Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

RENOVATION CONCEPTS FOR RESIDENTIAL BUILDINGS

Research status, challenges and opportunities

ZEN REPORT No. 19 – 2020

Matthias Haase, Nicola Lolli and Kari Thunshelle | SINTEF Community

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Preface

Acknowledgements

This report has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The authors gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Caverion, Nord-Trøndelag Elektrisitetsverk - Energi, Smart Grid Services Cluster, Statkraft Varme, Energy Norway, Norsk Fjernvarme and AFRY.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, an NRK-site in Steinkjer, Ydalir in Elverum, Campus Evenstad, NyBy Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

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Norwegian Summary

Rehabilitering av boligblokker – en analyse av 39 EU prosjekter som konkluderer med utfordringer og muligheter

Innhold og struktur:

1. del: Innledning

Flerfamilieboliger som dateres til mellom 1945 og 1980 representerer mer enn halvparten av den europeiske bygningsmassen. Disse bygningene har det største energibehovet siden de bruker mellom 65% og 80% av det totale energiforbruket til EUs bygninger. På grunn av alderen krever de fleste av dem renovering eller oppgradering nå.

It clearly emerges from this analysis that finding the "composition" of the recipe of a successful deep renovation is a challenging task.

2. del: Hoveddel

Denne studien ser på utfordringene og mulighetene i markedet for energioppgradering med prefabrikkerte fasadeelementer. Det ble utført en analyse av 39 europeiske prosjekter, og resultatene ble strukturert i tre typer barrierer:

Tekniske barrierer

- (i) Mangel på konsistente og standardiserte løsninger eller integrerte løsninger for å oppfylle nye og ulike krav til byggestandarder for energieffektivisering
- (ii) Mangel på fagarbeidere for å kunne utføre arbeidet
- (iii) Mangler i tekniske løsninger, og lange prosesser som reduserer eiernes interesse
- (iv) Sikkerhets / seismisk risiko forbundet med (dype energi) renoveringsprosesser (skader kan påføres boligene under ettermontering eller det råder usikkerhet om dagens sikkerhet i eksisterende bygninger)
- (v) Sluttbrukernes og eiernes mangel på teknisk ekspertise og tillit til effekten av energibesparelsen (lønnsomheten)

Økonomiske barrierer

- (i) høye forskuddskostnader og eiere som er motvillige til å låne midler til energirenovering
- (ii) Lange tilbakebetalingstider for renovering/oppgradering
- (iii) Manglende tillit hos potensielle investorer
- (iv) Utilstrekkelig og ustabil tilgjengelighet på finansiering
- (v) Mangel på attraktiv finansiering for huseiere med lav til middels inntekt
- (vi) Eksisterende økonomiske verktøy er utilstrekkelige og lite attraktive

Sosiale barrierer

- (i) Beslutningsprosesser som er lange og komplekse, spesielt i tilfeller av flereierboliger (sameier)
- (ii) Mangel på konsensus, forståelse og støtte fra brukerne som ofte hindrer effektiv godkjenning av intervensjonene
- (iii) Problemer med forstyrrelser under byggearbeid og/eller flytting (i tilfelle eiere/brukere må forlate hjemmene sine under prosessen)

(iv) Lav bevissthet om energieffektivitet og ikke-energirelaterte fordeler ved renovering/oppgradering

(v) Mangel på dialog mellom de forskjellige interessentene

3. del: Mulig anvendelse av resultater, samt involverte ZEN-partnere

De resulterende mulighetene blir diskutert og gir informasjon til ulike interessenter i markedet for dypenergi-renovering med ferdige elementer.

1. Teknologier
2. Renoveringsprosessen
3. Finansielle mekanismer og insentiver

4. del: Konklusjon

En tydeligere definisjon av den ønskede energiytelsen til et nesten nullenerginivå i den europeiske lovgivningen ville støtte en bedre koordinert tilnærming fra nasjonale myndigheter. Som en konsekvens av dette, vil det utløses mer innovasjon på feltet og underbygge en teknologiledelse for Europa på feltet.

100 most frequent words in EU prefab project documents analysed (see table in Appendix A for list of projects)

Summary

This study looks at the challenges and opportunities in the deep energy renovation market with prefab elements. An analysis of 39 European projects was conducted, and the results where structured in three topics.

It clearly emerges from this analysis that finding the "composition" of the recipe of a successful deep renovation is a challenging task.

Technical barriers

(i) A lack of consistent and standardized solutions or integrated solutions to comply with new and different building standards requirements on energy saving
(ii) Lack of skilled workers to carry out the work
(iii) Shortcomings in technical solutions, and long processes discouraging owners
(iv) Safety/earthquake risk connected with the deep renovation processes (damages can be done to the homes while retrofitting or unsure perception of the current safety of the existing buildings)
(v) End users' and owners' lack of technical expertise and trust in effective energy renovation savings

Financial barriers

(i) high up-front costs and owners reluctant to borrow funds for energy renovation purposes
(ii) Long pay-back times of retrofitting interventions
(iii) Lack of confidence of the potential investors
(iv) Insufficient and instable available funding
(v) Lack of attractive financing for homeowners with low to medium incomes who are usually not eligible for regular bank loans
(vi) Existing financial tools are insufficient and unattractive

Social barriers

(i) Decision-making processes that are long and complex, especially in cases of multi-owner houses (condominiums)
(ii) The lack of consensus, understanding, and support from the users that often hinder the effective approval of the interventions
(iii) The problem of disturbance during site works and/or relocation (in case owners/users need to leave their homes during the process)
(iv) Low awareness about energy efficiency and non-energy benefits of renovation
(v) Lack of dialogue between the different stakeholders

The resulting opportunities are discussed and provide information for various stakeholders in the deep energy renovation market with prefab elements.

1. Technologies
2. Renovation process
3. Financial mechanism and incentives

A clearer definition of the desired energy performance of a nearly Zero-Energy Building in the European legislation would support a more coherent approach by national governments. In consequence, this would trigger more innovation in the field and support a technology leadership of Europe in the field.

Contents

1. Introduction

Buildings represent between 45 and 50% of the stationary energy consumption in Norway (BPIE 2011). This sector is therefore central to achieving long-term goals in energy and climate policy. In the energy and climate context, the building sector is often regarded as twofold: (i) new buildings and (ii) existing buildings. The energy demand in new buildings, especially the heating needs, has been significantly reduced during this period (EC 2017).

Existing buildings, on the other hand, represent a greater challenge. Buildings in general have a long life-span, so the energy performance of the existing building stock will often reflect building practices and quality in construction at the time of construction, which can lie many decades back in time. In addition, existing buildings may also have been subject to maintenance of varying scope and quality throughout their lifetime. It has been acknowledged that parts of existing building stock have, in part, very poor energy performance.

A key to improve the energy performance of these buildings lies in exploiting the opportunity that arises when these buildings are due for major renovation. Therefore, when the building owners invest in major renovation, it represents a "window of opportunity" with regard to measures that can improve the building's energy performance and overall quality. In this context, it is advantageous to consider the measures to be implemented from different perspectives:

- repairing the building,
- bringing it back to its original function and standard,
- combined with specific measures to increase the energy performance of the building.

This study analysed 39 European projects, their advances of technologies and improvement in renovation processes, highlighting the main findings and conclusions from 9 projects. In this way, the development of knowledge of the scope and the energy ambition of such measures that occurred during the last decade was reviewed and could be summarized.

The work is structured in the following sections:

- The **first section** provides the background by looking at the definitions of the key concepts, defining the scope of this work and explaining the methodology for the systematic mapping study.
- The **second section** lists the studied projects and focuses on the main findings and conclusions from nine projects.
- The **third section** identifies and classifies the main barriers of all studied EU projects that have addressed the main barriers of deep renovation.
- The **fourth section** looks at the opportunities by developing a number of important success factors in deep renovation projects.
- The **fifth section** summarizes the work done in this report highlighting the different aspects in deep renovation projects.
- The **sixth section** concludes with several unresolved matters that should be in focus in future initiatives and interdisciplinary projects.

1.1. Background

The potential for energy conservation in buildings is largely dominated by the existing stock. In most industrialized countries new buildings will only contribute with between 10% and 20% of additional energy consumption by 20150, whereas more than 80% of buildings' energy use will be due to the existing stock (and Figure 1).

- The 2012 Energy Efficiency Directive established a set of binding measures to help the EU reach a 20% energy efficiency target by 2020. Under the Directive, all the EU countries are required to use energy more efficiently at all stages of the energy-consumption chain, from production to final consumption.
- On 30 November 2016 the Commission proposed an update to the Energy Efficiency Directive (EED), including a new 30% energy efficiency target for 2030, and measures to update the Directive to make sure the new target is met.
- To achieve the policy goal in the EU, the yearly renovation rate of the EU building stock has to increase to 2.5-3%.The development of new business models and collaboration of Small and Medium Enterprises (SMEs) in a fragmented market is expected to result in an increase in home renovations.
- The market for Single Family House (SFH) energy renovations is still largely dominated by SMEs with limited competencies.
- Multi-family residential buildings that date between 1945 and 1980 represent more than half of the European building stock. These buildings have the largest energy demand since they use between 65% and 80% of the total energy consumption of the EU building stock. Given their age, most of them now require retrofitting or refurbishing intervention.

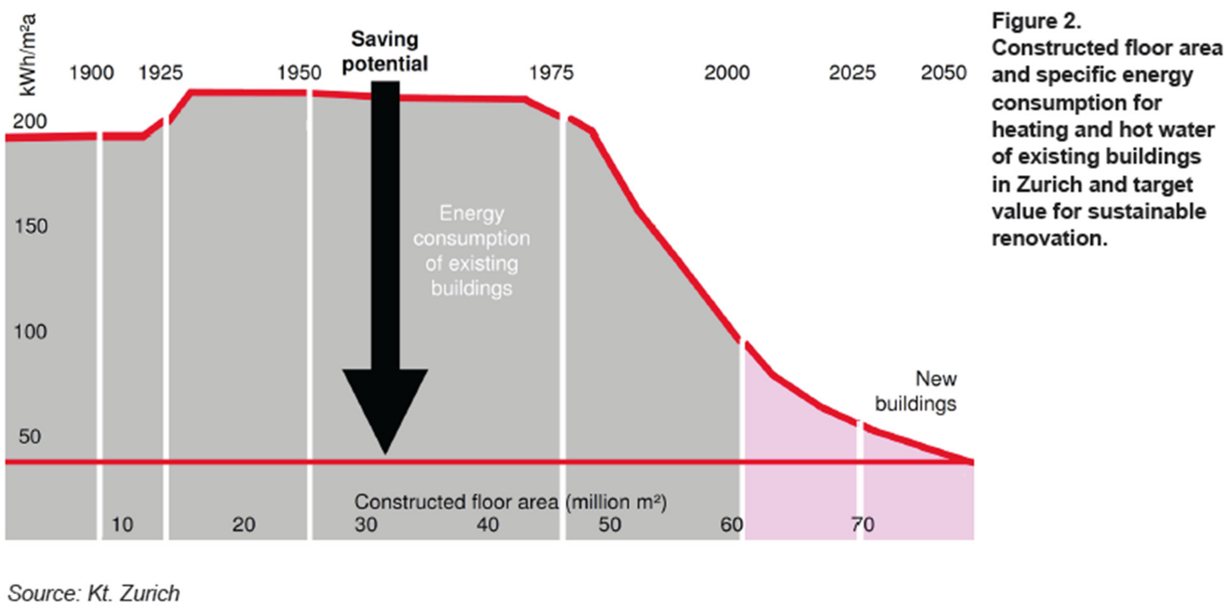

Figure 1: Construction work (in million m^2 floor area) and specific energy use (for heating and hot water) in Zurich (source IEA EBC Annex 50)

1.2. Definitions

nZEB (nearly zero energy buildings)

The latest revision of the EPBD (2018/844/EU) prescribes the Member States (MS) to take actions "to achieve a highly energy efficient and decarbonised building stock and to ensure that the long-term renovation strategies deliver the necessary progress towards the transformation of existing buildings into nearly zero-energy buildings, in particular by an increase in deep renovations". The definition of "nearly zero-energy building" for new constructions is given in the Directive 2010/31/EU[1], where "'nearly zero-energy building' means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby."

Although the EPBD defined a nearly zero energy building (nZEB), the Directive's definition leaves space for interpretation giving considerable possibilities to Member States to refine it. Member States (MS) are responsible to define in their national plans what constitutes an nZEB while considering the feasibility of implementing such a concept in their national contexts.

These definitions were expected to be included in the MS National Energy Efficiency Action Plans, and some more detailed definitions were proposed by the Commission in 2015 (the so-called "winter package") which looks at improving energy performance in buildings, binding targets for renewable energy sources, putting energy efficiency first, including a robust governance system for the energy union, seeking to establish a modern design for the EU electricity market, including respective adoption documents and non-legislative initiatives (EC, 2015).

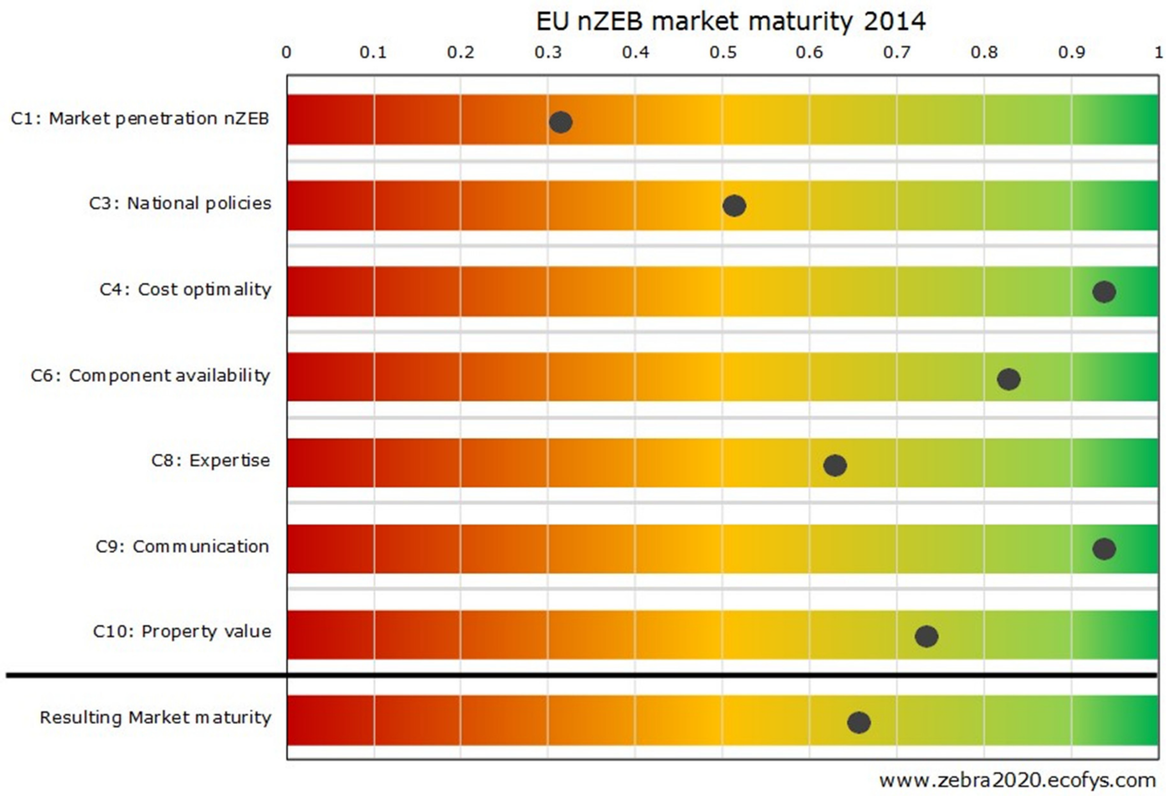

Figure 2: Market maturity of nZEB solutions (source: ZEBRA2020)

[1] https://eur-lex.europa.eu.

BPIE summarises in a comprehensive factsheet the current status of different approaches and indicators used by the EU MS (and Norway) for the nZEB definition of new and existing buildings (BPIE 2017). It highlights the link between the establishment of a definition and its gradual implementation and promotion in the market (see Figure 2). The findings show that the levels of ambition in defining an nZEB vary across the board. In 2015, a definition is available in 15 countries (plus Brussels Capital Region and Flanders). In three countries, the nZEB requirements have been defined and are expected to be implemented in the national legislation.

Deep Renovation

The Energy Efficiency Directive 2012/27/EU (EED) introduced the concept of deep renovation as a "refurbishment that reduces both the delivered and the final energy consumption of a building by a significant percentage compared with the pre-renovation levels, leading to a very high energy performance". Implementing a deep energy renovation means adopting an integrative approach at the whole building level, allowing for a more cost-effective process and for a higher energy savings in comparison to the adoption of separate energy retrofit measures (Simona et al., 2017; Glumac et al. 2013). Although the EU Directives (EED and EPBD) do not provide a quantitative definition of a deep renovation, it is possible to link the concept to the major renovation, introduced by the EPBD 2010/31/EU (Semprini et al. 2017) as a set of interventions fulfilling one of the following conditions:

1. either more than 25% of the surface of the building envelope undergoes renovation
2. or the total cost of the renovation of the building envelope or the technical building systems is higher than 25% of the overall value of the building (Majcen et al. 2015; D'Agostino et al. 2017).

The EED does not provide a quantitative energy saving target for deep renovation, but has stated that it represents a solution which is able to reduce both the delivered and final energy consumption of a building by a significant percentage compared with pre-renovation levels (DG-IP 2016).

Article 4 (of EED) requires Member States to set out national strategies for the renovation of their building stocks, thereby filling a major policy gap concerning the existing building stock.
This strategy shall include:

(a) an overview of the national building stock based, as appropriate, on statistical sampling;
(b) identification of cost-effective approaches to renovations relevant to the building type and climatic zone;
(c) policies and measures to stimulate cost-effective deep renovations of buildings, including staged deep renovations;
(d) a forward-looking perspective to guide investment decisions of individuals, the construction industry and financial institutions;
(e) an evidence-based estimate of expected energy savings and wider benefits.

This is still an ongoing process which is closely monitored. BPIE analysed 10 Long-term renovation strategies of different countries (Austria, Belgium (Brussels Capital Region), Czech Republic, Denmark, France, Germany, Netherlands, Romania, Spain and UK) (BPIE 2014). To achieve the required long-term transformation of the existing building stock the report concludes that benefits need to be quantified better, not only in terms of energy, carbon and cost savings, but also in terms of economic impact, societal benefits and environmental improvements. In this report the policy&regulatory aspects are not in focus.

Prefabrication (prefab)

Prefabrication describes the production of modules in a controlled environment like a factory. The prefabricated modules can then be transported to the construction site and installed in a relatively short period of time.

Definition

"*Rehabilitering*" av bygning innebærer en utbedring hvor det tas sikte på å istandsette til opprinnelig standard eller funksjonalitet. Til forskjell fra "oppussing", som er mer overflatiske tiltak, vil rehabilitering typisk omfatte delriving og bygging. Rehabilitering innebærer ingen vesentlig bedring i energiytelse ut over den effekt som nye og bedre materialer eller komponenter måtte ha.

"Totalrehabilitering" er en rehabilitering som omfatter mer enn 25 % av bygningens klimaskall (eller har kostnad på mer enn 25 % av bygningens verdi). Dette er hva EPBD refererer til som "**major renovation**". Begrepet "**renovation**", slik det brukes i direktivet, tilsvarer vårt norske rehabilitering.

Dersom en rehabilitering også innebærer en vesentlig forbedring i bygningens generelle funksjon eller ytelse, betegnes dette som en "oppgradering". Mer spesifikt, en vesentlig forbedring i bygningens energiytelse kalles en "energioppgradering".

En "*renovering*" innebærer bygningsmessige tiltak i et så stort omfang at bygningen framstår som ny. Plan- og bygningsloven opererer med begrepet "hovedombygging", forstått som tiltak som er så omfattende at hele byggverket i det vesentlige blir fornyet. Renovering og hovedombygging kan derfor betraktes som synonymer. Tekniske krav til nybygg er gjeldende ved renovering/ hovedombygging.

Det tredje sentrale begrepet, "*restaurering*", innebærer tiltak med tanke på en hel eller delvis tilbakeføring av en bygning eller gjenstand til en tidligere tilstand for å ivareta antikvarisk verdi eller arkitektonisk kvalitet. Her skal materialer og utførelse tilsvarende de originale søkes brukt.

Restaurering av bygninger er en viktig del av forvaltningen av Kulturminneloven.

De engelske begrepene "**rehabilitation**", "**renovation**" og "**restoration**" har en betydning som tilsvarer de norske begrepene beskrevet her. Innen EUs byggfaglige miljøer, og i policydokumenter, er det imidlertid også mange andre begreper som brukes for å beskrive tiltak på bygg. Det erkjennes i disse miljøene at begrepsbruken er uklar.

Textbox 1: From Enova-rapport 2015:10 Rehabilitering og energioppgradering av boliger. Drøfting av begreper og måling av omfang. (in Norwegian)

1.3. Objective of the work

This report highlights, through a literature reviews of past and ongoing funded European projects, the main barriers, obstacles, and opportunities that occur and emerge in the energy renovation market of residential buildings. Specifically, this report tries to find answers to the following questions:

- What are the main barriers to deep renovation?
- Which are the innovative technological solutions to overcome the obstacles in the energy renovation market?
- Which opportunities emerge from this?

1.4. Methodology for the systematic mapping study

The present study is based on a systematic mapping study designed to carry out an objective selection of literature sources relevant to the topic in question. Petersen et al. (2008) described how to conduct a systematic mapping study in connection with software engineering, and their proposed framework has since been implemented in other fields (Haase et al., 2019; Labonnote and Høyland, 2015). The same methodology was used in the present study. However, since the focus was put on EU funded projects, a focus was put on collecting EU project reports from various sources.

In this report, relevant (FP7, H2020) funded projects (2008–2020) have been revised. The review focuses on projects that deal with state-of-the-art solutions for deep renovations, including advanced technologies (and prefabricated systems) and systematic renovation strategies, and smart services used during the design, execution, and maintenance phases of the retrofit process. First, all important aspects of the related processes were systematically mapped, then relevant projects were identified. A list of nine projects with different Technology Readiness Level (TRL) were selected and relevant sources (internet and project reports) were used to describe the main findings and conclusions. Finally, the results of the analysis are presented in form of challenges and opportunities for the important energy renovation market. Conclusions summarize the findings and give concise recommendations for future work.

Search overview

The EU project database was systematically screened for projects that focus on the energy efficient renovation of buildings, following Boolean operators to refine the search process in terms of action description ("how") and object ("what"), and corresponds to the keywords set out in Table 1.

The search was performed on 7th November 2019 and produced the following keywords and classification.

- **Keywords**

The 39 projects gave access to 501 documents which were then subjected to keywording and classification based on their full text content. The keywording was performed in two steps:

- Firstly, abstracts were read in order to identify keywords and concepts that reflect the contribution of the publication in question.
- Secondly, all identified keywords were combined in order to develop a high-level understanding of the field of prefabricated façade systems as it applies to the construction industry.

Table 2 provides an overview of the main categories identified and their sub-levels and summarizes the specifications of each aspect. Note that governmental aspects were not included in the analysis.

- **Classification**

The classification scheme used here reflects the objectives set out in Section 1.3 (see Figure 3).

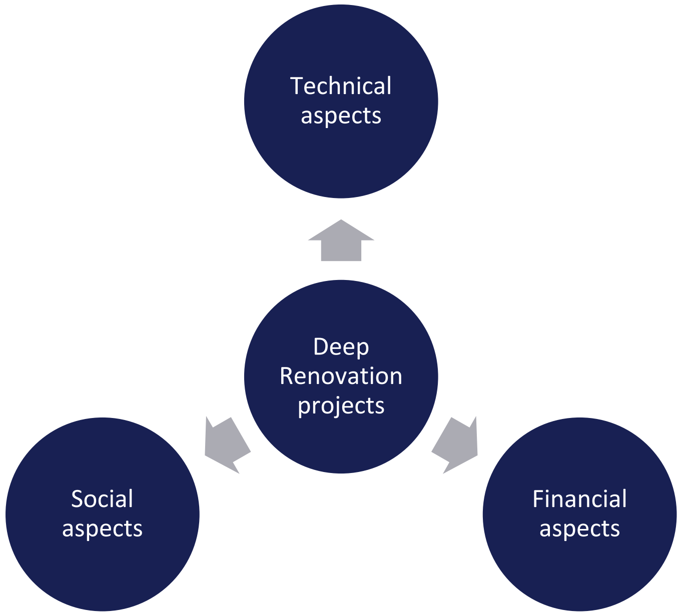

Figure 3. Classification of considered aspects of retrofitting projects

Each publication was mapped into the relevant categories using both manual and automated methods, including text queries. All the results were then reviewed manually in order to ensure consistency and to remove “false” or biased occurrences.

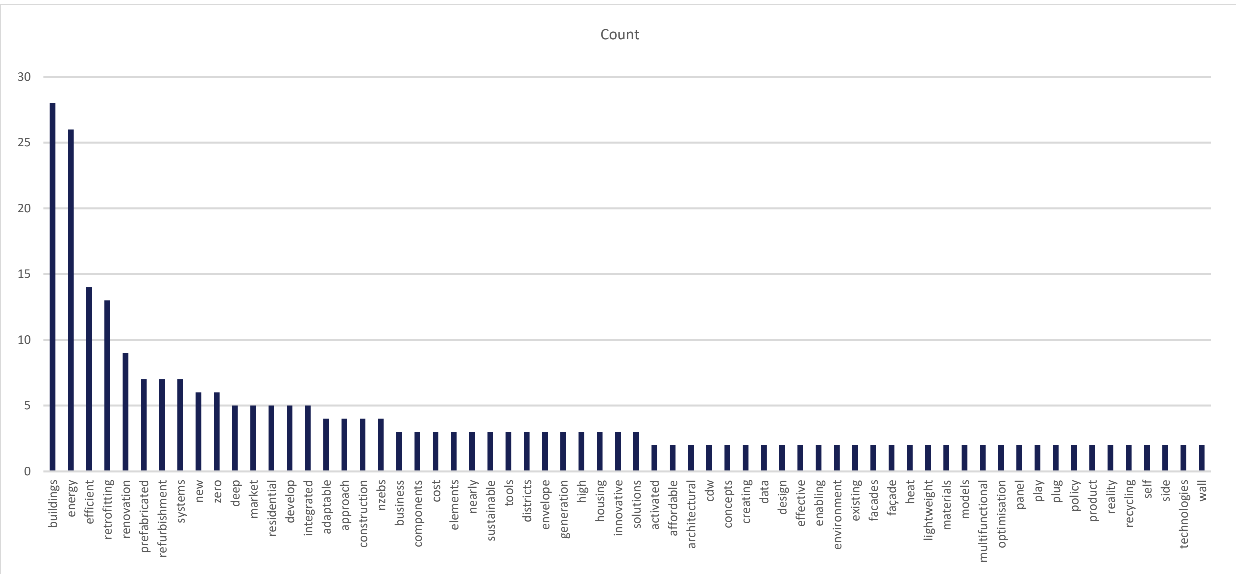

Figure 4: Count of keywords from 39 projects (minimum two counts)

Figure 4 shows the 64 words that were used in list of keywords at least two times. 33 words of those were used more than two times (three times or more), 19 keywords were mentioned more than 3 times (four times or more), 15 keywords were mentioned more than four times (five times or more), 10 keywords were mentioned more than five times (six times or more), eight keywords were mentioned more than six times (seven times or more). The four keywords with multiple mentions are listed in table 1 below. **Error! Reference source not found.** illustrates the used keywords by a word-cloud.

Table 1: The four keywords with most multiple mentions

keyword	Number of mentions
buildings	28
energy	26
efficient	14
retrofitting	13
renovation	9

Table 2: The different aspects and specifications in deep renovation projects (Note that governmental aspects were not considered further)

technologies	financial	social	governmental
Prefabrication	Financial aspects	Education	Preferential loans
BMS-ICT	Investment	Confidence (in construction professionals)	Tax incentives
Renewable Energy Supply RES	Return of investment	Consumer acceptance	Energy taxation
BIM BPSM	Funding schemes	Knowledge of available solutions and customizability	Energy Efficiency Obligation Schemes (EEOSs)
Multi-Benefit	Grants	Disruption	Energy Performance certification
HVAC	Subsidies	Decision-making process	Energy labelling schemes
Advanced Geomatics			
3D Print			
Smart Connector			

2. Technology Readiness Level development

For this report nine projects were studied in more detail. Table 3 provides an overview of the reviewed projects and the relevant url that were used to collect the information. From all the relevant EU projects in which SINTEF was partner, the following where chosen because they focus on different aspects of renovation. From each project, the objectives, main findings and conclusions are reported.

Table 3: Projects with duration and URL

Project name	URL	Duration
IEA EBC Annex 44	https://www.civil.aau.dk/Project+websites/integrated-building-concepts/	2004-2008
IEA EBC Annex 50	https://www.iea-ebc.org/projects/project?AnnexID=50	2006-2011
SUSREF	https://cordis.europa.eu/project/rcn/92302/factsheet/en	2009-2012
PROFICIENT	http://www.proficient-project.eu/	2012-2016
COHERENO	https://ec.europa.eu/energy/intelligent/projects/en/projects/cohereno	2012-2017
RETROKIT	https://cordis.europa.eu/project/rcn/104534/factsheet/en	2013-2016
ZEBRA2020	https://zebra2020.eu/	2016-2019
4RinEU	http://4rineu.eu/	2016-2020
RezBuild	https://rezbuildproject.eu	2017-2021

Given the chronological order that dictated the development of the different projects, it is clear that the results of preceding projects were used and implemented in the development of the following ones. In such a perspective, the IEA EBC Annex 44 on Integrating Environmentally Responsive Elements in Buildings was the first international project that focused on the integration of technologies, followed by Annex 50, which focused on prefabricated systems for the residential building sector. This was followed by the first EU project SUSREF (2009-2012), while the others started later (2011 until 2016). (see Figure 5).

Definition

"Annex44 *focuses on technologies that promote the integration of active building elements and communication among building services. In this perspective **Whole Building Concepts** are defined as solutions where reactive building elements together with service functions are integrated into one system to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality. **Reactive Building Elements** are defined as building construction elements which are actively used for transfer of heat, light, water and air. This means that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and energy storage. The development, application and implementation of reactive building elements are considered to be a necessary step towards further energy efficiency improvements in the built environment.*"

Textbox 2: The scope of IEA EBC Annex 44 (ANNEX44).

The following projects are highlighted in this report:

SUSREF, which developed technologies and methodologies for sustainable refurbishment of external walls.
PROFICIENT, which aimed at developing new business models for SMEs implementing energy efficient housing construction or retrofitting in a special housing sector, that of Collective Self Organised Housing (CSO).
COHERENO, which developed proposals and concepts for promising cross-sector and company business models for high efficiency refurbishment of single-family houses to nearly zero-energy housing.
RETROKIT, which developed and demonstrated multifunctional, modular, low cost and easy to install prefabricated modules in order to significantly increase the EU retrofitting rate and contribute to EU energy reduction commitments. RETROKIT's vision was to develop and demonstrate multifunctional, modular, low cost and easy to install prefabricated modules by addressing social, technological, industrial and economic barriers in order to increase the EU retrofitting rate and contribute to EU energy reduction commitments.
ZEBRA2020, which monitored the nZEB market transition and found that a significant share of nZEB definitions does not meet the intention of the EU directive on energy efficient buildings (EPBD). Thus, a recast EPBD was proposed and ambitious policy scenarios of the nZEB market transition by 2020, 2030 and 2050 were developed (Based on collected data).
4RinEU, which will answer to typical challenges in renovation, providing new tools and strategies to encourage large scale renovation of existing buildings, fostering the use of renewable energies, and providing reliable business models to support their applications.
RezBuild, which mainly aims at creating a collaborative refurbishment ecosystem focused on the existing residential building stock. Both projects are still in progress so that conclusions can be expected 2020.

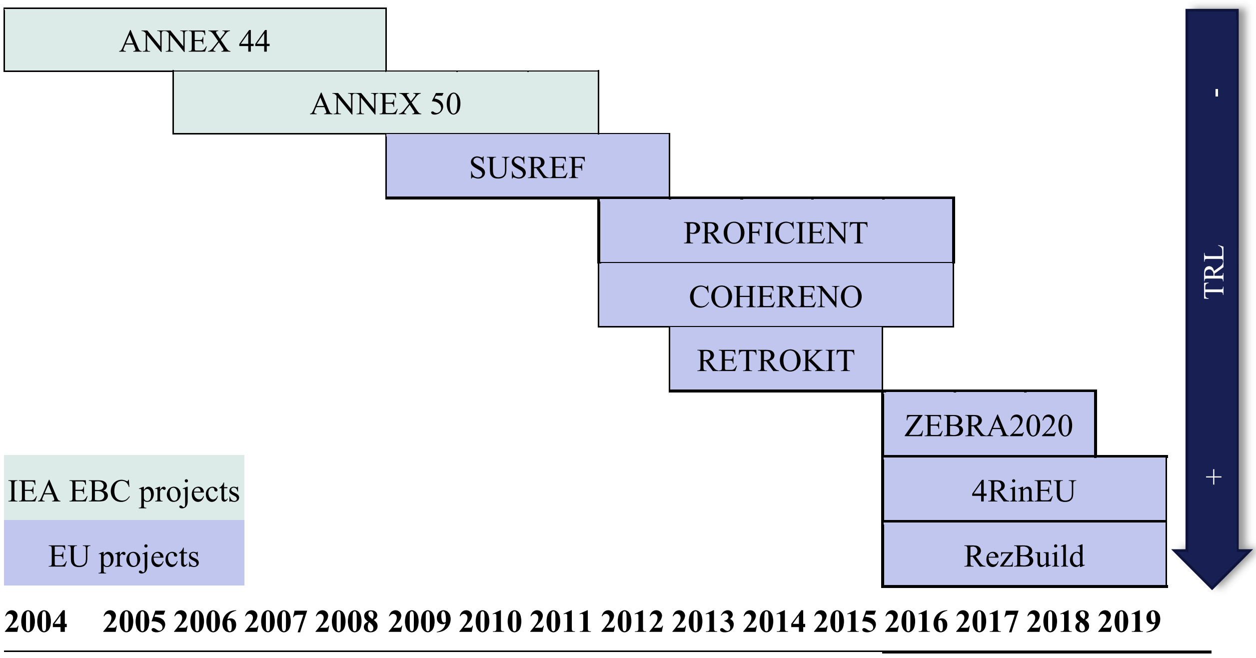

Figure 5: Timeline of the projects, illustrating development and how each project builds upon the previous one.

2.1. Projects under the umbrella of the International Energy Agency

There were mainly two projects from the International Energy Agency's Technology Platform on Energy in Buildings and Communities programme that are relevant: Annex44, which ran from 2004 until 2008, and Annex50, which started in 2006 and was completed in 2011.

IEA EBC Annex 44 Integrating Environmentally Responsive Elements in Buildings
Significant efficiency improvements have been made in building elements. However, the greatest future potential lies with technologies that promote the integration of active building elements and communication among building services. The development, application and implementation of reactive building elements was considered to be a necessary step towards further energy efficiency improvements in the built environment.
In this perspective Annex 44 defined the Whole Building Concepts as solutions where reactive building elements together with service functions are integrated into one system to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loads and indoor environmental quality. Reactive Building Elements were defined as building construction elements which are actively used for transfer of heat, light, water and air. This means that construction elements (floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and energy storage.

With the integration of reactive building elements and building services, building design completely changes from design of individual systems to integrated design of "whole building concepts, augmented by "intelligent" systems and equipment. Enabling technologies such as sensors, controls and information systems are needed to allow the integration. Design strategies should allow for optimal use of natural energy strategies (daylighting, natural ventilation, passive cooling, etc.) as well as integration of renewable energy devices.

Annex44 addressed the following objectives:

- Define state-of-the-art of reactive building elements
- Improve and optimise reactive building elements and technologies
- Develop and optimise new building concepts with integration of reactive building elements, building services as well as natural and renewable energy strategies
- Develop tools for the early assessment of the impact of reactive building elements on the environmental performance of buildings
- Develop guidelines for procedures and tools for detailed simulation of environmental performance of reactive building elements and integrated building concepts

There were four areas of research:

- Reactive Building Elements
- Integration in Building Concepts
- Design Tools and Environments Performance Assessment
- Implementation

Main findings

The main driving force for responsive building elements and integrated building concepts is the growing need and awareness for energy savings in the built environment together with increasing requirements for better health and indoor air quality in buildings.

Today, the construction industry is in the early phases of a revolution to reinvent the design process that was used before the introduction of HVAC equipment. Increasingly the awareness arises that the design process needs to be an integrated and joint effort between architects and engineers. However, several barriers appear when the borderline between architecture and engineering is crossed; the design process contains a lot of challenges to those who participate in the process. The main barriers for arriving at an integrated design process are the lack of knowledge, information and guidelines, successful examples and expertise. These barriers can hopefully be reduced by the deliverables of Annex44.

Lessons learned

Integration of responsive building elements with building services and energy systems in responsive building concepts have a number of important advantages:

- Integration of responsive building elements with energy systems will lead to substantial improvement in environmental and operating cost performance.
- It enhances the use and exploits the quality of energy sources (exergy) and stimulates the use of renewable and low valued energy sources (like waste heat, ambient heat, residual heat etc.).
- It will further enable and enhance the possibilities of passive and active storage of energy (buffering).
- It will integrate architectural principles into energy efficient building concepts (Figure 6).
- Responsive building elements lead to a better tuning of available technologies in relation to the building users and their behaviour.
- It enhances the development of new technologies and elements in which multiple functions are combined in the same building element.
- It will lead to a better understanding of integrated design principles among architects and engineers.

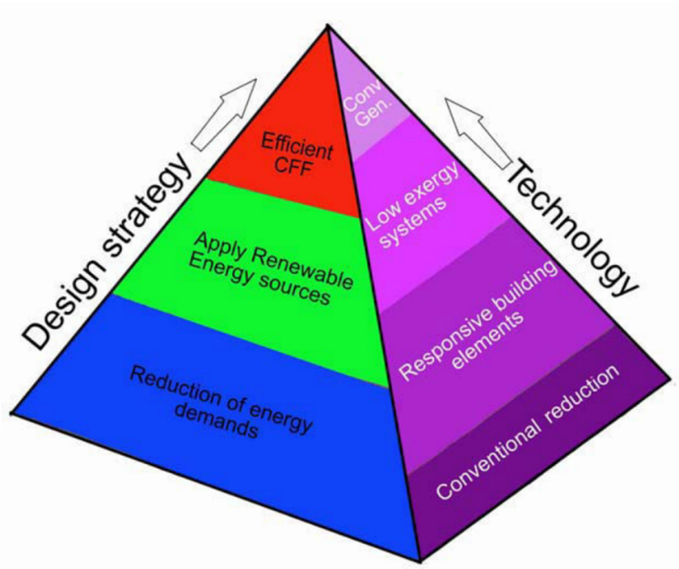

Figure 6: Design with RBEs (ANNEX44)

IEA EBC Annex 50: Prefab Systems for Low Energy/High Comfort Building Renewal

Five work programs were compiled by the applicants in cooperation with professionals from the Implementing Agreements Energy in Buildings and Communities, Solar Heating and Cooling, Photovoltaics, and the Heat Pump Programme (EBC, SHC, PV, and HPP) to reach their goals. The emphasis was put on the following aspects:

- Specification of holistic and integral retrofit concepts
- New development of prefabricated roof and façade solutions
- Complete integration of the energy distribution system with prefabricated components
- Integration of solar thermal systems in roof and façade elements
- Implementation of prototypes in demonstration projects
- Accompanying know-how transfer on national level

Main findings

- Extensive cataloguing of the different building types and the development of solution possibilities for prefabricated facade and roof elements.
- Planning tools for the development and planning of large size, prefabricated modules (e.g. 10-steps) were devised.
- A module documentation of the procedure of the development
- Development of a software called „Retrofit Advisor ", to carry out an economic efficiency analysis in early stage of the high-quality retrofit.
- Elaboration and development of holistic integral renovation concepts for typical multi-family buildings
- Monitoring, to enable important conclusions for future projects
- Dissemination (national and international), to allow effective intercommunication and knowhow transfer.

Lessons learned

Energy reduction measures are often not economically attractive by themselves. They have to be combined with measures that also create added value. A comprehensive renewal is an opportunity for measures that not only repair a building, but also improve it for future generations. They allow – if needed – improvements to the architecture and layout.

Fully integrated façade and roof modules have been developed in collaboration with European construction companies. The highly standardised modules consist of lightweight constructions, which can be prefabricated to any size by construction companies and mounted in collaboration with local contractors. These modules still allow flexibility and guarantee dimensionally correct application, excellent thermal insulation and fire protection according to individual national standards. Façade modules were developed in Austria, France, Portugal, and Switzerland. The solutions reflect the different national requirements relating to the building stock, the local climate, and the preferences of the construction industry. These are documented in the "Retrofit Module Design Guide".

Special 3D laser scanning technologies and photogrammetry were applied to precisely measure the existing building envelope to guarantee that the renovation modules would finally fit the existing building.

Laser scanning was used to all sides of the building which allows accurate surface mapping of the building and results an accurate representation of the building shape. Detailed measurements, irregularities and distortions of the building façades can be analysed and visualized by computer. The detailed data sets are then available for planning, accurate production of the prefabricated elements and for mounting of the modules.

Photogrammetry is most effective with buildings with facades characterized by mostly planar surfaces. It is much simpler to apply than laser scanning. The building can be photographed with a good digital camera and the pictures are completed with reference measurements. Special computer programs derive the geometry of the building surfaces based on the different points of views of the pictures, from which 3D measurements can be then taken.

Existing roofs may be completely removed and replaced by prefabricated roof modules. This allows optimised space use and the integration of modern technologies such as solar panels, mechanical ventilation, and so on. This opportunity is often used to create new and attractive attic apartments.

The establishment of building typologies is important for the development of standardised façade and roof modules with a large application potential. Special attention was given to building physics, fire protection and logistics. The work resulted in the development of four different renovation modules which were also demonstrated at six demonstration sites. The goal of an energy consumption of 30 to 50 kWh/m^2 per year for heating and domestic hot water was easily achieved. Solar installations on most of the buildings are further reducing the energy consumption to close to zero. The demonstration projects and case studies are documented in "Building Renovation Case Studies".

The development of an optimal renovation strategy is also important. For this purpose, the "Retrofit Advisor" was developed which allows evaluation and comparison of the economic, environmental and social impact of the existing situation, along with those different renovation strategies (see Figure 7).

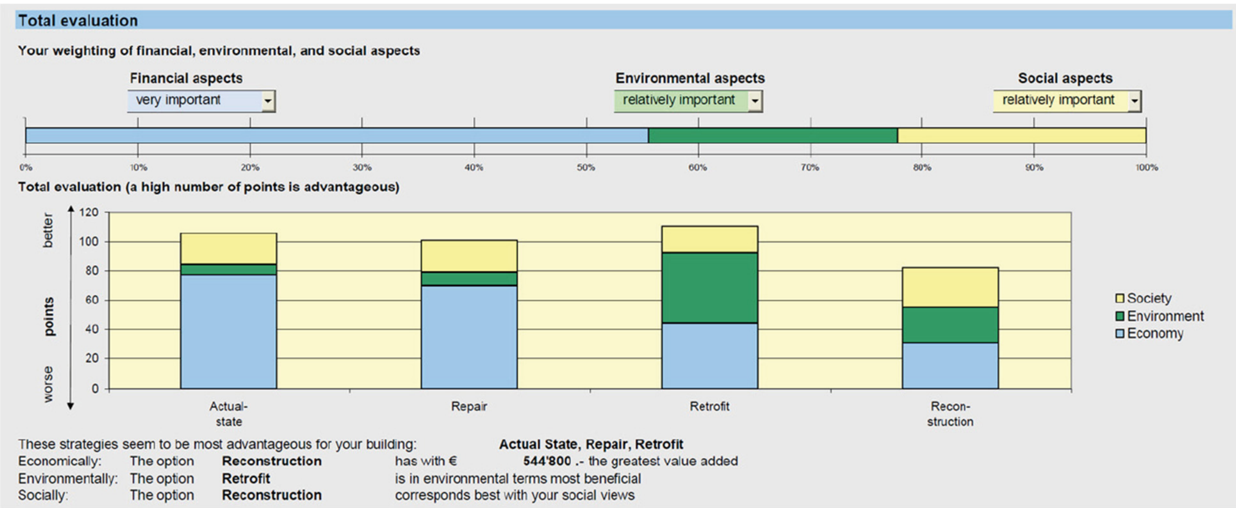

Figure 7: Screenshot of the "Retrofit Advisor" developed in the project (Annex 50)

2.2. SUSREF – Sustainable refurbishment of building facades and external walls

This project developed technologies and methodologies for sustainable refurbishment of external walls. SUSREF was based on the premise that:

- Refurbishment of external walls is one of the most efficient ways of reducing environmental impacts of European building stock;
- European building sector is facing huge needs of renovation; refurbishment of external walls is among the most urgent tasks;
- Although there are technological solutions, the risks and optimal solutions are not fully understood;
- External walls have an extensive effect on building performance and several aspects have to be taken into account when developing new concepts.
- Urgent needs of refurbishment are not only faced in the EU but also in neighbouring areas; development of functional and environmentally efficient technologies would support the European industry to export projects and the neighbouring areas to adopt sustainable technologies.

The objective of the project was to:

- Identify the needs to refurbish building envelops in the EU to understand the significance in terms of environmental and economic impacts;
- Develop a systemized method to manage the functional performance of solutions;
- Develop sustainable product concepts;
- Disseminate results for building industry, standardisation bodies, and policymakers in terms of technological knowledge, guidelines and recommendations.

Main findings

SUSREF assessed the potential savings in energy and costs with the help of scenarios for the refurbishment of external walls. The total investment cost was assessed to be 28000 million euro/year directed for the energy related refurbishment. On the other hand, the savings in energy costs were assessed to be 2500 million euro/year. The difference in annual Life Cycle Cost is on average 11 000 million euro within 20 years. In addition, it was assessed that the corresponding increase of labour would be 396000 man-years/year. The estimated potential CO_2 savings is 72 Mt/y.

Lessons learned

It was defined that the overall sustainability of the developed concepts and technological solutions of the project has to be assessed considering the following aspects:

- Durability and buildability,
- Impact on energy demand for heating and cooling,
- Impact on renewable energy use potential and on daylight,
- Environmental impact of manufacture and maintenance,
- Indoor air quality and acoustics,
- Structural stability and fire safety,
- Aesthetic quality and effect on cultural heritage,
- Life cycle costs and need for care and maintenance,
- Disturbance to the tenants and to the site.

2.3. PROFICIENT

This 7th framework project of the European Commission was not primarily focusing on renovation but aimed at developing new business models for SMEs implementing energy efficient housing construction or retrofitting in a special housing sector, that of Collective Self Organised Housing (CSO).
Among others, SINTEF was responsible for developing an analysis matrix for assessing the potential CO2 and energy savings from the implementation of different energy efficiency strategies. LCA calculations were included in the analysis.
Different business models and retrofitting methods have been applied throughout Europe, in order to improve the quality of the houses, improve energy efficiency, and involve residents in the organization and planning of the future of their houses.
End-users might be supported better if they are provided with good guidance materials and if they are informed upfront of the process flow, potential difficulties, and experience from other projects.
It should be clear and realistic what to expect, in order to avoid disappointments along the process or at the end. This is exactly where the role of supply-oriented business partners comes in.
With the right experience and cooperation, they can organize the best solutions for the end-users, mediating between the professional organized authorities on one hand, and the non-professional end-users on the other hand.

Main findings

The work in the project is structured according to the needs and offers of three main stakeholders in a CSO process: end users, SMEs and municipalities (Figure 8). The Proficient team has developed a web-based ‘CSO housing platform’ offering information and tools for each of these three stakeholders. A graphical image of the different stakeholders, and tools and information offered, is shown in Figure 8.

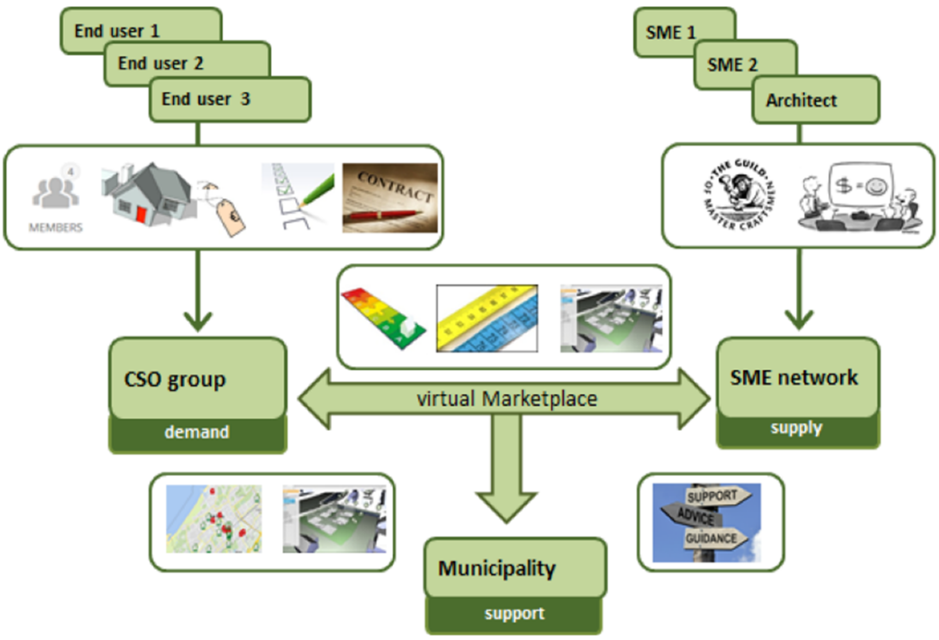

Figure 8: Graphical summary of the Proficient project

The three main stakeholders are:

1) End users, which we assume to have organised themselves into a CSO (Collective Self Organised) group. With their desire to build or renovate a building, they represent the demand side of a virtual marketplace. For this stakeholder, several tools were developed, such as organisational instruments (social media forum), a tool offering a first calculation of Total Cost of Ownership (TCO) of their building, checklists of requirements, and financial and regulatory information.
2) A number of SMEs, that may include an architect or process facilitator, but that also include SMEs like brick layers, carpenters, and installers, that have organised themselves into an SME network like a guild. With their ability to construct or renovate buildings, they represent the supply side of the virtual marketplace. As a group with all required expertise, the SME network offers an alternative to large construction firms that do not have the flexibility to satisfy the specific needs of a CSO group. For this stakeholder, the CSO housing platform offers an organisational platform as well as a number of organisational models, tailored to the needs of CSO. In addition, an optimised business model for CSO housing was developed, but details are not offered on the CSO housing platform due to its proprietary nature.
3) A landowner or building owner, often a municipality, promotes and supports the implementation of energy efficiency measures in buildings by offering a plot of land or a building to renovate.

The three stakeholders can meet in a virtual marketplace, where demand and supply can be matched. To facilitate a successful interaction between the stakeholders, the platform offers a number of functionalities, of which the main one is the Configurator, where municipalities can offer plots of land, onto which end users and architects can upload designs of dwellings. They can then assess the look of all dwellings on the plot in the actual environment (taken from GIS-Geographic Information System data). In addition, an Energy efficient Buildings Benchmarking tool, such as the analysis matrix, is downloadable, and an Energy optimiser tool is available to generate an optimal package of energy efficiency measures, e.g. using the IFC output file from a CAD design.
The CSO platform can be found at http://cso.house/. More information on the project can be found on the project website http://www.proficient-project.eu/.

Lessons learned
The description of the results demonstrates that the objectives set out at the beginning were reached. The results generated in the course of the project are very useful to stakeholders in a CSO housing process, in particular end users and SMEs. They were well disseminated to relevant stakeholders, including academia and the general public, in various ways. Several results are taken up for further commercial exploitation by the partners:

- The "Friends" CSO housing franchise concept will continue development, but progress depends on co-financing support by the building supply industry.
- The Energy Performance Calculation & Assessment Tool will be integrated as an autonomous module into the existing RE Suite for Real Estate Asset Management offered by DEMO.
- Transfer of the CSO housing platform is planned to third parties that are interested in the continuation of (parts of) its development, in particular the Municipalities of Rotterdam and The Hague.
- The Total Cost of Ownership (TCO) tool will be further developed by TNO and exploited as part of a set of fee-based BIM bots.

- The configurator will be further developed for the municipality of The Hague, iBuildGreen and other potential clients. Simultaneously, discussions are ongoing with third party software developers for the role of end user support. Components of the configurator and the BIM-interface will be integrated in the RE Suite.

2.4. COHERENO - COllaboration for HOusing Nearly Zero-Energy RENOvation

The IEE-funded project Collaboration for Housing Nearly Zero-Energy Renovation (COHERENO) aimed to assist in creating a volume market, specifically for single-family owner-occupied houses. The five participating countries include Austria, Belgium, Germany, Norway and the Netherlands. The main objective of COHERENO was to strengthen the collaboration of enterprises in innovative business schemes to develop NZEB renovation in owner-occupied single-family homes.
The project shows how existing barriers to effective cooperation can be eliminated and better services for different customer segments can be developed. While technological solutions for NZEB renovation are available at a demonstration level, there is a lack of supply-chain collaboration models. Better communication and awareness of each other's activities is one of the central ideas in promoting better collaboration between different service providers. Therefore, during the early stages of the project, experienced market players in participating countries and their roles within the renovation chain were mapped.
The models were to pave the way for refurbishment from a single source. From financing, consulting and planning, right through to implementation – all parties in the construction process are involved.
A major goal of COHERENO was to improve the quality of the construction measures by providing specific support to all stakeholders, thus increasing customer confidence.
With these two key aspects, nearly zero-energy houses can gain credibility and acceptance, and win a higher market share. It presented a way to better understand the usefulness of the business model as a market device for collaborating firms for realizing home energy renovations, by analyzing literature and action research observations (Figure 9). Joint innovation decisions during business model development were traced back for 24 groups emerging from the supply side in five European countries.
The business model development experiences show that effort is still required to support SME collaboration and to introduce basic marketing knowledge within SMEs, particularly to identify the customer segment and its values and to clarify the effectiveness of existing communication channels.

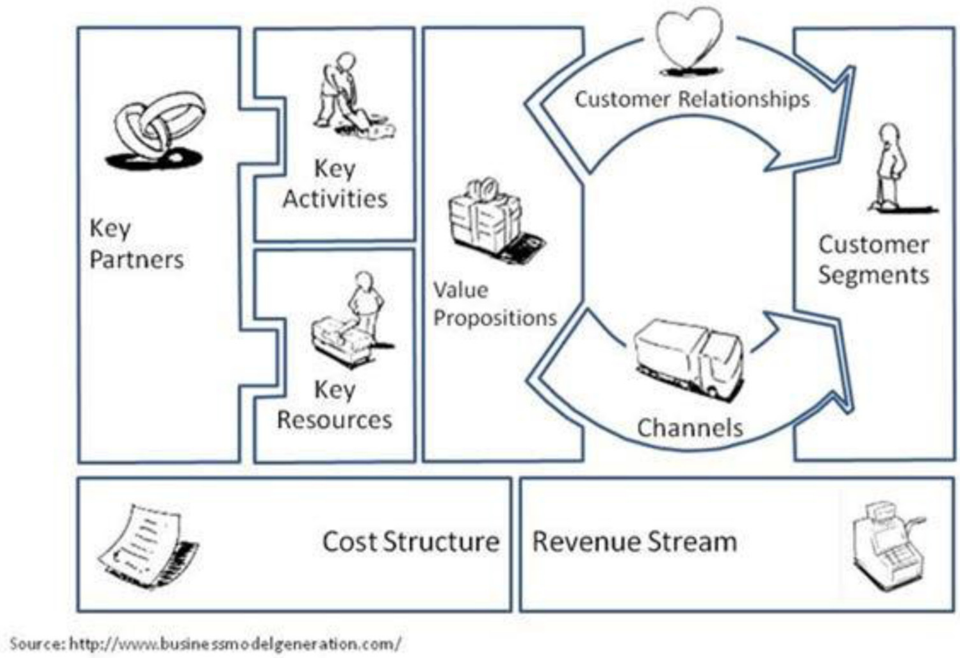

Figure 9: Business model canvas used in the COHERENO project

Main findings

The project showed how existing barriers to effective cooperation can be eliminated and better services for customer segments can be developed. While technological solutions for NZEB renovation are available at a demonstration level, there is a lack of supply-chain collaboration models. Better communication and awareness of each other's activities is one of the central ideas in promoting better collaboration between different service providers. Therefore, during the early stages of the project, experienced market players in participating countries and their roles within the renovation chain were mapped. Business Collaboration Events (BCEs) were organized in the participating countries to counter supply-side market fragmentation and encourage collaboration. BCEs paved the way for the uptake of new business models and represent the starting point for a long-term nZEB renovation network beyond COHERENO. With participants of the BCEs expressing interest and other interested nZEB frontrunners real business models were developed.

- The organization of 10 Business Collaboration Events (two in each of the five partner countries) to inform and encourage stakeholders to collaborate.
- 19 collaborative structures involving more than 50 organisations in the partner countries have been set up and can enter the single-family owner-occupied housing market.
- 'nZEB radars' to be used as tracking tools to identify nZEB single-family house renovations and to map frontrunners in the supply-chain.
- Report on the "Mapping of frontrunners in nZEB renovation of single-family houses" and on "Barriers and opportunities for business collaboration in the nZEB single-family house renovation market".
- Report on "Customer segments and value propositions in the nZEB single-family housing renovation market".
- Hands-on recommendations on Quality Assurance practice.

Lessons learned

- nZEB radars are useful tools to track energy efficient renovations.
- Listing of frontrunners in nZEB renovation is important for professional actors to match as well as for home-owners searching for experienced collaborative companies.
- It takes time to establish a tight business collaboration, to build trust between partners and to find the appropriate model for the group.

2.5. RETROKIT – Toolboxes for systemic retrofitting

The vision of the RetroKit project is to develop and demonstrate multifunctional, modular, low cost and easy to install prefabricated modules in order to significantly increase the EU retrofitting rate and contribute to EU energy reduction commitments.
Retrofitting is often associated with social, technological, industrial and economic barriers. The RetroKit project addresses these problems in order to increase the EU retrofitting rate and contribute to EU energy reduction commitments.

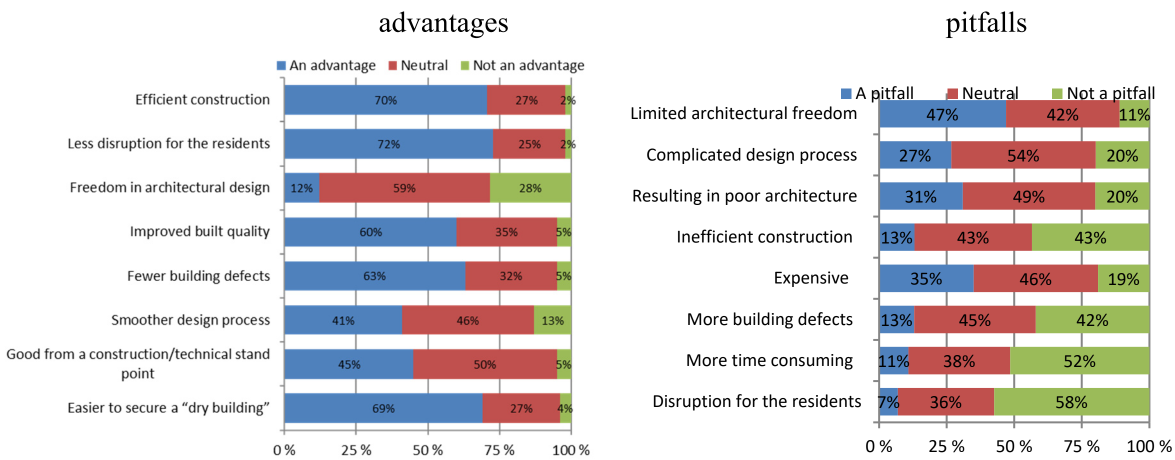

Figure 10: Results from a survey of stakeholders views and needs (RETROKIT) (526 / 4697 responded to questionnaire --> ca.12%)

Main findings

- Through the project the following improvements could be demonstrated:
    - Thermal comfort, mainly in winter (subjective AND objective)
    - Temperature factor (reduced condensation/mould risk)
    - Noise annoyance from outdoor sources
    - Sleep disturbance by outdoor noise
    - Perceived satisfaction with the home
    - Perceived quality of the home
    - Perceived overall comfort
    - Perceived comfort related to air movement
- The specially developed insulating elements allow insulation, heating pipes, ventilation, electricity and ITC to be integrated flexibly.
- These facade elements can be upgraded with additional functionalities during their service life.

- The existing HVAC systems in the building can be successively replaced by new systems without intrusion into the building structure or disturbing the inhabitants.
- This allows a gradual transition to LowEx building systems in the existing building stock.
- To be attractive to the market, the systems will be highly standardized with a multitude of upgrade and customization possibilities for all developed systems.

Recommendations (from interviews, see also Figure 10)

- Take measures to prevent /minimize unexpected adverse side-effects of a retrofit (ventilation noise, impaired lighting, overheating);
- Ensure that residents can control IEQ aspects relevant for their comfort, including ventilation, shading and lighting as well as temperature;
- Provide clear (including visual) information on the expected end result;
- Provide realistic information on potential inconvenience;
- Prevent inconvenience (e.g. noise, dust) through better coordination on site;
- Have a contact person available;
- Make a realistic time schedule for the retrofit process that can be complied with, and communicate aspects which may cause delay;
- Provide timely information if there are deviations from the schedule.

Recommendation (measurements, questionnaires)

Several points of attention for future retrofits can be proposed:

- In warmer climate region, the indoor temperature in summer is perceived as uncomfortable by most, and several respondents attribute a higher indoor summer temperature to the renovation. This suggests that (particularly in warmer countries), preventive measures directed to reduction of the risk of overheating in summer are warranted.
- (Perceived) energy efficiency after the retrofit still shows some room for improvement. In Madrid this was related to the heating system (which was unchanged).
- Pay attention to minimizing noise from mechanical ventilation systems.
- Aim at meeting energy use reduction targets, without compromising natural light e.g. by reduction of window surface area.
- Provide adequate control over solar shading (e.g. roller shutters), which is important both in terms of light as well as prevention of high indoor summer temperatures.
- And some points of attention:
    - Preventive measures to reduce risk of summer overheating are recommended *particularly in warmer climate regions*
    - Minimize noise from mechanical ventilation systems
    - Natural light
        - Avoid compromising natural light (window surface area)
        - Provide adequate control over sun shading (e.g. roller shutters)

2.6. ZEBRA2020 - Nearly Zero-Energy Building Strategy 2020

This project monitored the market uptake of nZEBs across Europe (creating an observatory) and thereby generated data and evidence for policy evaluation and optimization (providing a strategy to boost the market uptake of nZEBs). The project results are relevant not only to policy makers at the EU and Member State levels, but also to a broader range of market actors within the construction value chain. The main activities within the ZEBRA2020 project were:

- Monitor the nZEB market transition
- Involve and assist decision-makers to develop an nZEB strategy and provide recommendations
- Prepare a continuation of the nZEB market-tracking beyond the project duration
- The online data tools (zebra-monitoring.enerdata.eu) provide unique information regarding nZEB market development and nZEB characteristics.
- The online nZEB tracker (http://zebra2020.ecofys.com), based on a set of criteria, assesses the nZEB market maturity and visualizes the national nZEB markets dynamically (Figure 11).

Findings

Development in the NZEB sector has been hampered by a substantial gap in reliable data on current market activities, which makes it difficult for policy-makers to evaluate the outcomes of their policies and measures. Therefore, a key objective of ZEBRA2020 has been to monitor the market uptake of NZEBs across Europe and to provide data and input on how to reach the NZEB standard. The information gathered from the European construction sector and academia has been structured and analysed, and 32 recommendations have been derived.

- A significant share of nZEB definitions does not meet the intention of the EU directive on energy efficient buildings (EPBD) that the energy consumption should be "*nearly zero or very low amount*" and the remaining part "*should be covered to a very significant extent by energy from renewable sources*". Thus, a recast EPBD should require clear definitions of terms and thresholds, and gaps should be closed.
- Based on collected data, business as usual and ambitious policy scenarios of the nZEB market transition by 2020, 2030 and 2050 were developed (http://eeg.tuwien.ac.at/zebra).

Lessons learned

ZEBRA2020 findings show that more ambitious action is needed to facilitate a rapid NZEB market uptake. In order to achieve this, policymakers need to overcome several persisting barriers. According to discussions at ZEBRA2020's final conference and previous ZEBRA2020 results[2], these are the main challenges remaining:

- Absence of accessible and reliable data concerning the European buildings stock, making it difficult for policymakers and researchers to assess the challenges and prescribe the right solutions.
- Lack of professional skills and knowledge continues to be an important barrier and should remain a focal area of action. Better skilled workers are needed all throughout the value chain to ensure a smooth transition to NZEB and beyond.
- Compliance and monitoring regimes are currently not working properly. According to ZEBRA2020 results, only about half of the Member States monitor compliance of energy performance requirements in new buildings.
- The ZEBRA2020 real estate agents' survey[3] shows that the reliability and usefulness of EPCs are often questioned and the related costs are being considered to be dissuasive.

- The wide variety of national NZEB definitions (of which many have not yet been adopted) and concepts makes a meaningful comparison across boarders difficult.
- Non-existing lighthouse role of public buildings. A majority of Member States choses the “alternative approach” possible under Article 5 of the Energy Efficiency Directive[4], instead of leading the market through a deep renovation of the public building stock.
- Energy poverty and vulnerable residents is a European-wide problem, which needs further attention, in particular by shifting from fuel subsidy to energy efficiency support.
- What comes after 2020? There is a lack of a clear forward-looking perspective to guide the market.

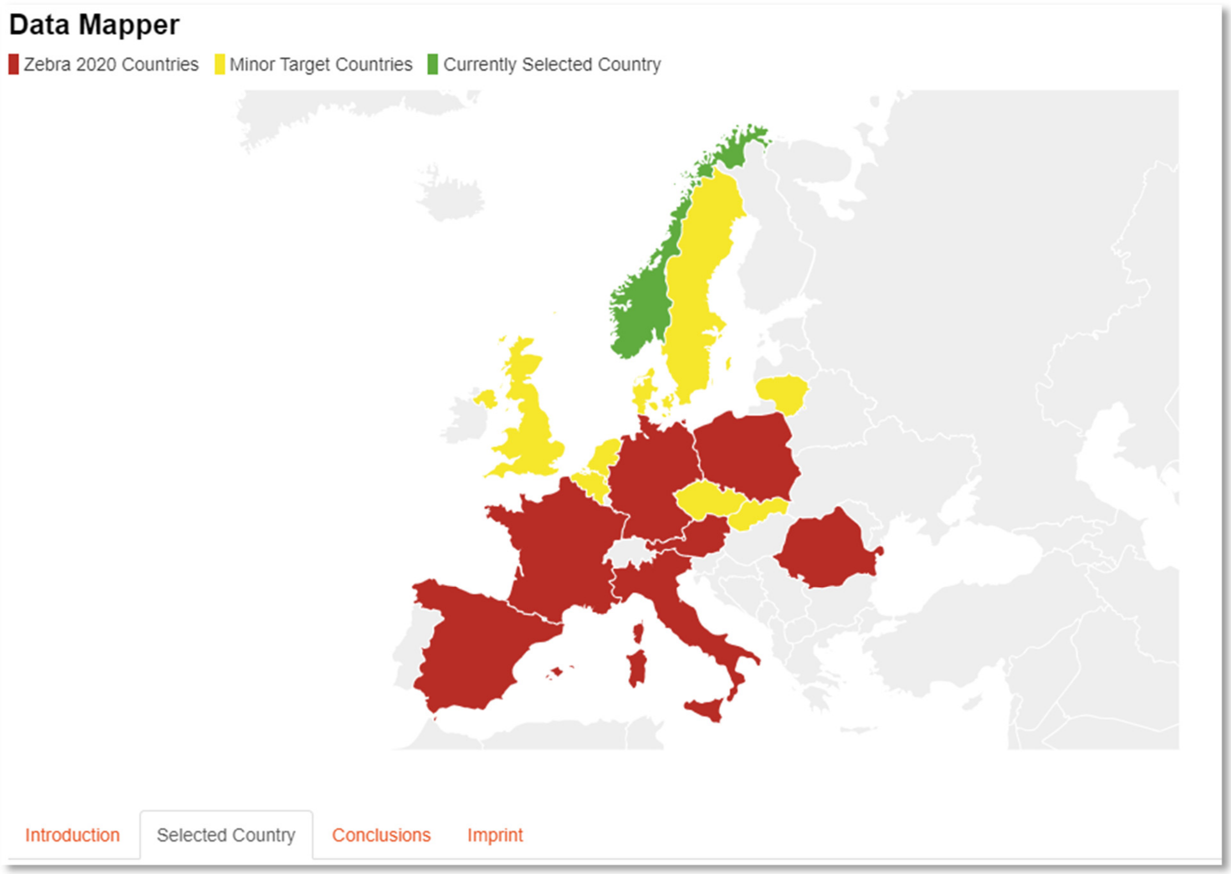

Figure 11: screenshot from the ZEBRA Data Mapper Tool (ZEBRA, nZEB tracker)

2.7. On-going projects

4RinEU (2016-2021)

The project 4RinEU seeks to find robust and reliable strategies for deep renovation of residential buildings, to increase the renovation rate in Europe by using prefabricated plug-and-play solutions. It is meant to provide an answer to typical challenges in renovation, providing new tools and strategies to encourage large scale renovation of existing buildings, fostering the use of renewable energies, and providing reliable business models to support their applications.

The challenge:

A big part of Europe's building stock is inefficient in terms of energy use, mainly as a consequence of:

- excessive heat losses through building envelopes
- lack of efficiency of the heating, ventilation and air conditioning systems

The renovation rate is low, and an increased rate is highly encouraged. However, barriers for deep renovation must be lowered. Renewable energy production is still often underestimated, despite a big availability of renewable energy sources.

Project goals

Prefabrication of recommended renovation concepts can be a solution for increased renovation rate. The goal is to develop concepts that can reduce the energy use by 60%, reduce construction time and cost as well as increased use of renewable energy and improved indoor environment quality.

4RinEU will minimize failures in design and implementation, manage different stages of the deep renovation process, from the preliminary audit up to the end-of-life, and provide information on energy, comfort, users' impact, and investment performance.

The 4RinEU deep renovation strategy is to encourage large scale renovation of existing buildings based on

- Robust technologies
- Usable methodologies
- Reliable business models

Renovation concepts for different geoclusters

The 10 4RinEU results are combined in tailored renovation packages designed for 6 different geographical areas in Europe. This approach aims to foster a broader application of the deep renovation strategy. The geoclusters are represented by 3 demo cases in Oslo - Norway, Soest - Netherlands and Bellpuig - Spain, followed by transfer of knowledge to early adapters in UK, Poland and Hungary.

Figure 12: Mounting of elements with integrated PV and ventilation ductwork, Oslo Demo Haugerudsenteret

Lessons learned

So far only the Norwegian demo at Haugerudsenteret is finalized. This is a 2-storey building with 8 small apartments owned by Boligbygg (Figure 12). The building was renovated from a 1970 poor energy standard to an energy efficient building with PV production within weeks on site. This is a true success story, with a dedicated project team and Lindal as the element producer. Important factors for success have been:

- Involvement of the element producer in the design phase to ensure a solution suitable for production, transportation and implementation.
- Sharing of knowledge and good technical discussion from all team partners
- High focus on use of BIM. Scan of existing building. Digital twin for both design and production.
- Focus on tolerances. It is important to fit new and existing construction elements, especially for windows and existing openings for ventilation.
- Mapping of condition of existing building construction and cladding. Mapping of hazardous components up front as well as to remove all existing wires, pipes, antennas etc on existing cladding is important.
- Focus on market acceptable solution. Optimization for rational production as well as high energy standard.
- As for many renovation projects, it can be hard to improve all factors to high energy standard. Existing slab on ground floor as well as compactness of the building can be hard to improve. The goal of reduction of energy use is achieved, but to reach the passive house level is not possible.

RezBuild

The REZBUILD project is mainly aimed at creating a collaborative refurbishment ecosystem focused on the existing residential building stock. Nowadays, the Near Zero Energy Building (NZEB) renovation methodologies are required as one of the key enablers supported by Horizon 2020 Framework Programme in order to promote business research and innovation through energy-efficient buildings.

REZBUILD will address these challenges by opening the construction sector with the integration of innovation technologies in order to pave the way towards an annual renovation rate of 2,5% instead of current rates lower than 1%.

The project will develop a multi-collaborative refurbishment ecosystem based on an APM platform able to interconnect in real-time the key steps of a tailored retrofitting plan among all stakeholders involved within the building renovation value chain. This innovative ecosystem will establish a collaborative framework including an efficient agile reporting and metrics of the data and information generated during the different steps of the refurbishment process (including simulations in the cloud, BIM approaches, existing open libraries, etc.), providing great communication capacities based on accessible interfaces (laptops, desktops, tablets and mobile phones), and offering a project assessment. In addition, external front-ends coming from other technologies (BEMS, BIM, RES or LCA/LCC) will be able to coexist boosting the process according to the stakeholders' tastes.
As a result of this approach, the ecosystem will drastically reduce the renovation time because it will provide real-time information to the stakeholders involved in the process as well as encourage a dynamic interaction among them.

3. Challenges

After analysis of EU projects that have tackled the main barriers of deep renovation through the search for innovative technological solutions to overcome the obstacles present in the market of energy requalification it was possible to identify the main barriers. The main barriers that have been found in the deep renovation processes can be classified in the following macro-groups shown in Figure 13.

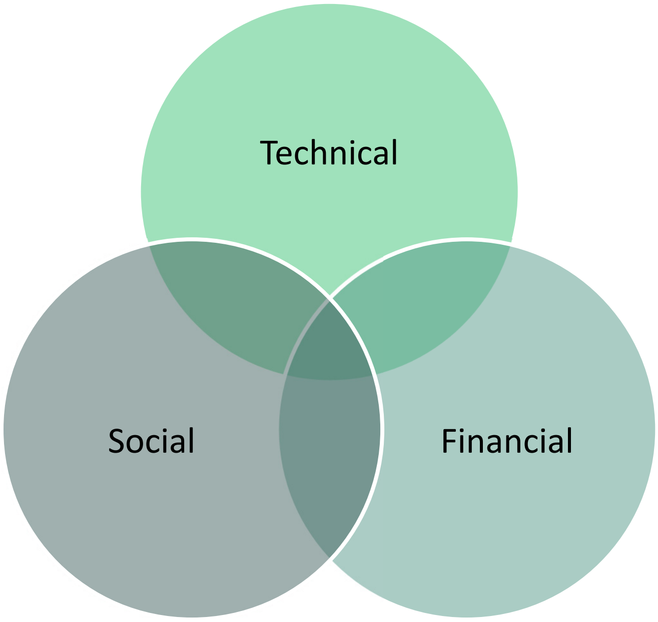

Figure 13: Classification of main barriers in deep renovation processes in EU projects.

As shown in Figure 13 the classification (see section 2 Methodology) can be divided into three aspects which adhere to the classification given in Table 2 (note that governmental aspects are not further considered). These aspects are described in the following sections.

3.1. Technical aspects in deep renovation projects

The EU projects were focusing on different technical aspects as listed in Table 4.

Table 4: Different technical aspects in deep renovation projects

number	aspect
1	A lack of consistent and standardized solutions or integrated solutions to comply with new and different building standards requirements on energy saving
2	Lack of skilled workers to carry out the work
3	Shortcomings in technical solutions, and long processes discouraging owners
4	Safety/compliance with stricter rules for reducing earthquake-caused risk of damage after deep renovation processes (damages or unsure perception of the current safety of the existing buildings)
5	End users' and owners' lack of knowledge of and trust in effective energy renovation savings

1. **A lack of consistent and standardized solutions or integrated solutions to comply with new and different building standards requirements on energy saving.**

Much effort was put on the analysis of the best integrated solution with respect to building type and climate but also the financial situation in several projects (list: ConZEBs, P2Endure, etc). The activities performed by some (P2Endure) projects aim to provide scalable, adaptable and ready-to-implement prefabricated (sometimes called Plug-and-Play (PnP) systems for deep renovation of building envelopes and technical systems. These innovative solutions are applicable for a wide range of building typologies, i.e. public buildings, residential buildings, and transformation projects. The prefab systems have to go through the whole production cycle (Figure 14), starting with innovative sensing technologies such as laser scanning of the existing building, thermal scanning and integrating with BIM, 3D printing of the elements, and implementing large-scale and live demonstration and monitoring projects that represent the main deep renovation typologies and real market demand in different EU geo-clusters.

Prefabricated façade elements bring innovation in the design process of building renovation by providing innovative tools and solutions. An important element is to include assessment of the impact of the proposed solutions by validating the design concepts and predicted performance with monitoring results to comply with building standards requirements on energy savings.
When it comes to energy performance of a building or its components, it can be evaluated in a number of ways. Regarding its components, reference is made to the components that have the greatest impact on the energy performance – the building envelope, the technical systems and renewable energy technologies. Quality control of solutions for individual building components might be necessary in addition to a performance check on building level. A large diversity of methods for quality assurance can be observed where each country designed its own approach (Refurb, D5.1). Regardless of the number of tools available for the homeowner on the topic of quality assurance, the majority of countries linked the quality assurance with loans or grants.

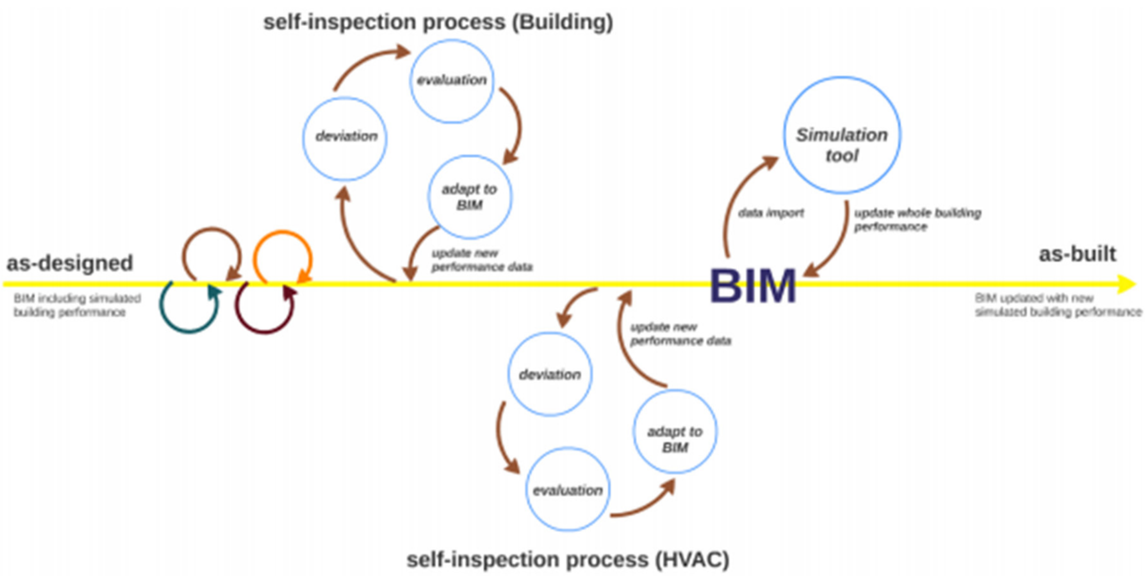

Figure 14: Visualization of the progressive steps known as “4M: Mapping-Modelling-Making-Monitoring”. (INSITER, www.insiter-project.eu/)

2. Lack of skilled workers to carry out the work.

Some projects focused on the development of educational material for planners and construction workers. Some projects, such as INSITER, focus on the automation of the whole renovation process (exploiting the possibilities in BIM). Since prefab elements need to be handled differently, this requires a different set of skills than traditional construction work (Figure 15).

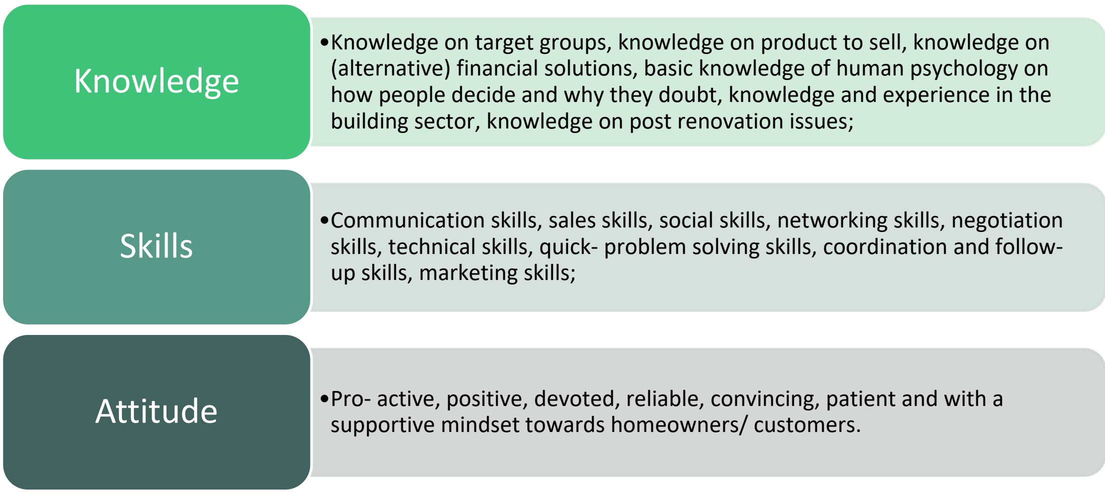

Figure 15: Set of best-practice competences of Single point of Contact persons (in One-stop-Shop business models) (REFURB, Deliverable D5.2 Report: Quality assurance approach; http://go-refurb.eu/)

3. Shortcomings in technical solutions, and long processes discouraging owners.

The technical solutions could not always be implemented as a complete set of solutions (D'Oca, 2018) (Figure 16). This has to do with owners' goals and vision but also financial deficits. Some projects focused therefore on the deployment of motivation techniques for building owners. E.g. one study has identified barriers for renovation in public-owned social housing related to type of residents, technical standard, financing, competence and strategies. Based on the three case studies of organizations providing housing for disadvantaged groups, the following advice was given for public housing providers on how to lower barriers and increase stakeholders' motivation for deep renovation:

- Consider the renovation process as a means to increase the residents' wellbeing and commitment to the dwelling. There can never be enough information about the process for the residents. Formalize the information process towards the residents, to avoid the dependence on enthusiasts in the organization.
- Technical standard should be adapted to the residents' skills. Go for a robust technology that works regardless of the skills of the residents. An advanced technology works flawlessly and as intended if it is easy to use by non-skilled persons (most of the residents).
- Visualize energy savings as savings for the municipality in total, despite different departments and budgets. This strengthens energy savings as a driver for renovation.
- To build competence in the organization, join research projects and aim for pilot projects.
- Plan with a sustainable communication strategy towards the residents. Use the media; positive media attention may be used to empower the stakeholders and workers in the project. (D3.5 4RinEU project, p. 9)

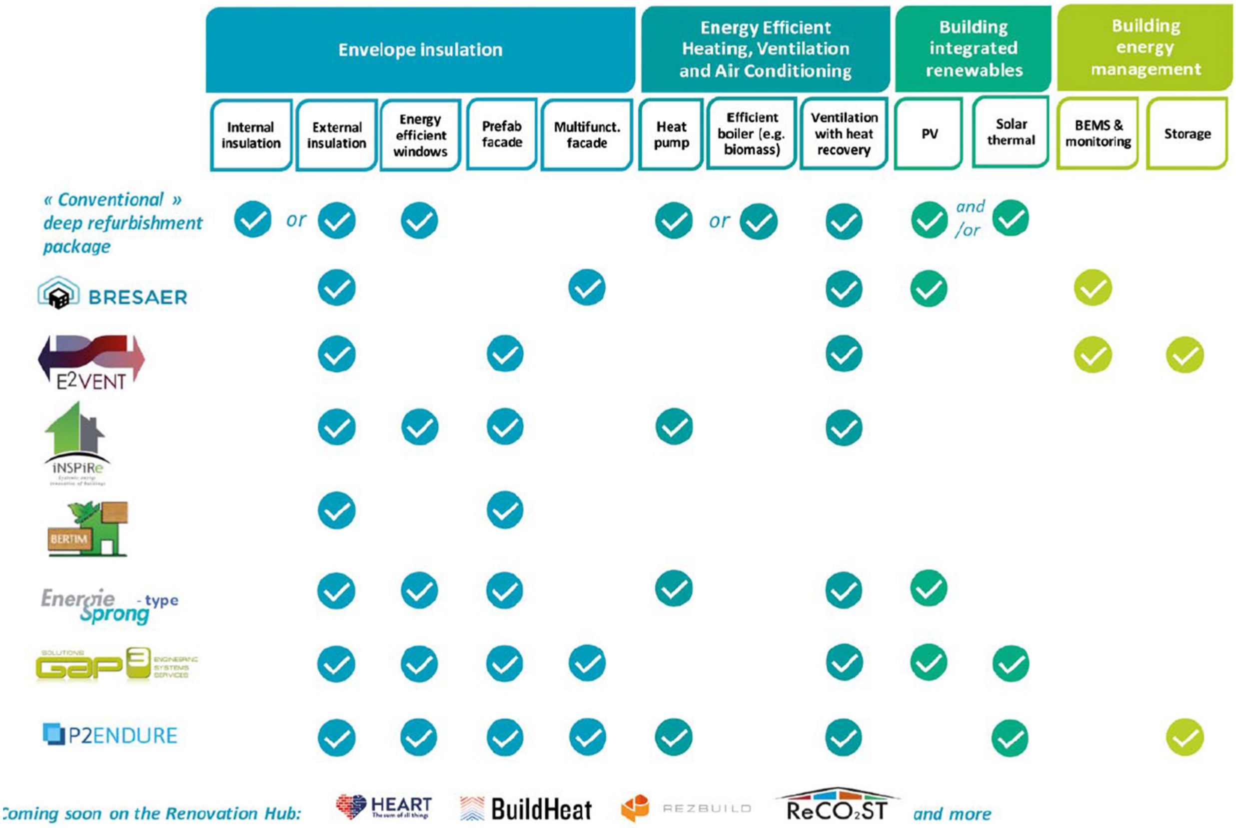

Figure 16: Renovation packages (STUNNING; https://renovation-hub.eu/)

Several projects identified the need to ensure high quality and delivery standards by using the customer's view as a starting point. It has become evident that it is necessary to ensure the quality of the entire renovation process, the so-called Customer Journey (CJ), to increase the probability of keeping the customers within the journey and actually in the end carry out a renovation successfully, meaning that the expected quality standards are met.
In order to achieve the ultimate goal to reduce energy consumption, the main challenge is to create customer confidence (Cohereno, D5.3 - report on creating customer confidence through quality assurance), getting homeowners on board a customer journey towards nZEB and keeping them until completion.

4. **Safety/ compliance with current rules for stability of building structures in earthquake-risk regions after major structural renovation (damages can be done to the building structure while retrofitting when there is uncertainty about the current state of the existing buildings).**

Safety standards have to be followed in construction work according to national standards. In many cases not only energy saving standards have evolved over time but also safety standards regarding load bearing, earthquake risks (in specific areas of the South of the EU), and fire safety. Homeowners have often only rudimental documentation of the existing structure of the building or documentation is not available. Then retrofitting measures might cause damages to the building structure. In demonstration projects this is specific focus on those issues but in other deep renovation processes these aspects might not be taken into consideration.

5. End users' and owners' lack of knowledge of and trust in effective energy renovation savings.

It has been observed that most of the homeowners decide to go for a step-by-step renovation. In that case, they should receive a renovation plan (roadmap) to follow at each step. This means also that they should re-enter in the CJ loop considering the original offer for deep renovation, to make sure they reach the nZEB level. The following actions are proposed to keep homeowners in the renovation process:

- Offering a roadmap to nZEB based on modules (of step-by-step renovation)
- Addressing 'co-benefits', i.e. energy savings combined with related advantages such as good indoor climate, comfort, health, and well-being as well as impact on market value of the property
- Sending follow-up offers based on their roadmap (as part of the business plan)
- Community gatherings in a fun setting, where people who have taken the first steps receive a positive feedback and can also share their experiences
- Offering continuing insight into the amount of money and energy saved (cumulative effect) through smart meter data collection and presentation
- Have a local consortium of energy related companies join forces to offer one complete nZEB renovation package (in a one-stop-shop) ; this local consortium guarantees the energy performance (Figure 15)
- Involve the local government: public-private-partnership to get consumers to step into the CJ and to create trust from the start;
- Dedicate efforts on CRM (Customer Relationship Management); keep track of (local) customers by sale departments and organize meetings for homeowners to stimulate them to take the next step for their dwellings;
- Consortia of local contractors could also reward their faithful customers with incentives (a discount, some type of present)
- Offer a certain subsidy as a 'reward' if a customer is willing to go to nZEB in one go.

3.2. Financial aspects in deep renovation projects

Different business models were developed and tested. They reach from OSS concepts, over partnerships with ESCOs, to new forms of financing (see Figure 17 for an overview). In general, the challenges related to financial aspects can be divided into 4 different aspects as described in Table 5.

Table 5: Different financial aspects in deep renovation projects

number	aspect
1	Investment
2	Return of investment
3	Funding schemes
4	Grants

1. **Investment.**

Financing aspects are among the highest barriers for owners and co-owners when it comes to renovations (Janda 2014; Mills and Schleich 2012; Zhao et al., 2015). Payback and up-front investment costs are crucial in the context of private economy and investment plans.

Figure 17: Business model illustration (STUNNING; https://renovation-hub.eu/)

2. Return of investment.

The payback time of the initial investment is one of the major barriers (Savacool 2017). Users and owners are not likely to consider investments that do not pay for themselves within 3–7 years. Therefore, the profitability of renovation in terms of building life cycle costs and long-term maintenance costs that can be avoided, thanks to energy efficiency deep retrofitting, should be evident. The initial investment costs can be high, and this is seen as an obstacle to consumer investment decisions. The most ambitious retrofits will undoubtedly require considerable upfront funding.

3. Funding schemes.

Lack of funding opportunities and/or inability to secure financing on acceptable terms is generally one of the most cited barriers to investing in energy efficiency measures (Nye et al. 2010). This applies at all the levels of ownership (from the level of the individual householder to the small landlords, to the case of fragmented ownership in condominiums and, finally, in the renting market, i.e., tenants).

4. Grants.

When the public spending decreases, funding opportunities become scarce, and the uncertainty and volatility of the schemes proposed increases. Policymakers at the European level are increasingly encouraging the reduction of grants. They are instead promoting revolving financial support that combine public and private resources, including the procedure of the Public Private Partnership (PPP) for large redevelopment. Yet, grants remain a significant argument to incentivize users and owners to renovate (Ferrante et al 2018).

3.3. Social aspects in deep renovation projects

In the context of innovative deep renovation practices, it is more urgent to understand what is relevant for end users when it comes to technological aspects, including how property owners perceive technological changes and how they assess their benefits and potential disadvantages (Sharifi and Yamagata 2016; Cali et al. 2016). Social challenges are summarized in Table 6.

Table 6: Different social aspects in deep renovation projects

number	aspect
1	Lack of education and confidence in construction professionals
2	Consumer acceptance of new technologies and innovative renovation solutions
3	Lack of knowledge of available solutions and customizability
4	Disruption factor
5	Decision-making in multi-apartment buildings

1. Lack of education and confidence in construction professionals.

There is an observed latent mistrust toward professionals. Together with the lack of properly trained energy efficiency professionals—in particular in local areas—lead to hesitation in investing in deep renovation. On the contrary, the overwhelming number of offers can weigh heavily in the balance when it comes to the final decision to renovate or not. Individual homeowners and users do not know where and how to find reliable experts and professionals and ask for advice and assistance (D'Oca et al. 2018). Taking such an important decision as a deep renovation is, for many, the second most important investment—after buying their home—that they will undertake in their lifetime. As a consequence, they demand some guarantees that the work will be done appropriately, and that the given advice is neutral and does not favour particular technologies or services. They are looking for long-lasting solutions that will be both economically and practically viable (Cali et al. 2016).

2. Consumer acceptance of new technologies and innovative renovation solutions.

Acceptance of new technologies by users and owners is often referred to as 'consumer acceptance', and it has been widely documented (Whiffen et al. 2018). It corresponds to behavioural aspects towards available technological solutions and the possibility of purchasing and using new products. It is shown that users and owners often distrust new technologies mainly due to their lack of knowledge, their perception, feelings, interpretation of information, and finally worries, risk, and inconvenience that they may feel and/or experience regarding new energy technologies. Training and awareness-raising activities are key elements for the acceptance of innovation; they are the first crucial steps to providing knowledge on the importance of improving buildings' energy efficiency through the application of the respective innovative technologies (D'Oca et al. 2018).

3. Lack of knowledge of available solutions and customizability.

The lack of knowledge about available solutions is a major obstacle. This is particularly relevant for energy efficiency solutions (Sharifi and Yamagata 2016; Cali et al. 2016; Abd-ur-Rehman and Al-Sulaiman,2018).

4. Disruption factor.

The disruption factor is also fundamental and needs to be assessed, especially in cases of deep renovations. It refers to all the troubles linked to refurbishment work for the occupant, which might impact on the decision to renovate. This aspect is confirmed by extensive literature and research that has pointed out that one of the main barriers to retrofitting is the disruption caused to users (Feige et al. 2013; Sovacool 2014). Favouring 'Plug-and-play' type solutions that limit the intervention on site should help to overcome occupants' reluctance to face renovation work. Major dissatisfaction can be avoided if the owners (occupant and landlord) have been sufficiently informed of the renovation plan and the possible disruption (van Opt 2015).

5. Decision-making in multi-apartment buildings.

A large part of the existing building stock in many European countries is composed of multi-apartment buildings, often with multiple owners and decision-making rules on necessary majorities can be complex. Making a decision for energy retrofits in multi-apartment buildings requires a majority in some countries, while in others, the consensus of owners should exceed 75% according to the national housing laws, and can even require unanimity (Kalmykova et al. 2016). Another aspect influencing consensus building is a potential uneven distribution of benefits and costs of an energy retrofit to the individual apartments (Whiffen et al. 2018). Making easily understandable information from the start of the renovation process could facilitate the complex decision-making process and consensus building in multi-apartment buildings. The provided information should focus on the benefits in terms of energy efficiency, housing quality, and indoor conditions, but should also specifically address multi-apartment building concerns relating to individual owners' rights.

Definition

Participative Design Approach.

To provide stakeholders with knowledge and skills, guiding them through an optimal decision-making process. Problems arise when homeowners are given too little information, the process goes too fast, and the financial consequences of the upgrade are not presented in an effective manner. Therefore, a good approach will consider the whole stakeholder chain involved in the retrofitting process, but two main groups are of primary concern, homeowners and construction professional. These two groups will therefore engage with a clear business case that raises their awareness of the multiple benefits of buildings' energy efficiency renovation. Specifically, the multiple benefits of nearly Zero Energy Deep Renovation (nZEDR) investments (energy savings , health and Indoor Environmental Quality (IEQ) benefits, and social and environmental benefits) including the impact on investment performance, must be measured and presented in ways in which key decision makers can understand, and account for more than just short-term energy savings, and nZEDR investments should be prioritised according to households' needs and interests. A good approach aims to support homeowner's decision-making process, significantly increasing the number saying yes to retrofitting to nZEDR within the European context. Building users are often understood as passive and occupant satisfaction as a clearly defined standard, common strategies for affordable, energy efficiency measures therefore target the physical context of the house and suggest mechanical solutions. However, homeowners are not passive and cannot be easily standardised and this has implications for the interest in retrofitting. In addition, understandings of the home and comfort are associated with questions of health, both physical and mental, social equality (standard of living), and sustainability.[1] Any engagement process that aims to encourage retrofitting should take into account social, physical and cultural factors that may be affected by the retrofitting process. Raising awareness and knowledge of the challenges faced both homeowners and construction professionals Stakeholder engagement is therefore required that includes qualitative and quantitative methods in a longitudinal process. The process will not only map the reasons for and potential solutions to, solving homeowner resistance to retrofitting. It will follow the process of choosing and testing technical solutions to achieving nZEDR, the development of financial solutions and digitalisation tools. These solutions will be considered within the context of user feedback (proposed main user groups are homeowners and construction professionals), energy practice, and knowledge and information exchange. Living labs are known for engaging with user groups in real-life contexts.[1] A living lab is an inclusive space bridging the gap between the social and technical context, with focus on participatory design methodology. The format, in interaction with homeowners, will support innovation, as well as technology, product and service development.

Textbox 3: Explanation of the *Participative Design Approach*

4. Opportunities

It clearly emerges from this analysis that finding the "composition" of a successful deep renovation is a challenging task. The following steps are needed to further succeed with deep renovation projects:

1. **To develop a solid business model, centred on the concept of the one-stop-shop, to support an all-inclusive technological package solution.**

To successfully sell the modular technical solutions to be developed and validated, a dedicated business model is conceived, based on a thorough market research and creatively centred on the value proposition concept of the "One-Stop Shop". To ensure efficient customer service and coordination in production, installation, life and decommissioning of the renovation components, the One-Stop Shop proposes a customized and integrative offer to the various customer segments identified, by internalizing all the activities involved along the renovation value chain.

2. **To develop and demonstrate robust, durable and cost-effective solutions for deep renovations to nZEB level.**

A seamless digital workflow process for building data acquisition and transfer to manufacturing sites, involving reduced material and construction defects or human errors, to be tested and validated in pilot sites, is needed. Protocols for collaborative use of building information (in design, production, construction and use) for nZEB renovated buildings platform are to be developed and coupled with commercial BIM software. This enables the installation in factory of moisture-control sensors in critical spots of the façade and roof modules. Sensors retrieve information on moisture level inside the modules and wirelessly transfer data to a central server for analysis and warning to the building managers.
By these means, total failure and renovation costs are reduced, as well as costs due to moisture related failure of the building shell after renovation.

3. **To minimize the homeowners' disruption during the deep renovation to nZEB level activities, by manufacturing and assembling all insulation and digital components in the factory, before delivery and on-site installation.**

All aspects of building renovation (building envelope, services and consultancy to the residents, building surveying and data acquisition) must be prefabricated and assembled in factory before delivery and installation on the renovation site. This includes (the specific configuration depends on each project) bio-based façade and roof modules with embedded compact ventilation systems, energy systems, solar energy harvesting systems, and sensors for indoor environment monitoring. Total renovation time and costs can thus be reduced by up to 20% compared with conventional renovation process. Inconveniences to homeowners are significantly reduced.

4. **To minimize the energy performance gap of Deep Energy Renovation and increase homeowners' comfort.**

The energy systems should be linked to the residents' actual use of the building to optimize the energy use. This can be developed by a self-learning monitoring system of the residents' energy use. Feedback to the residents on their own energy consumption will help track the energy efficiency of the installed measures

5. **To demonstrate customizable low-carbon solutions for nearly Zero Emissions Deep Renovations (nZEDR).**

Protocols for easy customization of façade modules for additional features need to be developed, tested and validated. Protocols for the separability of the sub-components of prefabricated façade and roof modules, for the easy dismantling of façade and roof modules and for the easy substitution of ventilation systems, energy systems and solar energy harvesting systems in façade and roof modules need to be developed, tested and validated.
Decommissioning, reuse or recycling of the roof and façade modules components would then be significantly facilitated, at a much lower cost and carbon footprint.

6. **To ensure the scalability and replicability of these new technical solutions and business model at EU level.**

The One-Stop Shop business model needs to be developed for and adapted to different European markets, after analysis of their national specificities (real estate market, competition, legal conditions, installation professionals, etc.) to facilitate large market uptake of package solutions for in-depth energy renovation at EU level.
The number of owners who decide to engage in in-depth energy renovations of their real-estate property increases at EU level (outside the inner circle of the three pilot countries) thanks to more attractive value propositions. Value proposition is in marketing, an innovation, service, or feature intended to make a company or product attractive to customers and it is used to build a business model.

5. Summary

Through the analysis of 39 projects it was possible to study the state-of-the-art of deep energy renovation (with prefabricated façade elements). A classification of barriers gave the possibility to derive several opportunities for future initiatives and interdisciplinary projects.

Table 7: Summary of different aspects in deep renovation projects

Technical aspects	Financial aspects	Social aspects
A lack of consistent and standardized solutions or integrated solutions to comply with new and different building standards requirements on energy saving	Investment	Lack of education and confidence in construction professionals
Lack of skilled workers to carry out the work	Return of investment	Consumer acceptance of new technologies and innovative renovation solutions
Shortcomings in technical solutions, and long processes discouraging owners	Funding schemes	Lack of knowledge of available solutions and customizability
Safety/earthquake risk connected with the major structural renovation processes	Grants	Disruption factor
End users' and owners' lack of knowledge of and trust in effective energy renovation savings		Decision-making in multi-apartment buildings

6. Conclusions

At the current stage, several matters remain unresolved that provide opportunities for future initiatives and interdisciplinary projects.

On technical aspects:

- To what extent can the existing technical solutions and current inhabitants' motivations respond to the need for a more 'energywise' resilient built environment after major disasters?
- What channels to reach out to demand-side and supply-side users for deep renovation technologies?
- Do plug and play solutions actually work for deep renovation practices at the large scale?
- Are an engaged team (including users) and technical solutions enough?
- What role can the One-Stop-Shop concept-based business plans play? (See Appendix C for explanation of concept)
- Others

On financial aspects:

- To which extent do we need policy and financial support to support penetration of deep renovation practices in the EU market? What role can the Long-Term Renovation Strategy (LTRS) of the EU play?
- Are national/local political and financial schemes needed to speed up deep renovation? If so, what key issues should they include?
- What type of financial instrument will be most effective to encourage the owners to undergo a deep renovation process? Incentives, loans, tax reduction? What role does the overall world economy play?
- What lessons have we learned from previous EU projects that can contribute to transforming theoretical findings into successful commercial products for the wider EU market upscale? Shall we focus on renovation rate or deep energy renovation? Which is more important?

On social aspects:

- Education/awareness programs are useful, but not enough alone, nor quick to implement.
- What trigger points will encourage inhabitants to take action for/against climate change?
- How to identify early adopters, i.e., the most eager users, owners, housing companies to foster the innovation spill-over effect?
- How much flexibility/freedom is needed/should be provided to end-users to ensure performance and effectiveness of measures?
- What needs (of the different actors) in the deep renovation process are not covered yet?
- Do the drivers for renovation change a lot among countries? Which ones are common?
- Which is the best way to engage the building occupants? At which stage of the deep renovation? How do we keep them interested?
- How can we manage that users perceive the direct and indirect benefits of a deep renovation? How can we better communicate the multiple benefits of deep renovation?
- Is a facilitator or brokerage service between stakeholders involved in the renovation process always needed?

Overall conclusions

- Importance of a high national political ambition and effective national energy efficiency requirements
- Importance of improving financial/economic support systems generally for the countries included in the study.
- Importance of increasing and equalizing knowledge among the energy retrofitting stakeholders (e.g. between building owners and energy efficiency contractors)
- Importance of national policy measures to overcome barriers for renewable energy (displayed e.g. through a need to increase certainty in the level of support that will be obtained through the economic support systems over the full lifetime of the plants).

Next actions

An original and necessary contribution in the form of a new project is needed to advance deep energy renovation in Europe and globally. The project should be uniquely positioned to address the technical, financial, human and organisational barriers which block the uptake of deep energy renovation of residential buildings:

- Focus on a thorough and professional selection of technologies (products and services) which, combined in a coherent and integrated package, address all the barriers identified. These technologies cover the whole life of a renovation project, from marketing and sales; advising and conception; production and assembling in factory; delivery and installation on site; building use and management; to decommissioning, reuse or recycling.
- Pursue the development of these technologies to bring them to market readiness. Some technologies have been developed in previous projects, but it is important to refine them, test them in pilot projects and improve them when necessary.
- Develop a solid customer-oriented business model organized around attractive value propositions.
- Business model can be based on the concept of One-Stop Shop, an all-inclusive structure proposing to homeowners all the products, services and activities necessary to the successful execution of a deep energy renovation project.

7. References

Abd-ur-Rehman, H.M.; Al-Sulaiman, F.A. Optimum selection of solar water heating (SWH) systems based on their comparative techno-economic feasibility study for the domestic sector of Saudi Arabia. Renew. Sustain. Energy Rev. **2016**, 62, 336–349.

BPIE, Buildings Performance Institute Europe. Europe's Buildings Under the Microscope. 2011, ISBN: 9789491143014

BPIE, Building Performance Institute Europe,"97% of buildings in the EU need to be upgraded," 2017.

BPIE, Renovation strategies of selected EU countries - A status report on compliance with ARTICLE 4 of the ENERGY EFFICIENCY DIRECTIVE, ISBN: 9789491143113, 2014

Calì, D.; Osterhage, T.; Streblow, R.; Müller, D. Energy performance gap in refurbished German dwellings: Lesson learned from a field test. Energy Build. 2016, 127, 1146–1158.

D'Agostino, D.; Zangheri, P.; Castellazzi, L. Towards nearly zero energy buildings in Europe: A focus on retrofit in non-residential buildings. Energies **2017**, 10, 117.

Directorate-General for Internal Policies. Policy Department A: Economic and Scientific Policy, (DG-IP 2016) Energy Efficiency for Low-Income Households; Study for the ITRE Committee: Brussels, Belgium, 2016.

D'Oca, S.; Ferrante, A.; Ferrer, C.; Pernetti, R.; Gralka, A.; Sebastian, R.; op 't Veld, P. Technical, Financial, and Social Barriers and Challenges in Deep Building Renovation: Integration of Lessons Learned from the H2020 Cluster Projects. *Buildings* **2018**, *8*(12), 174; doi:10.3390/buildings8120174

EED - Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, Energy Efficiency Directive, https://ec.europa.eu/energy/en/topics/energy-efficiency/targets-directive-and-rules/energy-efficiency-directive, access data: 04.12.2019

Enovarapport 2015:10 [in Norwegian] Rehabilitering og energioppgradering av boliger. Drøfting av begreper og måling av omfang. www.enova.no [Accessed 03 12 2019]

EU Commission, "EU Building Stock Observatory," 2017. [Online]. Available: https://ec.europa.eu/energy/en/eu-buildings-database. [Accessed 29 10 2017].

EU Commission, "Clean energy for all Europeans package", 2017. [Online]. Available: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans. [Accessed 07 12 2019]

European Commission, "COMMISSION STAFF WORKING DOCUMENT - IMPACT ASSESSMENT – Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/31/EU on the energy performance of buildings," no. {SWD(2016) 415 final, 2016.

Feige, A.; Wallbaum, H.; Janser, M.; Windlinger, L. Impact of sustainable office buildings on occupant's comfort and productivity. J. Corp. Real Estate **2013**, 15, 7–34.;

Ferrante, A.; Prati, D.; Fotopoulou, A. TripleA-Reno: Attractive, Acceptable and Affordable Deep Renovation by a Consumers Orientated and Performance Evidence Based Approach. WP4–Task 4.2 Analysis and Design of the Business Module; Huygen Installatie Adviseurs: Maastricht, The Netherlands, 2018.

Glumac, B.; Reuvekamp, S.; Han, Q.; Schaefer, W.F. Tenant participation in sustainable renovation projects: Using AHP and case studies (NL). J. Energy Technol. Policy **2013**, 3, 16–26.

Haase, M., Rønneseth, Ø., Thunshelle, K., Georges, L., Holøs, S. and Thomsen, J., Review of building services solution fitted for a low emission building stock in urban areas, proceedings of 40th AIVC Conference, 8th TightVent Conference, 6th venticool Conference, From energy crisis to sustainable indoor climate – 40 years of AIVC, p.616-623, ISBN: 2-930471-56-3, EAN: 9782930471563

Janda, K.B. Building communities and social potential: Between and beyond organizations and individuals in commercial properties. Energy Policy **2014**, 67, 48–55.

Kalmykova, Y.; Rosado, L.; Patricio, J. Resource consumption drivers and pathways to reduction: Economy, policy and lifestyle impact on material flows at the national and urban scale. J. Clean. Prod. **2016**, 132, 70–80.

Labonnote, N. and Høyland, K. Smart home technologies that support independent living: challenges and opportunities for the building industry – a systematic mapping study, Intelligent Buildings International 2015, pp. 1–26.

Majcen, D.; Itard, L.; Visscher, H. Statistical model of the heating prediction gap in Dutch dwellings: Relative importance of building, household and behavioural characteristics. Energy Build. **2015**, 105, 43–59

Mills, B.; Schleich, J. Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries. Energy Policy **2012**, 49, 616–628.

Nye, M.; Whitmarsh, L.; Foxon, T. Sociopsychological perspectives on the active roles of domestic actors in transition to a lower carbon electricity economy. Environ. Plan. A **2010**, 42, 697–714.

K. Petersen, R. Feldt, S. Mujtaba, M. Mattsson, Systematic Mapping Studies in Software Engineering, Proceedings of the 12th International Conference on Evaluation and Assessment in Software Engineering, British Computer Society, Bari, Italy, 2008, 68–77.

Simona, D.; Peter, O.t.V. ProGETonE Public Deliverable D2.1: Report on the State of the Art of Deep Renovation to nZEB and Pre-Fab System in EU; European Commission: Brussels, Belgium, 2017.

Semprini, G.; Gulli, R. Ferrante Deep regeneration vs. shallow renovation to achieve nearly Zero Energy in existing buildings: Energy saving and economic impact of design solutions in the housing stock of Bologna. Energy Build. **2017**, 156, 1–414.

Sovacool, B.K. Experts, theories, and electric mobility transitions: Toward an integrated conceptual framework for the adoption of electric vehicles. Energy Res. Soc. Sci. **2017**, 27, 78–95.

Sovacool, B.K. Energy studies need social science. Nature **2014**, 511, 529–530

Sharifi, A.; Yamagata, Y. Principles and criteria for assessing urban energy resilience: A literature review. Renew. Sustain. Energy Rev. 2016, 60, 1654–1677.

Van Opt, Peter,MORE-CONNECT: Development and advanced prefabrication of innovative, multifunctional building envelope elements for modular retrofitting and smart connections. Energy Procedia **2015**, 78, 1057–1062.

Whiffen, T.R.; Naylor, S.; Hill, J.; Smith, L.; Callan, P.A.; Gillott, M.; Wood, C.J.; Riffat, S.B. A concept review of power line communication in building energy management systems for the small to medium sized non-domestic built environment. Renew. Sustain. Energy Rev. **2016**, 64, 618–633.

Zhao, D.X.; He, B.J.; Johnson, C.; Mou, B. Social problems of green buildings: From the humanistic needs to social acceptance. Renew. Sustain. Energy Rev. **2015**, 51, 1594–1609.

A Appendix – Tables with EU projects

Funding Scheme	Type of Action	Project Name	URL	Description
H2020	IA	Drive-0	https://www.drive0.eu/	DRIVE 0 aims to come to a decarbonization of the EU building stock and to accelerate deep renovation processes by enhancing a consumer centred circular renovation process in order to make deep renovation more attractive for consumers and investors, more environmental friendly. This by combining the need for a circular building industry with the identification of specific local or national drivers to trigger and to motivate end-users for deep renovation, supported by an anthropology based and environmentally friendly approach to make it costumer-centred and respectful of local geo-material areas,
H2020	CSA	TripleA-reno (2018-2021)	https://triplea-reno.eu/	To foster new consumer and end-user centered business models and decision support tools, using evidence-based performances that facilitate decision-making
H2020	RIA	Progetone (2017-2021)	https://www.progetone.eu/	ProGETonE develops and proves an integrated approach to tackle two important needs in existing buildings: safety upgrades to face future earthquakes in seismic zones and nearly zero energy consumption to be aligned with EU climate change reduction targets. Residents in two pilot sites in Greece and the Netherlands will be involved in the design and implementation process from the beginning to consider their views and motivations, so as to deliver satisfying renovations for them and spread them to other EU citizens.
H2020	RIA	HEART (2017-2021)	https://heartproject.eu/	The HEART toolkit incorporates different components and technologies, which cooperate to transform an existing building into a smart building. In developing this toolkit, the project advances and improves energy efficiency and the use of renewable energies in buildings across Europe, particularly in Central and Southern Europe, where climate change is leading to increased electricity consumption both during summer and winter seasons.
H2020	RIA	STUNNING (2016-2019)	https://renovation-hub.eu/	The project STUNNING aims at building up a stakeholder community around a Renovation Hub designed as a knowledge sharing platform, providing information on innovative solutions for building renovation and novel business models (illustrated through case studies) for their adoption and large scale replication. The provided solutions involve affordable and adaptable refurbishment packages, taking into consideration the whole renovation value chain.
H2020	IA	RezBuild	https://rezbuildproject.eu	REZBUILD is a H2020 funded project aiming at defining an innovative and collaborative refurbishment ecosystem for transforming RE assets into Near Zero Energy Buildings (NZEB). The project, started in October 2017, will develop and implement 7 technologies to improve energy efficiency in residential buildings, considerably reducing the time for refurbishment and the pay-back period.

Funding Scheme	Type of Action	Project Name	URL	Description
H2020	IA	ENVISION (2017-2020)	http://www.energy-envision.eu/	The ‘ENVISION’ project will demonstrate a full renovation concept that, for the first time, harvests energy from ALL building surfaces (transparent and opaque). ENVISION’ focusses on energy harvesting of the façade, and works by absorbing the invisible part of the solar radiation (the near-infrared (NIR) part, roughly 50% of the solar energy spectrum) allowing visible aspects to be retained. The ‘ENVISION’ harvesting of solar energy is achieved via: 1. heat collecting non-transparent aesthetically pleasing façade elements by harvesting the NIR solar radiation, 2. heat harvesting ventilated glass by harvesting the NIR solar radiation, 3. electricity harvesting photovoltaic glazing solutions
H2020	CSA	ConZEBs (2017-2019)	https://www.conzebs.eu/	CoNZEBs identifies and assesses technology solution sets that lead to significant cost reductions of new Nearly Zero-Energy Buildings. The focus of the project is on multi-family houses. Close cooperation with housing associations allows for an intensive interaction with stakeholders and tenants. The project starts by setting baseline costs for conventional new buildings, currently available NZEBs and buildings that go beyond the NZEB level based on the experience of the consortium. It analyses planning and construction processes to identify possible cost reductions.
H2020	RIA	RE4 (2016–2020)	http://www.re4.eu/	Reuse and Recycling of CDW materials and structures in energy efficient prefabricated elements for building refurbishment and construction.
H2020	RIA	VEEP (2016–2020)	http://www.veep-project.eu/	Cost-Effective Recycling of CDW in High Added Value Energy Efficient Prefabricated Concrete Components for Massive Retrofitting of our Built Environment
H2020	RIA	INSITER (2016-2019)	https://www.insiter-project.eu/en	Through new self-inspection techniques, INSITER will fully leverage the energy-efficiency potentials of buildings based on prefabricated components, from design to construction, refurbishment and maintenance. It will scale-up the use of BIM for standardised inspection and commissioning protocols, involving all actors in the value-chain.
H2020	IA	4RinEU (2016–2020)	http://4RinEU.eu/	Robust and Reliable technology concepts and business models for triggering deep Renovation of Residential buildings in EU.

Funding Scheme	Type of Action	Project Name	URL	Description
H2020	IA	P2Endure (2016–2020)	https://www.p2endure-project.eu/en	P2ENDURE takes on a progressive principle: Build further on credible state-of-the-art solutions of 3D scanning and printing technologies in combination with prefab renovation systems, which are derived from tested results of recent EU and national R&D (Research & Development) projects. Develop modular processes for deep renovation through BIM-based design, engineering, production and installation for speeding up the implementation of the state-of-the-art solutions. Optimise and integrate the state-of-the-art solutions grounded in practical evidence of their performance through real deep renovation cases of public and residential buildings. Perform real deep renovation projects at a higher complexity level and with a larger performance impact than typical residential buildings through transformation of obsolete public and historic buildings.
H2020	IA	EENSULATE (2016–2020)	http://www.eensulate.eu/	Curtain wall system with lightweight (35% weight reduction) and highly insulating energy efficient glass modular components
H2020	CSA	ABRACADABRA (2016–2019)	http://www.abracadabraproject.eu	Renovation strategy coupling Adore, Assistant Building unit(s)—like aside or façade addictions, rooftop extensions or new building construction, with a densification retrofit policy
H2020	CSA	TransitionZero (2016–2018)	http://transition-zero.eu/	Net zero refurbishment solutions integrating standardized design of pre-fabricated technological modules and mass-production with innovative business case for housing associations
H2020	RIA	E2VENT (2015–2018)	www.e2vent.eu/	A systemic retrofit solution including the use of ventilated façade system, heat recovery units, photovoltaic cells, natural lighting and envelope insulation strategies.
H2020	RIA	BRESAER (2015–2019)	http://www.bresaer.eu/	Coupled cost-effective, adaptable, low-intrusive and industrialized envelope (for façades and roofs) with an innovative Building Energy Management System

Funding Scheme	Type of Action	Project Name	URL	Description
H2020	IA	BERTIM (2015–2019)	www.bertim.eu/	High energy performance timber prefabricated modules, a tool for mass manufacturing and holistic methodologies for the renovation process, from data collecting to installation
H2020	IA	REnnovates (2015–2018)	www.rennovates.eu	Smart services, technical solutions, energy-based communities.
H2020	IA	BuildHEAT (2015–2019)	http://www.buildheat.eu/	Standardized approaches and products for the systemic retrofit of residential buildings, focusing on heating and cooling consumptions attenuation.
H2020	IA	OptEEmal (2015–2019)	https://www.opteemal-project.eu/	Optimised Energy Efficient Design Platform for Refurbishment at District Level
H2020	IA	NewTREND (2015–2018)	http://newtrend-project.eu/	Integrated design methods
H2020	IA	IMPRESS (2015–2018)	www.project-impress.eu/	Prefabricated retrofitting modules supported by a BIM-based Iterative Design Methodology (IDM)
H2020	CSA	REFURB (2015–2018)	http://go-refurb.eu/	One-stop-shop model for energy renovations scanning integrated with Building Information Model (BIM) for deep renovation of building envelopes and technical systems.
H2020	IA	MORE-CONNECT (2014–2018)	www.more-connect.eu/	Prefabricated, multifunctional renovation elements for the total building envelope (façade and roof) and installation/building services.
IEE		NeZeR (2014–2017)	http://www.nezer-project.eu/	Smart and integrated NZEB renovation measures for nZEB

Funding Scheme	Type of Action	Project Name	URL	Description
IEE		ZEBRA 2020 (2014–2016)	http://zebra2020.eu/	Monitoring system of market uptake of refurbished nZEB including data collection and recommendations
FP7	CP-TP	A2PBEER (2013–2017)	www.a2pbeer.eu/	Retrofitting methodology for public buildings including existing available and newly developed innovative solutions.
FP7	CP-FP	ADAPTIWALL (2013–2017)	www.adaptiwall.eu/	Nanotechnology-based, multi-functional and climate-adaptive panels consisting of 3 elements: lightweight concrete with Nano-additives for efficient thermal storage and load-bearing capacity; adaptable polymer materials for switchable thermal resistance; and total heat exchanger with nanostructured membrane for temperature, moisture, and anti-bacterial control.
FP7	CP	iNSPiRe (2012–2016)	www.inspirefp7.eu/	Systemic renovation packages for residential and tertiary buildings.
FP7	CP-IP	MeeFS (2012–2016)	http://www.meefs-retrofitting.eu/	Multifunctional energy efficient facade system for residential buildings' retrofits.
FP7	CP-IP	HERB (2012–2016)	http://www.euroretrofit.com/	Holistic energy-efficient retrofitting of residential buildings
FP7	CP-IP	RetroKit (2012–2016)	www.retrokitproject.eu	Multifunctional, modular, low cost and easy to install prefabricated modules.
FP7	CP-TP	Proficient (2012-2016)	http://www.proficient-project.eu/	PROFICIENT aimed at developing new business models for SMEs implementing energy efficient housing construction or retrofitting in a special housing sector, that of Collective Self Organised Housing (CSO).
IEE		COHERENO (2012-2017)	https://ec.europa.eu/energy/intelligent/projects/en/projects/cohereno	COHERENO developed proposals and concepts for promising cross-sector and company business models for high efficiency refurbishment of single-family houses to nearly zero-energy housing.

Funding Scheme	Type of Action	Project Name	URL	Description
FP7	CP-FP	CETIEB (2011–2014)	http://www.cetieb.eu/SitePages/Home.aspx	Monitoring, control systems, and modelling tools of retrofitted indoor environments.
FP7	CP-IP	EASEE (2011–2014)	www.easee-project.eu/	Toolkit for envelope retrofit in existing multi-story and multi-owner buildings combined with novel design and assessment strategies, with scaffolding-free installation approaches.
FP7	CP-FP	SUSREF	https://cordis.europa.eu/project/rcn/92302/factsheet/en	SUSREF developed technologies and methodologies for sustainable refurbishment of external walls.
IEA	EBC	Annex50	https://www.iea-ebc.org/projects/project?AnnexID=50	Annex50 (Prefabricated Systems for Low Energy Renovation of Residential Buildings) which focused on prefabricated systems for the residential building sector.
IEA	EBC	Annex44	https://www.civil.aau.dk/Project+websites/integrated-building-concepts/	Annex 44 on Integrating Environmentally Responsive Elements in Buildings was the first international project that focused on the integration of "*technologies that promote the integration of active building elements and communication among building services.*"

RIA– Research and Innovation action
IA – Innovation Action
CSA– Coordination and Support Action
CP-TP– Collaborative Project targeted to a special group
CP-IP– Large-scale integrating project
CP-FP – Small or medium scale focused research project

B Appendix - Abbreviations

AEC: Architecture, Engineering and Construction industry
AR: Augmented Reality
BEMS: Building Energy Management System
BIM: Building Information Modelling
BLC: Building Life Cycle
CAD: Computer Aided Design
CNC Computerised Numerical Control
EBC: Energy in Buildings and Communities
EED: Energy Efficiency Directive
EeB: Energy Efficient Buildings
GUI: Graphical User Interface
HPP: Heat Pump Programme
HVAC: Heating, Ventilation, Air Conditioning
ICT: Information and Communications Technology
IFC: Industrial Foundation Classes
ISO: International Organisation for Standardization
KPI: Key Performance Indicator
LCA: Life Cycle Assessment
LCC: Life Cycle Cost
M&E: Mechanical and Electrical services
MEP: Mechanical, Electrical, Plumbing
MTT: Methods, Tools and Techniques
NDT: Non-destructive test
nZEB: nearly Zero Energy Building
nZEDR: nearly Zero Energy Deep Renovation
OSS: One-Stop-Shop
QC: Quality Control
QR code: Quick Response Code
RES: Renewable Energy Supply / System
SHC: Solar Heating and Cooling
SIG: Special interest group
SPOC: Single point of contact
TCO: Total Cost of Ownership
URL: Uniform Resource Locator
VR: Virtual Reality
WBS: Work Breakdown Structure
ZEB: Zero Energy Building / Zero Emission Building

C Appendix - Definitions

ZEB

Zero energy building – building with zero net energy consumption annually. Zero energy buildings can be operated autonomously from energy supply network, if energy is obtained in sufficient amount on the spot;

Zero Emission Building -building with zero carbon emission. Conceptually, a zero emission building (ZEB) is a building with greatly reduced energy demand, which is balanced by an (onsite/offsite) equivalent generation of energy (electricity or other energy carriers) from renewable sources. In a zero emission building such a balance is not achieved on the building energy demand but on the building greenhouse gas emissions. Different levels of ambition were defined in ZEB (www.zeb.no) regarding components and life cycle of the building.

Energy (Primary, gross, net)

Primary energy is the amount of energy at its source (without conversion, distribution, and transmission).

The difference between net and gross energy needs is that the latter includes losses from the heating and cooling distribution system, as well as the storage system inside buildings. Net energy need is for example useful for checking compliance with the passive house definition, while gross energy need is useful as a starting point for the design of heating and cooling supply systems.

System boundaries

The boundaries defining an energy system. Often it is important to define the system boundaries in order to be able to compare different systems with key performance indicators.

One Stop Shop (OSS) or one stop shop concept for home renovations

One can clearly distinguish ‘one stop’ and ‘shop’: these are the two main characteristics of OSSs:

- • A ‘shop’, meaning a business or public entity offering home renovation services.
- • A ‘one stop’, meaning it is one place to go to for the customer if they want a home renovation service (and they do not have to go shopping elsewhere).

OSSs typically include a SPoC – A single point of contact to homeowners

D Appendix – List of Figures

E Appendix – Elements for deep renovation

Modular Building Envelope

The building envelope modularity is the key answer for number engineering tasks including easy and rapid installation, possible dismantling and separation of the layers included in the structure. Besides that, the modularity allows cost-optimized solution and transferability of the technologies between different buildings. The modular system must be applicable to different building typologies, based on project knowledge (4RinEU, MORE-CONNECT, Driv-0), there are six main approaches possible to use. These solutions were developed to TRL 6-7 covering most of the modular variants for different buildings across the countries. 10 demonstration buildings have been built (renovated) and two Real-life learning labs have been started. The system includes modular extension to the roof (newly built attic apartments) or modular balconies for some of the typologies. The protype was developed to TRL 6, the modular façade elements are tested in real condition, but the final application of the system was not done yet. However, this hanging façade system has favourable environmental performance and any modular building envelope can benefit from the knowledge about the material selection and environmental optimization done within the project. Other projects developed modular solution allowing non-demanding replacement of each single module in the façade independently for its refurbishment, extension or other improvement to pro-long the façade lifetime and improve resilience of it. These outputs can be used to further develop prefabricated elements and provide way of simple and affordable refurbishment system by bringing-up a new mounting and dismantling procedure, anchoring system and improved environmental performance and recyclability of module's structural layers. This has the potential to bring the previously developed project ideas to higher TRL by incorporating the building users to the building refurbishment design process (i.e. by setting up the desired comfort level and thus the technical boundary condition to the modular elements). The recyclability and end-of life design stage solution of the new system improves its attractivity to the market.

Integrated Heat Recovery Ventilation

The choice of ventilation with heat recovery is important and sometimes crucial for the development of renovation concepts. The supply air should be organized in the bedrooms and living rooms while the exhaust in WC, bathrooms, and kitchens. The use of heat recovery ventilation units is a fundamental requirement to reduce energy consumption and improving IEQ and thermal comfort when addressing the renovation process. The ventilation system can be designed locally with ventilation units for separate apartments/rooms or as central with a common ventilation unit for the whole building. Heating of the object can be solved by units or in the case of low heat loss as warm air. To minimize disturbance of occupants the renovation concept is with minimal works inside of apartment.

The energy and economic benefits of a solution depend on the object's availability and system performance requirements. Ventilation concepts (TRL-5-7) were addressed in the several projects (RETROKIT, MORE-CONNECT, Meefs, IMPRESS, REnnovates, E2EVENT, BRESAER, INSPIRE, P2ENDURE) project (European Union's H2020 framework programme for research and innovation under grant agreement no 633477, www.more-connect.eu). Three most cost effective ventilation systems were centralized mechanical supply and exhaust with heat recovery, decentralized mechanical supply and exhaust with heat recovery (apartment based heat recovery) and decentralized mechanical supply and exhaust with heat recovery (room based heat recovery).[1] On the other hand, decentralized is more flexible to use. The main challenge for introduction of mechanical supply and mechanical exhaust ventilation in post-war apartment buildings is limited area of technical spaces and shafts. The most realistic duct placement is outside existing building envelope in additional thermal insulation layer that doesn't require extra indoor space and can be installed with a minimal internal construction works. The decentralized ventilation unit can be placed to loggia or wet room or integrated in the building façade near the window. Due to the compact size of the unit, it is possible to slightly reduce the size of the window and thus provide space for the air intake and exhaust for the air handling unit.

Solar Energy Unit

Co-simulation framework is needed to create 3D models and conduct solar analyses and geometrical optimizations by coupling both parametric modelling software allowing to control the geometric parameters (e.g., buildings' height, exposure and orientation of buildings' façades), solar and energy dynamic simulation tool for solar radiation maximization and energy generation for the buildings in the demonstration pilot projects. The innovative workflow allows supporting solar potential analysis, solar mapping visualization and energy generation calculation ranging from components to single buildings, through group pf buildings. The workflow allows estimating the direct, diffuse and reflected solar components by considering both complex overshadowing effects and inter-building and ground solar reflections on the all surfaces (roof and façades) of analysed fabric located in different urban-density environments (demonstration pilots projects). In that regard, to the total amount of solar radiation impinged on the surfaces (roof and façade) composing the building envelope will be mapped in the 3D model visualization. This allows localizing and selecting the most irradiated surfaces and/or start the process of solar optimization to maximize as much as possible the solar potential of the different surfaces. The visualization of the shadow cast during the day on the building envelope represents an essential factor for direct radiation computation. Supported by the visualization, it is particularly relevant to be able to identify the most suitable façades for the installation of PV system. The glass coloration process allows for a large selection of aesthetic choices and tailored roofing solutions. The product is already fully integrable in tilted roof constructions (>15°). Further activities need/will aim at demonstrating the integration of such a product in façade and roof modules, focusing on the installation procedures and anchoring systems.

Geocluster Approach

In order to increase the replication potential of the deep renovation packages (including technologies, methodologies and business models), a geo-cluster approach should be adopted. Starting from the knowledge and the outcomes from EU-funded projects (e.g. Ge2O, and others) the preliminary boundaries of at least four geo-clusters is advisable, according to a specific set of parameters (Figure blow).

In particular, in order to take into account the climatic conditions, the European Heating Index and European Cooling Index[1] should be adopted.

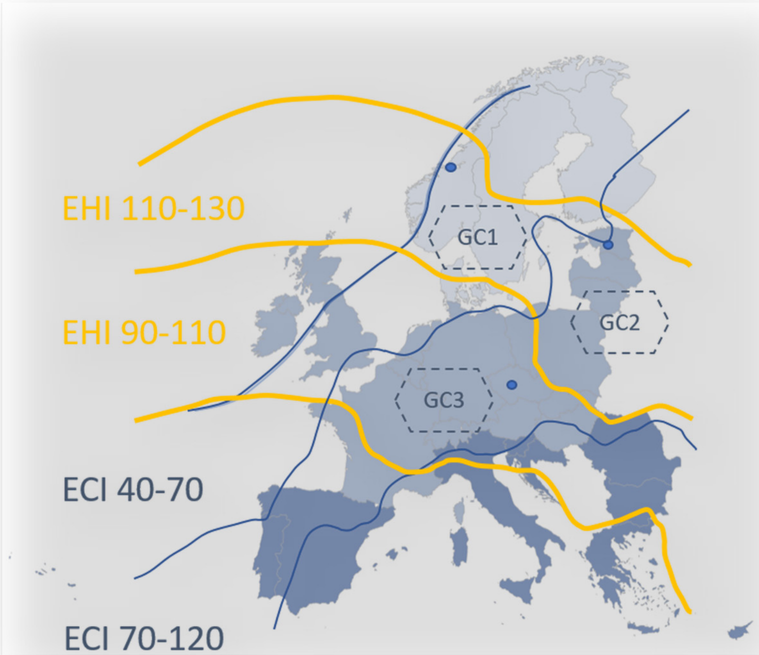

Figure A: Geoclusters in Europe based on EHI and ECI.

The following 3 geo-clusters that have been identified:
Geo-cluster 1. Climate zone 1: Northern EU. Northern Europe countries with cold climate (EHI between 110 and 130 and ECI between 40-70) covering the countries Norway, Sweden, Denmark, Finland.

Geo-cluster 2. Climate zone 2: Northern-East. Country with cold climate (EHI between 110 and130 and ECI between 70-120) which covers the countries Estonia, Latvia, Lithuania, Poland.

Geo-cluster 3. Climate zone 3 and 4: Continental West and Central and East (with EHI between 90-110 and ECI between 70-120) which covers the countries Czechia, Germany, France, Belgium, Netherlands, Luxemburg, Austria, Switzerland, Hungary, Slovakia, Slovenia.

VISION:

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