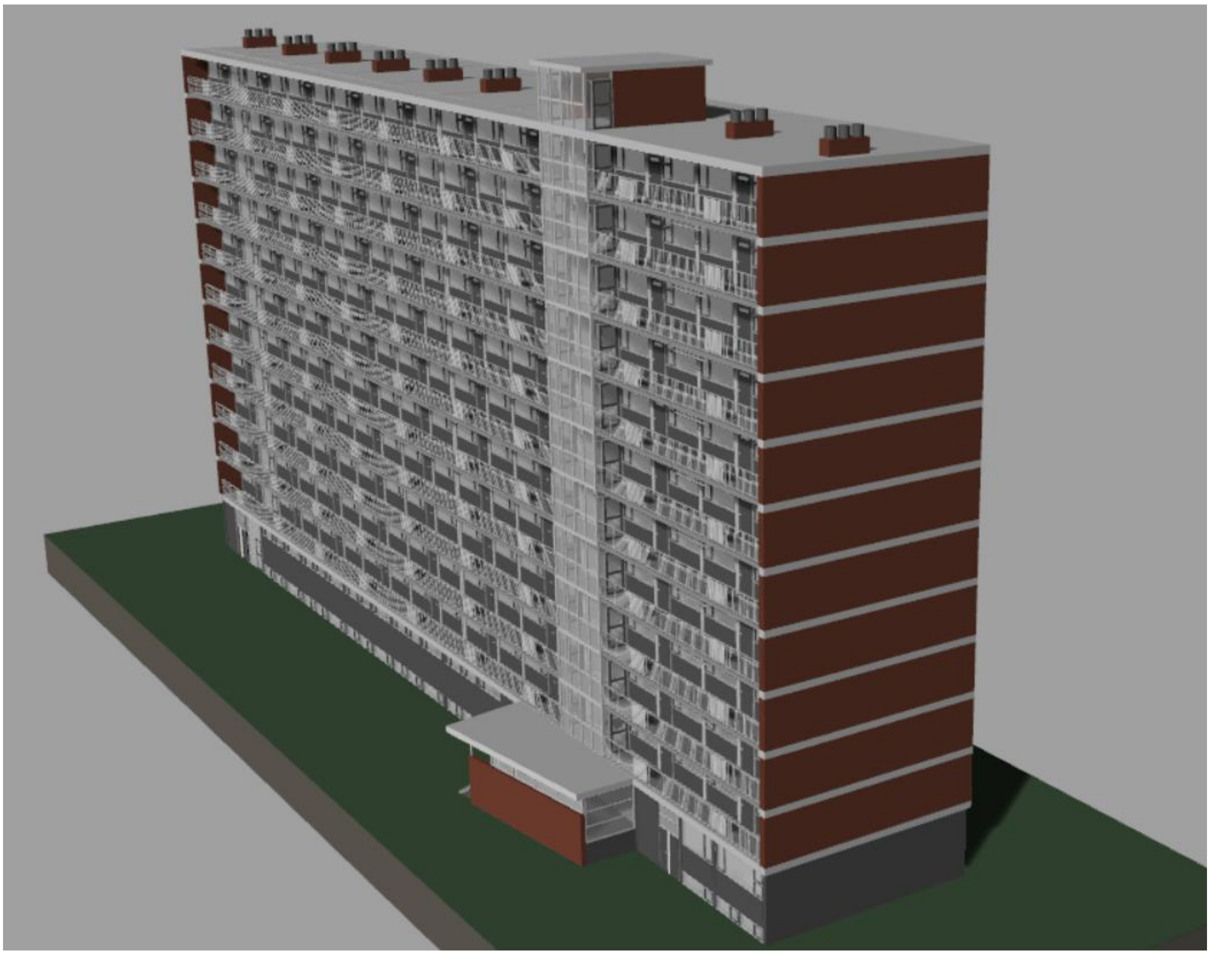


Floorplans 1st – 11th floor



Basic apartments close-up

Visualisation original building 3d model



Building analysis

With the knowledge of the site analysis and the interviews it might seem that the best thing would be to demolish the last four ensembles completely. I however believe that these flats have a lot of potential and that with the right strategy it should be possible to refurbish them so they can function well for many more years. That is the reason why I choose to look at the ensemble of the oldest flat in the neighbourhood to find out how it can be refurbished within the ideas of the original masterplan. The idea is to come up with a plan that is economically and socially feasible and that is more sustainable because the existing structure will be used instead of demolished and replaced. The main focus will be on the high-rise flat as it is the biggest challenge and will result in the most materials saved if it is maintained.

Current situation Leeuwerik ensemble (Google maps, 2017)

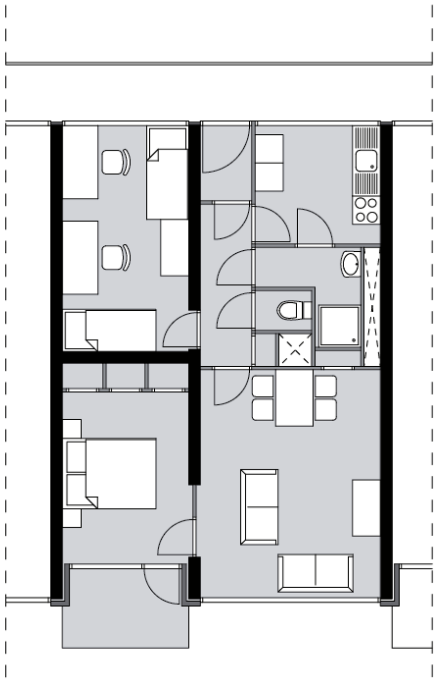
Typology and dimensions

The flat is a traditional gallery flat. For vertical access to the apartments there are the stairs and elevators (these stop every second floor). While for the horizontal access there are the gallery's. The flat contains 100 dwellings of which one is on the ground floor and the others on the 1^{st}-11^{th} floor with each layer containing nine homes. Seven of the nine homes are identical in space containing two bedrooms, a living room, a kitchen and sanitary rooms. For the two remaining homes, one has a bedroom extra and one has a bedroom less. This has to do with the location of stairs and elevators.

The flat is 36.1 meters high, 11.8 meters in with and 68.4 meters in length. The height difference between each floor is 2.8 meters. The apartments have a total with of 7.05m consisting of two parts one of 3.85m and one of 2.70m. The depth of the apartment is 10.1m. While the gallery is 1.34m wide. The living room is about 18.7m^2. The bedrooms are 13m^2 and 11.6m^2. The kitchen is 6.7m^2. The bathroom is 4m^2. The outdoor space of the balcony is 4.6m^2.

An issue with these type of apartments is that they do not live up to current day organizational, spatial living standards. From the interview with Woonbron and also from literature it showed that the biggest issues residents have is that the kitchen is too small, there is almost no space to cook. Also place for the fridge or an extra cabinet or is hard to find and eating in the kitchen is also not possible as there is not sufficient space for a dinner table. One family even had the fridge in their bedroom due to lack of space (Vlis, 2005, p. 69). Another annoyance is that the parent bedroom is only accessible through the living room. With the renovation of the Kiviet the interior of the apartments was improved upon but because the floorplan organization was not changed these problems persisted. The number one reason given in the interview with Woonbron why potential new residents turned down the apartments was because of the small kitchen.

Research done by (Scholte & Damen, 1998, pp. 8-11) show that for different functions not to be perceived as cramped a few minimum dimensions have to be taken into account. The living room is cramped if it is below 20m^2 and up to 25m^2 it is still perceived as small. For the kitchen, the minimum is 6m^2 and a bathroom is small if it is less than 2m^2. As can be seen above the living room is below the minimum and the kitchen just above. So, both spaces are actually quite small for current standards. The bathroom seems more spacious but because it has a l-shape it is still on the small side. The bedrooms are acceptable by current standards even though the width of 2.7m is a bit tight. Also the outdoor space could be a bit more spacious.



Rooms	**Dimensions**	
living room	3.85 * 4.85	= 18.65 m2
dining room	-	
main bedroom	4.82 * 2.70	= 13.0 m2
second bedroom	4.28 * 2.70	= 11.56 m2
kitchen	2.52 * 2.68	= 6.75 m2
bathroom	0.85 * 2.26 + 0.98* 1.28	= 3.18 m2
toilet	1.21 * 0.85	= 1.03m
outdoor space	2.55 * 1.69	= 4.31m
storage room		= 5.00 m2

Rooms	**Required for two person household**	
living room	3.75 * 3.95	= 14.81 m2
dining room	3.70 * 2.70	= 9.99 m2
main bedroom	3.85 * 2.70	= 10.40 m2
second bedroom	2.20 * 2.80	= 6.16 m2
kitchen	1.80 * 3.00 or 1.80 * 3.60	= 5.40 or 6.48 m2
bathroom	1.60 * 1.70	= 2.72 m2
toilet	1.15 * 0.85	= 0.98 m2
outdoor space	2.90 * 1.70	= 4.93 m2
storage room		= 5.00 m2

Current floorplan standard apartment with spatial shortcomings (own image)

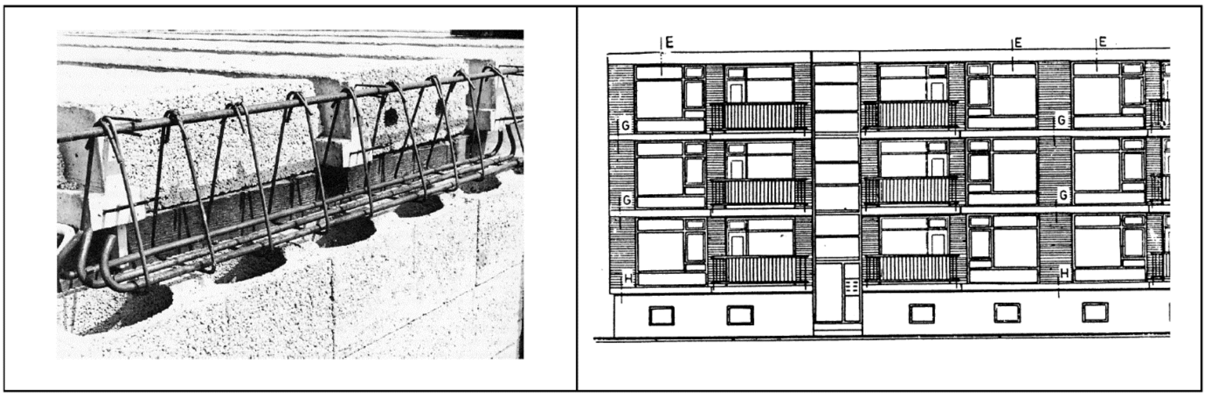
MUWI building system

The buildings in the Poptahof are built with the MUWI building system. The MUWI building system is a system invented after the second World War by Muijs and de Winter who had their company in the Dutch city of Vlaardingen. Between 1957 and 1968 more than thirty thousand homes were created using the MUWI system. This makes it by far the most successful post-war building system (Andeweg, 2013, p. 2).

The MUWI system is a small element system designed to use minimal amount of construction equipment and skilled labour. Both things that were scarce after the war. Also, the prefabricated concrete elements made it possible to achieve a much higher building speed than with traditional methods (Andeweg, 2013, p. 2).

The walls and facades were made of blocks that could be lifted by hand. The blocks had dimensions of 50cm in length, 19cm height and 21cm in width. The blocks had two holes in them making them look like an eight from the top. By placing them using a stretcher bond and pouring concrete in the holes a massive wall could be made (Andeweg, 2013, p. 3).

The floor consisted of pre-stressed concrete inverted T-shape beams also carriable by hand and hollow rectangular elements out of lightweight concrete. The beams were placed at intervals of 50-65 cm with the blocks in between. In Dutch, this floor is known by the name "broodjesvloer" in English it is called beam and block. The beams were only available in one size which made it necessary for the hollow block elements to be available in multiple sizes to be able to span varying distances (Andeweg, 2013, p. 3).



Floors, walls, reinforcement and typical façade with horizontal lines (Mazure, (1959))

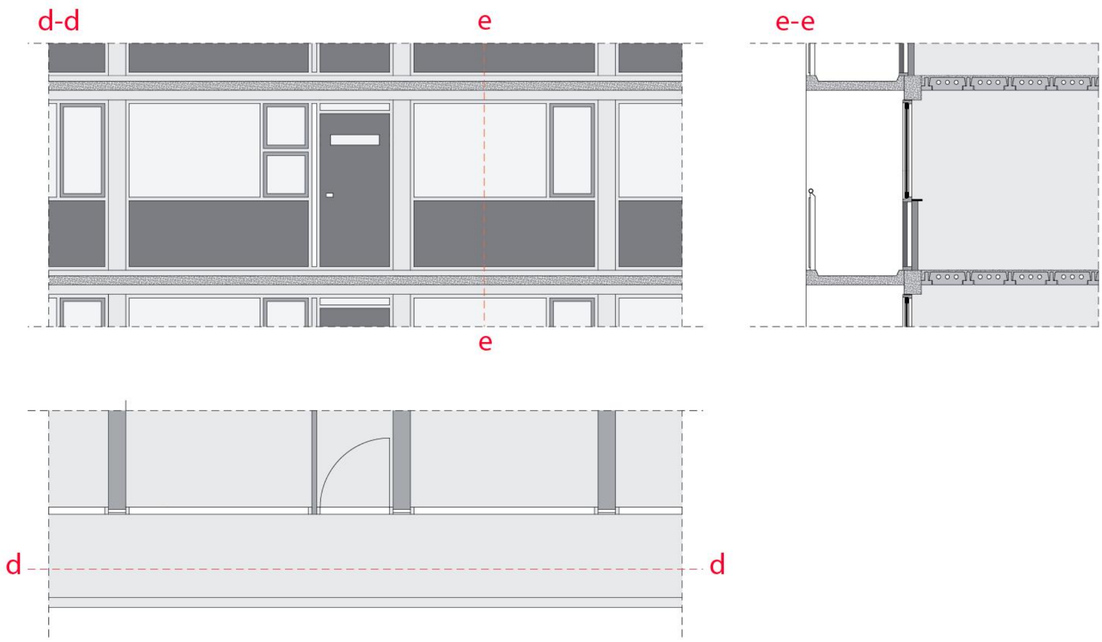
At the edges where the floor and the walls come together steel reinforcement was used. This leads to the typical image of horizontal floor lines in the façade. At the start the MUWI buildings were isolated from the inside. This caused thermal bridges and condensation on the floors and ceilings. To remedy this problem cavity wall were added to the outside decreasing the effect of thermal bridges (Andeweg, 2013, p. 3). Also, the balconies were detached from the main construction by putting them on consoles to limit thermal bridging (Liebregts, 2013, p. 2).

The big advantage of the MUWI system is that because of the simplicity, flexibility and quick adaptations to new technologies a large range of buildings could be made with this system. Many single-family homes and flats were built with this system. As long as certain dimensions were met floorplans could be very flexible varying from two to five rooms (Liebregts, 2013, p. 1).

When trying to renovate a MUWi building the flooring system can be a problem. Because the block elements are not available anymore in the right sizes, it can be an issue if floors get damaged during the renovation process. It is possible to replace an entire floor by a new system but this is a relatively costly operation. It is therefore wise to renovate the homes by leaving the party walls and the floors intact and to only make minimal cut-outs in floors and walls to connect spaces (Andeweg, 2013, pp. 3-4).

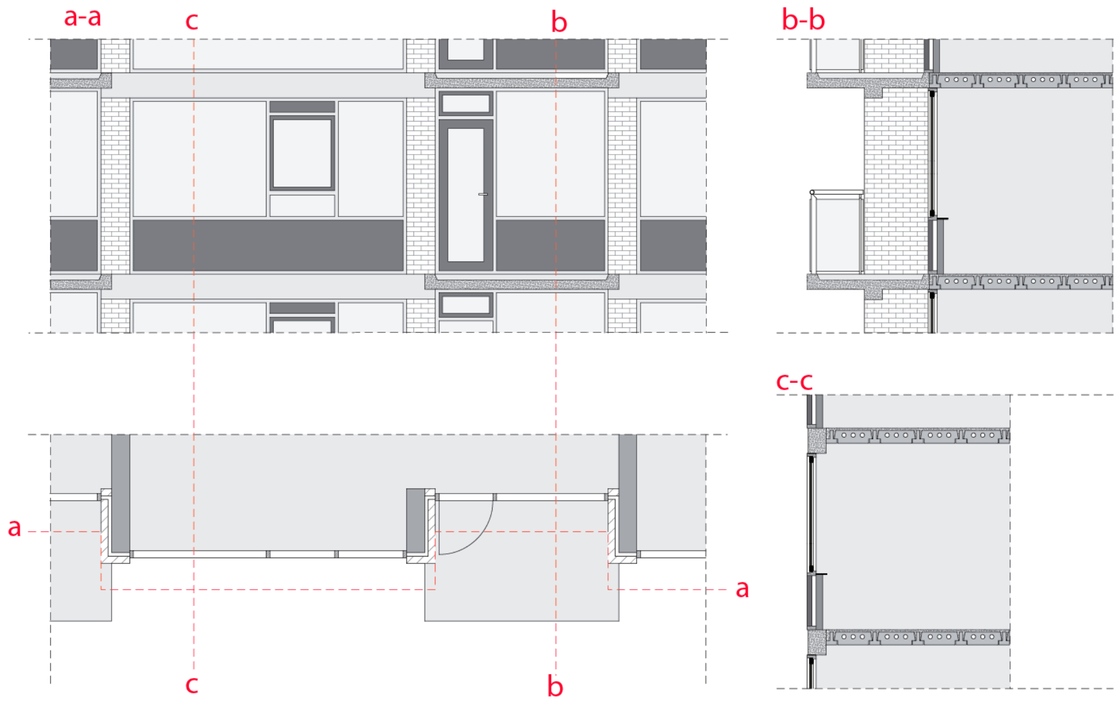
Façade system

Except for the outer ones, most apartments have two facades facing the outside. The gallery side façade and the apartment side facade. The gallery side façade is placed between the upper and lower lintel with the gallery in front. The façade exists of the main entrance with a door and two large window surfaces with a parapet of about 1m high. Both window surfaces have openable windows.



Gallery side façade and sections (own image)

The apartment side of the façade consists of a large window surface and a low parapet of about 0.7m and a deeper lying façade part with a smaller window surface combined with a door that provides access to the balcony. The reason the façade is deeper lying is to make place for the balcony without having a large protrusion.



Apartment side façade and sections (own image)

Originally in 1962 the façade was built up with a layer of 6.5 cm of glasal on the outside followed by a cavity of 6.0 cm and a layer of pumice cement stone on the inside of 9.0 cm. The window panes ware mad with single glazing. The entire façade was encapsulated by a wooden frame. While the glasal was responsible for keeping water out the pumice cement stone had the function to take care of the thermal and acoustic insulation.
During renovation process that followed in the 1984 the facades got improved. The windows got double glazing and the façade insulation was improved by adding insulation material in the cavity.

Climate installations

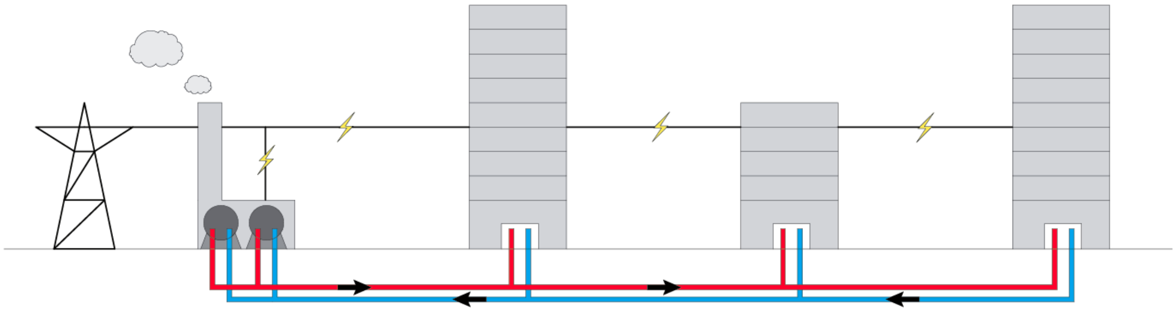
Originally the climate installation of the flat existed of the following components:
Central district heating by gas boilers located in a separate building providing all the flats of the Poptahof with heat (Vlis, 2005, p. 25). High temperature radiators in the apartments to disperse the heat. A central ventilation system that extracts air through the central shaft running through each vertical row of apartments with a separate chimney for each shaft. Fresh air comes in through ventilation vents, seams and open windows. Electricity is provided by the city network.

In 2006 under participation in the SESAC project the plan was made to switch to a more sustainable source of heat (Kruijff, 2006, p. 17). The idea was to create a city network for heat distribution where more sustainable means of heat production could be added over time.

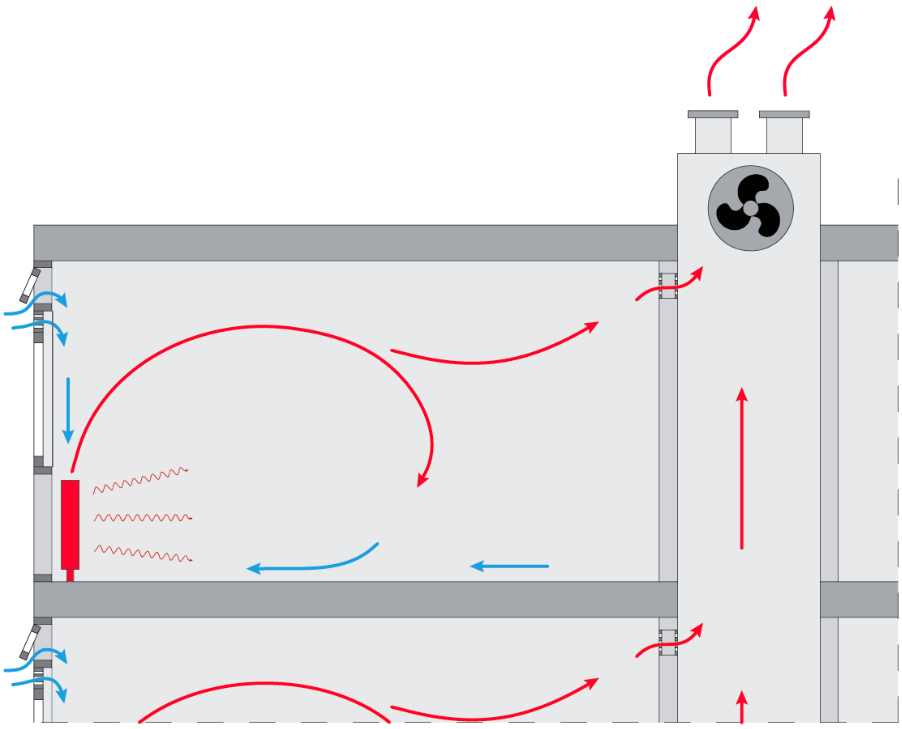
One of the heat sources would be residual heat form a waste water treatment plant AWZI. The heat would be extracted from the water using a heat pump and transported to the district heating center where it could be distributed to the buildings. This plant became part of the network in the North of Delft and there are currently plans to expand the network by also using residual heat from the biogas engines of the plant (Evides, 2017).

Another of these sources would be a geothermal heat well on the TU Delft campus but the plans for this are still being developed and in the spring of 2018 a decision will be taken by the university board (AD & Oremus, 2017).

As the Poptahof was also part of the SESAC project, all the necessary steps were taken and around 2010 a local network was created to be later connected to the city network. However, the city network is not yet completed and currently the buildings in the Poptahof are using combined heat and power units running on natural gas to reach the required heat demand (Agentschap NL, 2011, p. 17) . The older buildings receive water of 90 °C while the newer buildings get water of 70 °C.



Combined heat and power district heating and net electricity (own image)



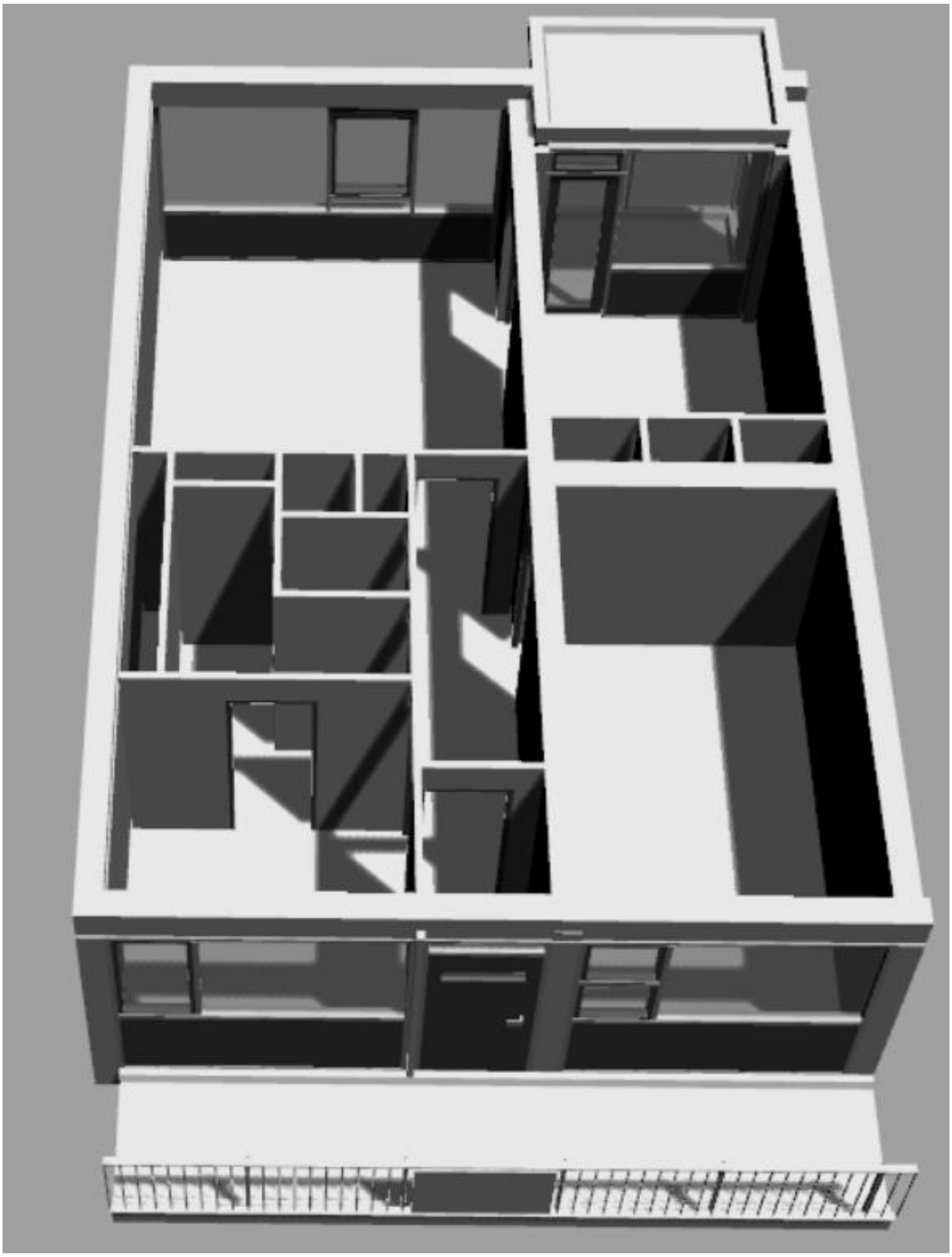
Ventilation and heating scheme with high temperature radiators (own image)

Addon design

Existing single apartment unit

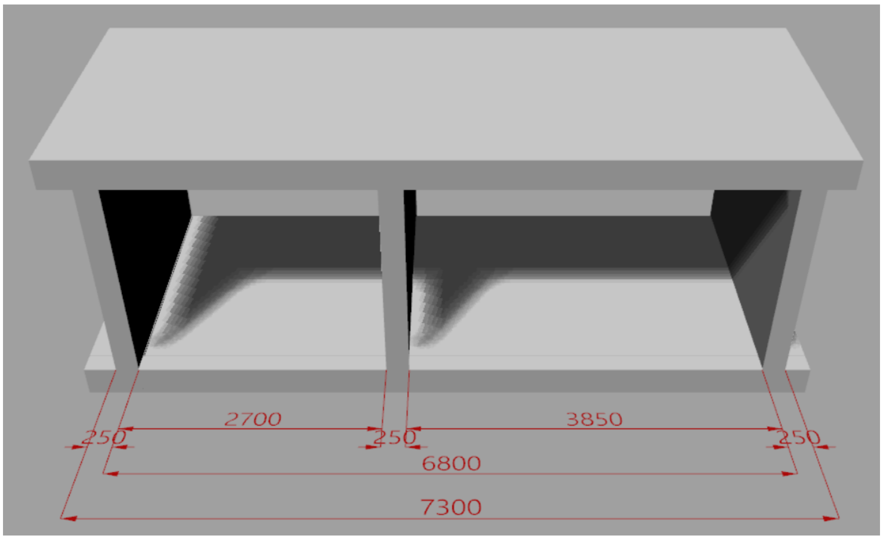
Gallery side façade (own image)

Balcony side façade (own image)


Apartment layout (own image)

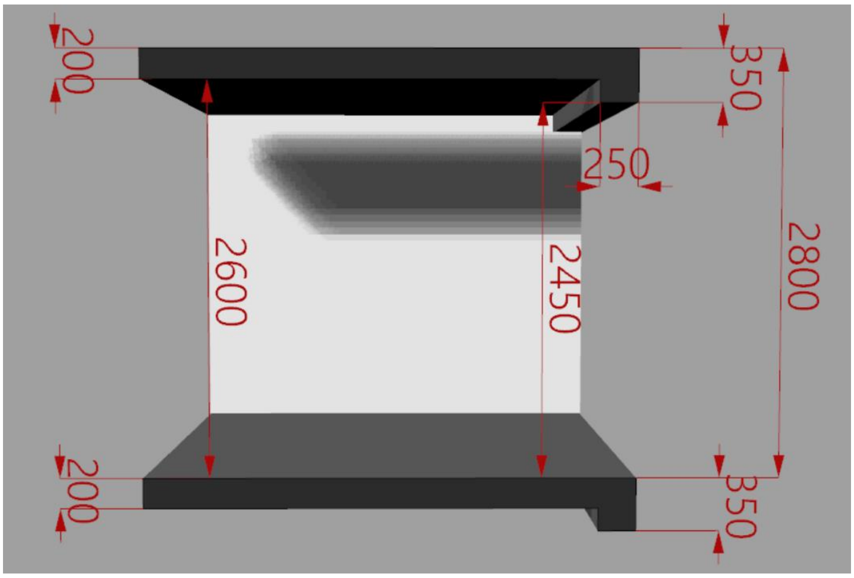
Existing structural dimensions

To determine the size of the addon reference dimensions of the existing construction of a existing gallery flat are used.



Frontal section façade with the dimensions of one apartment (own image)

What is important to not is that the maximum length of the addon has to be within 7.3m if it has to cover one standard apartment. There are two compartments and three loadbearing walls. This makes it possible to connect two or three frame structures to the façade. Connecting two frame structures on the outer walls means that the add-on has to span about 7 meters. The other possibility is to connect three frame structures and to have a separate addon for each compartment. In this case the first option is chosen because it will save space and materials plus it allows movement from one part of the compartment to the other trough the addon.

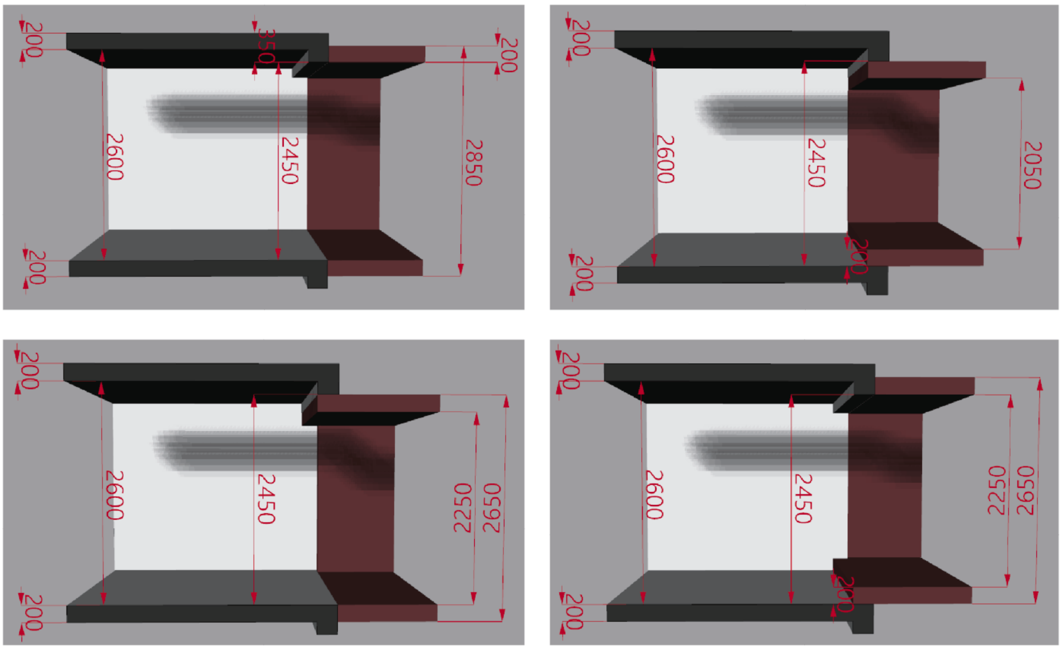


Cross section façade with heights of the existing construction (own image)

The cross section shows the maximum height the addon can have. With a floor height of 2.8m the addon will have to be around 2.6m high. The most important aspect to keep into account is the floor to ceiling height of the addon. Because multiple have to fit on top of each other and each has its own floor and ceiling there is limited space. To ensure that a person can stand up a minimal height of 2.1m should be retained. The more height there is available also helps daylight to enter the building and allows for vision to the outside.

Addon placement

There are main options to place the add-ons. The first one is in between the lintels, the second is against the lintels on the outside, the third is on top of the floor lintel and against the top lintel and the fourth is below the top lintel and against the floor lintel. Each option can have its own benefits and downsides.



Addon placement options (own image)

The two options on the left are not preferable because the addon has to be an integral part of the apartment. By having a height difference with the existing floor, it become a separate entity that does not merge well with the rooms. Also, it makes the apartments wheelchair unfriendly. The top left option is also not suitable because the total floor to ceiling height is below the minimum of 2.1 meters.

The top right option is potentially a good choice the only downside is that the total structure of the addon combined with insulation and finish has to be very slim to allow multiple addons to be stacked on top of each other. It performs the best however when it comes to floor-ceiling height with 2.45m.

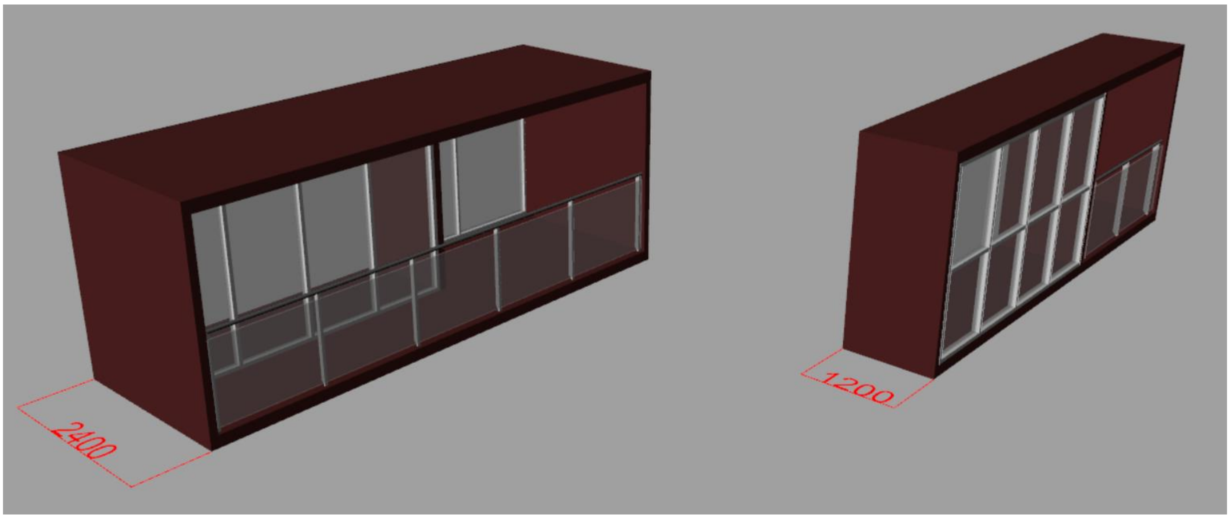
The bottom right option would probably the most suitable option. It is on the same floor level as the existing construction, it has a nice ceiling to floor height of 2.25 meters and it leaves space for other addons to connect to the existing construction.

Addon depth

To determine how big the addon should be in depth, different floorplan alternatives were made. Based on the floorplans two main types of addon depth seemed relevant one of 1.2m depth and one of 2.4m depth.

Floorplan variations (own image)

The add-on with 1.2m in depth is the minimal add-on, it allows for about 7m^2 of extra space but this increase is already enough to provide extra space for the kitchen and the living room which can both use a bit more space while at the same time also increasing the outer space which is currently a bit small. The addon with the depth of 2.4m provide about 15m^2 extra to the dwellings an is therefore a bit more luxurious. The kitchen and living room can be increased and a lot of extra outdoor space is made available to the residents.

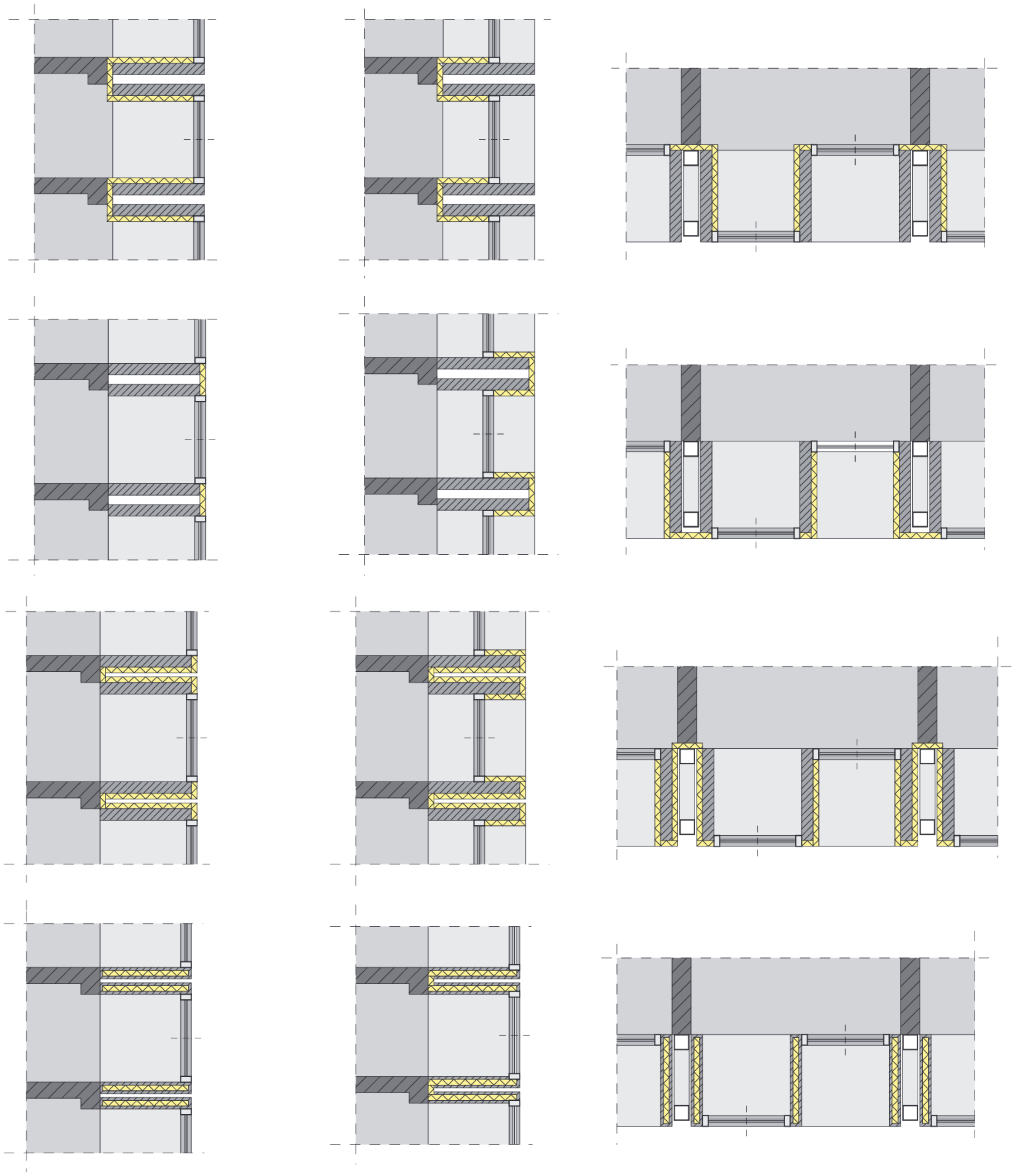


Add-on 2.4m and 1.2m in depth (own image)

Detailing options

Add-on insulation options

There are four main ways to insulate the add-on: on the inside, on the outside separately on the outside combined and within the construction using sandwich panels.

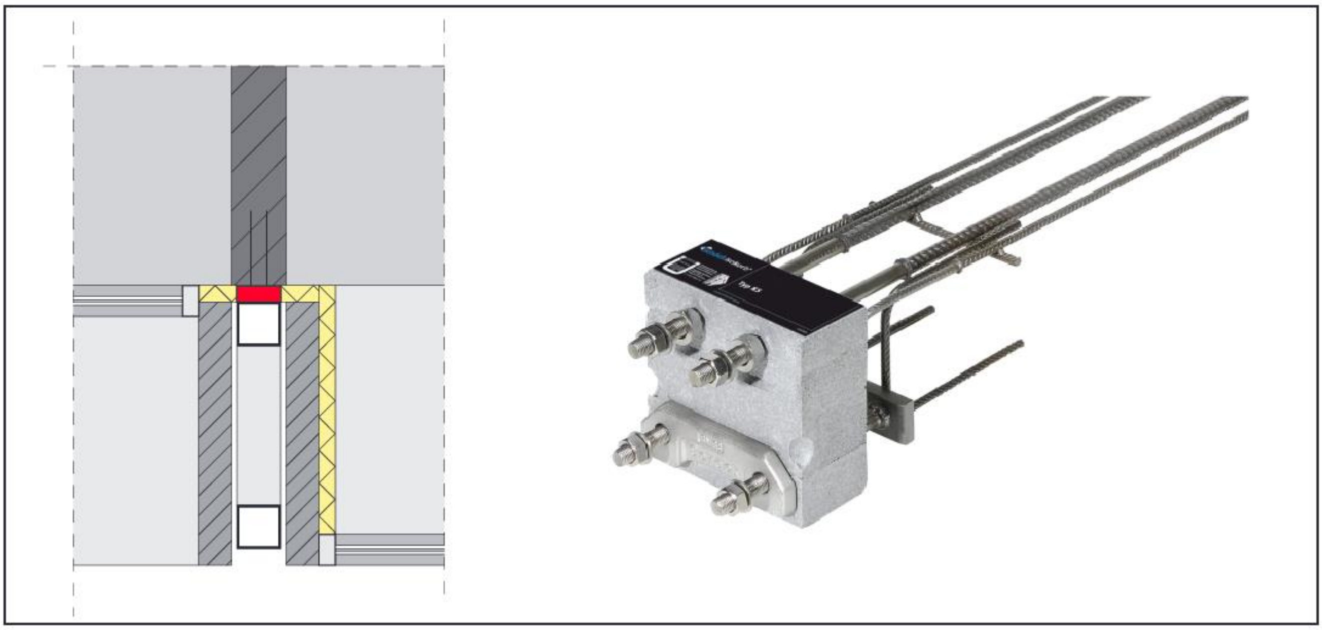


Possible insulation options (own image)

When comparing the four options the insulation on the inside and the sandwich insulation seem to be the best option. The main advantage of having the insulation on the inside is that only the inside parts need to be insulated and the addon can be easier attached to the construction frame without having to worry about thermal bridges. Also, the structural shell of the building can function as the façade instead of having to cover the outside insulation with an extra layer of plating to protect it. Another advantage of placing the insulation on the inside is that it can be placed during prefabrication and allows the add-ons to function separately without having to attach insulation material and protective plating on-site.

Frame insulation

To attach the steel construction frame to the building also precautionary measure have to be taken to avoid thermal bridging, while at the same time having a good connection to the building to ensure the stability f the frame. A good option to deal with the thermal and structural issue at the same time is by using an isocorf element. A hole is drilled in the wall of the building where the frame will be placed. The steel reinforcement rods are inserted, and the hole is filled with concrete. At the end of the isocorf element there is a thermal break that ensures that there is only minimal thermal contact between the steel frame and the concrete wall and in this way big thermal leaks can be avoided.



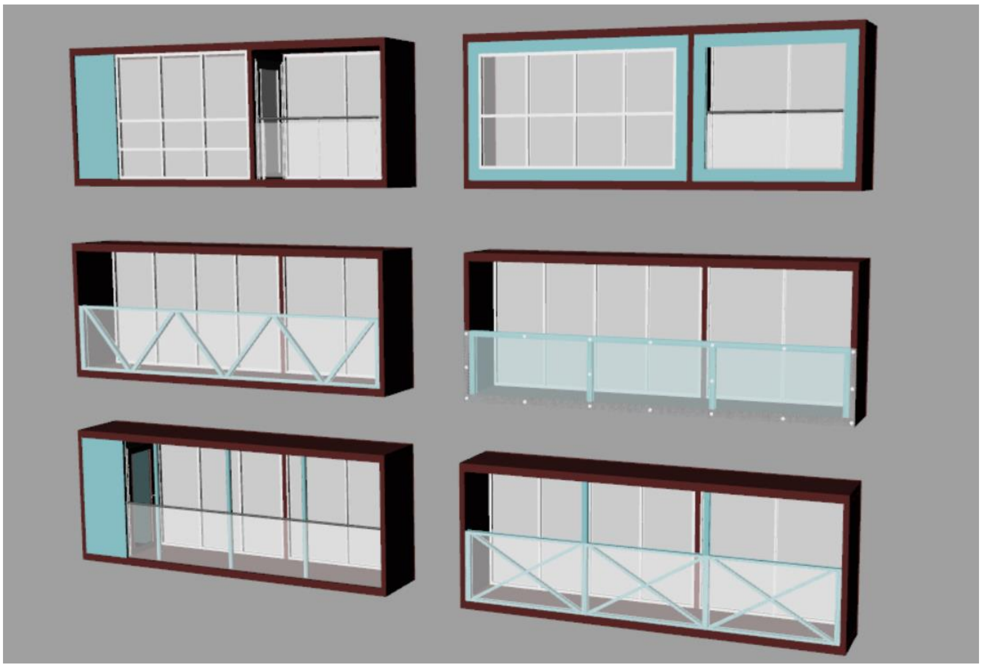
Isocorf element to avoid thermal bridges

Structural performance options

The structural integrity of the building is very important. Not only does the stiffness of the add-ons help to stabilise the steel construction frame, but because the add-on is demountable and has to be lifted as a unit it should have handle its own structural integrity. Because of the limited space to place the addon and the fact that the roof of one addon and the floor of the one on top has to fit within the same space there is no place for beams in between the add-ons. This means that ether the floor needs to be able to span the distance or a beam should be integrated within the add-on design to take some of the load of the floor element in order to be able to dimension it slimmer.

The image below shows six options

- Slab
- Framework
- Lattice girder
- Laminated glass
- Double slab and columns
- Columns with scaffolding



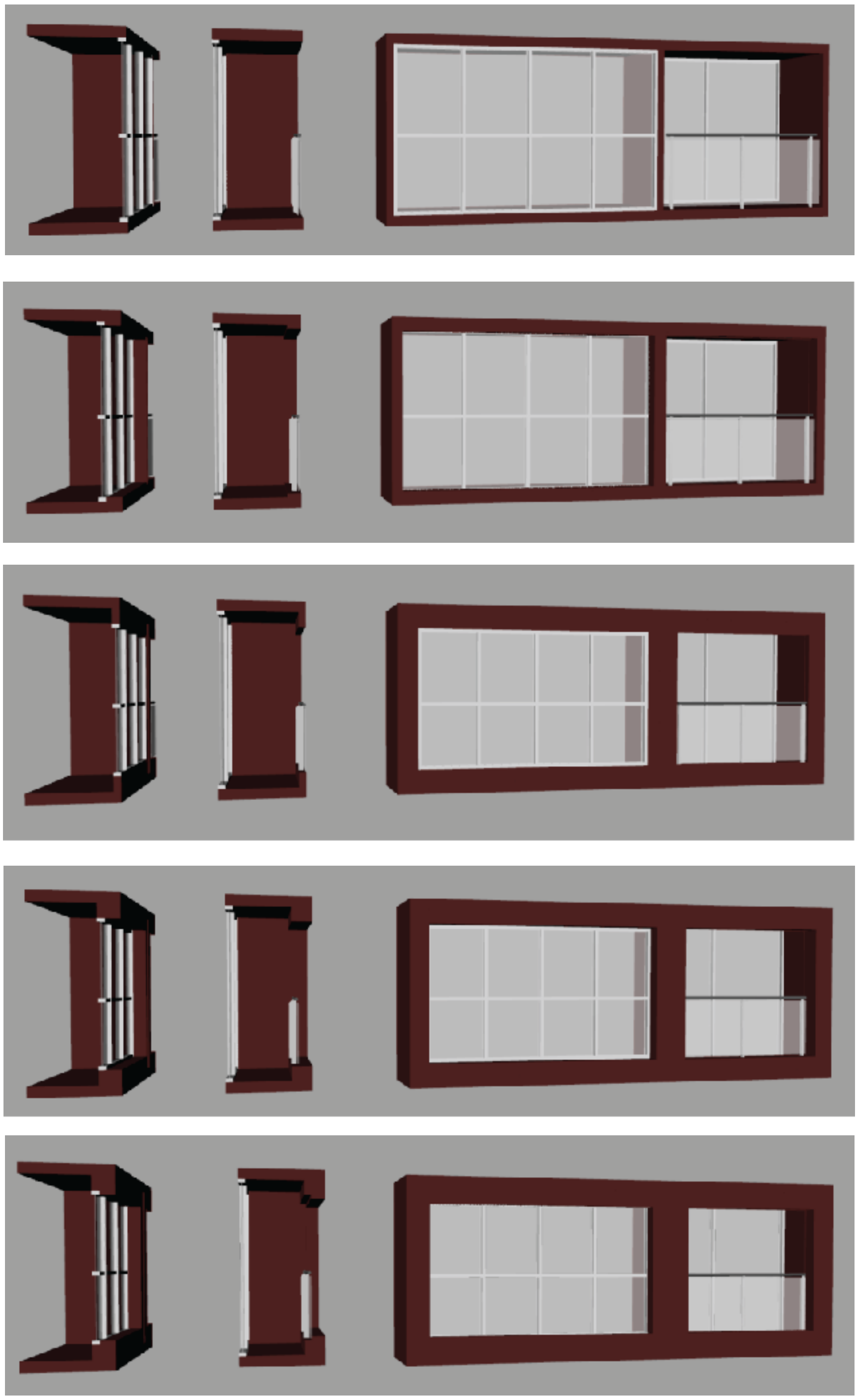
Structural enhancement options (own image)

The slab and the framework are most suited for the addon with 1.2m depth. They are both viable, but the main advantage of the frame structure is that it also functions as an integrated beam helping the floor span the distance and therefore the floor can be dimensioned slimmer.

The lattice girder, laminated glass, double slab and column with or without scaffolding are most beneficial for the add-on with 2.4m depth. They provide extra support and at the same time structural integrity to be able to handle the cantilever effects better and to span the distance in between the construction frames.

Place of window frame

The window frame can be placed at different places into the façade. It can be placed at the front, more to the back or hidden behind the structural element. In essence all options are possible, and it depends on the desired architectural image in combination with the type of window frame that is chosen where the best placement will be. Enabling maximum daylight entry and more view to the outside is in most cases the best choice so having the window frame behind the structural elements is preferable.

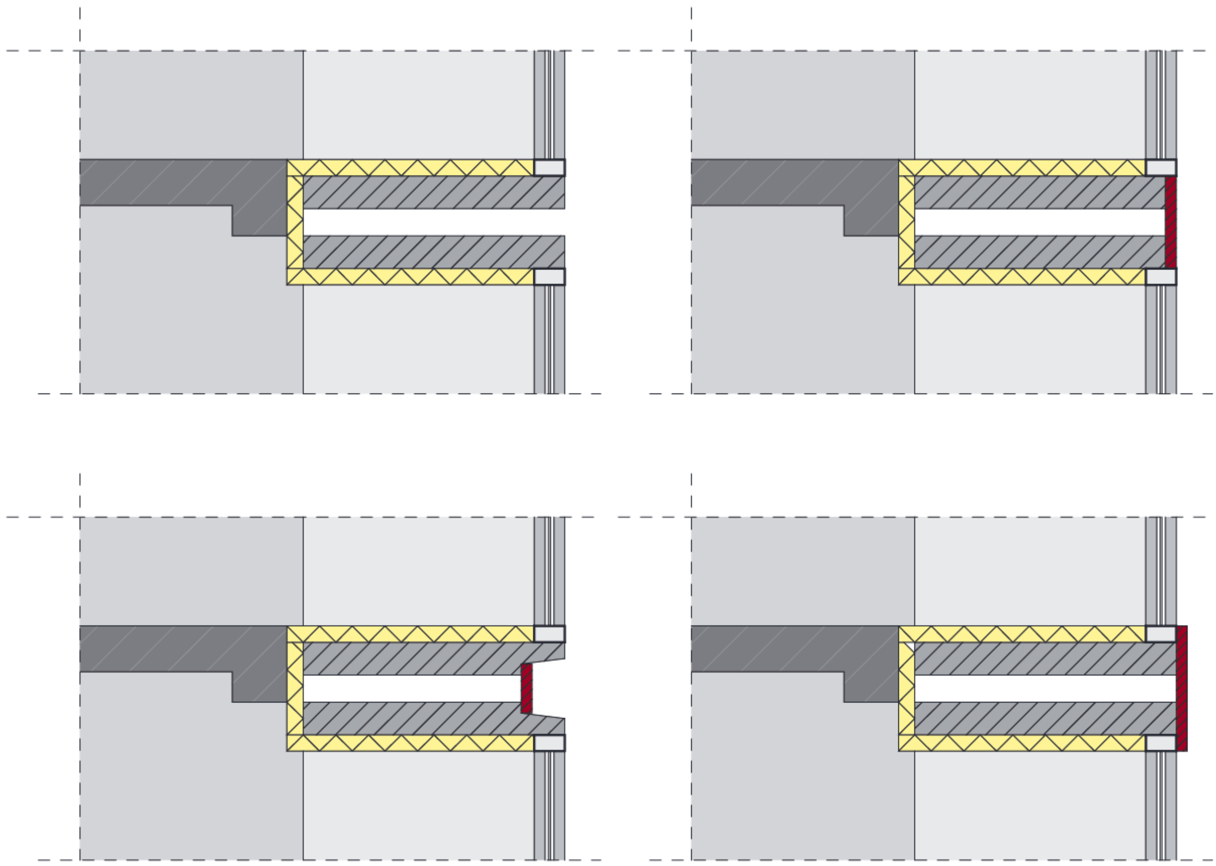


Window frame placements (own image)

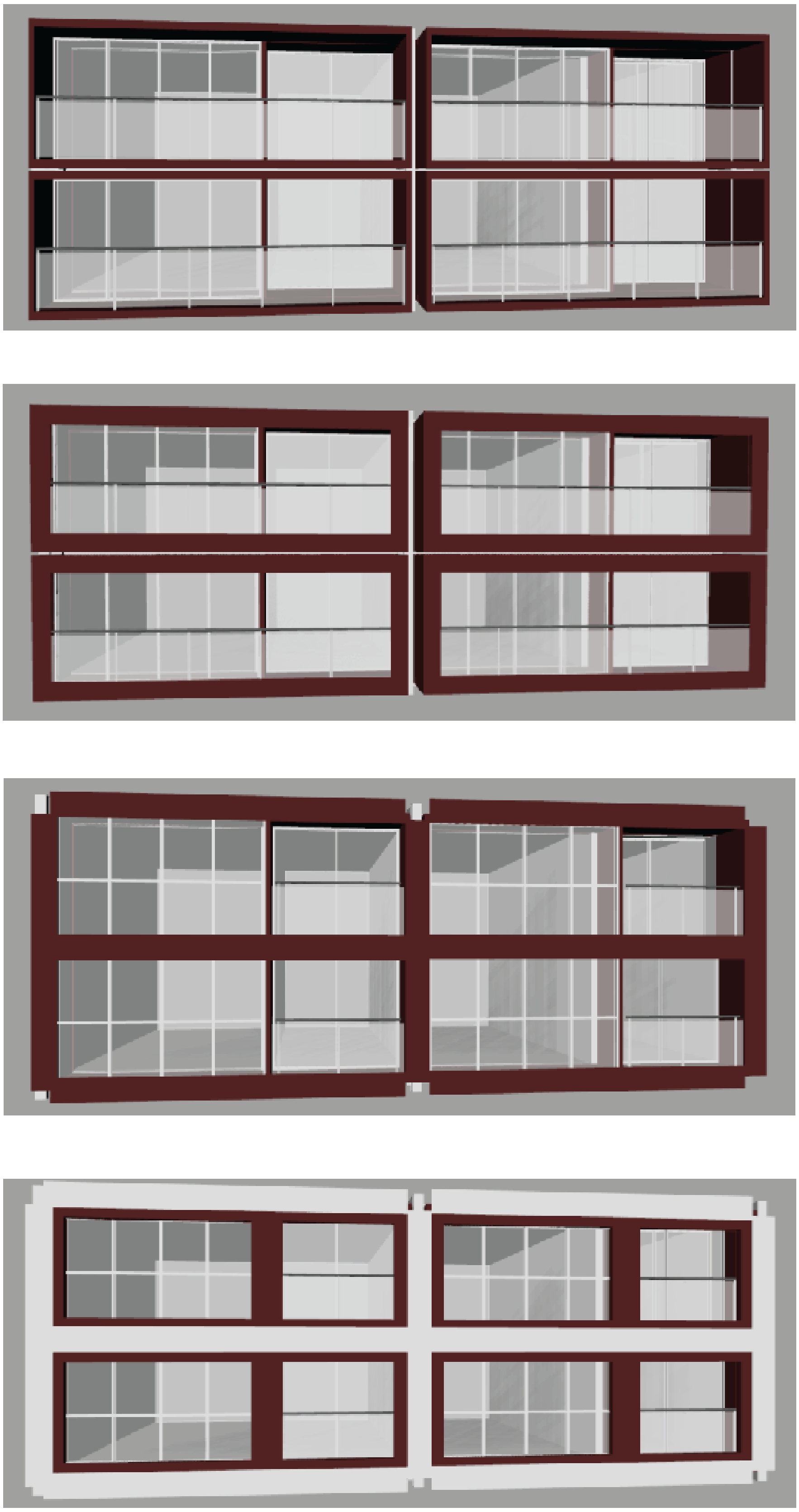
Façade panel finish

After attaching the add-ons to the building there is the possibility to close the space in between the add-ons with plating material. This changes the appearance of the building as instead seeing a single unit, multiple units can form a composition and by playing with this different appearance of the building can be achieved. Except for the aesthetic element the plating can also contribute to the performance of the units by blocking sunlight, keeping out rainwater, enhance the thermal performance by restricting airflow and keep birds and other animals away from the roof surface.

The big downside of adding the plating is that it has to be done after the addons are already in place. It will slow down the mounting process as an extra step needs to be taken. Also, when an addon needs to be replaced the plating needs to be taken down first. Where different size (depth) addons are placed next to each other it might be more complicated to reach the place to attach the plating. Visually it might also be less attractive as it can be unclear where one dwelling begins and ends taking away the personal image.



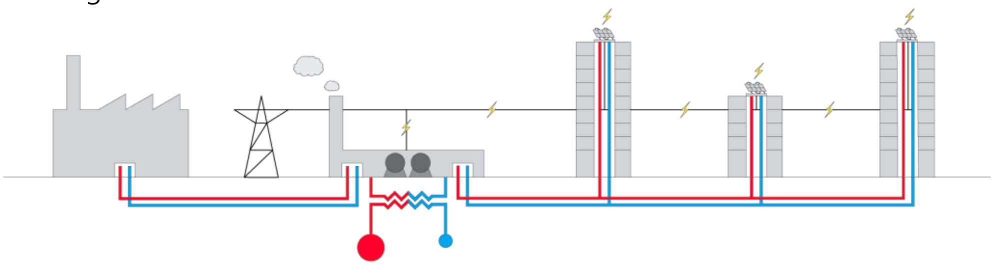
Different panel placements (own image)



Façade appearance with different panel finish (own image)

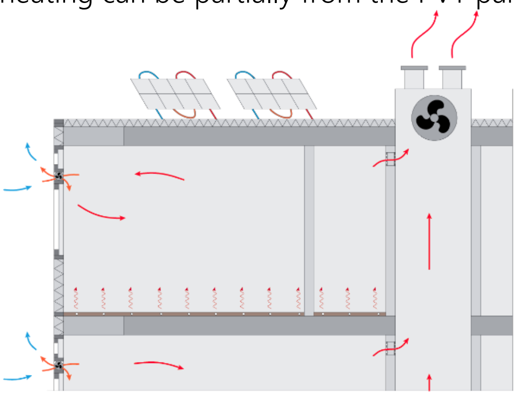
Revised climate system

To reach a more sustainable building the a few changes will have to be made to the climate system. On a large scale, the source of the district heating will have to change from the combined heat and power unit working on gas to residual heat from industries in this case the AWZI water treatment plant and heat from the geothermal well on the TU Delft campus. The flats will also provide their own contribution to the heat network with the PVT panels. A heat-cold storage mechanism needs to be added to the district distribution centre to be able to store the excess heat from the PVT panels so that this can be used when it is needed. This can compensate for the daily and seasonal cycles. The combined heat and power units can be used during the transitional period as backup, but the idea is to replace them with a heat pump that uses heat from the storage on the long term, so the buildings are not heated anymore by the use of gas.



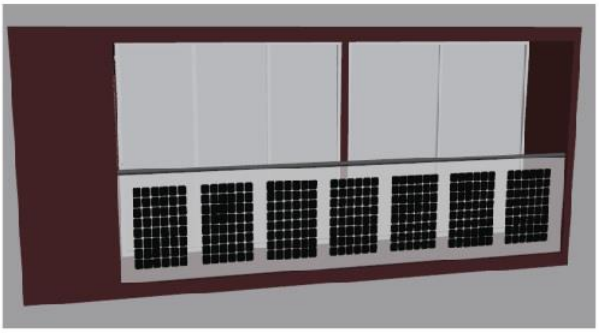
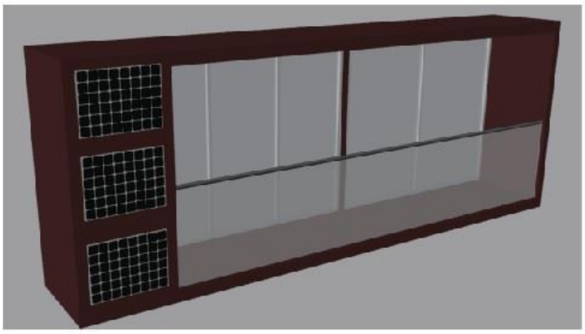
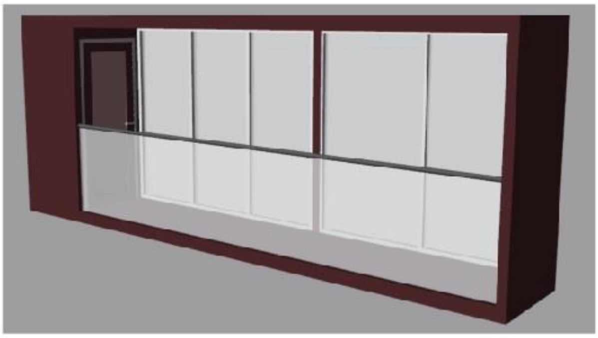
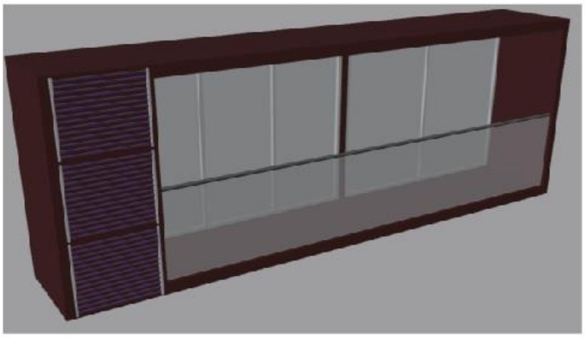
District heating from industrial heat and geothermal facility, heat-cold storage, PVT for local electricity and heat production and combined heat and power units as backup (own image)

On the appartment scale the ventilation system will be change to include decentral ventilation units with built-in heatexchangers. These will take care of the rooms located on the façade and minimize the heatloss through ventilation. For the bathroom, toilet and kitchen the old ventilation system can be used as these functions only need extraction of air to avoid sending poluted air throuout the house. The addon will provide opportunety to isolate the façade extra to take care of thermal bridges and to ensure air thight conncetoins of seams and joints. This would make it possible to install a low temperature floor heating system. The main advantages of this system over radiators and convectors are that the space will be more freely diviseble, it uses radiation heat only and spreds the heat nicely over the room providing high level of comfort. It can also provide acoustic insulation if the right system is used. The only big disadvantage is that the reaction time is slow but because a lightweight system will be used and possibly a smart thermostat this shoud not be to big a problem. The warm water for the floor heating can be partially from the PVT panels and partially from the district heating.



Ventilation and heating scheme addon design with decentral heat exchange ventilation units and low temperature floor heating, extra insulation and PVT on the roof (own image)

The changed climate systems do not have a huge impact on the addon what is important in their design is that they are detailed well so that they are airtight and well insulated. This allows for the use of low temperature heating system in this case the floor heating. The floorheating will be placed in the finishing floor and will cover the existing floor and the newly added add-on floor. Tohelp with the production of heat and electricity a few add-on variants have been desing that include solarpanels and solar thermal heat collectors. In the larger add-ons there is also room for a small shed which is also capable to hold equipment for climate installations if possible. Another extra addition that can be made is the use of a winter garden. In this case the balcony can be closed of from the outdoor environment to retain heat colelcted from the sun in winter, providing an extra insulation layer for the façade behind and a heatbuffer that can lower the need for heating in the dwelling.

Details

The first detail shows a vertical section of the wooden add-on. The addon has a height of 2.7 meters a length of 6.8 meters and a depth of 1.2 meters. The floor is made from glue laminated timber and is 14 cm tick. The front of the addon functions as a beam to give the floor extra support and is 40cm high and 14cm tick. The roofing of the addon also has an integrated beam which is 28cm high. The floor to ceiling height within the addon is 2.2m. The addon makes use of a phenolic foam insulation layer that is 8cm tick. For the wooden addon the goal was to make it as organically as possible therefore it has a plant-based membrane cover to protect it from rain water. The connection piece between the building and the addon is also made from wood with the same plant-based cover in order to show that it is possible to have a fully organic option.

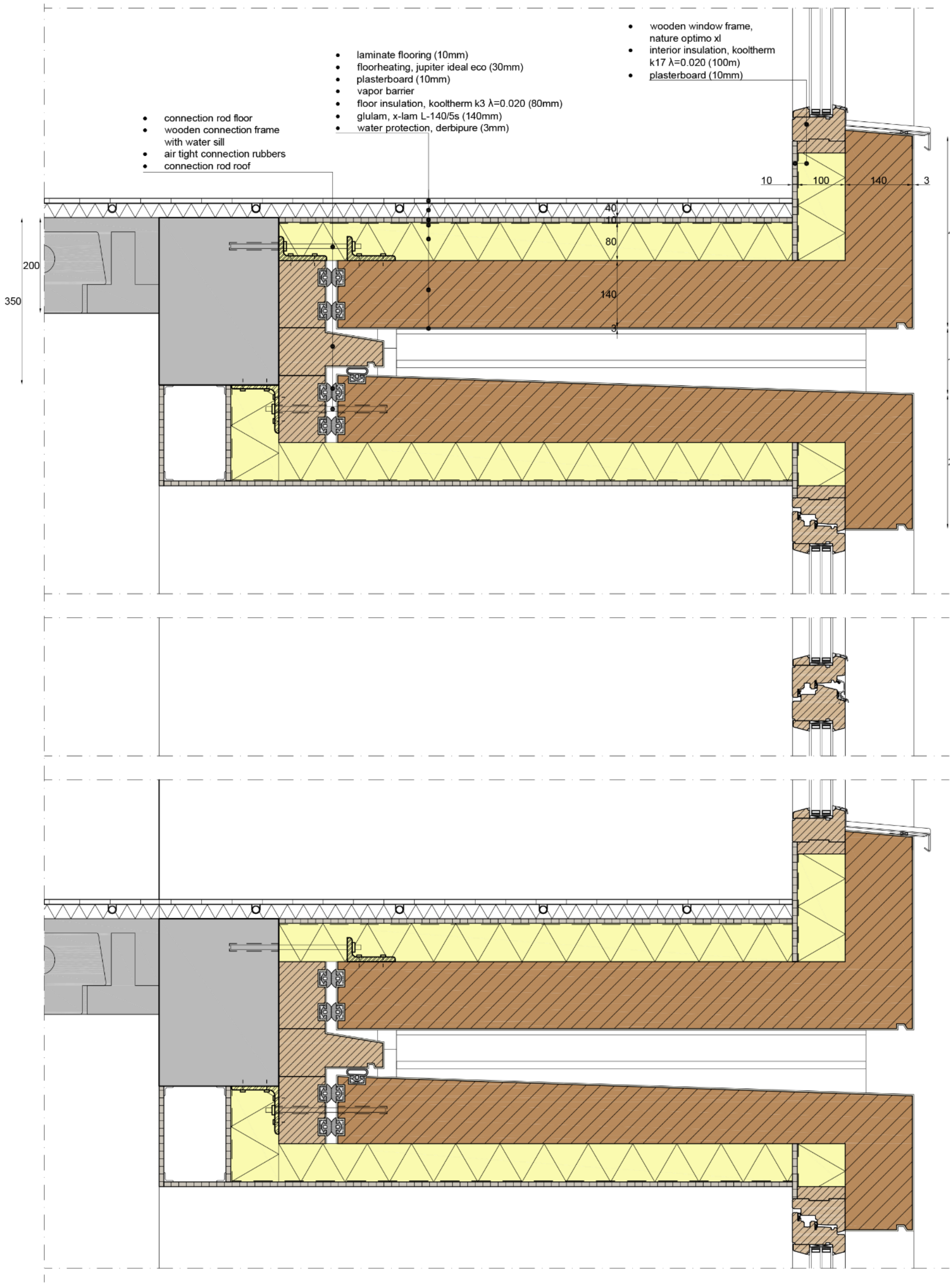
The second detail shows a vertical section of the concrete addon. The addon has a height of 2.7 meters a length of 6.8 meters and a depth of 1.2 meters. The floor is made from high performance concrete and is 12 cm tick. The front of the addon functions as a beam to give the floor extra support and is 34cm high and 12cm tick. The roofing of the addon also has an integrated beam which is 28cm high. The floor to ceiling height within the addon is 2.2m. The addon makes use of a phenolic foam insulation layer that is 9cm tick. The connection frame between de add-on and the structure is made from FRP to provide enough strength while at the same time avoid thermal bridges.

The third detail shows a vertical section of the FRP addon. The addon has a height of 2.7 meters a length of 6.8 meters and a depth of 1.2 meters. The floor is made from glass fibre reinforced polymers filled with PUR the total floor height is 22cm of which the grp is 1cm on both sides with 20cn filling in between. The front of the addon functions as a beam to give the floor extra support and is 40cm high and 22cm tick. The roofing of the addon also has an integrated beam which is 28cm high. The floor to ceiling height within the addon is 2.2m. The connection frame between de add-on and the structure is made from FRP to provide enough strength while at the same time avoid thermal bridges.

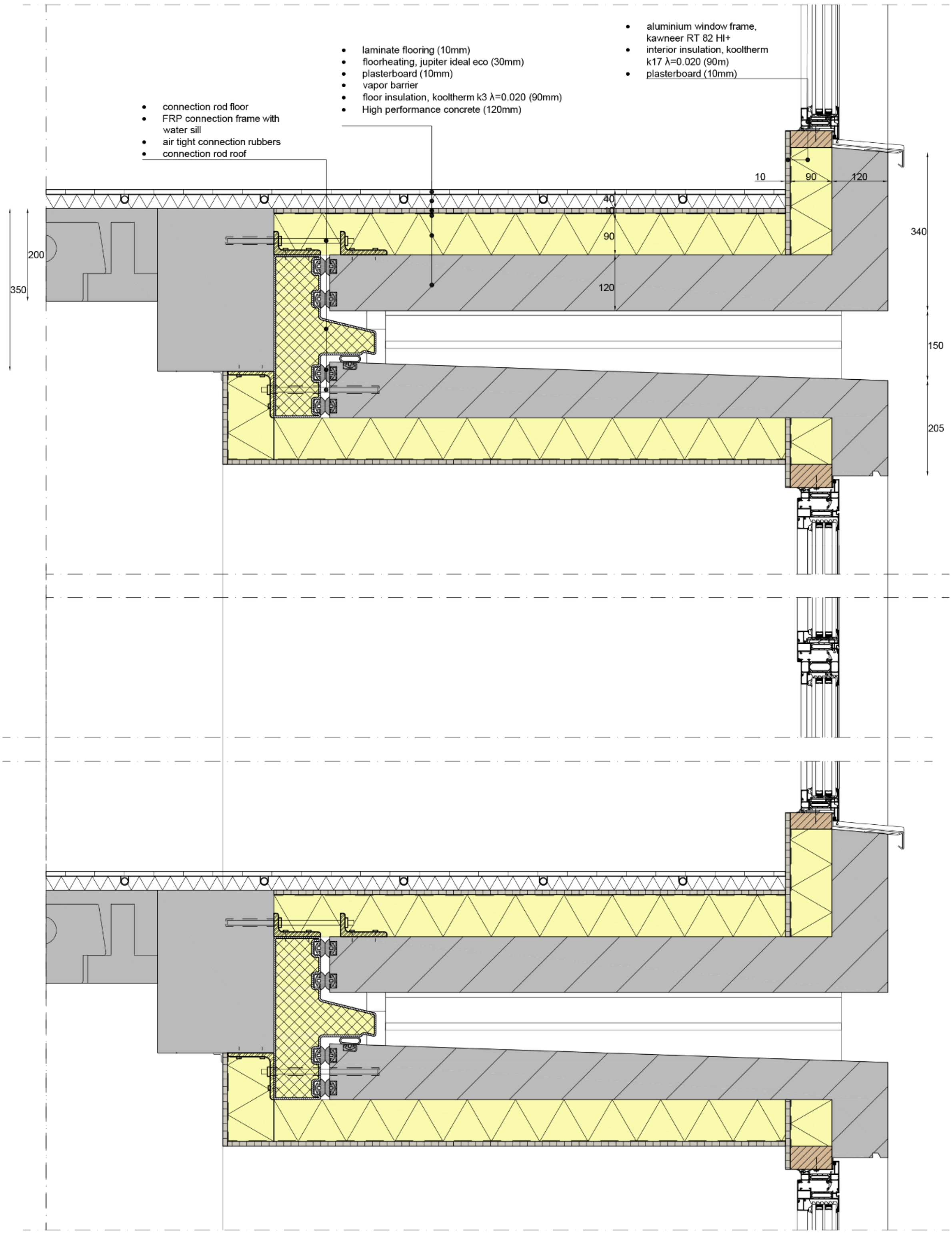
The fourth detail shows a horizontal section of the concrete add-on. This is to give an overview to how it is connected to the building and the construction frame in the horizontal plane.

The fifth and the sixth detail show sections of the docking system necessary to slide the addon in its place. The system is inspired on the same system used in a pallet jack. It consists of sets of wheels attached with small levers to a steel bar that moves the levers up and down by sliding horizontally. The steel bar itself is moved by a larger lever attached to a hydraulic jack.

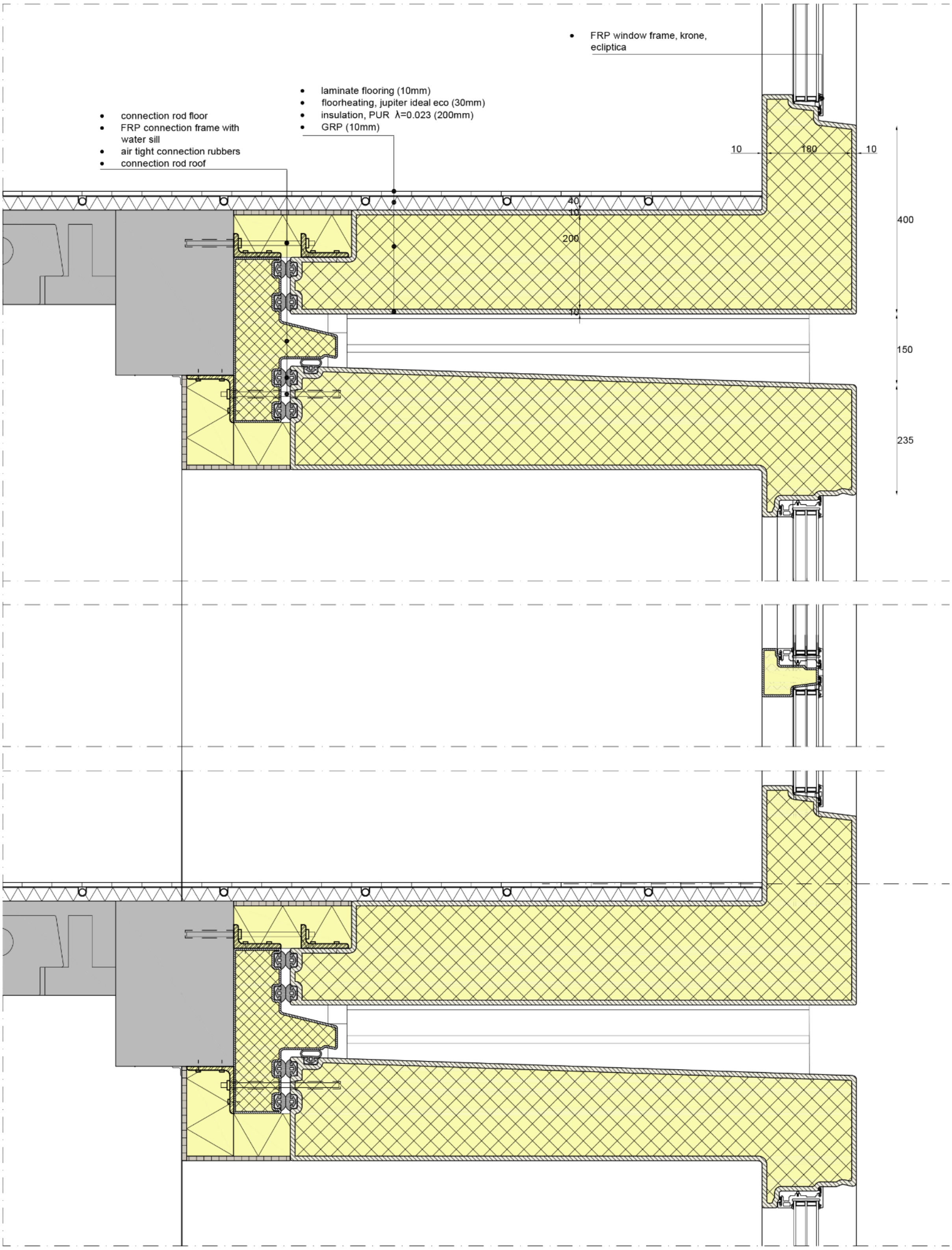
Vertical section wooden add-on 1:10



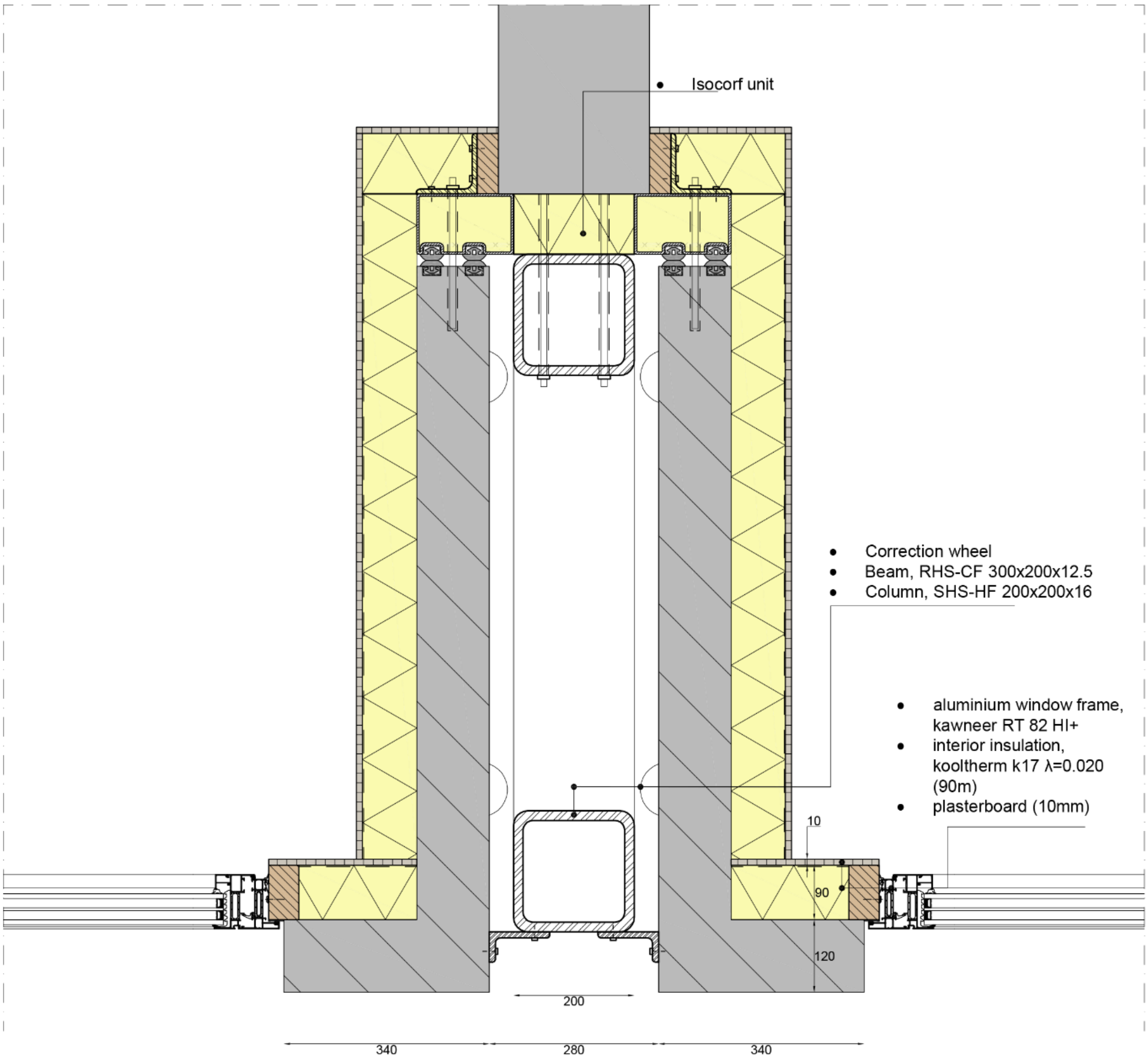
Vertical section concrete add-on 1:10



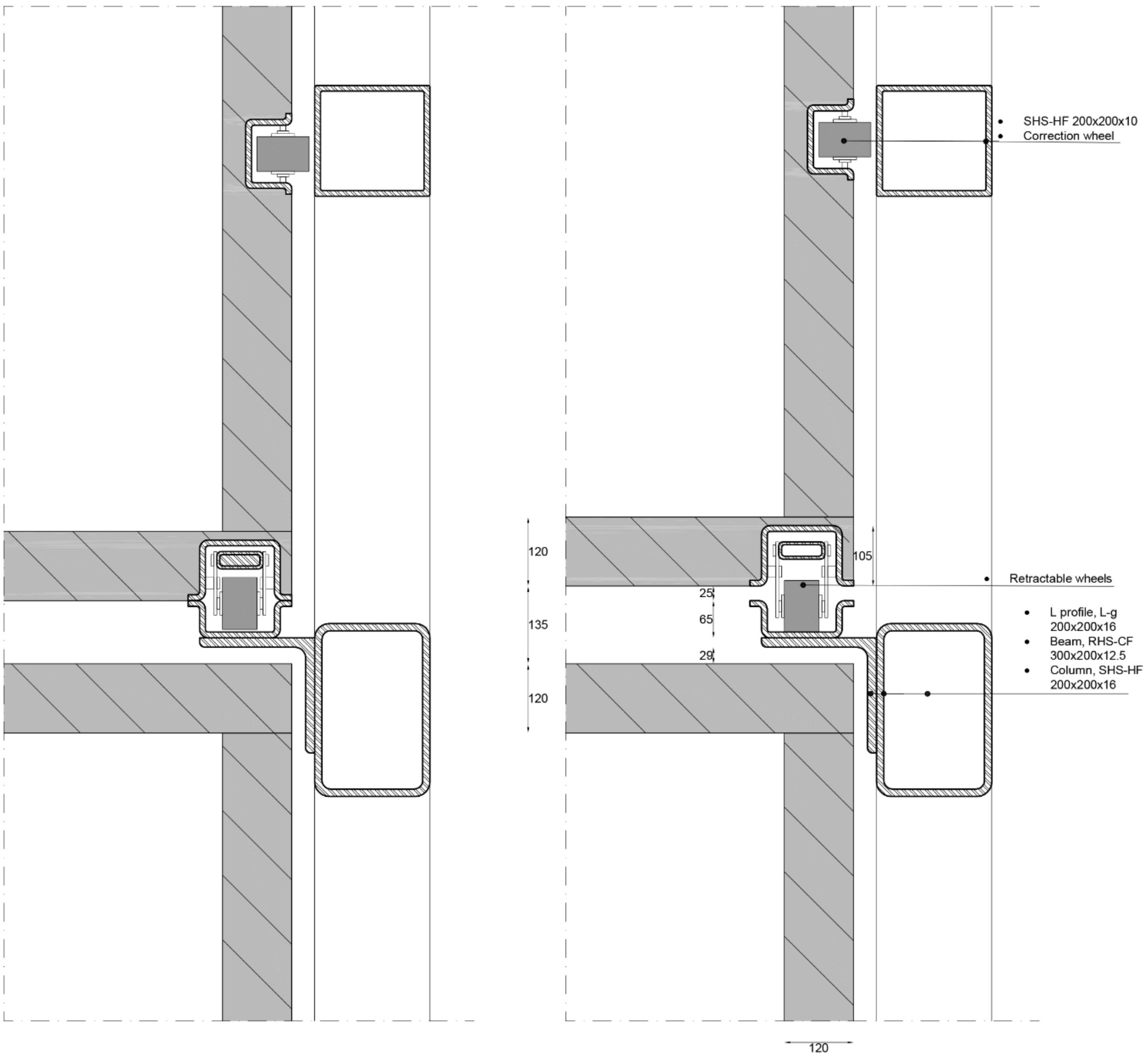
Vertical section GRP add-on 1:10



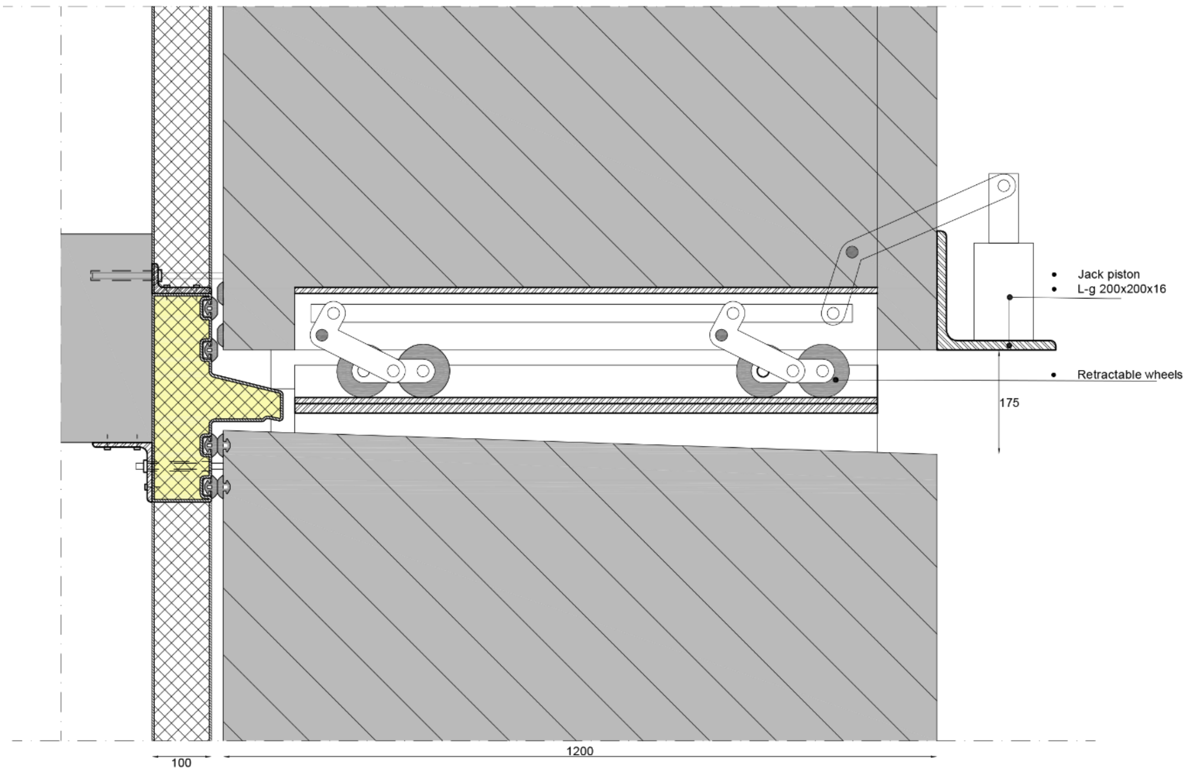
Horizontal section concrete add-on 1:10



Frontal section concrete add-on 1:10



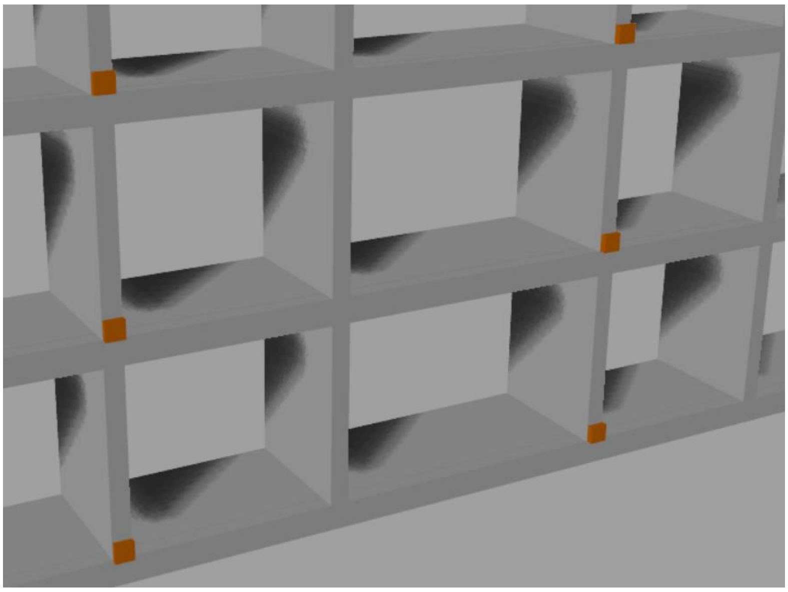
Side section concrete add-on 1:10



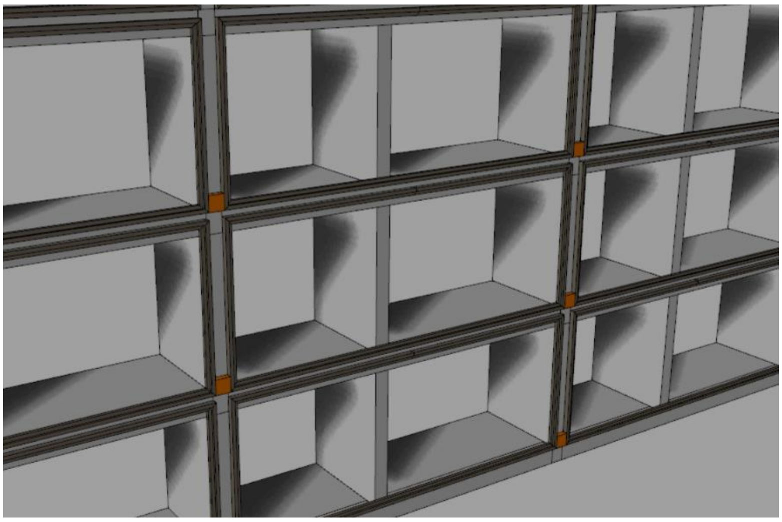
Pallet jack (Cisco Eagle, 2018)

Addon built-up

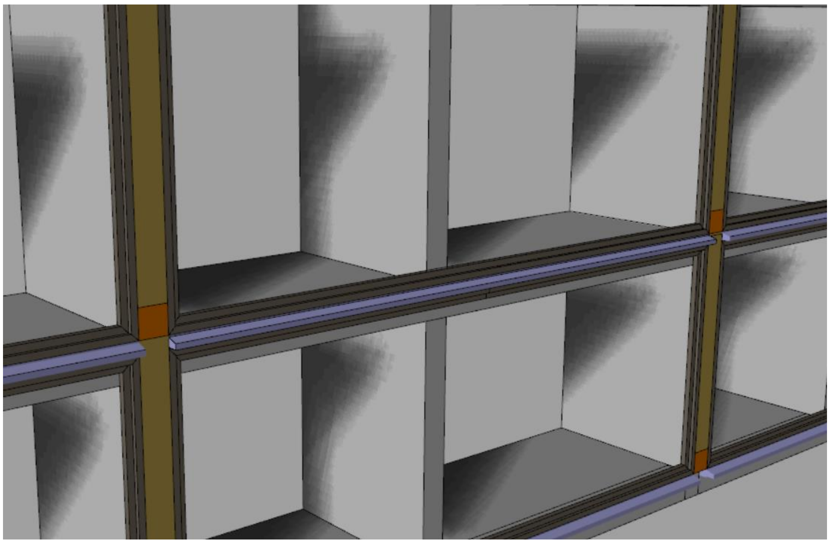
To attach the addon to the building a few steps have to be taken. The first step is to add foundation on which the load of the construction frame can rest. The second step is to disassemble the current façade of the building and to remove the existing balcony to make space for the add-on. The third step is to drill holes into the walls to secure the isocorf units. The fourth step is the built up of the construction frame columns and beams that can be attached to the façade. The fifth step is the placing of the connection frames including the insulation in between the frames covering the walls and placing the steel profiles that will be used to tighten the connection between the addon and the building. Then the sixth step is lifting the units with the wheel system extended in order to slide the addon into the frame. The seventh step is lowering down the addon into its place and connecting it on the inside to the steel profiles and on the outside to the frame construction.

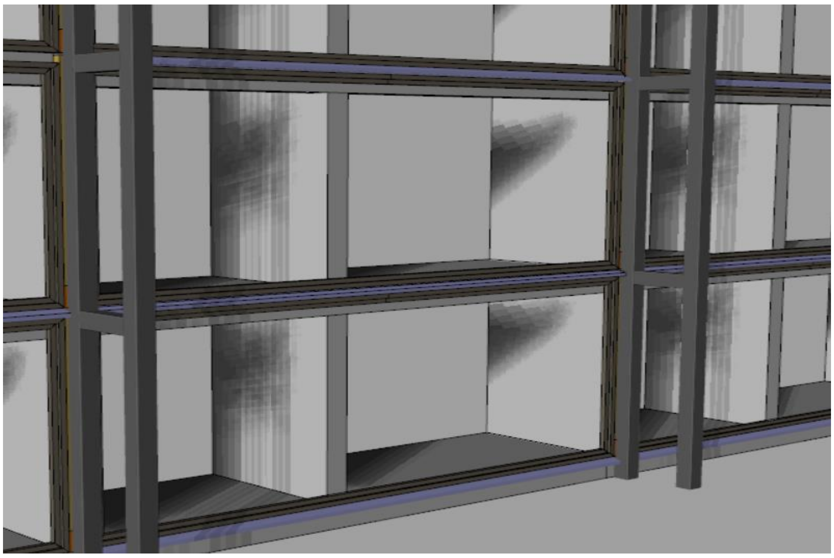


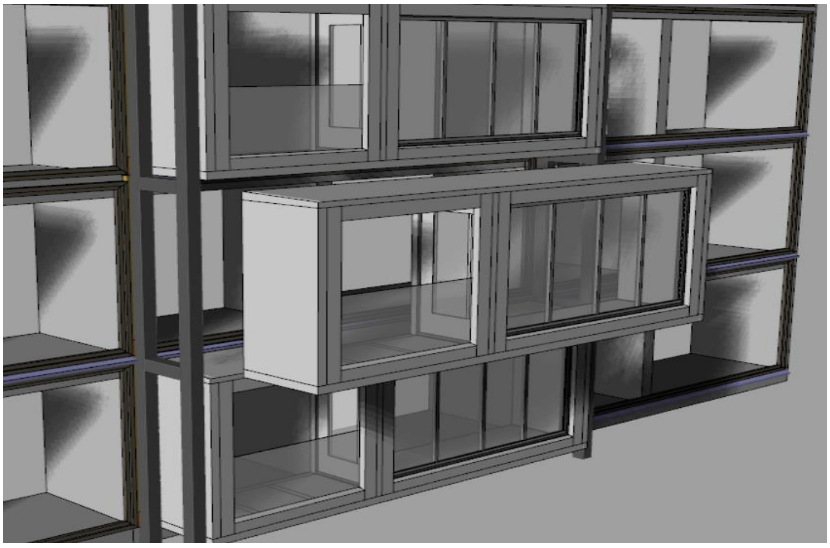
Installing isocorf units (own image)



Attaching the connection frames (own image)


Installing insulation and water sill (own image)


Attaching the loadbearing frame (own image)


Placing of the add-on

Performance

Thermal performance addons

To ensure that the add-ons have a good thermal performance, the addon should have an Rc (thermal resistance) value of 4.5 m^2K/W or higher and a U-value (heat transfer coefficient) of 0.24 W/m^2K for floors, walls and roof and 1.5 W/m^2K or lower for windows (BRIS bouwbesluit online, 2012).

To calculate the Rc-value the thickness (m) of the elements should be known and the lambda value (λ) of the different materials. The Rc value can than be calculated using the following formula Rc= thickness(m)/lambda (λ).

To get the U-value the different Rc values have to be added and this can be done with the formula U-Value = 1/(Sum of all R-Value) U-Value (of building element) = 1 / (R_{so} + R_{si} + R_1 + R_2 ...) With common values for R_{si} and R_{so} 0.12Km^2/W and 0.06Km^2/W.

Materials	Lambda λ in W/mK	Thickness of panels in m	Rc-value m^2K/W	Isolation materials	Lambda λ in W/mK	Thickness of insulation in m	Rc-value m^2K/W	Total Rc-value m^2K/W	U-value W/m^2K
GRP	0.32	0.020	0.06	PIR / PUR	0.023	0.20	8.7	8.76	0.112
Glulam	0.13	0.14	1.08	Phenolic foam	0.020	0.08	4	5.08	0.190
HP concrete	2	0.12	0.06	Phenolic foam	0.020	0.09	4.5	4.56	0.211

Add-on material	Window frames	U value W / m2K
Wooden add-on	Wood (M Sora, Nature Optimo XL)	0.89
HP Concrete add-on	Aluminium (Kawneer, RT 82 HI+	0.79
GRP add-on	GRP (Krone, Ecliptica)	0.71

As can be seen in the tables al the values for the façade, roof, floor and window frames are within the required values.

Environmental impact add-on

To get an idea of the environmental impact add-on three different add-ons have been designed with comparable dimensions to be able to compare them to each other. Height 2.7m length 6.8m and depth 1.2m. The goal is to determine the embodied energy and the CO2 production of each addon. To compare the add-ons as good as possible the window frames

will not be taken into account as it is possible to use the same window frame on all three add-ons. What will be taken into account are the structural elements and the insulation of the add-ons as these contribute to most of the environmental impact. To get to the embodied energy and CO2 values the following information is required: The density of each material in kg/m^3, the total qubic meters of each material m^3. With these two values the weight of the add-on parts can be determined, and the total embodied energy MJ and CO2 production kg CO2 determined.
The tables below give an overview of the required values to calculate the environmental impact of the add-ons.

Materials	Density kg/m^3	Young's modulus GPa	Embodied energy MJ/kg	CO2 production kg CO2 / kg	Thermal conductivity λ in W/mK	Life span years
GRP	1750	72-85	100	8.1	0.32	50
Glulam	450	12-14	12	0.84	0.13	35 - 40
High performance concrete	2800	25-27	3.58	0.48	2	100

Isolation materials	Thermal conductivity λ in W/mK	Thickness of panels in mm	Density kg/m3	Embodied energy MJ/kg	CO2 production kg CO2 eq	Shadow costs in € / kg	Life span years
PIR / PUR	0.023	104	33	101.5	21.90	1.84	75
Phenolic foam (Resol)	0.020	95	36	88	17.10	1.88	75

Wood add-on

Wood add-on	Density kg/m^3	Square meter m3	Kilo's kg	Embodied energy MJ/kg	CO2 production kg
Glulam 140mm	450	6.0	2700	32400	2268
Phenolic foam (Resol) 80mm	36	1.1	40	3520	684
Total			2740	35920	2952

GRP add-on

GRP add-on	Density kg/m^3	Square meter m3	Kilo's kg	Embodied energy MJ	CO2 production kg
GRP 2*10mm	1750	0.5	875	87500	7088

PUR 200mm	33	5.6	185	18778	3164
Total			1060	106278	10252

Concrete (HPC) add-on

Concrete (HPC) add-on	Density kg/m^3	Square meter m3	Kilo's kg	Embodied energy MJ/kg	CO2 production kg
HPC 120mm	2800	2.74	7672	27465	3682
Phenolic foam (Resol) 90mm	36	1.2	43	3802	739
Total			7715	31267	4421

As can be seen the GRP addon is the lightest followed up by the wooden add-on and then the high performance concrete add-on. This means that structural wise, transport wise and mount ability wise the GRP add-on is at an advantage because it is much easier to handle. So, if weight is the issue the GRP add-on is the best option.

When looking at embodied energy the concrete add-on takes the first place closely followed by the wood add-on and the GRP finishes last with almost three times more embodied energy than the other two. So, if reducing the energy consumption is the goal the concrete add-on is the best option.

When looking at the CO2 production wood performs the best followed by the concrete addon while the GRP ad-on performs the worst. SO, if the goal is to reduce the CO2 footprint wood would be the best option.

Steel structure

Materials	Density kg/m^3	Young's modulus GPa	Embodied energy MJ/kg	CO2 production kg CO2 / kg	Thermal conductivity λ in W/mK
steel	7800	200-215	20.1	1.37	50

One row over 12.5 floors and 11 add-ons

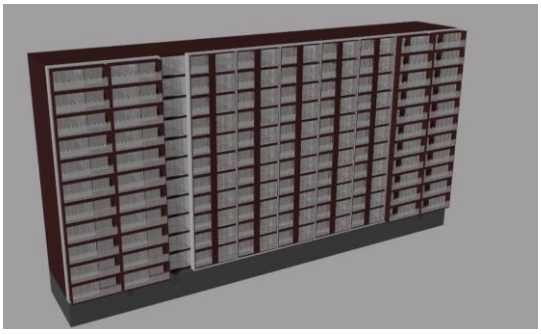
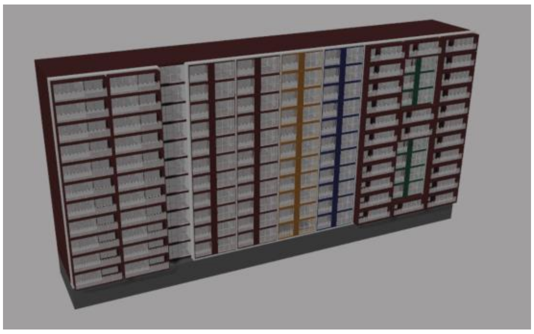
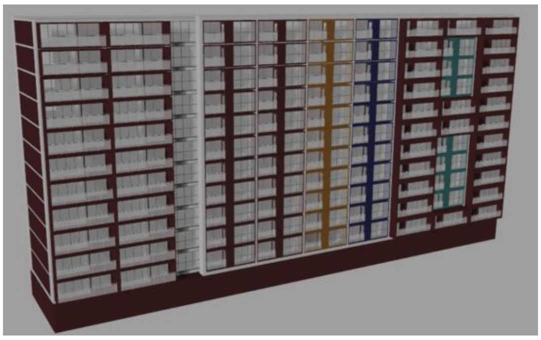
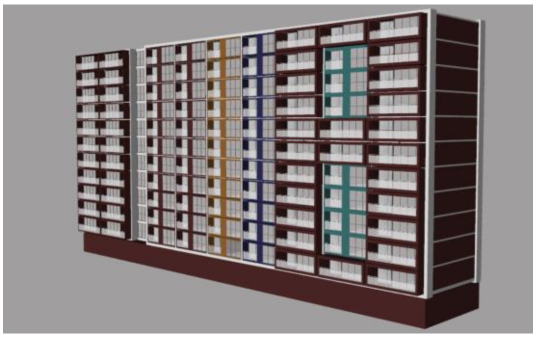
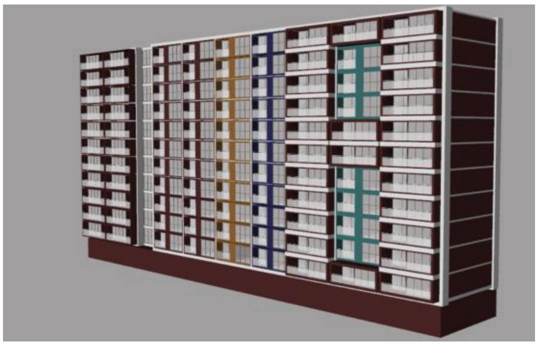
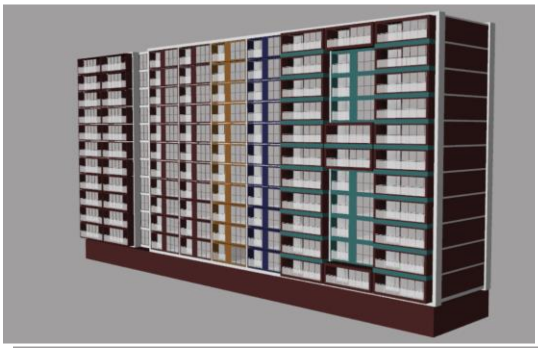
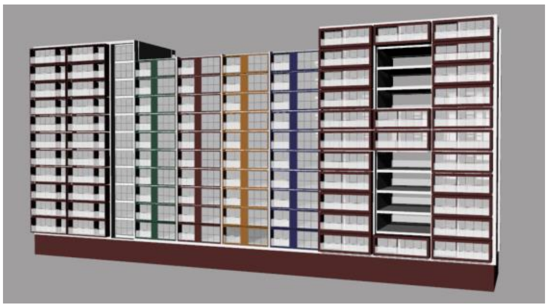
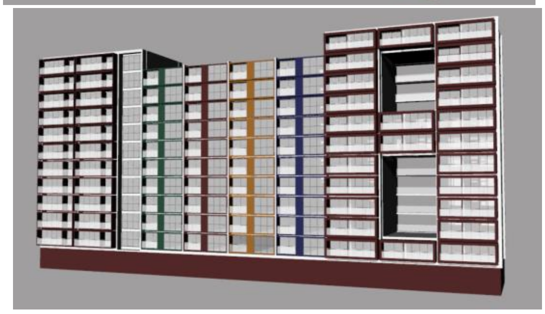
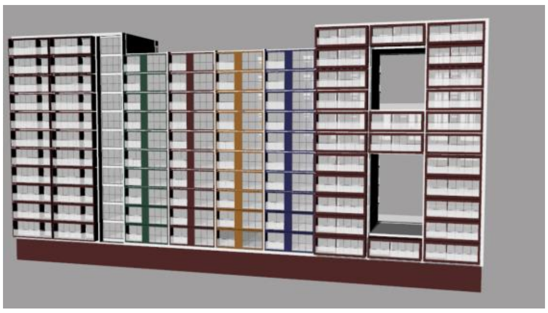
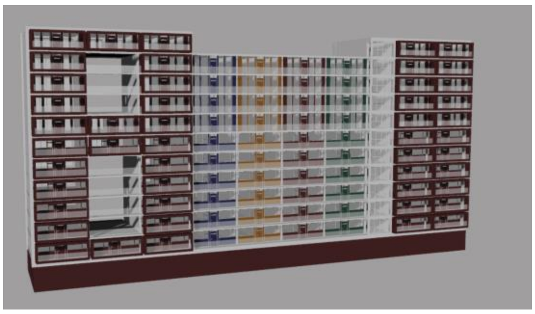
Column surface area 200x200x16= 0.011776 m2
Length columns 12.5 floors *2.8m = 35m
1 column is 35*0.011776= 0.412 m3
4 columns are required = 1.65 m3

Beam surface area 300x200x12.5 = 0.011878 m2
Length= 1m
1 beam is 1*0.011878 = 0.011878m3
2 per floor with 12 floors is 24 required = 0.285m3

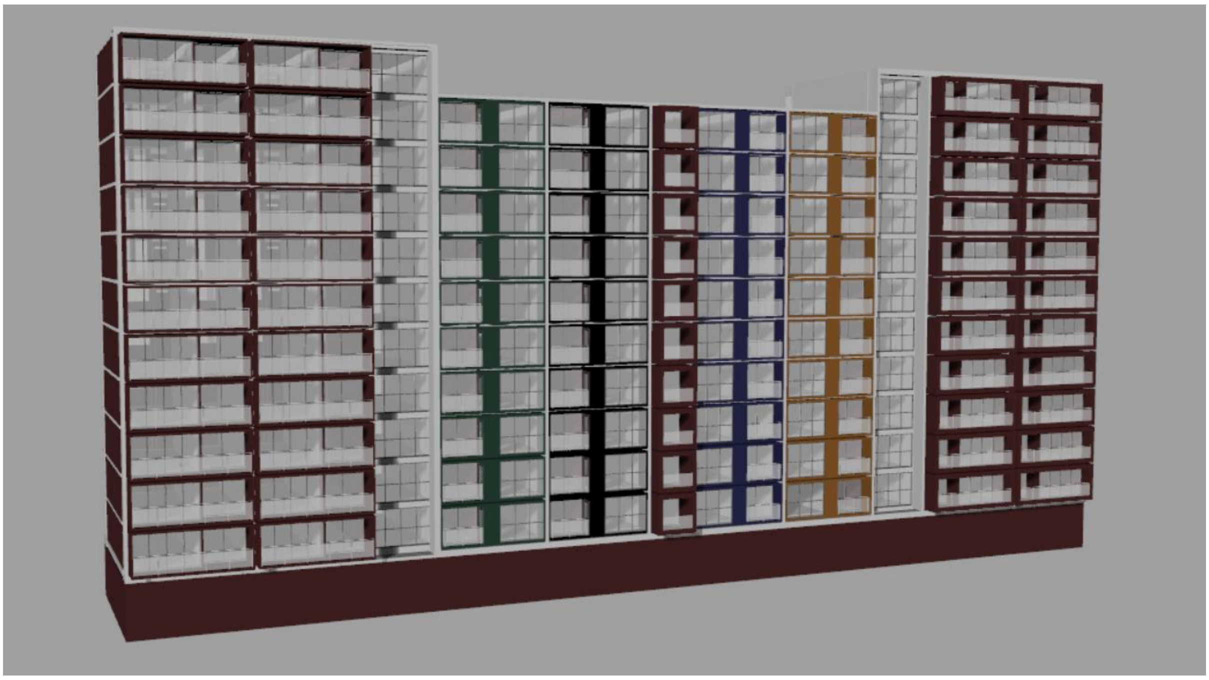
Steel structure	Density kg/m^3	Square meter m3	Kilo’s kg	Embodied energy MJ/kg	CO2 production kg
Steel (11 add-ons)	7800	1.935	15093	303370	20677
Steel per add-on			1372	27579	1880

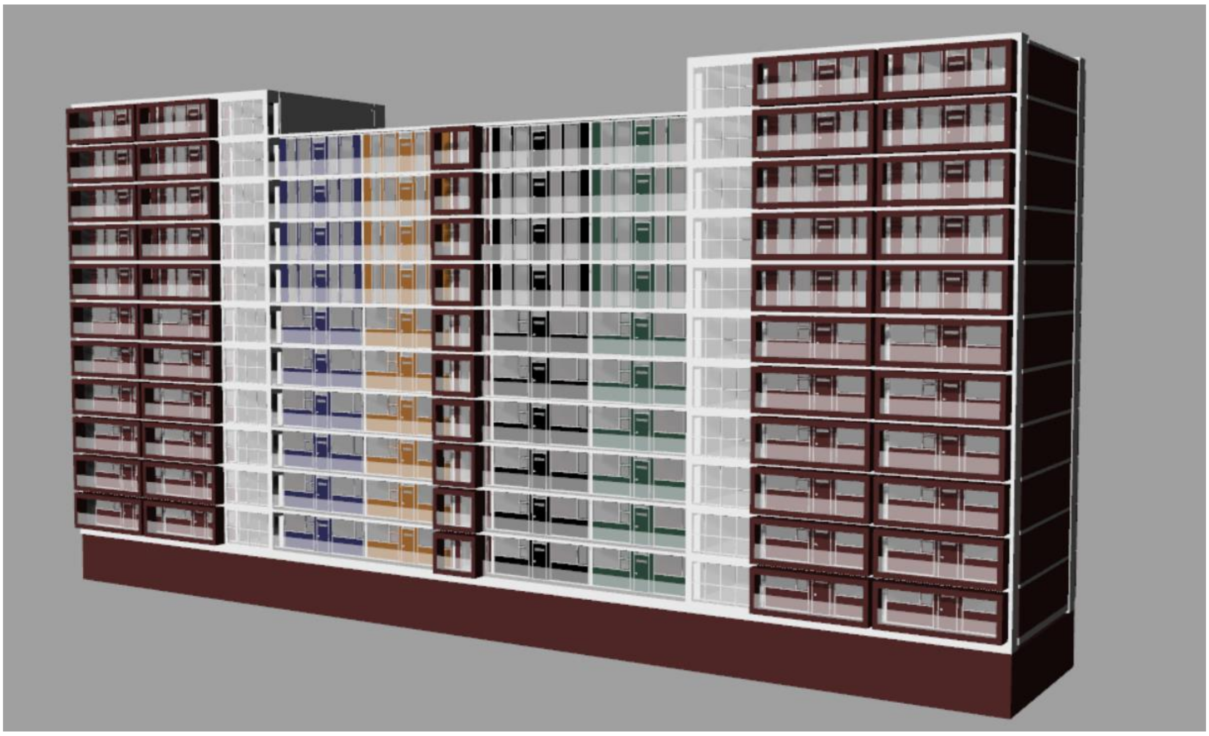
Important to note is that the wooden add-on and the concrete addon plus the added environmental impact of the steel structure still perform better than the GRP on embodied energy and CO2 production.

Case study building redesign

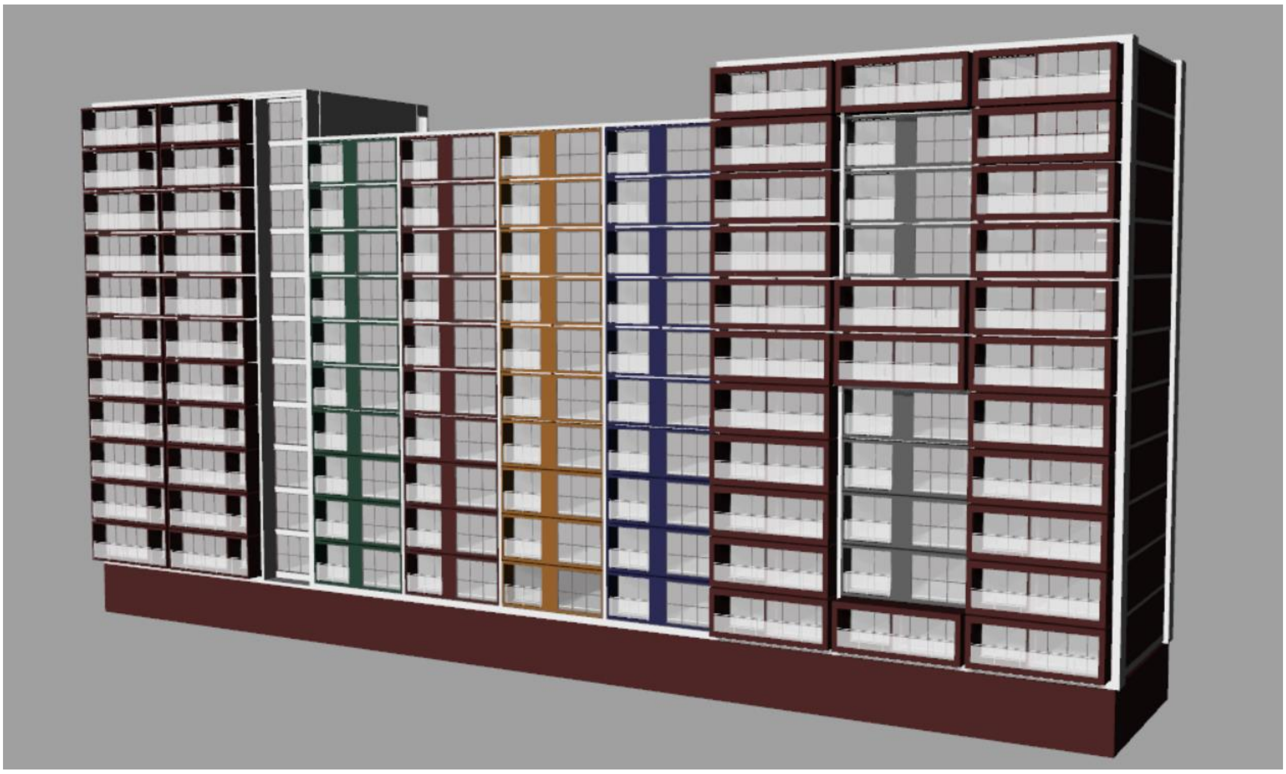











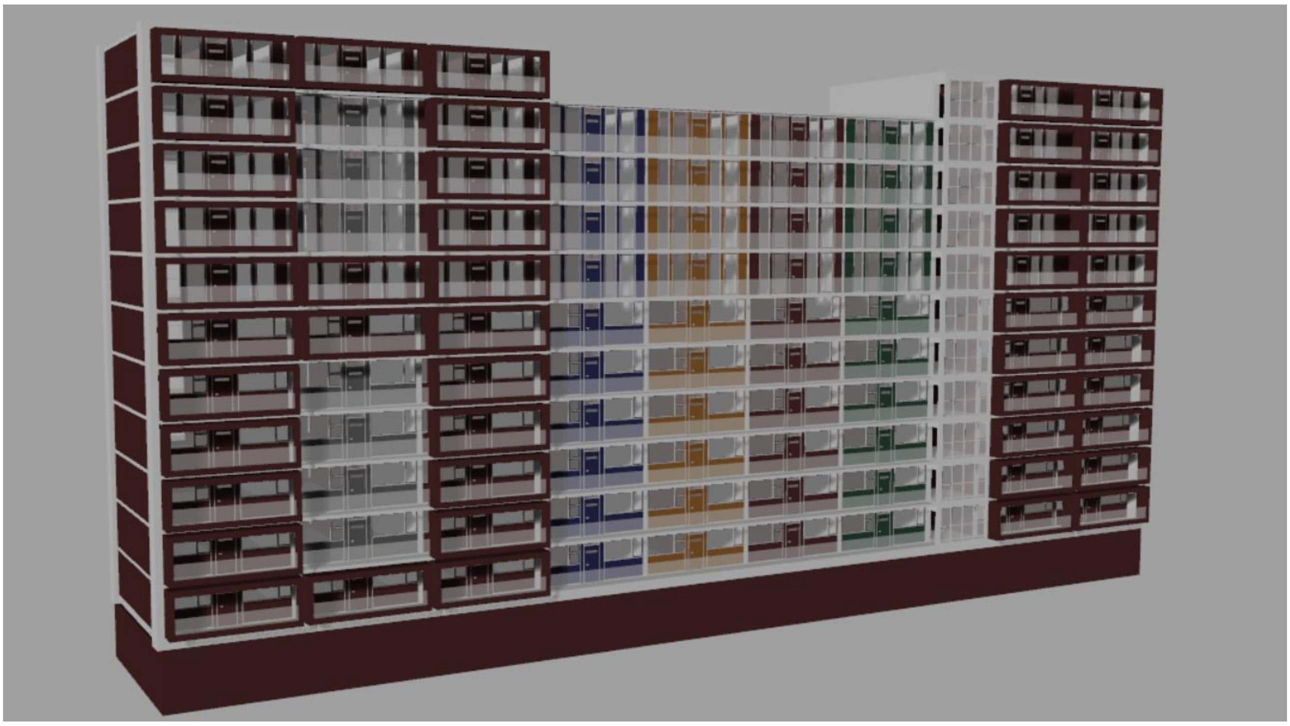
Visualizations variant 1



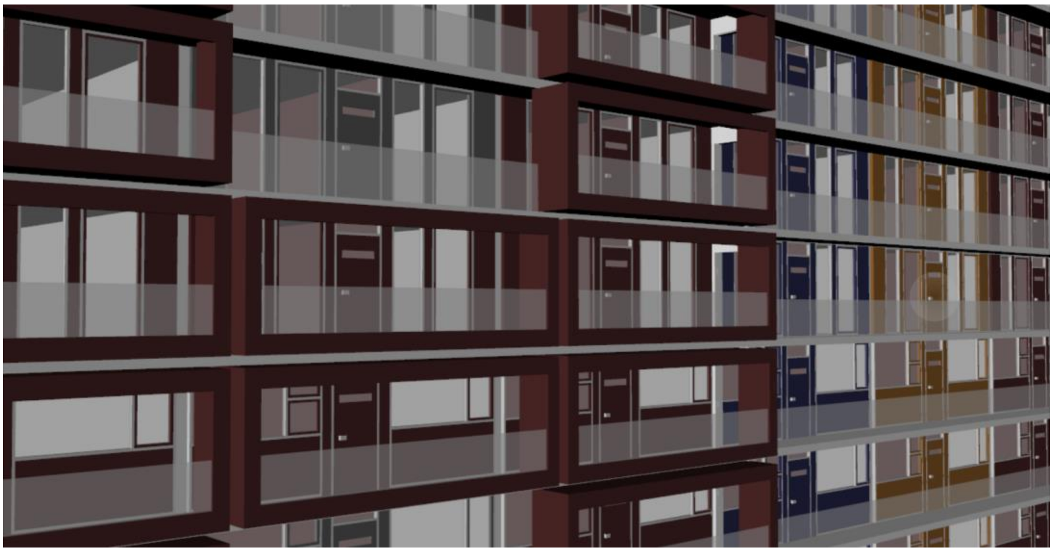


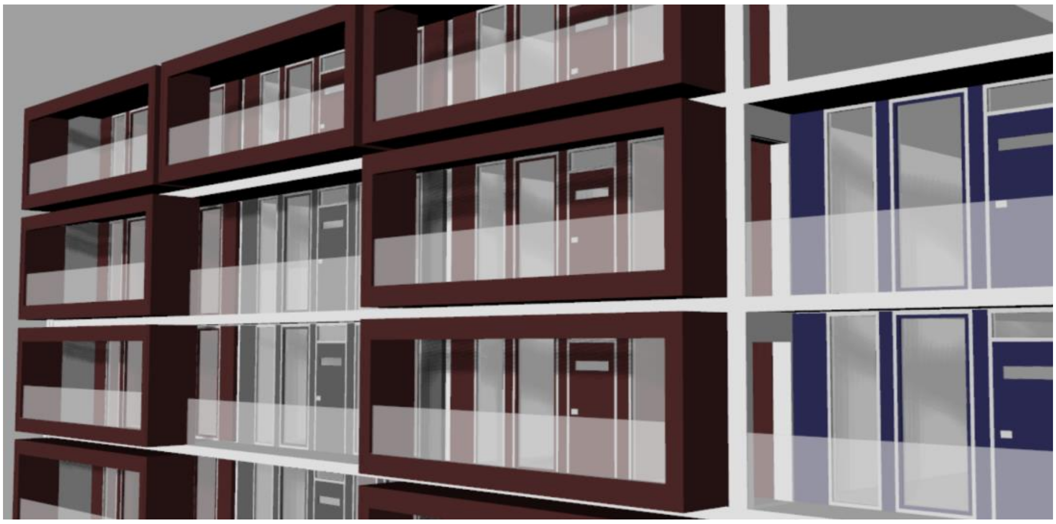
Visualizations variant 2

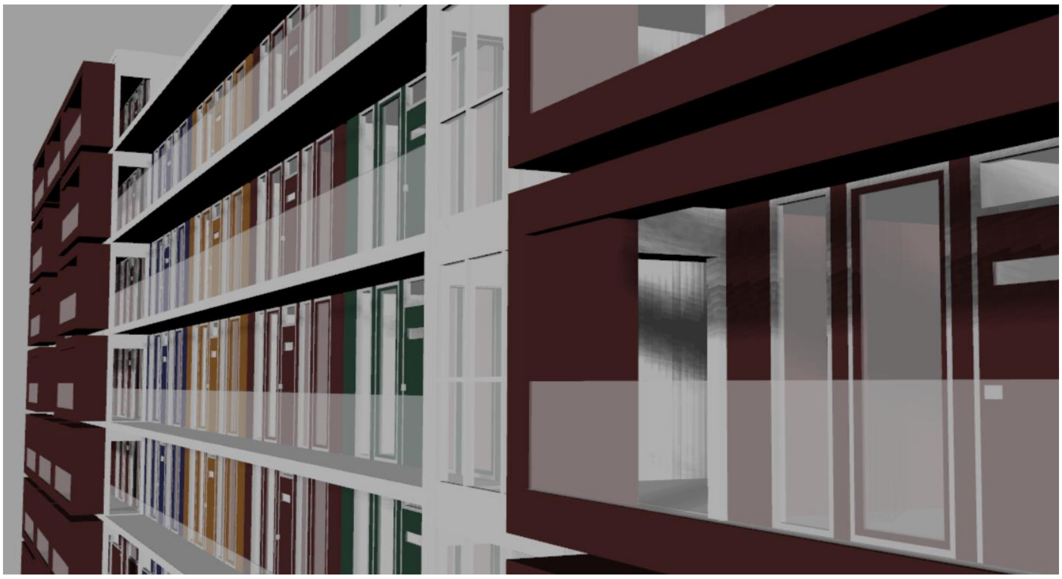




Gallery side solution







Conclusions

Current post ww 2 high rise residential buildings are facing many challenges including technical, spatial, environmental, social and financial ones. In order to tackle these problems this, report looked for a sustainable solution to be able to deal with as many of the issues as possible.

By looking at the challenges per layer building it became clear that as long as the building site and the structure of the building are still functioning well, there are many opportunities to improve the building.

After looking into the advantages and disadvantages of different approaches a refurbishment approach was chosen because a refurbishment project allows for drastic changes to the building enabling many options to deal with the existing challenges while at the same time maintaining large parts of the building which contribute to the sustainability of the overall project as resources and energy can be spared.

Within a refurbishment project there a few options to deal with the challenges a high-rise building. Because a lot of the technical and social issue where directly related to the façade of the building the façade replacement option, the wrap-it option and the add-on option seemed like the best solution.

The add-on approach was chosen because it seemed to be the most versatile approach. Not only can the add-on solve technical shortcomings of a building like thermal bridges and acoustic performance, but it also enables extension of the living areas, and the option to give the entire building a new and more diversified look which is often perceived as desirable by the residents.

Three main add-on types were looked at the hanging addon, the half supported addon and the self-supporting add-on. The choice fell on the self-supporting addon as the existing construction of the high rise residential flats was in many cases not dimensioned to handle extra weight and choosing for a hanging addon would therefore limit the possibilities very much allowing for less challenges to be solved.

Then a decision had to be made how to build up the add-ons. Using standard small element building construction methods and doing lots of work on site, would increase the time it would take to do the refurbishment dramatically. This would mean that the building would have to be emptied as it would not be usable during the construction and a loss of income for the owner. Therefore, the choice was made to go for a unitized approach. The add-ons needed to be fully prefabricated and be mounted on the building as a whole. Not only would it be possible to achieve a very high finish due to the construction happening in the factory under controlled conditions, but it would also reduce the time of the refurbishment drastically. If done well resident would only have to leave their houses for a shot time.

To develop the add-ons research was done into a case study project. The case study project dealt with a high rise flat 'De Leeuwerik' in the neighbourhood Poptahof in Delft. The flat was created in the 1960's and is in need of refurbishment as it is over fifty years old and does not meet the current sustainability standards. The flat provided a context to further develop the add-on design.

First the current state of the building was assessed. A thorough look was given to the dimensions of the building the construction type, the facades and the floorplans. Research showed that the best place to add- an addon on the building was at the side of the building opposite the gallery side.   The add-ons would be about 7 meters in with and 2.6 meters high and cover one single dwelling. By looking into the floor plans it became clear that an add-on between 1.2-2.4 meter in depth would be able to add sufficient space to the apartments to make improvements.

When trying to fit the first add-on designs onto the building it became apparent that adding separate units to an existing façade required a lot of space especially because each unit needs to have its own structural integrity a where walls and floors are usually shared between dwellings in this case each unit had its own parts. This meant that the add-ons hat to be designed in a smart way to optimize the use of space. This also had an impact on the choice of the different materials.

To make the loadbearing frame that needed to carry the add-on three material where looked at wood, concrete and steel and the decision was made to go for the steel structure. This was partially due to the limitation in space, but also because steel is very easy demountable and can be easily recused contributing to the sustainability of the design.

For the add-on three material types where looked at, wood, high performance concrete and FRP. The challenge was to find the right dimensions to handle the structural capacity while at the same time ensuring there is enough space for insulation and maintaining a reasonable floor height.

By making use of the strengths of the materials and by choosing the right types of insulation materials it became apparent that all three material options where viable. Each option has its own strengths and weaknesses. The wood for example less strong so it would need to be dimensioned bigger on the other had it requires less insulation because of its low thermal conductivity and it performs well on sustainability as wood is a renewable resource. The high performance concrete add-on was the strongest of the three options when looked at structurally. This meant that the unit could be made relatively thin. Because concrete is a very bad insulator on the other hand a thicker layer of insulation material is required, and it has to be designed very carefully to avoid thermal leaks. The third option the FRP was the lightest of the three and because it is a sandwich construction no extra insulation is required. Light weight construction can mean easier handling of the units and quicker assembly. The big downside of the FRP are the sustainability aspects. The materials are based on fossil fuels and cost large amounts of energy to make and can not be recycled.

Different design details where made of each variant to find out how to optimize each individual add-on to achieve the best performance. Because flexibility and demount ability where very important also research was done on how to connect the units easy on the building and also how to demount them. This is very important for the long-term flexibility of the building as it will be able to adapt over time to the demands of the users. It also enables the add-ons to taken away and used on other buildings extending their life time and thereby contributing to the sustainability of the design.

As the last part of the research there was some building design to see if it was actually possible to make an attractive building using the add-ons and to explore the architectural possibilities. Because of the different types of add-ons and the different sizes, colours and material types it is possible to give each building a very personal look, and due to the easy construction and demount ability it is relatively easy to adjust the looks of the building over time.

To come back on the research question:

What type of approach can ensure that post world war 2 high-rise residential buildings can keep providing a high-quality living space for their inhabitants while at the same time meet the sustainability goals for environmental, technical, spatial, social and financial viability?

The reusable add-on approach is definitely a solution that is worth using in a refurbishment project. It deals with the technical, environmental, spatial and social challenges of the building. It provides a high level of flexibility allowing for longer lifespans of buildings and a more sustainable building stock while at the same time improving upon the living standards of the residents.

.

Recommendations

Because the addon solution in this design only covers the apartment side of the building, another solution needs to be found for the other half, the gallery side of the building. In this report a visual idea is given of what this can look like, but it needs to be further developed to deal with the thermal, structural and accessibility issues of the gallery side façade.

More exact structural performance calculations of the add-on and the required frame construction should be made in order to optimize the design by minimizing loads and optimise the dimensions of each unit to ensure maximum space while maintaining good connections and structural integrity.

The sliding system to get the add-ons into the frame and out again needs to be further researched and developed. In the report a potential system is shown based on the workings of a pallet jack. This system could be further optimized, but with more research maybe even better solutions can be found that take less space and have minimal impact on the structure of the add-on while making it as easy as possible to demount the complete units.

Different building design compositions can be tested out. It would be nice if there was the opportunity for each resident to choose their own favourite add-on and be able to replace it over time if their needs change. However, the effects of this on the integrity of the building and the building composition should be looked at. Also, the plinth of the building that is often unimaginative will have to be addressed.

More financial calculations should be done to find out what the costs are going to be to produce the addon and the required frame construction to get a better estimation if it is financially viable to upgrade a building using the add-ons.

For this specific case study, a structural performance analysis of the construction of the existing building should be made to determine the condition. This to find out if it is actually worth it to save the construction and to find out what would really be possible structurally.

More research into the reuse of building parts needs to be done. What is the current market for used building parts, how easy can the parts be used on a different building and what is needed to incorporate used the building parts into a new design. Currently there are a lot of gallery flats in need of refurbishment so at this moment it is wise to invest in de add-ons but as more of the flats are demolished the usefulness of the addon might go down. So, research of how to incorporate them into new buildings would be wise.

Reflection

To determine if the project is a success a few things have to be taken into consideration. The project revolves around the question of what a good living space is and when is it sustainable. Many aspects of a good living space are quantifiable for example the technical performance and the environmental impact of a dwelling can be estimated, there are minimal spatial requirements and even financial performance can be predicted.

However, the quantification is much more complicated for the social and aesthetic elements concerning a building. What is seen as a good place to live at a certain time might not be so a few years later and the fact that a certain building or place is desirable does not only depend on the building itself but also on its surroundings and personal preference.

Meeting the technical, environmental, financial and spatial demands does not automatically ensure that the quality of a dwelling is good and certainly not over longer time spans. An important aspect therefore is being able to adapt a building over time to comply with new demands and trends.

Because the design is part of a refurbishment project and the original buildings were not designed with the goal of adaptability in mind keeping these buildings up to date over longer time spans can become quite a challenge. It is therefore very important to consider if it is in the long term more beneficial to keep the existing buildings and invest resources and materials into making them comply as good as possible to current standards with the risk that they are still suboptimal, versus a replacement strategy that includes designing a new building that is up to current standards, and is designed to easily be changed over time.

In this project it was chosen to keep the building to see what was possible in order to help decision making about what to do with a building when it is no longer up to date. This to make a well-founded decision considering all the qualities that are necessary for a well-functioning building (technical, social, financial, environmental and spatial). The final decision to choose for the add-on refurbishment strategy depends on the timespan in which the building is still expected to function and the condition and location of the current building. The approach is best suited for a building that is in a good condition and is in a desirable location.

For this specific project the addon solution was chosen over the wrap it strategy and façade replacement strategies even though these were also viable options, because it is a complete approach that targets the same challenges as the other two options but also has the possibility to add space to a dwelling and more drastically change the appearance of the flat. The choice for the addon is a long-term approach that tries to extend the lifetime of the building maximally in order to preserve the already available resources and reduce the energy consumption of the building. However, in the case that the situation changes, and it is decided that the building has to be demolished, the addons can quickly be demounted and reused on a different flat while maintaining their value and this is where I think that the real strength of this project lies.

References

Abbas, S., Nehdi, M. L. & Saleem, M. A., 2016. Ultra-High Performance Concrete: Mechanical Performance, Durability, Sustainability and Implementation Challenges. *International Journal of Concrete Structures and Materials,* 10(3), pp. 271-295.

Adelaide Hydronic Heating, 2017. *Heating and Wellbeing.* [Online]
Available at: http://www.adelaidehydronicheating.com.au/heatpumps.html
[Accessed 24 September 2017].

AD & Oremus, F., 2017. *TU krijgt 45 miljoen voor koppeling aardwarmte.* [Online]
Available at: https://www.ad.nl/delft/tu-krijgt-45-miljoen-voor-br-koppeling-aardwarmte-br~a60c54a9/
[Accessed 23 September 2017].

Agentschap NL, 2011. *De kunst van duurzame energietransitie, Innovatieve gebiedsontwikkeling in de praktijk,* Utrecht: Agentschap NL, Ministerie van Binnelandse Zaken en Koningkrijksrelaties.

Allesoverzonnepanelen, 2017. *Alles over zonnepanelen.* [Online]
Available at: http://www.allesoverzonnepanelen.nl/voorwaarden/dakhelling/
[Accessed 20 august 2017].

Allesoverzonnepanelen, 2017. *Verschil tussen monokristallijne en polykristallijne zonnepanelen.* [Online]
Available at: http://www.allesoverzonnepanelen.nl/kennisbank/productie-van-silicium-zonnecellen/soorten_kristallijne_zonnecellen/verschil-tussen-monokristallijne-en-polykristallijne-zonnepanelen/
[Accessed 4 September 2017].

Andeweg, M., 2013. *Niet-traditionele bouwmethoden uit de periode 1945-1965,* Delft: Tu Delft.

Apricus, 2017. *Flat Plate Solar Collectors.* [Online]
Available at: http://www.apricus.com/flat-plate-solar-collectors-3/#.WbZdUCgjFPY
[Accessed 8 September 2017].

Aviodrome air photography, 1965 -1970. *Poptahof after completion.* Lelystad: s.n.

Aviodrome, air photography, 1963. *Construction of the Poptahof.* Lelystad: s.n.

Battum, M. v., 2002. *Enige (on)mogelijkheden van portiekagewoningen bij herstructurering van vroeg naoorlogse wijken,* Delft: Faculteit Bouwkunde afdeling Volkshuisvesting en Stadsvernieuwing.

Brand, S., 1994. *How Buildings Learn, What happens after they are built.* New York: Viking Press.

BRIS bouwbesluit online, 2012. *Bouwbesluit online 2012.* [Online]
Available at: http://www.bouwbesluitonline.nl/Inhoud/docs/wet/bb2012/hfd3/afd3-6
[Accessed 20 juli 2017].

Brouwers, R. G. D. d. & Heeswijk, H. v., 2013. *Nieuwe kansen voor de galerijflat, Ideeën en aanbevelingen voor de komende vijftig jaar.* Amsterdam: NDCC.

Centrometal, 2017. *CVSKC-10 (vacuum tube solar collector).* [Online]
Available at: http://www.centrometal.hr/en/cvskc-10/
[Accessed 2017 September 2017].

CES edupack , 2017. *CES database,* Cambridge: Granta.

Cisco Eagle, 2018. *Ox Pallet Truck.* [Online]
Available at: http://www.cisco-eagle.com/catalog/product/153895/ox-pallet-truck-48-long-x-27-wide
[Accessed 12 April 2018].

ClimaRad, 2016. *ClimaRad 2.0.* [Online]
Available at: http://www.climarad.nl/wp-content/uploads/2015/11/ClimaRad_2.0_productinformatie-2016.004.pdf
[Accessed 22 September 2017].

Derbigum, 2018. *Vegetal Reflective membrane.* [Online]
Available at: http://me.derbigum.com/products-solutions/ecological-solutions/vegetal-reflective-membrane
[Accessed 4 April 2018].

Dobbelsteen, A. v. d., Huijbers, K. & Yanovshtchinsky, V., 2013. *Architectuur als klimaatmachine, Handboek voor duurzaam comfort zonder stekker.* Amsterdam: SUN.

Duijvestein, C. & Dorst, M. v., 2004. *Concepts of sustainable development.* Manchester, University of Manchester.

Duijvestein, K., 1997. *Ecologisch bouwen.* Delft: Tu Delft, Faculty of Architecture.

ECN, 2016. *Energietrends 2016,* s.l.: ECN Energie-Nederland, Netbeheer Nederland.

EGM architecten, 2017. *Stadsdeelcomplex, Zeer milieuvriendelijk en energiezuinig gebouw in Leidschenveen-Ypenburg.* [Online]
Available at: https://www.egm.nl/projecten/79
[Accessed 18 September 2017].

Elkington, J., 1997. *Canibals with Forks.* Oxford: Capstone Publishing.

Ellen Macarthur Foundation, 2012. *Towards the circular economy, Economic and business rationale for an accelerated transition,* Cowes: Ellen Macarthur Foundation.

Envirovent, 2017. *heatSava.* [Online]
Available at: http://www.envirovent.com/specifier/products/single-room-heat-recovery/heatsava/
[Accessed 21 September 2017].

EPEA & Returnity Partners, 2015. *Cradle to Cradle: The Cradle of the Circular Economy.* [Online]
Available at: http://epea-hamburg.org/en/content/cradle-cradle-cradle-circular-economy
[Accessed 15 April 2017].

European Comission, 2016. *ec.europa.eu.* [Online]
Available at: http://ec.europa.eu/environment/archives/eussd/index.htm
[Accessed 29 01 2017].

European Commission, 2017. *Circular Economy: Commission delivers on its promises, offers guidance on recovery of energy from waste and works with EIB to boost investment,* Brussels: European Commission.

eurostat, 2015. *Sustainable development in the European Union, 2015 monitoring report of the EU Sustainable,* Luxembourg: European Union.

Evides, 2017. *Duurzame warmte voor woningen in Delft.* [Online]
Available at: https://www.evidesindustriewater.nl/duurzame-warmte-voor-woningen-in-delft/
[Accessed 25 September 2017].

ExSolar, 2017. *Monocrystalline vs Polycrystalline vs Thin film Solar Panels.* [Online]
Available at: http://www.exsolar.co.za/mono-vs-poly-vs-thin-film-panels.html
[Accessed 18 August 2017].

Funda, 2016. *www.funda.nl.* [Online]
Available at: http://www.funda.nl/koop/verkocht/capelle-aan-den-ijssel/appartement-49712818-wilgenhoek-55/
[Accessed 20 April 2017].

Geldermans, R., 2016. Design for Change and Circularity. *Elsevier,* Volume 96, p. 11.

Geldermans, R. & Rosen-Jacobsen, L., 2015. *Circular material & product flows in buildings,* Delft: Delft University of Technology.

Google maps, 2017. *Poptahof.* Delft: Google.

Graaf, A. v. d., 2005. Heat pump for comfort, with added energy savings. *Delft Outlook, 2,* p. 6.

Gruis, V., Visscher, H. & Kleinhans, R., 2006. *Sustainable neighbourhood transformation,* Amsterdam: IOS Press.

Hammond, G. & Jones, C., 2011. *Inventory of Carbon & Energy (ICE) version 2.0,* Bath: University of Bath.

Hekkenberg, E., 2011. *Efficiënte herstructurering, Een onderzoek naar de mogelijkheden van meer flexibiliteit in de stedelijke herstructureringsplannen van woningcorporaties,* Mijdrecht: Amsterdam School of Real Estate.

Hermelink, A. H. & Müller, A., 2011. *Econimics of deep renovation,* Berlin: Ecofys by order of Eurima - European.

Hewalex, 2017. *Solar collector KS2000 TLP.* [Online]
Available at: http://www.hewalex.eu/en/offer/flat-plate-collectors/solar-collector-ks2000-tlp.html
[Accessed 8 September 2017].

IBIS Power, 2017. *PowerNest.* [Online]
Available at: http://www.ibispower.eu/products/powernest-2/
[Accessed 6 September 2017].

ISSO, 2017. *9.3.5 Zonneboiler.* [Online]
Available at: https://kennisbank.isso.nl/docs/overig/energievademecum/2015/9/9.3/9.3.5
[Accessed 9 September 2017].

Jin-Hee, K. & Jun Tae, K., 2012. Comparison of Electrical and Thermal Performances of Glazed and Unglazed PVT Collectors. *International Journal of Photoenergy,* Volume 2012, p. 7.

Jin-Hee, K. & Jun Tae, K., 2012. *The experimental performance of an unglazed PV-thermal collector with a fully wetted absorber,* s.l.: Elsevier Ltd.

Jupiter, 2017. *Jupiter IDEAL EPS 30.* [Online]
Available at: http://www.jupiter-idealeps.nl/jupiter-ideal-eps/
[Accessed 23 September 2017].

Klimaatatlas, 2017. *Klimaatatlas, gemiddelde globale straling 1981-2010.* [Online]
Available at: http://www.klimaatatlas.nl/klimaatatlas.php
[Accessed 23 august 2017].

Klimaatatlas, 2017. *Klimaatatlas, Gemiddelde jaarlijkse windsnelheid 1981-2010.* [Online]
Available at: http://www.klimaatatlas.nl/klimaatatlas.php
[Accessed 23 August 2017].

Knaack, U., Klein, T., Bilow, M. & Auer, T., 2007. *Facades, Principles of construction.* Basel: Birkhäuser Verlag.

Konstantinou, T., 2014. *Facade Refurbishment Toolbox, Supporting the Design of Residential Energy Upgrades,* Delft: Architecture and the Built Environment.

Konstantinou, T., 2015. A Methodology to Support Decision-Making Towards an Energy-Efficiency Conscious Design of Residential Building Envelope Retrofitting. *Buildings, 5,* p. 21.

Konstantinou, T. et al., 2015. *An integrated design process for a zero-energy refurbishment prototype for post-war residential buildings in the Netherlands.* South Africa, CIB, p. 10.

Konstantinou, T. & Knaack, U., 2001. Refurbishment of Residential Buildings: A Design Approach to Energy-Efficiency Upgrades. *Elsevier,* p. 10.

Kristinsson, J., 2010. *Ademend raam.* [Online]
Available at:
http://www.kristinssonarchitecten.nl/projecten/projecten.php?framehoogte=&insertframe=&ins

ertfram=&projectgroep=innovaties---&projectnaam=Ademend%20raam
[Accessed 20 September 2017].

Kristinsson, J., 2012. *Integrated sustainable design.* Delft: Delft Digital Press.

Kruijff, K., 2006. *Warmte voor Delft, Europees demonstratieproject SESAC,* Delft: Gemeente Delft.

Leupen, B. & Mooij, H., 2008. *Het ontwerpen van woningen, Een handboek.* Rotterdam: NAi uitgevers.

Liebregts, M., 2013. *Muwi-bouwsysteem, het meest verspreide bouwsysteem,* Eindhoven: Kennisbank bestaande woningbouw.

Lunos , 2017. *Regulated ventilation with e^2 with heat recovery.* [Online]
Available at: http://www.lunos.de/en/product/e_with_heat_recovery/
[Accessed 21 September 2017].

Maehlum, M. A., 2017. *Which Solar Panel Type is Best? Mono- vs. Polycrystalline vs. Thin Film.* [Online]
Available at: http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/
[Accessed 4 september 2017].

Mazure, J., (1959) . Systeembouw. *De ingenieur*, August.

McDonough, W. & Braungart, M., 2002. *Cradle to Cradle, Remaking the Way We Make Things.* New York: Macmillan.

Middelkoop, R., 2017. *Mono-, Ploy-, of dunne film panelen?,* Weesp: Solar Clarity.

Milieu Centraal, 2017. *Gemiddeld energieverbruik.* [Online]
Available at: https://www.milieucentraal.nl/energie-besparen/snel-besparen/grip-op-je-energierekening/gemiddeld-energieverbruik/

Milieu Centraal, 2017. *Hoe werken zonnepanelen.* [Online]
Available at: https://www.milieucentraal.nl/energie-besparen/zonnepanelen/hoe-werken-zonnepanelen/
[Accessed 3 September 2017].

Milieu centraal, 2017. *LTV lagetemperatuurverwarming.* [Online]
Available at: https://www.milieucentraal.nl/energie-besparen/energiezuinig-huis/energiezuinig-verwarmen-en-warm-water/ltv-lagetemperatuurverwarming/
[Accessed 23 September 2017].

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2016. *Cijfers over Wonen en Bouwen 2016,* Den Haag: Ministerie van Binnenlandse Zaken en Koninkrijksrelaties.

Ministerie van Economische Zaken, 2016. *Energierapport, Transitie naar duurzaam,* Den Haag: Ministerie van Economische Zaken.

Ministerie van Infrastructuur en Milieu, 2016. *Nederland circulair in 2050, Rijksbreed programma Circulaire Economie,* Den Haag: Ministerie van Infrastructuur en Milieu.

Molenaar & Co, 2009. *Poptahof Delft.* [Online]
Available at: http://molenaarenco.nl/architectuur-projecten/67/poptahof-delft/
[Accessed 15 March 2017].

Mustard, S., Rowlands, R. & Kempen, R. v., 2009. *Mass Housing in Europe: Multiple Faces of Development, Change and Response,* London: Palgrave Macmillan.

NIBE database, 2018. *Milieu classificaties.* [Online]
Available at: https://www.nibe.info/nl
[Accessed 4 march 2018].

Palmbout, 2004. *Delft Poptahof.* [Online]
Available at: http://palmbout.nl/cubeportfolio/delft-%C2%AD-poptahof/?lang=en
[Accessed 15 March 2017].

Pflug, M., 2015. *1945 Woningnood: volksvijand nummer 1, Wederopbouw en het ingrijpen van de overheid,* Amsterdam: Canon volkshuisvesting nederland.

Poel, B., Cruchten, G. v. & Balaras, C. A., 2007. Energy performance assessment of existing dwellings. *Energy and Buildings,* Issue 39, p. 393–403.

Poolheatpumps, 2017. *Solar Panels for Pool.* [Online]
Available at: http://www.pool-heater-pumps.com/solar-pool-heating/techno-solis/4x12-solar-pool-panel-2inch-header.html
[Accessed 8 September 2017].

Poptahof, 2017. *Poptahof.* [Online]
Available at: http://www.poptahof.nl/poptahof-in-beeld/planning-poptahof/

Quietrevolution, 2017. *The qr6 vertical axes wind turbine.* [Online]
Available at: https://www.quietrevolution.com/
[Accessed 5 September 2017].

Raghab, M., 2015. *Vertical axis wind turbines,* s.l.: s.n.

Ramos, A. et al., 2017. *Solar-Thermal and Hybrid Photovoltaic-Thermal, Systems for Renewable Heating,* London: Imperial College London.

Reda, F., 2017. *Solar assisted ground source heat pump solutions : effective energy flows climate management.* Cham: Springer.

Roeloffzen, J., Lanting, R. & Scholten, N., 2004. *High-Rise Housing In The Netherlands: Past, Present And Sustainability Outlook,* Delft: TNO Bouw.

Sark, W. v., 2014. *Opbrengst van zonnestroomsystemen in Nederland,* Utrecht: Universiteit Utrecht .

Scholte, W. & Damen, T., 1998. Kleine woning meest kwetsbare catergorie. Nadere analyse van de aandachtsvoorraad. *Renovatie & Onderhoud*, June, pp. 8-11.

Smets, A. et al., 2016. *Solar energy, the physics and engineering of photovoltaic conversion technologies and systems.* Cambridge : UIT.

Somer, K., 2007. *De functionele stad, De CIAM en Cornelis van Eesteren, 1928-1960.* Rotterdam: NAi Publishers.

Sopogy, 2017. *SopoHelios MicroCSP Collector.* [Online]
Available at: http://sopogy.org/blog/tag/concentrating-solar-power/
[Accessed 8 September 2017].

Stegers, R., 2009. Stoere zonneschoorstenen voor natuurlijke ventilatie. *VMRG vereniging metalen ramen en gevelbranche,* p. 4.

Straub, A. & Vijverberg, G., 2015. *Verbeteren van de woontechnische kwaliteit van de sociale huurwoningvoorraad,* Utrecht: Nethur.

Tesla, 2017. *Tesla powerwall.* [Online]
Available at: https://www.tesla.com/powerwall
[Accessed 7 augustus 2017].

Thiel, L. v., 2014. *Watergebruik Thuis 2013,* Amsterdam: TNS Nipo.

TNO, 2015. *Vervangende Nieuwbouw,* Delft: TNO.

Turkington, R., Kempen, R. v. & Wassenberg, F., 2004. *High-rise housing in Europe: Current trends and future prospects,* Delft: Delft University Press.

Vergoossen, R., 2016. *Ultra High Performance Concrete, AR0532 Innovation & Sustainability,* Delft: Royal HaskoningDHV.

Vlis, I. v. d., 2005. *Poptahof, Een delftse buurt vol idealen.* Delft: Van Marken Delft Drukkers.

Wiki Delft, 2017. *www.wikidelft.nl.* [Online]
Available at: http://www.wikidelft.nl/index.php?title=Poptahof-noord_(buurt)

Windfinder, 2017. *Windfinder, wind and weather statistics Delft.* [Online]
Available at: https://www.windfinder.com/windstatistics/delft
[Accessed 8 september 2017].

Windside, 2017. *WS-4.* [Online]
Available at: http://www.windside.com/products/ws-4
[Accessed 5 September 2017].

Woningnet Haaglanden, 2017. *Woningnet Haaglanden Woningaanbod.* [Online]
Available at: https://www.woonnet-haaglanden.nl/woningaanbod/totale-aanbod/details/?dwellingID=171628
[Accessed 20 March 2017].

Woonbron, 2014. *Poptahof door de Jaren heen.* [Online]
Available at: http://www.poptahof.nl/poptahof-1962/
[Accessed 10 March 2017].

Zonnepanelen weetjes, 2017. *zonnepanelen weetjes.* [Online]
Available at: https://www.zonnepanelen-weetjes.nl/zonnepanelen-kopen/
[Accessed 19 august 2017].

Zonnepanelen-weetjes, 2017. *Rendement zonnecollector.* [Online]
Available at: https://www.zonnepanelen-weetjes.nl/zonnecollector/rendement-zonnecollector/
[Accessed 10 September 2017].

Zonwatt, duurzame energie, 2017. *zonwatt.* [Online]
Available at: http://www.zonwatt.nl/zonnepanelen-technische-informatie/
[Accessed 20 august 2017].

Appendix A

Spatial Design Options

The gallery typology is typical for the post ww2 residential high-rise flats. The usually similar apartments of the flats are placed in rows and stacked into a multilayer slab with on one of the long sides galleries to make the dwelling accessible. On the other side of the flat there is usually a similar space in the form of a balcony functioning as outdoor space. A big advantage is that daylight can enter the dwelling from two sides and also outdoor view is to both sides of the building.

The gallery flats also have a few disadvantages. The first one is that because the gallery is along the façade it disrupts the privacy of the adjacent rooms. This can be dealt with by placing the rooms with higher privacy sensitivity on the opposite façade and by keeping window openings along the gallery small. This however is not optimal and usually one or multiple rooms including a bedroom will have privacy issues or noise hindrance due to placement along the gallery façade. Other options are creating more space between the façade and the gallery or even lowering the gallery relatively to the dwelling to avoid direct inwards view. This is however not always possible and might lead to extra costs.

The second disadvantage is that part of the façade is being occupied by the entrance and further circulation space to get to the other rooms in the apartment. Not much can be done about this except from keeping the entrance as minimal as possible.

A third disadvantage is that the galleries take away daylight from the apartments situated below. This can be avoided by using maisonette type dwellings and extending the upper façade to the edge of the balcony. An added benefit of maisonette type apartments is also that there is only one gallery needed per two or even three apartment layers. Because there are less galleries this also frees up an extra façade for rooms that require privacy. A big disadvantage of the maisonettes is the fact that they require staircases that take up space otherwise usable as living area (Leupen & Mooij, 2008, p. 154).

Minimal required room dimensions
Minimal room dimensions vary per resident composition. For gallery flats 1 -4 residents can be expected. In general, these residents can be divided into four main groups: starters, two-person households, families and seniors (Battum, 2002, p. 29).

For starters, an apartment with two bedrooms is sufficient. They are usually a one-person household so one bedroom could be sufficient, but an extra room can serve as study or guest room and can also be used in case of family expansion. The room dimensions are as follow (Battum, 2002, p. 31):

living room	3.15 * 3.95 meters
dining room	3.15 * 2.20 meter

main bedroom	3.25 * 2.70 meters
second bedroom	1.80 * 2.80 meters
kitchen	1.80 * 2.40 meters or 1.80 * 3.00 meters
bathroom	1.10 * 1.80 meters
toilet	1.15 * 0.85 meters
outdoor space	minimal
storage room	5.00 square meters

The biggest issues with these dimensions concerning current flats are that often the living room, dining room combination lacks the required space of 19.4 m^2. So, to make the current flats viable for today's standard a solution needs to be found to deal with this.

For two persons households, a two-bedroom apartment is also sufficient, but it should be more spacious than a starter apartment providing more flexibility. The room dimensions are as follow (Battum, 2002, p. 34):

living room	3.75 * 3.95 meters
dining room	3.70 * 2.70 meter
main bedroom	3.85 * 2.70 meters
second bedroom	2.20 * 2.80 meters
kitchen	1.80 * 3.00 meters or 1.80 * 3.60 meters
bathroom	1.60 * 1.70 meters
toilet	1.15 * 0.85 meters
outdoor space	2.90 * 1.70 meters
storage room	5.00 square meters

The biggest issues with these dimensions concerning current flats are that often times the living room is too small. The second compartment of the flat is not wide enough for the main bedroom. The bathroom is too small, and the outdoor space should be big enough to fit a four-person table (Battum, 2002, p. 34).

For family apartments, the minimum requirement is three bedrooms. The second and third bedroom can be of comparable size. The kitchen should be a bit bigger offering more storages space and the bathroom should offer more space. The room dimensions are as follow (Battum, 2002, p. 35):

living room	3.75 * 3.95 meters
dining room	3.70 * 2.70 meter
main bedroom	3.85 * 2.70 meters
second bedroom	2.20 * 2.80 meters
third bedroom	2.20 * 2.80 meters
kitchen	1.80 * 3.00 meters or 1.80 * 3.60 meters
bathroom	2.05 * 1.70 meters
toilet	1.15 * 0.85 meters
outdoor space	20 square meters
storage room	7.0 square meters

The biggest issues concerning current flats if they want to be applicable to current day standards for families is that the living room is often too small, the third bedroom is not there or is too small, the bathroom is not big enough and there is a lack of outdoor space.

For seniors, a two-bedroom apartment should be sufficient. It is important to note that elderly usually have less to spent so the house should be small to be affordable but also big enough to move around with a walking aid. The room dimensions are as follow (Battum, 2002, p. 37):

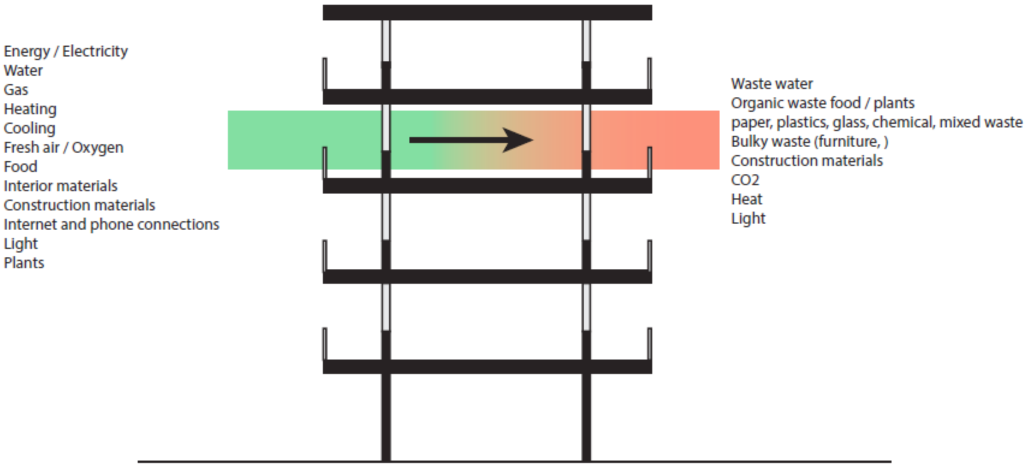
living room	3.35 * 4.15 meters
dining room	3.35 * 2.40 meter
main bedroom	3.45 * 2.90 meters
second bedroom	2.20 * 2.80 meters
kitchen	1.80 * 2.40 meters or 1.80 * 3.00 meters
bathroom	2.10 * 1.75 meters
toilet	1.15 * 0.85 meters
outdoor space	2.90 * 1.70 meters
storage room	5.00 square meters

The biggest issues concerning current flats if they want to be applicable for seniors is the associability. When that is arranged, the living room should be enlarged together with the bathroom and the outdoor space to reach current day spatial requirements and to enable the seniors to easily move through the house (Battum, 2002, p. 36).

Appendix B

Building streams

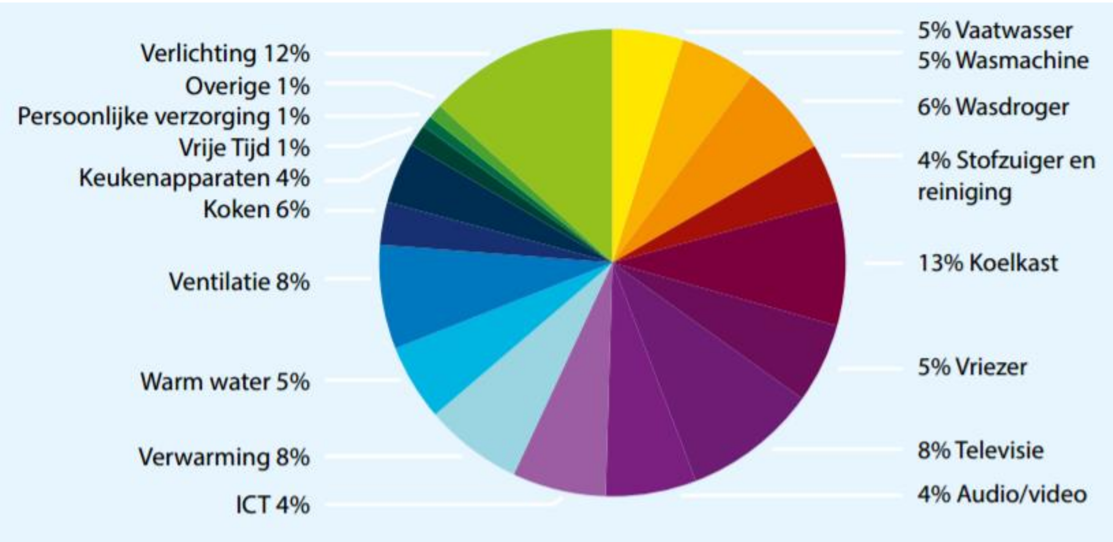
To be able to improve upon the current building systems in is important to map the current building streams of high rise residential buildings in order to find out how much improvement can be made by using different systems.



Steams (own image)

For some of the streams it is not possible to influence them by building design as they have more to do with consumer choices. For the stream that can be addressed and or made circular within the building a short description and estimate of the total amount will be given.

Electricity
The average Dutch household consisting of 2.2 persons uses about 3000 kWh of energy per year (ECN, 2016, p. 7). With the biggest consumption coming from the fridge, lighting, ventilation and heating.



Electricity use per appliance (ECN, 2016, p. 9)

Gas
The gas usage of the average Dutch household consisting of 2.2 persons is about 1432 m^3 (ECN, 2016, p. 7). Most of this gas is used for heating but in some households also for cooking. Even though the use of gas is on the decline it will still require some effort to stop using this type of fossil fuel.

Heating / Cooling
For homes that do not use gas for heating but city or district heating the amount is around 35 GJ. About 7GJ is for warm water and the other 28 for heating (Milieu Centraal, 2017).

Water
The average person in a Dutch household uses 119 litres of water per day. From this amount about 51 litres are used for showering 34 litres for flushing the toilet and about 14 litres for washing in the washing machine which accounts for up to 83% of the total water usage (Thiel, 2014, p. 8). The rest of the water is spread out over other tasks requiring water like cooking, drinking and washing hands.

Air
The minimum required air capacity per room is 7 l/s per person. For living area's an amount of 0.9 $l/s/m^2$ is required and at least 50% needs to be clean air from outside the building. A kitchen area requires at least 21l/s. The toilet room requires 7l/s. The bathroom requires 14 l/s.

The utility closet requires 2l/s. A storage room requires 7l/s and this is the same for the laundry cabinet unless it is bigger than 2.5m^2 then it requires 14 l/s. The maximum airspeed allowed is 0.2 m/s to avoid air draft (BRIS bouwbesluit online, 2012).

Construction materials
Construction materials are harder to quantify as parts of them might last as long as the building, but it is important to choose the right materials that are not scarce or toxic and that can be reused or recycled at the end of their lifetime.

Options sustainable building systems

There are many building systems that can be used but because sustainability is an important aspect, only systems that make use of renewable resources will be discussed. The systems also need to be applicable on high rise residential buildings and maintain their function in an urban area.

Electricity
To be able to provide the buildings with a clean sustainable form of electricity there are a few options. The easiest one is to take electricity from the net from companies that use renewable energy sources. These sources include solar, wind, tidal, wave, hydroelectrical, geothermal, biofuel, biomass and biogas energy. Downsides of using the net is that there is not enough renewable energy yet to provide everyone with energy and sustainable sources are prone to fluctuating prices until better storage solutions are found.
Of the sustainable electricity producing systems only solar, wind and biofuel / biogas can be used on the scale of a single building. As it is inefficient to produce biofuels and biogas on a small scale for a single building they will most likely have to be brought form a separate production facility outside the building. This leaves wind and solar as the two main sources of locally small scale produced energy.

Solar energy is harvested by install photovoltaics on the building to capture local energy provided by the sun. This is a good option however the yield will most likely not be sufficient to provide all the dwellings with power and as the sun does not shine at night there needs to be some storage mechanism or connection to the net. Because high rise flats have a limited surface to put the panels and up to 100 households, the surface is in most cases not enough. Current photovoltaic panels yield about 100-125 kwh/m^2 and have an average size of 1m*1.5m . This puts the required surface area per household with an average use of 3500 kwh/y at around 28-35m^2 requiring 19- 24 panels (Dobbelsteen, et al., 2013, p. 234).

Wind energy is gathered with wind turbines. Large wind turbines are usually not an option in urban areas as most of the wind is taken away by the tall buildings leaving the wind turbine to function suboptimal. However, small wind turbines on top of buildings remain an option. Again, a storage system or collaboration with the net is a necessity to keep a steady flow of electricity throughout the day. A small turbine can produce 500-1200kWh/ year meaning that about 3 are needed to serve a single household (Dobbelsteen, et al., 2013, p. 237)

Biofuels or biomass can be turned into energy using an anaerobic digestion system or a combined heat and power unit. The anaerobic digestion system makes use of biomass to create biogas that can eventually be burned for heat and power using the combined heat and power unit. The biomass can come from all organic waste produced in the buildings but also from plants. There has to be enough supply of biomass for the system to work so it is best to do this on the scale of an entire neighbourhood.

Heating

Passive systems for heating focus on gathering internal heat, solar heat and trying to maintain it by applying insulation and regulating heat loss trough ventilation. The easiest way to capture solar heat is to use glass surfaces in the façade that allow the sunlight to enter a room to warm it up. Another option is the use of mass to capture the heat and slowly release it into the surrounding area.

The active systems can be classified into heat producing systems, heat storing systems and heat distribution systems. Heat producing systems can be solar collectors, geothermal installations, all types of heaters as long as they run on renewable forms of electricity, biomass or biogas. Solar collectors are quite a good option as they can be placed on the roof and façade of the building to provide hot water. They do compete with photovoltaics panels for sunlight unless a combined system is used. But they rely on the renewable resource of sunlight to provide heat throughout the year.

Geothermal heat is only effective when applied for large projects with more than 1500 dwellings. There also has to be the possibility to drill a deep well which is a costly endeavour and requires a permit. As the temperature gained from geothermal wells in the Netherlands Is usually between 60 and 70 degrees Celsius it can mainly be used for low temperature heating. This means that the heat system chosen for the buildings has to be compatible with this (Dobbelsteen, et al., 2013, p. 99).

Other types of heating systems are heat pumps, boilers, stoves, combined heat and power units. All of these require a form of energy either form electricity, biogas or biomass to produce heat. Using electricity to make heat is not very sustainable as the higher form of energy, electricity gets turned into a lower form of energy, heat. It is therefore better to use high efficiency boilers or stoves on biomass or biogas to produce heat. If this is done on the scale of a block or multiple blocks efficiency can be even improved more. It is even better when there is a network of city or district heating were residual heat from factories or other sources can be exchanged with buildings that require heat. In this way already produced heat can be used instead of consuming more energy to provide the required heat (Dobbelsteen, et al., 2013, p. 121).

For storage, heat and cold storage well can be used. This system collects heat during warm periods and cold during cold periods usually in water and stores it underground to use when necessary. The system works best with low temperature heating (Dobbelsteen, et al., 2013, p. 100). It is also possible to use the steady ground temperature to cool or to heat water or air this can be done with a ground heat exchanger. Other types of heat exchangers can also be applied to minimize heat loss from warm waste water and ventilation air. By passing along the heat exchanger the heat is taken out of the water and air as much as possible keeping the heat in the building.

Heat distribution can be done by using for example stove and fire or electric glass plane heating which are both fairly direct ways of heating a room or it can be done more indirectly by heating water or air and distributing them through the building. Systems that use water can work by low temperature heating or high temperature heating. With low temperature heating the water temperature used for heating does not surpass 55 degrees Celsius. Because a large surface area is needed for low temperature heating the heat is spread more evenly providing more comfort to the residents. The time it takes for the room to heat is longer than with high temperature heating so residents need to get used to this. The low temperature system can be used for floor / wall heating, radiators, convectors and concrete core heating. The big advantage of low temperature heating is that it can use heat from sustainable sources as long as the building is well isolated (Dobbelsteen, et al., 2013, p. 87).

Cooling

Passive cooling mechanisms are primarily sun shading and natural ventilation. Sun shading is available in many variations including fixed sun shading and movable sun shading with horizontal or vertical lamellas. The passive systems are usually very effective as they provide heating or cooling with minimal energy cost.

Active systems for cooling are usually not applied in residential buildings in the Netherlands unless the heating system also has the function to cool. This is because the amount of days that it is so hot that active cooling is needed is relatively low especially when passive cooling systems are well applied. So, active cooling systems will not be further discussed.

Water

Water can be separated into rain water, drink water, domestic water and waste water. The systems concerning water are either to retain water or to clean it so that it can be reused.

For rainwater having a good retention system is essential. In this way, the water can be kept in the area while mixing it with the dirtier waste water from buildings and overflowing sewer systems can be avoided. For rainwater retention, it is possible to use green roofs, areas designated for surface water and storage tanks. Because of how clean the rain water is it can be used as household water with minimal filtering. A green roof can filter the water and extract unwanted particles before it is stored. To use rain water for drinking water more elaborate means of filtration are required. By using multiple techniques like membranes, oxidation, UV lighting and carbon filters the water can be made clean enough to drink. Systems that clean the water on a small scale do exist but at the moment it is not yet allowed to use them in the Netherlands due to strict water quality regulations. So, for drinking water it is smarter to use water from the central water treatment company especially in cities where the infrastructure is already there.

After the water is used and it becomes waste water it is necessary to clean the water before being able to discharge it onto surface water or reuse it. In our current system, the water drained by the sewer system to be treated at a water treatment plant. It is also possible to treat it on site so that it can be immediately be cleaned and either reused or discharged onto surface water. As mentioned before almost all the water except for waste water from the toilets named black water can be reused as household water after a filtration process. For mechanical filters,

usually the first step makes use of a sceptic tank to let particles settle down. The cleaner top layer of the water gets passed through a filer to take out further pollution. Then there are also biological filters that clean water making use of microorganisms. These include constructed wetlands, infiltration fields, and compact systems making use of recirculating water through layers filled with microorganisms.
To deal with the black water the use of an anaerobic digestion system in combination with a heat and power unit is recommended. The black water can be turned into biogas and biomass to produce heat and power. Even though decentral systems are possible for cities it is still more efficient to make use of central systems as less pumps, storage tanks, piping and filtration systems are required (Dobbelsteen, et al., 2013, pp. 262-268).

Ventilation

Ventilation is necessary to deliver oxygen to each room while eliminating carbon dioxide, water vapor, fragrances, dust particles and ensuring formaldehyde and radon emissions from materials do not accumulate to reach dangerous levels (BRIS bouwbesluit online, 2012).

The two main ways of ventilating are through passive ventilation and active ventilation. Ventilation has an impact on sustainability because trough ventilation indoor air is exchanged with outdoor air causing a change in room temperature. During cold periods ventilation will lead to heat loss while during warm periods ventilation can cause unwanted heat gain. These heat fluctuations need to be compensated for to maintain a stable indoor temperature. Because heating and cooling can have a big impact on energy consumption ventilation can have a big impact on the sustainability of a building. So sustainable ventilation means choosing a system that can ventilate efficient without causing a huge increase in demand for heating or cooling.

Passive ventilation can be done in a few ways. The easiest way is making use of cross ventilation also called natural ventilation. Two or more openings are available in the façade and through wind pressure and suction air will flow from one opening to the other ventilating the room. The second option is making use of an air shaft or a chimney that uses wind suction on the roof but also the thermal flow of air to extract air out of a building allowing fresh air to enter through openings in the façade and ventilating the building (Dobbelsteen, et al., 2013, p. 148). This chimney effect can be further enhanced by making use of an air turbine, the venturi effect or solar heat. The air turbine works with direct wind drive helping to extract air through the chimney. The venturi effect works by leading airflow through a narrow space increasing the speed of the airflow creating negative pressure and thus enhancing the extraction of air through the chimney. The solar chimney works by enhancing the upward thermal airflow by heating the air.

Because wind and sun are not always available and can be affected by surrounding buildings in most cases it is wise to also make use of an active ventilation system. There is a large variation of mechanical systems. Some of the systems are central others decentral and some fully control supply and extraction while others only provide supply or extraction of air keeping the other flow natural. When the goal is to use as many passive systems as possible hybrid systems are a good option. Hybrid systems make use of passive systems but also have mechanical ventilators installed that can function as a backup for when the natural systems fail to provide enough airflow. When passive systems are not an option a full mechanical system can be used to supply and extract air. These systems can provide a very stable airflow but use more energy than hybrid systems. Decentral systems can also be used like the breathing window or the climate radiator. In both cases air is directly subtracted and returned through the façade limiting the need for airflow channels but both systems are mechanical and limit the use of passive techniques.

To keep a stable room temperature and to avoid draft ventilation air should be preheated during cold periods and preferably cooled during hot periods. Passive ways to heat the air can be achieved by making use of a solarium or a double skin façade or a passive solar collector where the air can heat up before it is supplied to the building. In all these cases, solar heat is accumulated in a space in front of the façade where the ventilation air flows through before it enters the building to be preheated. Another alternative is to make use of the stable temperature at 5 or more meters below the earth. By placing tubes in the ground and leading the ventilation air through these tubes the ventilation air can be preheated or cooled making use of the 10-12 degree Celsius available in the ground (Dobbelsteen, et al., 2013, p. 159). Other possibilities to cool with air are making use of night ventilation and by just increasing the amount of ventilation also the cooling effect can be increased as long is the air is cooler than the indoor temperature.

Then there are also active ways to preheat or cool the ventilation air. Systems like the breathing window or the fully mechanical ventilation often make use of a heat exchanger. The heat exchanger causes airflow that leaves the building to exchange its heat with air entering the building reducing heat losses and conserving energy. The heat exchanger usually works best with mechanical systems as it requires incoming and outgoing air to pass each other and this is more difficult with natural systems. In some cases, the heat loss that is compensated by using the heat exchanger is so big that it justifies the use of a mechanical system over a passive system. Other ways of heating the air are by making use of the existing heaters like the climate radiator. In this case the air is heated by passing it along the hot surface of the radiator to warm it up before as it enters the room. More direct ways of heating and cooling are also possible for example by having it pass the boiler or a cooling element as it enters the building (Dobbelsteen, et al., 2013, pp. 165-167).

Materials

Materials are an important aspect in the sustainability of a building. In the Netherlands about half the material flows are due to building construction. This comes down to about 130 million tons of material used per year and 16 million tons of waste. The most used materials in building construction are wood, stone, metal, plastics and glass. To assess the impact of each material in a construction project a complete lifecycle analysis is required. The different steps in the lifecycle are: resource extraction, processing, manufacturing, assembly, use, disposal or possible reuse. And between all these steps there is also transportation. During each step of the process energy is used and by comparing lifecycles it can be determined what material choices would be the best from a sustainability perspective (Dobbelsteen, et al., 2013, p. 274).

The main benefit of wood is that it can be regrown. This means that if it is sourced from a well-managed forest it can be a very sustainable material. The travel distance plays a large role when using wood as bringing wood from the other side of the globe is not so sustainable. The lifespan of the wood is dependent on the type of wood the treatment and the detailing. At the end of its lifecycle wooden parts can be burned to recover part of the energy it took to make them (Dobbelsteen, et al., 2013, p. 277).

Stone is a material that is sourced from the earth. Stone is relatively heavy so transport is in most cases expensive. When in use stone can last very long with only little maintenance. The most used type of stone in construction is concrete. Even though there are many innovations it is not possibly yet to reuse al the concrete that is released during demolition of a building to make new concrete. Because only part is reused the need remains. This is from a sustainability perspective a large disadvantage (Dobbelsteen, et al., 2013, p. 278).

Metals have to be extracted from ores found in the earth. The extracting of ores out of the earth and the required transport and processing already consumes a lot of energy. In use, the metal can make up for this a little as they enable a building to be built light and demountable. Also, their long-life span and reusability can compensate for the large amount of energy needed initially. Most metals can be reused almost completely by melting and this is usually more energy efficient than initial processing (Dobbelsteen, et al., 2013, p. 281). This means that in the long run very little ore will be needed to maintain a steady metal production as the old metal will be reused first.

Plastics are made from petroleum. Because petroleum is a scarce resource, plastics are not a very sustainable option. Because plastics deteriorate visibly the components are almost never reused. They can be granulated to produce recycled plastic often times with lesser quality than the original plastic or they can be burned for energy recovery. Currently there are bio based plastics under development that would not require oil and that would be biodegradable (Dobbelsteen, et al., 2013, p. 283). This bioplastic would be a much more viable product to use from a sustainable point of view.

Glass is mainly made out of silica extracted from sand. Initially glass was mainly used for windows, but with the newest innovations glass can also fulfil a structural role. Glass is quite heavy so it is quite expensive to transport but because sand is widely available it can usually be made close the construction site. Glass from buildings is still quite hard to reuse due to the treatment and coatings that the glass receives. Because of this glass is not yet very sustainable as a building material. But because of its good properties it is still widely used.

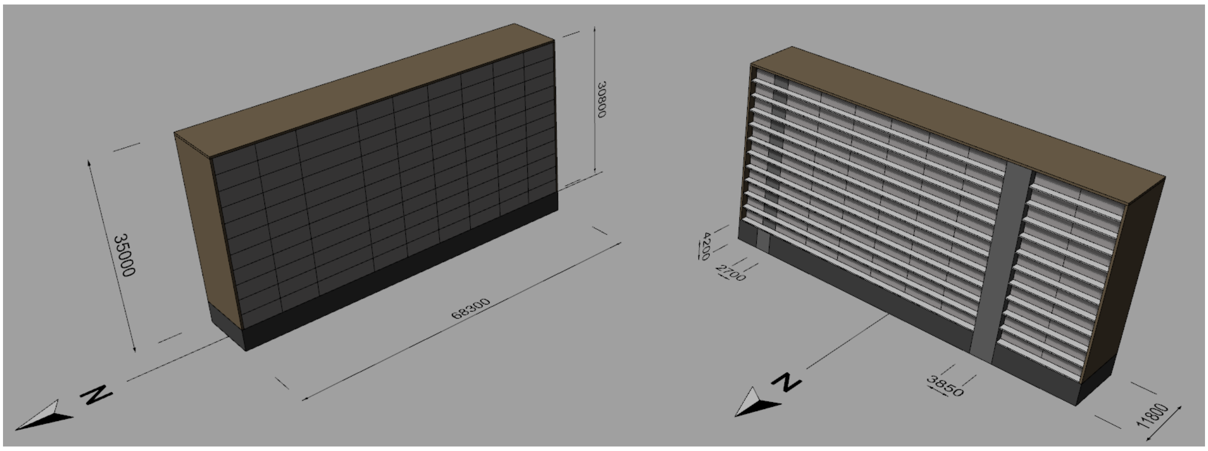
Potential yield of chosen systems for gallery flats

Gallery flat assumptions

To find out the potential of the different climate systems it has to be checked if the systems are applicable for a gallery flat and what the actual yield could be. The following assumptions for gallery flat are chosen based on the case study example: The flat is 11 layers high with a 1.5-layer plinth and each layer is 2.8m high. Total height of the flat is 35m and of the living layers 30.8m. The flat is 11.8 meters in depth and 68.3 meters in length. The bottom layer of the flat contains storage space and 1 apartment while the eleven layers on top contain 9 apartments each making the total count 100 apartments. The building contains four sides, the gallery side, the apartment side and the two end facades. The elevator and staircase shafts situated on the gallery side are 3.85m and 2.7m in width.

Surface area
Roof: 11.8m * 68.3m = 806m^2
Apartment side of the building: 68.3m * 30.8m = 2104m^2
Gallery side of the building: (68.3m - 3.85m – 2.7m) * 30.8m = 1902m^2
Elevator / staircase shafts: (3.85m + 2.7m) * 35m = 229m^2
End facades: 11.8m * 33.6m = 397m^2
End plinths: 11.8m * 1.5-layer * 2.8m = 50m^2
Gallery side plinth: (68.3m - 3.85m – 2.7m) * 1.5-layer * 2.8m = 259m^2
Apartment side plinth: 68.3 * 1.5-layer * 2.8m = 287m^2

Orientation
For the orientation two variants will be taken into account. The first variant is with the long axis of the building oriented north – south and the second variant with the long axis oriented east-west. On the basis of these two examples the potential of most other cases can also be estimated.



Flat dimensions and orientations (own image)

Demands

- Electricity: average of 3000 kWh per family of 2.2 persons with 100 apartments = 300000 kWh total

- Heat: 35 GJ per household with 100 apartments = 3500 GJ total (972222 kWh)

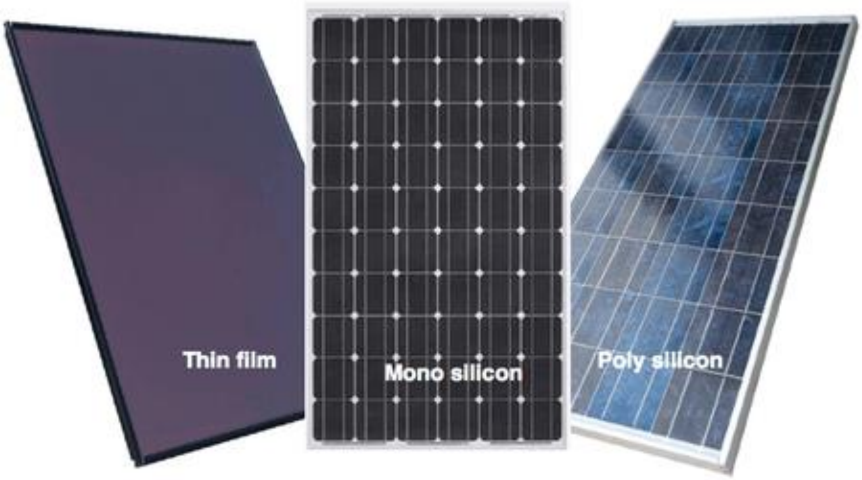
- Cooling: this is only done using passive systems or in combination with a heating system or ventilation system

- Water: 119l per household times 100 = 11900 l total

- Ventilation air: toilet 7 l/s, bathroom 14 l/s, kitchen 21 l/s, laundry room 7 l/s, storage room 7 l/s, utility closet 2 l/s, the rest of the house about 60m^2 requires 0.9 l/s/m^2 is 54 l/s = 112 l/s per apartment. So, for 100 apartments the total comes to 11200 l/s.

Photovoltaic panels

PV panels make use of solar radiation to produce electricity. The most commonly used photovoltaics panels in the Netherlands are the monocrystalline panels and the polycrystalline panels. Together they account for about 95% all the panels being used with the remaining 5% being thin film solar panels (Milieu Centraal, 2017).



The main photovoltaic panel types (ExSolar, 2017)

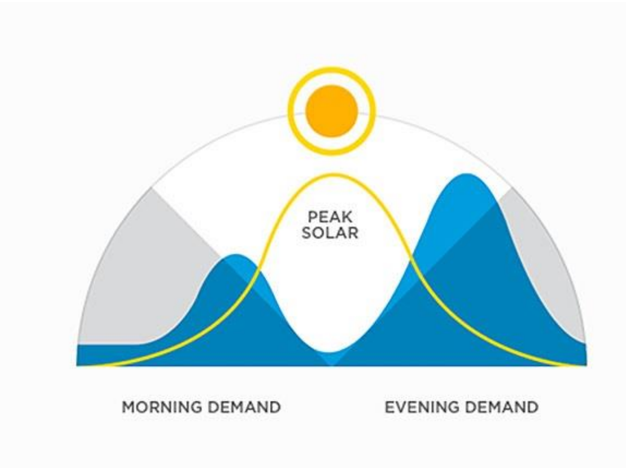
The monocrystalline panels are the most efficient at about 14-20% which also gives them the highest yield per m^2. The panels have a black uniform color and can be recognized by the rounded of edges of the cells. Because of their production process and material usage these types of panels are also the most expensive, but they have the potential to last up to 50 years. The panels have a considerable dip in efficiency when dealing with higher temperatures and in situations with indirect sunlight or shade (ExSolar, 2017) (Allesoverzonnepanelen, 2017) (Maehlum, 2017) (Middelkoop, 2017).

Polycrystalline panels have an efficiency of 12-16%. The efficiency is lower than the monocrystalline cells due to the manufacturing process that makes use of many small crystals compared to one big crystal. The colour usually consists of many shades of blue. The panels are a cheaper than the monocrystalline panels therefore these panels are the most suitable for locations that have a lot of placement area to compensate for the lower efficiency. The panels have a life expectancy of about 25 years. The same as the monocrystalline panels also these panels suffer from lower efficiency when dealing with higher temperatures and indirect sunlight or shade (Allesoverzonnepanelen, 2017) (Maehlum, 2017).

Old generation thin film panels have an efficiency of 6-10%. Even though this is much lower than the mono and polycrystalline panels these panels do not suffer so much from losses due to high temperatures and indirect sunlight or shade. They have an even coloured blue /black surface. They are the cheapest type of panels, so they are ideal in situations where there is a large surface area for them to be placed. The weight of the panel is also significantly lower than that of the other two making it a good alternative for places where weight is an issue like lightweight constructions. Also, the panels are flexible making them easier to integrate on different surfaces. The lifespan of the panels however is a bit shorter than that of the other types of panels the expectancy is 20 years (ExSolar, 2017) (Allesoverzonnepanelen, 2017).

New generation thin film panels have an efficiency of 13-15%. They are known under the name CIGS or CIS, this stands for the materials it is made of copper, indium, gallium, selenide. They look the same as the original thin film panels, and are also flexible and lightweight. They also have little losses with high temperatures or indirect sunlight and shadow. Because of this they are very good for east/west orientations. Downsides are they are still very expensive, and the lifespan is not yet known as they are still a very new product (Middelkoop, 2017) (Allesoverzonnepanelen, 2017).

The Biggest advantage of solar panels are that they can be used as a small-scale solution to provide a building with energy. They are easy to integrate in a building and easy to place and they can also easily be scaled up as long as there is enough surface area to place them on. A large disadvantage of photovoltaic panels however is that they require a means of storage. This is not only necessary on the daily basis to compensate for the day and night cycle but also on a seasonal basis, as in summer much more energy is captured from the sun than in winter. A possible small-scale storage mechanism can be a battery pack like the tesla Powerwall (Tesla, 2017).

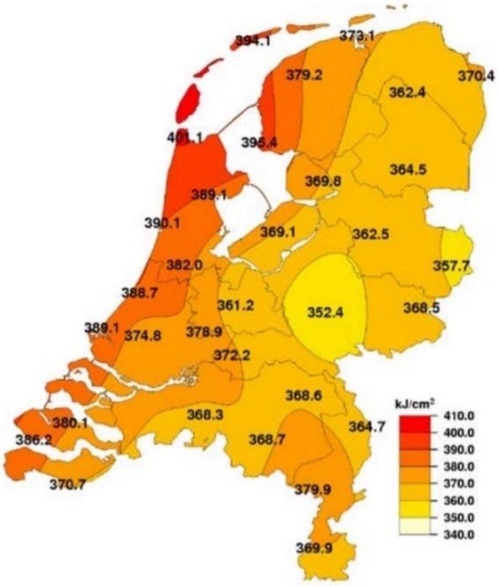


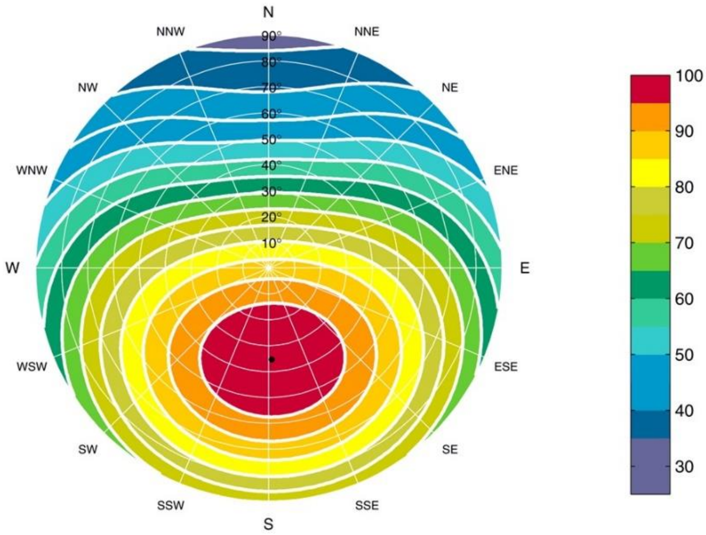
Electricity demand curve versus PV potential / Tesla Powerwall electricity storage unit (Tesla, 2017)

To find out how much electricity photovoltaics can provide a few things are important. The first is the yearly global irradiation of a given location as this determines how much sunlight falls on a spot and can be harvested. For the location of the case study Delft, the climate atlas of the KNMI gives 375 kJ/cm^2 per year between the years 1981 and 2010 (Klimaatatlas, 2017). While the yearly irradiation was 377.1 in 2011, 364.7 in 2012 and 374.8 in 2013 (Sark, 2014). So, if the average irradiation of 375 kJ/cm^2 is taken times the factor 2,778 the total irradiation is 1041.75 kWh/m^2 per year.

The second important aspect is the angle at which the panels are placed and the orientation. The best angle is at 35-36 degrees tilt with a southern orientation (Allesoverzonnepanelen, 2017). This can be seen in the image and the table below.

The third variable is the type of solar panel that is chosen and its efficiency. For the calculations a efficiency of 15% is chosen as this allows for each type of panel to be used and accounts for the loss in efficiency over time about 0.5% per year (Milieu Centraal, 2017).





(left) Yearly global irradiation in The Netherlands for 2013 (Sark, 2014)
(right) Solar radiation at different angles and orientation (Allesoverzonnepanelen, 2017)

Expected yield depending on the roof angle and orientation (in degrees relative to the south)

Roof angle	Zuid	Zuid-oost/Zuid-west								Oost/ West	Noord-oost/Noord-west								Nrd
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
0	87%	87%	87%	87%	87%	87%	87%	87%	87%	87%	87%	87%	87%	87%	87%	87%	87%	87%	87%
10	93%	93%	93%	92%	92%	91%	90%	89%	88%	86%	85%	84%	83%	81%	81%	80%	79%	79%	79%
20	97%	97%	97%	96%	95%	93%	91%	89%	87%	85%	82%	80%	77%	75%	73%	71%	70%	70%	70%
30	100%	99%	99%	97%	96%	94%	91%	88%	85%	82%	79%	75%	72%	69%	66%	64%	62%	61%	61%
40	100%	99%	99%	97%	95%	93%	90%	86%	83%	79%	75%	71%	67%	63%	59%	56%	54%	52%	52%
50	98%	97%	96%	95%	93%	90%	87%	83%	79%	75%	70%	66%	61%	56%	52%	48%	45%	44%	43%
60	94%	93%	92%	91%	88%	85%	82%	78%	74%	70%	65%	60%	55%	50%	46%	41%	38%	36%	35%
70	88%	87%	86%	85%	82%	79%	76%	72%	68%	70%	58%	54%	49%	44%	39%	35%	32%	29%	28%
80	80%	79%	78%	77%	75%	72%	68%	65%	61%	56%	51%	47%	42%	37%	33%	29%	26%	24%	23%
90	69%	69%	69%	67%	65%	63%	60%	56%	53%	48%	44%	40%	35%	31%	27%	24%	21%	19%	18%

Yield depending on orientation and roof angle of solar panels (Zonwatt, duurzame energie, 2017)

PV Calculations
Roof area 806m^2. Solar panels 1.5m^2 each. 0º roof angle. Orientation south. Panel efficiency 15%. Total solar irradiation 1041.75 kWh/m^2. Temperature between 10-25º Celsius.

Roof
806m^2 / 1.5m^2 = 537 panels can maximally fit on the roof. This gets the total panel surface area to 805.5m^2. At an angle of 0º only 87% of 1041.75 kWh/m^2 falls on the panels is 906 kWh/m^2. Of this 906 kWh/m^2 only 15% is converted to electricity is 136 kWh/m^2. 805.5m^2 * 136 kWh/m^2 = 109506 kWh per year can be harvested from the roof. This is about 1/3 of the total electricity demand of 300000 kWh per year. In reality, the number of panels able to be place on the roof will be even less as there is also space required for people to move around on the roof for cleaning and maintenance of the system.

The solar panels can also be put at an angle of 35º at a south orientation this would mean they could capture 100% of the incoming irradiation. But because of the angle the panels cause shade making the required placement space 2.5m^2 instead of 1.5m^2 (Zonnepanelen weetjes,

2017) . Roof area of 806m^2 / 2.5m^2 = 322 panels. 322*1.5m^2 is 483.6 m^2 of surface area. The yield of the panels again is 15% so 1041.75 kWh/m^2 * 0.15 = 156 kWh/m^2. Final yield is 483.6 m^2 *156 kWh/m^2 = 75568 kWh. This is about 1/4 of the total demand. So placing them flat would mean a higher yield because of a larger surface area.

Facade
Solar panels can also be added to the south façade. The placement angle would be 90º with a 69% of the incoming irradiation captured. With a panel efficiency of 15% this would mean 1041.75 kWh/m^2 * 0.69 * 0.15 = 107 kWh/m^2.
Adding panels to the east / west façade. The placement angle would be 90º with a 48% of the incoming irradiation captured. With a panel efficiency of 15% this would mean 1041.75 kWh/m^2 * 0.48 * 0.15 = 75 kWh/m^2.

On the end plinth of 397m^2 and a south orientation this would give a yield of 42479 kWh.
On the end plinth of 397m^2 and an east/west orientation this would give a yield of 29775 kWh.
The apartment side of the building is 2104m^2. Assuming only 1/3 of the façade can be used for the placement of solar panels this results in 701m^2.
For a south orientation, this would mean 701m^2 * 107 kWh/m^2 = 75042 kWh
For an east/west orientation this would mean 701m^2 * 75 kWh/m^2 = 52575 kWh
Conclusions
These calculations show that if the building is orientated North- South total electricity harvest is 109506 kWh from the roof, 42479 kWh from the end plinth and 2* 52575 kWh from 1/3 of the east and west façade = 257135 kWh is 85% of the energy demand can be met.

These calculations show that if the building is orientated East-West total electricity harvest is 109506 kWh from the roof, 2*29775 kWh from the end plinths and 75042 kWh from 1/3 of the south façade = 244098 kWh is 81% of the energy demand can be met.

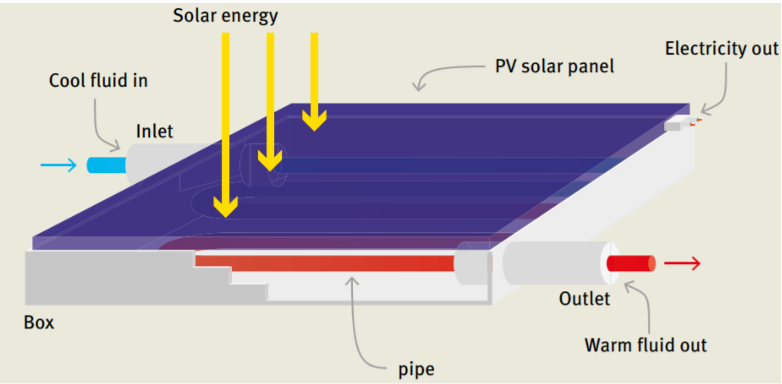
The yield can still increase if a larger part of the façade is covered with the panels or if they are placed at a better angle on the façade.

Photovoltaic thermal hybrid solar collector (PVT)

An alternative to the photovoltaic panels is the combined system of photovoltaic and a thermal solar collector. The big advantage of this system is that apart from harvesting electric energy it also harvests thermal energy making use of the same surface area. An added advantage is that the photovoltaic panels also get cooled by the solar collector part making them produce electricity at a steadier efficiency as the efficiency usually goes down with 0.4% for every degree Celsius above 25ºC (Ramos, et al., 2017, p. 13). PVT collectors are usually divided into two categories, PVT-liquid and PVT-air collectors. The ones using liquid (often times water) consist of a box with PV on top and pipes running underneath to collect the heat. The one using air do not require the pipes only a box with air flowing over or under the PV panels. The liquid variant is more efficient, but the air variant is cheaper and easier to install. The heat from the systems could be used directly but is usually a heat exchanger is used or even required in the case of hot tap water. In some cases, also a heat pump is needed to get the water to the desired temperature. As with the PV only system the PVT system requires a storage system to cope with the daily and seasonal discrepancy in supply and demand. Some systems can generate up to

95% of the heat demand but only 30% of this is generated in the winter when it is mostly needed (Ramos, et al., 2017, p. 7).

For the electric energy, a home storage battery can be the solution while for the thermal energy a heat/cold storage system might be required. The average thermal efficiency depends on the type of PVT collector glazed ones with water pipes can reach 38% while unglazed variants have an average efficiency of 24% (Jin-Hee & Jun Tae, 2012). If instead of the water pipes a fully wetted absorber is used thermal efficiencies can go up to 51% (Jin-Hee & Jun Tae, 2012, p. 148). Even though the glazed variant performs better on thermal efficiency and total efficiency the unglazed version performs better on electrical efficiency as it allows for more cooling of the photovoltaic panels.



Workings of a liquid PVT system (Ramos, et al., 2017)

PVT Calculations

The chosen system is the glazed system with water pipes running underneath. Because this seems to be the most suitable market available system. This system can be placed on the façade but due to high costs and lower expected yields I combination with difficult integration (running water) and difficulty with maintenance it might be wise to only use this system on the roof. For the electric yield, the same values will be used for the PVT panel as calculated for the PV only panels as possible increases will only be 1-2% depending on the conditions. For the average thermal efficiency, the value of 38% will be used.

Roof area 805.5m^2. Solar panels 1.5m^2 each. 0º roof angle. Orientation south. Panel electrical efficiency 15%. Panel thermal efficiency 38%. Total solar irradiation 1041.75 kWh/m^2.
1041.75 kWh/m^2 * 0.87 = 905.67 kWh/m^2 at a 0º roof angle. 905.67 kWh/m^2 * 0.38 = 334kWh/m^2
805.5m^2 * 334 kWh/m^2 = 277216 kWh is 998 GJ.

With a total demand of 3500 GJ this system is able to provide 28% of the heating demand. It is however large enough to provide all the warm water which is 700 GJ for 100 households.

Wind turbines

Wind turbine use wind energy to produce electricity. Wind turbines can be divided into two categories horizontal and vertical wind turbines. As mentioned before large horizontal standing turbines are not on option in urban areas as the wind they require gets taken away by the large buildings. So, the alternative are vertical wind turbines on top of buildings. The vertical wind turbines are subdivided into two type of designs Savonius and Darrieus wind turbines (Raghab, 2015).

Important aspects to keep into account when selecting a wind turbine are the cut in windspeed, this is the minimum windspeed required for the turbine to function. Other important aspects are the swept area, the size, the shadow it gives, the noise it makes, the vibrations it causes, the minimum annual windspeed, the maximum windspeed that it can handle and of course the energy it produces. Two examples are shown below.

QR6 (Quietrevolution, 2017)

WS- 4B (Windside, 2017)

Darrieus type vertical windturbine QR6
Cut in windspeed: 4.5 m/s
Swept area: 16m^2
Size: 5.5m tall, 3.1m diameter
Minimum annual windspeed: 5 m/s
Vibrations: low
Noise level: low
Maximum windspeed: 52.5 m/s
Output at 4 m/s: 1500 kWh / year
Output at 5 m/s: 4000 kWh / year
(Quietrevolution, 2017)

Savonius type vertical wind turbine WS -4B
Cut in windspeed: 2-5 m/s
Swept area: 4m^2
Size: 5.15m tall, 1.05m diameter
Minimum annual windspeed: 5 m/s
Vibrations: no vibration
Noise level: 0 dB at 2m distance
Maximum windspeed: 60 m/s
Output at 4 m/s: 400 kWh / year
Output at 5 m/s: 2000 kWh / year
(Windside, 2017)

However, when looking at the total wind in the Netherlands for most places the average barely exceeds 4.5 m/s and in urban areas windspeed is even less (Klimaatatlas, 2017). When looking at the case study location Delft the average windspeeds are 3-4 m/s (Windfinder, 2017) this means that most turbines won't have enough wind to start producing energy and also that the yield will be so low that it is not worth it to even place the wind turbine.

Month of year	Jan 01	Feb 02	Mar 03	Apr 04	May 05	Jun 06	Jul 07	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	Year 1-12
Dominant wind direction													
Wind probability >= 4 Beaufort (%)	7	12	9	16	10	16	6	3	5	11	13	14	10
Average Wind speed (m/s)	3	4	3	4	4	4	3	3	3	3	4	4	3
Average air temp. (°C)	1	5	7	9	13	16	20	20	17	13	10	6	11

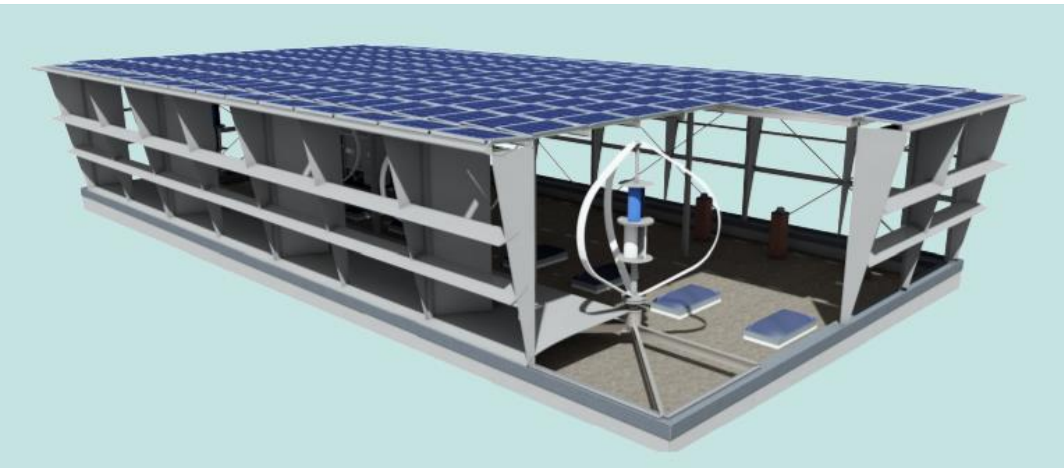
Average windspeeds Delft 2012-2013 (Windfinder, 2017)

For locations with more wind and an average of 5m/s wind turbine can be an option but still scalability remains a problem. Unlike with PV panel adding extra windmills on top of a building will affect the total energy output as the more wind turbines are being placed the more they will interfere with each other causing a suboptimal performance.

Combined wind and solar

There are currently systems being developed that combine wind energy and solar energy in one integrated solution. A big advantage of this is that it would enable very efficient usage of available area on the building. An example of this is the Powernest by IBIS power (IBIS Power, 2017). Because of the wind tunnel effect created by the cage construction windspeeds are enhanced and turbulence reduced making the wind turbines more efficient. Also, the PV panels are cooled by the wind tunnel effect making them yield more.

Powernest at 30m high, building with 10.8
Cut in windspeed: <3 m/s
Swept area: 16m^2
Size: 4.2m tall, 4m diameter
Minimum annual windspeed: 5 m/s
Vibrations: low
Noise level: <40 dB
Maximum windspeed: 60 m/s
Output: 280-385 kWh/m^2 / year
(IBIS Power, 2017)

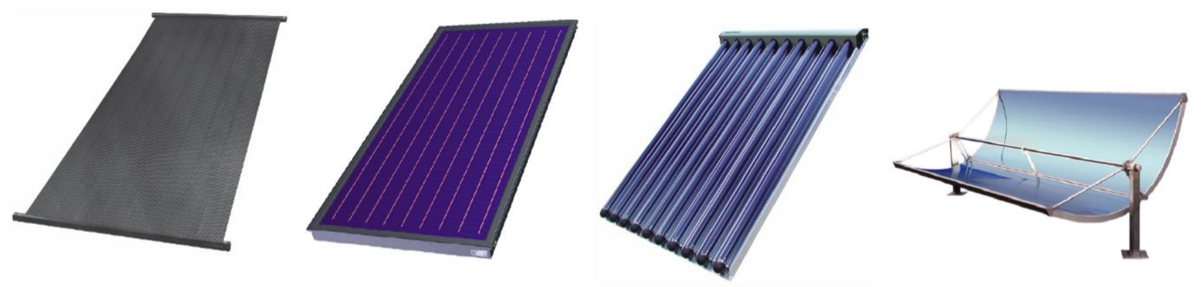


Powernest 2.0 (IBIS Power, 2017)

With a roof surface of 800m^2 and a yield of 280-385 kWh/m^2 this could lead to 224000-308000 kWh yields per year for the entire roof which would be 2/3 to full demand of electricity needed for the building. This would be a great feat as up to now it was not possible yet for a 10-layer building to fully produce its own energy. However, measurements are still being done to see if the systems can live up to the expectations, and as the system is being scaled up to cover the entire roof and wind turbines are added, there is a chance efficiency will drop due to turbines taking away each other’s wind or influencing each other in a negative way.

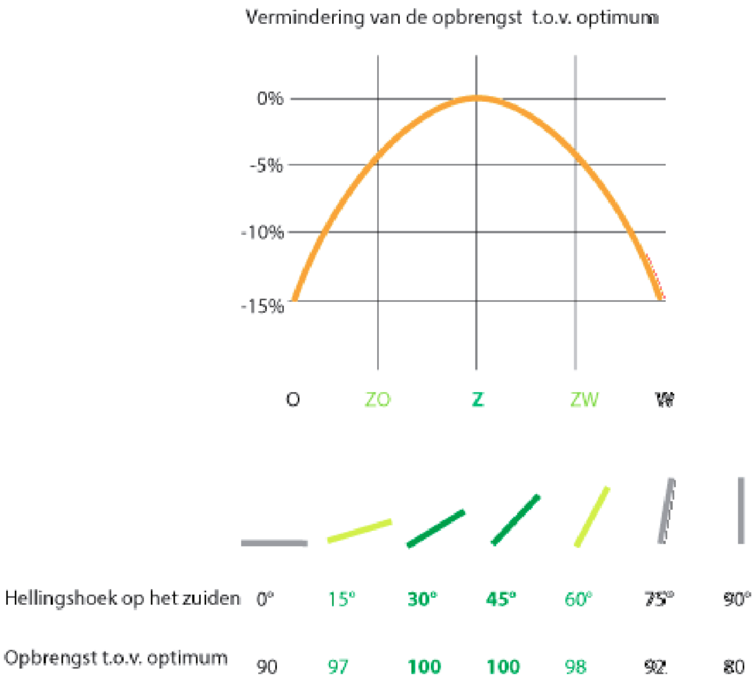
Solar thermal collector (liquid)

There are four types of liquid solar thermal collectors, uncovered flat plate, covered flat plate, vacuum tube and concentrated solar collectors (Smets, et al., 2016, p. 378). They can be divided into three categories low, medium and high temperature. The low temperature solar collectors are the uncovered collectors. These collectors do not have a cover and the sun strikes the absorber directly. This is most suitable to reach small temperature differences and this type of collector is therefore mostly used for pool water heating. The medium temperature solar collectors are the covered collectors. These collectors have a cover of transparent material trapping the heat and can reach temperatures of 100 ºC. These types of collectors are also the most common used ones because they are relatively cheap and simple. The high temperature collectors are the vacuum collector and the concentrated solar power collector. The vacuum collector works by trapping heat within vacuum glass tubes. Because the vacuum tubes isolate very well this system is able to capture a lot of heat and reach high temperatures. This system is expensive but can be used for home applications. The concentrated solar collectors work by focussing incoming solar irradiation onto a receiver. The receiver can get so hot that steam can be produced to power a turbine. The system is therefore mostly usable on an industrial scale (Smets, et al., 2016, p. 385).



Uncovered flat plate, covered flat plate, vacuum tube and concentrated solar collector (Poolheatpumps, 2017) (Hewalex, 2017) (Centrometal, 2017) (Sopogy, 2017)

The two best options to use on a residential building are the flat plate covered collector and the vacuum tube collector. The efficiency of the systems is very dependent on the specific collector. Variables are the optical characteristics of the glass, absorber efficiency, type and temperature of circulated fluid, the isolation values. And then there are also other variables like the ambient temperature, the angle, orientation and total irradiation for a given location.



Optimal angle and orientation for solar collectors in the Netherlands (ISSO, 2017)

The optimal angle for maximum capture of solar irradiation is along the same range as for the PV panels. However, depending on the storage mechanism for the captured heat it might be better to put the panels at an angle of 50º as this enables them to capture more heat in the winter period when it is most needed. With a seasonal storage system, this is less important as the heat captured in the summer can also be used during winter. As can be seen in the image the decrease in efficiency at a suboptimal angle is less for solar collectors as they make more use of indirect light. To get the maximum surface area on the roof the panels will have to be laid at an angle of 0º. For the flat plate collector, this would mean a 10% reduction in efficiency. For the vacuum tube collector, however the tubes can be put at an angle to allowing the vacuum tube panels to perform at the best angle efficiency (ISSO, 2017).

Solar collector calculations

To have an estimate of the yield of the solar collector systems a yearly average of 4.7GJ / 2.5m^2 per year is taken for the flat plate collector and 5.1GJ / 2.5m^2 per year for the vacuum tubes (Zonnepanelen-weetjes, 2017). Both are at an angle with no efficiency losses. This gives 1.88GJ/m^2 / year for the flat plate collector and 2.04GJ per year for the vacuum tube collector. With a solar irradiation maximum of 1041.75 kWh/m^2 = 3.75 GJ/m^2. This would give the flat plate collector an efficiency of 1.88/3.75= 50% and the vacuum tube collector 2.04/3.75= 54%

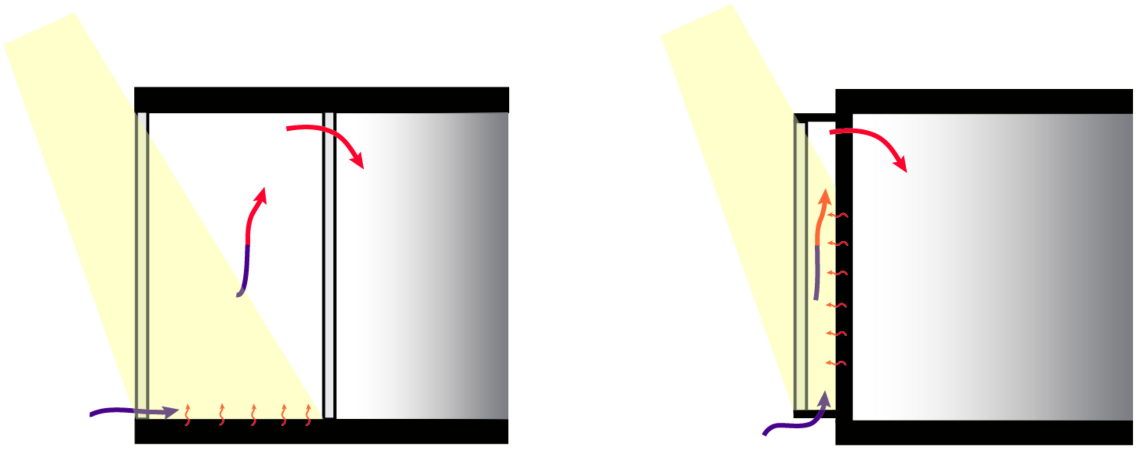
For the roof area of 806m^2 placed full of flat plate solar collectors at an angle of 0º south the yield would be: 806m^2 * 1.88 GJ/m^2 = 1515 GJ times the factor of 0.9 for the roof angle is 1363GJ in total. This is almost 39% of the yearly requirement.

For the roof area of 806m^2 placed full of vacuum tube collectors at an angle of 0º south the yield would be: 806m^2 * 2.04 GJ/m^2 = 1644 GJ (47%) in case the tubes are not turned towards the sun also a factor 0.9 is required getting the total to 1480 GJ which would be 42% of the total demand.

If the facades especially the south facing one would also have integrated solar collectors the yield could be higher. However, when choosing for the solar collectors it has to be taken into account that they compete with PV panels for placement area. Since producing electricity is still more beneficial than producing heat in most cases it is better to choose for PV or PVT panels.

Passive solar collectors (air)

Passive solar collectors work by capturing sunlight on a surface and trapping the heat with the use of a glass surface. The heat can then radiate from the surface into a room or it can be used to heat up air before it enters a room. Conservatories, fully glazed balconies, second skin facades and trombe walls are all examples of systems that work as passive solar collectors (Dobbelsteen, et al., 2013, p. 157).



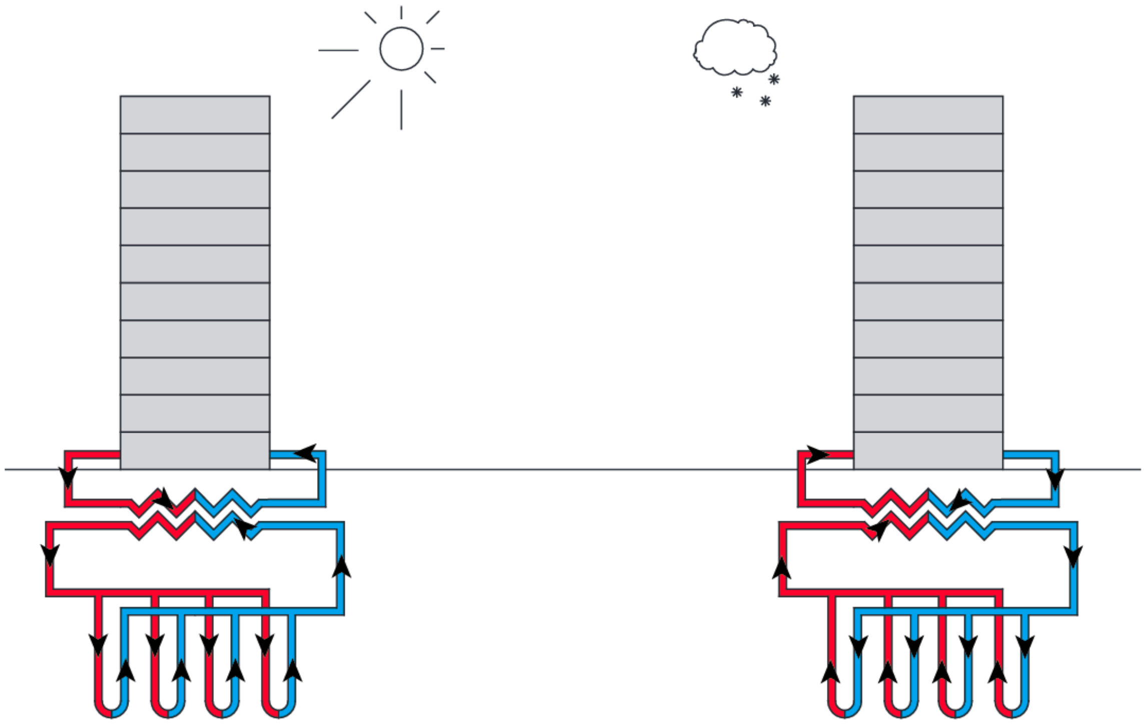
ventilated second skin façade and ventilated trombe wall (own image)

To calculate the effect of the passive solar collectors many variables need to be known, the outside and inside temperature, the amount of solar irradiation entering, the heat loses of the system, the amount of air entering plus the air velocity. As all the factors can vary a lot it is hard to put an exact number on the effectiveness of the system because it is very case specific. However, the systems do help to conserve energy and to reduce the total heating demand of a building. They also contribute to a better thermal comfort by reducing the temperature difference between incoming air and room air minimizing draft.

Ground coupled heat exchangers

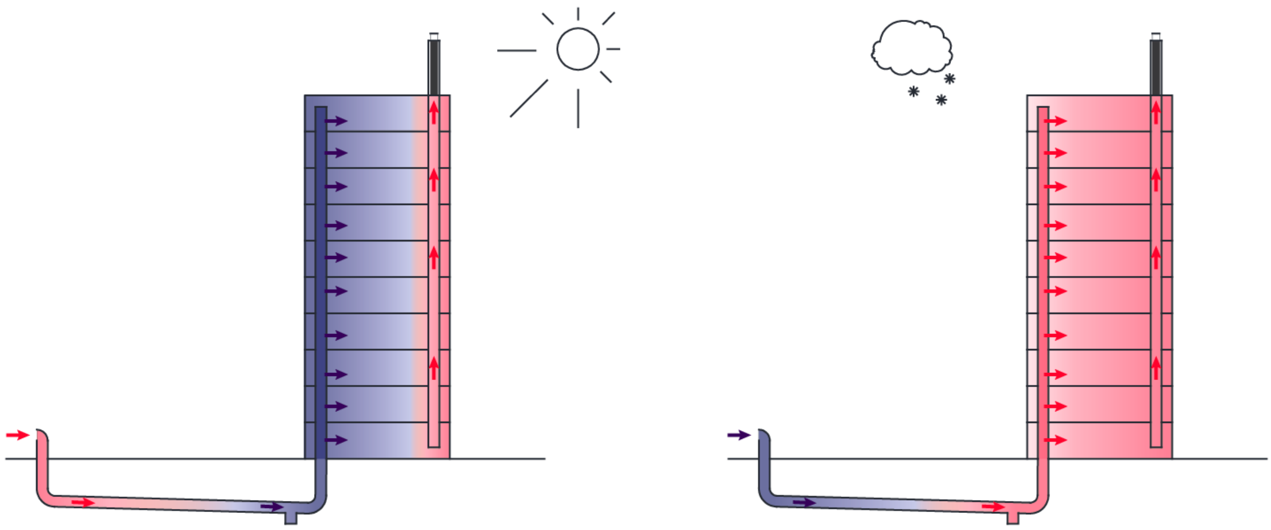
Ground coupled heat exchangers exist in two types air based and liquid based ground exchangers. They work by extracting heat or cold from the earth that has a stable temperature of 10-12 ºC throughout the year at about 5m deep (Dobbelsteen, et al., 2013, p. 159). The possibility to install the systems depend on the soil condition and weather there is enough available space.

The liquid heat exchangers can be used in combination with a heat pump to produce water for heating system and hot tap water. It can be placed ether vertical or horizontally in the ground. Placing it vertical requires it to be included early in the design as it is usually integrated in the foundation as part of the driven piles. In refurbishment projects where most of the foundation is already in place this would require separate holes to be drilled making the placement of this system an expensive endeavor. The tubes can also be placed horizontally. This would require a lot less drilling but the available surface area needs to be a lot bigger. For high-rise flats with a high housing density chances are that there will not be enough available surface area. Another important aspect that has to be taken into account is the regeneration of the earth. If the system is only used for heating or cooling slowly the efficiency of the system will go down as the ground heats up or cools down affecting the overall performance of the system. Because the system only uses a pump to circulate the water and a heat pump to further heat the water it is a fairly efficient and sustainable system. If the building is well isolated and if there is enough area available this system could provide the building in its heating demand (Dobbelsteen, et al., 2013, p. 102).



Earth- liquid heat exchanger in summer and winter (own image)

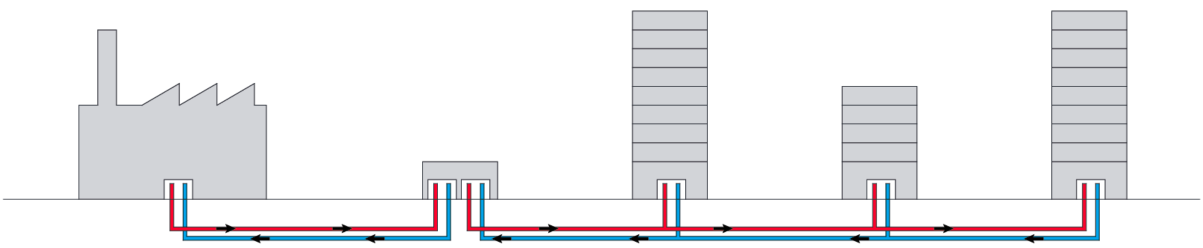
The air heat exchangers work in a similar way only in this case air is circulated through the pipes. The air can be used in combination with a heat pump to produce hot water but it can also be used as ventilation air. Because the air is already preheated it lowers the heat demand of the building and minimizes potential heat losses. A large disadvantage is that the air needs to be brought to each apartment requiring extra ducts and shafts which are currently not available in most high rise residential flats as they rely on natural ventilation for air inflow. Also, it has some of the same problems as the liquid system, depletion over time lowering the efficiency unless it is regenerated and the required surface area is very large. The required area for the tubes is about 2-3 times the area that needs to be heated (Dobbelsteen, et al., 2013, p. 159). Because of these requirements the system is most suitable for an integrated design instead of an addition as is the case in a refurbishment project. However, it remains a possibility and with the right design strategy it can be applied.



Earth-air heat exchanger in summer and winter (own image)

City / district heating

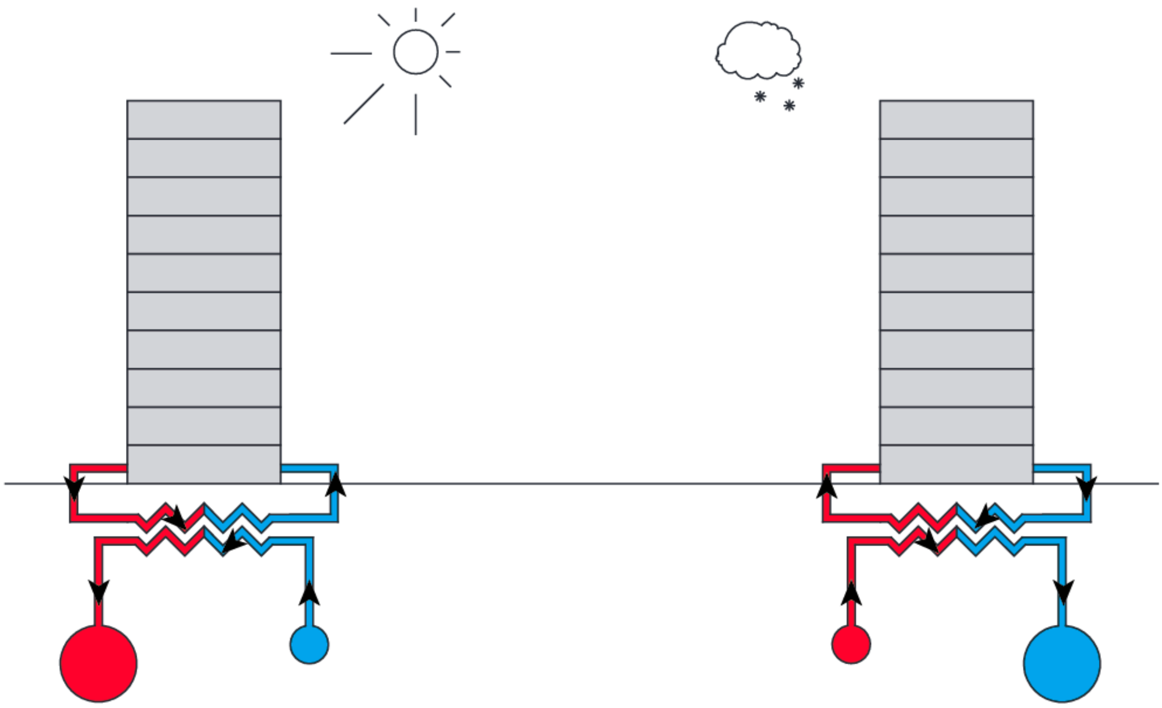
City or district heating is a system that uses heat from industries and other sources to provide warm waters to area's in the city. Requirements for this system is the availability of heat in the vicinity and a distribution network of isolated ducts to transport the water with minimal heat loss. From the heat producing facility the heat is transported to a distribution centre in the neighbourhood where the water can be dispersed to the buildings with or without extra heating from a heat pump depending on the heating system of the building and if hot drink water is required. The main advantages are that the distribution centre can get heat from many different sources and allow buildings to share their own produced heat. Some disadvantages are the high initial investment to build the distribution network and that the heat sometimes comes from unsustainable sources like coal or gas powerplants. Better sources would be geothermal heat wells and biogas or biomass plants but also other industries like water and waste treatment plants or other industries where there is a heat surplus caused by the processes being ran (Dobbelsteen, et al., 2013, p. 121).



District heating (own image)

Heat / cold storage

Heat and cold storage systems are systems that uses water to store heat and cold in the ground layers called aquafers. The layers are at 20-150 meters below the surfaces. Usually the system consists of a heat well and a cold well that have to be placed at least 150m apart to avoid interference. The system is very useful in combination with intermittent sources as it allows for a constant heat or cold flow even when there is nothing being produced. Heat produced by thermal solar panels during the day can be used during the night and heat captured in summer can be used in winter. As with other systems a heat pump can be used to further heat or cool the water if necessary (Dobbelsteen, et al., 2013, p. 100).

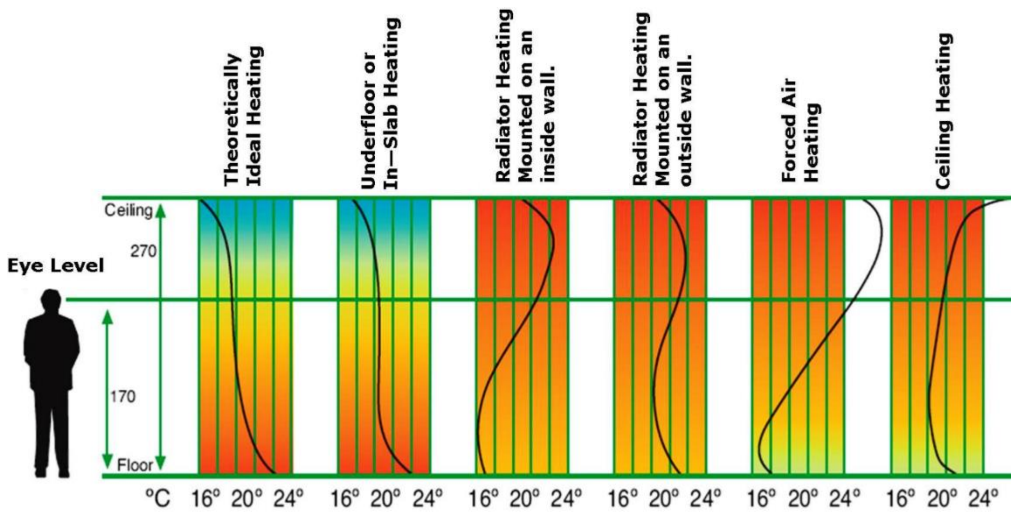


Heat / cold storage in summer and winter (own image)

Low temperature (LT) heat distribution systems

Low temperature heating is suitable to warm well-insulated houses. By using low temperature heating less energy is required and a comfortable indoor temperature can be reached. Instead of using water of 80°C water of 25- 55°C can be used. This means that heat from sustainable sources can directly be used. This includes heat from solar thermal collectors but also heat-cold storage units and earth heat exchangers in combination with heat pumps. Other advantages are that there are less heat losses through the transportation pipes and no chance of scourged dust particles in the air. The low temperature heating can be dispersed by LT radiators, LT convectors and LT floor / wall heating (Milieu centraal, 2017).

LT radiators are a bit bigger than high temperature radiators and because of the extra surface area they can use water with lower temperature to cover the same heat demand. Radiators make us of radiation and convection to heat a room. Radiation is usually seen as the most pleasant form of heating as it heats the person directly. Heating through convection means air circulation and this causes the air up in the room to be hot while the air on the floor can be relatively cold. This leads to a lower comfort level. Convection heating can also lead to draft and a less healthy indoor climate due to circulation of dust particles.



Heating curves for different systems (Adelaide Hydronic Heating, 2017)

LT convectors only use convection to heat a room. Even though this system has all the disadvantages mentioned before it still has its benefits. The system uses less water than the LT radiator to heat the room, it also does this quicker than a radiator. Another big advantage is that a convector can be placed in front of a glass plane without parapet and still function without losing heat through the glass by radiating it to the outside.

Lightweight floor heating system (Jupiter, 2017)

LT floor and wall heating use only radiation heating and distribute the heat very evenly through a room. There are two main types of floor heating systems heavy and light. The heavy systems use tubes poured in a concrete floor. The big disadvantage of these systems is that they are very slow to react and are therefore only useful in rooms where a constant heating demand is required. The lighter system makes use of lightweight isolating panels that can be placed on top of the existing floor with a thin aluminum plate on top to spread the heat. These systems heat much quicker due to the lower mass and are much easier to place. This makes these systems much more suitable for renovation projects, especially as the thermal isolation can also provide acoustic isolation something that is often times lacking in post war flats.

Passive ventilation systems

The solar chimney is a passive ventilation system that uses sunlight to heat up air creating thermal draft and causing fresh air to enter the building due to lower air pressure on the inside than on the outside. Solar chimneys usually consist of a transparent outer layer with an absorber on the inside to collect heat from solar radiation. This heat is then transferred to the surrounding air. The solar chimney can either be placed along the façade or on top of the building as long as it gets enough sunlight to create the required draft. The effectiveness of the solar chimney depends on the height, the volume and on differences between the exiting and surrounding air temperature. Large disadvantages are that the solar chimney only works when the sun is shining so additional ventilation will always be needed to ensure the minimum required ventilation is reached (Dobbelsteen, et al., 2013, p. 162).

Solar chimney ROC Twente (Stegers, 2009)

Venturi chimney (EGM architecten, 2017)

A venturi driven ventilation system uses its form to create differences in airspeed to creating draft and low pressure in a building and extracting the air to allow fresh air to enter. Some of the systems have the ability to rotate to place themselves in the right wind direction. The system has the same disadvantage as a solar chimney as it also relies on an intermittent source wind. This means that extra backup mechanical ventilation s always required.

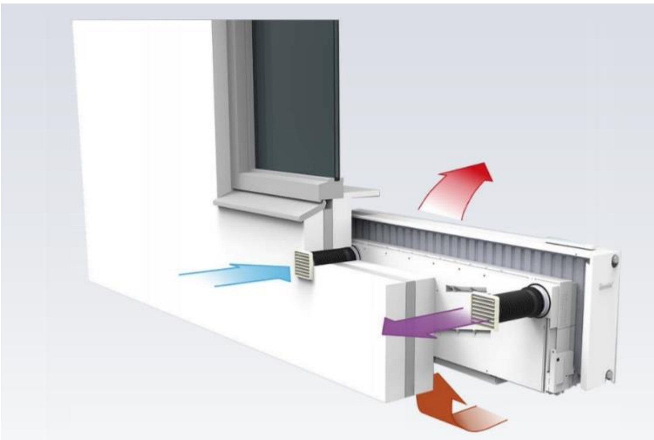
Both of these passive systems can be used the passively ventilate a flat but the question remains if it is worth it to invest in them for a residential building in the city. The solar chimney works the best during the day when the sun is shining and this is when the ventilation demand is usually at its lowest as most people will go to work. For the venturi chimney the windspeeds have to be sufficient and as seen before this is not always the case in city areas. Combine this with the fact that a mechanical ventilation is needed as backup either way and it becomes questionable if it is worth it to install one of these systems on a residential high rise flat. It might be wiser to use the roof or façade area to place some extra solar panels to produce electricity for the mechanical ventilation fans.

Decentral ventilation systems

The breathing window or wall is a decentral ventilation system that is integrated in the façade and ventilates a room while passing air by a heat recovery unit. Main advantages are that the room does not require ducts ore shafts to supply or extract air and that there are less heat losses through ventilation. This is very handy for renovation projects as often times duct space is limited and heat losses through ventilation are a major problem. Each room can have its separate ventilation with an air exchange rate suited for its function. The air is filtered before it enters the room so the air is free of fine dust and pollen. Some of the systems have sensors enabling them to ventilate based on CO^2 levels or humidity minimizing heat loss through over ventilation. Disadvantages are that rooms that are not at the façade cannot be ventilated with this system. Also, the bathroom, kitchen and toilet still require is system that only extracts air to ensure humid air and smell are not spread throughout the house. Other possible disadvantage is that each unit has to be connected to electricity to function.

(left) HeatSava concept (Envirovent, 2017)*, (mid) Lunos system* (Lunos , 2017)*, (right) Breathing window* (Kristinsson, 2010)

The climate radiator is a variation of the breathing window with the difference that the air can also actively be preheated instead of only passively through the heat exchanger. Because of this the ventilation air is always at a comfortable temperature. Of course, this system does require the use of radiators as main heating source and they should be placed in front of the façade to connect the airpipes to the outside. This can be a problem if large glass façades are desired as using radiators causes a lot of heat loss to the outside and placing pipes through the glass surfaces is not really an option.



Climate radiator (ClimaRad, 2016)

Appendix C

To gain more information about the Poptahof and the possibilities for renovation interviews were held with Woonbron and Molenaar & Co architects.

Interview: Woonbron

This is a summary of the interview with Jaap van Zwet area coordinator of Woonbron, the housing association that owns the buildings in the Poptahof.

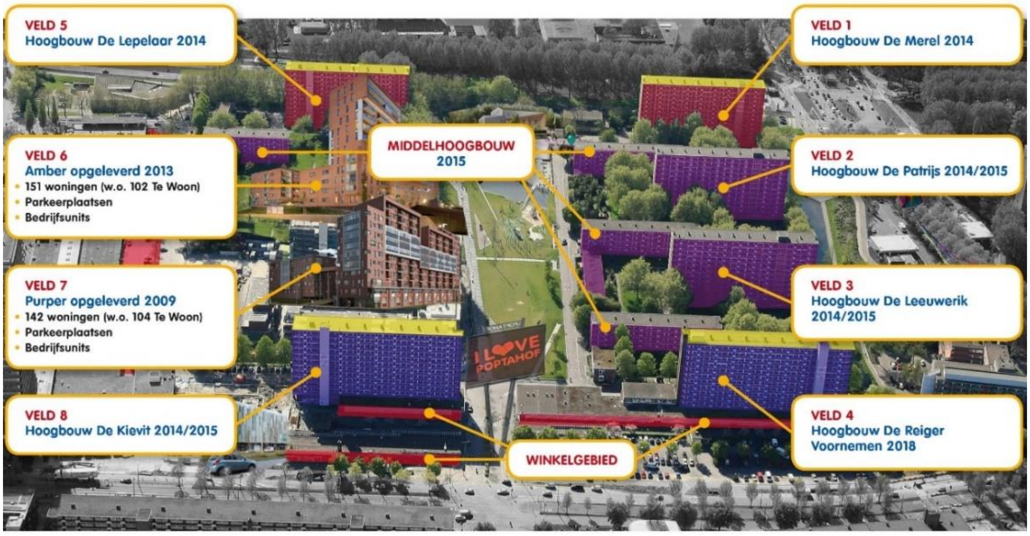
About 15 years ago, the plan was to restructure the entire Poptahof. Because the buildings in the inner part of the neighbourhood have the longest supply route it was decided to start with these ones. The current Acropolishof was the first ensemble of buildings to get restructured and a refurbishment strategy was chosen. Based on an urban plan by Palmbout Urban Landscapers a competition was organised. The architecture bureau of Molenaar architects won the competition. (more on this in the interview with Molenaar architects). Part of the refurbished buildings would remain social housing while part of the buildings would become private owned housing to finance the project and improve the social mix.

During the construction phase parts of the building construction had to be broken down for the renovation. The construction turned out not to be strong enough and the deconstruction caused instability of the building which meant that the entire building had to be jack posted. This caused severe time delays and extra costs for the project. Because the bearing walls had to stay in place also the inner spatial quality turned out not to be optimal. Also, the fact that the new inhabitants of the Acropolishof were mostly residents from the neighbouring flat that was next in line for restructuring turned out to be a bad move as they took existing social problems with them to the new flat leading to a higher rate of antisocial behaviour in the flat up to this day.

After the debacle of the first project Woonbron made the choice to change the strategy for the second restructuring project and to use demolition and replacement as restructuring tools. Again, the strategy was used to combine private owned housing with social housing to reach to good social mix. Because the building was new there was much more design freedom, so the spatial quality is better than in the first project. During the construction of the Palmyraplaats the economic crisis hit so further restructuring programs for the Poptahof were cancelled. Because of the restructuring plans, maintenance on the remaining 1960's flats in the Poptahof had not been done for the last several years. Now that the restructuring in the short term was cancelled, maintenance was far behind. In 2014 it was decided that maintenance would take place to prolong the lifetime of the flats and to keep them liveable.

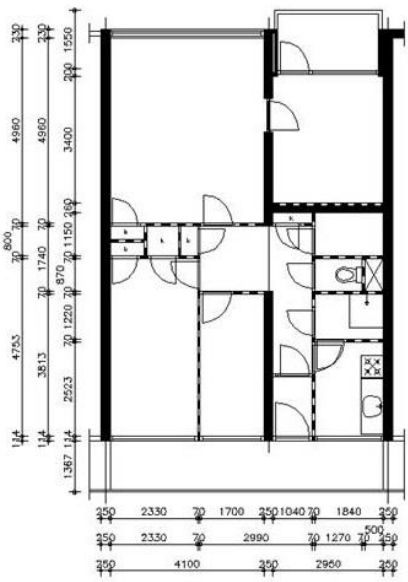
For the two inner flats of Poptahof north, Patrijs and Leeuwerik, that are also the oldest flats and in the worst condition it was decided to extend the lifetime by 15 years. Afterwards Woonbron would look for investors to demolish and replace them. The maintenance included painting the facade, recoating the floors, installing an intercom, city heating and led lights.

The outer flats at the west side of the Poptahof, Merel and Lepelaar, that are in a bit better condition would have to last for 20 years. They received the same maintenance as the inner flats and also new elevators.



Overview Poptahof planning (Woonbron, 2014)

The flats along the eastern border of the Poptahof, Kiviet and Reiger would receive a more thorough renovation prolong their lifetime to 25-30 years. This is because the flats are in the most favourable location close to public transport and the shopping centre. Renovation on the Kiviet started in 2015 and is almost finished while the renovation of the Reiger is planned for 2018. The renovation of these flats is much more conservative than the renovation of the Acropolishof. The interior and exterior of the apartments are renewed. The construction and the floorplan organisation stay mostly the same. The façade gets better insulation and a new look but the overall layout stays the same.



Renovated Kievit and current floorplan (Woningnet Haaglanden, 2017)

Nearly all the flats in the Poptahof consist of social rented housing with the exception of a few homes in Acropolishof and Palmyraplaats that were used to finance the restructuring projects of those two buildings. Most of the apartments are family homes for 1-4 people. The price range is adjusted to the quality of the flats with a maximum of €710 which is the top rate for social rented homes. In this way Woonbron can ensure that the homes never stay empty for long.

Interview Molenaar & co architects

This is a summary of the interview with Joris Molenaar of Molenaar & Co architects about the Acropolishof renovation in the Poptahof.

n 2005 Molenaar architects was selected by Woonbron to realise their restructuring plan Purper for the ensemble now called Acropolishof. The plan was designed based on the urban design plan of Palmbout urban landscapers and was architectonically supervised by Mecanoo architects. The urban plan of Palmbout devided the Poptahof into eight islands. Each island consisted of one high-rise flat one low-rise flat and a row of houses. Together they would form an ensemble with a personal look connected by an elevated courtyard. By improving the green area surrounding the buildings this would lead to a renewed neighbourhood. The architectural vision of Mecanoo included adding volumes and subtracting volumes from the existing buildings to achieve a new look. The vision was primarily form based. Within these limits Molenaar architects managed to come up with a design consisting partly of renovation and partly of new building construction. The main issues that Molenaar architects tried to address were the monotony of the buildings, improving the social mix and increasing the energy efficiency of the buildings.

To address the monotony the appearance of the buildings was changed by playing with surfaces and volumes the building ensemble got its own look. Also, different colors of brickwork were chosen giving the building ensemble a personal look. Special attention was given to the transition from public to private from the park to the courtyard with hedges to an elevated street. For the social mix the building was divided into the social rented housing combined with private owned houses. Also, the organization of the buildings changed allowing for more variety in apartment types and sizes.

The renovation project of the Acropolishof was part of the European project Sustainable Energy Systems in Advanced Cities (SESAC). The goal of this project was to stimulate local economy while at the same time minimizing CO_2 emissions. For energy efficiency, a new well insulating facade was placed and sealing were applied thoroughly. Also, the south façade was provided with patches of solar cells producing electricity for the building. The old gas boilers were also replaced by city heating combined with a heat recovery unit.

The renovation of the existing buildings consisted of stripping them down to the construction, reorganising the spaces and adding a new façade. However, when the building process started it soon became apparent that the refurbishment plan was far from ideal. Royal Haskoning that was in charge of the structural stability of the building proclaimed that that the existing construction could barely keep itself up. The MUWI building system that was used for the flat consisting of small elements did not allow for such drastic changes as proposed. To make the cut-outs in the building and the additions had become a serious challenge. Even the proposed brick façade was deemed a danger to the structural capacity of the building.

After some redesign, it was still possible to make some cut-outs by jack posting the building and small additions were possible by adding reinforcement. The add-ons on top for example had to be cancelled. Instead separate structures were made next to the existing building with their own separate loadbearing structure.

In the end, Joris Molenaar still believes in his design but he regrets the mistakes that were made. Because the building was not suitable for the way in which it was renovated the project ended up costing much more and taking much longer to complete. It would have been better if the design would have been made in a way that was better suitable for the existing building. He also still believes that renovation is an important issue for sustainability as part of the existing materials and energy saved within the construction can be reused in this way. So, he thinks it is still worth to do a renovation project, but then based on the existing structure and the possibilities that it gives.

Renovated Acropolishof (Molenaar & Co, 2009)

Urban plan Poptahof (Palmbout, 2004)