DESIGN ADAPTABILITY OF THE 2NDSKIN PROJECT IN THE NORTHERN EUROPEAN MARKET OF RESIDENTIAL BUILDINGS

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1 Introduction

1.1 Background

Buildings are the center of our social and economic activity. Yet, the energy performance of the building sector is inevitable poor as it is among the most significant CO₂ emissions sources in Europe. Facts have shown that construction represents 40% of the final energy consumption in OECD (Organization for Economic Cooperation and Development) member countries (Zavadskas et al., 2008). This percentage regards the energy used in the manufacturing industry, construction and operation of buildings. Thus, the refurbishment of existing buildings in order to reduce consumption is critical (Magrini, 2014).

Europe’s target for 2020 is to have 20% less greenhouse gas emissions than it was in 1990. The European Member States have committed to 80-95% CO₂ decrease in 2050 towards a low-carbon economy (BPIE, 2011a). Meanwhile only 1% of new constructions are added to the building stock (Thomsen, 2010), while the largest part refers to existing buildings which most of them seek for upgrade. In Europe, most of buildings built after World War II display low energy performance. Specifically, they are poorly insulated and being 50 years old, have reached end of life (Andeweg, 2007).

Refurbishment of the residential stock is the essential key to the rising requirements for lower energy use and high living standards (Konstantinou, 2014). Besides the energy savings, an economic and social potential supports the idea of renovating the existing building stock instead of newly built buildings (Itard et al., 2008). There is evidence that demolition does not lead to sustainability as reuse does (Thomsen et al., 2008). The CO₂ exhaust in landfills has a great environmental impact, while the biggest source is construction with 30% of the total volume (Power, 2008). Improvement of the quality of building envelope is urgent. Needless to say, such an improvement requires efficient communication of all parties involved such as local authorities, housing corporations, owners, architects and civil engineers (Andeweg, 2007).
Refurbishment tackles greenhouse gas emissions by reducing the energy consumption of the building stock. There are various degrees where the refurbishment could exist. Meanwhile it has been stated that “deep” renovation could achieve 60-90% energy savings (BPIE, 2011a). Besides the energy savings there are other requirements that a refurbishment project should take into account in order to succeed. Social and economic aspects, as needs of various stakeholder groups should attract more attention towards sustainability (Zavadskas et al., 2008). As previously mentioned, refurbishment is necessary to reach the future demands of decarbonisation levels. Therefore, the existing building stock seeks for upgrade of the physical condition and energy performance, with the minimum disturbance for the interior space. Given that the refurbishment is a complex task, many aspects need to be taken into account.

Thus, the “2ndSkin” project of TU Delft presents a refurbishment approach of Dutch residence which scopes to bring all the stakeholders together by inverting the traditional decision making process, to incorporate their expertise into an innovative building technology project to achieve zero energy (2ndSkinReport, 2015). Important part of the 2ndSkin project is the elaboration of performance criteria, concerning energy consumption, occupants' disturbance and comfort, robustness, simplicity, etc. (2ndSkinReport, 2015). The research project aims at mass-implementation solution that can be applied in a variety of cases. Therefore, the upscaling of the project in Europe is a step that needs to be done.

The post-war period is a significant turning point for construction, as there was a switch from traditional methods to fast and economical production of massive building units (2ndSkinReport, 2015). In The Netherlands the building stock accounts for approximately 7.5 million dwellings (CBS, 2015). Meanwhile, post-war dwellings represent 1/3 of the residential stock (Itard et al., 2008), from which 1.3 million account for social housing (Platform31, 2013). There
are many housing associations dealing with the building stock and trying to upgrade the energy label D-E (apprx. 350-400 kWh/m2/year primary energy) of post-war residence (AgentscapNL, 2015). The annually energy consumption appears to be 20,000 kWh/dwelling/year (2ndSkinReport, 2015). The renovation of residence from 1950’s to 1980’s is characterized essential, as the buildings were poorly insulated and performed bad in airtightness due to technical, architectural and social aspects (TES, 2015). At the end of the 2ndSkin project and if applied in a national level, 3.4 Mt CO₂ would have been saved (2ndSkinReport, 2015).

After careful investigation the 2ndSkin team concluded in a list of different building types, according to wall, window, roof type, balcony location etc. which are in need for renovation (2ndSkinReport, 2015). For the purpose of 2ndSkin project there has been selected a building reference of post-war period, i.e. the porch apartment blocks (portieketagewoning) that it is located in Rotterdam-Zuid (see figure 1.1). The reference building considered the most common type in the area of investigation. It should be pointed though that the upscaling of the project and mass-implementation were mentioned as requirements of the 2ndSkin team.

Figure 1.1-Reference building of 2ndSkin concept in the Netherlands (source: 2ndSkinReport, 2015, p. 4)
The integrated façade system as illustrated in figure 1.2 has a preliminary concept design. The design focuses on three axes, the Skin of the building envelope, the building services such as ventilation, space heating energy production and water and user interaction like monitoring. The design principle aiming to a zero energy building is based on “Trias Energetica”. Firstly, the goal is to prevent the use of energy (prevention), then to use renewable resources as widely as possible and finally to use fossil fuels as efficiently as possible. Therefore, the building envelope needs to decrease energy demand for space heating and cooling by increasing the thermal resistance and improving the air tightness of the components. Specifically, the refurbishment concept regards the replacement of existing windows and the addition of insulation on the opaque elements of the façade and roof. Moreover, pv panels installed on the roof for energy savings and installations for improving the ventilation.

Figure 1.2-Exploded view demonstrating the production sequence of the 2ndSkin concept (source: 2ndSkinReport, 2015, p. 8)
Therefore, it would be beneficial if we could export the refurbishment concept to Europe’s market. By discussing the adaptability of the retrofit solution in other building types, the efficiency of the project could increase. Furthermore, a future upscaling could be the refurbishment of buildings in similar climate that show potential for energy upgrade. For the purpose of this research the starting point is the basis of the 2ndSkin project but the intention is to make it flexible and adaptable in order to be applied in other building types besides the reference one and offer design variation. At the end of the research the refurbishment strategy needs to comply with the initial requirements of the project, reflect an architectural character and high energy performance.

To begin with, Germany is a potential market for the project as belongs in Continental climate region as the Netherlands. The country shows great motivation and action for applying a refurbishment concept as there is an energy saving legislation that is constantly developing aiming for nearly zero energy buildings (Inspire, 2014b). The sustainability in construction has become a mainstream since the 1990s. Moreover, Germany has the largest population in Europe with 81.7 million, the largest number of residential buildings in Europe with 39.43 million and dominates the heated floor area with 67% (Inspire Report, 2014). Therefore, Germany is a key country to target the retrofit solution of the 2ndSkin project.

Specifically, the research focuses on applying the project on a German residential building of post-war period, which presents most of the German dwellings that seek renovation. The most popular German buildings types are similar of the porch apartments of the initial case study of the 2ndSkin project in the Netherlands. Thus, the most adequate case study that reflects the most popular building type in Germany and could be searched in relation with the Dutch case study is the multi-family houses with three or four floors and single leaf masonry as construction type. Therefore, the German case study
has similarities with the original case study and at the same time different characteristics that give the opportunity to investigate the flexibility and adaptability of the design concept.

In the end of the research, the result would be a design concept adequate for the German market that investigate the design flexibility of the 2ndSkin concept, offers design variation at the owner and recommends how the concept can be transformed to be applied in other buildings in Europe.

1.2 Thesis

1.2.1 Problem Statement

If we are to tackle the climate change, it is claimed that the most effective way to do so is through improved energy efficiency of the building sector that has a major environmental impact. Decrease in use of fossil fuels and embracement of renewable energy sources through energy upgrade of the existing buildings could attack the global phenomenon.

Refurbishment of the old residential buildings that present high energy consumption could improve their environmental footprint. Europe has committed to minimize the CO$_2$ emissions by 2050. Europe's residential building stock has great potential for energy savings. Starting from the Netherlands, the refurbishment concept of 2ndSkin of TU Delft proposes an integrated façade system that aims to a zero energy building. The upscaling of the project in the growing market of Europe is important as could achieve better performances and improvement of the design.

By looking at the bigger picture the retrofit concept could take place in another European country than the Netherlands. Thus, the context could be different, and therefore it is important to investigate how the design of the 2ndSkin project
could be flexible and adaptable to be employed in other building type regarding a variety of key elements like the building type, the building construction and the building services/installations. Moreover, the architectural character of the project in combination with building technology and high energy performance will define the final design.

1.2.2 Aim of the research

The export of the 2ndSkin project has been as an important factor and as a sharp answer in the growing market addressed. This research by having the 2ndSkin project as a starting point will discuss the design flexibility of the refurbishment concept by applying the design on a German residential building of the post-war period. The key elements of a broad analysis and comparison between the case studies would be the building type, the building construction, the building services and the architectural aspect. At the end, the aim of the research is to explore the design adaptability of the 2ndSkin concept for achieving zero energy building and optimize the concept for future applications.

In the literature part of this study the aspects of refurbishment will be discussed. An overview of the state of the art of the refurbishment in Europe will be made by discussing characteristics, building typologies and energy performance of the residential building stock. By examining several countries in Europe, Germany would be the next target for the 2ndSkin concept as reflects the highest potential for the purpose of this research. Therefore, the literature study continues with the analysis of the German housing stock regarding key elements like the building type, the construction type and the building. In the end of the study a residential building in Germany would be the case study of this research.

A comparative study of the reference buildings will take place throughout
this research. The 2ndSkin concept would be applied on the new case study. A thorough analysis and comparison between the two case studies in Netherlands and Germany will result in design variation that will discuss the flexibility and adaptability of the 2ndSkin design. The evaluation of the design will be hold regarding the advantages that the design offers at the building and the users while reflecting an architectural character.

1.2.3 Boundary conditions

The research will focus on the following aspects:

- Refurbishment of the residential buildings of post-war period.
- The research will be hold into the Northern European residential building stock.
- The reference building in the Netherlands and the 2ndSkin design will be a starting point for the research.
- Germany will be the key-country for exporting the 2ndSkin concept.
- A German residence will be the study case for the design to focus on. The results and recommendations will be applicable in European countries with similar characteristics.
- The comparison between the buildings in Netherlands and Germany will focus on key elements that can be formulate as follows:
  - The first focal point will be: the building type including the number of floors and apartments and the size.
  - The second focal point will be: The building construction including the wall construction, the window/wall ratio, type of balcony, roof construction and materials.
The third and final focal point will be: The building services/installations including space heating and hot water, cooling if needed, ventilation, and further installations.

The design will focus on the façade of the building with possible adjustments and recommendations of the interior space.

An integrated façade design will be the final product, by focusing on the application of the 2ndSkin project.

The evaluation of the design will be made by reflecting architectural character and offering design variation.

1.2.4 Research Question/s

Main research question
The main question of this research can be formulated as follows: “How can the 2ndSkin design be flexible and adaptable to be applied on a German residential building regarding the building type, the building construction and building services, while exploring design variation of the façade composition?”

Sub-questions
Refurbishment
Which aspects motivate a refurbishment project and which criteria considered as barriers?

Europe
Which are the main characteristics of the European residential stock regarding age, housing types, ownership and tenure, building type and construction and energy performance?

Which European country shows the highest potential for energy upgrade and why?
**Comparative study**

Which are the main differences between the reference buildings?

Which are the key elements for the research to continue with?

**Design**

How the 2ndSkin design could be flexible and adaptable when applied on the German building type?

What design elements could be combined with the 2ndSkin concept by reflecting an architectural character?

Which are the limitations of the 2ndSkin design?

**1.2.5 Methodology**

In figure 1.3 the structure of the thesis is illustrated. The chapters of the thesis are indicated by the numbered parts and have been divided in five sections: introduction, literature study, comparative study, design and conclusions. The first part includes the introduction and the graduation plan.

The literature study has been covered by the second section where the state of the art of refurbishment in Europe and the German housing stock are analyzed further. In the beginning of the former, the focus will be on refurbishment definitions, refurbishment motivations and barriers and challenges. Afterwards the residential stock in Europe will be presented with focus on size and age of the residential stock, ownership and tenure, building type and construction and energy performance of housing stock. The latter is about the German housing stock. It is important to present the argumentation for choosing Germany as the next target of the 2ndSkin project. Furthermore, the context of building sector along with construction types and energy performance of
German housing stock will be presented.

The comparative study includes the comparative study of reference buildings in the Netherlands and Germany. First, the 2ndSkin project description will take place by presenting key elements like building type, construction/details and building services. Subsequently, the same key elements of the German case study will be analyzed further. The design section includes the application of the 2ndSkin project on case study in Germany. At this part design adjustments along with design limitations will be hold. Next part is the designing of additional elements that can be applied on façade construction and offer design flexibility to the concept. The design samples will assess the structure adaptability based on elements such as windows, balcony, materials etc. In the end, a specific façade design will be chosen as a combination of the façade samples and the basis application of the 2ndSkin concept. Moreover, a design catalogue will be offer a design variation for the façade of the building. The design will be adequate if reflects an architectural character; all zero energy building traits of the 2ndSkin refurbishment concept and offer design flexibility.

In this research the emphasis will be on design adaptability of a refurbishment concept of Northern European residence. In that way, recommendations can be given in the last section concerning similar residence construction existing in this type of climate.
1. Introduction of research and graduation plan

2. State of the art of Refurbishment in Europe
   - Refurbishment
   - Residential Stock in Europe

3. The German housing stock
   - Characteristics
   - Building typology
   - Energy performance
   - Building Sector
   - Construction type
   - Building services

4. Comparative Study of Reference Buildings in NL & DE
   - 2ndSkin/NL
   - Construction type
   - Building services
   - Details
   - Case study Germany

5. Application of 2ndSkin on case study in DE
   - Design adjustments
   - Design adaptability
   - 2ndSkin limitations

6. Designing additional elements
   - Samples façade constructions
   - Evaluation:
     - Architectural character
     - Design flexibility

7. Conclusions
   - Recommendations
   - Evaluation
   - Design catalogue
   - Design suggestion
1.2.6 Relevance

The decrease of the CO2 emissions could be tackled with refurbishment of the existing building stock. The design adaptability of a refurbishment concept for zero energy buildings will be discussed. Therefore, the export of the 2ndSkin project into the German residential market in correlation with energy upgrade of residential buildings will result in an efficient and adaptable design. Furthermore, by taking into account the impact of the building typology, the building construction and the building services, sustainability becomes the directional aspect.

The exploration of the designs’ flexibility will bring knowledge about specific parts of the existing structure that we have to focus on when upgrading a building. Particularly, the research will result in key-elements of the structure that play an important role to apply the 2ndSkin refurbishment concept. Moreover, there would be recommendations for similar cases in Europe’s building stock that can deploy the design. Finally, the research contributes to the existing knowledge about design adaptability of the 2ndSkin façade system.
# 1.2.7 Time planning

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Task</th>
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<tr>
<td>January</td>
<td>Preliminary literature research, P1 Presentation, Final graduation plan</td>
</tr>
<tr>
<td>February</td>
<td>State of the art of refurbishment in Europe, Refurbishment (definitions, motivation, barriers)</td>
</tr>
<tr>
<td>March</td>
<td>Residential stock in Europe: characteristics, building typology, energy performance</td>
</tr>
<tr>
<td>April</td>
<td>Construction stock, building sector, energy performance</td>
</tr>
<tr>
<td>May</td>
<td>Choice of Germany reference building</td>
</tr>
<tr>
<td>June</td>
<td>Comparative study of reference buildings in NL and DE</td>
</tr>
<tr>
<td>July</td>
<td>2nd Skin project extensive description</td>
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<tr>
<td>August</td>
<td>2nd Skin project extensive description, analysis building construction, building services (DE &amp; NL)</td>
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<tr>
<td>September</td>
<td>Application of 2nd Skin concept on case study in DE</td>
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<tr>
<td>October</td>
<td>Concept adjustments, Define 2nd Skin concept limitations</td>
</tr>
<tr>
<td>November</td>
<td>Samples of possible facade elements (windows, balcony, etc.)</td>
</tr>
<tr>
<td>December</td>
<td>P3 Presentation, Evaluation of the samples</td>
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**Timeline:**
- **P1 Presentation**: January
- **Final graduation plan**: February
- **State of the art of refurbishment in Europe**: March
- **Refurbishment (definitions, motivation, barriers)**: April
- **Residential stock in Europe: characteristics, building typology, energy performance**: May
- **Construction stock, building sector, energy performance**: June
- **Choice of Germany reference building**: July
- **Comparative study of reference buildings in NL and DE**: August
- **2nd Skin project extensive description**: September
- **2nd Skin project extensive description, analysis building construction, building services (DE & NL)**: October
- **Application of 2nd Skin concept on case study in DE**: November
- **Concept adjustments, Define 2nd Skin concept limitations**: December
- **Samples of possible facade elements (windows, balcony, etc.)**: January
- **P3 Presentation, Evaluation of the samples**: February

**Note:** The schedule is approximate and may vary depending on the project's progress and external factors.
2 State of the art of refurbishment in Europe

2.1 Refurbishment

2.1.1 Definitions of refurbishment

For the purpose of this thesis it is important to clarify the term of refurbishment and the extent that exists. Giebeler et al. (2009) states that there is no a single term that covers the range of building measures applied on existing building stock. There are different types of intervention in buildings that create a range of measures. The figure 2.1 illustrates the various levels of intervention.

Figure 2.1-Intervention levels for buildings (source: Konstantinou, 2014, p.70)

Throughout this thesis the term of refurbishment is the one that suffices the scope of the research. As the starting point is an existing refurbishment project of residence. The term is between maintenance and conversion. The main difference of refurbishment with the former is that maintenance refers to replacement or repair of problematic components. Moreover, conversion concerns the loadbearing structure or interior layout while refurbishment does not (Giebeler et al. 2009). There are various degrees at which the refurbishment occurs. Giebeler et al. (2009) states that refurbishment could exist as partial, normal or total. Partial refurbishment refers to one element of the building like the roof or the façade. Normal refurbishment involves an entire building or an autonomous part of it. Total refurbishment could be an extensive project as the building is left with the loadbearing structure.

The EPBD uses the term “major renovation” (DIRECTIVE, 2010/31/EU) where the total cost of the renovation regarding the façade or the technical building system is more than 25% of the actual value of the building or 25% higher
than the façade system which is been renovating. Meanwhile, the BPIE (2011a) report presents the terminology of “deep renovation”. The term is related with refurbishment measures that result in energy savings of 60-90%. The term “integrated refurbishment” applies at this thesis as concerns the refurbishment of a building envelope integrating building elements like ventilation and heating sources.

2.1.2 Motivation for refurbishment

There are several aspects that motivate a building refurbishment. To begin with, the decrease of the environmental impact towards sustainability is the main motivation for refurbishment. Besides energy upgrade, financial and social aspects considered as critical incentives for refurbishment. When the owner decides to invest in energy renovation of a building then financial profit comes from the reduced energy bills and the property value has been increased. When it comes to social motivation, a functional building could be a better housing for the occupants. Sometimes comfort could lead to refurbishment as insulation enhancement results in thermal comfort for the user. Furthermore, functional weakness could be a motive. Most of the times the motives are linked to each other, having as priority the energy efficiency through the refurbishment strategy (Konstantinou, 2014).

2.1.3 Barriers and challenges

Needless to say that there are various motivations for refurbishment but there are also barriers that could obstruct the procedure. The BPIE (2011) in the report “Europe’s Building under the microscope” classifies a collection of information on particular barriers such as financial, related to awareness, advice and skills, institutional and administrative, and the separation of expenditure and benefit.

Some of the most important factors related with the financial barriers are the
lack of funds and the failure to meet finance terms. Moreover, the energy bills have a minor share of the household expenditure accounting for 3-4%, thus they are not a major concern (BPIE, 2011). The second category regards the consumers and their lack of information related with technologies. They need to be aware of the energy efficiency measures.

Institutional and administrative barriers are linked with regulatory and planning obstacles. Moreover, multi-stakeholder issues could delay a refurbishment project as multiple owners could be difficult to agree on vital decisions. The last and most complex category is the separation of expenditure and benefit. It is related with the fact that different parties are correlated with a property, thus financial issues may occur and delay the refurbishment of a building.

2.2 Residential stock in Europe

It is essential for the study to elaborate on the state of the art of the building stock in Europe. That is because a comprehensive analysis of the status quo will lead the research into the next country-target for exporting the refurbishment concept of 2ndSkin. The literature available concerning the current period of time seems to be limited, although there are databases such as Inspire, Tabula, BPIE etc. in the open literature. Those sources provide extensive surveys regarding Europe’s residential building stock while focusing on individual country members. All gathered data are relating with size and age of building stock, ownership and tenure, construction types and energy performance.

For the purpose of this thesis the characteristics of the European residential stock will be elaborated according to the Inspire survey (Inspire, 2014a), where it has been stated that a retrofit concept should focus on countries that belong totally or partially in the colder climates, are large and have high energy use. These key countries include France, Germany, Italy, Netherlands, Poland and UK.
### 2.2.1 Size and age of European residential stock

The European residential building stock consists of residential and non-residential stocks (Figure 2.2). The various building types could affect the refurbishment strategy in terms of size, decision-making, energy performance etc. In Europe the overall residential floor area considered to be 17.6 billion m² (Inspire, 2014a). It is estimated that 15.1 billion is heated area, of which 72% concerns the countries; Spain, Italy, France, Germany, UK and Poland. The residential stock is divided in single family houses (SFHs) and multi-family houses (MFHs). The latter could have higher potential for refurbishment as the exterior of an apartment block seems to be more homogenous than the façade of single family house.

In table 2 there is a summary of the floor areas along with heated floor areas of SFHs and MFHs. It can be observed that Germany has the highest floor area and the largest heated area with approximately 3230 Mm² and 3200 Mm² respectively. Italy and France are coming next with approximately 2500 Mm² floor area.

![Figure 2.2-Residential floor space (source: BPIE, 2011, p.30)](image)

Across Europe there are several periods of times which are correlated with specific construction techniques and building regulations. The need for quick and low-cost housing during the post-war period resulted in high energy consumption dwellings. The prefabricated and composite components were very popular and used in construction during the 1950s and 1960s (Inspire,
Until 2000 the construction rate has slowed down and it is considerably low during the last decades. Table 2.1 illustrates the gradual decrease of construction in time.

The age of the building is linked with the energy use for most of the buildings that seek renovation for energy upgrade. The majority of the residential buildings have been built before 1970 as it has been indicated in table 2.1, and especially during the post-war period of 1950s and 1960s (Inspire, 2014a). Moreover, table 2.2 illustrates the SFH and MFH construction for the six key countries.

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Table 2.1—Construction by age band in million m² (source: Inspire, 2014)

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<tr>
<th>Countries</th>
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<tr>
<td>Italy</td>
<td>2576.9</td>
<td>1638.4</td>
<td>491.5</td>
<td>1146.8</td>
</tr>
<tr>
<td>France</td>
<td>2479.5</td>
<td>1615.8</td>
<td>1098.7</td>
<td>517</td>
</tr>
<tr>
<td>UK</td>
<td>1924.5</td>
<td>1828.5</td>
<td>1627.2</td>
<td>201.1</td>
</tr>
<tr>
<td>Germany</td>
<td>3229.7</td>
<td>3197.4</td>
<td>1950.4</td>
<td>1247</td>
</tr>
<tr>
<td>Netherlands</td>
<td>630.8</td>
<td>624.5</td>
<td>499.6</td>
<td>124.9</td>
</tr>
<tr>
<td>Poland</td>
<td>942.1</td>
<td>932.7</td>
<td>522.3</td>
<td>410.4</td>
</tr>
</tbody>
</table>

Table 2.2—Summary of floor areas per country in million m² (source: Inspire, 2014)
2.2.2 Ownership and tenure of European residential stock

Across Europe there are several types of tenure that vary from country to country. According to database available from Inspire survey (Inspire, 2014a) most of the European residential stock is owner occupied. Figure 2.4 shows the residential tenure of EU-27 countries. It can be seen that owner occupied ranges from 46% to 97% of dwellings. The rest of the tenure is divided into social and private rental.

It is easier for the process of a refurbishment project if there is only one owner of the property as the decision-making can be fast and efficient. Therefore, when a residence is rental the process becomes more complex. Thus, countries that have large rental sectors will find difficult to apply wide-scale refurbishment strategies. On the other hand, public sector could take the lead of implementing renovations as many opportunities for profit could occur (BPIE, 2011).

Figure 2.4-Residential tenure by country (source: Inspire, 2014, p. 24)
2.2.3 Building type and construction of European residential stock

As mentioned before there are two building types that can be found in the residential stock. The single family houses (SFH) as a single dwelling which can be a detached, semi-detached or terrace house. On the other hand, multi-family houses (MFH) could be a flat, a complex of flats or an apartment block (Inspire, 2014a). Figure 2.5 indicates typical houses of both cases in Europe.

In Europe as figure 2.2 illustrates the residential floor area involves 64% of SFH and 40% of MFH. The countries that have higher MFHs than SFHs percentages are few like Latvia with 74%, Italy and Estonia with 70% and Spain with 67% (Inspire, 2014a). Nevertheless, a refurbishment concept of a MFH could be cost effective as the payback of energy bills could be high. That is a parameter that has to be taken into account when targeting a retrofit project.

The most common construction types are brick, block or stone masonry, reinforced concrete and timber (BPIE, 2011). Regarding the single family houses the construction type that has been used at the most is masonry with either solid or cavity wall. In case of cavity wall construction, insulation has been used in between. At multi-family houses masonry and concrete dominate the construction. Furthermore, during the post-war period the high rise MFH

![Figure 2.5- An apartment block in Europe, Figure 2.6-Typical single family house (source: BPIE, 2011, p. 31)](image-url)
2.2.4 Energy performance of European residential stock

The building sector is the biggest energy consumer in Europe. For a refurbishment project it is efficient to investigate the energy consumption in buildings in order to target the retrofit strategy. Since 1945 there has been improvement related with thermal performance in some countries like Denmark, France, Germany, Netherlands and UK (Inspire, 2014a). On the other hand, some countries still require regulations for improving the energy consumption and controlling the CO₂ emissions. Figure 2.7 shows CO₂ emissions per useful area by country. It is indicated that countries like Poland, Ireland, Latvia present significantly high numbers, while Germany or UK have approximately moderate CO₂ emissions. However, there is room for improvement and action needs to be taken in order to meet the decarbonisation levels of 2050.

Figure 2.7 - CO₂ emission per useful floor area by country (source: BPIE, 2011, p.44)
The energy performance of a dwelling is correlated with factors like the installed heating system, building envelope, climate conditions, behavioral characteristics and social conditions (BPIE, 2011). The oldest dwellings present lowest performance levels as they consume more energy. The insufficient thermal insulation of building envelope in combination with thermal leaks at connection points between window frames and wall construction are reasons for high energy use. For that reason air tightness levels becomes priority for a building. An appropriate air tightness level is needed as very high or very low levels can cost problems linked with high energy consumption or poor indoor air quality, respectively. In table 2.3 the u-values of wall construction by country are presented. It is obvious that there was an improvement through years and the breakthrough was after 1970.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>2576.9</td>
<td>1.8</td>
<td>1.6</td>
<td>1.6</td>
<td>0.9</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>France</td>
<td>2479.5</td>
<td>2.4</td>
<td>2.4</td>
<td>1</td>
<td>0.7</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>UK</td>
<td>1924.5</td>
<td>1.8</td>
<td>1.8</td>
<td>1.3</td>
<td>0.6</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Germany</td>
<td>3229.7</td>
<td>1.7</td>
<td>1.3</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Netherlands</td>
<td>630.8</td>
<td>1.8</td>
<td>1.7</td>
<td>1.6</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Poland</td>
<td>942.1</td>
<td>1.7</td>
<td>1.4</td>
<td>0.9</td>
<td>0.9</td>
<td>0.6</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 2.3 – Residential wall u-values by country (source: Inspire, 2014)

Furthermore, in colder climates space heating is the dominant consumer as we can observe from table 2.4. Uses like cooling, domestic water heating or lighting present extremely low consumption compared to space heating. Germany has the maximum total floor space and the highest space heating consumption with 527kWh/m², thus could be a country for targeting a refurbishment project. Countries such as Italy, France and UK have approximately half of Germany’s heating consumption. In some countries that belong in warmer climates like Italy have higher cooling demand and still the need for heating consumption is
relatively high. The reason for this situation is the insufficient thermal envelope insulation. When cooling or heating is the case, thermal insulation of a building is significant as minimizes the heat losses or gains.

<table>
<thead>
<tr>
<th>countries</th>
<th>Total floor space (Mm²)</th>
<th>Heated floor area (Mm²)</th>
<th>Cooled floor area (Mm²)</th>
<th>Total Space heating consumption (kWh/m²a)</th>
<th>Total DHW consumption (TWh/a)</th>
<th>Total cooling consumption (kWh/m²a)</th>
<th>Total lighting consumption (TWh/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>2576.9</td>
<td>1638.4</td>
<td>109.2</td>
<td>225</td>
<td>32</td>
<td>1.6</td>
<td>10</td>
</tr>
<tr>
<td>France</td>
<td>2479.5</td>
<td>1645.8</td>
<td>124</td>
<td>311</td>
<td>49</td>
<td>2.3</td>
<td>11</td>
</tr>
<tr>
<td>UK</td>
<td>1924.5</td>
<td>1828.3</td>
<td>9.6</td>
<td>280</td>
<td>73</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>Germany</td>
<td>3229.7</td>
<td>3197.4</td>
<td>48.4</td>
<td>527</td>
<td>91</td>
<td>0.3</td>
<td>14</td>
</tr>
<tr>
<td>Netherlands</td>
<td>630.8</td>
<td>624.5</td>
<td>9.5</td>
<td>73</td>
<td>17</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Poland</td>
<td>942.1</td>
<td>932.7</td>
<td>6.6</td>
<td>163</td>
<td>35</td>
<td>0</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 2.4 –Total energy consumption in residential buildings by use and country of the six European countries (source: Inspire, 2014)

2.3 Conclusion

After going through aspects like size and age, ownership and tenure, building type and construction and energy performance of European residential stock, there is an understanding of possible country-targets for exporting the refurbishment concept of 2ndSkin. The six big countries were a starting point for this research as several databases like BPIE, Inspire etc. have clarified that a retrofit concept should be targeting on them. Subsequently, as these countries account for 72% of residential stock (Inspire, 2014), one out of the six could be a case study for the 2ndSkin project.

Across Europe, the majority of the buildings built before 1970 resulting in high energy consumption dwellings as they were low cost constructions with insufficient thermal insulation. Regarding building typology, single family houses (SFH) are the most common type accounting for 64%. Multi-
family houses (MFH) accounting for 40% appear to be a proper building type for refurbishment as they have a homogenous façade. Most of the European dwellings are owner occupied. Furthermore, the most popular construction type of the buildings built before 1970 is brick masonry. Finally, space heating as an end-used was the dominant consumer that requires most of the attention in order to minimize the CO2 emissions of building industry.

Across Europe, Germany is related with most of the residential floor area accounting for 30%. Moreover, German residential stock presents the highest percentages of heated floor area along with space heating consumption (see table 2,4). Therefore, for an efficient refurbishment scenario which goals for minimizing the greatest energy consumer of Europe and for decreasing the CO2 emissions, Germany is the perfect target.

On top of it, there is social motivation for energy upgrade as the country shows great effort for being part of the Europe’s renovation strategy. The most recently BPIE report (BPIE, 2014) has stated that the German renovation strategy has delivered the most details out of all countries examined. Moreover, Germany has included renovation in the context of German “Energiewende”, aiming to use almost exclusively renewable energy sources (BPIE, 2014). Concluding, an overview of the German residential stock will provide information needed for a retrofit concept and will support the choice of the country as the next target for exporting the 2ndskin project.
3 The German housing stock

3.1 The German building sector

Sustainable urban development has become Germany's mainstream since the 1990s (SustainableDevelopmentPlatform). The National Institute for Standards and the Association of engineers are in charge of endorsing sustainability in building services (Inspire, 2014b). The Federal government has bound to achieve nearly carbon-neutral building stock by 2050. The goal is a very low energy demand and mainly by renewable resources.

BPIE report (BPIE, 2014) states that the German government identifies that the tools available are insufficient for achieving this goal. However, there is an energy saving legislation that is constantly developing. The latest version of Energy Saving Regulation (ENEV) concerns the energy certification for buildings, minimum energy efficiency for new buildings, refurbishment for the existing ones and energy efficiency for heating, cooling, ventilation, and domestic hot water supply and inspection intervals for air conditioning plants (Inspire, 2014b).

Overall, Germany comprises one of the most suitable targets for a refurbishment concept, as being to the Continental climate region like Netherlands making it a proper region for applying the retrofit scenario based on similar principles. Besides, Germany has the largest population in Europe with 81.7 million, the
highest number of residential buildings with 39.43 million and the largest floor area with 3,230Mm$^2$ (Inspire, 2014).

The building stock involves about 19.9 million buildings, where 18.2 million are residential and 1.7 million are non-residential buildings as can be seen in figure 3.2 (BPIE, 2014). In figure 3.3 the construction frequency of all buildings in Germany is shown, where the breakthrough was after the 1950s. Specifically, 41 million homes are included at the residential stock where 68% were built before 1979 and the largest proportion accounting for 43% was built between 1950 and 1979 (BPIE, 2014). Regarding the non-residential buildings, 22% are administration buildings, 14% are both retail and agricultural, and 13% are hotels, cafes and restaurants. When it comes to ownership and tenure, as illustrated in figure 2.4, about 42% of the residential stock is owner occupied, about 53% is privately rented and 5% is social rented.

![Frequency of building construction in Germany](image)

Figure 3.3-Frequency of building construction in Germany (source: Tabula, 2012, p.42)
3.2 The German residential building typology

The recent Inspire survey (Inspire, 2014) presents an overview of the German building typology. According to the database available, the German housing stock consists of single family houses or terraced houses with 34% and 14%, respectively. Multi-family houses account for 35% and large multi-family houses for 17% (see figure 3.4).

After the 1950s there has been a great increase in the number of dwellings as the amount of all building types almost tripled (see appendix). The average size of a single family house in Germany is about 110m² in the early years and 117m² today (Inspire, 2014a). The multi-family homes were smaller having an average size of 62m².

Moreover, figure 3.5 indicates the number of flats per various size MFHs. The most common distribution appears to be 3-4 flats per MFH with 53.7%. The least common flat distribution is 13+ with a percentage of 8.7%.

<table>
<thead>
<tr>
<th>Number of flats per MFH</th>
<th>3-4</th>
<th>5-6</th>
<th>7-12</th>
<th>13+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of MFHs</td>
<td>53.7%</td>
<td>18.6%</td>
<td>19%</td>
<td>8.7%</td>
</tr>
</tbody>
</table>

Figure 3.5-Number of flats per MFH in Germany (source: Inspire, 2014a, p.89)
3.3 The German residential construction typology

According to the database the dominant German wall construction of residence is single leaf masonry. Between 1949 and 1957 there was a reconstruction period, and after the war the buildings were mainly made out of debris material. There was some development in building construction while the social housing had started to build. The type of the construction was mostly brick work. In the early 1950s prefabricated blocks had been introduced in East Germany, nevertheless they account for less than 7% of dwellings (Inspire, 2014a).

Afterwards, during the period 1958-1968 the multi-storey buildings and the heat protection standard were introduced (Inspire, 2014a). That was the time were the precast concrete slabs were used massively. In the next decate the sandwich construction started to be used in building industry (Inspire, 2014a). Furthemore, at that time single family houses started implementing the prefabricated concept. Between 1984 and 1994 there was an improvement in technical requirements in order to offer thermal protection. As a result the first low energy houses made their appearance.

![Figure 3.6](image)

**Figure 3.6-Residential u-values in Germany per component by age band (source: Inspire, 2014a, p.90)**

Figure 3.6 illustrates the u-values of both SFHs and MFHs in Germany per component such as roof, wall, floor, windows by age band. It can be seen that over time there was improvement in thermal insulation. Wall u-value remained the same the last decades reaching 0.4, while the rest slightly upgraded, with roof u-value equaling 0.2, floor u-value 0.3 and windows u-value 1.6.
The construction type in Germany can be characterized both by masonry and reinforced concrete construction (see appendix). However, SFH masonry construction was mainly used. Most of the housing built before 1970 appear not to have insulation within the wall construction. It has been observed that most of the single family houses built before 1945 had roof overhangs. Furthermore, at the same period of time the majority of houses had external sun shading, while after 1945 had internal shading protection (Inspire, 2014a).

**3.4 Energy performance of residential building stock**

In German buildings, natural gas is the main energy source accounting for 46% as figure 3.7 shows. We can observe that oil is still used in 24% of dwellings, district heating system is used by 17% and bios is heating 4% of the houses. Coal and electricity are coming in the end of the list with 2% and 4%, respectively (ENTRANZE, 2012). The CO₂ emissions of energy consumption have similarly distribution, with gas and oil having the highest percentage and coal the lowest (see appendix).

As regards to heating systems, the majority of German dwellings (91%) have a central heating system, which can be classified as collective or individual (ENTRANZE, 2012). Individual heating systems of dwellings account for 39% and collective central heating for 36% (ENTRANZE, 2012). Moreover, 16% of dwellings have district heating and only 9% have room heating (figure 3.8).

Figure 3.9 presents the average energy consumption of SFHs and MFHs in
Germany. The end-uses are space heating, domestic hot water, space cooling, lighting and electricity including lighting and appliances (ENTRANZE, 2012). The average annual energy consumption of SFHs is significantly higher than the MFHs accounting for 253 kWh/m² and 180 kWh/m², respectively (inspire, 2014a). The end-uses of both building types that have consumed the least energy are lighting and space cooling. In particular, the ENTRANZE report (ENTRANZE, 2012) states that only 1% of the dwellings use air conditioning.

<table>
<thead>
<tr>
<th>End-use</th>
<th>Average annual energy consumption (top down)</th>
<th>Average annual energy consumption in SFHs (age weighted)</th>
<th>Average annual energy consumption in MFHs (age weighted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating</td>
<td>165 kWh/m²/year</td>
<td>253 kWh/m²/year</td>
<td>180 kWh/m²/year</td>
</tr>
<tr>
<td>Domestic hot water</td>
<td>28 kWh/m²/year</td>
<td>28 kWh/m²/year</td>
<td>28 kWh/m²/year</td>
</tr>
<tr>
<td>Space cooling</td>
<td>7 kWh/m²/year</td>
<td>7 kWh/m²/year</td>
<td>7 kWh/m²/year</td>
</tr>
<tr>
<td>Lighting</td>
<td>4 kWh/m²/year</td>
<td>4 kWh/m²/year</td>
<td>4 kWh/m²/year</td>
</tr>
<tr>
<td>Electricity (lighting, appliances, cooking)</td>
<td>36 kWh/m²/year</td>
<td>36 kWh/m²/year</td>
<td>36 kWh/m²/year</td>
</tr>
</tbody>
</table>

Figure 3.9-Average energy consumption by end use in residential buildings in Germany band (source: Inspire, 2014a, p.91)

3.5 State of refurbishment in Germany

There have been significant efforts in Germany for reducing the energy consumption. Specifically, BPIE report (BPIE, 2014) has indicated that there was a decrease in space heating consumption from 205 kWh/m²/a in 2000 to 147 205 kWh/m²/a in 2014. Aside from that according to IWU study (Tabula, 2012) the renovation rates during 2000-2009 related with the residential sector can be found in (figure 3.10):
About 1% p.a. of housing stock built up to 1978 has undergone exterior wall renovation. The wall insulation increased from 8cm to 14cm.

1.5% p.a. received upgrade of thermal insulation of top floor ceilings. Increasing from 12cm increased to 18cm.

Below 1% p.a. regards the basement ceiling insulation.

1.5% p.a. of the housing stock have renovated the windows as 40% have already low-e glazing.

3% p.a. is the annual renovation rate of the main heat source.

Figure 3.10-Annual insulation rates of residential buildings in Germany band
(source: Tabula, 2012, p.21)

3.6 Conclusion

After reviewing German residential stock, this literature overview supports the idea of targeting Germany for exporting the 2ndSkin project. Facts have shown that there is room for improvement regarding energy upgrade of German housing stock. To begin with, the Energy Saving Regulation already covers a range of essential aspects that need improvement and have to be taken into account in retrofit projects. Furthermore, building renovation strategies are
a realistic scenario for Germany as energy upgrade of the building stock has been driven by various forces in the country the last decades.

It could be efficient to apply refurbishment strategies in Germany as it has the largest population in Europe with 81.7 million, presents the highest number of residential buildings in Europe with 39.43 million and the most m² of heated floor area along with the highest space heating consumption.

Multi-family houses of the German residential stock could be the building typology for applying the refurbishment concept as account for the 35% of the housing stock and appear to be similar with the reference building in Netherlands. Specifically the MFHs that have 3-4 flats per building are the most common building types in Germany. When it comes to construction type, the most popular one is a single leaf masonry construction of brick or reinforced concrete. Therefore, a German reference building has to be defined in order to investigate the design's flexibility and adaptability in terms of construction and building services.

As far as energy consumption of the German residential stock is concerned, space heating is by far the most important end-use that consumes most of the energy with approximately 77% of the total. Individual heating systems appear to be the most widespread. Furthermore, the decrease in space heating consumption shows that there is motivation and action regarding energy upgrade of existing buildings. The annual renovation rates could be improved in terms of renovating the building envelope, the heating system, the ventilation, etc. Germany has potential for implementing the refurbishment concept of 2ndSkin.

After extensive searching into the literature a study case in Germany reflecting the aforementioned criteria has been identified. The Breslauer Complex is a multi-family residential building of the post-war period in Germany. It regards two types of residence constructed in 1967 at the area of Gartenstadt at the
suburbs of city Krefeld. A 3-storey and a 4-storey apartment block arranged in L-shape form 3 identical complexes.

For the purpose of this study the 4-storey apartment block has been chosen as shows potential for investigating the design’s adaptability. The housing association -Wohnstatte Krefeld- that owns the property underlines the substantial energy upgrade. The buildings are rented by the housing association and most of them have not undergone any significant renovation. The main reason that the housing association asks for upgrade is the increasing number of vacant apartments.

When it comes to the building construction, the structure consists of load-bearing masonry brick walls and concrete in-situ slabs. The façade is made out of lightweight concrete blocks and brick cladding. There are balconies as incised loggias (figure 3.11). Moreover, neither the façade nor the floors have insulation as it would be illustrated later in details description. At the next steps of the research an extensive description of the building in Germany will take place, leading to an intergraded façade design.

Figure 4.1 - 4-storey apartment block in Breslauer complex, Germany
(source: Konstantinou, 2014)
4 Comparative study of reference buildings

Given that the main goal of the research is to export the 2ndSkin concept into the European market while investigating design’s adaptability, there are characteristics that influence the design and need to be clarified. It is obvious that there are key elements regarding the construction or floor plans that affect the design process and could determine a final design for this research. In both case studies, elements like the type of balcony or the size of the windows vary, resulting in different design approach. Moreover, the analysis of these characteristics will contribute to determine the limitations of the 2ndskin design.

Floorplans

Nonetheless the 2ndSkin refurbishment concept focuses on the façade, the floorplan plays an important role. That is because it determines the location of the utilities, the staircase, the ventilation shaft etc.

Balcony: type and location

The connection between the slabs and the balcony is a critical point for the design, as it determines the thermal bridging. The balcony is part of building’s envelope, thus demands special treatment. There are four types of balconies: French balcony, loggia, loggia/overhang and overhang.

Wall construction

The condition of the existing wall construction is crucial as defines its ability to handle the panels added to building’s envelope. Specifically, in cavity walls the wall joints need to be checked and probably to be replaced. Furthermore, the façade elements show the design potential by having focus on the envelope.
Window layout

The size of the windows, window/wall ratio and the parapet that vary in every case study define the size of the paneling of the 2ndSkin envelope, the substructure location, the ventilation pipes and air inlet.

Roof construction

If the roof construction is flat or pitched is important, as the 2ndskin refurbishment concept places the upgraded building services unit and PV panels on the roof. Therefore, the roof needs to be check if there is available space and which is best location for the installations.

Floor slab projection

The connection between the wall and the floor slab except from being a thermal bridge, defines the design of the façade. If there is slab projection, then the façade panels need to accommodate the space for the slab while solving the thermal bridging.

Entrance

The way the entrance is constructed influences the design of the envelope. The entrance could have or not have added element to signify the spot like protection covers. The way these cover are made could affect the panels of the façade and determine the design.
4.1 Study case in Krefeld, Germany

Building construction

The Breslauer Complex in Krefeld is the study case of this research. Specifically the 4-storey building includes 16 apartments. To begin with, the building has north, south oriented façades (west-east orientation from the long façades), two central staircases adjacent to the long west façade along with kitchen and bathroom. Every floor has four apartments, three out of them have an area of 62m$^2$, while the forth apartment is 82m$^2$ (figure 4.5).

The structure consists of load-bearing masonry brick walls of 175 mm and concrete in-situ slabs of 130mm. The façade is made out of 24 mm lightweight concrete blocks and brick cladding (figure 4.2). The balconies are constructed as incised loggias. Furthermore, the windows have been replaced in the 80s with double glazed, PVC framed windows. The majority is from floor to ceiling. In the west façade there are small sized windows at the bathrooms and glass pavers across the staircases. At north-south short façades there are no windows, the walls are blind. The window wall ratio is 50% and the parapet is part of the façade panel. The U-value of the glass is 1.20 W/m$^2$K.

The ceiling of the basement and the attic is 130 mm thick in-situ concrete floor with no insulation. Moreover, neither the façade nor the floors appear to have insulation. The building has a pitched roof of 12° slope, made out of timber joists, a wooden casing and sealed with bitumen roofing membranes. It
appears that there is no slab projection at the façade and there is a cover frame around the entrance doors at the west façade.

The analysis of the west and east façades resulted in vertical zones that show the areas with similar characteristics (figures 4.7, 4.8). Specifically, in case of west façade there are five zones of various openings. Zone 1 refers to windows from floor to ceiling that have opaque parts at the bottom. Zone 2 includes square windows that have at the bottom lightweight concrete blocks. Zone 4 signifies the entrance doors and the pavers across the staircases. Windows of

Figure 4.3 - 4-storey apartment block in Breslauer complex, Germany
(source: Google earth)

Figure 4.3, 4.4 - East, West facade of the 4-storey apartment block in Breslauer complex, Germany (source: Konstantinou, 2014)
Figure 4.5 4.6- Current floor plan of 4-storey apartment block in Germany and Cross section (source: By the author)
ZONE 1: Window floor to ceiling
2110mm transparent
2500mm opaque: frame

ZONE 2: Square window
1570mm transparent
2500mm opaque: concrete block

ZONE 3: Rectangular window
1135mm opaque: wall
630mm transparent
opaque: wall

ZONE 4: Ground floor window
600mm transparent
400mm opaque: wall

ZONE 5: Entrance
2380mm pavers
2735mm Entrance door
Concrete frame around

Figure 4.7 - Analysis of West facade of study case in Germany
(source: By the author)
ZONE 1: Balcony Window
- 4078mm transparent
- 2600mm opaque: concrete rail

ZONE 2: Square window
- 1570mm transparent
- 2500mm opaque: concrete block

ZONE 3: Ground floor window
- 600mm transparent
- 400mm opaque: wall

Figure 4.8 - Analysis of East facade of study case in Germany
(source: By the author)
zones 3 and 5 present the smaller sized windows that are located at bathrooms and ground floor, respectively. Moreover, all the window types of the first floor have shutters in contrast with the rest of the floors. Looking at the east façade there are three zones with openings. The first is about the balcony openings where there is a concrete railing at the front. Zone 2 includes square windows as in case of west elevation and the third zone refers to the ground floor windows.

**Building services**

When it comes to energy consumption, gas is the main energy source. There is central heating system with panel radiators. The space heating occupies most of the energy consumption, as in most of the cases in Germany. Moreover, there is no mechanical ventilation, as natural ventilation seems to be the only solution. Finally, the energy label of the 4-storey building is E, F.

**Current problems**

After analyzing the building envelope and the building installations, there have been identified some problems. Firstly, the complete lack of thermal insulation on external walls and roof results in inadequate structure for today’s energy requirements. The minimum required thermal resistance by the German regulations is 0.24 W/m²K while the building presents 1.20 W/m²K. Moreover, the thermal bridging at the balcony slabs is another problem identified.

Additionally, the windows and doors are 25-30 years old, meaning they are outdated and need replacement. There is no sound insulation on the floor, ceiling or walls and prefabricated element of the façade are deteriorated as plaster fall-off, reinforcement’s shows corrosion on the concrete etc. In the interior area the ventilation is problematic, the installations are outdated and the thermal bridging also enhances the phenomenon. The apartments are inaccessible for handicap as there are no lifts or ramps and that is a problem as mostly elderly live in the area.
4.2 Reference building in NL

Building construction

The reference building located in Rotterdam-Zuid was the initial study case of the 2ndSkin refurbishment concept. The post-war building is a 4-storey apartment block. There is a central staircase accessible in the front façade that leads to two apartments per floor. The building is orientated north-south from the long façades, there is a central staircase adjacent to the north façade along with the kitchen (figure 4.15). The construction is massive wall 150 mm with reinforced concrete slabs 140mm and brick cladding with cavity and no/little/outdated insulation. Moreover, the balconies are half loggia/half overhang which have been made on site in combination with the floor.

The windows of the building are large size and incorporate lightweight parapet. Most of the windows are from floor to ceiling and the window wall ratio is 60%. At the west-east short facades (figure 4.10) there are long narrow windows at the living room of each floor. The windows are PVC framed with double glazing of 4.3 W/m²k U-value.

The roof is flat and it is consisted of 105mm concrete, 100 insulation and 50mm finishing. Moreover, the ground floor is 100mm concrete.
There is slab projection of 80mm that divides the load of brickwork over the story floors and played a crucial role in the 2ndSkin design concept. Moreover, there is cover above the entrance door and an exterior staircase that leads to the door which is above ground level.

Figure 4.11 - Reference building in Rotterdam-Zuid   (source: Google earth)

Figure 4.12 - South facade of reference building in Rotterdam-Zuid   (source: By the author)
Figure 4.13 - Elevations of reference building in Rotterdam-Zuid
(source: 2ndSkin team)

Figure 4.14 - Cross sections of reference building in Rotterdam-Zuid
(source: 2ndSkin team)

Figure 4.15 - Plans of reference building in Rotterdam-Zuid
(source: 2ndSkin team)
**Building services**

About the technical installations of the building, the main energy source is gas and the heating system is central with individual panel radiators. There is no mechanical ventilation, thus it is natural. In conclusion the building has D, E energy label.

**Current problems**

It has been identified that the structure lacks of insulation on external wall, thus the thermal performance is insufficient. Moreover, the windows need replacement as they are outdated and present low performance. The current requirement for the U-value in Netherlands is $0.37 \text{ W/m}^2\text{K}$ while the building presents $4.3 \text{ W/m}^2\text{K}$. Moreover the thermal bridging at the balcony slabs is another problem identified as the slab projection increases the phenomenon.

Additionally, there is no sound insulation on the floor, ceiling or walls. The brickwork of the façade is deteriorated and seeks renovation. Moreover, there is mould on the interior walls as there is only natural ventilation. The building installations are outdated and need to be updated. If there is need for handicap access it is not possible as there are no lifts or ramps.

**4.3 Comparison of reference buildings in Netherlands and Germany**

After having analyzed the reference building in Netherlands and Germany, an overview in table 4.1 summarizes the characteristics of both cases. As mentioned in the beginning of this chapter, there are characteristics playing more important role for the purpose of this research. These regard mainly the building construction.

To begin with the building in Krefeld presents approximately double sized floor plan and number of apartments. Both cases have similar layout, where some utilities like kitchen in both buildings and bathroom in Krefeld are adjacent to façade. The wall construction is significantly different, as in Rotterdam it is prefabricated wall with air cavity and brick cladding, whereas the wall
construction in the other case is masonry brick wall with lightweight concrete blocks and brick as cladding. The existing structure is important as depending on the case different treatment and adjustments needed to be applied in order for the wall to resist the weight of the 2ndSkin panels added on the exterior layer.

Additionally, the façade layout varies in both cases as in the first building the window wall ratio is 60% and the short façades have narrow window frame. In contrast, in the second building the window wall ratio is 50% and the short facades are blind. Thus, the design for the 2ndSkin panels has to deal with the façade variations in different ways. Furthermore, the type of the balcony determines the façade design since in the first case they are half loggia and half overhang while in the other case they are incised loggias. In consequence, the design has to consider the thermal bridging and the existing layout of the balconies.

Critical characteristic for the design is also the slab projection. If there is extension as in the case of Rotterdam then the façade panels need to be adjusted according to the existing structure. The structure of the roof, pitched or flat affects as well the refurbishment concept, since installations like PV panels and heat recovery unit need to be incorporated. Moreover, the structure of the entrance doors could influence the façade design. In the first building the entrance is lifted above ground level where there is an exterior staircase, a cover above the door and a transparent area across the staircase. Whereas, in the second building there are concrete covers around the entrance doors and pavers across the stairs.

In conclusion, the aforementioned characteristics that vary in every case study could determine the design of the 2ndSkin concept, as they could affect dramatically the façade layout. The research based on those elements will elaborate on various design samples that would incorporate design’s adjustments, limitations and variations in order to answer the requirements of the project.
Table 4.1 - Comparison of reference buildings in Netherlands and Germany (source: By the author)

<table>
<thead>
<tr>
<th>Building Structure</th>
<th>Building 1</th>
<th>Building 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>Netherlands</td>
<td>Germany</td>
</tr>
<tr>
<td>Location</td>
<td>Zuid-Rotterdam</td>
<td>Gartenstadt, Krefeld</td>
</tr>
<tr>
<td>Date of construction</td>
<td>1956</td>
<td>1967</td>
</tr>
<tr>
<td>No of storeys</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>No of apartments</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Orientation</td>
<td>North-South (long façades)</td>
<td>North-South (short façades)</td>
</tr>
<tr>
<td>Floor plan</td>
<td>Kitchen and staircase adjacent to façade</td>
<td>Kitchen, bathroom and staircase adjacent to façade</td>
</tr>
<tr>
<td>Structure</td>
<td>Reinforced concrete slabs 140mm</td>
<td>Concrete in-situ slabs 130mm</td>
</tr>
<tr>
<td>Load bearing walls</td>
<td>Massive wall 150mm</td>
<td>Masonry brick walls 175mm</td>
</tr>
<tr>
<td>Façade</td>
<td>Cavity wall, brick cladding (short façade, narrow windows)</td>
<td>24mm lightweight concrete blocks, brick cladding (short façade, blind wall)</td>
</tr>
<tr>
<td>Windows</td>
<td>u-PVC Frame, Double-glazing, 25-30 years</td>
<td>u-PVC Frame, Double-glazing, 25-30 years</td>
</tr>
<tr>
<td>Glass</td>
<td>U-value=4.3 W/m2K</td>
<td>U-value=1.20 W/m2K</td>
</tr>
<tr>
<td>Balcony</td>
<td>Half loggia/half overhang, Made on site, in combination with the floor</td>
<td>Incised loggias</td>
</tr>
<tr>
<td>Roof</td>
<td>Flat roof, Concrete 105mm, insulation 120, finishing 50mm</td>
<td>Pitched, 12° slope. Timber joists, wooden casing bitumen roofing membranes/attic floor in-situ concrete 130mm</td>
</tr>
<tr>
<td>Ground floor</td>
<td>Concrete 100mm</td>
<td>Concrete in-situ slabs 130mm</td>
</tr>
<tr>
<td>Slab projection</td>
<td>Slab extensions needed to divide the load of the brickwork over the story floors</td>
<td>No extension</td>
</tr>
<tr>
<td>Parapet</td>
<td>Part of the façade panel</td>
<td>Part of the façade panel</td>
</tr>
<tr>
<td>Window wall ratio</td>
<td>60%</td>
<td>50%</td>
</tr>
<tr>
<td>Entrance</td>
<td>Cover above door</td>
<td>Cover frame around door</td>
</tr>
<tr>
<td>Energy source</td>
<td>Gas</td>
<td>Gas</td>
</tr>
<tr>
<td>Heating system</td>
<td>Individual panel radiators</td>
<td>Individual panel radiators</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Natural</td>
<td>Natural</td>
</tr>
<tr>
<td>Curret energy label</td>
<td>D, E</td>
<td>E, F</td>
</tr>
</tbody>
</table>
4.4 2ndSkin Concept description

As mentioned before the 2ndSkin project developed for the reference building in the Netherlands and aims to zero energy use of a dwelling. Specifically the design focuses on three axes, the skin of the building envelope, the building services and user interaction. The integrated façade system that has been developed will decrease the energy demand for space heating and cooling by increasing the thermal resistance and improving the air tightness.

In figures 4.16, 4.18 it have been illustrated the assembly sequence of the 2ndSkin concept onto the reference building in the Netherlands. After the removal of the existing windows/doors, the first step is to install the substructure on the existing wall consisted of wooden posts and U steel profiles. Second step is to apply the central panel attached to the sub-structure through timber sticks. There are integrated the layer of insulation in combination with the ventilation pipes. Figure 4.17 shows the ventilation inlet at the bottom part of windows. Third step is the basic...
prefabricated panels at the left and right of the main wall including the new windows, shading devices and the insulated ceiling above storage/garages. Timber sticks have been used to attach these panels.

**Forth step** is the internal lining with the new railings. Fifth step is the façade cladding which material could vary. After the assembly sequence of the 2ndSkin on the building envelope, would be the roof insulation and final the installament of the PV panels and solar collectors. When it comes to building services, the research team has been developed three different ventilation strategies concerning the air inlet and outlet. For the purpose of this research the ventilation system would be collective air via façade. There is a recovery unit installed on the roof and the ducts running through the façade. If there is an existing ventilation duct it can be used after have been repaired as air outlet.

![Figure 4.18- Building sequence of 2ndSkin concept of reference building in Netherlands (source: 2ndSkin team)](image-url)
The innovated system itself is an integrated prefabricated wall element applied on the existing wall. As figure 4.19 shows it is consisted of 3 layers, A) IVM insulation (RC=3.0) and the plant systems integrated in the panel, B) the basic prefabricated wall element (RC=3.5) and windows/doors and C) the wall cladding incorporated in the prefabricated element.

The requirements of the system, specified by the team are:

- Modular system
- Easy installation
- Demountable (maintenance should be possible from the outside)
- Lightweight
- Sustainable (if possible recyclable or biobased)
- Building physical properties (water resistance, UV resistant, etc.)
• Fire safety
• Identity (contemporary buildings with clear identity)
• Affordable
• Scalable

5 Application of 2ndSkin project to case study in Germany

5.1 Design and process requirements

After having analyzed the case study building in Krefeld and having a thorough knowledge of the 2ndSkin concept, the next step of the research is to apply the design to the 4-storey apartment block in Germany. Through this process important questions of the research will be answered. For instance, the flexibility and adaptability of the 2ndSkin concept will be assessed in terms of designing. The research by focusing on critical elements as mentioned before, like the balcony design, the wall construction or the window layout, will result in a design that deals with those key elements and proposes solution for the upgrade of the building. The design is focused on the envelope of the building, thus a façade design concept will be the final product.

There are three dimensions that reflect the design requirements. The first and the most important one is the technical dimension. Therefore, the research starts with having the 2ndSkin concept as the basis point for improving the thermal performance of the building’s envelope, improving the indoor air quality and updating the existing installations. The 2ndSkin system with the ventilation pipes, the insulation boards and the cladding have to be adjusted in terms of dimensions, building sequence and materials in order to be applied to the building in Germany. Depending on the intensions of the owner and besides the exterior upgrade which can take place without removing the residents, an interior renovation of the facilities and wall treatment while having
removed the residents could increase the value of the apartments. Moreover, after applying the 2ndSkin concept the next step of the research regards the designing of additional elements like closed balcony, lift, sunshades or different cladding. The design samples in form of a catalogue will reflect the potential and flexibility of the 2ndSkin concept for introducing new design elements and offering a design variation.

The architectural dimension comes next, where the façade composition could be enhanced. Specifically, the modernization of the architectural appeal is a parameter of the research, along with improving the aesthetics and increasing the user’s comfort. Additionally, it would be beneficial if the apartments where user-friendly for all ages and offer high living conditions. One last dimension is the economical which does not affect the design but in the end if applying the 2ndSkin refurbishment concept there would be energy savings and low energy costs. Moreover, the overall renovation of the building could result in high rent apartments and a fast payback for the owner.

Along with the design requirements there are process requirements which regard the important values that lead the design process. As mentioned before, the goal of the research is to investigate the flexibility and adaptability of the design. By applying the concept to the German case study, additional design elements could be proposed that could expand the design and offer design variety for the refurbishment project. Furthermore, the design will assess the limitations of the 2ndSkin concept and evaluate the overall design.

5.2 Concept idea for applying the 2ndskin project

The concept idea for applying the 2ndSkin project is first to employ the layers on the existing structure and wrap the building’s envelope (figure 5.1). The ventilation pipes, the insulation boards and the cladding will be attached on
the existing structure through the sub-structure like U-beams and wooden posts (see Appendix C for drawings). Moreover, under the pitched roof there would be located the heat recovery units.

A decisive parameter for the design is the window layout, the location of the ventilation pipes and the panel design meaning the sizes and their location. The intention of the façade composition is to preserve a vertical zoning by upgrading and redesigning the windows which inspired by the existing façade. The design of the windows is based on the functionality of the uses and the intention to have floor to ceiling windows for more light transmission. Thus, the window design inspired the air outlet, which has to be at the top of the windows.

Furthermore, after applying the ventilation pipes and the insulation boards comes the cladding which is wooden stripes in horizontal and vertical dimension. Specifically, ThermoWood is an excellent material of timber cladding, because of its improved durability. The heat treatment process is what makes this material special. The improved performance is achieved simply by the controlled application of heat and steam. It is more stable than untreated wood due to the changes that occur at the timber that it is less able to absorb or lose moisture. Thus, the potential for shrinkage, swelling or distortion is limited.

Moreover, the high temperatures reduced the internal stresses of the structure. Therefore, there are limited possibilities for twist and warp. Thermal conductivity of ThermoWood is reduced by 20-25% compared to normal softwoods. The thermal conductivity of thermowood is \( \lambda = 10 \text{ W}/(\text{m} \cdot \text{k}) \) compared to the value of untreated timber that is \( 0.12 \text{ W}/(\text{m} \cdot \text{k}) \). During the heat treatment the resin from the timber is removed. Thus there is no resin leakage at the coating of the surface. This result in combination with the improved stability leads to a lower maintenance required.

The cladding design inspired be the existing facade composition and the
substructure of the system, which determines the width of the vertical zones. The different orientation of the wooden strips creates a polymorphic façade composition and enhances the vertical zones.

5.3 Alterations made on the existing structure

For the purpose of this design and in order to achieve the design inspiration there were made alterations at areas of the existing structure. The goal was to create an interesting façade composition where the character of the design would be clear and architecturally appealing. By trying to keep a vertical zoning at the window areas, some parts of the existing structure had either to be removed or covered. For creating the design of the windows, the function of the rooms, the location of the ventilation pipes and users’ comfort, played an important role and lead the design.

At the west elevation as figure 5.2 shows, in red color were the parts of the existing structure which were removed in order to accommodate the new windows. The most characteristic alterations of this façade are the bathroom openings which became longer and the glass blocks of the staircases which were removed in order to provide more light in the interior. Moreover, in the middle of this façade there are sleeping rooms adjacent to the exterior wall.
Thus, the bottom part of the structure has been removed in order to improve the living conditions of the interior space and create an ambient environment. The diversity of the opening design will distinguish the diversity of the functions which will be reflected on the façade’s design. The cover of the entrance door was removed and replaced with a new design.

Looking at the east façade, changes were made as well in order to accommodate the new design. In figure 5.3 in red color are the parts that have been removed while in green the parts that have been covered. Specifically, this façade is been characterized mainly from the balconies. Furthermore, the old concrete railings have been removed so new ones will be applied. Moreover, the ground windows that were located below of the balconies have been covered to ease the paneling application. The rest of the opening areas belong to sleeping rooms, thus a floor to ceiling opening will be applies at these areas.

In general, some other alterations that need to be mentioned are the air ducts of the interior which were eliminated to two at each apartment to facilitate the outlet of the steel air. Moreover, part of the exterior wall at the roof had to be removed so that the ventilation pipes could be connected with the heat recovery units located into the roof construction.
5.4 Window design

The window design resulted from the intention to preserve the vertical zoning that characterized the façades and especially to designate each window design to each indoor function. Moreover, the location of the 2ndSkin panels affected the placement of the windows and the size.

Looking at the west façade, there have been designed four types of windows. Window type A (figure 5.7) refers to the living room opening and it is from floor to ceiling window with dimensions of 1610x2400mm that has two operable parts. Meanwhile, a translucent railing close to the window offers the user the opportunity to keep the window totally open and be safe. Window type B (figure
5.5) is the opening of the kitchen, and the design offers interior flexibility for accommodating furniture. The size of window type B is 1175x1650mm and it is operable.

Figure 5.5- Window types B of West facade

Figure 5.6- Window types C of West facade

Figure 5.7- Window types A of West facade

Figure 5.8- Window types D of West facade
Next to the kitchen and adjacent to façade are the bathrooms, where operable window, the C type (figure 5.6) is designed for this area. The window size is 735x1650mm and the main feature is the bottom part of the glass that is sandblasted translucent part for privacy while enabling light transmission. Window type D (figure 5.8) regards the staircase area and sizes 630x2400mm. Two windows have been applied at previous area of every floor, and signify a long transparent zone of the staircases.

At the east façade the dominant window designs are two. The balcony opening, type E (figure 5.10) has two operable parts and one stable. It sizes 3870x2400mm and covers full length of the opening. Meanwhile, a translucent railing completes the design of that area and creates an ambient environment for the users. The last window type F (figure 5.11) is designated to the sleeping rooms. It is from floor to ceiling window of 1175x2400mm. The window has a stable bottom part that it is sandblasting translucent glass, while the top part is operable. What is more all of the window types besides the staircase window frame (type D) have integrated sunshades located at the top of the windows.

Figure 5.9- East facade. Window types
Figure 5.10 - Window types E of East facade

Figure 5.11 - Window types F of East facade
5.5 Panel application step by step

As described in previous chapters the existing structure consists of masonry wall and brick cladding or concrete prefabricated blocks (figure 4.2). The refurbishment concept of 2ndSkin is applied to the 4-storey apartment block in Krefeld only from the exterior by focusing on the façade design. The goal is to upgrade the building and propose a design variation of the concept. Therefore, at this chapter, the building sequence concerning the panels application will be discussed step by step.

After the existing structure has gone through the alterations, like removal of some parts of the non-loadbearing structure, the first step is to apply the wooden post of 70x250mm connected with the structure through U-beams. The places of the posts have been chosen in order to support the panels and to prevent them from buckling. Figure 5.12 presents the building sequence of the west façade, where in brownish color is the structure after the changes made, while in grey color the floor slabs are illustrated. The locations of the wooden posts are clear.

The next step for the building sequence of the west façade is the attachment of the central panels which have integrated the ventilation pipes at the inner side including the air inlet mechanisms located at the top of the windows (figure 5.13). Every long surface consists of two long panels dividing the total height approximately in the middle. Each panel has attached wooden sticks of 50x50mm which are screwed with the larger posts. The third step for the general building sequence of the west façade refer to the application of the right and left panels that include the window frames as well (figure 5.14). At every window frame there is a top and bottom panel attached while in most of the cases there is a narrow panel at the sides of the frames with profile of 70x220mm.
Figure 5.12 - Building sequence of West facade. Step 1

Figure 5.13 - Building sequence of West facade. Step 2

Figure 5.14 - Building sequence of West facade. Step 3
Figure 5.15 - Panel grid of West facade

Figure 5.16 - West facade elevation

Figure 5.17 - West facade plan
The elevation in figure 5.15 illustrates the panel division of the west façade. The window panel zones are fixed together on site or beforehand and applied on the façade as one piece. After the application of the panels comes the wood cladding screwed on them through the supporting system (figure 5.16). The system of the cladding consists of 42x42mm wooden batten attached to the thermowood stipes (profile of 21x118mm) and the width of the zones is based on the location of the wooden posts.

On the other hand, the east façade with the balconies follows a similar building sequence. The first step is the attachment of the 70x250mm wooden posts to the structure through U-beams. In order to keep in line the balconies with the exterior panels of the sides, a wooden beam of 100x260mm is fixed on the two vertical posts at the sides (figure 5.18). The balcony structure is illustrated in detail at the appendix C. The second step of the building sequence is the attachment of the central panels including the ventilation pipes boards through the smaller wooden sticks screwed with the vertical posts (figure 5.19). In that step as well, there is 100mm rockwool insulation applied on the sides of each balcony.

The third step is the application of the right and left panels which in that façade there are two types (figure 5.20). One case is the right or left panel that includes the window frames of the sleeping rooms, while the other case involves the balconies. Specifically, in every balcony vertical zone there is a top and a bottom panel attached to the structure. Afterwards, and the window frames are placed at the openings. In figure 5.21 the grid of the panels of the east façade is illustrated. The last step of the façade layers is the wood cladding that completes the façade design by creating a playful façade composition (figure 5.22).
Figure 5.18 - Building sequence of East facade. Step 1

Figure 5.19 - Building sequence of East facade. Step 2

Figure 5.20 - Building sequence of West facade. Step 3
Figure 5.21 - Panel grid of East facade

Figure 5.22 - East facade elevation

Figure 5.23 - East facade plan
The cladding design is very flexible and can result in various façade compositions by changing the orientation of the stripes or the width of the zones. Although the elevations proposed correspond to the design inspiration while providing functionality at the building, the west elevation could incorporate longer windows at the kitchen and bathroom and result in other composition (figure 5.25).

Figure 5.24- Design proposed for west elevation

Figure 5.25- West elevation with longer window design
5.6 Window detail description

One of the critical designs of the 2ndSkin concept application on the apartment building in Germany was the window detail. In this chapter, the building technology of the window type B will be discussed and explained in detail. Looking the design from a general view, we can understand the building sequence of the layers applied to the existing structure. Figure 5.31 illustrates the cross section of the window detail.

In figure 5.26 the exploded view of the design shows the building sequence. As discussed before, on the existing structure there have been attached wooden posts of 70x250mm with steel U-beams. The next step is the application of the central panels that include the ventilation pipes. In detail, the prefabricated panels are consist of fiber cement sheet of 10 mm and EPS insulation of 200mm. Meanwhile, the plant system includes the pipes of 80mm diameter and a mechanism for ventilation which located at the top of the windows. The prefabricated panels are attached to the posts through smaller wooden sticks of 50x50mm.

The third step is the application of the right and left panels that include the window frames which have integrated sunshades. The metal element for water drainage it is included as well at the whole system. The forth step of the building sequence is the linings which will cover the open parts around of the window frames and the inner areas of the wall that are open and need to be covered to enclose the system. Smaller wooden sticks and beams are attaced in order to create the grid for applying the linings. Figure 5.29 shows the interior view of the windows without the linings, and figure 5.30 presents the view of the interior after applying the complete system.

The last step is the wooden cladding. Wooden stripes of 21x118mm profile have been applied in vertical or horizontal direction. There are wooden batten
of 42x42mm that connect the prefabricated panels with the stripes. In that way, a ventilated cavity in between offers air circulation for the structure. The stripes are thermowood pine profiles that have been used in the market and have high durability and performance.

Figures 5.27 and 5.268 are close views of the system with the layers applied at the structure. The 3D models present the facade design and explain in detail the technology behind the concept. Moreover, the horizontal and vertical details of the window (figures 5.30, 5.31) illustrate how the critical points of the window designed solved. That would be the final result of applying the 2ndSkin design on the German case study.
Figure 5.27, 5.28- 3D views of building sequence of window type B and C. East facade
Figure 5.29- Interior view of window type B and C with no linings. East facade

Figure 5.30- Interior view of window type B and C with linings. East facade
Figure 5.31- Cross section of window type B. East facade

Existing structure:
- Precast concrete block 300mm
- Prefabricated panel 1145x220mm:
  - Fiber cement sheet 10 mm
  - EPS Insulation Board 200mm
- U-steel profile
- Bitumen vapour barrier

Existing structure:
- Bricks cladding 105mm
- Concrete slab 130mm
Interior finishing:
- Plasterboard 12mm
- Aluminium window with integrated shading system

Exterior:

Thermowood Cladding:
- "Channel" profile 21x118mm
- Ventilated cavity
- Wooden batten 42x42mm

Plant system integrated in the panel:
- Ventilation pipe Ø 80mm
- Air inlet mechanism

Interior:

INTERIOR

Exterior

EXTERIOR

1600
2600
750
Figure 5.32- Vertical detail of window type B. East facade

Figure 5.33- Horizontal detail of window type B. East facade
6 Designing additional elements

6.1 Open/Closed balcony design concept

The first concept for creating additional design elements that could be applied in combination with the basic 2ndSkin paneling is to close the open balconies of the East facade (figure 6.1). Through the study of the building in Krefeld there were some observations that lead to this design variation.

In particular, at every floor there are three apartments that have area of 62 m² and one that is slightly bigger. For that reason the opportunity to use the extra space adds value at the building and improves the living conditions. Specifically, if the balcony closes then each apartment gain the extra space of 6.4 m² at the living room area. Finally, the closed balcony area works as a buffer zone for the interior and enhances the energy performance of the building.

For this design there was a reference project that inspired the idea. It is located in Paris and it is designed by Moussafir Architects in 2010(fig. 6.3). The project involves the upgrade of a whole neighborhood in Northern Paris. The architect’s intention was to have extended balcony boxes for creating a spatial value.
The need for designing a balcony structure in front of the closed balconies is a result of this design addition. That is because, the residents could not lack the ability of enjoying a balcony. Thus, this design variation manages to offer both extra space and balcony area. The critical part of the balcony design is now transferred to the exterior edge of the structure, where the old railings were.

The building sequence for this design variation involves three steps. To begin with, the first step is to have same floor level at the exterior and interior, as the balcony slab is 140mm below the interior floor. That is solved by applying a wooden floor. Afterwards, the window frames will be applied at the end of the construction line so as to take advantage the full length of the balcony (figure 6.5). To deal with this thermal bridging a prefabricated insulated panel has been applied and the critical edge. The panel has height of 400mm and is fixed at the slab with an angle steel element (figure 6.8, Appendix C).

The second step is to apply I-beams of 140mm in front of the structure and prolong the balcony structure along with the floor (figure 6.6). The I-beams are connected with C-beam of 45x120mm and result in a self-supported structure that does not add weight at the existing structure. The last step of the sequence
Figure 6.5 - Step 1 of the closed balcony concept

Figure 6.6 - Step 1 of the closed balcony concept

Figure 6.7 - Step 1 of the closed balcony concept
is to attach wood cladding at the steel structure and provide privacy to the users (figure 6.7). Glass translucent railings that will allow light transmission complete the design concept. In conclusion, the wooden framed balcony structure creates an extruded volume that enriches the façade composition (figure 6.9).

Figure 6.8- Vertical section of the closed balcony concept
6.2 Elevator design concept

The second additional element of the design variation is the addition of elevator at the West façade. The west façade is the one that signifies the circulation as facilitates the staircases. The absence of an elevator at the 4-storey apartment block could cause problems at the elderly or handicaps. As the goal of the refurbishment concept is to upgrade the living conditions by improving the circulation and the current floor plan.

For achieving the addition of an elevator
at the building, the adequate location is the exterior site. In particular, there has been added one elevator at the corner of the building, along with two transparent staircases at the short sides. There is also designed a new floor plan that takes advantages the space of the previous staircases and creates two sleeping rooms for two of the four apartments (figure 6.13). Additionally, a structure out of steel I-beams of 140mm creates an exterior passage with width of 1.40m that leads to the new entrances of the apartments.

Figure 6.11- 3d perspective of elevator concept

The first floor apartments are accessible by private exterior staircases. For the rest of the entrances there are designed buffer zones at the living rooms which can be partially or fully closed. The exterior skin of the elevator and the new staircases is translucent glass. The windows at the old staircases have been designed to accommodate the sleeping rooms. The structure is self-supported and does not affect the existing structure or the application of the 2ndSkin layers. The passages besides been used for circulation, they could be common area for interaction and communication between the neighbors.
Figure 6.12 - Elevation of elevator concept

Figure 6.13 - New floor plan, elevator concept
6.3 Sunshades and cladding material design concepts

Sliding sunshades

The third design addition for creating design variation and flexibility of the refurbishment concept is the application of sliding sunshades. The design of the 2ndSkin application proposed window frames with integrated sun shading system. Therefore, different sunshade design could result in an interesting façade composition and will give the opportunity to the user to adjust the sliding sunshades in different positions.

The need for sunshades at the east façade is obvious at figure 6.14. Thus, there has been designed a system that can be applied and do not affect the structure. There were some projects that inspired this design. Specifically, figure 6.15 illustrates a residential building in Mexico designed in 2013. The sun shading system is consisted of perforated fixed panels in front of the balconies that protect from the glare without blocking the sunlight.

Another reference project that inspired the design was a hotel in Germany designed by the Ingenhoven Architects in 2014 (figure 6.16). They have
designed an operable turn-slide sunshade system that can cover the whole length of the façade. Both cases create an interesting relation between sunlight and shadows makes the design unique.

For the case study building there has been designed a system of three striped lattices made out of modified wood or bamboo composite that are lightweight and will not create stability problems at the structure. The lattices are operable and could slide in line in front of the balcony. The sun shading system will not affect the 2ndSkin design and both could be applied in combination.
Cladding material

A suggestion for another cladding material for the 2ndSkin concept could be the cradle to cradle ceramic tile. The ceramic tiles even though are made of raw materials, they are UV-resistant and lightweight compared to stone tiles façades. The application of the ceramic tiles on façade system enriches the aesthetics and the sustainability of a building by reducing the carbon footprint. The application of this system offers flexibility as can be easily modified during the lifespan.

The tiles are anchored onto the support system and can be visible or invisible.
The support system is consisted of horizontal and vertical aluminium profiles. Moreover, the system creates a ventilated cavity in between the wall and the tiles. The rainwater and condensation are drained away through the circulating flow of the air in the cavity. The color of the tiles chosen for the design is grey beige and the sizes vary from 30x60cm to 60x60cm. In figure 6.23, there is a reference building in Netherlands that applies the ceramic tiles at the facade.

6.4 Catalogue of the additional design elements

The following catalogue is an overview of the design elements that explore the flexibility and adaptability and in the end expand the 2ndSkin refurbishment design. All of the elements are applied on the building in combination with the prefabricated panels of the 2ndSkin concept. The application of the new elements does not neglect the refurbishment concept; on the contrary it is a requirement of the design. Each one of the additional elements offers advantages at the users and responds at their needs. They could be employed in combination or individual depending on the owner’s intention.
**Figure 6.24- Catalogue of additional design elements**

<table>
<thead>
<tr>
<th>Addition</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Open/Closed Balcony</strong></td>
<td>![Image]</td>
</tr>
<tr>
<td>- Extra space of 6.4 m²</td>
<td></td>
</tr>
<tr>
<td>- Self supported structure as balcony addition</td>
<td></td>
</tr>
<tr>
<td>- Wooden cladding</td>
<td></td>
</tr>
<tr>
<td><strong>Sunshades</strong></td>
<td>![Image]</td>
</tr>
<tr>
<td>- Modified wood or bamboo composite</td>
<td></td>
</tr>
<tr>
<td>- Sun trasmission</td>
<td></td>
</tr>
<tr>
<td>- No glare</td>
<td></td>
</tr>
<tr>
<td><strong>Cladding</strong></td>
<td>![Image]</td>
</tr>
<tr>
<td>C2C ceramic tile</td>
<td></td>
</tr>
<tr>
<td>- Lightweight</td>
<td></td>
</tr>
<tr>
<td>- Sustainable</td>
<td></td>
</tr>
<tr>
<td><strong>Elevator</strong></td>
<td>![Image]</td>
</tr>
<tr>
<td>- New floor plan, two rooms extra</td>
<td></td>
</tr>
<tr>
<td>- Exterior staircases and corner elevator</td>
<td></td>
</tr>
</tbody>
</table>

*Source: www.mosa.com*
Addition Elevation 3D Model Detail

- Wooden balcony floor
- Steel C-beam 45x120mm

A

- Open/Closed
- Balcony
- Extra space of 6.4 m²
- Self supported structure as balcony addition
- Wooden cladding

B

&

C

- Sunshades
- Modified wood or bamboo composite
- Sun transmission
- No glare

Cladding

C2C ceramic tile
- Lightweight
- Sustainable

D

- Elevator
- New floor plan, two rooms extra
- Exterior staircases and corner elevator

Vertical section

Vertical section

Horizontal section

*source www.mosa.com
6.5 Design suggestion

Through the design process, the goal was to explore the design flexibility and adaptability of the concept. In the end of the design process, there is a design suggestion for the apartment building that combines the 2ndSkin refurbishment concept with some of the design samples. Specifically, the first part of the design process proposed a design concept for applying the 2ndSkin design concept including the ventilation pipe system, the prefabricated insulation panels and the cladding. The second part of the design process introduced four design additions that expand the philosophy of the 2ndSkin concept.

The design suggestion proposes the closed balcony design concept along with the structure as new balcony area. Moreover, the design suggestion includes the sliding sun shading system application and the c2c ceramic tile cladding in combination with the wooden cladding applied at the balcony frames. Figures 6.25 shows the design suggestion of the East façade. There are four extruded volumes at the balcony zones which are the new balcony structures as the old ones are used as interior space.

The sun shading system is been applied in front of the balconies and the three sliding lattices could cover the whole length are kept together as one piece. Moreover, the wooden cladding is used at the steel structure in order to frame the volumes. Meanwhile, the ceramic tile cladding is used at the rest parts of the façade. The are many possibilities for the façade composition as the design proved, therefore the choice could be taken from the owners of the building.

These design choices resulted from the intention to satisfy the resident’s needs, to add features at the building that are essential and improve their living conditions. This design concept reflects diversity and at the same time symmetry and adds architecture and functional value at the building. The design concept of the elevator considered as a non-priority for the building.
The advantages of the design suggestion concerning the design elements are the following:

- 2ndSkin panels: Improved thermal performance and air quality and updated installations

- Closed balcony: Extra space of 6.4m² at every apartment and new balcony structure

- Sunshades: Individual control of the sunshade system, glare protection

- Thermowood cladding: High performance, durability

- Ceramic tiles: Lightweight, sustainable cladding

Figure 6.25- 3d perspective of design suggestion, East facade
7 Conclusions, Evaluation, Recommendations

The goal of the research was to export the retrofit concept into the Northern European market of residential buildings and specifically to Germany as resulted to be the most potential country for the refurbishment concept. The study focused on exploring the design adaptability and flexibility of the 2ndSkin refurbishment project by applying the concept in a typical German residential building. Moreover, the design showed how it is possible to expand the 2ndSkin design and resulted in various façade compositions along with a catalogue with design concepts of different scale.

**Design evaluation**

**Is the 2ndSkin system flexible?**

The design process of the research has proved that the 2ndSkin design is flexible to be applied on a typical case study in Germany. Moreover, the design catalogue expanded the features that can be combined with the system and in the end improves the aesthetics, the functionality and the performance of the building.

**How the system affected the building?**

The application of the 2ndSkin refurbishment concept on the German building, offered various advantages that increased the value of the building. Specifically, the 2ndSkin system offered energy upgrade through the insulation panels, updated installations, ventilation system for better indoors climate and PV panels. Moreover, the façade composition including the window placement and the wooden cladding offered an improved appearance enhancing the character of the building.

Furthermore, the second part of the design was dedicated to the design of additional elements. The concepts proposed like the open/closed balcony, the
elevator, the sunshades and the ceramic cladding respond to different needs and expand the design flexibility of the 2ndSkin concept while improving the functionality of the building and satisfying the user.

The first design addition is the open/closed balcony concept that transforms the exterior balcony area of the east façade to interior space and at the same time introduces a steel self-supported structure for new balcony areas. By taking advantage the old balcony area, each apartment gains 6.4 m² of extra space that works as a buffer zone. That concept gives the opportunity to the users to expand the living room and improve their living conditions.

The second design concept includes the introduction of a new circulation system. It has been proposed new transparent staircases at the corners of the building and an elevator at the north-west corner of the building. The old staircase areas are transformed into sleeping rooms of 12m², adding extra space at two apartments of every floor. The new entrances at the apartments are accessible through an exterior passage system that also connects the two corner installations. The concept improves the living conditions as makes the building accessible for everyone and offers more space at the apartments. On the other hand, the design involves the installation of a steel structure system that occupies the full length of the façade and dominates the façade composition.

The third design concept concerns a sun shading system applied at the existing balconies of the east façade. The system includes three lightweight striped panels that slide on ranks and could cover the whole length of the balcony. The advantage of this structure is that they offer glare protection and light transmission at the same time. The three sunshades could gather at one place, thus minimizing the space they occupy. The disadvantage of this concept is that the lattices might block the view and annoy the users. The last design addition is the different cladding material. The cradle to cradle ceramic tiles
are lightweight, have high thermal performance and it is sustainable.

**How the building affected the system?**

The 2ndSkin system consists of 4 elements that have concerned the research, the wooden posts, the ventilation, the windows and the insulation panels. The cladding system could vary and create different façade compositions, thus it is not a limitation for the design. Specifically, the wooden posts placement is flexible enough as they can be in any location as long as they support the panels. The factor that affects the placement of the wooden posts is the window wall ratio. The limitation is that between two posts needs to be a panel unity that includes either windows or ventilation pipes. In both reference buildings there has been designed minimum spam of 1.20m and maximum of 5.20m.

On the other hand the ventilation system is an element that is not that flexible. The ventilation via the façade system, facilitates the rooms adjacent to the façade. The factors that affect the ventilation location are the floor plan and the window size and placement. The air inlet mechanism could be from the top of the windows (adequate for floor to ceiling windows) with minimum needed height of 180mm, as in case of the German building or from the bottom as in the Dutch case with minimum height of 350mm. The design is limited in case of rooms that are located in the center of the apartment.

The windows are the next important element of the system. The factors that affect the design and placement of the windows are the existing layout and the architect’s intention. Therefore, the window design is flexible and as proposed for the German case study can involve various window sizes like floor to ceiling windows.

The last important element of the 2ndSkin application is the insulation panels. The factors affecting their placement and design are the window wall ratio, the balcony, the slab projection and the roof. Particularly, if the balcony
construction is half loggia/half overhang like the building in Rotterdam, there is need for short panels applied at the slab of the balcony. On the other hand, if the balcony is incised then extra substructure needs to keep the balcony in line with the rest of the façade.

The window wall ratio along with the roof structure affects the panel shape and size, and generates a panel design variety that affects the prefabrication process. The parameter of the slab projection like the Dutch case determines the placement of the façade system. If the slab projection does not exist like the German building then the façade system has to leave minimum gap of 140mm of the existing structure for applying the panel including the pipes. After investigating both cases the minimum panel section is 68x220 mm, and the maximum size of the panel is 3.5x8 m in both directions.

**What is essential for future applications?**

For the future, similar porch apartments of the northern European market could be the next target of the 2ndSkin refurbishment design. Therefore, the aforementioned factors affecting the elements of the 2ndSkin application are significant for the design. Although, in order to apply the 2ndSkin design in other case studies, there are two factors that are the most essential ones and determined in the end the design. The first is the window size and placement regarding the existing layout and the design proposed for the building. That is because it affects the ventilation location which is the starting pointing for the 2ndSkin application.

The second essential factor of the 2ndSkin application is the balcony structure. Through this study there have been studied the incised and the half loggia/half overhang structures, which resulted in different designs. This factor in both cases demanded different treatment which determined the final design.
Arguments in favor and against the 2ndSkin system and the proposed design

The design offers many advantages at the building and increases its value. To begin with, the façade system applied improves the energy performance of the building. Moreover, the installations have been updated and there has been also introduced ventilation system that advances the living conditions of the occupants. The system presents fast and easy installation, it is sustainable and scalable. Even though the 2ndSkin system has been studied in only two reference buildings we conclude that it is very flexible to be applied in similar case studies.

Besides the flexibility and adaptability, that was the main focus of this research there has been proposed a design catalogue with design concepts that expand the basic 2ndSkin system and offer great advantages. The design concepts range from small to large scale, like the sun shading system or the elevator concept. They correspond to various needs of the occupants and propose efficient solutions. Concerning the façade composition, it has been proved through the design that the system is so flexible that can result in different façade compositions when adapting the wooden cladding, or applying ceramic tiles.

On the other hand, there are arguments against the system applied. The 2ndSkin design has been applied in two reference buildings, the one in the Netherlands and the other in the Germany. These building types are the most common ones and concern the majority of the residential buildings in both countries. Nonetheless, there are still other building types in Europe that seek for renovation. For example in Germany one other large residential group is the single-family houses, which present different characteristics for the design to deal with.
Additionally, looking at the design it has been resulted that the ventilation is not that flexible. Particularly, the ventilation through the window-façade system facilitates the rooms adjacent to the exterior wall, while in other buildings besides the porch apartments there could exist rooms located at the middle of the floor plan. Another disadvantage of the design is when there is no slab projection the width of the façade system is significantly large with linings of 0.50m. Thus, this might make the interior space darker or create an unpleasant volume under the window frames.

Last but not least, the study has not taken into account the cost. Thus, this factor could change the design that would satisfy the needs of the housing corporation. Especially, at the design catalogue the large scale concepts of the open/closed balcony and the elevator involved the application of many new elements that might be very costly or could not be fast to install. The budget could lead to different design suggestion than the one proposed of the study.

**Recommendations.**

Looking at the drawbacks of the design, we could suggest that the ventilation pipe could also be applied at the interior space and ventilate central rooms. In that way the ventilation system becomes more flexible. Furthermore, the pipe system could also incorporate water pipes and facilitate bathroom and kitchen, but it would be challenging to deal with the maintenance of the system. Another disadvantage of the system was the occasion when there was a short window, and thus the façade had large width (no slab projection case). In that case, we could suggest removing the façade parapet when it is not part of the load bearing structure.

The next step for the 2ndSKin project could be to export the design to other European markets. For instance, the 2ndSkin design could be applied on a residential building of Southern climates and deal the different demands. Moreover, if we are to remain in the Northern climates, there are more building
types to explore that seek for upgrade. The building type of single-family houses is one big group of the German residential stock that could be the next target of the project.

Additionally, the fact that the research did not take into account the cost maybe resulted in different design concepts. Thus, it would be advisable to include a business plan when dealing with the refurbishment scenario. All in all, we saw that the 2ndSkin design could be very flexible and adaptable to incorporate more building types and offers a great design variation of the façade composition. In conclusion, it would be beneficial to continue applying the 2ndSkin system in Europe and tackle the climate change by minimizing the CO₂ emissions of the construction.
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**Links**

http://webtool.building-typology.eu/#bm
http://www.one-stop-shop.org/
http://panel.hiveproject.eu/index.php
http://www.housingeurope.eu/resource-569/mapping-of-ousing-in-7-countries
http://www.enerdata.net/enerdatauk/
http://www.inspirefp7.eu/target-building-simulations/
http://www.buildingsdata.eu/country-factsheets
http://bpie.eu/national-initiatives/germany/
http://ec.europa.eu/energy/en/topics/energy-efficiency
http://www.iwu.de/home/
http://www.metsawood.com/global/Products/thermowood
http://www.archdaily.com/467679/via-cordillera-js-dmg-architects
http://www.archdaily.com/540787/lanserhof-tegernsee-ingenhoven-architects
http://www.mosa.com/nl-be/mosa/duurzaamheid/cradle-cradle/
Appendix A

![Figure 9.1- List of reference buildings by 2ndSkin project (source: 2ndSkinReport, 2015, p.10, 11)]
Figure 9.2 - List of reference buildings by 2ndSkin project (source: 2ndSkinReport, 2015, p.10, 11)

<table>
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<th>Baualtersklassen</th>
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<tr>
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<td>1,465</td>
</tr>
<tr>
<td>Anzahl Wohngesamtheiten in Tsd.</td>
<td>10,400</td>
<td>2,670</td>
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Figure 9.3 - Living space and frequencies of dwellings and residential buildings in the German building stock (source: Tabula, 2012, p.18)
Figure 9.4- German residential building type matrix (source: Tabula, 2012, p.14)
<table>
<thead>
<tr>
<th></th>
<th>National (still regional specific)</th>
<th>1969 ... 1973</th>
<th>High-rise Building (Hochhäuser)</th>
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<td>High-rise Building (Hochhäuser)</td>
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<td>1949 ... 1959</td>
<td>Generic (Basis-Typ)</td>
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<tr>
<td></td>
<td>Eastern Germany / former GDR (now Bundesländer)</td>
<td>1958 ... 1968</td>
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<td>Generic (Basis-Typ)</td>
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<td></td>
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<td>Generic (Basis-Typ)</td>
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<td>Eastern Germany / former GDR (now Bundesländer)</td>
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<td>1979 ... 1983</td>
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Figure 9.5 - German residential building type matrix (source: Tabula, 2012, p.15)
<table>
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<tr>
<th>element identification</th>
<th>code of the construction year group</th>
<th>short characterization of the construction type</th>
<th>short characterization of the construction type, national language</th>
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<th>detailed description, national language</th>
<th>picture</th>
<th>first year of period</th>
<th>last year of period</th>
<th>u-value (in W/m²K)</th>
<th>u-value (in m²K/W)</th>
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<tr>
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<td>DE.10</td>
<td>steel roof with 10 cm insulation</td>
<td>Dachdeck mit 10 cm Dämung</td>
<td>wooden rafters, 14 cm insulation, 4 cm insulation below, planter boards</td>
<td>Dämung 14 cm zwischen und 4 cm unter den Holzfiguren</td>
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<td>Sandwich-Element (Zwei-Schicht-Platte)</td>
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<td>1978</td>
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<td>Holzbalkenwand / Holzrahmenbau oder Leichtbeton-Fertigteil mit 6 cm Dämung</td>
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Figure 9.6 – Construction Element Catalogue (source: Tabula, 2012, p.75)
Figure 9.7 – Examples of typology of German residential stock (source: Tabula, 2012, p.86)
Figure 9.8 – residential building stock in Germany by age and typology (source: Inspire, 2014a, p.88)

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Figure 9.9 – Primary energy consumption (left) and CO2 emissions (right) of the German residential building stock for space heating and hot water (source: Tabula, 2012, p.55)
3D perspective of 2ndSkin application, West side
3D perspective of Design suggestion, East side