Renewable, prefab, wooden façade elements for post-war residential buildings in the Netherlands

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Abstract

In the Netherlands are many modular, post-war buildings that are at the end of their lifespan and that are in need for a solution to lower their energy use and carbon dioxide emissions. One way to do this is by renovating the façade. In this paper the best way to build renewable, prefab, wooden façade elements for post-war residential building in the Netherlands is researched.

This is done by a literature study and reference study on modular, post-war buildings and neighbourhoods, followed by literature studies to answer the sub questions about how wood can be (digitally) produced, why wood is carbon neutral and how the existing and new materials of the façade can be reused or recycled. Other questions that will be answered are what wood is available close to the location and how can that be used? Furthermore, a reference study is done to learn from existing modular systems and a literature study is done towards the use of wood for a comfortable indoor climate and different (all-)wood connection methods will be discussed. The last part contains a first idea for a wooden façade system.

With the answers to all the questions, information is gathered that can be used by designing renewable, prefab, wooden façade systems.

1 Introduction

1.1 Background

There are many post-war homes in the Netherlands. The modular built homes are built in the period from 1950 until 1975 (BouwhulpGroep advies en architectuur, 2013) and are often completed in hundreds of numbers. They cover a large part of the current housing stock in the Netherlands. When these post-war homes were built, little attention was paid to the structural quality. They did not start paying more attention to this quality until in the second half of the 1970s, when the energy prices rose (Klijn & Westra, 1987, p. 43).

As a result, the early post-war homes are badly insulated and the installations are often outdated. The energy consumption of these homes is therefore excessive and this results in high energy costs for the residents.

To lower these costs, a lot of the homes are renovated into energy neutral homes. This happens by insulating different building parts such as the façades, roofs and floors and also by replacing obsolete installations. When it comes to insulating the peel, most can be achieved from the renovation of the façades. Therefore the focus of this paper is on the renovation of this part of the building.

A positive side-effect of a renovation to an energy efficient home is that the amount of carbon dioxide emissions of the property goes down too. This is a good thing, because emissions of greenhouse gases, including carbon dioxide, need to be brought down drastically to contribute to solving the climate change challenge (Ürge-Vorsatz, Danny Harvey, Mirasgedis, & Levine, 2007, p. 380). The Dutch goal is to reduce the amount of greenhouse gases by 80 per cent in 2050, compared to 1990 (Hellinga, 2010, p. 5). But not only energy use of buildings has influence on the carbon dioxide emissions in the building industry.

Many different materials are used for the construction and renovation of homes, of which the most traditional ones are concrete, steel and wood. A disadvantage of many of these materials is that they need a lot of energy to be produced (Bribián, Capilla, & Usón, 2011, p. 1139).

Wood is in fact the only traditionally used building material which has a negative carbon footprint (Houtinfo.nl, 2016; Sikkema & Nabuurs, 1995, p. 155). This is why the material wood is fascination from an ecological point of view. The use of this material does not only lower the footprint of the use of the homes, but also that of the homes self. Therefore, wood is an ideal material for renovating the façades of the not energy efficient post-war, modular buildings.

The aim of this research is therefore to find a solution to renovate post-war, modular buildings by using wood. De research question that will be answered is therefore:

> *"What is the best way to build renewable, prefab, wooden façade elements for post-war residential buildings in the Netherlands?"*

1.2 construction of the paper

The question will be answered in three different parts. Firstly, by conducting a literature study on modular, post-war buildings. Secondly, different sub questions help doing research towards the different possibilities of wood. Furthermore three different existing modular, wooden façade systems will be studied. The last part will contain the proposal of wooden façade elements.

1.3 Limitations

As previously noted, this paper will focus on wood as material to improve the façades of post-war buildings to make them energy efficient and carbon dioxide neutral. Other building parts will be taken out of consideration.

Furthermore, for this research, a case study is chosen. This is because this paper is a part of a graduation project, focussed on the renovation of buildings from the 1960s in Vrieheide, Heerlen.

1.4 Relevance

This project focusses on buildings in Vrieheide from the 60s, but the kind of buildings that can be found here, can be found in many other places of the Netherlands. The way that this design makes these buildings energy / CO_2 neutral is thereby not only interesting for locations in Parkstad, but can be seen as a more general approach for the renovation of post-war, modular buildings.

Furthermore, this report can be seen as an inspiration to re-think the use of materials that embody carbon dioxide in the construction industry.

2 Method

This research exists of three parts. In the first part, the requirements for the façade elements will be defined. This will be done after a literature study towards the post-war residential buildings and neighbourhoods and a study towards the three most common post-war residential building types.

After the requirements are written down, the design of the façade elements will be studied. This will be done by answering the sub questions with literature studies and by testing different existing façade systems. The sub-questions that will be answered are:

- What elements should be produced?
- What is a carbon footprint and what does carbon neutral mean?
- What is the carbon dioxide cycle of wood?
- How can the existing façade be recycled?
- How can wood be recycled?
- What wood can be found in the surroundings?
- How can this wood be applied?
- What engineered wood can be used and produced?
- How can the digital process be used to produce the façade elements?
- What timber connections are possible?
- How can the timber façade be connected to the existing concrete structure?
- How can a comfortable indoor climate be created using the properties of wood?
- What modular wooden systems do exist and how do they meet the described requirements?

The last part will contain the first designs of wooden façade elements, based on the studies in the previous chapters.

3 Results

3.1 Post-war modular buildings

After the Second World War there was a shortage of homes. To solve the housing shortage, new building methods were tested. Instead of the traditional buildings, prefabricated, modular buildings were built (Blom, Jansen, & van der Heide, 2004, p. 25).

Construction methods

The first method that was tested is the stack work construction method (stapelbouw). With this system, houses were built with a concrete structure and floor panels and concrete blocks walls (Airey system; Figure 1)(Blom et al., 2004, p. 25). The various parts were made in the factory and assembled at the building plot (Zijlstra, 2006, p. 26). A lighter version of this construction method is the timber framed structure of B-G. For almost all these modular systems, brick masonry walls were used for the exterior walls (BouwhulpGroep advies en architectuur, 2013, p. 52).

Then new methods were used to further increase the production speed and construction speed: the dry construction method (elementenbouw) and the poured concrete construction method (gietbouw). A downside of these ways of building was the high costs for the necessary construction crane. To make the buildings profitable, higher buildings needed to be built. From that moment on, more porticos and gallery flats were built (Figure 2) (Blom et al., 2004, pp. 27, 28).

Quality of buildings

The quality of post-war homes can be found in the plans of the houses. The house-separating walls are load bearing walls and all partition walls are non-bearing parts of the buildings (BouwhulpGroep advies en architectuur, 2013, p. 8). Therefore, the walls in all houses can be replaced and removed (Figure 3).

Furthermore, the concrete structure is mostly in good condition, in contrast to the shell: the façades and roofs are barely or not insulated. In addition, the more than fifty-year-old houses are at the end of their life cycle (Hoogendijk, 2012, p. 27).

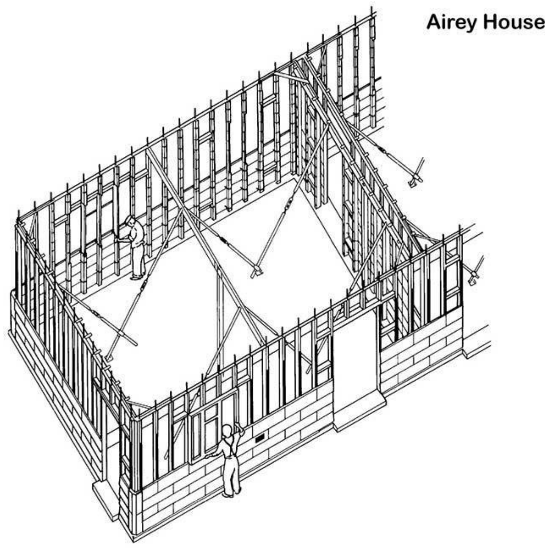


Figure 1. Airey house ("What is a Airey house?," 2015).

Figure 2. Cranes to build higher modular buildings (BouwhulpGroep advies en architectuur, 2013, p. 19).

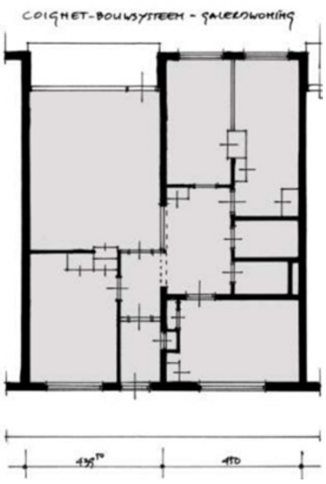


Figure 3. Coignet-building system - gallery flats (BouwhulpGroep advies en architectuur, 2013, p. 19).

3.2 Post-war neighbourhoods

The fast construction methods made it possible to build and produce in series and in mass. As a result, entire neighbourhoods were built of equal, modular homes.

The three most built residential building types are terraced houses, portico flats and gallery flats. The different building types were used in one neighbourhood to create diversity (Figure 4) (Blom et al., 2004, p. 35).

The neighbourhood allotments changed too. Instead of the traditional closed building blocks, open buildings blocks were designed. Blom et al. (2004, pp. 36-38) described the three most common forms as strips shaped, court shaped and stamped buildings allotments (Figure 5-7).

The strip shaped allotment is a reaction to the standard, closed building blocks and is oriented on the sun. The north side of the building is connected to paths that lead to the roads. Gardens are located on the south side of the properties. The building blocks are mainly built back-facing-back or front-facing-back. A quality of these allotment is the applied communal green between the housing blocks.

The court shaped and stamped allotments are variants of the strip allotments and were used to create a more differentiated neighbourhood. Despite this, the neighbourhoods have a monotonous image and miss variety.

3.3 Case studies

Terraced houses – Vrieheide, Heerlen

The neighbourhood Vrieheide was built in the beginning of the 1960s. The architect of the buildings is Peter Sigmond.

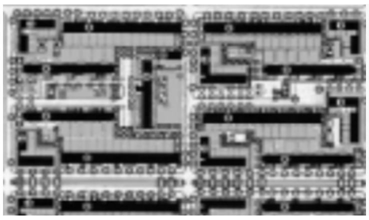
Idea (Bertholet, 2015, pp. 29-34)

The ideas that Peter Sigmond had for the houses in this neighbourhood, was to create a typology that could be built in high speed and with low costs to solve the housing shortage.

The front of the building blocks is positioned towards the north and the back towards the south and is thus oriented on the sun. A few of the blocks have an east-west

Figure 4. Variation in the neighbourhood with different building blocks (Bernaards, 2016).

Figure 5. Strip shaped allotment in the neighbourhood Griffioen, Middelburg (Stichting Boemenburt Griffioen, 2016).



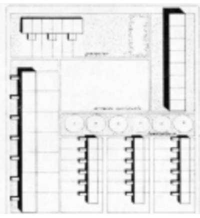


Figure 6 (left) .Court shaped allotment in the neighbourhood Kanaleneiland, Utrecht (Blom, Jansen, & van der Heide, 2004, p. 43).

Figure 7. Stamp allotment in the neighbourhood Pendrecht, Rotterdam (Blom et al., 2004, p. 44).

orientation. The building 'strips' are stamped through the neighbourhood. Communal green is placed between the housing strips, which gives the area a park-like appearance.

The houses have overhangs on two sides, so the ground floor can be used as a covered outdoor area or to expand the house. This makes it possible for the residents of the neighbourhood to give an own identity to their homes (Figure 8-11).

Structure

The architect designed a building with concrete walls and overhanging floors on two sides, built following the poured construction method. The concrete house-separating walls and the floors created the stability of the terraced houses (Figure 12).

Plans

Figure 12 shows the plans of the 120 square meter terraced houses. On the ground floor are only storage spaces and a stair. On the south side of

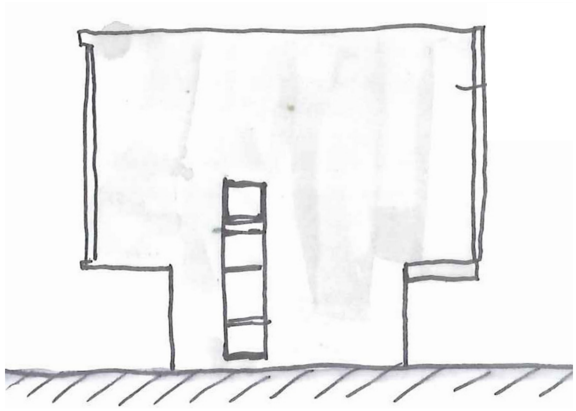


Figure 8. Original, concrete, west facade of the terraced houses in Vrieheide (own ill.)

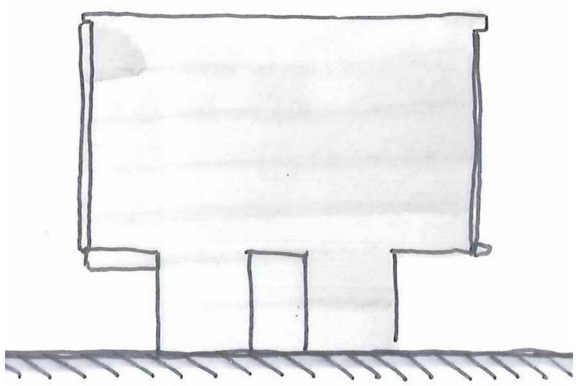


Figure 9. Original, concrete, east facade of the terraced houses in Vrieheide (own ill.)

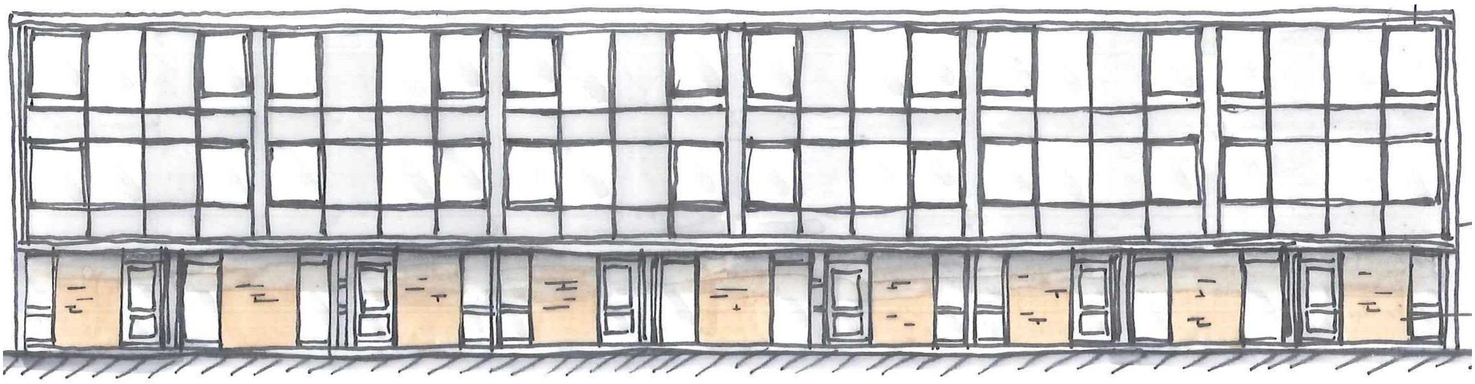


Figure 10. Original north facade of the terraced houses in Vrieheide. The ground floor is made as brick masonry cavity wall and the facade of the first and second floor is a aluminium framed curtain wall with panels and glass. (own ill.)

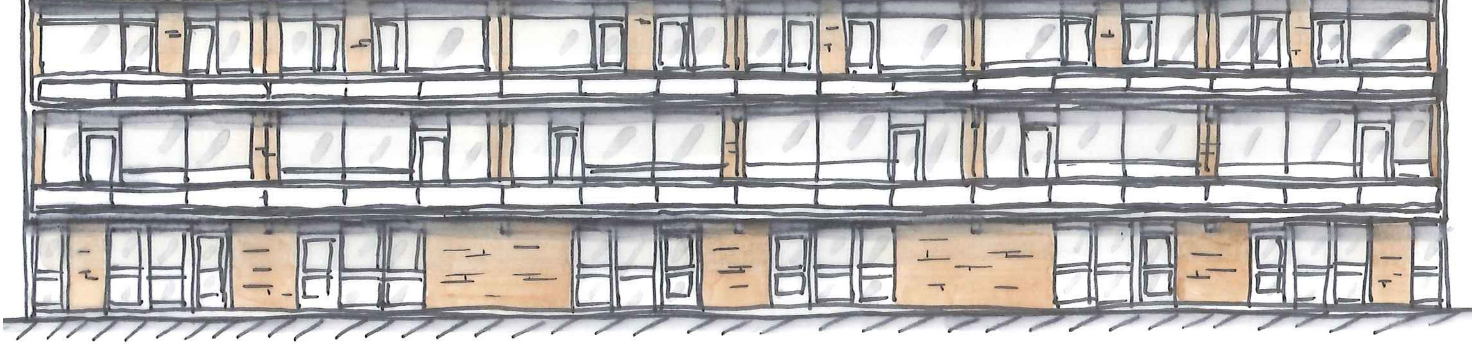


Figure 11. Original south facade of the terraced houses in Vrieheide. The ground floor is made as brick masonry cavity wall. The first and second floor have balconies and the facade is made of brick mansonry walls and wooden framed elements with panels and glass. (own ill.)

the first floor is the living room and the kitchen is located on the north side. On the second floor are three bedrooms, of which two are connected to the balcony.

Materials

As has been mentioned, the construction is made of concrete elements. The ground floor façades on the front and back of the houses consist of brick cavity walls. Furthermore, curtain walls are used on the first and second floor of the north side of the building (Figure 13). These curtain walls are constructed of aluminium frames with panels and glass. On the back the façades, between the balcony, floors are made of brick cavity walls and wooden frames with panels and glass. The parapets on the inside of the buildings are made of brick masonry (Figure 14).

Current state - Terraces houses

Although the homes initially were part of a rental corporation, they are now in the possession of owner occupants. Because of this, the responsibility for the maintenance is the residents themselves.

Problems

The problems that can be found on the outside of the buildings are (Figure 15 – 19):

- cracks in the side façades
- roofs with green growing upon them
- damaged curtain wall systems
- bad maintained back façades and balconies
- wild growth of extensions to the houses on the ground floor
- wild growth of extensions to the houses on first and second floor of the south façade
- thermal bridges by consoles and balconies

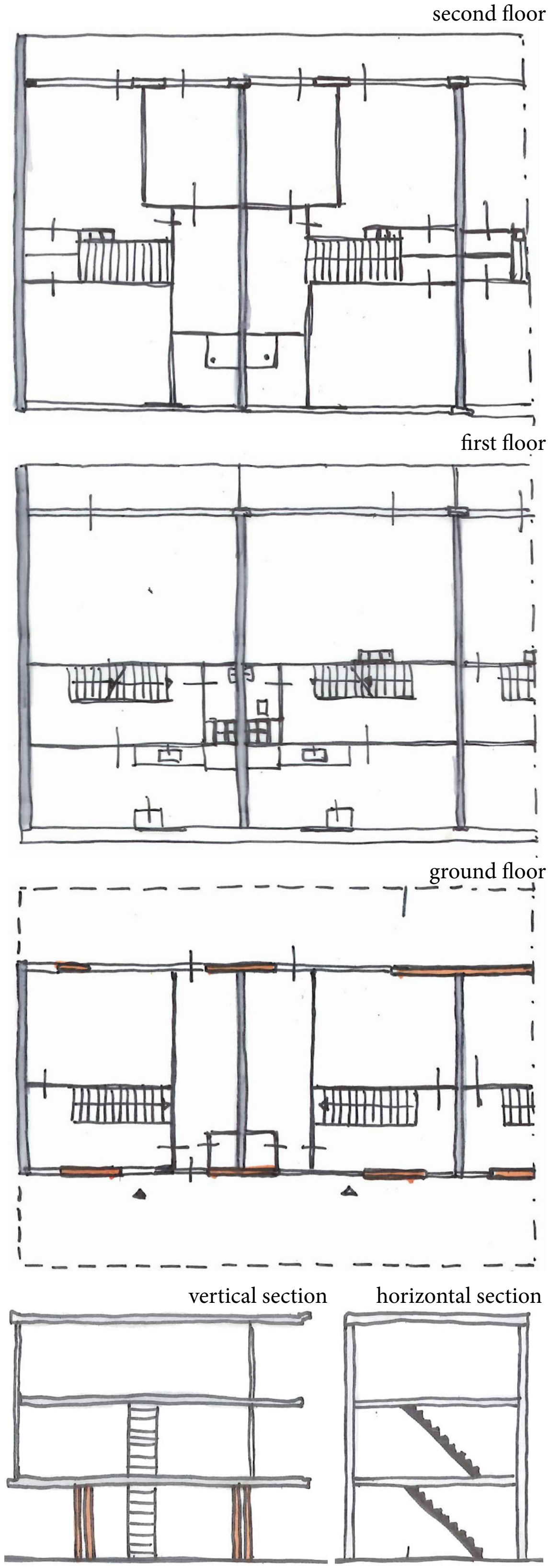


Figure 12. Plans and section of the concrete structure of the houses in Vrieheide. The cavity walls and stairs provide the stability of the building block (own ill.).

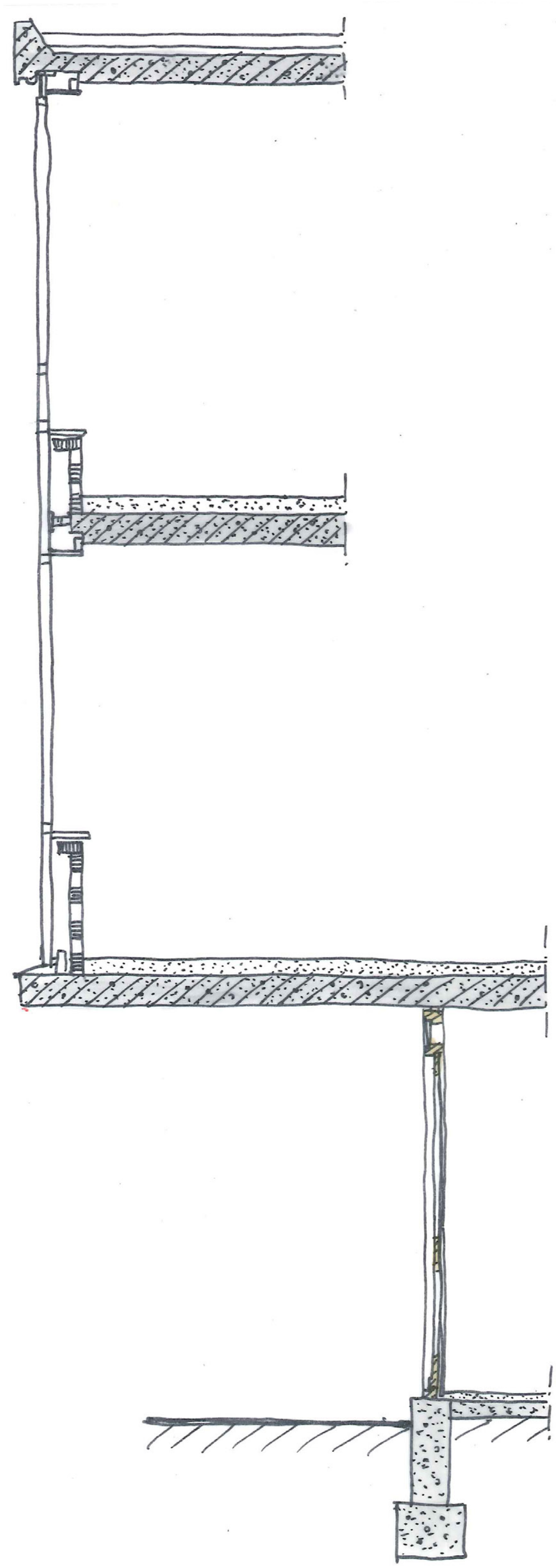


Figure 13. Section of the north façade of the terraced houses in Vrieheide (own ill.).

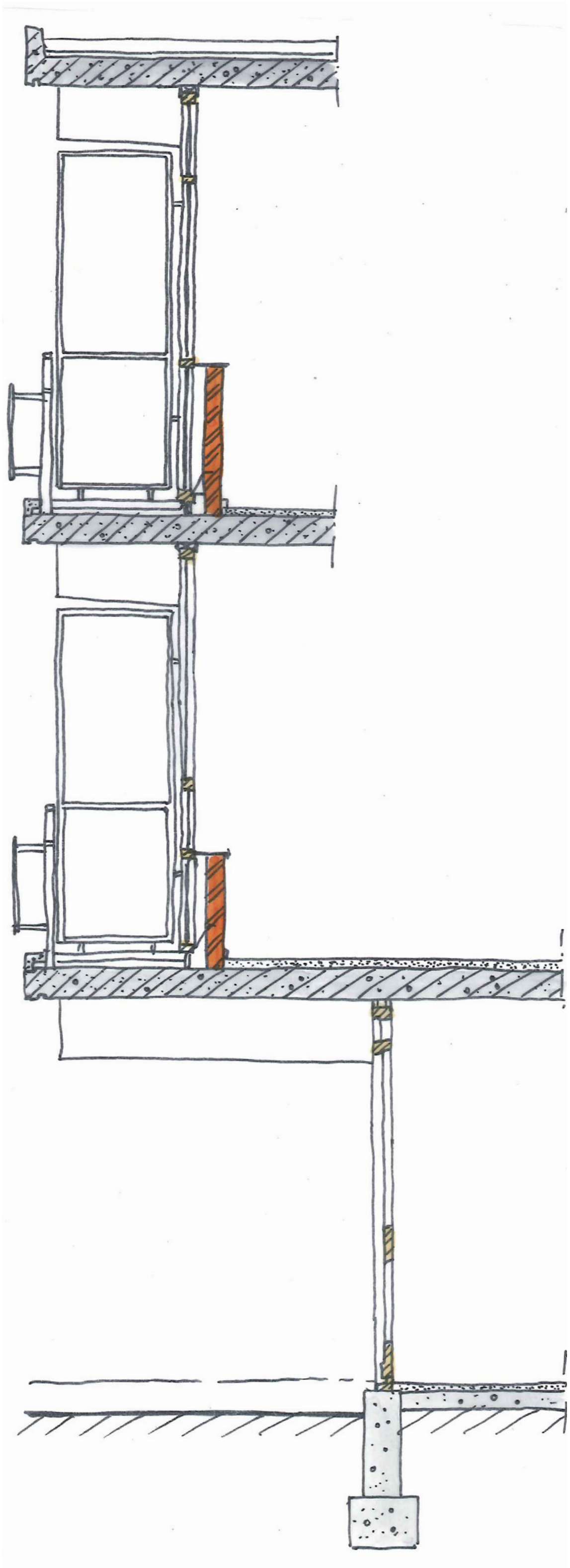


Figure 14. Section of the south façade of the terraced houses in Vrieheide (own ill.).

Other problems are that:

- plans don't meet current requirements: many residents changed the size of their bathroom and ground floor
- the panels between the balconies and the parapets on the inside of the homes contain asbestos (Figure 20 & 21).
- the buildings are not insulated (Figure 20 & 21)
- the buildings have energy label E
- the area suffers from pauperization
- the public green is not everywhere well maintained (Figure 19)
- there are big single layered windows
- there is a loss of identity of the neighbourhood, caused by the badly maintained (the impoverished) buildings en surroundings

Qualities

- the possibility to enlarge the ground floor
- the freely movable interior walls
- the strong structure
- the identity of exterior: the white, concrete side walls and aluminium curtain walls

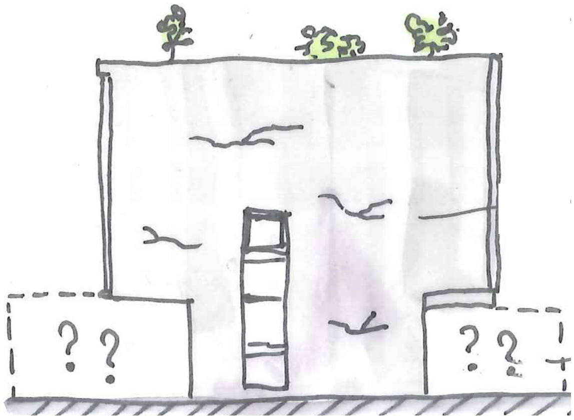


Figure 15. Current state of the west façade (own ill.).

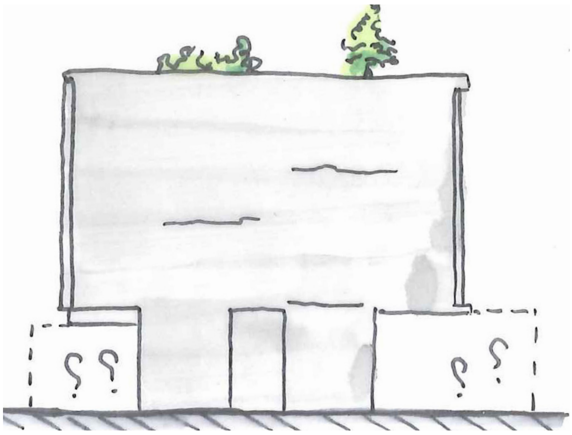


Figure 16. Current state of the east façade (own ill.).

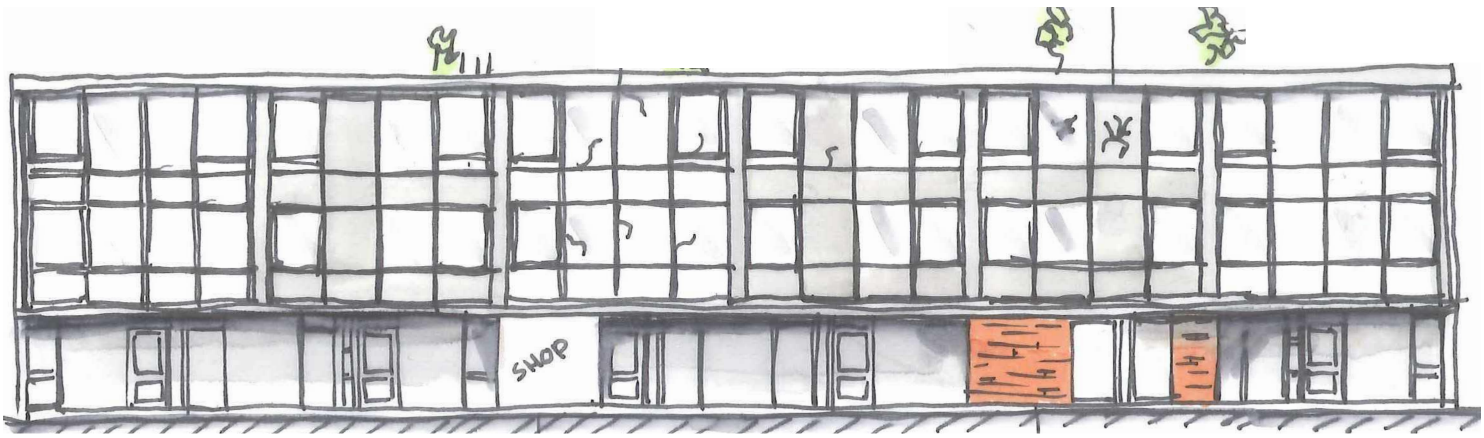


Figure 17. Current state of the north façade of the terraced houses in Vrieheide (own ill.).

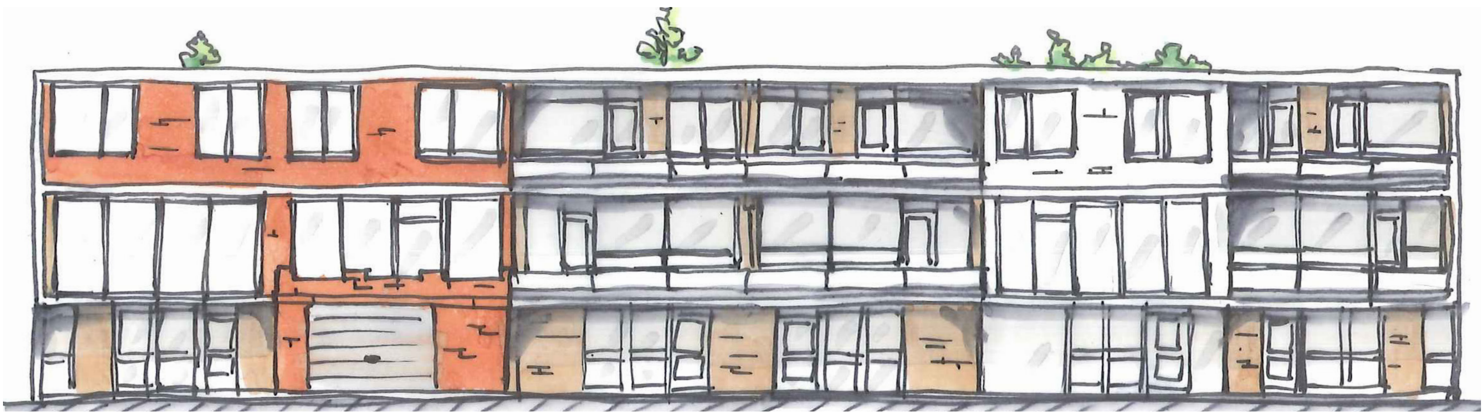


Figure 18. Current state of the south façade of the terraced houses in Vrieheide (own ill.).

- the position of the building blocks between
- the communal green
- the large windows to connect with the outside area

Possibilities
- making the façades energy efficient by insulating
- insulating the balconies
- renewal of the façades
- create more variation
- expanding homes / create new spaces on ground floor
- expanding the first and second floor at the back

Figure 19. The neighbourhood Vrieheide has a park-like appearance. This is because between the building strips are not roads, but green areas (own ill.).

1. added insulation
2. elements with asbestos
3. non insulated parts

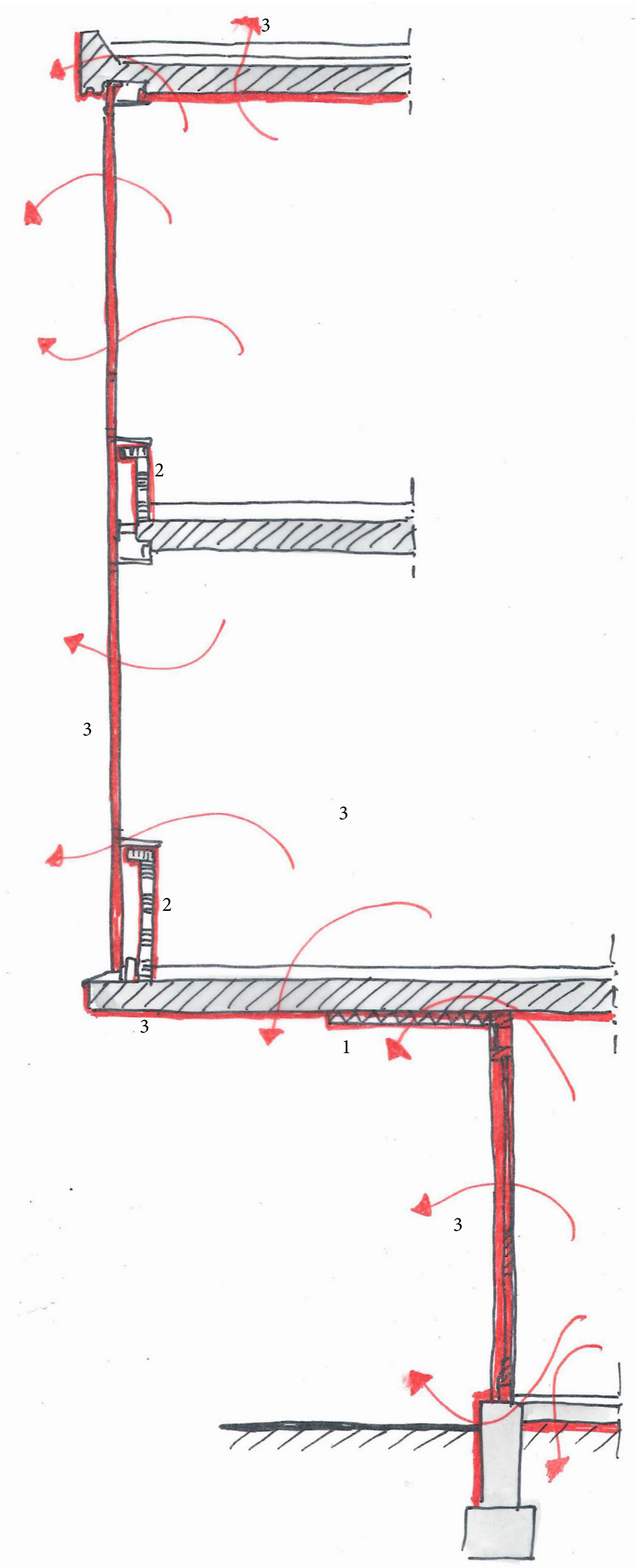


Figure 20. Section of the north façade of the terraced houses in Vrieheide with illustrated problems (own ill.).

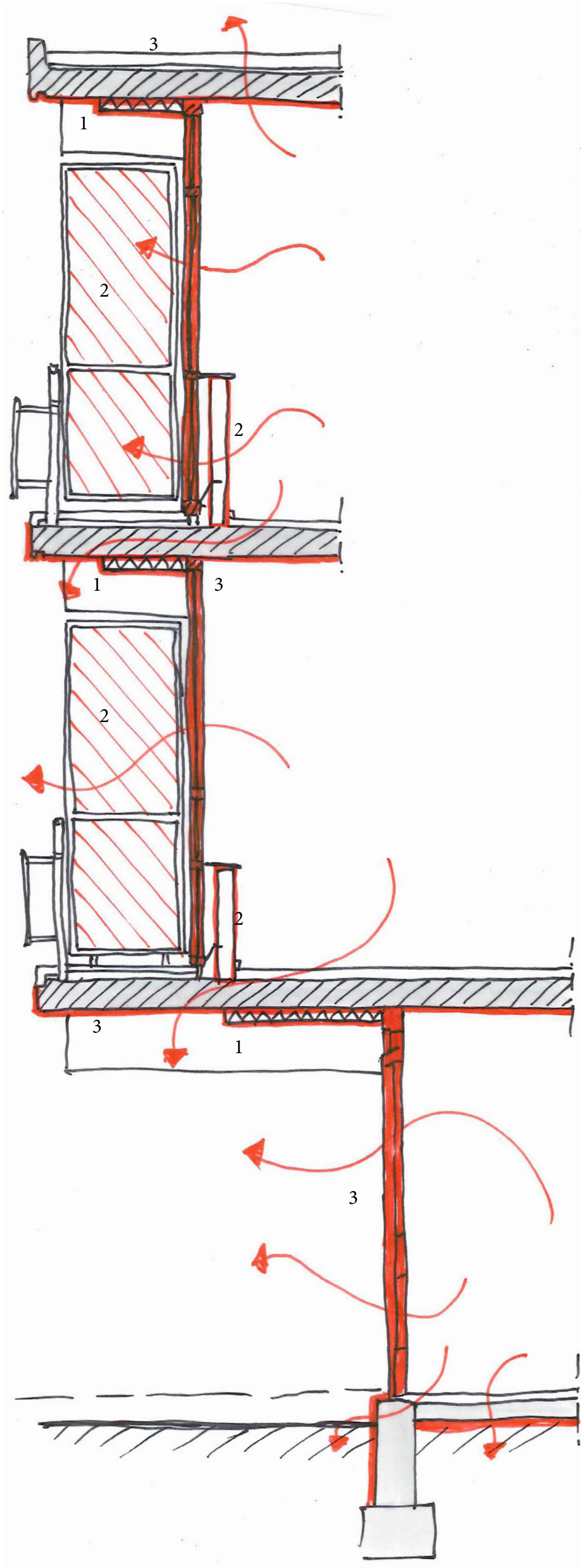


Figure 21. Section of the south façade of the terraced houses in Vrieheide with illustrated problems (own ill.).

Gallery flats – Vrieheide, Heerlen

The two tower flats in the neighbourhood Vrieheide are built on behalf of housing corporation Vasco Mij in the 1960s (VASCOMIJ, 1962) (Figure 22-24).

Idea

As mentioned previously, the high-rise buildings are the result of new construction methods anc created a varied neighbourhood.

The tower flats in Vrieheide are built as another solution for the housing shortage in Heerlen (in addition to the terraced houses). The gallery flats are placed in a park. On two sides of the apartments window strips are placed. For this, the residents should get the feeling of living between the green (Figure 26).

Structure

The structure of the tower flats consists entirely of concrete slaps and floors and is built following the poured construction method. The apartment separating walls are the load bearing walls of the construction. In the centre of the building is a core with the lift shafts and staircases (Figure 24).

Plans

The buildings contain four different oriented apartments on every floor. The staircase is placed close to the entrance and the elevators are positioned in the centre of the building (Figure 24). Figure 25 shows one of the flat apartments. The closed functions are close to the core of the building and the living room, kitchen and bedrooms are connected to the balconies.

Materials

On the outside of the concrete structure a brick masonry wall was applied. Between the with bricks cladded walls are wooden frames with panels and glass.

Figure 22. Aerial view of the district Vrieheide (Openbare werken, 1963).

Figure 23. Apartment complex in Vrieheide (Bos, 1969a).

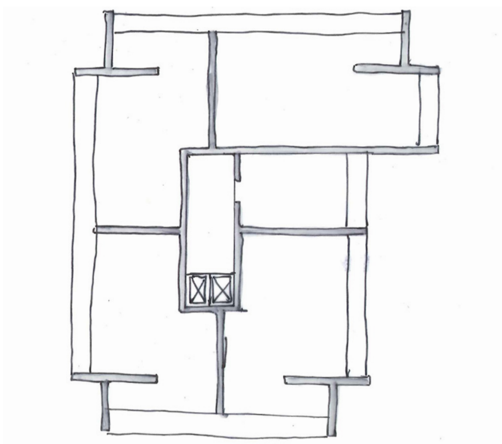


Figure 24. First floor of gallery flats with four apartments (own ill.).

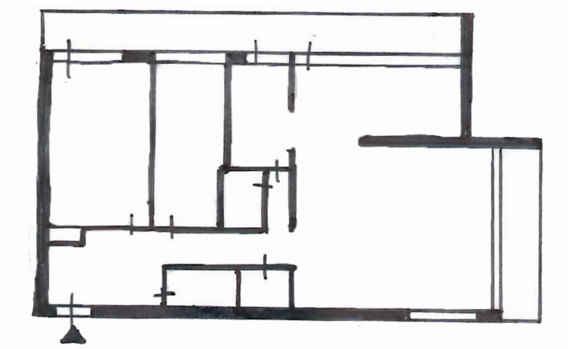


Figure 25. Plan of one of the apartments (own ill.).

Figure 26. The gallery flats are surrounded by a green area called 'Vrieheidepark'(own ill.).

Figure 27. Surrounding area of the current tower gallery flats in Vrieheide (own ill.).

Current state – Gallery flats

Problems

The gallery flats are owned by a housing association and are - because of this - well-maintained (Figure 28-31). The problems that can be found are the following:

- the buildings are not insulated
- the buildings have energy label E
- the public green is not everywhere well maintained (Figure 27)
- the big singled glasses
- the big windows are on the north façade
- consoles and balconies form thermal bridges
- the floors cause contact sound between the homes (Rotterdam energiebesparing, n.d.)

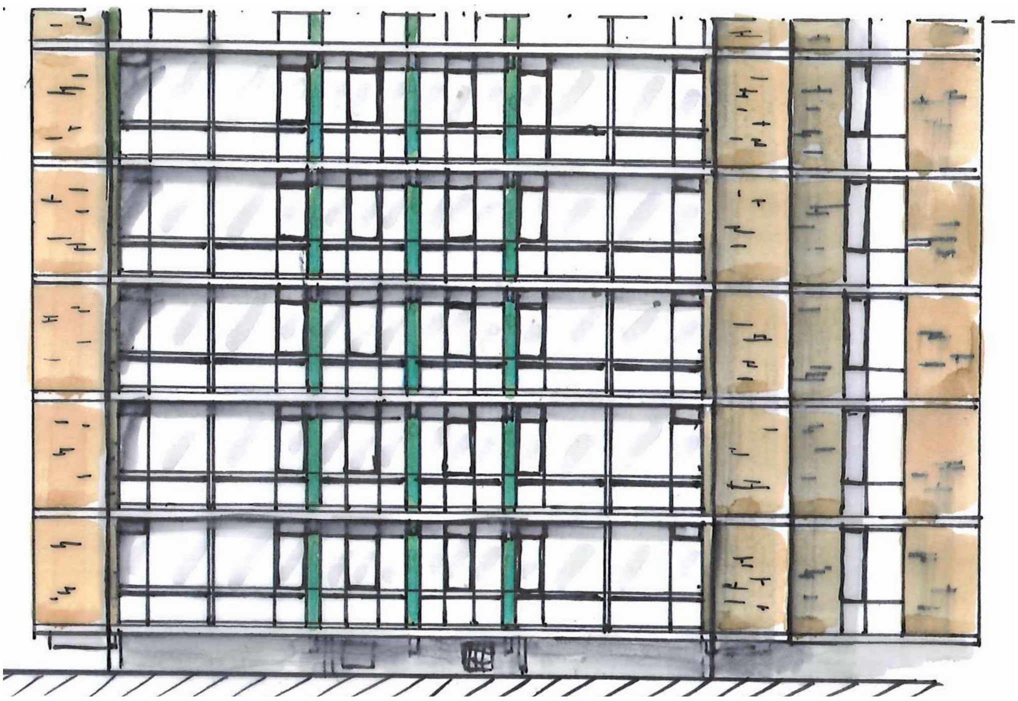


Figure 28. Current south façade of the tower gallery flats in Vriehedepark (own ill.).

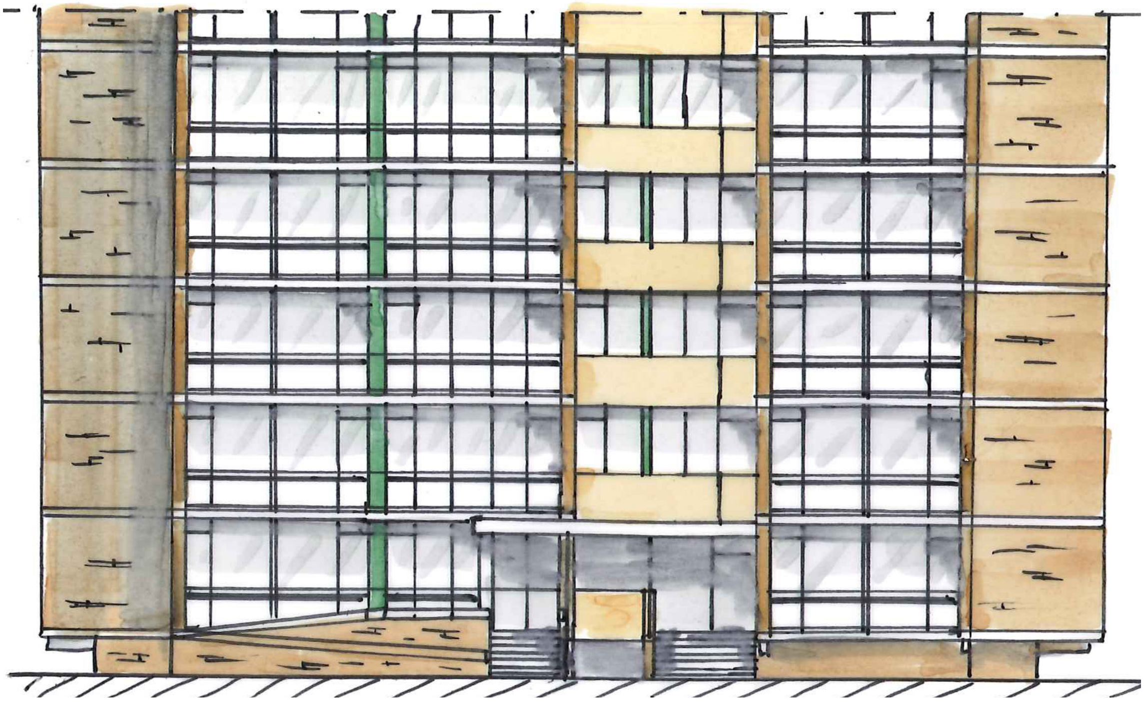


Figure 29. Current east façade of the tower gallery flats in Vriehedepark (own ill.).

Qualities

- the free movable walls
- the strong structure
- the position of the building blocks between the communal green
- the large windows to connect with the outside area

Possibilities

- making the façades energy efficient by insulating
- decreasing the window area
- insulating the balconies
- renewal of the façades
- creating more variation

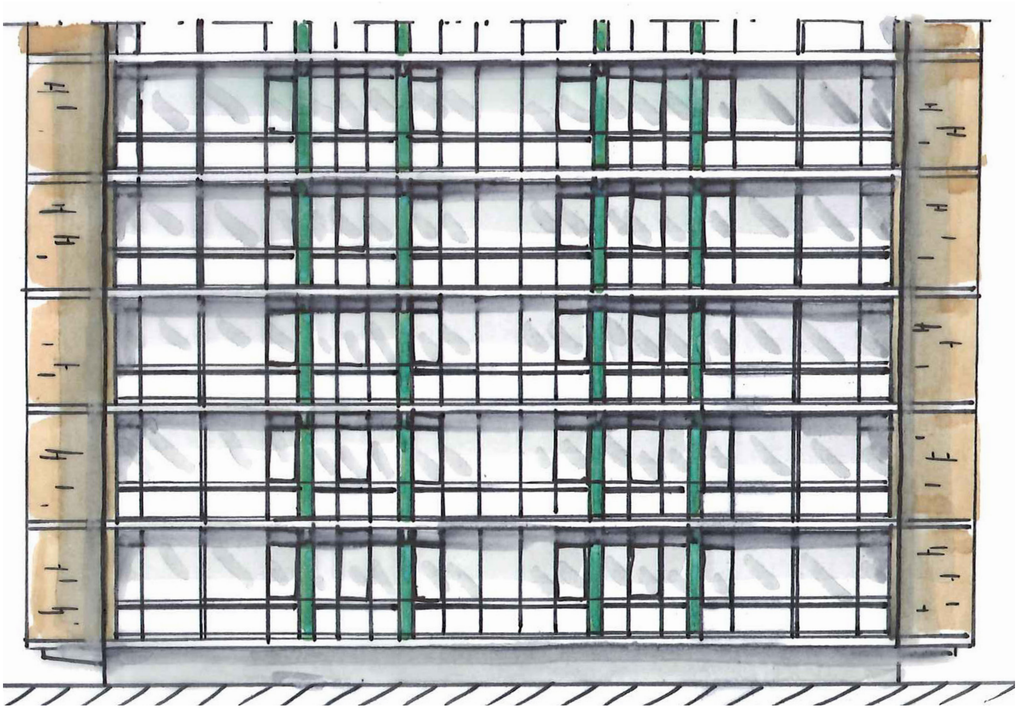


Figure 30. Current east north of the tower gallery flats in Vriehedepark (own ill.).

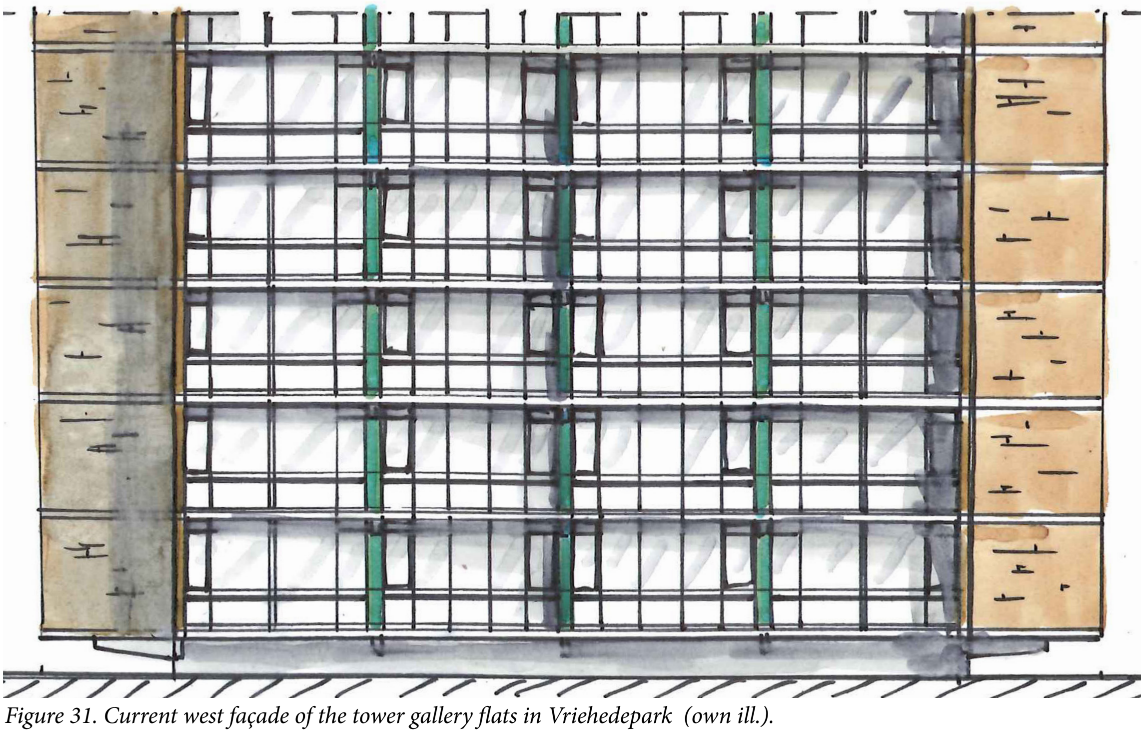


Figure 31. Current west façade of the tower gallery flats in Vriehedepark (own ill.).

Portico flats – Hof van Delft, Delft
In the 1960s various portico flats are built in the Hof van Delft in Delft (Figure 33-34).

Idea
The building blocks are built back-facing-back. The front façade is oriented east or west. At the front of the buildings the streets towards the bigger roads are positioned. Communal green can be found at the back (Figure 32). The buildings are also located next to a bigger green area. The aim of building these buildings was therefore to let people live between the green and to decrease the housing shortage.

Structure
The structure of the portico houses consists of concrete walls and floors. The building separating walls are the load bearing walls of the buildings (Figure 35).

Plans
In the front of the building is a staircase leading to the different floors. To this staircase are two houses that are connected at every storey. The 75 square meter homes have a big living room running from the front till the back of the building. The bigger bedroom is connected to the front and the other bedroom, kitchen and bathroom are connected to the back (Figure 35).

Materials
The concrete structure is covered in a layer of brick masonry. The front and back façade are made of brick masonry cavity walls, except for the part with the balcony. Here is made use of a wooden framed system of panels and glass.

Figure 33. Buildings seen from Mees Avenue from W.H. Lion Avenue to the west. In the background the apartment on the corner of Foreestweg / Provincialeweg (A.P.I. Kerklaan, 1984b).

Figure 34. Homes on the east side of the Knuttelstraat 2-48 seen to the north (A.P.I. Kerklaan, 1984c).

Figure 32. Green surroundings of the portico homes in Hof van Delft, Delft (own ill.).

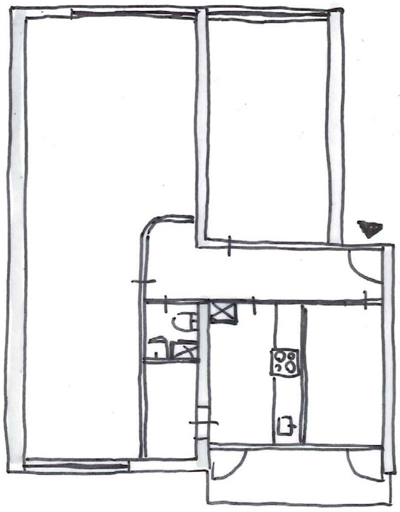


Figure 35. Plan of one of the portico homes in Hof van Delft, with concrete walls and brick masonry façades (own ill.).

Current state – Portico flats

Problems

The problems of these houses cannot be found in the exterior, because the buildings are very well maintained (Figure 36-40). Nevertheless, the buildings do have some problems that cannot be seen from the outside:

- the buildings are not insulated
- the buildings have energy label E
- consoles and balconies form thermal bridges
- the floors cause contact sound between the homes (Rotterdam energiebesparing, n.d.).

Qualities

- the free movable walls
- the strong structure
- the position of the building blocks between the communal green
- the large windows to connect with the outside area
- windows on the east and west side

Possibilities

- making the façades energy efficient by insulating
- decrease of the window area
- insulating the balconies
- renewal of the façades
- create more variation

General results for the post-war buildings

The general results of the study towards the post-war residential buildings are that there is a lack of variety by the monotony of buildings in the neighbourhoods and that the neighbourhoods of the building with the surrounding green is important, but also lost.

Furthermore, the quality of the buildings can be found in the still reliable concrete structure and the great flexibility of the plans. In contrast to the structure, the façades of the buildings have a low quality.

Therefore is in this study chosen not to design an addition to the existing façades, but

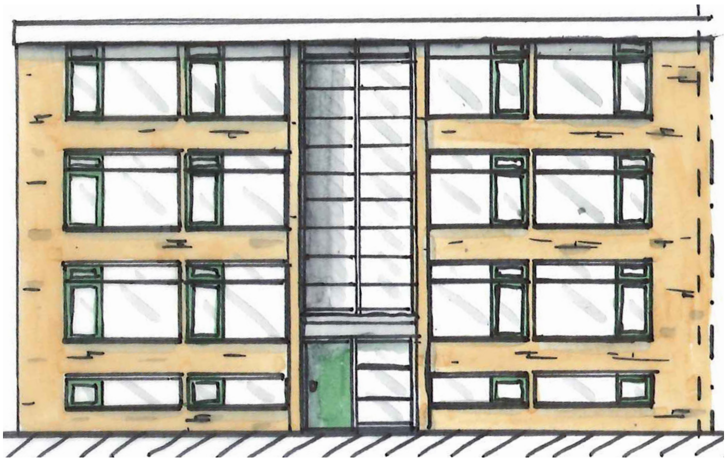


Figure 36. East (or west) façade of the portico homes in Hof van Delft, Delft (own ill.).

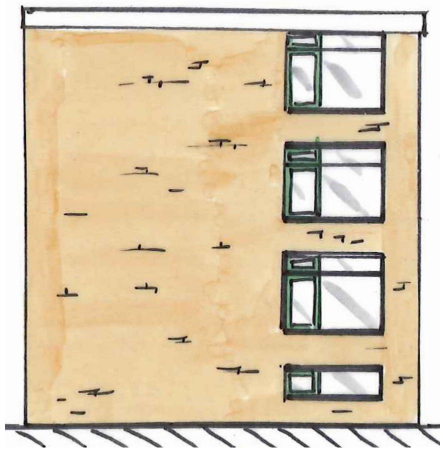


Figure 37. South (or North) façade of the portico homes in Hof van Delft, Delft (own ill.).

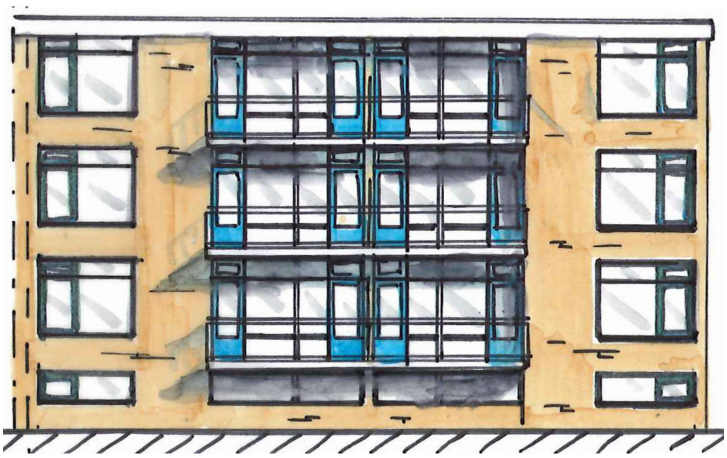


Figure 38. West (or east) façade of the portico homes in Hof van Delft, Delft (own ill.).

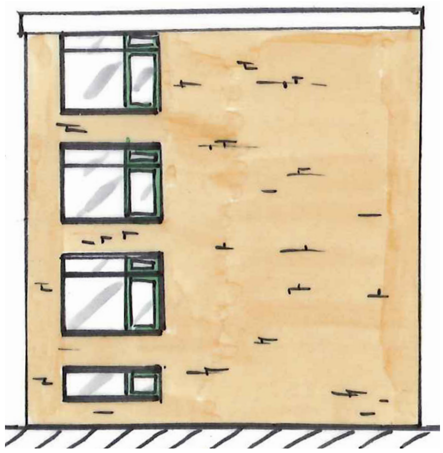


Figure 39. North (or South) façade of the portico homes in Hof van Delft, Delft (own ill.).

to design a replacement for the existing façades. The buildings therefore needs to be stripped to the structure.

3.4 Requirements

By using the knowledge of the previous chapters, the following requirements are drawn. The façade elements need to:

- be applicable to modular, post-war residential buildings
- be made energy efficient by insulating
- solve the thermal bridges
- improve the indoor climate
- improve the relation with the green outside area's
- have a high quality appearance
- create variation
- be carbon neutral
- be all-wood
- lightweight

3.5 Production

Before a design can be made for the façade elements, the production of these elements should be mentioned. In the established requirements was named that the elements need to be applicable to the modular, post-war residential buildings, but also need to create variation.

Because of the enormous amount of post-war buildings, mass production seems a logical option. Also, because these buildings are the result of mass production and because it could be a solution to stop people making messy extensions to their homes.

However, these extensions to the existing (Figure 17, 18) show that residents of the neighbourhood feel the need to enlarge and individualise their own house. Furthermore, the lack of the variation in the neighbourhood is mentioned as one of the problems of post-war neighbourhoods. And, - although there are built many similar houses – it is hard to mass produce façades when the dimensions of the structures of the buildings differ from one another. These are the reasons why one system won't work for these buildings.

Still there could be thought of a way to mass produce and to create variation in these façade elements at the same time. Or there could be thought about creating two different systems: one for mass production and one for individualization. This also, because there is the difference of houses that are owned by rental corporations and houses that are of owner occupants.

Figure 40. Green area's between the portico flats in Hof van Delft, Delft (own ill.).

3.6 Building carbon neutral with wood

Carbon footprint and carbon neutral

The definition of carbon footprint given by Wiedmann and Minx (2008, pp. 4, 5) is that “the carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product.” When a carbon footprint is equal to zero, it is called ‘carbon neutral’ (Kumar, Sharma, & Vashista, 2014).

The carbon dioxide cycle of wood

When wood is produced in a sustainable way, the material can be carbon neutral. This is because it takes up as much CO2 during the growth as it releases during decay or combustion (Figure 41). Furthermore, the production of wood requires relatively little energy for forestry and wood processing. As a result, as long as wood is not burned, the carbon footprint of the material is not neutral, but even negative. (Frühwald, 1997; Goverse, Hekkert, Groenewegen, Worrell, & Smits, 2001, p. 54; Herzog, Natterer, Schweitzer, Volz, & Winter, 2004, p. 48)

3.7 Renewability of the existing façade

Recycling of the materials of post-war buildings

The future of the materials of the existing façade elements has also effect on the carbon footprint. By combustion of these elements, many carbon dioxide will be produced. Therefore, the possibilities for reuse and recycling of the materials is considered.

The materials that were used for the façades in the case studies are: wooden window frames, aluminium window frames, wooden panels, single layered and double layered glass, and brick masonry (bricks and mortar).

Wooden window frames

The wooden window frames that are used in the post-war building can be recycled into OSB boards (Figure 42).

Aluminium window frames

The aluminium window frames could be reused in total with the panels and glass or could be

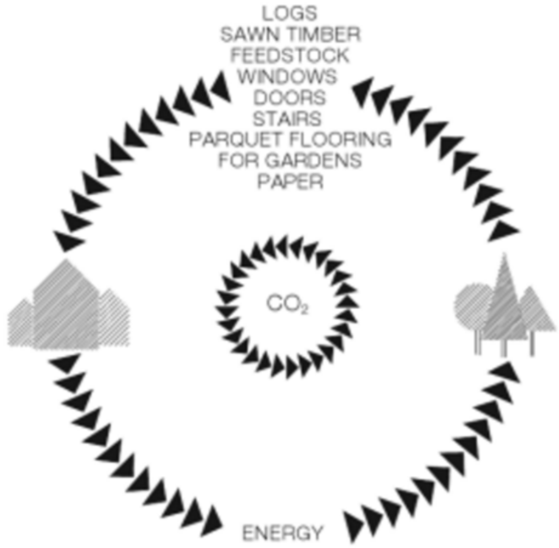


Figure 41. Total life cycle of timber, which corresponds to the carbon dioxide cycle (Herzog, Natterer, Schweitzer, Volz, & Winter, 2004, p. 48).

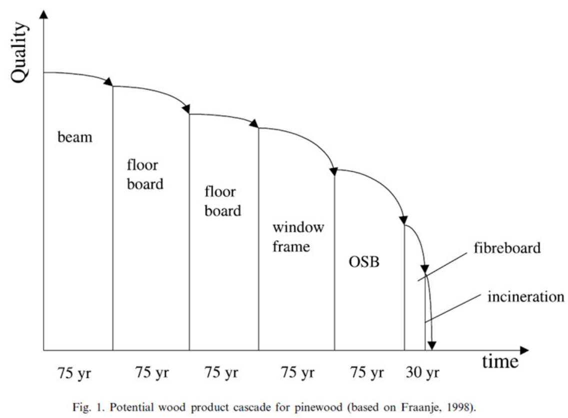


Figure 42. Potential wood product cascade for pinewood (based on Fraanje, 1998) (Goverse et al., 2001, p. 66).

melted into a totally new product. By recycling aluminium instead of making new aluminium, about 95% less energy is needed (Jonkers & Dreijerink, 2011, p. 7).

Wooden panels

The wooden panels that are used in the wooden and aluminium frames can be reused in smaller pieces. And, when the panels are damaged too much, they can be recycled into fibreboards (Figure 42) or paper.

Glass

If the glass in the window and door frames is removed carefully and the glass is pure (no kit, paint, sand etc.) it can be reused. Furthermore, broken glass can be 100% recycled into new glass products or glass containing products (Versele & optie Bedrijfskunde, 2006, p. 26).

Brick masonry
Most exterior walls and parapets are built out of brick. In the first case study the parapet on the interior contained asbestos, but when the parapet is of good quality, the bricks can be reused. However, not as construction material. This is because the bricks get damaged by the demolition and are hard to separate from the mortar. A way the materials can be reused is as foundation material underneath highways (Kowalczyk & Fraanje, 2002, p. 5).

Wood recycling
Recycling of wood can be done in three different ways: product reuse, material recycling and energy recovery (Worrell et al., 1994). Product reuse is defined as reusing the product in its original form. In case of material recycling, products are reused as secondary material (Figure 43) and in case of energy recovery, the material is incinerated and energy is recovered. (Goverse et al., 2001, p. 64)

3.8 Materials for façade elements

Not only the use of timber is of influence on the amount of CO2 that is produced, but also the transport of the wooden elements and the replant of trees after hacking. In this chapter will be studied where sustainable planted trees can be found close to the location of Vrieheide, Heerlen. Also, there will be researched what kinds of timber are available at these locations and how they can be used in the façade.

Wood in the surroundings
Vrieheide is a neighbourhood in the south of the Netherlands. In 2014, Staatsbosbeheer started a submarket called Hollands Hout® to stimulate the use of wood in the Netherlands (Hekhuis, 2015).

However, Vrieheide is only a few kilometres away from Germany and Belgium and therefore timber could also be obtained from forests here. In Figure 43 can be seen where woodworking places and forests can be found.

The woods that can be found within 200

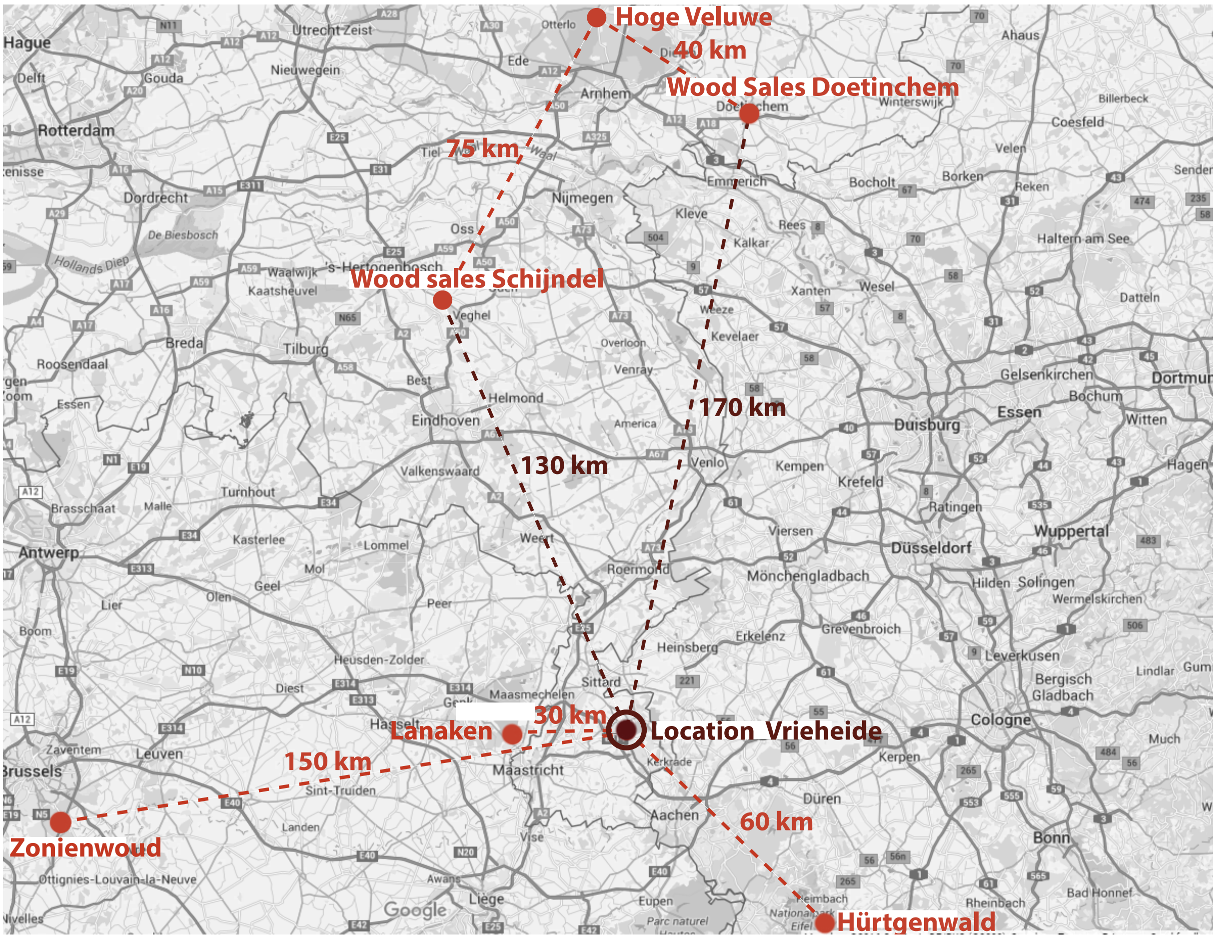


Figure 43. Homes porch on the east side of the Knuttelstraat 2-48 seen to the north (own ill.).

kilometres from the location are: larch, douglas, spruce, pine-tree, oak, beech and american oak (Hollands Hout, n.d.; Landesbetrieb Wald und Holz NRW, 2010; Zoniënwoud, n.d.).

Wood applications

(Fraanje & Pel, 1999; Stichting Probos, 2009)

Larch

Larch can be used for the structure of a building, window frames, windows, façade panelling, interior panelling. The wood contains a lot of resin and is therefore very usable as exterior wood (Hollands Hout, n.d.). Durability 3-4: In Europe larch is one the most durable kind of softwood (Centrum Hout, 2014).

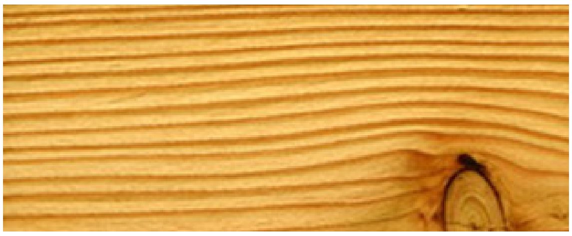


Figure 44. Larch wood (own ill.).

Douglas/Oregon pine

Douglas timber is also usable for outside panelling of buildings, because of the amount of resin in the wood. Furthermore, the wood can be used for interior panelling, window frames, windows, floors, triplex and beams.
Durability – 3

Figure 45. Douglas wood (own ill.).

Spruce

The Spruce can be used to make spars, construction wood, structural, window frames, windows, doors, floors and interior and exterior cladding. Durability – 4-5

Figure 46. Spruce wood (own ill.).

Pine

The wood of the pine-tree can be used as construction timber too, but needs to be painted and is thereby for this research a less interesting kind of timber. Durability – 4

Figure 47 Pine wood (own ill.).

Oak

Oak can be used for the window frames, , doors, beams and structural wood.
Durability – 2

Figure 48. Oak wood (own ill.).

Beech

Beech is mainly used on the inside of a building. Because of it is very hardwearing, it is used for window sills and as parquet. Durability – 5

Figure 49. Beech wood (own ill.).

American red oak

Timber of the American red oak is used for veneer and triplex and panelling. Durability – 4

Figure 50. American red oak wood (own ill.).

3.9 Engineered timber

Solid timber product

These products are mainly used for structural properties. Because this paper is not about creating a structure of timber, but a self-wearing façade, only the following product will be mentioned: glued laminated timber.

Glued laminated timber (glulam)

Glued laminated timber is an improvement on solid timber. It has a higher strength and flexural stiffness (Jeska & Pascha, 2014, pp. 47, 48). It consists of at least three dried softwood boards or laminations glued together with the grain parallel. Glulam can be made in simple, straight components, but curved forms are possible too. Wood (of previous paragraph) that can be used to create glulam are: spruce, fir, pine, larch and Douglas fir (Herzog et al., 2004, pp. 40, 41).

Glulam can be used for frames. The product is very interesting because of its high aesthetic value, but also because it can be manufactured with the use of computer numerical control (CNC) technology (Jeska & Pascha, 2014, pp. 47, 48).

Wood based products

Wood based products are boards and veneers made from small pieces of wood pressed together. To make wood based product, the same materials as for the glued laminated timber can be used, but also timber that is less usable for solid timber, such as beech (Herzog et al., 2004, p. 41). Now, some examples of wood based products wil be used.

Three- and five-plycore plywood

This product exists of three or five plies glued together and can be made of softwoods such as spruce and Douglas fir. Plywood can be used as planking for walls and outdoors (if weather protected) (Herzog et al., 2004, p. 42).

Laminated and structural veneer lumber

These products exists of bonded, dried softwood veneers. The laminated version is made from lighter veneers and thereby has less load-bearing capacities. The elements can be made of veneers, spruce, pine and Douglas fir (Herzog et al., 2004, p. 42).

Plywood, blockboard, laminboard

These are boards, made of layers of softwood or hardwood veneers (or a combination) and covered in a veneer or hardboard layer. For these products mainly pinewood and redwood are used (Van den Dobbelsteen & Alberts, 2005, p. 29). The advantage of elements of plywood is that they be very well manufactured with the use of CNC machines.

Oriented strand board (OSB)

This is a board, made of wood chips of softwood and poor quality hardwood. The elements are joined by glue (Van den Dobbelsteen & Alberts, 2005, p. 30). OSB boards are often used on the inside of vapour open, wooden façades (described in 3.9).

Particleboard

This product is made of waste wood and thinning wood (OSB often is recycled into particleboards). They elements are glued together and finished with a layer of paraffin wax (Van den Dobbelsteen & Alberts, 2005, pp. 30, 31). Particleboards are used for interior wall covering.

Wood fibreboard

Wood fibreboards are made of even smaller wood fibres than OSB and particleboards. The chips are connected by glue or artificial resin (Van den Dobbelsteen & Alberts, 2005, p. 31). Wood fibreboards can also be used for the interior walls.

Wood fibre insulating board

There are also insulating boards made of wood chips. They can be used as insulations for the façade.

3.10 Digital fabrication

To be able to create elements that are not only adaptable to one kind of post-war building, but also to buildings with different dimensions, there could be made use of flexible machines.

Furthermore, the products need to be easily mass and serial produced. And to lower the amount of energy use, machines (and wood) close to the building location should be used. Thereby it is important that the required equipment is common and thereby available in many woodworking places.

CNC machines
The equipment that are used in combination with CAD/CAM software within a digital fabrication process are CNC machinery. These machines are very interesting because of their many benefits: they are able to produce prefabricate panels in large scale, with specific tolerances, low budget and with high processing speed. Furthermore Larsen and Schindler (2008) concluded that, though CNC machinery are used to automate the production of simple components, CNC machines can be used for mass-customization also.

There are two different types of CNC machines: nesting and point to point milling. Point to point milling is mainly used for beam elements and nesting CNC machines for panels. For this is why this last option is the most interesting (Ashley, Gordon, Stanley, & Wilbrink, p. 28).

All systems do work following the same principles, but they differ in the amount of axis and drill and cutting heads.

CNC machines can be divided in two groups: stationary machines and run machines. In stationary machines the work piece is fixed on the machine table for processing. In case of run machines, the work pieces are positioned by the machine and processed in different places" (Tannert, Schmidt, & Lam, p. 2).

The most common frees machines are with 3 axis, which should be considered while designing the façade elements. In Figure 54 can be seen what digital joints can be made with timber.

3.11 Connections

Timber connections

All-wood connections
Different ways to connect wooden elements without using non-wood materials are dowels, Japanese joints, and vegetable glues.

In the Japanese architecture, constructions were developed in the seventh century. There were only natural glues and low

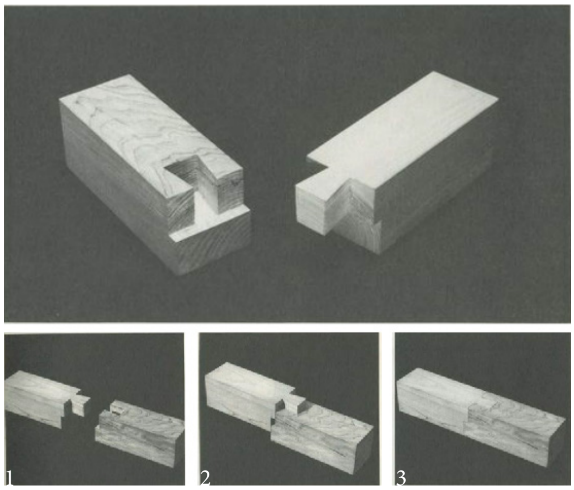


Figure 51. The stepped dovetailed splice, a splice joint.
1 Male and female
2 The male slides into the female
3 Assembled splice (Sumiyoshi & Matsui, 1991, p. 2).

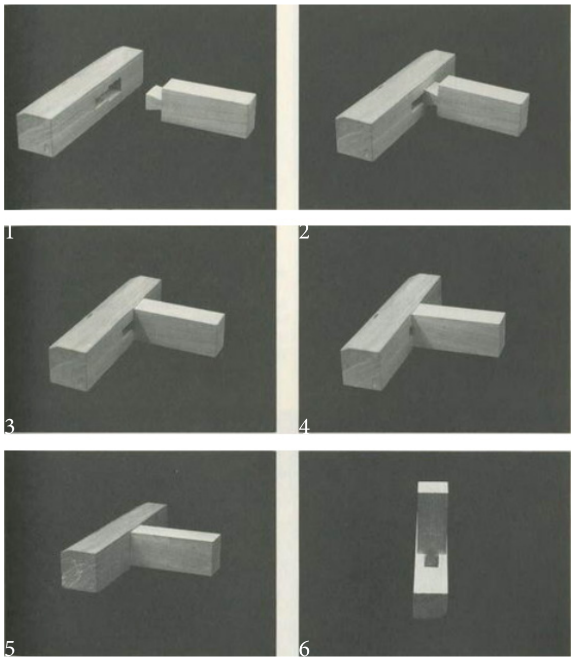


Figure 52. The blind wedging joint, a connecting joint.
1 Male and female
2 The dovetail slidesinto the bigger end of the mortise.
3 same
4 The dovetail isshifted into the smaller end of the mortise. 5 Assembled joint
6 The plug isnot shown for clarity (Sumiyoshi & Matsui, 1991, p. 50).

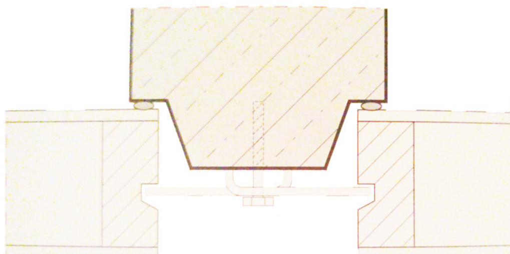


Figure 53. The blind wedging joint, a connecting joint (Meijs & Knaack, 2010, p. 68).

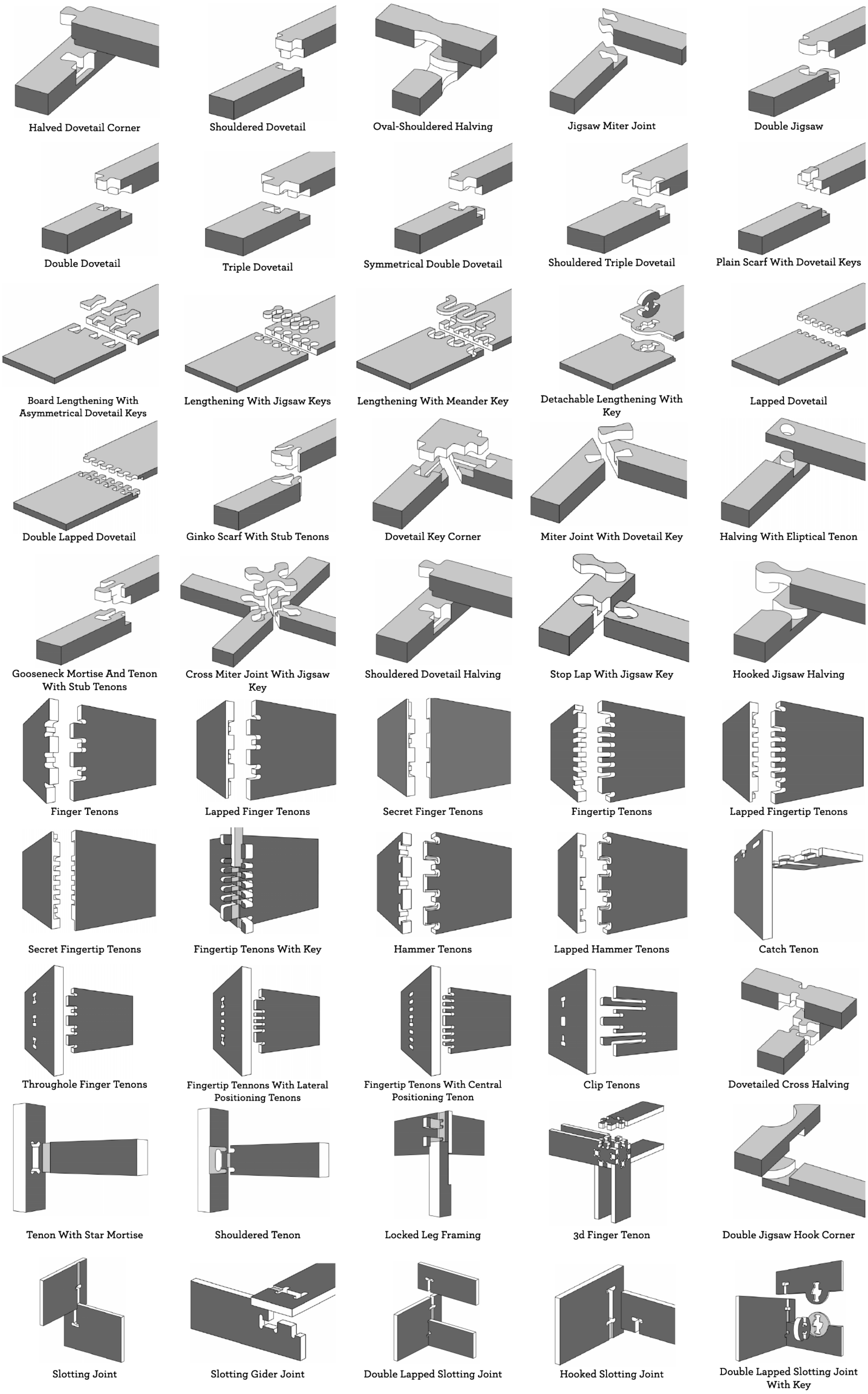


Figure 54. 50 digital joints (Scheff-King, n.d.).

quality structural metals available then. To create strong structural connections, all-wood joints were developed (Tannert et al., p. 20).

Sumiyoshi and Matsui (1991) described two kind of joints: The splicing joints (Figure 51) that connect the two ends of beams, and the connection joints (Figure 52) that connects beams in angles. The simple Japanese joints and connections can be designed with CAD software (Tannert et al., p. 20).

Furthermore, there are vegetable glues, but these adhesives are not yet sold in the construction industry. However, there is a kind of glue which is used for the manufacture of sheet material such as OSB panels, triplex, multiplex and particle boards, namely soybean based glue.

Non-wood connections

Other (non-wood) connections can be made with the use of nails and screws. A benefit of these methods is that the nails and screws can be removed easily again. Thereby wooden elements and also the metal elements, can be reused. When using as little of these as possible, their impact on the carbon footprint will be small.

Wood and concrete connection

The most common way to connect wood to concrete is with the use of an angle iron and nails, screws or bolts to connect to the wood and a mechanical or chemical anchor for the concrete (Meijs & Knaack, 2010, p. 68) (Figure 53). To be able to demount the elements, the mechanic anchor has the preference.

There are also glues to connect wood to concrete, but these adhesives are not designed for heavy loads and could not be removed easily anymore.

3.12 Indoor climate

Humidity

Wood is a hygroscopic material, which means that it can absorb water and hold the water molecules (van der Linden, Erdtsieck, Kuijpers-van Gaalen, & Zeegers, 2011, p. 30). When the humidity in a room increases, wood can absorb water and when the humidity decreases it can release it again. This way, the material functions as a natural buffer (Padfield, n.d.).

Vapour open and airtight

To regulate the humidity naturally and to prevent condensation problems in wooden constructions, a façade should be build vapour open.

To make vapour open buildings, only vapour permeable materials need to be used. Moreover, it is important that the materials on the inside are less porous than the materials on the outside of the façade. To make the façade weather proof, a vapouropen foil or cladding can be used in the outer layer (Figure 55-56) ("Damp-open isoleren," n.d.; vree, n.d.).

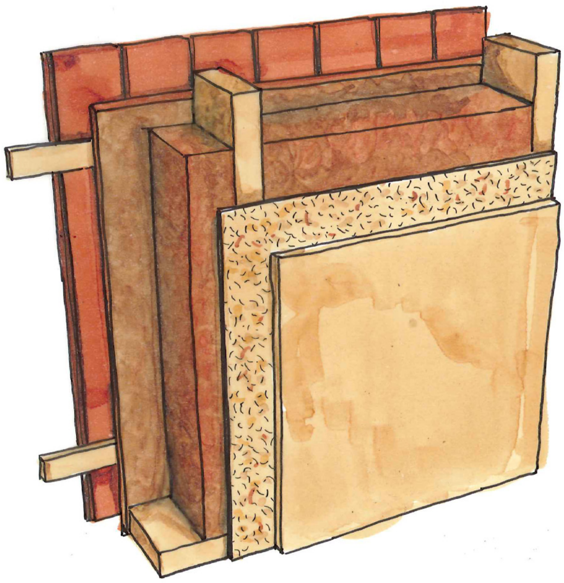


Figure 55. Example of a vapour open façade (own ill.) (back to front) 1. cladding of Douglas, 2. spruce slats, 3. wood fiber insulation, 4. spruce frame, 6. OSB board, 7. clay plaster.

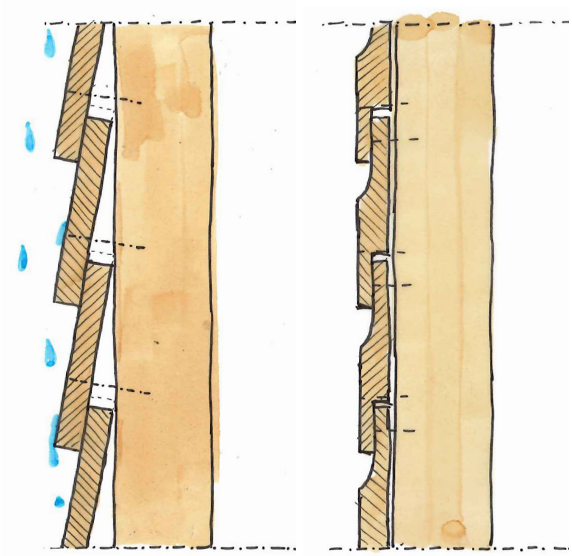


Figure 56. Weatherboardsto make a weather (rain) proof, but not water proof façade (own ill.)

To make sure no air is moving through the façade, the façade also needs to be airtight. A wooden building can be made airtight with the use of a OSB panel on the inside. The seams need to be closed with tape. A biodegradable tape made of cellulose – Sellotape – could be used for this, though these tapes are not (yet) sold as tapes for the building industry.

Daylight
For a residential building it is important to take into account that the inhabitants do need enough light during the day. Furthermore, direct sunlight on the south façade should be blocked with exterior sun shading.

The light falling on the north façade is only indirect daylight and therefore window openings cannot be used to heat the building.

Ventilation
Ventilation can be regulated naturally by adding vents above windows and doors and by adding windows that can be opened to the façade.

3.13 Reference projects

Facit homes®
This example of a digital fabricated house is of Facit Homes. The prefab houses are made of plywood. All parts of this system are cut using a computer controlled cutter and are assembled by two people into lightweight blocks. Furthermore, they can be easily and rapidly assembled at the location (as LEGO brick, Figure 57). By placing insulation material in the cavity of the blocks, the structure is made insulating (Facit Homes Limited, 2016).

Figure 57. Construction of a Facit home (Facit Homes Limited, 2016).

ModCell®
Another prefab system is of ModCell. They produce prefab construction existing of a wooden frame with straw bale and hemp insulation (Figure 58). To connect the frame parts some screws are used, but the overall product is carbon positive (moviesatWDA, 2010).

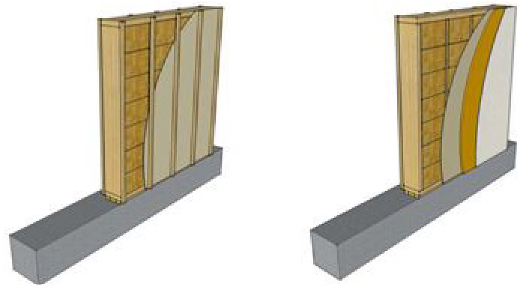


Figure 58. Two straw systems of ModCell (ModCell, 2016).

RIKO®
Riko created different façade elements with a timber framework construction filled with cellulose flake insulation. A final layer of insulation and a cladding to be chosen by the customer are placed on the exterior wall. An OSB panel is placed on the interior (Figure 59). The elements are available in different dimensions and connected with screws (RIKO, n.d.).

Figure 59.One of the RIKO façades (RIKO, n.d.)

Raico®
The last used reference is a timber curtain wall of Raico® (RAICO Bautechnik GmbH, n.d.). This system is based on a functional system made of aluminium and EPDM, decoratively concealed by timber profiles (Figure 60a).

The system can be added to any structural frame made of timber based material from 50 mm width. One engineered timber element that is used in combination with the system is the laminated timber of Stem® (Stem, 2012a). The kinds of wood that are mostly used to create these frames are redwood, spruce, oak and ash (Stem, 2012b).

They also designed a system for prefabricated frames, so they can be connected to each other on site (Figure 60b).

Knowledge existing systems

From all systems, only the Raico system is a curtain wall system. This system can be digitally produced. Furthermore it can be used in combination with other elements to create façade elements.

The other three façades have also interesting components. The Facit home system, for instance, is a system made with digital fabrication and shows how with the use of many of the same modules different buildings can be fabricated.

ModCell and RIKO give both a good example of all wood façades (except for the use of some screws). Furthermore, the systems created by RIKO are full façade systems. The system does not only consist of a structure and insulating material, but also of an interior and exterior cladding.

3.14 First ideas catalogue

The first idea is to create elements with a width of for instance 60 cm (or maybe two widths; 60 cm and 120 cm). By creating elements with the same width but with different covers and openings, out of these elements can be created different façades, that are applicable to different

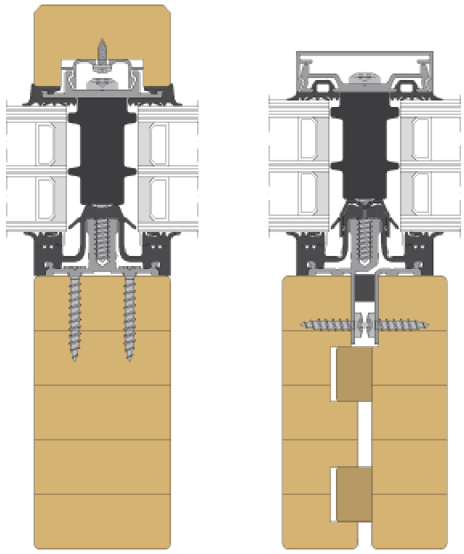


Figure 60. Two timber frames structures (RAICO Bautechnik GmbH, n.d.).
a. Curtain wall, decoratively concealed by timber profiles
b. Prefab version of the curtain wall system

Tabel 1: Different systems compared to the requirements.

	Facit homes	ModCell	RIKO	Raico	Explanation
Applicable to the post-war buildings	bad	bad	bad	Yes	They are designed as new building elements.
Insulating	yes	yes	yes	yes	
Thermal bridges	well	well	well	well	They form no big thermal bridges, but also are not applicable as solutions for the thermal bridges by consoles and balconies.
Indoor climate	well	well	good	well	The RIKO system can be used as vapour open façade structure.
Relation green areas	-	-	-	-	This depends on the amount of windows, not the system itself.
High quality appearance	no	no	yes	yes	The finish of the exterior is not incorporated in the ModCell and Facit home systems.
Create variation	yes	yes	yes	yes	There is freedom in the exterior and in the location of openings in every system.
Carbon neutral	yes	yes	yes	yes	The systems are even carbon positive.
All-wood	almost	almost	almost	no	In all systems screws are used to connect different building parts.
Lightweight	yes	yes	yes	yes	

sized post-war buildings. (Figure 61)

To create these façade elements, easy connectable blocks should be designed. These can be made of four planks that can be digitally produced. Therefore they don't need metal connections (Figure 62).

Such a system can be connected to a window system (for instance the Raico system) to create openings into the façade system.

Furthermore, these blocks should be completed with insulation in between and a wooden façade on the outside and OSB panel on the inside. This contributes to a vapour open construction (Figure 63).

By making smaller elements, there can be chosen between two building methods. In the first case residents build up their own façades. In the second case, in the factory the panels can already be assembled and be added to the building in one big element.

This system makes it also possible to create extensions to the existing buildings. This could be done by creating not only straight panels, but also corner elements or corner connections.

Of course, these are the first idea for a façade system. In the continuation of this paper further research will be done to the design of the facade elements.

Figure 61. First idea for a façade system (own ill.).
a. First idea of a system to create different possible façade elements that can be connected to each other
b. Idea of prefabricated blocks om 60 x 60 cm that can be connected to each other

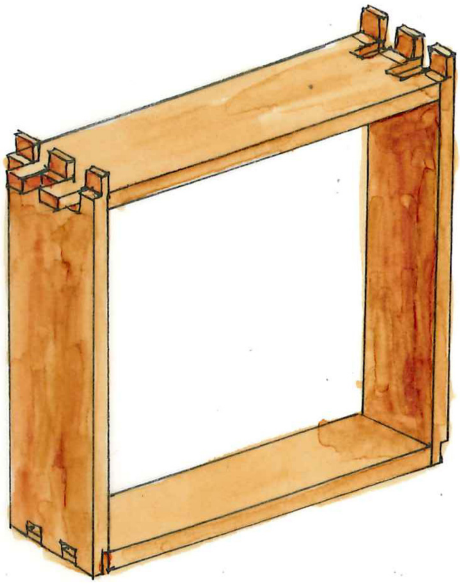


Figure 62. First idea of a digtial produces structure of 60 x 60 cm to build different façade elements (own ill.).

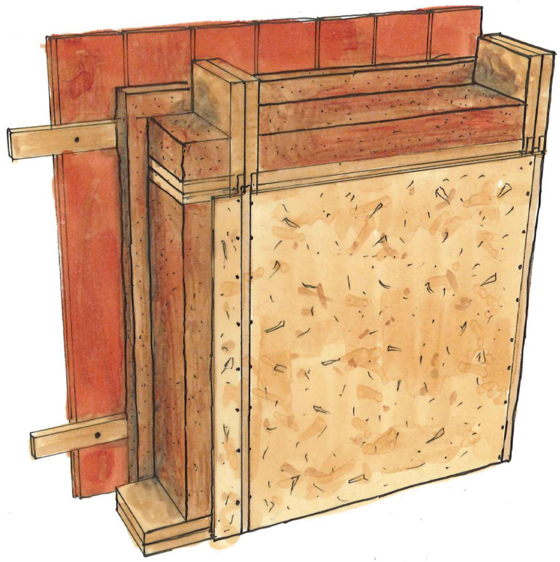


Figure 63. Example of a vapour open façade (own ill.) (back to front) 1. cladding of Douglas, 2. spruce slats, 3. wood fiber insulation, 4. (digital fabricated) spruce frame, 6. OSB board with sellotape.

4 Conclusion and discussion

In the Netherlands are many modular, post-war building that are at the end of their lifespan and that are in need for a solution to lower their energy use and carbon dioxide emissions. In this paper the aim is to give a solution for the façades of these buildings. The research question that was answered is:

"What is the best way to build renewable, prefab, wooden façade elements for post-war residential buildings in the Netherlands?"

4.1 Answer to the questions

To answer the research question, first a research was done to understand modular, post-war buildings and neighbourhoods. Furthermore, three different case studies with the three different building types were studied.

The modular, post-war buildings are built to solve the housing shortage. The structure of the buildings is mostly made of prefab or poured concrete that was covered with brick. The plans of these buildings are still of high quality, because of the loadbearing house separating walls. The concrete structure is also still in good condition. However, the shell of the buildings are badly insulated and at the end of their lifecycle.

The three building types that were mostly used with these new methods were terraced houses, gallery flats and portico flats. The neighbourhoods were built with strip shaped, court shaped and stamped buildings allotments with green areas placed in-between. To create diversity, the different building types were used together in a neighbourhood. Yet, there is a lack of variety in these post-war neighbourhoods. After these studies was concluded to strip the buildings to their structure and to design a replacement for the existing façades.

With help of the typology studies, the requirements for the façade elements were set up and the different aspects for these elements were examined. Firstly, the production of the elements was discussed. Because of the enormous, but varied amount of modular post-war residential buildings, mass production was considered. Important for the elements is that the wooden façade elements need to be easily produced but not all be the same, because they need to create variety in the buildings.

Another aspect of the element is that is needs to be carbon neutral. This can be done by using as much as possible wood, because of its carbon negative footprint. Furthermore, by reusing timber, carbon dioxide can be stored even longer in the materials. Also, timber materials and the materials that are used for the existing façades of the post-war buildings are considered. These materials can all be fully or partly reused or be recycled into new products.

In the surrounding area of the case studies that were used (the neighbourhood Vrieheide) the following woods can be found: Larch, Douglas, Spruce, pine-tree, oak, beech and American oak. Larch and Douglas can be very well used for the exterior, spruce and oak for window frames and doors, and larch, Douglas, beech and American oak for interior panelling.

These materials can also be used to create engineered timber. Glulam is such a kind of timber, made of laminated layers solid wood. It can be very well used for frames and be manufactured with CNC technology. Other engineered timber are wood based products: boards and veneers that are made from small pieces of wood pressed together. These products can be made of all available kinds of timber.

To generate the façade elements, traditional methods can be used, but also digital fabrications can be applied. With the use of CAD/CAM software and CNC machines, panels can be produced in large scale, with specific tolerance, low budgets and in high processing speed. Also, the machines can be used for mass-customized products.

Furthermore, research was done to what (wood-)connections. Non-wood can be found in the use of dowels, Japanese joint and vegetable glues. The drawback of these connections is that the (complex) Japanese joints are mainly meant for bigger structures and that glues make it harder to reuse the elements. However, glue can be used to create the different fibre and chip boards. Nails and screws can also be used to connect, though they have a negative carbon footprint. In the design the focus should be at using as less possible non-wood material, but when using it, use it so that it can be removed and reused again.

The connection between wood and the concrete structure cannot be done with wood, but can be made with iron elements.

The indoor climate of the building can be positively influenced by the use of timber. This can be done by making a vapour open construction, so the walls can dry and the humidity of the rooms can be regulated naturally. To do this all materials need to be vapour open. Furthermore, the interior of the houses can be improved by implementing enough windows in the façade. Ventilation can be regulated by vents and windows that can be opened.

There are already modular, wooden systems available. These products from Facit home®, ModCell®, RIKO® and Raico® are all compared to the requirements. Though none of the products meets all the requirements, some aspects could be used for the façade elements.

With the help of all these results a start was made for the design of the timber elements, but a final answer to the research question is still needs to be designed.

4.2 Future research

This research is part of a broader graduation project. It will be used to create a final façade system for post-war buildings and will be implemented in the residential buildings of Vrieheide, Heerlen.

Some of the criteria are not fully researched yet. The first one is the ability of the elements to solve the thermal bridges in the design. The other one is the ability to improve the relationship with the surrounding green. For the further development of the façade elements, especially focussed to the location Vrieheide, this should be studied too.

Also, to come to a final façade design, a further research by design needs to be done. This could be done by designing different kind of solutions with help of the information from this paper. Then, these designs should be compared with the requirements and be adjusted till they meet the requirements.

When a façade design is made the carbon footprint should be calculated to proof the difference between the existing façade and the new façade.

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