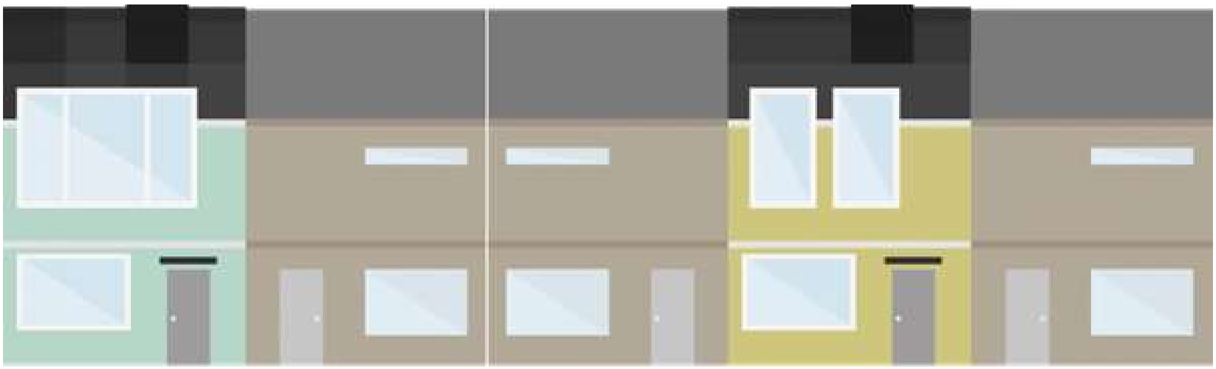


MORE-CONNECT 633477

FINAL PUBLISHABLE REPORT

MAY 2019

MORE-CONNECT

Development and advanced prefabrication of innovative, multifunctional building envelope elements for Modular Retrofitting and smart Connections

Contract No.: 633477

Report: Final Publishable Report

Work Package: Work package 1, Task 1.8
Deliverable: D 1.7

Status: [*public*]

Prepared for:
European Commission
EASME
Project Advisor: Mr Miguel Angel Romero

Prepared by:
Peter Op 't Veld, Huygen IA
Martina Carrabs, Huygen IA
John van Oorschot, Zuyd University of Applied Science
May, 2019

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION'S H2020 FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION UNDER GRANT AGREEMENT NO 649473.

EXECUTIVE SUMMARY

Deep renovation in Europe

Reducing fossil energy and the related CO_2 emissions from the EU housing stock are the most important and complex targets, in order to fulfill the 'EPBD recast', which states that all buildings/houses should be renovated to operate with 'nearly zero or very low amount of energy. The EU housing stock consists of around 250 million dwellings, but it cannot be applied common solutions for the whole European countries because the housing stock in question is very diverse and is located in different climate zones with different heating and cooling demands. Besides, such factors as different ownership situations, different market organization and regulations should be accounted for. Due to this complex situation, the European building sector has not been able yet to devise a structural, large-scale retrofitting process and systematic approach.

The MORE-CONNECT project tries to solve these problems by proposing an approach based on a combination of product innovation, process innovation and innovative market, in a process of cost and quality optimization, driven by motivated and innovation-driven SME's. In fact, the main reasons why deep renovation is not still widely spread in Europe are that processes involve many sub-disciplines and most of the times they are long and full of failure risks; moreover building sector is very fragmented and the market is not end-users needs-oriented.

The MORE-CONNECT approach

The MORE-CONNECT project offers an innovative retrofitting process by applying prefabricated multifunctional renovation elements which could reduce not only costs, but also renovation time and disturbance for occupants and, at the same time, enhance quality and performances, both in terms of energy efficiency and indoor climate. Especially for deep-renovation processes, an approach focused on national/regional circumstances is needed, having at the same time a common European way to act. For this reason, seven different geo-cluster were involved in the project, making up the MORE-CONNECT team.

The objectives

Firstly, the MORE-CONNECT project deals with the development of cost optimal deep renovation solutions, toward introduction of energy efficiency and renewable energy systems, according to nZEB renovation concepts. Deep renovation promoted by MORE-CONNECT is based on using pre-fab multifunctional modular elements for both façade and roof and installation/building services. These elements can be combined, selected and configured by the end-user, based on his specific needs. Using pre-fab elements allows to build a mass production process which implies a reduced price for end-users. Furthermore, these elements have been combined with the implementation of new fully automated production lines, to reduce production times. In fact, the high level of prefabrication and the use of smart connectors limit the actual renovation time on site from 2 months to a maximum of 5 days, with minimum disturbance for occupants too. A very important issue of the approach used is the high level of quality management during the production process and monitoring of performances of the most essential parameters related to energy use and remote diagnostics of the most important installations and building services. This ensures clients a high guarantee of interventions quality. The MORE-CONNECT project provided also the development of a one-stop-shop concept, to improve the relationship between end-users and production companies. Finally, in order to achieve a decarbonization of the European building stock, MORE-CONNECT made several steps towards an nZEB-oriented retrofitting, using a local approach instead of waiting for international directives. The MORE-CONNECT approach focuses mainly on local production of renewable energy and on the reduction of energy loss in buildings; however, implement strategies for changing inhabitant behavior still has a key role in achieving nZEB retrofit, because energy is used by people and not by buildings.

Technology development

The technology development started with the selection and development of the components that are necessary to achieve wanted quality. As first, an inventory was made of the initial performance criteria that these components should have, on the basis of the requirements provided by each MORE-CONNECT geo-clusters and countries. The selected criteria are used as a reference during all the project phases to assess the performances of the solutions.

The next step was to design a set of basic modular elements for façades and roofs, using a decision-making tree, which helps to determine the dimensions and shapes of wall modules and location of connections of the integrated building technologies. A prerequisite of these modular components is that they should be suitable to be combined in the multifunctional modular renovation elements and be suitable to be processed in an automated production process.

The integration of embedded ventilation systems is a major challenge for practical application of modular elements. For this reason, a clear guidance for selection of most appropriate ventilation systems has been developed, taking into account buildings' construction, maintenance as well as operation costs. In addition, the technical solution for modular HVAC units has been provided.

To encourage the application and integration of renewables, an inventory and an overview of existing technologies have been performed, in order to identify and underline the main technical and social barriers as well as the political context, at the global and local level, regarding the integration of renewable energy production in buildings.

As the prefab multifunctional elements contain several components (for example ducts, ventilation grilles, connectors) which could form thermal bridges and cause a local decrease in performance, it is necessary to integrate high-performance insulation materials, like vacuum ventilation panels (VIPs) and aerogels, with modular facade and roof elements. Also, smart connectors have been developed, in order to simplify building process and limit the actual renovation time.

Concept development and system integration

In order to have a common reference for the design of prefab panels, a matrix has been developed, which classifies building types and common features in each geo-cluster, as well as providing the specifications for the development of prefab elements. Thanks to this matrix, it's more clear what elements can be jointly developed and which need local adaptation.

After that, the performance specifications and criteria of the prefab facade elements were described; also, the material impacts of prefab elements, i.e. the insulation package, in terms of embodied energy impact, decreasing the operational energy savings were studied. NetZEB is chosen as reference level (thus 100% reduction situation), since at that point operational energy has no CO_2 and fossil fuel impacts anymore, and the CO_2 and fossil fuel impacts from materials invested become decisive. This work has resulted in a combined tool for decision making for optimization of operational energy use, embedded energy use, renewable production and costs.

With the previous steps, a platform for retrofit concepts could be developed. The platform gives an easy insight in modelling a concept, the available freedom in choices of facade elements, and act as a basis for descriptions of real market retrofit concepts.

In order to implement a deeper analyses and evaluation, MORE-CONNECT has developed a techno-economic assessment methodology for life cycle assessments. The methodology is based on the comprehensive evaluation of all energy, GHG-emissions and cost impacts; it also includes embodied energy use and related GHG-emissions for the materials used for the solutions MORE-CONNECT provided. Moreover, an inventory and collection of requirements on short-term and long-term monitoring systems were performed, useful respectively for the experimental elements and for the final renovation elements.

Production and process innovation

One of the innovations introduced by MORE-CONNECT is the use of geomatics to obtain a clearer building knowledge and more precise model. This tool is very important to avoid design errors and costs increase during the construction process thanks to its higher precision.

Geomatics could also be used in connection with BIM, but a significant amount of time is still needed for the processing of the data and translation of the information from a point cloud to simple a BIM model. Anyway, MORE-CONNECT developed a detailed state-of-the-art of the application of BIM and its constraints in relation to building renovation and tools for energy analysis.

As already said, the prior objective of the MORE-CONNECT project is to make deep renovation process more user-friendly and attractive for its end-users. To reach this goal, tools and platforms have been implemented to support the decision making on renovation concepts and for modeling building and performance characteristics. In fact, home owners can model different scenarios, choose the solutions that suit them better and understand which is the needed investment and the potential energy saving connected with their choice. The same tool can also be used by concept developers and suppliers to show their clients the consequences in terms of, for example, investment costs versus savings and added qualities. Their help could be very important for end-users to increase their awareness about energy use and potential improved energy efficiency of buildings.

MORE-CONNECT also promoted improvement of production lines, especially in reduction of the production costs or in reduction of the need of manual work. Various areas of improvements were involved, such as processes related to the mass production, marketing and sales processes, logistics.

The MORE-CONNECT demonstration and pilots

All the technologies and the concepts related to deep-renovation that have been developed in MORE-CONNECT have been implemented, demonstrated and tested in five real settings located in each project-partner country, involving mostly multifamily building, except for the Latvian case, which consists of a typical brick multi-apartment building, very common in the rural areas and small cities. Also, two new single-family buildings were used for in deep testing in the Netherlands and one mockup building in the Czech Republic. The MORE-CONNECT pilot projects have involved precise dwelling types, characterized by a simple and repetitive structure, such as row houses and apartment block. Renovation occurred in different ways for each country, but a common approach may be identified, as following explained. The building deep-renovation process starts with the analysis of the selected building, assessing the current inside comfort conditions and energy consumptions, and investigating the quality of structures, doors and windows. To get accurate information about the external envelope, sometimes a 3D laser scannings of the building has been conducted. After, the renovation needs are evaluated, the design phase begins. The MORE-CONNECT strategy consists of a demolition of the existing walls and replacing them with prefabricated wall elements, as happened in the Dutch case, or when it's possible, to attach the insulation element onto the existing walls. The prefab modules are usually provided with structural wooden frame, thermal insulation, new high-performance windows, and integrated technologies. Renovation also includes the roof, in which a layer of insulation on top of the existing roof is applied, with options to integrate solar thermal or photovoltaic systems. In case of particular conformation, some project-specific, detailed solutions can be developed to adapt each building to modular walls. The main advantage of this renovation strategy is that the installation of the prefab elements takes a few working days and very little disturbance for tenants. In fact, when the prefab elements were placed over the existing walls, tenants could stay in their homes during installation operations. While when existing walls were removed, installation took place from the inside, therefore no scaffolding or manual labor is needed, apart from fixation to the existing concrete walls. All the operations are performed by specialized dedicated teams who are familiar with the product and with processes. In order to reach a very low level of energy use, installations renovation is also required: most of the times, renovated buildings are provided by mechanical ventilation with heat recovery, heat pump for hot water use and for heating, and PV panels for electricity generation.

Market and replication

A pre-selection of the favorable concepts has been made, for having a base of what will be offered to end-users; this is performed with respect to initial performance criteria which have been selected at the beginning of the renovation process. Also, the pre-selection is done with a specific focus on each geo-cluster, but with a common approach and a common base quality. For each geo-cluster, the most common favorable renovation concepts were insulation of walls and roof; in some cases, like the Netherlands' case, the ground floor insulation too; windows replacement; installation of new heating and ventilation system. This pre-selection was reviewed after the results of the first tests in the pilots, selecting only the most favorable concepts, for which a business plan was elaborated, focusing on investigating the business possibilities for bringing the MORE-CONNECT solutions to the market and for making possible to fulfill mass needs. A different business plan has been elaborated, according to the final concepts selected by each project partner.

The MORE-CONNECT project also provided the development of a One-Stop-Shop concept, which aims to bring together producers and end-users: in this concept, an inventory of existing situations, specific end-user demands and possible renovations is available for end-users. Furthermore, some valorization models were elaborated, to describe in more detail how the business plans are going to be implemented. In particular, valorization models go beyond the business plans by specifying the channels, multipliers and market actors for bringing the MORE-CONNECT solution to the market, by mentioning subsidiary financing offers or strategies or other supporting services, as well as by identifying potentially necessary regulatory and supporting framework conditions.

Key cornerstones

For many partner countries of the project, all the technologies proposed by MORE-CONNECT approach have been applied for the first time at this scale. One of the first challenges was to cope with the high investment costs of the deep-renovation, which tend the be recovered over a relative long period of time. In particular, operations regarding the building envelope, the installations and the finishes are the most expensive, which makes deep-renovation not very different from the new construction in terms of costs, if demolition and land cost are excluded. It has been estimated that in both cases the return on investment is about 40-50 years within the social housing market. However, the MORE-CONNECT approach not only reduces operational energy costs, by improving energy performance, but adds value to the general quality of the building too, in terms of improving indoor living comfort, longer duration of the building, little disturbance for occupants during renovation works. If all these features were taken into account in calculating the return on investment, the MORE-CONNECT deep-renovation approach would be more affordable for homeowners.

Conclusions

One of the main difficulties found with MORE-CONNECT approach is the generalized lack of knowledge on innovative deep retrofit design methodologies. This leads end-users to be wary of renovation and they are in general still reluctant. Despite all the innovations carried out by MORE-CONNECT, the implementation of technological solutions for deep retrofit and pre-fab systems could be further developed in further (EU) projects, using a more holistic approach and user-centric design processes. There's also the need to improve the relationship between costs, environmental aspects and quality, because major traditional construction companies have a completely different approach with which MORE-CONNECT cannot compete. In fact, traditional companies have very low bids and most of their income is due to extra work and failure costs, all that MORE-CONNECT tries to avoid, in favor of client' needs. Furthermore, MORE-CONNECT solutions have a higher quality if compared to traditional solutions, so that it takes them far from the general building market.

Table of Contents

1. INTRODUCTION

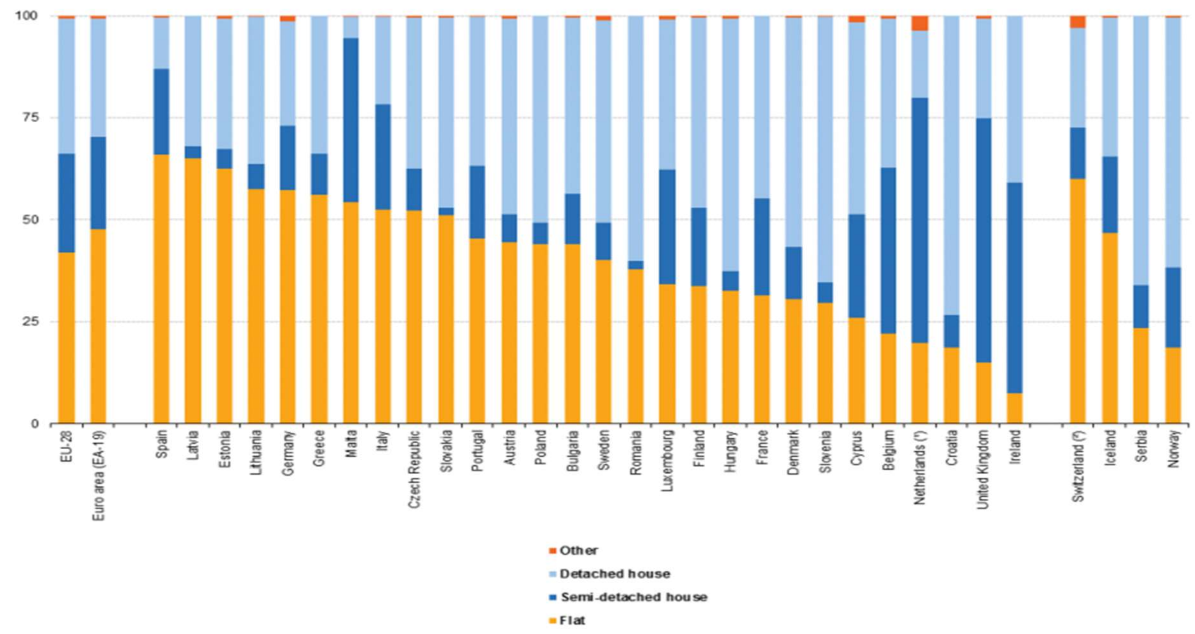
1.1 The European housing stock

The EU housing stock consists of around 250 million dwellings, which all in some way consume energy, mostly fossil energy, for operational use. (However, it should be noted that in fact *people* use energy, for their comfort at home, work, etc. and not *buildings*). The EU has set a target to reduce this fossil energy consumption and the related CO2 emissions, issuing the directive known as the 'EPBD recast', which states that all buildings/houses in some way should be transformed to operate with 'nearly zero or very low amount of energy required'. Therefore, the renovation rate in EU needs to increase from the present level of 1.2% per annum to at least 2-3%. This is no sinecure, since the housing stock in question is very diverse and is located in different climate zones with different heating and cooling demands. Besides, such factors as different ownership situations, different market organization and regulations should be accounted for.

Energy use in buildings accounts for roughly 40 % of Europe's total final energy consumption, the share of households being 27 % of the total. Final energy from renewable sources in households in the EU 28 accounted for only 15 %. In 2012, greenhouse gas emissions generated by households caused 19 % of Europe's total emissions. From the total EU housing stock, around 66 % is built between 1945 and 2000, 22 % before that, and 10% after 2000.
Greece, Spain, Ireland, Portugal, Croatia and Bulgaria have the youngest housing stock, with the largest proportion added after 2000.
Regarding the oldest fraction, where the housing stock was mainly built before world War II, Finland, Slovakia, Greece and Cyprus have the least, less than 1 in 10 dwellings built before 1946. By contrast, more than one third of the housing stock in Denmark, Belgium and the United Kingdom was constructed prior to 1946.

Another significant difference is the costs of housing: they may vary from 20% to 40% of income in the EU 28. This, in turn, means that on the one hand the interest in reducing these costs might be high, but at the same time the remaining budget to invest might be low for that same group and vice versa. In the light of energy reduction, the type of dwellings and the distribution of population per dwelling (Figure 1.1) are the factors to be considered.

The main difference may be observed between the people living in flats/apartment blocks, and the ones residing in individual houses (terraced, semi-detached and detached). This is a significant difference in the light of potential solar energy generation on or nearby the house: The average roof surface per house and per inhabitant differs greatly.
The average useful floor area occupied per person is a directly related factor, which has a direct impact on the energy demand: The housing statistics report shows that people in Luxembourg occupy the largest useful floor area, 66 m2/cap, and in Romania this index is the lowest – 15 m2/cap.
These are two exceptions, in the majority of countries this indicator is between 25-50 m2. However, this already can imply the difference in the heated surface of a factor 2! It is interesting to analyze how these occupied square meters are distributed over different climate zones in the EU, which relates directly to the surface area of solar panels required in particular geo-clusters considering their solar electricity potential. If smaller useful floor area were occupied in the areas with low insolation, it could theoretically compensate for the lack of solar energy, and vice versa.



(1) Provisional data.
(2) 2014.
Source: Eurostat (online data code: ilc_lvho01)

Figure 1.1 Characteristics of the European housing stock

1.2 What is the definition of deep renovation?

Conventional state of the art energy renovation focuses on isolated system upgrades, i.e. façade, lighting and HVAC equipment. These renovation are most largely effectual in their anticipated goals, simple and fast to deploy, but they often miss the opportunity for saving more energy cost-effectively.
A deep energy renovation is a cost-effective whole-building process that employs integrative design to attain larger energy savings compared to the ones achieved through the adoption of separate energy retrofit measures. According to the EU Energy Efficiency Directive, the deep renovation process represents a solution able to reduce both the delivered and final energy consumption of a building by a significant percentage compared with the pre-renovation levels; typically more than 60% energy saving , while increasing user comfort and indoor environmental quality (IEQ) levels.
Deep renovation are cost-effective since higher energy performance is resulting in the lowest cost during the estimated economic lifecycle of the building, and quicker Return on Investment (RoI) for implemented solutions through energy savings.
The definition of deep renovation applies within the framework of major renovations, under two conditions: either more than 25% of the surface of the building envelope undergoes renovation or the total cost of the renovation of the building envelope or the technical building systems surpass for more than 25 % the value of the building.
Typically, deep energy renovation combine together energy efficiency measures such as the integration of energy efficient façades with improved insulation, air sealing of windows, moisture management, controlled ventilation and equipment, as well as HVAC systems with heat recovery ventilation sized and integrated within the opaque envelope and walls, as well as active energy components incorporating RES in the building façade and roof, equipment, air sealing, moisture management, controlled ventilation, insulation, and solar control so that dramatic energy savings are achieved
Component quality and durability, good indoor air and overall environmental quality (IAQ and IEQ), alongside optimal building performance, while minimizing investments and operational costs is

achieved through systems thinking. For this reason, deep energy renovation oftentimes make use of energy modelling tools and building information modelling (BIM) that integrate all the environmental, financial and policy decision-making mechanisms.

So, summarizing, a **deep energy renovation** is a *cost-effective whole-building* process that employs integrative design to attain larger energy savings compared to the ones achieved through the adoption of separate energy retrofit measures.
Deep renovation packages include **integrated solutions** combining sets of renovation measures, as well as an advanced integrated design method, dynamically including production, monitoring, control and operation of smart components and systems.
A deep renovation process represents a solution able to reduce both the delivered and final energy consumption of a building by a significant percentage compared with the pre-renovation levels; typically more than **60% energy (cost) saving,** while increasing user comfort and indoor environmental quality (IEQ) levels.

1.3 Deep renovation – the situation in Europe

Decarbonization of the EU building stock is one of the most important and complex fields to achieve a decarbonized European society in general. While, as mentioned in section 1.1, the built environment is responsible for 40% of final energy consumption in the EU, embodied energy in buildings can account for up to 60% of the building's life cycle energy, with collateral embodied CO_2. Yet, the social and environmental urgency of large-scale integrated retrofitting of the European building stock is widely acknowledged and supported by the European Member states. However, the European building sector has not been able yet to devise a structural, large-scale retrofitting process and systematic approach. The main reasons for this deadlock are:

- the European building sector is fragmented and not able to offer holistic, integral solutions for nZEB deep renovation toward nearly Zero Energy Building (nZEB) for reasonable costs and good quality;
- the European building process is typically based on a 'layered' structure, with many labour actions on the buildings site, with many sub disciplines involved, leading to extra costs and failure risks;
- the European building market is typically top down and supply driven, with a mismatch between the offered products and the end-users needs and the end-user's affordability;
- due to long-lasting renovation process and failures risks during that process, customers hesitate to renovate their property; sometimes high operating cost are more acceptable for owners-residences than deep renovation with low exploitation/ energy costs; a faster and quality guaranteed renovation solution is needed.

There is a challenge to overcome these barriers by applying prefabricated multifunctional renovation elements which have the potential to reduce costs, reduce the renovation time and disturbance for occupants and, at the same time, enhance quality and performances, both in terms of energy efficiency and indoor climate. As the larger building companies are usually very traditional and have no specific economic interest in this transition, it is most likely that this transformation in building practice will be initiated by motivated innovative SME's, combined with production-line-design specific experience.
The challenge of the MORE-CONNECT project is to make this major step forwards by a combination of product innovation, process innovation and innovative market approach, in a process of cost and quality optimization, driven by motivated and innovation-driven SME's.
There are 250 million houses to address, which makes H2020 projects on deep renovation – such as MORE-CONNECT – very valuable to explore how mass retrofit can be deployed and applied.

1.4 The MORE-CONNECT objectives

This leads to the following four main qualitative objectives for MORE-CONNECT:

1. The development of cost optimal deep renovation solutions towards nZEB concepts with the possibility of extra customize (cost-effective) features

The first objective is the development of optimal configurations of energy efficiency and renewable energy systems, as one of the quantitative objectives is the offering of nZEB renovation concepts. These concepts will be preselected, i.e. in balance between demand reduction and renewable production, looking for the most optimal mix within the range of term 'nearly' in Nearly Zero Energy. Next to it, a life cycle approach will be used to assess the modular renovation solutions.

2. The development and demonstration of prefabricated multifunctional modular renovation elements in series of 1 concepts, in a mass production process

The second objective is to develop and to demonstrate a platform for prefabricated, multifunctional renovation elements for the total building envelope (facade and roof) and installation/building services. These elements can be combined, selected and configured by the end-user, based on his specific needs. The configuration can be made on the basis of a pre-selection of elements, based on the specific properties and measures of his home inventoried by advanced geomatics with various aesthetic and architectonic appearances. As input into advanced Building Information Modelling systems it can control and steer the further production process of these elements. In this way unique series of one can be made in a mass production process for the same reduced price of mass production.

3. The development and demonstration of new fully automated production lines for multifunctional modular renovation elements

The third objective is the development of newly designed automated production lines that effortlessly support line production that is effective on series-1 as well as large series and seamlessly combine into mass customization principles; aimed at supporting prefabrication for extreme retrofitting of homes.
Extreme automation makes it possible to produce end-user-defined (by choice) integral products efficient in small (1) as well as large series. Machine instructions then need to come from automated computerized numeric control instruction generation based on Building Information Modelling (BIM) and in-situ measurements. Plant management is organized in software solutions that support line-balancing as well as JIT (just in time) and flow. Line design needs to support scalability in product complexity, support of more than one product-market combination and output. This will lead to a blueprint for the design and structure of a platform for a fully automated production line, as a further basis for product-market-combinations in several countries.
MORE-CONNECT demonstrates that a model for one common platform for a fully automated production line can be used in different geo-clusters.

4. The offering of a one-stop-shop to the end-users to renovate their homes

The fourth objective is a development of a one-stop-shop concept for the end-user, but also for the production. In this 'one-stop-shop' proposition the end-user will deal with only one party, responsible for the total renovation, starting from an inventory of the existing situation, inventory of specific end-user demands, translation into modular renovation kits, mounting and installing, financing and aftercare. The high level of prefabrication and the use of smart connectors (mechanical, hydraulic, air, thermal, electrical, ICT) will limit the actual renovation time on site to a maximum of 5 days with a goal for an average of two days, including the complete or partial removal of the existing facades and roofs or other elements. During the renovation the occupants can stay in their homes and have a minimum disturbance. The end-users will get a guaranteed energy cost proposition for their renovated homes, based on their individual household profiles. An energy cost and performance guarantee are possible by the high level of quality control during the production process and the monitoring of performances of the most essential parameters related to energy use (ventilation, heating, indoor air temperature, micro climate conditions, electric appliances etc.) and remote diagnostics of the most important installations and building services.

1.5 The MORE-CONNECT approach

1.5.1 The four MORE-CONNECT pillars

The MORE-CONNECT approach and concept are based on the following four pillars:

- *product innovation,*
- *process innovation,*
- *cost, environmental and quality optimisation,*
- *the needs and perception of the end-user.*

Product innovation:

Product innovation includes the selection of sustainable materials and sustainable detailing based on LCA, including recycling of materials, bio-based materials, flexible, easy to disassemble, and the use of secondary materials. The technologies and components, necessary to come to a NZEB renovation will be combined and integrated as much as possible in multifunctional elements. Low embodied energy will be a criterion in the design and development.

Three main modular elements are discriminated:

- **Modular facade elements**, combining all facade functions like:
  - thermal insulation, acoustic insulation, moisture safety, water and air tightness
  - daylight and solar shading
  - ventilation with heat recovery
  - heating and cooling emission
  - fire safety
  - burglary protection
  - architectural quality and visual upgrading of the neighbourhood
  - extra features as heat storage
  - renewable energy production on facades

- **Modular roof elements**, including productive outfitting for renewable energy production and rainwater collection.
- **Modular 'engines'**, combining all necessary installations and building services in one prefab unit, with easy plug and play connections for installing.

A specific feature is the development of **Plug and Play connections** of modular components. These Plug & Play connectors make it possible to reduce the renovation time. Smart combinations of components and executions ensure extra performances for nZEB concepts, healthy indoor climate, safety, accessibility. The various components communicate by integrated (wireless) sensors and control components for performance diagnostics and control.

Process innovation:
These multifunctional elements will be produced and offered as tailor-made solutions for individuals as well as for housing companies, in mass production with the possibility of 'n is 1 series'. This needs a process innovation. This process innovation will be achieved by three steps:
1. Use of advanced geomatics to make inventories and gauging of buildings and buildings stock.
2. Web-based and/or digital decision tools will link building characteristics, building (energy) potentials, end-users demands to program requirements, technical solutions, component combinations in concepts, production automation.
3. This will be processed in BIM systems for the steering of industrial processes and for enhanced quality assurance.

This will lead to a transition of existing production facilities of building envelope elements to automated and computer-controlled production and assembly process.
In an innovative design process interdisciplinary teams will focus on systemic solutions aimed at combining/integrating the involved systems and systems levels like building and energy-installation as well as production and product-design.

Cost optimization:
Cost optimization will be achieved by:
- Integration of several technical components, at all systems levels ranging from placeholders to ventilation system or wall or roof, corresponding with the function of the element in multifunctional elements.
- Integration of systems leads to integration of components
- Re-design of components and renovation concepts for industrial assembling the component for reducing the amount of materials, time and costs
- Development of smart Plug & Play connectors for quick and easy installing
- Re-design to a integrated product, industrial, cost efficient, sustainable and demand-driven production
- Scale advantages due to mass production in an extremely automated line production process
- Minimizing interior works in apartment (ventilation ductwork for example)

Business models and advanced energy services will be developed for each geo-cluster.

Quality optimization:
Quality optimization is achieved on two levels:
1. On process and production level by quality enhanced control of the production process.
2. On application level by remote diagnostics of the performances of the prefab elements.

Shortened renovation process is not so weather dependent, which provide more moisture safe solutions.

Performance optimization:
Performance optimization, 'get more for the same or less money' by:
- systemic approach of for example building physics versus energy installations
- systemic approach using production accuracy to reach buildings/installation performances almost without extra effort and reaching better performance at the same time

Needs and perception of the end-user:

The individual interest of ordinary residents/end-users is mostly not focused on energy saving, but there are plenty desires for improving the houses, such as improving the indoor air quality, thermal comfort, to improve the acoustic quality, protection for burglary, etc. Many of these improvements are efficient to combine and to integrate with energy saving measures.
MORE-CONNECT focuses on the development of one-stop-shop concepts, systems of performance guarantees in combination with energy cost guarantee propositions.

Figure 1.2 The MORE-CONNECT pillars

1.5.2 Different solutions for geo-clusters using common platforms for the production lines

In European countries, climate conditions, building technologies, building traditions and culture can differ to a large extent. Therefore MORE-CONNECT project is focusing and working in different geo-clusters (see *Figure 1.3*). Following geo-clusters are addressed:

<u>Geo-cluster 1: Northern.</u> This cluster is focusing on solutions for the Scandinavian market (cold climate), There will be a special focus on nZEB renovation concepts for post-war multifamily dwellings in Denmark.

<u>Geo-cluster 2: Continental Northern East.</u> This cluster is focusing on a collaboration between two Baltic States (Estonia and Latvia). There will be a focus on the possibility of application of prefabricated products (wood construction) for typical post-war Soviet multifamily buildings; this typical building typology has a very high level of replicability, not only in Baltic countries but also in other former East-European countries as well as a very high energy saving potential. Next to it, as the Baltic industrial partners are also active in the Scandinavia countries a further implementation is envisaged on the Scandinavian market (with similar cold climates).

<u>Geo-cluster 3: Continental Centre.</u> This cluster focuses on Czech Republic and solutions for continental climates. There is a special attention for the application of advanced prefabricated solutions (as first introduced in Europe in the framework of the IEA ECB Annex 50 project Prefabricated Systems for Low Energy Renovation of Residential Buildings), cost optimization and life cycle approach (based on the experiences of IEA Annex 56 Cost effective Energy and Carbon Emissions Optimization in Building Renovation and IEA EBC Annex 57, Embodied energy).

Geo-cluster 5: Mediterranean. This cluster is focusing on solutions for mild and warmer climates, with a pilot for the Portuguese market. There will be specific emphasis on summer comfort, the (avoiding of) energy use for cooling, by smart passive and responsive building element solutions and technologies, as well as the integration of renewables in the concepts.

Geo-cluster 6: Western Central. This cluster focuses on the Dutch/Belgium markets. There will be a special focus on NZE renovation solutions for large scale single family post-war dwellings projects from the 60's and 70's in the Netherlands, characterized by poor building physical and thermal performances. These projects are typically built in concrete bearing tunnel structure with easy to fully remove and replace facades and roofs.

Although the product-market-combinations will differ in the addressed geo-clusters, the platforms for the automated production lines will be basically the same (as comparable with the production platforms world-wide car industry).

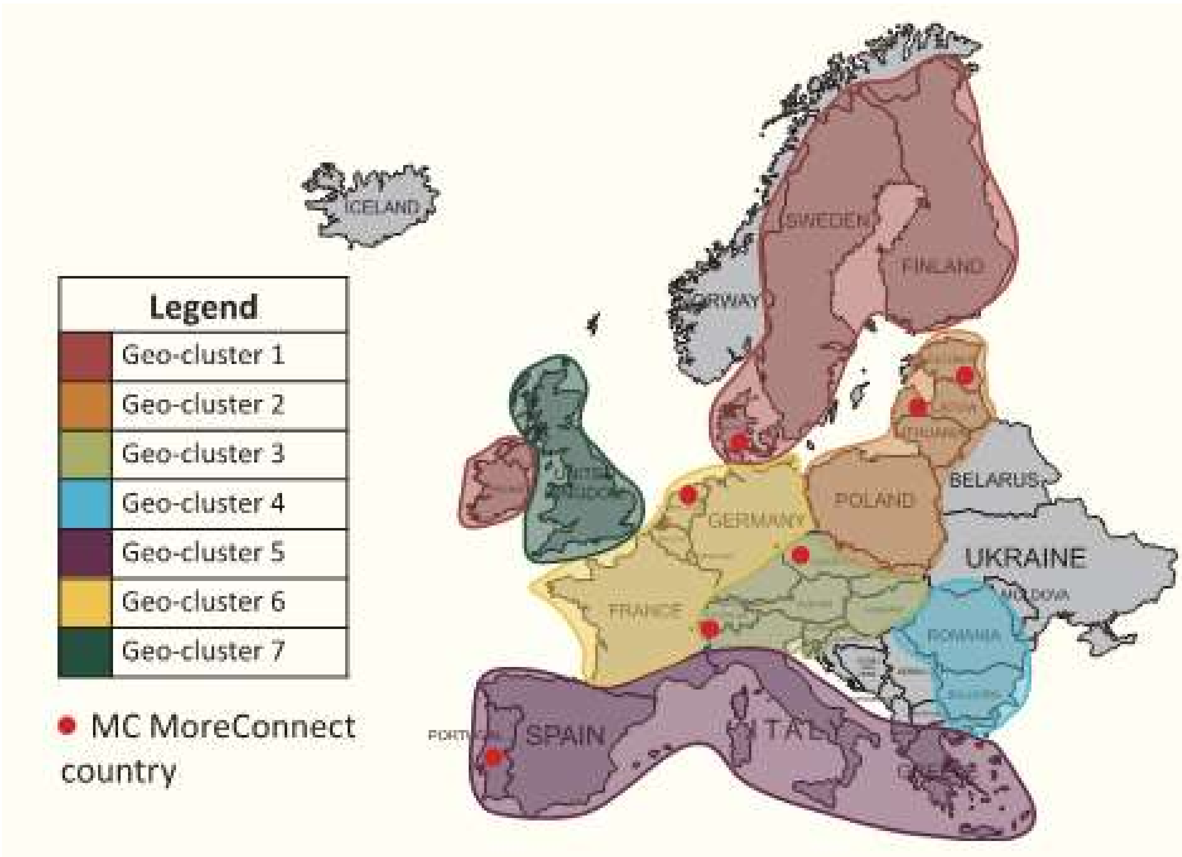


Figure 1.3 The MORE-CONNECT countries and geo-clusters

1.6 From MORE-CONNECT towards (nearly) Zero Energy Retrofitting

The technical developments in MORE-CONNECT is just a step towards a decarbonization of the European building stock and towards nZEB retrofitting.
Zero or nearly zero energy houses (nZEB buildings) are in fact houses that meet their energy demand by on site production of (renewable) energy, that is, by limiting consumption of fossil fuels and replacing them with local, building-connected generation.

There is an ongoing discussion whether energy neutral buildings could sometimes be a better option, namely, the houses that use only renewable energy, which can be produced elsewhere, either in the direct vicinity, or by the classic grid. National power supply systems are also in transition in most countries, and they will also eventually shift towards renewable energy production. For the housing sector, however, it has been decided to start as locally as possible, and not to wait until the whole system has been transformed. In some countries, local district heating will still be the major option to explore.
This is the starting point in analyzing retrofitting concepts for housing. With this in mind, to create zero energy houses, or nearly zero energy houses 4 main areas can be targeted:

1. (Local) production of renewable energy;
2. Reduction of energy loss in buildings;
3. Adaptation of building use;
4. Changing inhabitant behavior.

The MORE-CONNECT approach focuses mainly on areas 1 and 2, assuming the usual mode of operations for areas 3 and 4. Although it might turn out that to reach real zero energy targets and possibly beyond – energy plus houses, which, for instance, include energy generation for electric driving, areas 3 and 4 might have to be addressed as well. Within area 3, for instance, there is an option that the heated (or cooled) area should be reduced square wise. Within area 4, there is an option that average temperature levels are reduced or differentiated among different rooms. In some retrofit concepts, areas 3 and 4 are already addressed. Although knowing the fact that in fact *people* use energy and not *buildings*, area 4 might be one of the most important means to achieve decarbonization of the European building stock, MORE-CONNECT limits its scope to the steps 1 an 2, i.e., giving the technical boundary conditions to the further necessary steps.

The MORE-CONNECT approach focuses mainly on heating and ventilation (cooling), since this energy demand is related to the building itself. Household-related energy use will not be influenced by retrofitting directly. Optimization in energy and materials input will mainly be ensured by optimization of heating/ventilation. If areas 3 and 4 are left out, household energy is a set demand that can be supplied by the related given amount of extra energy generation.
Consumer behavior and behavioral change are now specifically addressed in a number of H2020 projects like MOBISTYLE www.mobistyle-project.eu, encompass http://www.encompass-project.eu/, UtilitEE www.utilitee.eu and TripleA-reno http://triplea-reno.eu.

1.7 The MORE-CONNECT team

As the transition to a large-scale renovation, facilitated by the application of prefabricated modular renovation elements, is a EU wide challenge, the MORE-CONNECT team is composed based on an approach and application in the different geo-clusters, addressed in MORE-CONNECT. Moreover, extended experience from earlier deep renovation projects learned that especially for renovation an approach is needed suitable for national/regional circumstances in terms of climate, building technologies and traditions and cultural habits. Nevertheless, a substantial part of the basic innovations in technologies, products, production and processes can be developed commonly in a European approach with modifications and tuning to local circumstances and needs.
The selection of the geo-clusters is based on countries with experience with the first applications of prefabricated renovation elements (The Netherlands, Denmark), extended experience in applied research on prefabricated renovation, the potential of large scale replication (Latvia, Estonia, for post-

war soviet residential buildings, also in other new member states with typical post-war Soviet buildings). Also, different relevant climates zones are addressed (cold, moderate, warm, continental).

In order to be able to make a real step forward there is deliberately chosen to work with SME companies instead of larger building companies.

To achieve two important objectives of MORE-CONNECT, i.e., the development of the prefab modular elements and the development of the automated production lines, two types of companies are selected: companies in manufacturing prefabricated renovation elements (WEBO, ZTC, Matek, Darkglobe, Invela, RD Rymarov) and companies in installing and construction, working with prefabricated (modular) renovation elements (BJW, Latvia Wood Construction Cluster, REF, RD Rymarov). As one of the quantitative objectives is a renovation towards nearly zero energy, renewable energy production is an absolute necessity. For that reason Ennogie is participating, a company specialized in the development and production of innovative integrated energy producing roofs.

The substantial industrial and commercial involvement in the project (10 companies from 5 countries) is meant to ensure exploitation of the results. This is needed to achieve the specific measures which are proposed for exploitation of the results of the project and to ensure an impact on European scale, for different climates, culture and building traditions.

The consequences of working with SME's, rather than working with large international building companies, is that direct knowledge support is needed in each geo-cluster involved. In order to give the SME's an effective and direct support, a national knowledge provider (university or building research institute) is linked to the national SME's.

The selected knowledge institutes and knowledge providers have an extended experience in international collaboration and international project on holistic retrofitting, prefabricated retrofitting, renewable energy integration, building physics and materials.

The MORE-CONNECT team and the specific roles of the participants are shown in table 1.1

Table 1.1 The MORE-CONNECT team

	Participant organisation name	Short name	Country	Specific role
1	Huygen Installatie Adviseurs	HIA	NL	SME consultant and knowledge provider Project coordination Testing and monitoring Dutch RLLL
2	Zuyd University	ZUYD	NL	University, knowledge provider Expert in LCA and zero-material impact approach System integration and concept development
3	BJW	BJW	NL	SME concept developer Concept development and process innovation, designing automated production lines.
4	WEBO	WEBO	NL	SME timber frame producer
5	Riga Technical University	RTU	LV	University, knowledge provider Development BIM applications Testing and monitoring Latvian pilot
6	Latvia Wood Construction Cluster	LWCC	LV	Association of wood constructors
7	Technological Centre of Zemgale	ZTC	LV	SME timber frame producer
8	Tallinn University of Technology	TUT	EE	University, knowledge provider Technology development Testing and monitoring Estonian pilot
9	AS Matek	Matek	EE	SME timber frame producer
10	REF Ehitustööd	REF	EE	SME construction company
11	University of Minho	UMinho	PT	University, knowledge provider Technology development Testing and monitoring Portuguese pilot
12	Darkglobe	DGlobe	PT	SME prefab element producer
13	Cenergia	Cenergia	DK	SME consultant and knowledge provider
14	Ennogie ApS	Innogie	DK	SME producer of integrated PV roofs
15	Invela ApS	Invela	DK	SME developer and applier of robotics
16	Czech Technical University in Prague	CVUT	CZ	University, knowledge provider Technology development Geomatics and BIM development Testing and monitoring Czech RLLL
17	RD Rýmařov	RDR	CZ	SME timber frame producer
18	Econcept	Econcept	CH	SME consultant and knowledge provider

2 TECHNOLOGY DEVELOPMENT

2.1 Introduction

The MORE-CONNECT project started with the technology development, as a basis for the further concept development and the production of a new generation of prefab integrated multifunctional façade and roof elements, as well as prefabricated platforms for building services. This started with the selection and development of the components that are necessary to achieve a certain base quality and, additionally, extra qualities. Prerequisite is that these components should be suitable to be combined in the multifunctional modular renovation elements and be suitable to be processed in an automated production process. The first step was to make an inventory of the initial performance criteria and requirements. These criteria were used during all the project phases to assess the performances of the solutions. The developed technologies had to comply with the requirements of the end-user and be suitable to be applied as plug & play to the platforms. Components are able to 'communicate' with:

- the occupant/user, as well as actively (controlled by the user) as passive (user parameters)
- external signals and parameters, like weather forecasting and remote control
- other components to control and adaptive optimization

As the prefab multifunctional elements contain several components (for example ducts) the overall thermal quality will be assessed (dynamical cold bridge simulations). If necessary, improvements can be made by detailing or the use of high-performance insulation. Therefore an extended technical review took place on the latest developments in super insulation materials.

An important part of the technology development is the use of smart connectors. In order to limit the actual renovation time on the site, the components and modular renovation elements will be equipped with advanced easy to use 'plug & play' connections, mechanical, air tightness, hydraulic, air, electric and ICT.

2.2 Initial performance criteria

The modular building envelope's retrofitting elements decrease most of all heat loss through the building envelope that is usually the largest component in energy use of old residential buildings. Nevertheless, required properties for the modular building envelope's retrofitting elements may depend on specific building and balance of measures for energy saving and energy production on site. Therefore, it was analysed what kind of requirements exists for modular elements to meet following targets:

- nZEB i.e. national nearly zero energy definition (if available in specific country);
- deep renovation with 80 % reduction of primary energy for:
    - space heating (+ pumps);
    - space cooling;
    - ventilation (heating, cooling, fans);
    - domestic hot water (DHW).
- ZEB i.e. Zero Energy Building = the primary energy use = 0 kWh/(m² a) (on annual basis) for:
    - space heating (+ pumps);
    - space cooling;
    - ventilation (heating, cooling, fans);
    - domestic hot water.

Results are presented in this report on initial performance criteria.

Table2.1 National design values for the indoor air quality for residential buildings in MORE-CONNECT geo-clusters and countries.

Indoor air quality criteria	Geo-cluster and country						
	GC 1	GC 2		GC 3	GC 5	GC 6	Switzerland
	Denmark	Estonia	Latvia	Czechia	Portugal	Netherlands	
Heating season (cold/winter)							
General air change rate h^{-1} $l/(s\ m^2)$ $m^3/(h\ pers)$	0.5 0.3	0.6 0.5, 0.42 (detached house)	0.6	0.5 25	Winter: 0.40 h^{-1} Summer: 0.60 h^{-1}	0.7	0.19
Supply air to living room and bedrooms l/s, pers	7.0	6.0	4.2	6.9	7[2)]	7	
$l/(s\ m^2)$	1	1.0	3	-	1[2)]	0.7	
Exhaust air flow, l/s a) kitchen b) bathrooms c) toilets	20 15 10	20 15 10	17-25 14 7	[1)] 27.8/41.7 13.9/25 6.9/13.9	20[2)] 15[2)] 10[2)]	21 14 7	11-167 <8-11
Corresponding CO_2 above outdoors (400 ppm), ppm	N/A	800	Not defined directly	1100	Maximum concentration [3)] 984 ppm	800	600-1000
Recommended ventilation during unoccupied hours, $l/(s\ m^2)$	N/A	0.05-0.1	N/A	0.1 h^{-1}	N/A	0.1 h^{-1}	0.14

2.3 Development of basic modular façade and roof elements

The first step was to design a set of basic modular elements for façades and roofs. The development was initially focused on collection of requirements on the renovation packages from all the geo-clusters in MORE-CONNECT. From this information overall requirements were derived on the wall modules. Therefore, a decision-making tree was developed, which helps to determine the dimensions and shapes of wall modules and location of connections of the integrated building technologies.

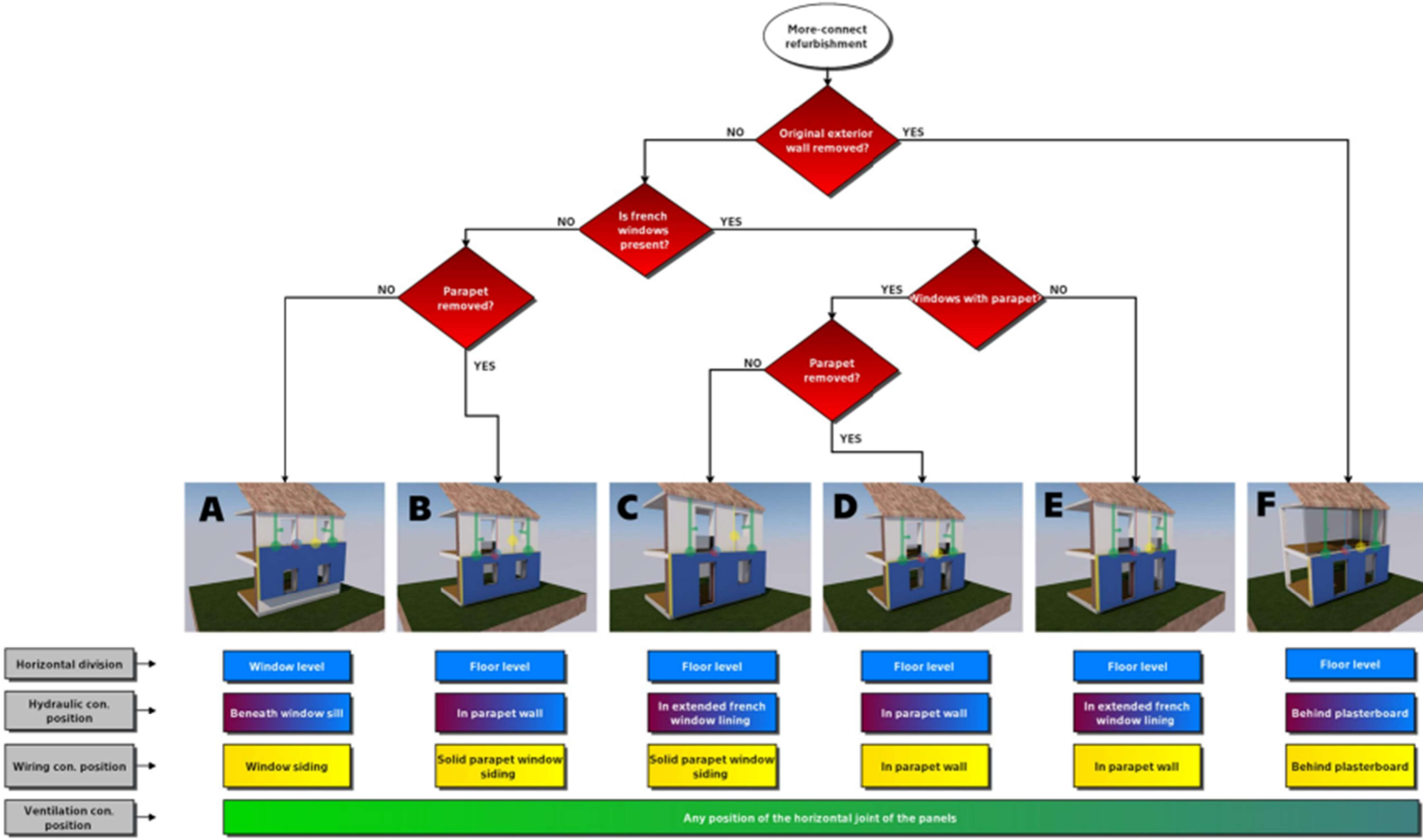


Figure 2.1 Process for determination of wall modules' shapes and positions of connectors.

In the next step this design method was further elaborated for the Czech pilot building (i.e. a test building as a real life learning lab). A set of renovation packages was developed with listings of modules, which will be further generalized so that the modules can be used in various climatic conditions.

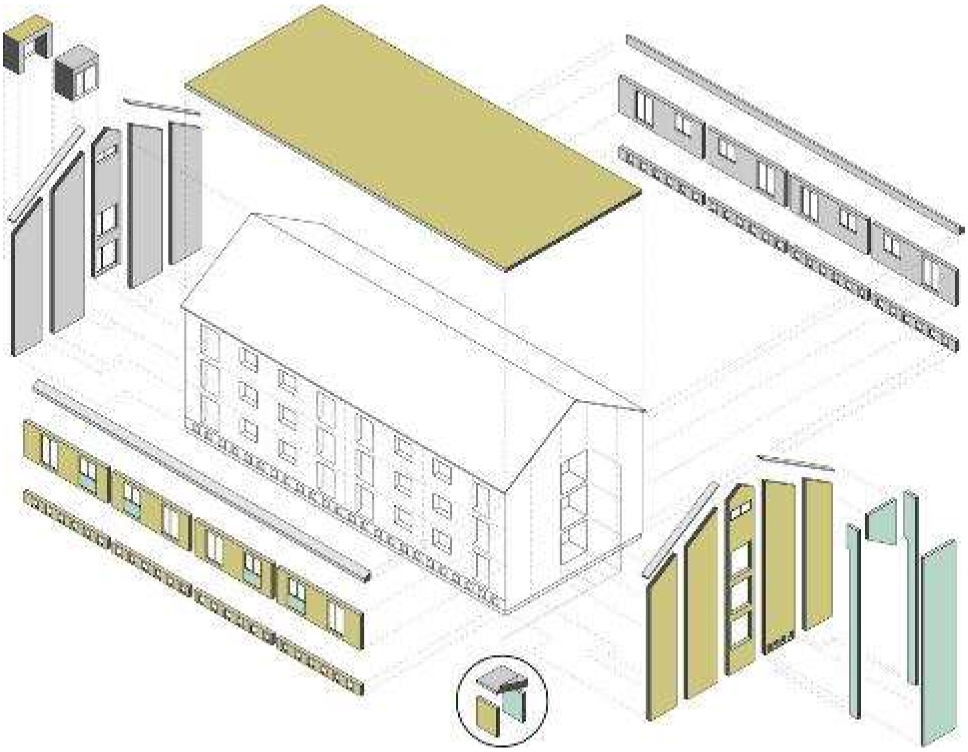


Figure 2.2 Renovation package for the Czech pilot case.

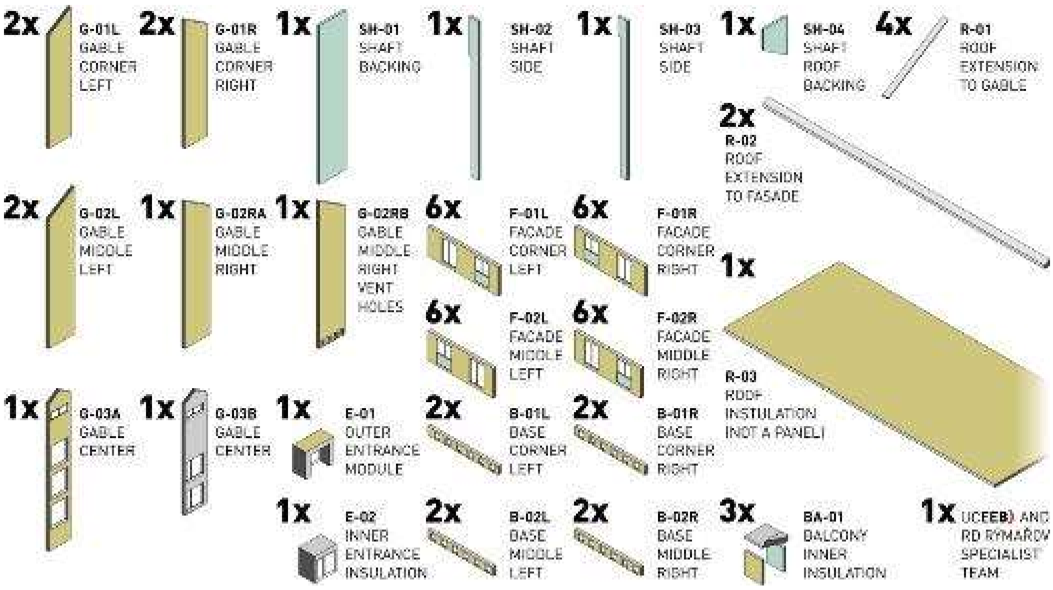


Figure 2.3 List of modules for the Czech pilot case.

These results are presented in this report.

2.4 Development of prefab platforms for building services ('house engines')

This work started with a technology inventory and review of all components that are necessary to climatize the residential buildings as part of the demonstration pilots in MORE-CONNECT. The main challenge of this deliverable was to define HVAC systems' dimensions and design specifics in four addressed European geo-clusters. The integration of embedded ventilation systems is a major challenge for practical application of prefabricated panels. In the scope of this task, the analysis of ventilation systems' design in the project countries was performed and main design parameters, such as necessary air flow, duct diameters and air velocity were defined. To compare the actual necessary ventilation air volumes from country to country a case building has been chosen. A comprehensive ventilation strategy analysis is made and necessary ventilation volumes for case building are calculated for each of the participating countries. A SWOT analysis was made for different types of ventilation systems providing a clear guidance for selection of most appropriate ventilation systems taking into account buildings' construction, maintenance as well as operation costs. In addition, the technical solution for modular HVAC units has been provided. This work is based on the survey done in each project geo-cluster and practical calculations taking into account the information submitted by partners. The installation and the maintenance costs were calculated using standard catalogues. The possible principles of these 'house engines' are described and the main possibilities of them described in the report HVAC solutions. This also includes a report on design and dimensions of the necessary components for a prefab installation platform. A first proof of principle has been constructed for a pilot dwelling in Heerlen, the Netherlands.

Figure 2.4 First proof of principle of a prefab 'engine' – installation platform

Two different ventilation solutions were installed in the Estonian pilot. This concerns an apartment based balanced (supply/exhaust) ventilation unit with heat recovery and centralized balanced (supply/exhaust) ventilation unit with heat recovery for future comparison (installation, efficiency, IAQ, thermal comfort, etc.). HVAC elements (pipes) were integrated into prefabricated modular wall elements.

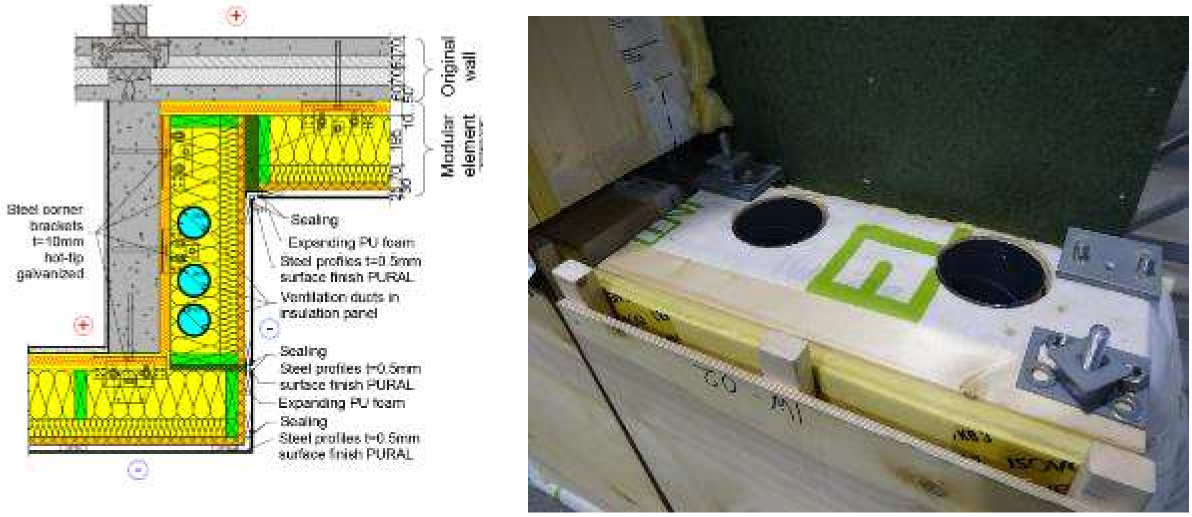


Figure 2.5 Embedded ducts in façade panels for the Estonian pilot

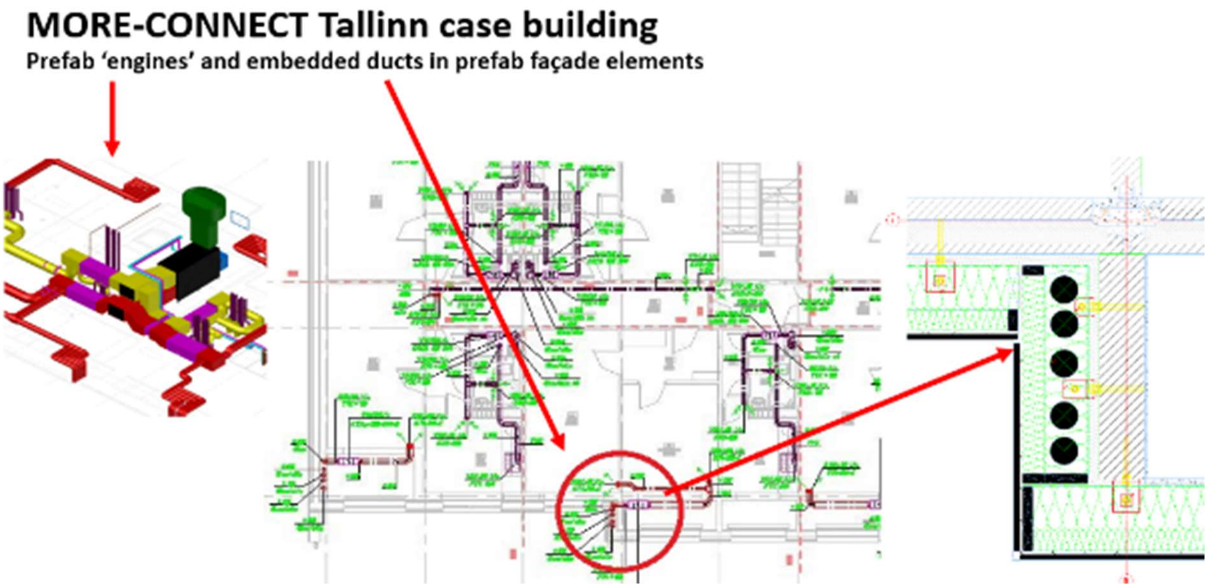


Figure 2.6 Prefab 'engines' for the Estonian pilot and connections to the embedded ducts

2.5 Integration of renewables

In order to achieve nearly zero energy renovation of residential buildings the application and integration of renewables is a major boundary condition. Therefore, the integration of renewables in the MORE-CONNECT concepts is a key element. This work started with an inventory, followed by the development of the state-of-the-art of building integrated renewable energy technologies, the overview of the technical/social barriers as well as the political context, at the global and local level, regarding the integration of renewable energy production in buildings. An extensive literature review has been performed in order to identify and describe the most up-to-date building integrated renewable energy technologies available (solar photovoltaic, solar thermal, wind, biomass, geothermal), including real case studies. This work also addressed a detailed list of the technical/social barriers and description of the political context at the global level. Each project participant then detailed the specific barriers and political context for its geo-cluster.

Moreover, each geo-cluster characterized its pilot case (climate analysis, space availability) to enable a future optimization of the most suitable renewable energy technologies to integrated, see report Integration of Renewables - Technology Overview.

A set of roof elements including renewable energy production (PV, solar collectors) were integrated to Estonian pilot.

Figure 2.7 Integration of renewables in the Estonian pilot

Also, in the Czech and Danish pilot integrated solar roofs by Ennogie were applied:

Figure 2.8 Integration of renewables in the Czech (left) and Danish (right) pilots

2.6 High Performance Insulation

A technical inventory report with a review on super insulating materials (SIM), is devised on the State of the Art of the latest HPI developments and products on the market.
HP insulation was integrated with modular facade and roof elements on prototype and full-scale level) The prefab multifunctional elements will contain several components (for example ducts, ventilation grills, connectors). This could lead to local situations were the thermal performances of prefab elements are weakened by these embedded elements. Therefore, the overall hygro-thermal quality of facade and roof should be assessed on its total thermal quality including thermal bridges, where necessary by using (dynamical) cold bridge simulations. If necessary, improvements can be made by detailing or the use of high-performance insulation materials like VIP and aerogels.

2.7 Smart Connectors

A specific feature in MORE-CONNECT is the development of Plug and Play connections of modular components. These Plug & Play connectors make it possible to reduce the renovation time. Smart combinations of components and executions ensure extra performances for nZEB concepts, healthy indoor climate, safety, accessibility. The various components communicate by integrated (wireless) sensors and control components for performance diagnostics and control.

The work started with a technical inventory and literature survey in which the different connector possibilities were analysed:

- One set of the combined connectors – built in the facade panel
- The individual connector placement will be adapted according to standard
- The opposite connector - flexible placement

The selection and/or further development of smart connectors scan be done following this decision tree. This decision tree was specifically made for the design of connections' location and ducts routing.

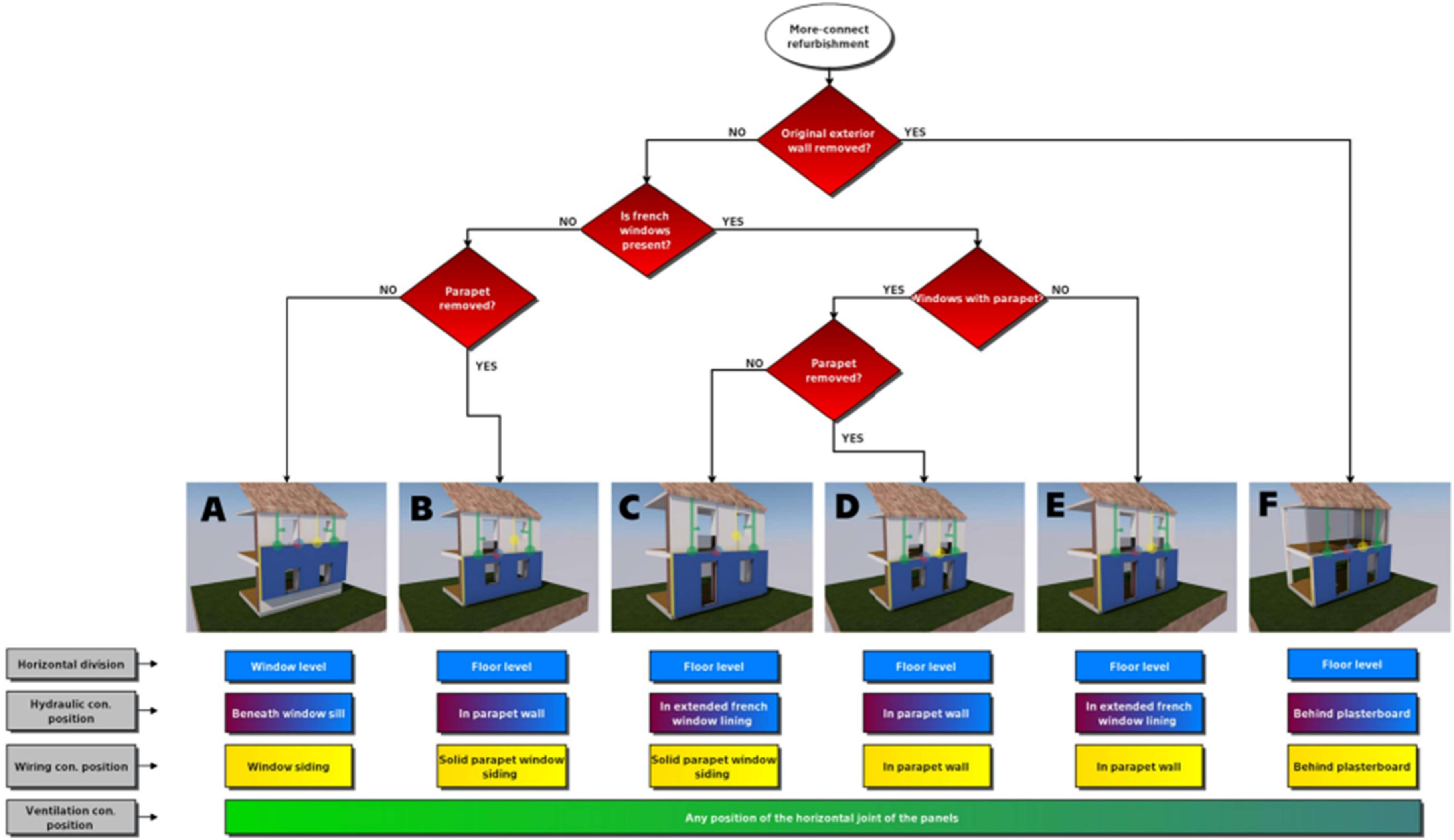


Figure 2.9 Selection of smart connectors

The following connectors were further developed within the project:

Mechanical connections, for fast and flexible mounting on the existing constructions and frameworks

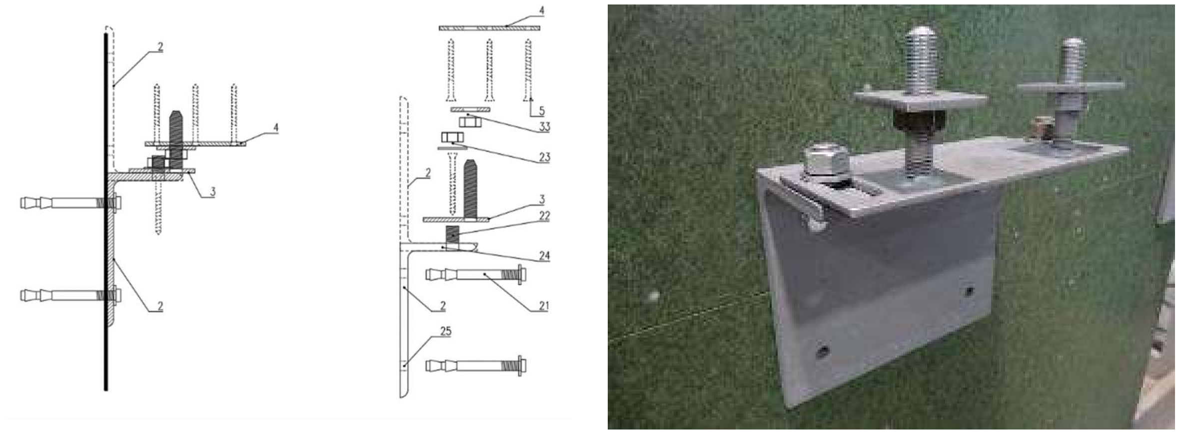


Figure 2.10 Mechanical connectors (Utility model: Bracket; Owners: Tallinn University of Technology. Authors: Targo Kalamees; Priority number: U201700012; Priority date: 28.02.2017.)

Air connectors, for integrated air ductwork:

- Metal ductwork: Socked connectors with sealing element
- Better fire resistance
- Separate ductwork for each window -> lower spreading of noise
- Connections with two sealing rings
- Socket connections up to 500 mm long

Figure 2.10 Connectors for air ducts

Airtightness of foamed joints between modular elements were tested in laboratory and on site to be used to tighten joints between modular elements, where using the tape is not possible. Click system was not possible because of too thick distance.

Figure 2.11 Connections for airtight joints

Hydraulic connectors, for the connection of integrated heating/cooling emission systems to the MORECONNECT 'engine'

- Connection between panels – **pushfit connectors:**

Figure 2.12 Hydraulic pushfit connectors

- Connections inside pannel – **pressed connectors:**

Figure 2.13 Hydraulic pressed connectors

Temperature compensator on the pipeline allows adjustable pipeline end allowing connection. Fixing of pipeline only on the top of the panel.

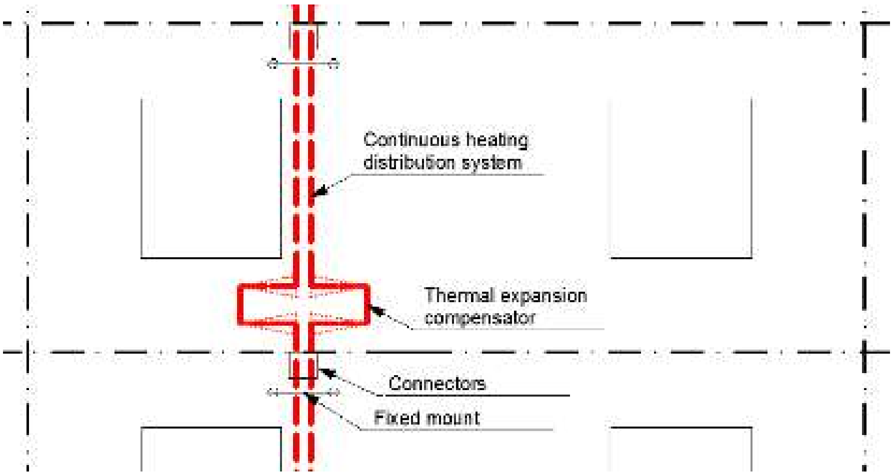


Figure 2.14 Thermal expansion compensators

- Electric connectors for power connection if necessary in the elements (power plugs or integrated appliances and connections for control and communication of integrated functions.

Connections for control and communication of integrated functions:
- Distribution of power 230VAC to the flats (wall sockets and lights)
- Distribution of Photovoltaic DC bus to string the integrated PV panels
- Distribution of ethernet
- Distribution of communication bus and power for sensors and controller
- Selection of proper cabling and connectors for the panels

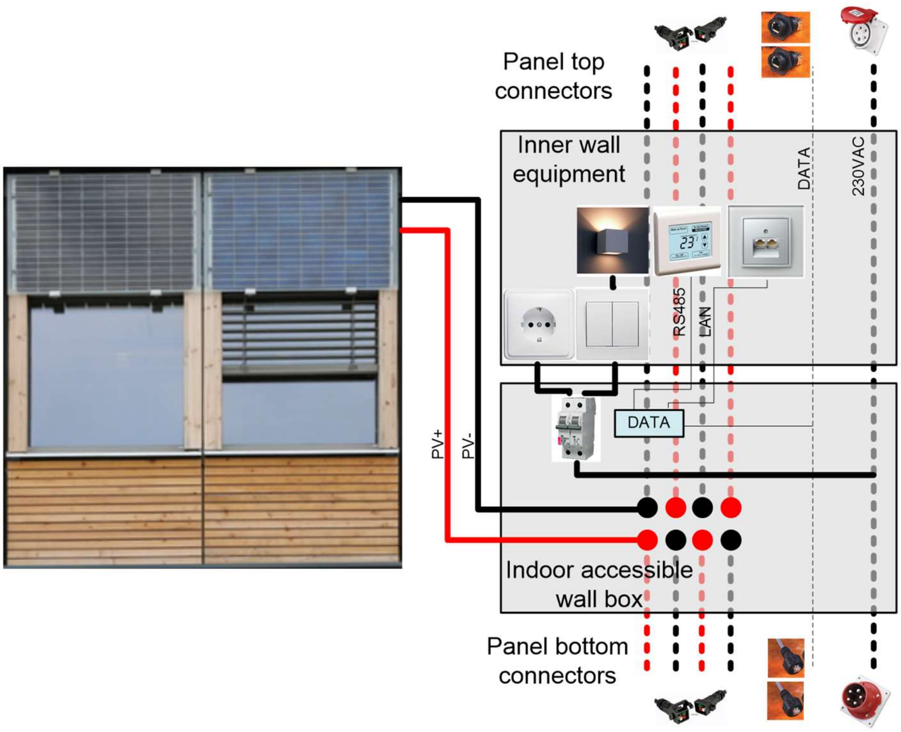


Figure 2.15 Electric connectors for power connection and data

These results are presented in this report on smart connectors.

2.8 Advanced controls

In MORE-CONNECT following areas were investigated and developed:

- Approach and algorithms for optimal usage of locally generated RES energy. The effort was connected with advanced simulations of the renewable energy sources integrated on the roof and facade retrofitting modules. The simulations of energy generated and used were carried out for Czech and Estonian MORE-CONNECT case studies. Three energy system architectures were defined including various control algorithms covering systems with and without energy storage as well as partially controlled load approach.
- Renewable energy sources forecasting service. Literature review was carried put in this field and according this review the main aspects of RES forecasting were identified. PV-Forecast web service developed by UCEEB was used as a part of the energy flow control algorithm and currently it is tested in the Czech Republic.
- Advanced controls and monitoring systems. The work related to this particular topic included development of indoor environment quality sensors and their connection to the control systems as well development of sensors for heat transfer and moisture safety of high-performance building envelope and their connection to the control systems. This development allows wired as well as wireless communication interfacing. Other works are related to sensors systems for continuous diagnostics of the timber structures with respect to moisture (system MoistureGuard).

This is an example of advanced control and monitoring on centralized supply and exhaust ventilation with heat recovery mounted on modular roof element and covered with modular wall elements:

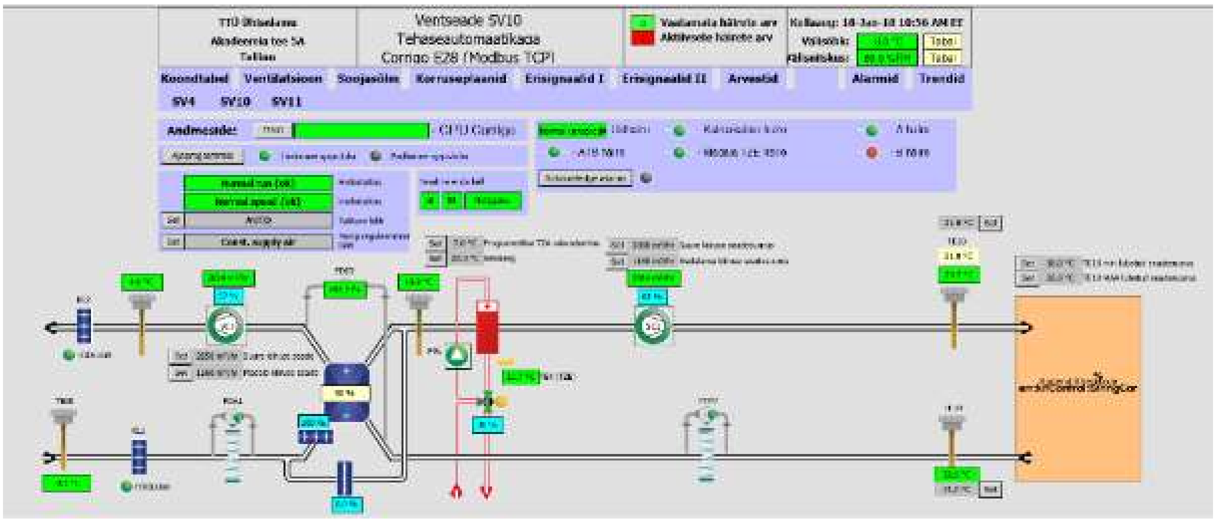


Figure 2.16 Advanced control and monitoring central supply and exhaust ventilation with heat recovery

These results are presented in this report on advanced controls.

3 CONCEPT DEVELOPMENT AND SYSTEM INTEGRATION

3.1 Introduction

The next step, after the Technology Development, is to come to a Concept development and System Integration. This step makes the link between all the technical possibilities, the actual application in houses in the different geo-clusters and the conditions set for optimal processing and production, leading to a range of choices for the user/owner of the house.

This step started with an inventory and classification of different building configurations in the geo-clusters addressed, the development of load bearing structure alternatives for the different types, optimization of the configuration of the elements itself: technical, environmental and demand driven, and in combination with 'house engine' options, as well as a range of structural connectors of the elements to the facade and roof structure. This will provide the bandwidth of possible alternative configurations for different types of houses, and the basis for the tools to develop to inventory the wishes of the end-user and to translate these wishes into a program for seceding and producing the concept.

3.2 Typology of building stock for relevant market in the geo-clusters

Before coming to a further concept development, it was necessary to develop a common typology analyses of the most relevant buildings types in the geo-clusters concerned. Therefore, at first the most common building types in each geo-cluster were determined. Next, these building types were analyzed for their core features, to learn what the basic building technology has been during construction, and from there analyses what could be the bare construction suitable for a prefab panel retrofit. Once these common and different features of each geo-cluster are documented, its clear what elements can be jointly developed and which need local adaptation.

A matrix is developed that classifies building types and common features in each geo-cluster, as well as providing the specifications for development of prefab elements

Figure 3.1 Conceptual idea of the housing assessment format: property will be assessed like the MORE-CONNECT contractor / provider would do in case of a tender.

Table 3.1: The housing assessment format

Parameter	Assessment
Monumental status	The building cannot be renovated with prefabricated facade elements when the building is considered monumental (major adjustments to the building (design) are prohibited.
Building aesthetics	Aesthetic building design could impede renovation when the facade is replaced with prefabricated elements
Business case	(Additional) financial slack (mortgage, income, savings from energy and maintenance cost reduction) to cover the investment, i.e. the business case for the project.
Site plan	Accessibility of the building site when considering renovation with prefabricated elements (logistics).
Legal requirements	Alterations to the building design and floor plan (increase of floor space) have consequences for the building permit.
Energy grid	Interconnectedness with energy grid: possibilities to deliver surplus of energy to the grid.
Housing typology	Assessment of housing typology including: (semi-)detached, mid-row / end-row terraced, multifamily housing with/without galleries, maisonet, other types of MFH (high-rise)
Architectural design characteristics	Assessment of the floor plan of the building: typology and dimensions (x,y)
	Assessment of the cross section of the building: dimensions (z)
	Assessment of roof design (shape, overhang): typology, U-value [W/(m2K]
	Assessment of facade design: fixed-free; open-closed; U-value [W/(m2K]
	Building extensions and complementary facade elements: bay window, France balconies, et cetera
Structural design characteristics	Loadbearing scheme: inclusion of (front-back) facade in the load bearing structure?
	Assessment of structural capabilities foundations
	Assessment of vertical structures (including openings)
	Assessment of roofing structure
Building technical system	Assessment of indoor climate systems with respect to heating/ cooling and available energy sources (district/central heating system and renewables)
	Assessment of ventilation system: inclusion in facade/roof structure
	Assessment of electrical wiring: inclusion in facade/roof structure
	Assessment of water piping: inclusion in facade/roof structure
	Assessment of drainage system: inclusion in facade/roof structure
Building performance	Assessment energy performance: costs, energy consumption
	Assessment environmental impact: CO_2 emission
	Assessment of building acoustics including noise from service systems and the acoustic performance of the building envelope and separation walls (between apartments)
	Assessment of the daylight level in the dwellings (when affected by the renovation)
	Assessment of the Air tightness
	Assessment of moisture safety / hygrothermal design

An overview of main housing types in the addressed EU regions, classification of suitability for different prefab façade renovation configurations is presented in this report.

3.3 Modular Concepts: development and design selection.

Building on the results as described in 3.2 the performance specifications and criteria (based on an optimization approach) of the prefab facade elements were described. This included analyses for

different type of load bearing structures, ways of connection, and physical performance requirements, as for instance securing air tightness operation during installing of elements. Also, the material impacts of prefab elements, i.e. the insulation package, in terms of embodied energy impact, decreasing the operational energy savings were studied. This included different insulation levels compared with accompanying PV levels to make the retrofitted house a 0-house. 0-Energy is chosen as reference level (thus 100% reduction situation), since at that point operational energy has no CO_2 and fossil fuel impacts anymore, and the CO_2 and fossil fuel impacts from materials invested become decisive.
The 80 % reduction situation can then be established by installing less PV panels, with the advantage that in future when the 0-energy situation is required, the building is already optimized for that. From the findings recommendations are made for materialization of elements.
This work has resulted in a combined tool for decision-making for optimization of operational energy use, embedded energy use, renewable energy production (on site, PV) and costs. With retrofit or refurbishment with CO_2 reduction in mind, this optimization is an important task, as it leads to a decision of the renovation strategy, the concepts that have to be developed and the further system integration. A decision has to be made between how much insulation will be added, which in many cases directly relates to the amount of PV elements that have to installed to generate the remaining operational energy demand. In the end this is a trade-of between investing materials: for more insulation or extra PV panels. This is even more clear when we arrive at a 0-energy buildings target, or even energy plus buildings: actually, in that case there is no impact anymore from the operational energy, other than materials invested. The PV panels are a materials investment that comes inclusive with energy (generation). This is an example of how the tool can be used:

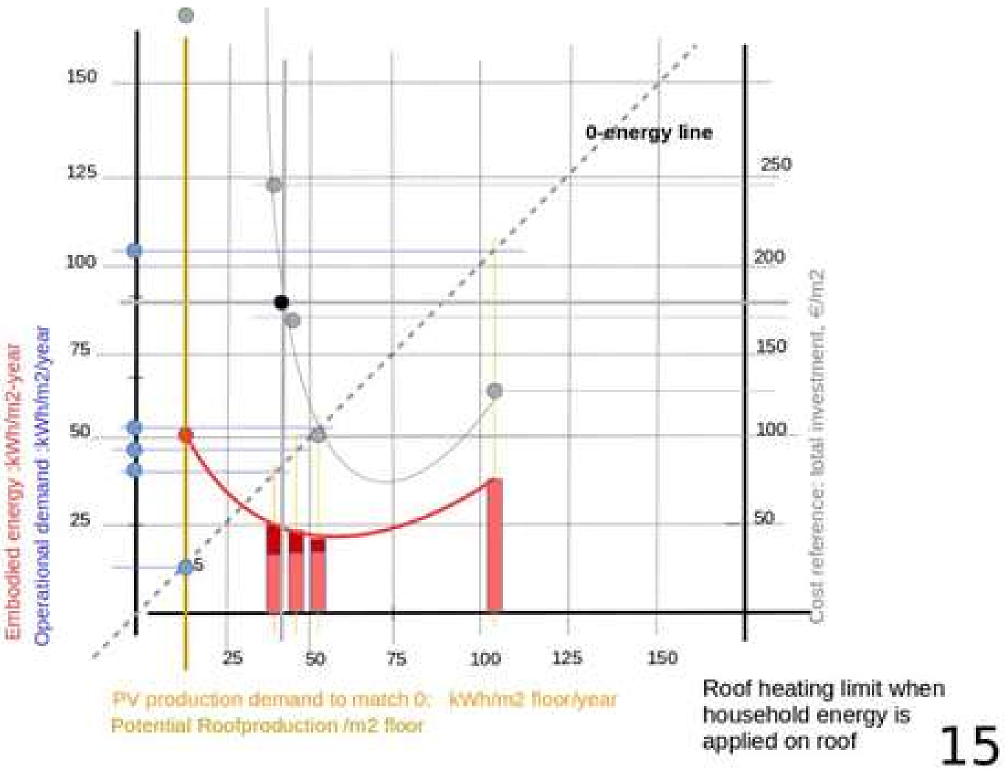


Figure 3.2 Example of the output of the combined tool for decision making for optimization of operational energy use, embedded energy use, renewable production

The tool that optimizes the combined energy and materials performance of the alternative configurations in relation to local typologies is available on the MORE-CONNECT website.

3.4 Modular Concepts platform development

From the previous steps a platform for retrofit concepts could be developed, using the findings and analyses from the work on Technology Development, specifically in the technical detailing of prefab facade models. The platform gives an easy insight in modelling a concept, the available freedom in choices of facade elements, and act as basis for tor descriptions of real market retrofit concepts.

To frame this work, first, a benchmark study was developed based on previous experiences with modular deep-retrofitting. Since 2007, building upon modular retrofitting principles, several projects have been completed specifically in the Netherlands (Energiesprong) and therefore the benchmark in particular includes the experiences from these projects. The experiences from the 'Energiesprong' program were also used in a number of other H2020 projects such as Transition Zero and Refurb.

Secondly, the design specifications were developed of the demonstration projects which are part of the MORE-CONNECT project. These projects constitute the building blocks of "MORE-CONNECT 1.0" (i.e. first version of a modular, deep retrofitting approach). Finally, several design guidelines have been developed which constitute 'MORE-CONNECT 1.0'. Taken together, this work is considered the key task with respect to system integration. Most important one is the [morphological design approach and tool](). This approach was for example used and tested in the MORE-CONNECT pilot Presikhaaf, Arnhem, the Netherlands.

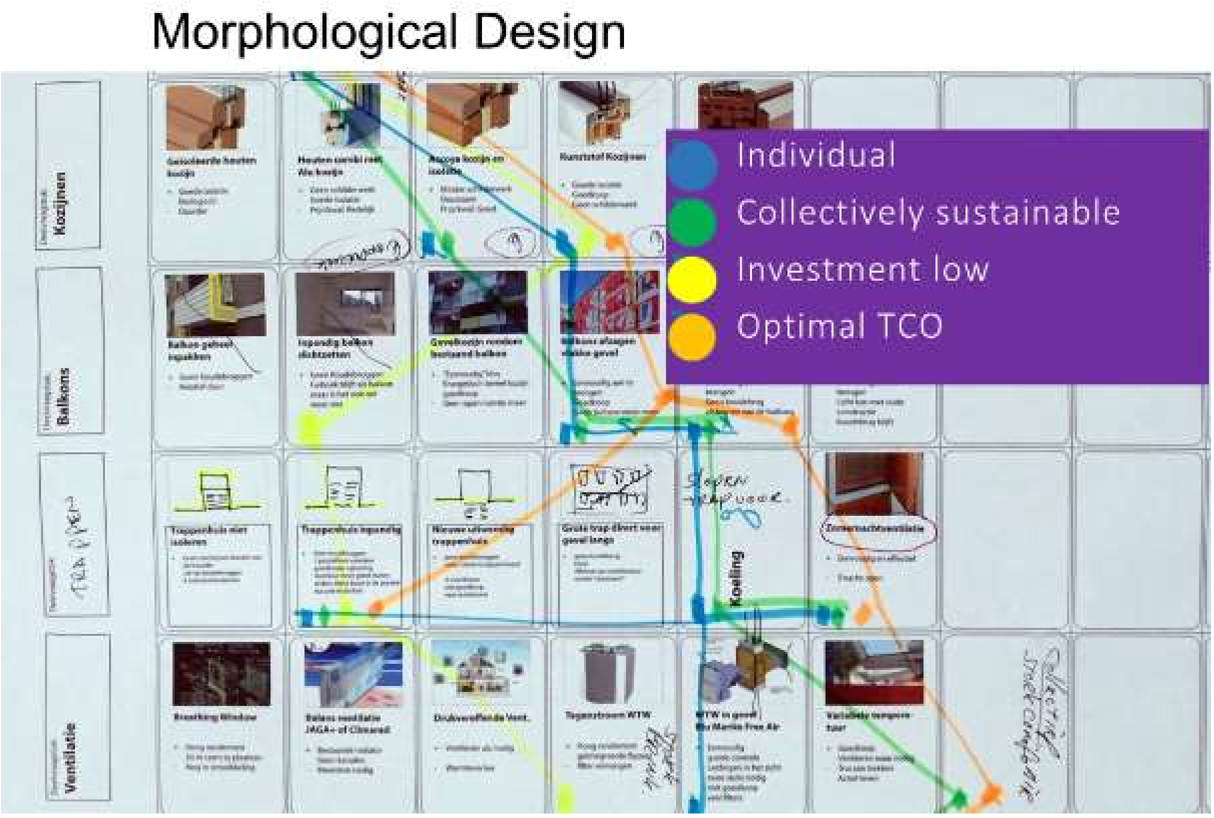


Figure 3.3 Example of the morphological design approach, pilot Presikhaaf Arnhem

3.5 Life cycle Assessment of concepts

MORE-CONNECT goes one step deeper in the analyses and assessment by developing a techno-economic assessment methodology for life cycle assessments of favourable concepts. The methodology is based on the comprehensive assessment of all energy, GHG-emissions and cost impacts resulting from MORE-CONNECT solutions. It includes embodied energy use and related GHG-emissions for the materials used for MORE-CONNECT-solutions. For the sake of analytical clarity and consistency the net effects of the MORE-CONNECT-solutions are determined by comparing the overall energy, GHG-emissions, and cost impacts of MORE-CONNECT-solutions with the impacts of renovation solutions needed anyway for the corresponding building element which restore full functionality of the corresponding building element but are not designed to reduce energy and GHG emission impacts. The methodology is also used for the pre-selection of favourable concepts for the pilots and for the final selection of favourable concepts.

3.6 Performance Monitoring and Control of Integrated Systems

An inventory and collection of requirements on short-term and long-term monitoring systems was performed. The short-term monitoring systems will be used for the experimental elements, whilst the long-term monitoring and control systems will be designed in variants for the final renovation packages. The outcome of this work is a set of embedded integrated control systems, optimizing control strategies according to user requirements and energy demands and long term monitoring system and data analysis.

4 PRODUCTION AND PROCESS INNOVATION

4.1 Introduction

The second pillar of MORE-CONNECT is the development and demonstration of new automated production lines for multifunctional modular renovation elements. This concerns production lines for mass customization, applied in an extreme automated line-production, with the possibility to produce in a 'series of 1'. These automated production lines support a line production that is effective on series-1 as well as large series and seamlessly combine into mass customization principles; aimed at supporting prefabrication for extreme retrofitting of homes. The automation makes it possible to produce end-user-defined (by choice) integral products efficient in small (1) as well as large series.

Machine instructions comes from automated computerized numeric control instruction generation based on BIM and in-situ measurements. Plant management is organized in software solutions that support line-balancing as well as JIT (just in time) and flow. Line design supports scalability in product complexity, support of more than one product-market combination and output.

The work has following phases:

- a preparation phase in which the technologies to be used in the production lines will be investigated how to implemented in the process (geomatics, BIM)
- a first adaption of the production line to produce the selected concept renovation modules
- the implementation of a quality control process in the production lines
- final adaption of the product lines to a fully automated process
- development of a decision and configuration tool for end-users

4.2 Advanced Geomatics

MORE-CONNECT looked into possibilities of advanced geomatics with the vision that a building can be scanned and the digital image can serve as the first step in the total automated production process. Therefor an overview is made of geomatics techniques that can be used for building reconstruction and to show advantages of their integration into different project phases. This provides information to civil engineering companies in order to be knowledgeable in the field of geomatics.

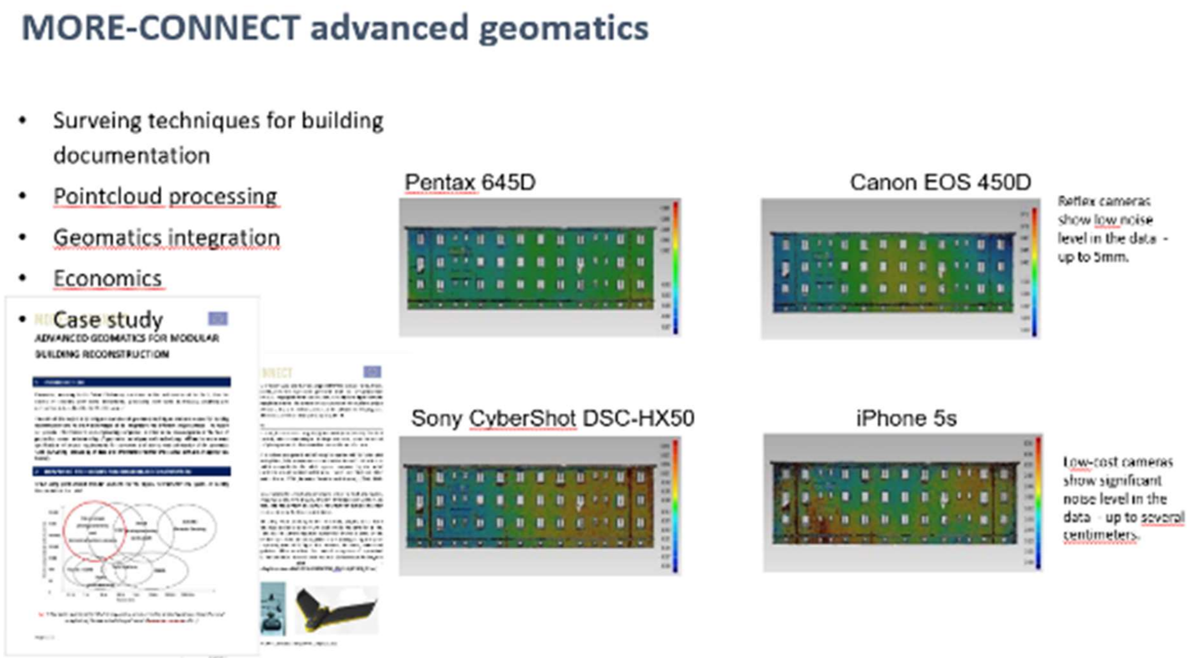


Figure 4.1 Advanced geomatics, comparison between different cameras

Better understanding of geomatics techniques and methodology will lead to more exact specifications of project requirements for surveyors and also to cost optimization of the geomatics work (surveying, processing of data and information transfer into desired software in appropriate format). Photogrammetric and laser scanning methods have been used and tested for the building documentation. Testing shows that both methods are convenient. Use of a particular method is based on project specifications and requirements as well as on ordering party preferences. Use of Ground control points (GCP) is recommended for higher accuracy demands (<5mm) and when larger objects (residential houses) are of interest. Geodetic total station provides fine and quick GCP measurements. An overview of the advanced geomatics technologies can be found in report 'Advanced Geomatics'.

4.3 Modelling building and performance characteristics and end-user needs

In MORE-CONNECT a number of tools and methodologies have been developed to support and accelerate the number of renovations in Europe by making the renovation process more user friendly and attractive for its (end) users. Specifically, the 'Tool to optimize the combined energy and materials performance of the alternative configurations in relation to local typologies' supports the decision making on renovation concepts, especially the optimization between operational energy, embodied energy, costs and the use of the available roof surface for energy production. Also, a platform for (aesthetic) configurations and user/owner options within the basic elements configuration and within performance criteria including a methodology for a morphological design approach for deep renovation (see 3.4). This methodology is supported by a digitized tool for modelling building and performance characteristics, based on different renovation scenarios. The tool is focused and organized for two different types of end users. The first and most important target group is home owners, considering a renovation of their homes. The second target group consists of third party developers, concept developers and suppliers. Besides these two target groups, the tool is also mentioned to be used by the partners in MORE-CONNECT and beyond (suppliers).

Building users and owners:

The tool is dedicated to house owners, to support decision making for the renovation of their homes. Once there is an initial interest of a house owner for renovation, the tool is presented to house owners as it gives them an easy to use, attractive digitized tool making them understand actual potential energy saving and renewable generation potential on the site they will gain when considering certain renovation scenario. Home owners can model, without a need of professional/expert guidance, different building renovation scenarios. For example, improvement of insulation of building envelope, improvement of Indoor Environmental Quality, by different ventilation strategies and systems, possible renewable energy generation on the site. In this way home owners get a first-hand experience and understanding about the estimated potential energy savings (compared to the current state) and needed investment connected with these renovation measures. Furthermore, return of investment can be assessed if all data is available. By evaluating possible renewable integration, a user can evaluate how self-sufficient he can be in terms of energy generation on the site (solar).

Third party developers, concept developers and suppliers:

This target group can use this tool by adding their concepts and/or products, to show the consequences to their clients in terms of, for example, investment costs versus savings and added qualities. A first objective of the tool is to get the public more aware about energy use and potential improved energy efficiency of buildings. Informing the public by giving a clear insight in potential savings can have a large impact on the reduction of energy consumption and CO_2 emissions.

4.4 BIM application

BIM application in MORE-CONNECT is focused on a seamless integration of BIM with integral computerized numeric control production in which BIM is aimed at construction, not at production/fabrication. A detailed state-of-the-art is developed of the application of BIM and its constraints in relation to building renovation, tools for energy analysis that can be used with BIMs and potential for design automation. Figure 4.2 shows the BIM workflow process in MORE-CONNECT to enable the intended automated process of digitalization of building information, related energy simulations, design of the modular solutions, production of visualizations, production, quality control, delivery and on-site assembly. For each of the steps were summarized available technical solutions and the whole pre-production process was tested on a case study.

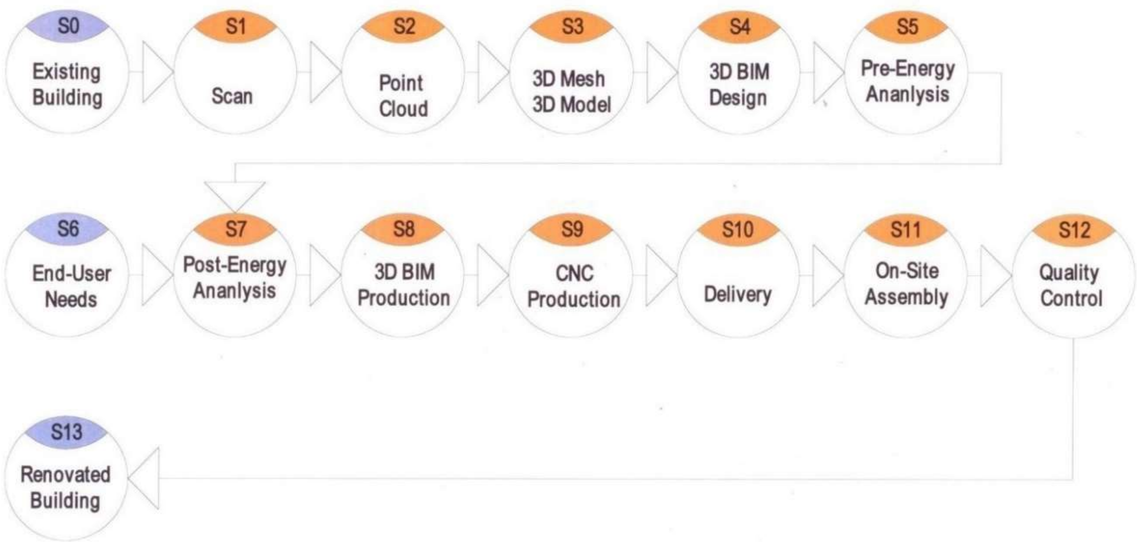


Figure 4.2 BIM process work flow in the MORE-CONNECT pilots

The fully digital preparation of the building simulations and drawings was found not to be completely feasible, still a significant amount of time is needed for the processing of the data and translation of the information from a point cloud to simple BIM model.

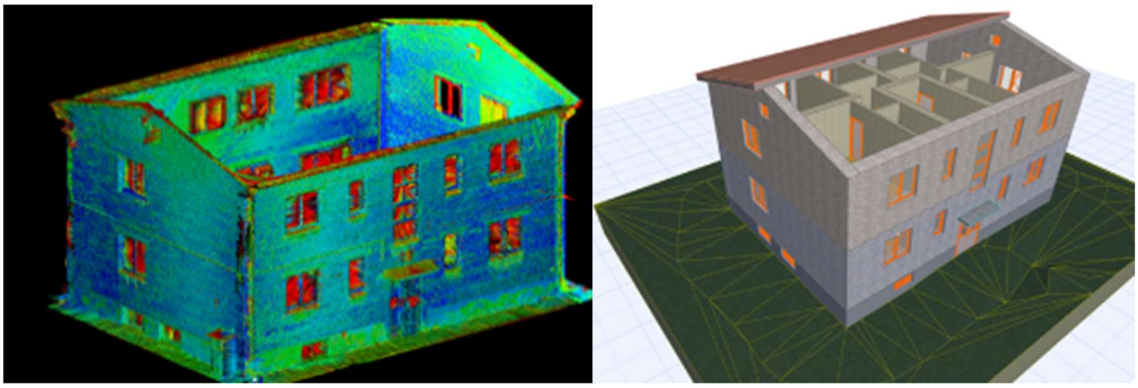
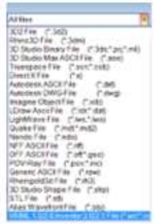
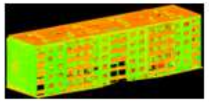


Figure 4.3 Surface model of a two-story apartment building visualized with Leica Cy-clone software (left) and resulting BIM model.

An overview of the advanced geomatics technologies can be found in this report 'BIM application'.

Table 4.1 Summary of cloud to BIM conversion results for the MORE-CONNECT pilot buildings

Project location, Provide two letter country code	Sample of the building's point cloud representation Please, insert one illustrative picture of scanned building (other please put in the attachment)	Total net area of the building, m²	Equipment used for 3D scanning and software	Number of scan stations	Total onsite scan time, hours	Point cloud size, format and size	Software used to transfer point cloud into 3D building model ArchiCAD, REVIT, other – what?; native format of resulting model, size	Creation of 3D BIM model					External energy evaluation software	Potential software to be used for machinery/production (CNC)	
								Automatic, Semi-automatic or Manual	Name of add-on or plug-in if used Provide short description of the procedure	Total time spent on model creation, hours	Internal energy evaluation module	Export file format used	Name	Name	Acceptable import formats
LV	 original scanned file used *.pts, ~3.9 GB	559	Scaner FARO 3D 120 ; Software Faro Scene and Leica Cyclone	9	6	*.e57, ~682 MB	ArchiCAD, *.pln, ~10 MB	Manual	Manual tracing with point cloud in background	~16, depends on experience and building complexity	EcoDesigner STAR	*.ifc	IDA ICE (currently not all informatio n correctly imported from original file)	SEMA (dot no accept data import from *ifc file)	 IFC
						*.rcs, ~1 GB	Revit, *.rvt, ~4 MB no windows recognized by external sowtware	Manual	Manual tracing with point cloud in background	~16? Depends on experience and building complexity	MagicCad and RIUSKA ** extra cost*				
EE		773	Leica ScanStation C10; Software Leic Cyclone	10	6	*pts ~900MB	Revit *.rvt	Manual	Manual tracing	The model was based on drawings	MagicCad and RIUSKA ** extra cost*	*.ifc	IDA ICE (currently not all informatio n correctly imported from original file)	AutoCad plugin software "Seina Paneel" And/or HsbCad	
CZ		576	Surphaser 25HSX; Geomagic Studio	9	6	*.las, ~190MB	Autodesk Recap360, Autodesk Revit	Manual	Manual tracking	~10	Autodesk Insight360	*.ifc	Autodesk Green Building Studio	CadWork	Btl dxf ifc
NL		24 * 85	Laser Scanner FARO 3D	10	6	Appr. 1 Gb	Autodesk Revit	Manual	Manual tracking	>40	Not done by Webo/BJW	*.ifc	PHPP	Vertex (export from Revit to Vertex)	Btl Ifc dxf
PT		345	Topographic survey digital with gps	4	6	~30 Mb	Trimble	Semi-Automatic	Semi-Automatic	8	Tekla	*.dxf	Tekla	Tekla	*dxf

4.5 Adaptation of production facilities

Most of the industrial partners of MORE-CONNECT consortium have had existing production facilities in operation, but some of them introduced new production techniques. The production partners identified potentials for improvement of production in terms of production volumes, in reduction of the production costs or in reduction of need of tedious manual work. Over the course of the project the industrial and academic partners cooperated in order to unleash these potentials and drafted technical plans and blueprints to achieve that.

Although in the project was not included budget for major improvement of production lines, the experience from the project and interaction with other partners brought ideas for innovation in the respective production processes and various actions to improve the production took place. In addition to that, a new robotic system for on-site shaping and finalization of external thermal insulation of buildings has been developed, tested and demonstrated along the project.

Details of the processes provide descriptions of the existing pre-production and production processes and employed imagination to define a theoretical ideal extreme scenario of massively up scaled production. Possible paths are described to the extreme scenarios by identification of the main bottlenecks that would be preventing the existing facility from achieving fully automated production process. After that short-term implementation strategies are described that would shift the existing production closer to the desired goal in short-term outlook. Plans were drafted for technology improvements' implementation and in some cases went even further to model and draw schemes for pre-production process and blueprints for an improvement the production lines. In some cases, some of the improvements were implemented (depending on budgets available). At the end they briefly evaluated the potential of designed improvements to reduce the production cost or increase the production output.

The description of the pre-production and production processes was made in most cases in a form of block schemes of process flows supplemented by comments.

The definitions of the massively scaled-up production scenarios had free form and free time horizon, so the outcomes varied among the partners. RD Rýmařov had an ambition to scale up the production volumes by two orders of magnitude WEBO has defined its ambition as reduction of 50 % of manual work whilst boosting output 1.25-fold. Goal of ZTC was transition to line production with sequentially arranged automated work stations; for AS MATEK the ambition was to more integrate the vertical value chain in order to be closer to the customer and realize higher margins instead of being subcontractor, and also to shift to higher level of automation. DARKGLOBE had an ambition to further promote the standardized products that would allow for upscaled mass production. They also plan to invest in automation and extension of the existing facilities. Ennogie was aiming for fully robotized production process. INVELA aimed at continuous use of their robots during the whole retrofitting or construction of a building.

Figure 4.4 Advanced robotic technologies developed by Invela

The described paths to the upscaled mass production included various areas of improvements like complete changes in the marketing and sales processes (digitalization, use of virtual reality for customized configurations in interaction with BIMs in pre-production processes); significant changes in logistics of supplies leading to just-in-time delivery; re-design of all elements to fit the mass production (reduce number of needed parts, unification of some elements, optimization of structure and shape); massive improvements in the production (continuous production using new production lines, new robotic workbenches, digitalized quality control procedures etc.) and spatial extension of the production facilities; enhanced logistics of delivery to construction sites (including optimization of packaging/stocking in containers); improved and digitalized organization of the construction (or rather assembly) process on site.

The short-term implementation plans included digitalization of the pre-production process; purchasing new single work stations; unifying variety of used materials and construction details; streamlining factory layouts; exploration of favourable material alternatives; supporting the sales teams to increase production volumes; and development of new production tools.

The blueprints for improvements in some cases included additions of new automated work stations into the existing flows, in some cases completely new production lines were designed.

Despite the short budgets in the MORE-CONNECT project itself, some industrial partners were able to make significant improvements, usually using the MORE-CONNECT for planning and designs and other external sources for purchase of the machines. For instance, over the course of the project, RD Rýmařov was able to design and purchase a new automated line for production of wall modules. WEBO made improvements in automation and moved towards real production lines. ZTC was able to purchase a new CNC speedcut machine and butterfly tables. Ennogie was able to improve their assembly stands and INVELA was able to test different types of industrial tools with their robots. Finally, the industrial partners briefly evaluated their achievements and future potential coming from the improvements.

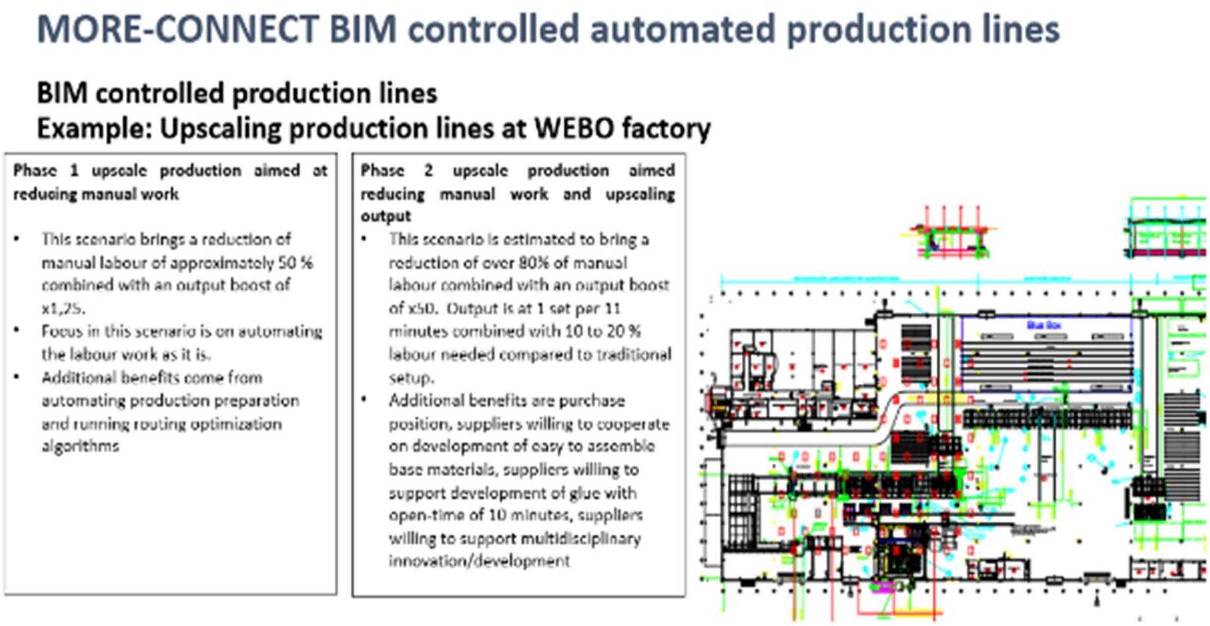


Figure 4.5 Upscaling of the production lines at the WEBO factory

4.6 Quality control and assurance of the process and the output

The shift towards new BIM controlled production technologies gave the opportunity for enhanced quality management processes. At the start of the project various quality management systems were already in use. For instance, RD Rýmařov had a certified production process according to ETAG 007 (by the European Organisation for Technical Approvals) and ZTC quality control was performed according supervisory authorities approved internal quality control process at ETA 18/0308, while the Dutch WEBO had in place (besides standard ISO 9001) the KOMO system, a Dutch system for Inspection and Research of Materials for Public Works operated by KOMO Foundation. Other industrial partners had their own systems designed in accordance with their local legislative requirements.

Whereas the quality management process in the pre-production stage was much about communication with the client and among the members of the design team a making sure that what has been designed and modelled met the client's requirements, the quality management in production was more complex. Usually each production facility had set the quality check points in the production process. The quality checks were made using various methods from visual checks to counting of elements to measuring of the precision in elements' dimensions and visual checks of quality of details crafting and quality of sealings. It was quite common to have digitalized production tools (such as CNC machines) but the quality control procedures were not automated so far.

Each of the industrial partners had slightly different approach to provision of warranty on the finalized construction work: RD Rýmařov was used to deliver finalized prefabricated single-family houses and they provide full warranty for the whole construction according to Czech legislation, which is usually 5 years. WEBO provided 10 years warranty for the prefab elements. At MATEK the warranty conditions were fixed by each contract. REF held full warranty according to the Estonian legislation and it is common, that a general contractor holds 2-5 % amount of the subcontract price over the warranty period. Different situation was with Ennogie, which provides just the PV roofing tiles to external installers who keep the warranty. Similarly, Invela planned to provide just the robotic tool, and let the craftsmen using the tool to keep their warranties.

Various progress in the quality management was noted by the project partners over the course of the project. RD Rýmařov had chance to practically validate the delivery of the modules for retrofitting and gained a detailed knowledge on production times and developed their know-how on quality control in large production series. ZTC have managed to receive ETA (European technical approval) marking on factory and its quality management processes. REF reported progress in preventing various bottlenecks in in planning, new insights in testing and data sharing. DARKGLOBE made advance in development of modules to fulfil various requirements like thermal or acoustic properties. Innogie improved installation process, streamlined their cabling assembly and also start to use new digital tools to improve internal operations. INVELA developed a system to collect on site data to improve the quality management processes. WEBO and MATEK reported that they had a high level of quality management standards already before the project started.

The lessons learnt include various types of experience. RD Rýmařov learned lessons from communication between the retrofitting construction site and the pre-production and production teams. WEBO made proof of their concept. ZTC learned that the improvement of quality management processes is possible in small steps, by continuously improving each step of production. MATEK has chance to work with new materials and made experience with higher demand on architecture. REF learned that there is need for closer cooperation between business and academia, that developing new products is hard to plan and schedule ahead and found how complex task energy simulations can be. At Ennogie the lessons learned included feedback-based optimizations in workflows as well as in products and higher precision of site measurement and project control. Invela got experience, that instead of making a specific robot 100% integrated to make just one task or a specific job on-site, it brought much more value to the building sector and the individual client if they could use or work with a robot platform ready for them to integrate together with their own partners or suppliers in their specific geo-clusters.

5 THE MORE-CONNECT DEMONSTRATION AND PILOTS

5.1 Introduction

The technologies as well as the concepts that have been developed in MORE-CONNECT have been implemented, demonstrated and tested in real settings as well as in industrial settings (demonstration of new production and processes) as in practice (demonstration and testing of the developed modular renovation elements).
The testing and demonstration in practice is organized on six locations:

Five real settings with deep renovation with prefab renovation elements:
- The Netherlands: 4 multifamily buildings, Presikhaaf, Arnhem
- Latvia: 1 multifamily building, Saules iela 4a, Cesis
- Estonia: 1 multifamily building, Akadeemia tee 5A, Tallinn
- Denmark: 1 multifamily building, Korsløkkeparken, Odense
- Portugal: 1 multifamily building, Edificio Mota Pinto, Gaia *(not completed during the project duration)*

Two Real Life Living Labs, small buildings for in deep testing
- Czech Republic: new built test single family house with prefab renovation elements, UCEEB lab, Buštěhrad
- The Netherlands: single family house, Breitnerstraat, Heerlen

An overview of the outcomes and experiences of the MORE-CONNECT pilot sites can be found in the 'Report with analyses of total renovation processes in the pilots'.
Numerous videos for the MORE-CONNECT pilots are available on the MORE-CONNECT YouTube channel: https://www.youtube.com/channel/UCIQOv2m826mA1zhzU7rNZAg/videos .

5.2 The demonstration projects

5.2.1 The Netherlands

The chosen housing type and the underlying rationale

Since 2006, deep-renovation have been implemented in the Dutch single-family housing. The deep-renovation rationale includes the substantial energy efficient improvement of the building envelope. Therefore, the building envelope is replaced by prefabricated elements and micro energy generation technologies are installed (like heat pumps and photovoltaics). The repetitive aspect of building construction makes these buildings very suitable for an industrialized renovation approach.
Row houses with tilted or flat roof are a dominant housing type. There are more than 4 million homes that were built between 1950 and 1985, which are in need for renovation in order to be suitable for the next 40 to 50 years. The repetitive aspect of building construction makes these buildings very suitable for an industrialized renovation approach.
More recently the application of this approach also has been demonstrated in apartment buildings as showcased by the Dutch demonstrator project. Within the Netherlands this housing type (multi-family housing with common staircase) encompass about 254,000 housing units.

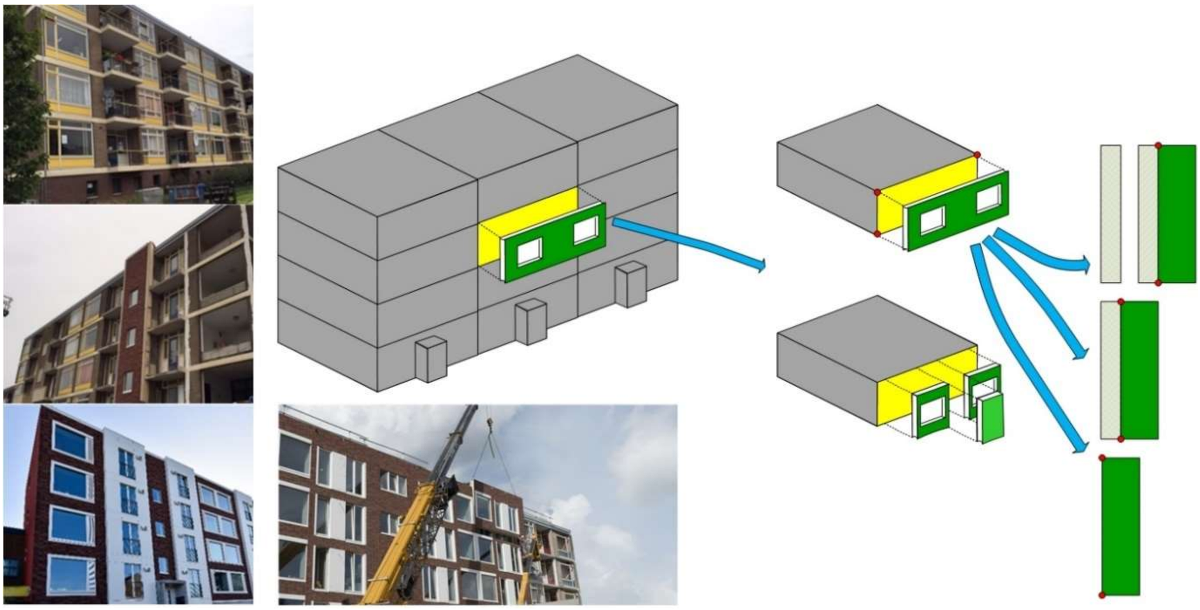


Figure 5.1 Underlying rationale deep-renovation approach Dutch demonstration project

General strategy chosen to renovate the housing type

We have chosen to remove front and back walls and replace those with prefabricated wall elements that close the opening at a high level of airtightness. Fixing the elements from the inside makes it possible to place the elements without scaffolding.

The elements are completely finished in and outside so no manual labor on the building spot is needed apart from fixation to the existing concrete walls.

Elements also contain ventilation ducts; replacing the old walls makes it easy to reach all rooms without the need to work inside the building. Good ventilation is essential since good insulation and good airtightness bring the need for good ventilation.

In order to reach very low level of energy use the ventilation is also combined with a heat recovery installation.

Hot water for household use and for heating is generated using a water/water heat pump.

Electricity is generated by PV panels. Around 28 panels generate enough kWh over year to supply all electricity needs.

Technical concept chosen for renovation

This is a summary of the energy efficiency improvement measures included in the Dutch demonstration project:

- Removing front and back facade (inner and outer layer of the cavity wall) and installing prefabricated façade modules front and back facade (new aesthetic façade design), with a heat resistance coefficient of Rc 7,51 W/m2·K (UWall = 0,133 W/m2K) and an airtightness Qv;10 value of 0,25 dm3/(s·m² Ag)
- Adding insulation and new finishing (brick-like tiles) to left and right facing facades
- Installing new windows with triple glazing
- Installing a new (mechanical) ventilation system with heat recovery (efficiency >74%)

After the design and engineering of the façade the execution of the project comprised several steps. First, parts of the balconies protruding outside the façade were removed while the remaining part of the balconies was added to the floor area of the apartments. This was done to adjust the building envelope to be compatible with a deep-retrofitting approach based on prefabricated façade modules.

The next step of the deep retrofitting project was decommissioning of parts of the façade. Third, the ground floor level (storage rooms of the apartments) was insulated with EPS insulation blocks. Fourth, the prefab modules were installed. The prefab modules consist of structural wooden frameworks and contain glass wool insulation (25 cm). The triple glazed windows with wooden frames were factory mounted in the prefab façade elements. The finishing of the elements consists of brick slips glued on the prefab modules (off-site), or plaster affixed to 60mm XPS added to the prefab element (on-site). The heat resistance coefficient of the façade is about Rc = 7,51 m2·K/W (UWall = 0,133 W/m2K). For the roof an on-site system was applied by adding a layer of insulation on top of the existing roof.
The HVAC system installed consists of several components. The HR100 condensing boiler was replaced by a more efficient HR107 condensing boiler. The original radiator system was adjusted to the smaller heat demand. Ventilation is provided by mechanical ventilation with heat recovery.
In addition, residents could decide to further improve their apartments, such as the installation of a soundproofing wall between adjacent apartments.

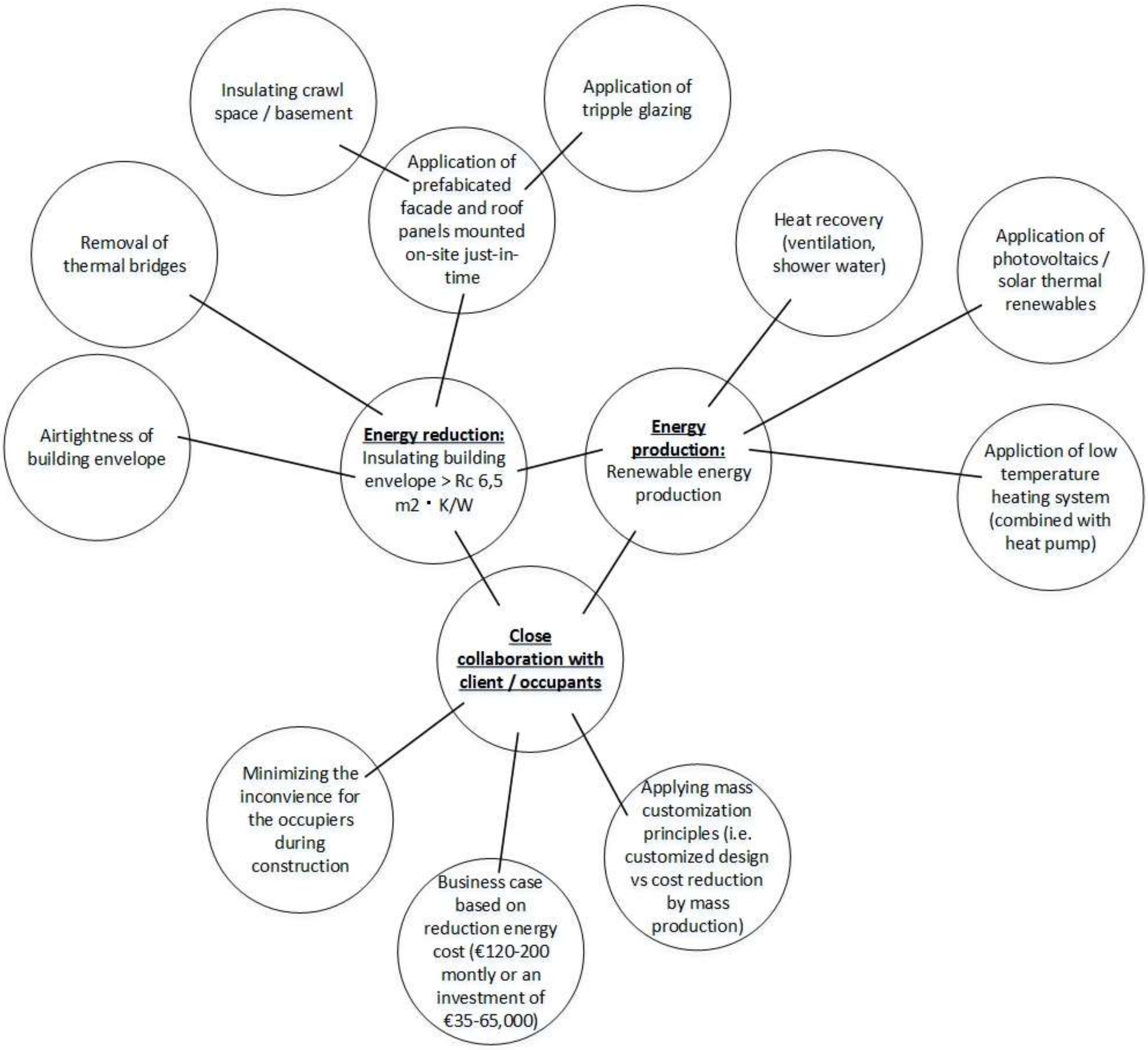


Figure 5.2 Key aspects of the deep-renovation concept Presikhaaf

4. Installation strategy

All installations are combined in a skid. When placed in the attic the installation is placed in one run when the roof is open. Prefabrication leads to smaller risk of failure and less labor time especially when produced in larger series.

The design implies that there is only one way to fix different installation parts.

Installation engine contains a heat pump with vessel, ventilation, heat-exchange, converter and monitoring hard and software. It is connected to two thermostats – in the living room and master bedroom. The house will have a very steady temperature of 21 in the living room and 19 in the bedrooms.

Ventilation ducts coming from the attic reach all rooms. Moisture sensors are placed in the kitchen and the bathroom, they regulate the need for extra ventilation in case of use.

Concerning the organization, the first 3 apartment buildings (out of 4) were subcontracted to a main contractor. For the final apartment building the project organization form was changed to a side-by-side contract, because the client was not satisfied with the performance of the main contractor: The project did not benefit from the modular deep-renovation approach offered by WEBO.

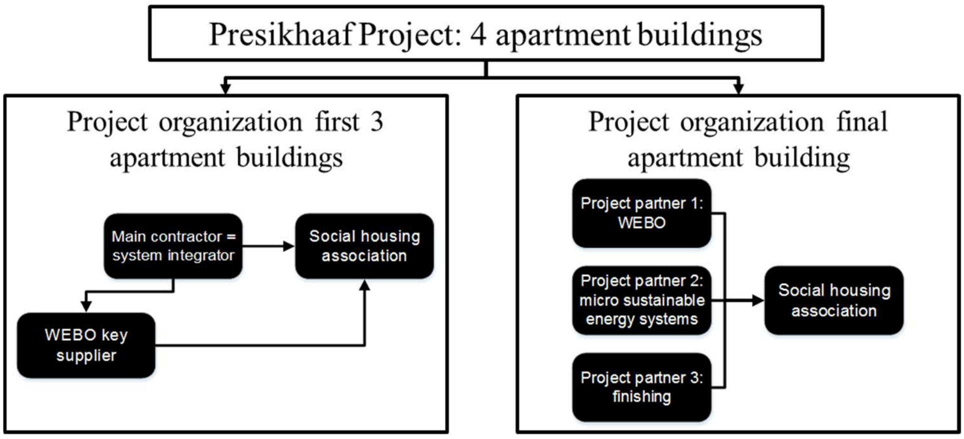


Figure 5.3 The change in project organization after the first apartment buildings had been completed.

Installation on-site by 'dedicated teams': No major problems were encountered during transport and installation of the facade elements. The plug-and-play connectors resulted in several advantages with respect to time (short mounting time), cost (no scaffolding required), and quality (decrease in the number of deficiencies). The façade elements were installed by specialized 'dedicated teams' who are familiar with the product.

The 'click and span' interface for fast installation was further improved by applying a simplified anchor with an airtight tape (developed by WEBO together with Fischer). This connection is much easier on the construction site.

With respect to the infill of the dwelling most of the work is completed by craftsmen on-site in contrast to modular construction principled applied for micro sustainable energy technologies and the building envelope. Each of these components reflect about 1/3 of the building costs. In particular the infill could benefit from modularization and industrialization, combined with dedicated teams who install the infill components, to reduce costs.

Figure 5.4 Installation of pre-fabricated wall elements at the Presikhaaf project.

In sum, theory suggests that the organizational structure should be adjusted to the modular product design (referred to as the mirroring hypothesis). If this precondition is not met it could result in performance issues as was confirmed by the Dutch demonstration project.

Conclusions and guidelines

Monitoring data are used to manage the systems as well as to attest the correct working of the combination of renovation elements and installations.

Monitoring proves that calculations were correct for energy use as well as comfort and healthy indoor climate.

In the Dutch pilot following lessons were learnt. Until recently apartment buildings were not considered. The first pilot buildings have been renovated applying the same core principles as applied in single family housing projects. Thus, the deep-renovation of the apartment buildings in Presikhaaf is one of the early examples which proofs that also this type of buildings can be renovated towards energy zero and a demonstrator of the MORE-CONNECT solution. The MORE-CONNECT solution encompasses several innovations including plug-and-play mounting without scaffolding and geometrics to facilitate the design and engineering of the façade modules.

Figure 5.5 The improved architectural appearance of the demonstration project (Presikhaaf, Arnhem)

Design of the project also include engineering or pre-production and depends on the conditions set during project acquisition. The supplier of the prefabricated façade elements (WEBO) was selected as preferred supplier by the client, in particular of the limited number of available competitors in the market. The following key performance indicators turned out to be decisive: high insulation, airtightness, certified industrial production, integrated ducts, finishing included, geometrics (laser scanning, point cloud), design-for-manufacturability (BIM, 3D design), integrated product delivery including on-site installation, short lead time on-site <10 days, portfolio of successful completed projects. Concerning design and engineering of the project, due to accurate laser scanning of the existing property the client perceived lower project risks – i.e. lower failure cost emerging van deviations. The point cloud derived from laser scanning had to be turned into building design manually. This is problematic – and not yet solved by the supplier – while it is time consuming and error prone.

Figure 5.6 Cloud representation in the BIM system (left) and final design (right)

The initial (architectural) design was adjusted according to predetermined design rules related to the modular façade system. As a result, building extension like balconies were removed and replaced by a self-supporting structure (opposite façade).
Modular façade consists of several fixed design rules. Nevertheless, some unique, project specific, detailed solutions need to be developed (design flexibility). Fixed design rule contributes to an efficient design and engineering process; (aesthetic) design 'bottlenecks' are identified and solved early in the project.

WEBO was responsible for the quality of the (integrated) design of the façade. Within traditional construction projects several stakeholders share the responsibility of design (like for example precast panel floor systems which involve the structural engineer, supplier of the floor system and the contractor).

5.2.2 Latvia

The chosen housing type and the underlying rationale

The Latvian pilot building is a typical brick multi apartment building built in 1967. The pilot building is a silicate brick residential house with a lateral bearing system. The house has a wooden roof structure with slate covering. The building has simple, rectangular floor plan. It has two floors with similarly designed flats. The house has a hip roof with a number of chimneys. All old wooden windows were replaced by PVC windows 7 – 10 year ago.

The building represents typical buildings constructed in the 1950 – 60-ies. This type of building is very common in the rural areas and small cities. The selected building type has a high replication potential. Design and construction of buildings in the rural areas are usually associated with higher costs in comparison with the buildings located in cities.

b

Figure 5.6 Demo Building before renovation.

General strategy chosen to renovate the housing type

All initial data for technical project development were gathered during the start. In the very beginning, the agreement between homeowners, the housing company and Riga Technical University was signed. Before developing the technical project, the IAQ measurements, thermography and blower door tests were performed. According to the measurements, air tightness of the building envelope was 4.5 m^3/m^2h. U-values of external building envelopes were around 0.3 $W/(m^2 \cdot K)$ for ceiling, 0.95 $W/(m^2 \cdot K)$ for walls and 1.9 $W/(m^2 \cdot K)$ for windows. Quality of the construction work is very poor. The extra thermal insulation of the ceiling has many air gaps between mineral wool mats. Window/wall connections are not insulated and sealed properly.

Figure 5.2. Technical conditions of the Demo Building.

Technical concept chosen for renovation

Taking into account poor technical condition of the building it was decided to focus modular retrofitting on improvement of external building envelope. The general strategy included development and installation of prefabricated modular thermal insulation panels. Modular solution is based on the wooden frame. Extra attention is paid to air tightness of panel joints.

The main target was to get walls below 0.18 W/(m^2·K), windows below 1.1 W/(m^2·K) and ceilings below 0.11 W/(m^2·K).

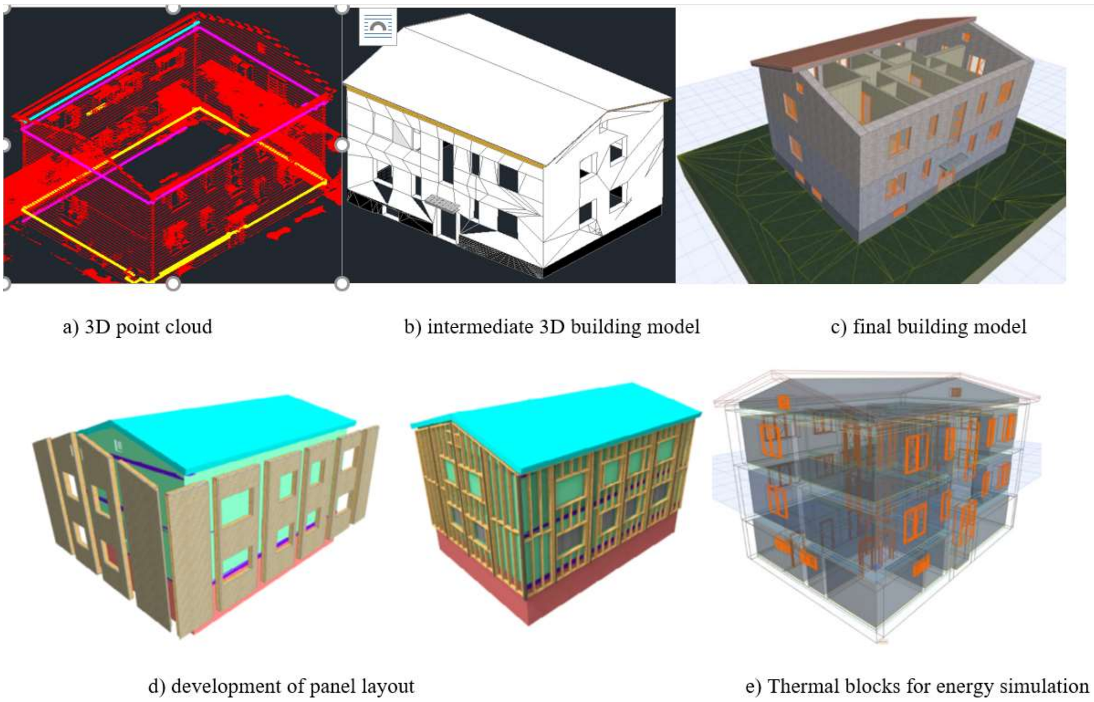
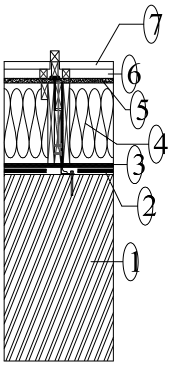


Figure 5.3 Retrofitting process of the Demo Building.

Prefab panels



1 – Existing wall;

2 – Connection layer between the existing wall and modular panel – low-density mineral wool;

3 – OSB;

4 – Thermal insulation, λ – 0.033W/(m·K);

5 – Wind protection, plasterboard;

6 – Ventilated air cavity;

8 – External finishing – wood planks;

Figure 5.4 Final layout of modular prefabricated thermal insulation panel.

The moveable scaffolding was used to prepare the building for panel installation and crane lifting was used for panel mounting (Figure 5.4).

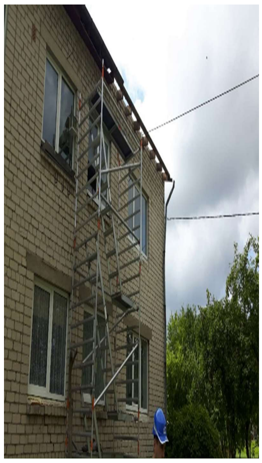


Figure 5.5 Use of scaffolding or crane lifting for retrofitting.

In total, panel mounting took five working days and required six workers on site. Five days included also time to deal with problems with replacement of some panels. Taking into account experience gained, panel mounting time can be reduced up to three working days for similar buildings.

Conclusions
Installation of renewables was not taken into consideration due to bad condition of roof supporting structure and absence of central hot water supply system. Installation of PV was also limited due to home ownership specifics. There are four owners, thus, the calculation of the electricity supplied to the grid and received back would require extra effort to run a complicated metering system.
The proposed modular retrofitting allowed significant reduction of on-site construction work.

5.2.3 Estonia

The chosen housing type and the underlying rationale
Building type chosen represents a typical multi-story apartment building made of prefabricated large concrete panels and constructed during the 1960-90-ies period in Estonia, where about 65% of people live in this type of apartment buildings. The design service life of these buildings was 50 years, which is almost over for the formerly constructed buildings, therefore, these buildings need current renovation. As it is typical of many older buildings, there are several topical problems, such as serious thermal bridges, mold growth at the external intersections of roof-wall, high energy consumption, insufficient ventilation, overheating during winter, unsatisfactory thermal comfort. Fresh air inlet was initially designed through the slits around untightened wooden window frames and natural exhaust via kitchen and sanitary rooms to the central shaft. The building had a one-pipe radiator heating system without thermostats and the room temperature for the whole building was regulated by a heat substation depending on the outdoor temperature.

The pilot building is a 5-storey TUT dormitory building with the total area 4,318 m^2, constructed in 1986. The existing 250mm concrete panel exterior wall consists of two concrete sections and insulation layers: 60mm external reinforced concrete slab + 70mm wood-chip insulation layer + 50mm phenolic foam insulation layer + 70mm internal reinforced concrete slab. The existing flat roof with parapet is covered with bitumen felt and insulated with wood-chip boards. The thermal transmittance of the existing envelope is U=0.9 - 1.1 W/(m^2·K).

Therefore, the results of the pilot renovation within the framework of MORE-CONNECT project at Tallinn University of Technology campus in the student dormitory building conducted in 2017 give opportunities to very easily disseminate the results to the existing (and quite large) similar building stock and give an input to further development of nZEB design of the integrated and multipurpose renovation of living houses with modular external envelope panels.

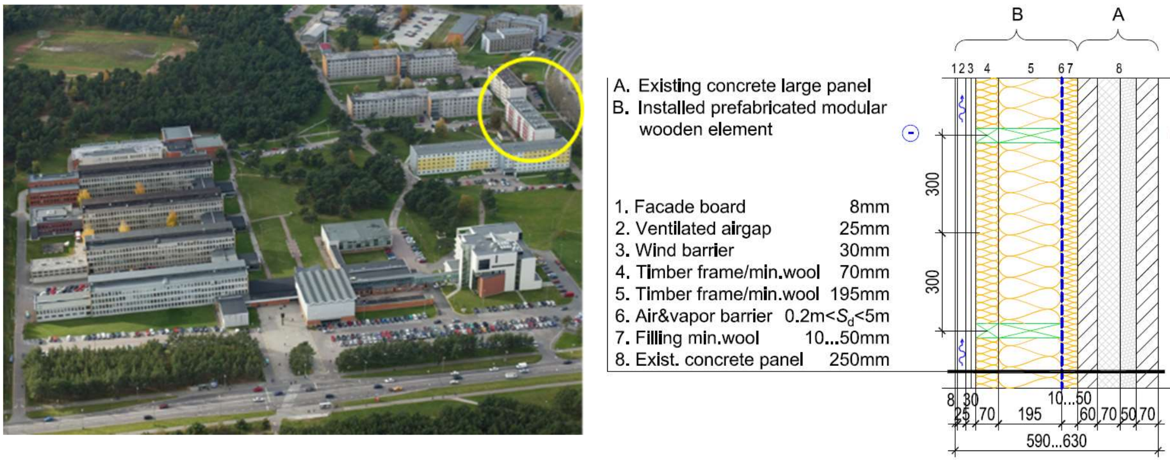


Figure 5.6 Location of the pilot building at TUT campus in Tallinn, Estonia (left) and basic design of wall insulation modules, placed onto the existing concrete wall (right).

2. General strategy chosen to renovate the housing type

The general renovation solution implied that lightweight modular prefabricated panels were installed onto the existing envelope (roof and walls), without demolishing the existing loadbearing structures. The living spaces of flats would be enlarged with the help of closing open balconies with the same modular panels and would be closed with glazing, and thus would become an additional living space. The basement walls were insulated in-situ with an external thermal insulation composite system.

Figure 5.7 Pilot building at the renovation stage in summer 2017 (left) and the final overview after the renovation in autumn 2017 (right).

The current aesthetic state is not very demanding as it represents widely used soviet-time concrete multi-story house building traditions from the 1960-90-ies. The value of a property could be raised via renovation according to the MORE-CONNECT principles (placing a prefabricated facade and roof panels). The quality and time schedule could be optimized thanks to the controlled preliminary installations made at the insulation modules factory (preinstalled windows, facade boards, mold drips, flashings, etc.) and shortened installation period at the building site. It was intended to realize the installation of the modules with help of pulleys (for workers) and with crane (panels lifted directly from the transport vehicle to the installation place).

Figure 5.8 Installation of the module panels on the walls (left) and onto the roof (right) in the pilot building in Tallinn, Estonia, in summer 2017.

3. Technical concepts chosen for renovation

In the pilot project, the building envelope was supposed to be insulated and rendered with the help of prefabricated modular renovation elements. To get accurate information about the unevenness and roughness of the existing surfaces of external envelope and inhomogeneity of windows location, 3D laser scanning of the envelope was conducted before the design. Self-supporting modules were hanged onto the existing wall surface with the help of designed fixings, allowing adjustment of the modules in all three directions. Therefore, there was no need for additional foundation for the wall module panels.

The total thickness of a modular element in the current project was 340-380 mm, depending on the surface flatness of the existing wall. To fill the unevenness and roughness of the existing surface, it was planned to add 10-50 mm light mineral wool as a filling layer onto the inner side of the modular element. The timber-frame structure was filled with 265 mm mineral wool in two layers and covered with 30 mm dense mineral wool wind barrier. The 25 mm ventilated air gap was covered with 8 mm finishing hardboard, which also provides a firm rain screen to the structure beneath. For protection from weather impacts during the construction process and from constructional moisture, the inner side of the module is designed to be protected with air and vapor barrier layer. The designed thermal transmittance of the external wall is U_{wall}=0.11 W/(m^2·K) and the airtightness of the entire building envelope is q_{50}<2 m^3/(h·m^2). To avoid thermal bridges and minimize the impact of air leakages, smart connectors and innovative fixings, as well as sealants and polyurethane (PUR) foam will be used at critical joints.

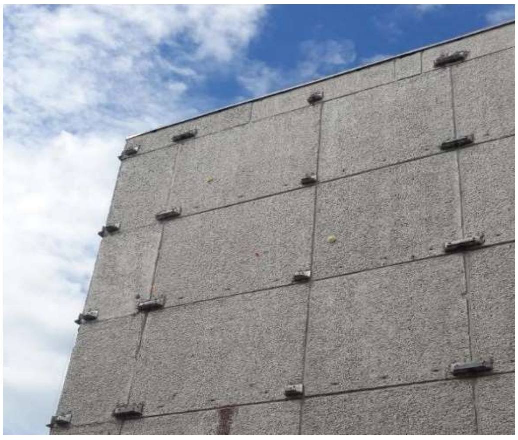
 

Figure 5.9 Steel corner brackets for mounting wall modules.

Designed roof elements were installed on the custom-built timber structure because the original roof has an inward slope and a parapet. Therefore, technical appliances (e.g. heat exchangers, duct dispensers, automatics etc.) were placed under the formed slope roof in 0.6-1.2m high attic between the old and new roof. The total thickness of the thermal insulation in the roof modules is 340 mm, U_{roof}=0.10 W/(m^2·K).

Solution with highly insulated modular panels installed onto the existing concrete wall may prevent moisture dry-out and could pose a higher risk of mold growth. One of the most critical hygrothermal design tasks was the selection of a vapor barrier for the wall module. The most influential parameters here are a built-in moisture dry-out after the installation of the insulation modules (requires a relatively permeable vapor barrier) and the long-term performance where a vapor-tightening barrier is required because the joints of the original wall would not be air and vapor tight. Cracks and openings in the walls contribute to the uncontrolled moisture flux into the structure. With hygrothermal analysis, it was found that in our region the south-west oriented wall has about 20% higher moisture content than other sides of the building envelope and considering the impact of the wind-driven rain, the wall has almost 50% higher moisture content. Analysis showed that the moisture content in the whole external concrete slab is about w = 110 kg/m^3 in the most critical periods, in the last quarter and the first months of the year. The required hygrothermal performance of the studied solutions was ascertained with a smart vapor retarder with changing vapor tightness 0.2 m < S_d < 5 m, when the initial moisture content of the existing large concrete panel was $w \leq$ 110 kg/m^3, or with 22mm OSB as a vapor control layer, when the initial moisture content of the existing large concrete panel was $w \leq$ 75kg/m^3, or with PE-foil as an air and vapor barrier, when the initial moisture content of the existing large concrete panel was $w \leq$ 55 kg/m^3.

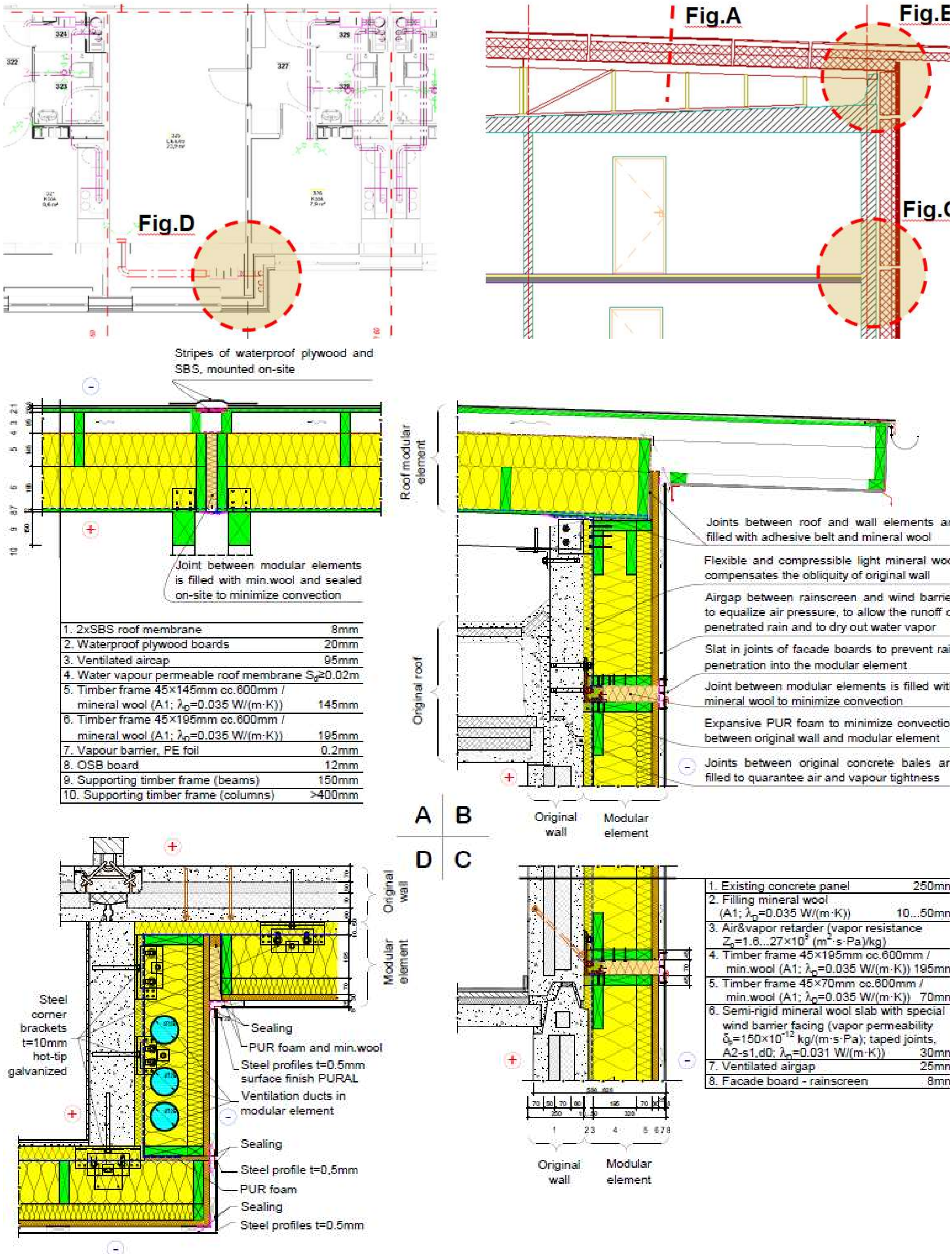


Figure 5.10 Design solutions at different structural points of the nZEB pilot.

4. Conclusions

A pilot nZEB renovation of a typical large-panel concrete apartment building was conducted in Estonia. This is one of the first deep energy renovations that has been designed to correspond to the nZEB target for new buildings. In addition to the use of prefabricated modular panels for building envelope insulation, the design solution includes many other tasks to be addressed, including parallel comparison of two different ventilation solutions: apartment based balanced VHR and centralized balanced VHR; parallel comparison of heating of DHW by solar collectors and sewage heat recovery.

The analysis and the whole process of design itself showed that it is essential to consider the initial state of the building when highly insulated module panels are intended to be used for an nZEB renovation. The installation of the wooden modular elements indicated that a substantial thorough initial work ("measure twice and cut once") and concentration on moisture safety issues are needed. Roof elements must be installed before the wall elements to prevent the wetting of the original external wall due to wind-driven rain and rain from the temporary roof.

The interaction between the design process and the construction work at the building site is of decisive importance and poses a major challenge. Engineers and designers should include hygrothermal modelling into design practices to assure moisture safety of the structures and their sustainability in the long term. The analysis, design and other preparation activities associated with the integrated nZEB design process gave us a unique experience, showing weak links in the chain and helping to prevent major faults in the construction of the pilot and in the further design processes.

Figure 5.11 Well-insulated building envelope with onsite energy production is needed for nZEB.

5.2.4 Denmark

The chosen housing type and the underlying rationale

In Denmark, housing generally consists of single-family houses and apartment blocks. Either the use of prefabricated elements or robots for facade and gable wall insulation and finishing would generally not be cost-effective for individual single-family houses. Therefore, apartment blocks are most suited for energy renovation using the technologies developed within the MORE-CONNECT project. The majority of apartment blocks are owned and administered by social housing companies. Many of these apartment blocks were constructed in the 1950-ies to 1970-ies in 3-5 stories. This is the background for choosing one of such buildings as the Danish pilot project, which is one out of seven blocks of a department called "Korsløkkeparken afd. 34" administered by Fyens Almennyttige Boligselskab – FAB. The block selected as the pilot building is referred to as building 34.6. It has 170 apartments, which after the renovation will be turned to 166 apartments. The building is 205 m long and 13.6 m wide and has 5 stories. The total living area is 13,685 m² and the basement area is 2,737 m². The photos below show the Danish pilot building before and during renovation.

Figure 5.12 Danish pilot Korsløkkeparken before and during renovation

General strategy chosen to renovate the housing type

Generally, this type of buildings are energy renovated as part of the total renovation plan for the area under consideration, which means all the blocks of the department and the outdoor areas around the blocks are retrofitted. The energy renovation part of this total makeover typically includes the following activities:

-replacement of windows;
-installation of a mechanical ventilation system with heat recovery;
-additional roof insulation;
-insulation of facades and gable walls. Depending on the current conditions of the existing external walls this additional insulation will be partial or complete.

The replacement of windows and insulation of the facade typically require the use of scaffolding.

Considerations

External insulation of facades and gable walls is costly and is normally only carried out when the condition of the existing walls is rather poor and the walls are in need for repair, for example, with a new external climate protection layer. In this situation adding a layer of insulation becomes a marginal cost and the costs will be managed by the housing association.

Technical concept chosen for renovation

The energy renovation technologies developed as part of the Danish participation in the MORE-CONNECT project include:

- Photovoltaic (PV) roofing elements;

- Robot finishing of an insulated gable walls.

These two technologies are therefore chosen to be part of the total energy renovation concept for the building in Korsløkkeparken, which also comprises:

- - replacement of windows;
- -installation of mechanical ventilation systems with heat recovery;
- -additional roof insulation.

Considerations

The overall energy renovation concept is well-known in Denmark, so no special considerations were made.

Prefab panels

Figure 13 shows the placement of the solar photovoltaic panels on the very long building and how the solar roof is finished and how it fits aesthetically well with the renovated façade.

Figure 5.13 Schematic view of the placement of PV panels and the final view of the renovated façade with solar roof.

Figure 5.14 shows the completely renovated building with the robot gable wall decoration.

Figure 5.14 Gable walls insulated by robotics including milling of the projects' name

Considerations:
The size and architectural integration are important issues that have been considered in the installation of the PV-roof panels. The size is important because of the Danish legislation with respect to the use of the electrical output of the PV system. In the situations where the produced electricity cannot be used for the operation of the building (pumps, fans, elevators and lighting in the stairwells) it has to be delivered to the grid without any payment. Therefore, the size of the PV system has to match the running operational load of the building. For the insulation of the gable walls and robot finishing the main considerations included the timing of the general renovation process and the integration with the other wall finishing.

5.2.5 Portugal

The chosen housing type and the underlying rationale
The Portuguese pilot building is a building located in Vila Nova de Gaia, Porto Metropolitan Area, in the northern region of Portugal. It is a social housing neighbourhood, built in 1997, and managed by Gaiurb (a municipal company). It is a multifamily building with three separate blocks, each with three floors, corresponding to six apartments (a two-bedroom apartment and a three-bedroom apartment per floor). In total, eighteen apartments constitute the building (Figure 5.15), which has a gross heated floor area of 1,265 m^2.
In terms of typology and construction characteristics, the building is representative of about 40% of the Portuguese multifamily buildings, which justified its selection as a pilot in this study. It also presents additional common characteristics typical of this significant parcel of the Portuguese built environment. For example, as the majority of the Portuguese residential building stock, the building is not equipped with a central heating system. Some of the apartments have portable electric heaters, although the majority does not have any heating system installed. Additionally, building envelope presents some signs of deterioration, although on a small scale. The common parts of the building (stairs, halls and walls) show signs of mould and are in a higher state of deterioration. Inside the apartments, thermal discomfort has been reported – both in winter and summer – and mould is clearly

visible in the corners of the walls and near the windows. Extensive mould areas can also be found on some of the ceilings of the rooms and bathrooms. All these issues highlight the need for renovation.

Figure 5.15 General view of the Portuguese pilot building.

General strategy chosen to renovate the housing type

The general strategy is based on a modular approach to improve the overall performance of the facade. In that way, prefabricated modules were planned to be added to the existing facade, using crane lifting as a working method. Calculations indicate that an estimated 25% reduction in primary energy use is possible just with the application of the prefabricated modules alone. However, as the project has set the reduction of at least 80% of the primary energy use as its main objective, other measures had to be considered in addition to the application of the prefabricated modules. In this context, it was planned to place additional layers of insulation on the roof and in the cellar. Existing windows are already double-glazed and therefore their replacement was not considered at this stage. Additionally, the building manager chose not to use solar panels for domestic hot water (DHW), but after the renovation, as part of the second phase, it was planned to install a biomass boiler, improving significantly the building systems performance for both heating and DHW preparation.

Considerations:

Adding modular, prefabricated elements to the existing facade will allow faster interventions, as well as will help avoid disturbing the occupants.

Technical concept chosen for renovation

The prefabricated module planned to be implemented on the facade of the building was designed to reduce operational energy demand and increase hygrothermal comfort inside the apartments. Additionally, there was a concern about the choice of materials that constitute the facade panel, which includes a wood frame and a cladding based on a recycled material in order to reduce embodied energy and carbon emissions.

It was planned for the modules implementation to be vertically oriented (10 m height) (Figure 5.16) and using standard metal connectors assembled on the exterior wall (Figure 5.17). The renovation solution includes the application of an additional insulation layer of mineral wool put between the existing facade and the prefabricated modular system.

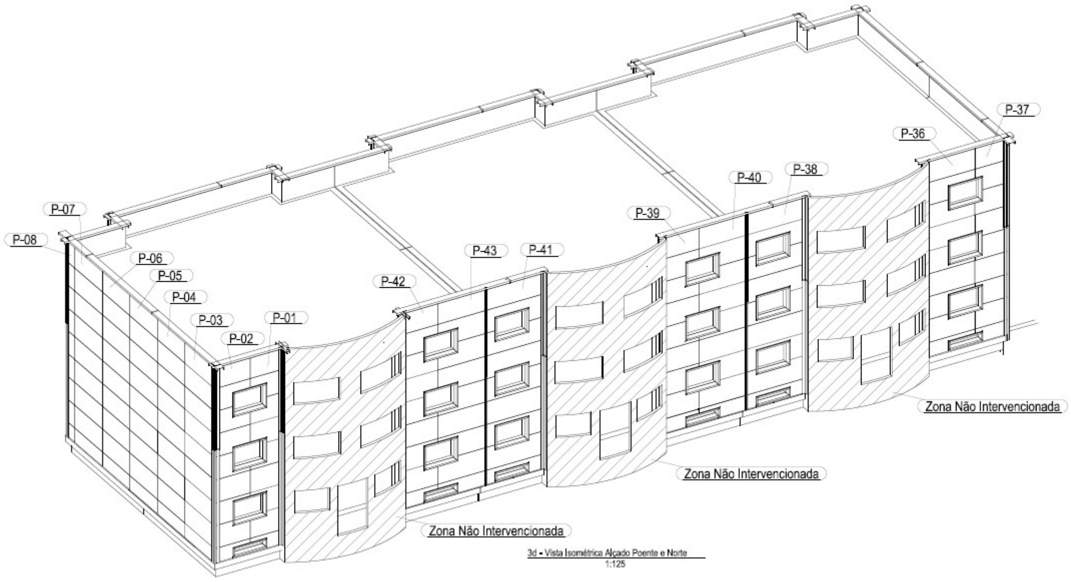


Figure 5.16 Planning of prefabricated façade module installation

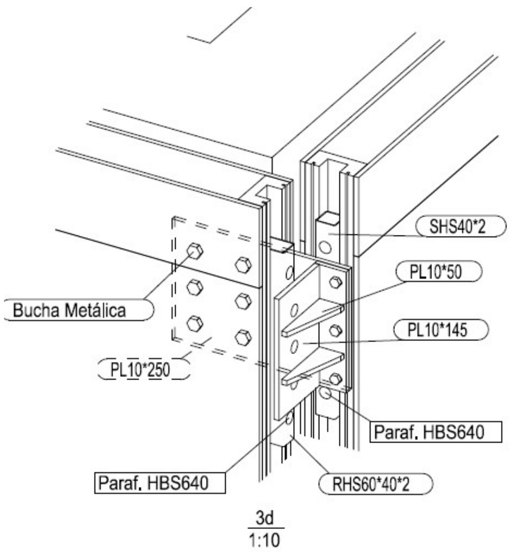


Figure 5.17 Elements of panel fixation.

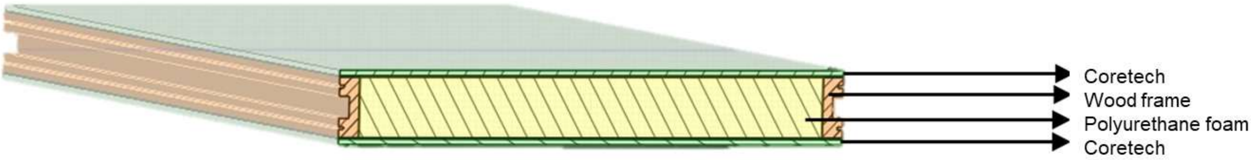
Prefab panels

The developed MORE-CONNECT prefabricated modular solution comprises a wood frame, an internal/external cladding made of Coretech® sheets and a filling material of polyurethane foam (Figure 5.18).

During the development process, both aluminium and wood were considered for the module structure (frame). The initial structure was considered to be in aluminium because it is a widely used material in Portugal in this type of prefabricated structures and in the construction sector in general. Nevertheless, wood is characterized by a higher thermal performance than aluminium, allowing reducing thermal bridges, particularly in the connection between modules.

Coretech® is a recycled material made from waste components of the car industry such as kraft and cellulose paper, polyurethane foam, fabrics and fiberglass. It offers such attractive characteristics as high durability, water and fire resistance and a very good thermal performance. Although it is not widely applied in the Portuguese construction sector, there are already several applications of Coretech®, both in building envelope insulation and external cladding of buildings. Other advantage of this material is the possibility of applying any material as external coating/cladding (paint, ceramic, plaster, etc.).

Polyurethane foam was chosen as a filling material of the prefabricated elements given its high thermal performance and high durability.
The Coretech® panel is 10 mm thick, the wood frame 100 mm and polyurethane foam 100 mm. In total, the prefabricated module has a thickness of 120 mm. The connection between the modules is a male-female connection in the wood frame.
In order to be tested in the laboratory facilities, 2.55 m long and 1.00 m wide prefabricated modules were produced (Figure 5.18). Nevertheless, the solution can be applied in different sizes, depending on the characteristics of the building. In the Portuguese pilot building, the dimensions of the panels are 10.0 m long and 2.4 m wide.



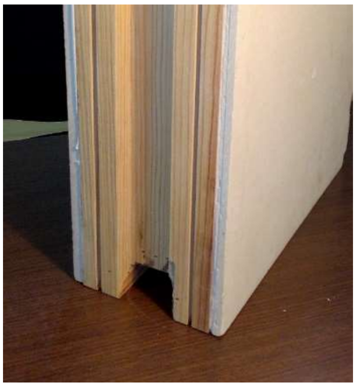


Figure 5.18 Illustration of the prefabricated module and Frame detail and prototype assembly

Due to the stiffness of the prefabricated element, there was a need to create an interface between the existing building wall and the prefabricated element, capable of absorbing the irregularities of the surface, guaranteeing a continuous insulation. This interface would efficiently prevent formation of thermal bridges and improve the energy performance of the solution. The chosen material to act as interface was mineral wool (MW) with a density of 25 kg/m^3.

Considerations:
Planned optimization of the industrial production line and mass production of the prefabricated panels are expected to significantly reduce the final costs of the modules and make them more cost-effective.

Conclusions
So far, the process has faced several challenges. Consideration of the life cycle and embodied energy in the choice of materials led to frequently non-consensual discussions regarding the need for balance between technical and structural features and sustainability concerns, which calls for a more integrated perspective from all stakeholders in the process.
In addition, planned (and functionally adequate) dimensions for the prefabricated modules are not usual for Portugal, which is likely to cause difficulties regarding both transportation and installation.

5.3 The Real Life Learning Labs

5.3.1 Czech Republic

The chosen housing type and the underlying rationale

Based on the statistical research, a 3-story building built in the period from 1946 to 1960 is the most widespread multi-family residential building in the Czech Republic. About 5% of the complete Czech multifamily housing stock belongs to this type. A post-war residential block in Milevsko was chosen as a reference building, by its typology and materials the building is representative of a significant part of the residential housing stock of the Czech Republic due for retrofitting.

This particular building, used as social housing, has 24 studios (room, kitchen, bathroom, hall), 31 m^2 each, in three stories (see Figure 5.19). Technical or housing facilities and cellars were put in the basement, which is partially situated under ground. Entrance to the building is located on the northern facade, leading to a wide central hall with north-south orientation. On the southern facade, central hall ends with a loggia. Each flat has two windows oriented either to the east or to the west. The building has a gable roof (33°); the attic space is currently unused. Building has longitudinal wall structural system made of bricks (450 mm), ceilings are made of reinforced concrete. Facades are plastered, windows and exterior doors are partly original, partly (3 out of 24 studios) replaced with insulating double-glazing, all with wooden frame.

Figure 5.19 Typical building representative of the typology in question in the Czech Republic.

In the time the reference building was build, usual U-values varied (there were no standards then): 0.76–1.72 W/(m^2K) for the roof, 1.07–1.70 W/(m^2K) for the walls, 0.76–1.22 W/(m^2K) for the floor and 2.18–3.44 W/(m^2K) for windows and doors. The total heat loss of the building is 2,037 W/K from which ventilation is responsible for 12 % and the remaining 88 % is accounted to heat flow by transmission. The annual energy consumed by one reference building is around 1,050 GJ.

General strategy chosen to renovate the housing type

The general strategy was developed based on the analysis of the typical representatives of the selected typology, their technical shape and needs, and on the SWOT analysis of typical common retrofitting interventions that are offered in the market nowadays.

The limitations imposed by the building typology are conditioned by the fact that the major part of the building envelope is at the same moment the load bearing structure – typically the masonry walls of

450–600 mm form the supporting structure for the concrete floor structures. Therefore, there is no option for replacements, the only way is to make an addition to the existing walls.
Czech industrial partner of the project is company RD Rýmařov, the largest national producer of prefabricated family houses made from panels with a timber structural system. Therefore, technology development started from the company's existing portfolio of panels and installation practices (direct installation of the elements by mobile crane from trucks that come just in time).

Technical concept chosen for renovation
A new system of anchors was developed that enable fixing of the panels on the existing facade (panels are hanged – no new foundation is needed). On the long facades with windows, the standard panels will be installed in horizontal position at the height of one floor. Their length will be up to 8 m for ease of manipulation by the crane. On gable walls, some panels might be installed also in the vertical position.

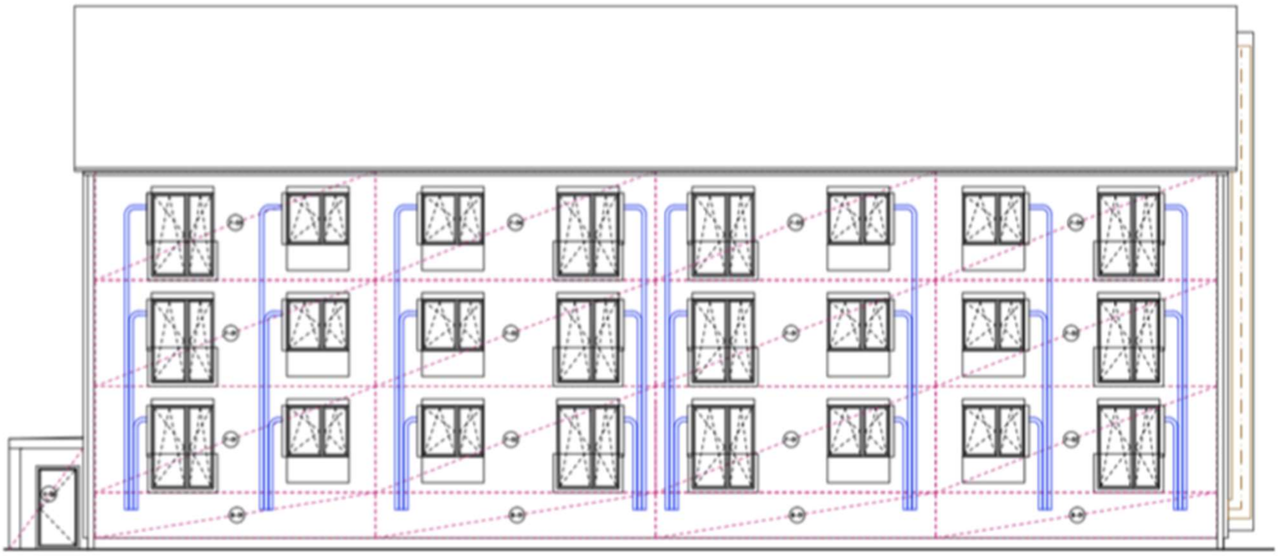


Figure 5.20 Set of 12 standard panels and 4 plinth panels on the eastern facade. New prefabricated entrance (on the left), new "chimney" accommodating new HVAC ducts (on the right).

At the plinth, there will be a set of special panels that provide connection from the horizontal air ducts (installed under the ceiling in the basement) to the vertical air ducts in the standard wall panels. Thus, the fresh air is distributed from the central HVAC unit in the basement through the wall panels to the air inlets that are placed just between the new windows in panel cores and the existing walls.
At the roof, the old layers of ceramic tiles on lathes are removed and new roof panels ready for the integrated PV system are attached onto the existing rafters, the system comes separately afterwards. There are special elements that provide closing the gap between the wall and roof panels.
Special modules are also developed to be attached at one sidewall; they create a new "chimney" which includes air inlets and outlets to and from the central HVAC unit with heat recovery.

Prefab panels
Each standard panel consists of a structural core made from timber frames, which are filled with thermal insulation and decked by fire resistant boards from both sides, and windows are fixed to the

structural elements. On the outer side of the core, plaster finishing is applied on wood fiberboards (see Fig. 5.21).

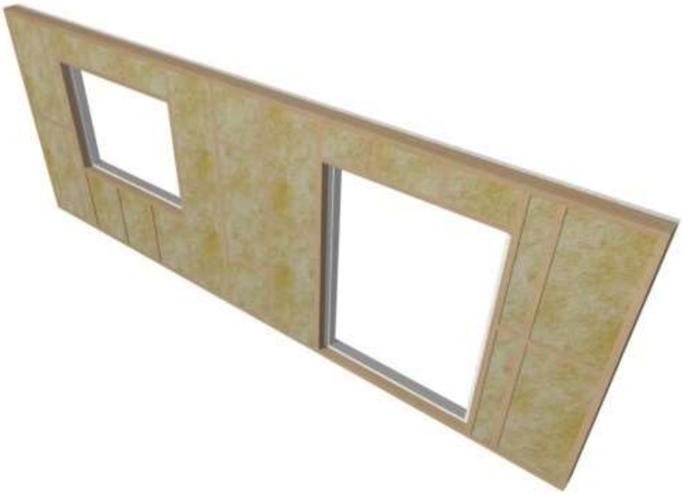


Figure 5.21 Structural core of a wall panel made of timber elements, fire-resistant boards from both sides filled with mineral wool.

On the back side of the core there is a layer of soft thermal insulation 120-140 mm thick. This soft layer integrates air ducts for mechanical ventilation of each flat, new wiring for sensors and internet distribution and piping for the cases a new heat distribution system is needed (see Fig. 22). In the same layer outlets of the ventilation air are also integrated, which are attached to the frame adjacent to windows.

Figure 5.22 Soft layer on the back of the core, which will be in contact with the wall of the existing building.

The prefab wall panels are attached to the existing masonry wall, usually 450 mm wide. Additional extension of the openings (after dismantling the old windows) for larger windows is possible, as well as the finishing. The window sills and jambs are finished by cladding made from furniture boards. The wiring and piping are accessible through small doors in the window jambs; the design of all technological boxes is airtight. The final setting is presented in Fig 5.23.

Figure 5.23: Final setting of the external wall module on the existing wall structure.

Production of elements – incl. design, characteristics of elements and testing
The MORE-CONNECT modules were produced at the production facility of RD Rýmařov and after that transported to UCEEB to install the technologies) and to make the quality control procedures.

Figure 5.24 Assembly of modules

Design of HVAC engine and monitoring and control system)

Following figure shows the design drawings and tools of the HVAC engine and control system for the mock up house.

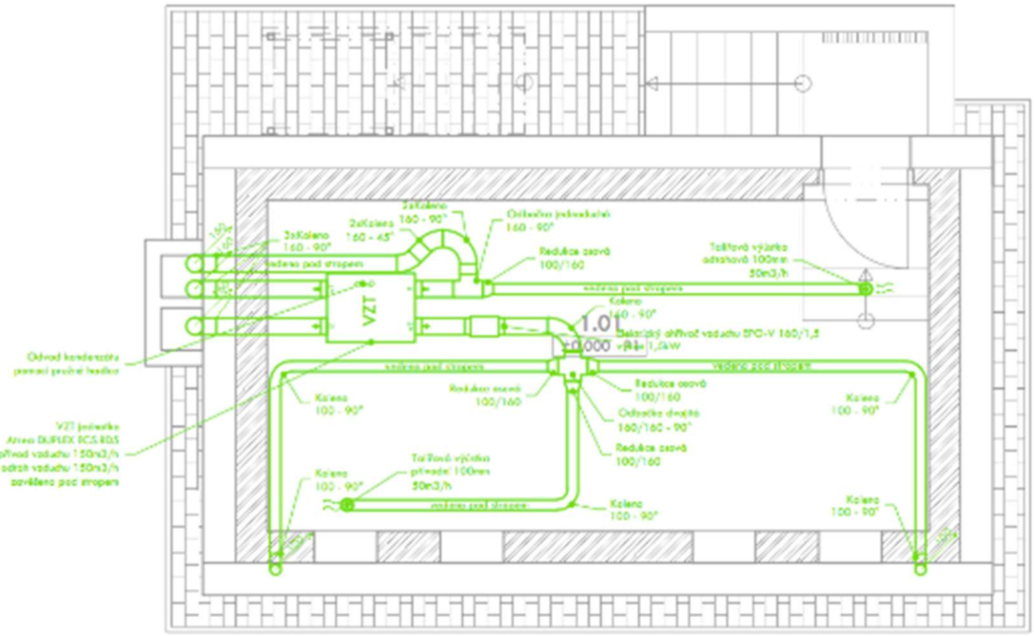


Figure 5.25 Design of the HVAC engine of the building

Mounting of elements – carrying out the renovation

The construction elements were mounted in one day and the whole process is in the video available at https://www.youtube.com/watch?v=wbltRnaSpjg . Afterwards the PV roof was finished.

Figure 5.26 Installation of PV roof

After the renovation – showing the final result
The mock up building is part of an excursion route for the visitors of CVUT-UCEEB and we show them the building, which has a tags for the visitors describing the particular elements of the modular retrofitting and the movie from construction.

Figure 5.27 The completed Czech Real Life Learning Lab.

5.3.2 The Netherlands

The chosen housing type and the underlying rationale
Since 2007 in the Netherlands several deep retrofitting projects have been completed, based on an application of prefabricated, modular building envelope elements. These projects involve mostly typical Dutch terraced (single family) housing owned by social housing associations.
The majority of these experiences have been carried out in the national program 'Stroomversnelling' However, directions for improvement have been identified and possibilities for upscaling (new markets) have been suggested. Following suggestions for further improvements and developments have been given:

Technological innovations:
- Plug-and-play connection between façade module and building structure: using click-and-span connections
- Retrofitting without the application of scaffolding on-site.
- Improvement prefabrication efficiency (improvement of both the design and the production of façade elements)

Process innovation:
- Minimal hindrance, dwellings remain occupied during the project: retrofitting within a single day
- Improvement office processes: supply chain average office cost in chain is approximately 30%
- Shorten the supply chain: approximately 10% profit and marketing costs per cut out
- Smoothen the supply chain by multidisciplinary design and integrated processes
- Scale, production and purchase: this should be upscaled from 500 pc to 10,000 pc, appr. 30%; design and materials innovation for production

General strategy chosen to renovate the housing type
The two real Life Learning Lab houses are situated in the Breitnerstraat 23 and 28 Heerlen, the Netherlands. These are terraced houses, built around 1960 en 1961, mostly in blocks of 3 to 6 houses. This building style is typical for that period in this part of the Netherlands (South Limburg). House Breitnerstraat 23 is further investigated in the MORE-CONNECT project.

The general idea is that the building envelope totally removed and replaced by:

- Multifunctional facades (prefab): these are new types of prefab facade including decentral combined heating and ventilation units (heat recovery, CO_2 controlled) for the living room and combined heating and ventilation units (convectors with fresh air supply) for the bedrooms
- Partly prefab solar roof
- Existing building services replaced by so called 'prefab engines', i.e. a prefab installation platform

The renovation of both dwellings is completed by the end of 2015.

Figure 5.28 The Dutch Real Life Learning Lab, rowhouse Breitnerstraat Heerlen

In general following renovation measures have been applied:

- All duct work and piping/plumbing integrated in prefabricated facade and roof elements, i.e., ventilation, heating, electricity water
- Facade and roof elements have a modular composition and will be installed 'plug & play'
- Exact sizing by 3D measuring (using the advanced geomatics technologies)
- Casings with Low Emitting glazing
- Roofs, two types of roofs are tested:
  - Dwelling Breitnerstraat 23: timber frame elements with integrated PV
  - Dwelling Breitnerstraat 28: SCX-solar System
- A unique designed separate prefab module for the building services (box or house engine), including a heat pump, DHW supply, storage, exhaust fan, PV inverters and controls. This module is is placed in a special space, integrated in the roof. This box can be removed out of the dwelling from outside for replacements, service and repairs.
- Special features:
  - End facade dwelling Breitnerstraat 28 is equipped with solar collector wall
  - Long term measurements on personal thermal comfort and personal health reception for two personas in dwelling Breitnerstraat 23.

Details on technologies :

- BIPV for renewable electricity production. Double glass panels, cemented in special frames (100% recyclable) with traditional PV panels. DC/AC => Kaco with logsysteem
- Air/water heat pump with inverter technology for heating and DHW
- Storage tank 200l coupled with heat pump.

- Decentral Ventilation systems (DC motor) combined with decentral convectors, integrated heat recovery for living rooms; demand controlled (CO2), integrated in the facades.
- Combined heating emission and ventilation systems by convectors (‘Low H2O’ with forced convection) for low temperature heating, also integrated in the facades.

Some performance indicators:

Rc facades:	5,5 m^2K/W
Rc roofs:	6 m^2K/W
EPC value conform Dutch standards:	0.0 (= energy zero on the meter)
Yearly energy demand:	ca. 1.400 kWh
Yearly energy supply by PV:	ca. 4.000 kWh
Yearly surplus of non-building bound energy:	ca. 2.600 kWh

Heating generation:	air/water heat pump
Ventilation:	ground floor: local MVHR
	first floor: forced air intake by fan driven convectors
	mechanical exhaust in kitchen and service rooms

Technical concept chosen for renovation

For the renovation of the two RLLL houses both the facades and the roofs were totally removed. In following figure some details of the design of the new façade and roof elements including connection are given:

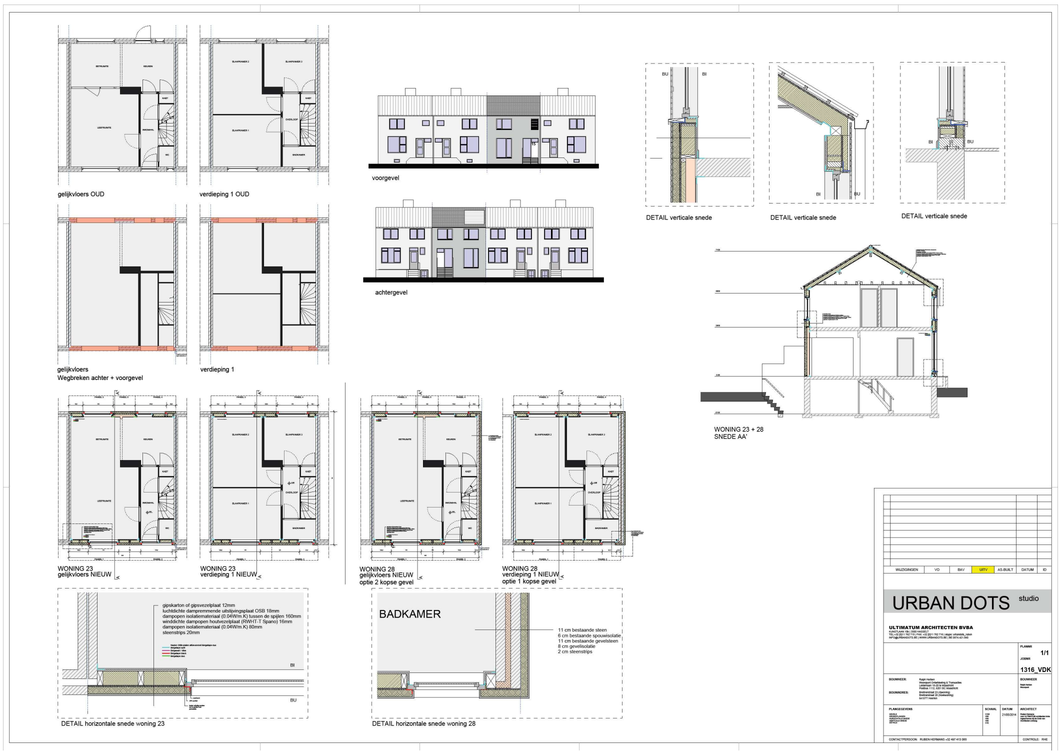


Figure 5.29 Design of the renovation

The basic prefab elements were manufactured at HEDACH, Bullingen, Belgium and assembled at Lambrechts, Genk, Belgium. The manufacturing of the basic elements were done in a BIM controlled automated process:

Figure 2.30 BIM controlled production of the façade elements

As these facades and roofs were still experimental types, the assembling was done manually:

Figure 5.31 Assembling of the integrated prefab facades

Figure 5.32 Assembling of the PV roofs

Production of the ‘house engines’

A special feature of the renovation of the RLLL houses is a special designed and prefab constructed platform for the building services: a box with the dimensions of 1,5 x 1,5 x 1,5 m for the heat pump, DHW production and storage, exhaust fans and PV inverters.

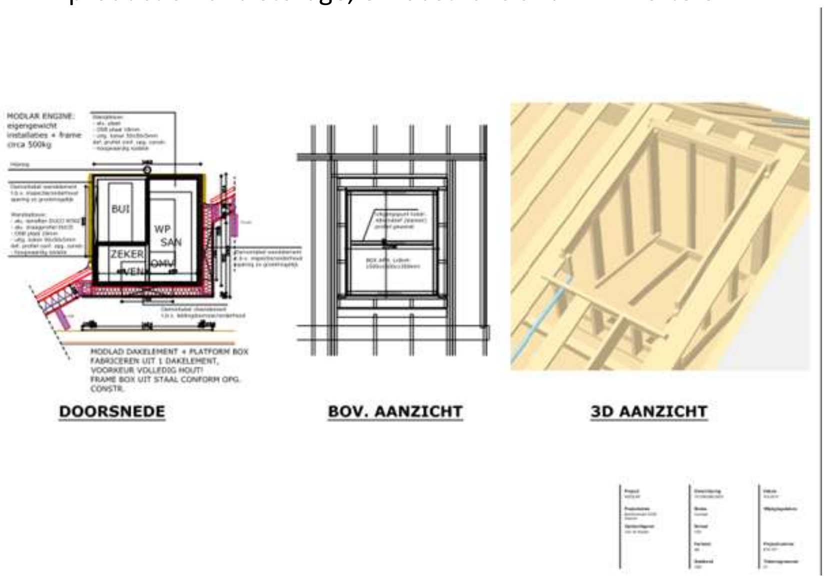


Figure 5.33 Design of the roof and place for house engine

Figure 5.32 Installing the PV roof and house engine

Final result

Following pictures show the final results of the renovation:

Figure 5.33 After completion: Front façade, back façade and interior living room

6 MARKET AND REPLICATION

6.1 Introduction

Parallel with the work on System Integration and Production and Process a pre-selection has been made of favourable concepts to develop and finally to market as basis of what will be offered to end-users. This is done with a specific focus on each geo-cluster, but with a common approach and a common base quality. The starting point are base concepts with base qualities, complying with the quantitative objectives and the basis assessment parameters. Next to the base quality a number of variants with extra qualities were developed (concerning energy efficiency, comfort, safety etc.).
This pre-selection was reviewed after the results of the first tests in the pilots. For the final concepts business cases were elaborated for introduction to the market for each Geo-cluster. The business cases were judged on applicability to mass consumption (after early adoption). To reach mass there is the need to fulfil mass needs on an affordable level. This is one of the main drivers for this project. This is a specific learning from the Dutch Energiesprong transition programme.
The second step in the exploitation phase was the definition of the 'energy services' based on one-stop-shop concepts. This includes a full elaboration of the one-stop-shop concept, including a description of the partners and the form of the entity that is going to do the exploitation of this one-stop-shop concept.
Also a system of performance guarantees was developed, based on the performance and quality control of the process and the performance control in practice by remote diagnostics.

6.2 Selection of favourable concepts to market.

The first stage is a pre-selection of favourable concepts which are to be developed and tested in the pilots. These pre-selections rely on results of the work done as described in sections 2 and 3 and on assessments of the technical solutions developed. The pre-selection is performed with respect to initial performance criteria which have been determined for the pre-selection (see section 3). It uses a common assessment methodology which has been worked out for this pre-selection as well as for the upcoming final selection of favourable concepts. The selection of favourable concepts has been done with a specific focus on each geo cluster and the technical solutions developed for the five geo-clusters. This resulted in the definition of the following indicators to be assessed for performance measurement and used for the pre-selection:

- Impact on primary energy use of the building, including embodied energy use related to the application of energy related measures
- Impact on greenhouse gas emissions, measured by CO_2 equivalents
- Impact on life-cycle costs, based on initial investment costs and costs for operation and maintenance of MORE-CONNECT-solutions

For the selection of favourable concepts the following assessment procedure was applied:

1. Definition of framework parameters: Economic parameters used in the assessments (such as energy prices, interest rates and exchange rates), emission factors, primary energy factors and climate data for the specific geo-cluster.

2. Definition of the reference building and necessary building data for the assessment: Dimensions and energetic properties of all building elements having an influence on the energy performance and GHG emissions.

3. Assessment of the reference case: Determination of the «anyway renovation» measures for the reference buildings, of related service lifes of the measures carried out as well as of associated costs, maintenance costs, and resulting energy needs of the building. Calculation of the impacts

on primary energy use, greenhouse gas emissions and costs for the «anyway renovation» - reference case. The «anyway renovation» measures are measures which restore the full functionality of the building elements with renovation needs, yet without improving energy performance (see Figure 6.1).

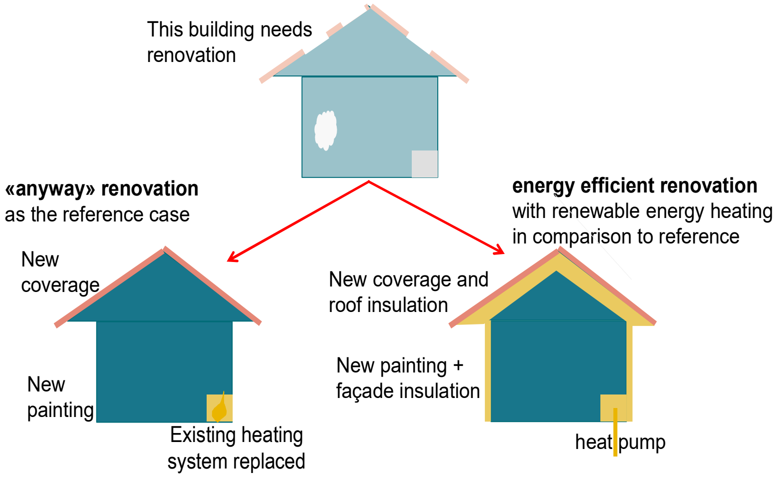


Figure 6.1 Distinction between «anyway renovation» and energy efficient renovations

4. Definition and assessment of different renovation packages with MORE-CONNECT-solutions: MORE-CONNECT measures are combined to renovation packages, starting with the most economical MORE-CONNECT solutions first. Related service life, associated costs, maintenance costs and resulting energy needs of the building are investigated and assessed and the impacts on primary energy use, greenhouse gas emissions and costs for the renovation case with MORE-CONNECT measures are determined.

5. By comparing the impacts of the reference anyway renovation case with those of different renovation packages of MORE-CONNECT measures and with different heating systems on greenhouse gas emissions, primary energy use and costs, the effects of the MORE-CONNECT-solutions are illustrated and their favourability compared to a reference renovation can be demonstrated.

6. The impact of particular assumptions or input factors are demonstrated by sensitivity calculations with respect to specific assumptions such as on energy prices or initial energy performance of the reference building – this step is carried out for the final selection of the favourable concepts only.

7. Evaluation and selection: Based on these assessments, the selection of the favourable concept can be made.

Figure 6.2 summarizes the procedure for assessing the (net-) impacts of MORE-CONNECT solutions on cost, primary energy use and CO_2 emissions:

1. Definition of the reference building

Collect the necessary building data for the assessment: Dimensions and energy properties of all building elements having an influence on the energy performance and GHG emissions.

2. Definition of framework parameters

Define economic parameters such as energy prices, interest rates and exchange rates, emission factors, primary energy factors and climate data, etc.

3. Definition and assessment of the reference case

Define “anyway renovation” measures for the reference case, determine related service lives, associated costs, maintenance costs, energy needs. Calculate impacts on primary energy use, greenhouse gas emissions and costs for the reference case.

4. Definition and assessment of different renovation packages

Define which MORE-CONNECT measures are investigated. Aggregate measures to renovation packages, starting with the most economical first. Determine related service lives, associated costs, maintenance costs, energy needs. Calculate impacts on primary energy use, greenhouse gas emissions and costs for the renovation case with MORE-CONNECT measures.

5. Comparison

Compare the impacts of the reference case with different renovation packages of MORE-CONNECT measures and with different heating systems on greenhouse gas emissions, primary energy use and costs

6. Sensitivities

Carry out sensitivity calculations, at least with respect to energy prices and initial energy performance of the reference building.

7. Evaluation and selection

Evaluate and take informed decision on which renovation concept to choose for pilots.

Figure 6.2 Overview of the assessment procedure for the selection of favourable concepts for the pilot projects

For the assessment of various possible renovation packages with MORE-CONNECT-solutions and the resulting selection of the favourable concepts, the following type of data was gathered by project partners of each geo-cluster:

- Data on dimensions and characteristics of the building of the pilot project or of another reference building typical for the ones to be targeted by the MORE-CONNECT market concept in the geo-cluster.
- Data on hypothetical "anyway-renovations" that would typically have to be carried out anyway just to restore the reference building's functionality, yet without improving the energy performance of the building, including data on costs of such measures to assess the economic effectiveness of the actual renovation measures in comparison with them.

- Data on different options for MORE-CONNECT renovation measures: For each building element which is renovated, data on various different material options or different efficiency levels are gathered, in order to create a variety of options based on which an optimization can be made.
- Data on heating systems, hot water systems, and cooling systems, if applicable: Cost data for these systems cover a span of possible sizes of these systems, as the actual size and related costs depend on the level of renovation measures carried out on the building envelope
- Embodied energy and embodied greenhouse gas emissions of the materials used in the specific variant of MORE-CONNECT-solution

According to the methodology, graphs were then developed to illustrate the primary energy, greenhouse gas emissions and cost impacts of the investigated options for packages with MORE-CONNECT renovation measures to support optimization and selection of favourable MORE-CONNECT-solutions and concepts.

Following the implementation of the pilot projects, the pre-selected favourable concepts have been reviewed. A final selection of favourable concepts was made. The same project partners responsible for the pre-selection of the favourable concept were also responsible for the final selection of the favourable concept based on LCA.

6.3 Life cycle analyses of favourable concepts for each geo-cluster

The work on the life cycle assessments was started already in connection with the pre-selection of the favourable concept. The methodology document which was prepared for providing instructions how to select the favourable concept also described the common methodology followed by project partners to carry out the life cycle assessments of the favourable concepts. The data which is used in these assessments is specific for each geo-cluster. For all geo-clusters life cycle analyses were carried out by project partners from each geo-cluster. The assessments included also aspects of material impact and related embodied energy and emissions.

Already for the pre-selection of the favourable concepts life-cycle assessments had been carried out, including also aspects of material impact and related embodied energy use and emissions. For the final selection of favourable concepts, life cycle assessments were repeated and adjusted as necessary by project partners. Project partners also took the following aspects into account when making the final selection of the favourable concept, as compared to the pre-selection:

First, it was made sure that the building, with which calculations are made for the final selection of the favourable concept does represent a common type of building for the respective geo-cluster. All project partners could continue to make use of the building for which the pre-selection assessment has been carried out, as all of these buildings were typical for their geographic area.

Furthermore, project partners included experience from the pilot projects in the final selection of the favourable concept.

In addition, for Czechia, Denmark and Estonia, the assessment was extended in comparison with the pre-selection by making additional calculations based on assumptions on future cost reductions of the MORE-CONNECT solutions due to a more automated production line, use of robots and mass production. For Portugal this had already been included in the pre-selection concept.

In **Czech Republic**, the finally selected favourable concept consists of the following elements: insulation of the walls with a MORE-CONNECT panel including 20 cm of mineral wool as a main insulation layer, insulation of the attic floor with 40 cm of blown wood fibre insulation and of the basement ceiling with 14 cm of mineral wool, new triple-glazed windows, and a ventilation system combined with warm-air heating. Wood pellets are the most favourable heat source based on the optimisation results; however, complications can be found regarding the need of pellets supply and storage, and many buildings in Czechia are already connected to a district heating system, which is why the final favourable concept foresees connection to district heating.

In **Denmark**, the finally selected renovation concept includes an insulation of the roof with 30 cm mineral wool, an insulation of the wall with 20 cm of mineral wool, new 3-layer low energy windows, a balanced mechanical ventilation system with a high efficiency heat recovery, and 19 m^2 PV per apartment. For the final selection of the favourable concept, it was taken into account that the MORE-CONNECT solution based on a solar roof replaces another roof renovation, which therefore contributes to the cost-effectiveness of the MORE-CONNET approach. A wood chip burner was identified to be the heating system with lowest life cycle costs and lowest primary energy consumption. However, the change of heating system was not considered as one of the renovation technologies to be part of the concept. For the selected favourable concept, district heating was chosen, as the large majority of apartment buildings in Denmark, including the pilot building, are connected to a district heating system.

In **Estonia**, the finally selected favourable concept includes an insulation of the wall with a MORE-CONNECT prefab element including 20 cm of mineral wool, a roof insulation with a MORE-CONNECT prefab element including 30 cm of mineral wool, new windows with an U-value of 1.1 W/(m^2 K), a new two-pipe heating system, a supply-exhaust ventilation system with heat recovery, and 30 kW of PV-panels. Compared to the pre-selected favourable concept, several changes were made, to lower investment costs for building renovation, while nevertheless at least achieving the same energy efficiency as new apartment buildings, which have EPC class C. Main changes compared to the pre-selection were:

- The MORE-CONNECT wall element is lighter and easier to produce (U-0.15 W/m^2K)
- The roof is not insulated with a prefabricated element
- Thermal transmittance of windows is increased to U-1.1 W/m^2K
- The basement floor is not insulated
- Solar collectors are not used
- More PV-panels are added to the roof

The larger PV system has the advantage of further contributing to reducing greenhouse gas emissions, as in Estonia the greenhouse emission factor associated with the electricity mix is high, since electricity production is to a significant extent based on shale oil. As heating system, district heating was kept as heat source for the favourable concept, because in Estonia, when a building is located in a district heating area, it is mandatory to use district heating, and wood pellets in large buildings were considered to be complicated to use.

Also in **Latvia**, the existing district heating system was chosen as heating system. Existing legislation requires that buildings in areas covered by existing district heating keep their connection to the district heating grid. In terms of the renovation measures of the building envelope, the finally selected favourable concept in Latvia includes a replacement of the existing windows by new windows of an U-value of 0.9 – 1.0 W/(m^2 K) and an insulation of the wall with a MORE-CONNECT prefab element with an insulation of 15 cm mineral wool. The experience from the pilot project showed that costs were significantly higher than originally estimated. To reduce costs and to make the solution more attractive on the market, the favourable concept therefore, includes less wall insulation than the pre-selected favourable concept with a wall insulation of 20 cm mineral wool. However, it is expected that some optimization of production and construction costs can be achieved in the future due to possible market upscale and mass production, which could again increase the attractiveness of higher levels of insulation.

In the **Netherlands**, the finally selected favourable concept was identical to the pre-selected favourable concept. It comprises an insulation of the wall with a MORE-CONNECT prefab element including 28 cm of mineral wool, an insulation of the roof with a MORE-CONNECT prefab element including 28 cm of mineral wool, an insulation of the ground floor with PUR insulation and an U-value of 0.22 W/(m^2 K), new windows with triple glazing and a U-value of 0.8 W/(m^2 K), the installation of an HVAC engine including heat recovery, and the installation of 40 m^2 of PV panels. In terms of greenhouse gas emission reductions, wood pellets and using heat pump were found to be in general the most favourable options for the heating system. To summarize, the favourable concept comprises renovation of the building envelope, introducing ventilation with heat recovery and combining this with renewables on-site, including PV panels.

In **Portugal**, the finally selected favourable concept consists of the installation of a prefabricated MORE-CONNECT module in combination with a 10 cm layer of mineral wool between the pre-existing exterior walls and the prefab module, 6 cm of added insulation to the roof and cellar, and a biomass boiler for heating and domestic hot water. Based on the assessment carried out, it was confirmed that taking into account embodied energy and embodied carbon emissions of the materials used does not change the selection of the favourable concept, despite the observed increase in values of primary energy and carbon emissions.

6.4 Business cases for the market concepts for each geo-cluster

The development of the business plans builds on the results of other work carried out within the MORE-CONNECT project. In particular, the pre-selected favourable concepts, the insights obtained from the pilot projects and the final favourable concepts were made use of. The business plans focus on investigating the business possibilities for bringing the MORE-CONNECT solutions to the market.

Business plans were developed for each geo-cluster through cooperation between the knowledge partners and the industry partners: For Czechia by Czech Technical University in Prague and RD Rýmařov, for Estonia by Tallinn University of Technology and AS MATEK, for Latvia by the Latvian wood construction cluster in cooperation with Riga Technical University, for the Netherlands by Zuyd University of Applied Sciences in cooperation with WEBO, and for Portugal by University of Minho in cooperation with Dark Globe. For Denmark, two business plans were developed, as two different types of MORE-CONNECT solutions were developed by two project partners, Ennogie and Invela.

The business plans consist of the following elements:
- A description of the MORE-CONNECT solution to be brought to the market
- External framework analysis
- Internal business analysis
- SWOT analysis
- Conclusions with respect to market opportunities, market strategy and cost optimization
- Outlook to the future development of the approach in the market

The procedure for putting these elements into context with each other has been as follows:

First, the proposed MORE-CONNECT solution and the key insights from the pilot projects were summed up. Subsequently, based on expert know-how from both industrial and academic partners an external framework analysis comprising a market, customer, competition and trend analysis was carried out. This was followed by an internal business analysis addressing the used technology, product and manufacturing processes, sales strategy and organization, distribution and partners. All results were then combined to elaborate a SWOT analysis where strengths, weaknesses, opportunities and threats of the MORE-CONNECT solution were investigated. This in turn gave the basis for drawing conclusions with respect to market opportunities, market strategy and cost optimization. Finally, a brief outlook was given on the future development of the approach in the market.

The results of the development of the business plans are presented as deliverable D6.3 in separate documents for each geo-cluster. For the Estonian/Latvian geo-cluster, two complementary documents were prepared, with the Estonian business plan focusing on the potential domestic market, and the Latvian business plan focusing on export.

For the different geo-clusters, the following conclusions were drawn in the business plans:

In **Czech Republic**, it is considered that there is a high business opportunity for the developed product as the market demand for energy saving solutions and products that improve the quality of the indoor environment is rising. The first market segment to be addressed are individual house owners looking for a complex and technologically developed product and the opportunity lies in communicating them the advantages of the product as it is a complex energy-saving solution that improves the indoor environment at the same time. The favourable concept is the cost-optimum solution chosen from many possible variants, particularly when taking into account expectations on future cost reductions due to mass production. It is planned to offer primarily the optimum solution, on the other hand the product is flexible enough to offer what the customer in his/her specific conditions demands. It is expected that the introduction of the MORE-CONNECT solution will be slower than originally expected, but that the market potential is high.

In **Denmark**, the MORE-CONNECT solution developed by Invela based on the use of robots is considered to have good chances of further market introduction due to the fact that the building industry is growing and that all over Europe there is a shortage of craftsmen and labour. The overall condition of the buildings in Europe is poor and a lot of the buildings are far from the new energy standards of today's buildings. This means there is a big market potential for energy renovation throughout Europe. This potential can only be exploited with the integration of robots in the building industry to increase the overall output. The modular robot platform will be able to save labour time on-site from 10% up to 80% depending on the tasks and processes performed. This gives the craftsmen excess time to execute more renovation projects. Furthermore, it will provide better quality and reduce costs for end-users.

For the other MORE-CONNECT solution from Denmark, which is based on a solar roof which completely replaces the traditional roof and which is developed by Ennogie, three demand-segments were identified to be favourable. The first segment comprises landlord-to-tenant, large commercial and initial residential projects. In this segment there are great opportunities to sell directly to bigger projects without cost to a reseller. Installers that can offer their customers an Ennogie Roof as an alternative to traditional solutions make up the second segment and can act as multipliers. Builders and contractors are the third segment that focusses on new buildings. New fully automated production facilities allow for economies of scale which will lower the price of the Ennogie Roof and make it more competitive according to price. Ennogie's MORE-CONNECT solution is a fully competitive product compared to other BIPV products on the market. After monitoring the pilot building in Denmark, the Ennogie Roof has been launched in the Danish market.

In **Estonia**, renovation of apartment buildings has been identified as the main renovation activity, due to the currently available subsidy programs. Current renovation activities come to approximately 200 apartment buildings per year. The outlook for the MORE-CONNECT solution depends on the continuation of the renovation subsidy programs and the capability to organize and demonstrate renovations with prefabricated wooden elements. It was estimated that in order to make the MORE-

CONNECT renovation solution well known and more mass-produced, it is necessary to renovate approximately 30-50 buildings per year with prefabricated wooden elements. But in order to achieve that kind of market demand, the cost of the MORE-CONNECT solution has to be in an affordable range for the renovation market. At the moment, prefabricated module panels developed for the MORE-CONNECT pilot building for achieving the nZEB level energy efficiency are considered to be too expensive for the wider renovation market. The current state of research indicates that changing the product only by focusing on a simpler prefabricated element and installation system itself is not enough for significant cost reductions in the near future. Further cost reductions require the effect of economies of scale. If they are achieved, the prefabricated MORE-CONNECT solution could be one of the main solutions used in future renovation projects. However, more research and development or external stimulation of market demand is needed for that.

In **Latvia**, it was considered that the MORE-CONNECT solution can probably not be applied to the national market at the moment, because the average income in Latvia is low. The retrofitted panels in the Latvian pilot project cost approximately €170/m^2 including all expenses, whereas the average income in the country is 437 EUR disposable income per household inhabitant per month. It was therefore considered that export markets like Denmark or the Netherlands offer the more promising possibilities for bringing the MORE-CONNECT solution to the market. In these countries, labour costs are higher, and the MORE-CONNECT solution can significantly reduce the amount of cost-relevant local work input. However, the average income level in Latvia is growing every year since 2010, and, therefore, it is planned to return to the Latvian market in the future, when the MORE-CONNECT solution will be affordable for more Latvian households. Moreover, the demand for energy-efficient thermal insulation solutions is going to increase for the same reason as in the export markets. In particular, Latvia has set rather ambitious energy-efficiency and energy consumption related national targets to be reached, in can therefore be expected that additional measures are going to be put into place to promote building renovation activities.

In the **Netherlands**, market uptake of the MORE-CONNECT solution and similar solutions based on prefabricated elements has already taken place. The MORE-CONNECT solution links to the Dutch deep-renovation approach developed in the ‘Stroomversnelling’ program. Modular renovation with prefabricated façade elements and additional ‘engines’ hosting several sustainable technologies regarding heating, hot water and ventilation is already a proven concept in the Netherlands. As a result this approach has become one of the dominant (favourable) deep-renovation concepts in the Netherlands. Moreover, despite concerns about the relatively high investments and payback time, recent studies showed that this approach encompasses a viable business case.

In **Portugal**, the primary market segment to be addressed is multifamily residential buildings. In particular, strategic and sales efforts are projected to focus primarily on public housing associations in urban areas, although privately owned residential buildings can and will be addressed too. There is a significant number of social housing buildings managed and owned by public housing associations with the adequate characteristics for a successful application of the MORE-CONNECT solution and in need for repairs and energy performance improvements. In addition, the focus on this type of buildings allows for economies of scale considerations, as well as taking advantage of several available incentives and funding opportunities. The central point of the strategy to bring the MORE-CONNECT solution to the market is the adoption of a cost-effective, industrialized and modular solution to improve the insulation of the building envelopes and consequently minimize primary energy consumption with reduced installation time and reduced users’ disturbance. It is expected that optimization of the production lines will potentially lead to a significant reduction of costs.

6.5 Models for a one-stop-shop concept

The development of the One-Stop-Shop concept has been done first in the Netherlands. In this 'One-Stop-Shop' proposition the end-user will deal with only one party, responsible for the total renovation, starting from an inventory of the existing situation, inventory of specific end-user demands, translation into modular renovation kits, mounting and installing, financing and aftercare. The One-Stop-Shop approach needs to be transferred to the other geo-clusters and MORE-CONNECT phases in order to become applicable in their country specific contexts. The One-Stop-Shop concept aims to bring together producers of wall, window, roof, building integrated technical systems and energy systems for comprehensive retrofit solutions for potential customers. The ZEB-renovation promises key results in comfort, healthy indoor climate as well as solutions that include household energy generation (NOM: Nul op de Meter). The proposed design process is organized in interdisciplinary teams resulting in earning the ZEB Guarantee.

The MORE-CONNECT One-Stop-Shop platform includes the following activities:

- Design (tool)
- Permits (comply with local laws, rules and regulation)
- Prefabricated building envelope elements
- Financing (and local subsidies)
- Construction / assembly
- Monitoring (energy performance guarantee)
- Maintenance and management
- Customer service
- Marketing

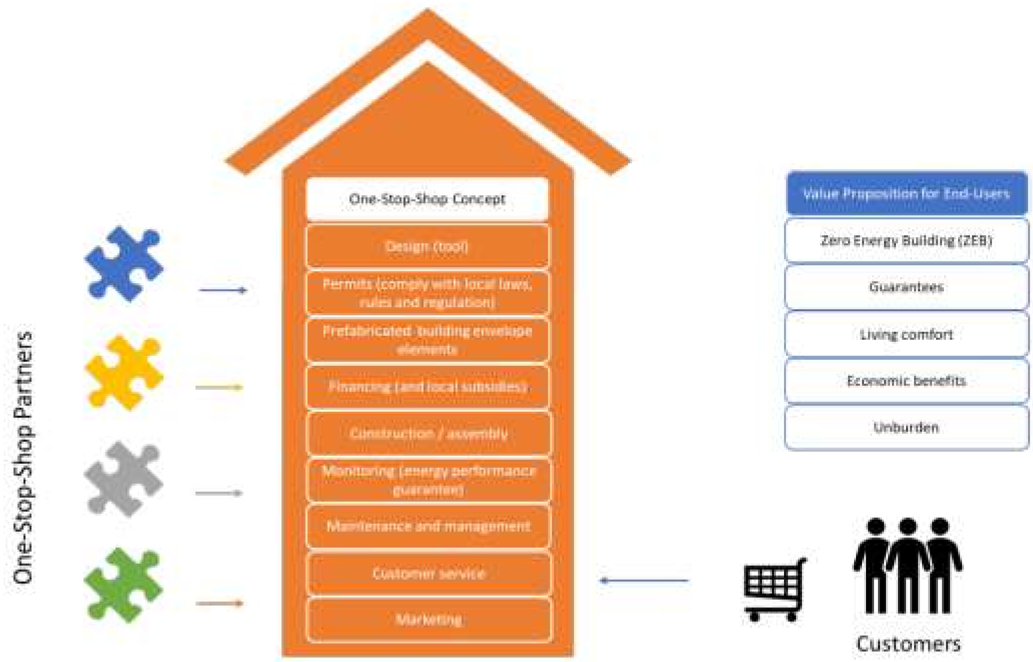


Figure 6.3 Schematic model of the MORE CONNECT One-Stop-Shop

Performance guarantees and monitoring

An important component of the zero-energy building (ZEB) deep renovation is that the houses are actually ZEB. The homeowner, tenant or the professional landlord depend on the zero-energy promise. Developers and builders must therefore develop their concepts in such a way that the requested and promised performance is in fact guaranteed. To guarantee performance, quality assurance is

important to guarantee the energy cost to the end-users, i.e. 1) Before, during and after construction and 2) By monitoring during the management phase.
In order to design the MORE-CONNECT guarantee, we leverage experiences gained from two Dutch projects, i.e. 'de Stroomversnelling'
The performance guarantee approach is translated to other geo-clusters in order to become applicable in their country specific contexts. At the moment is still not sure whether performance guarantees are needed for support in the country specific business and market cases. The methodology, ingredients and tools are now available for all participants to use.

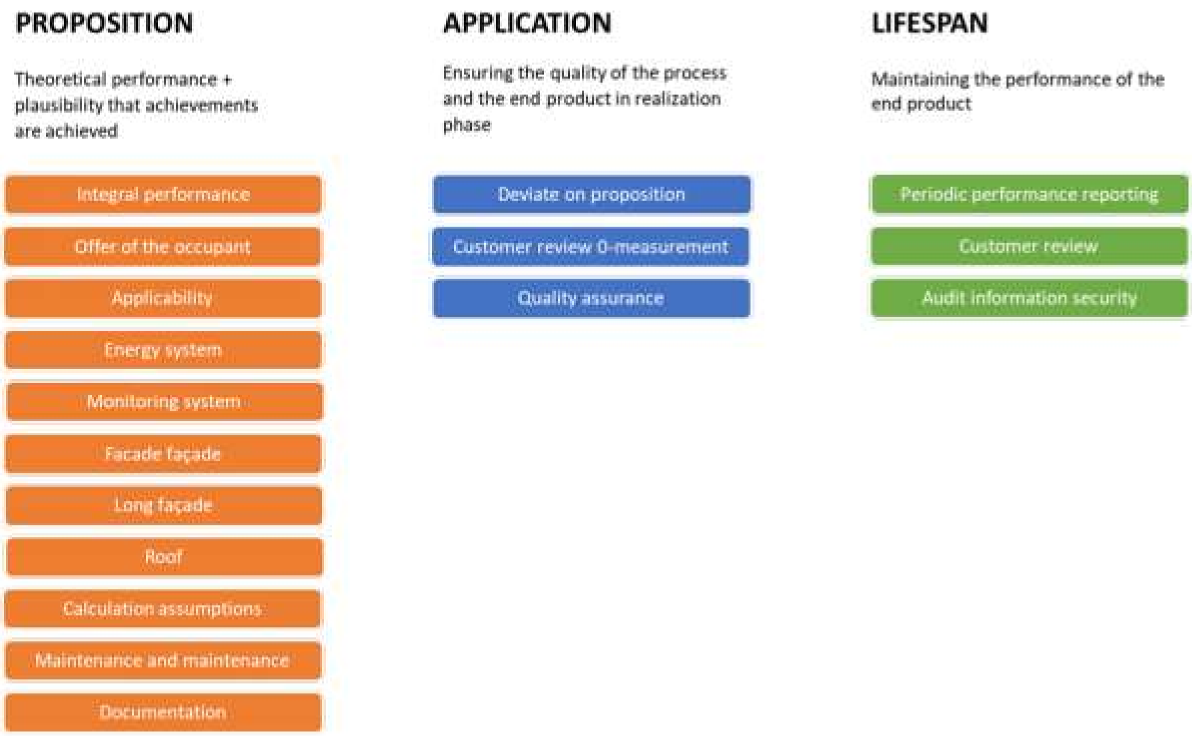


Figure 6.4 MORE-CONNECT ZEB guarantee in three levels

Energy services for guaranteed energy user propositions
The basis of an energy service is an agreement between two parties in which a certain consumption may not be exceeded under certain preconditions.
For the One-Stop-Shop based on ZEB (ZeroEnergyBuilding), guaranteeing the energy performance (use and production) is essential. A framework for an energy service is set up for the total energy use, based on the provision of guaranteed energy use / charge propositions. This means that the One-Stop-Shop concept, as well as other suppliers of ZEB, will conclude the 'Total Energy Cost Guarantee Contracts' with their customers.

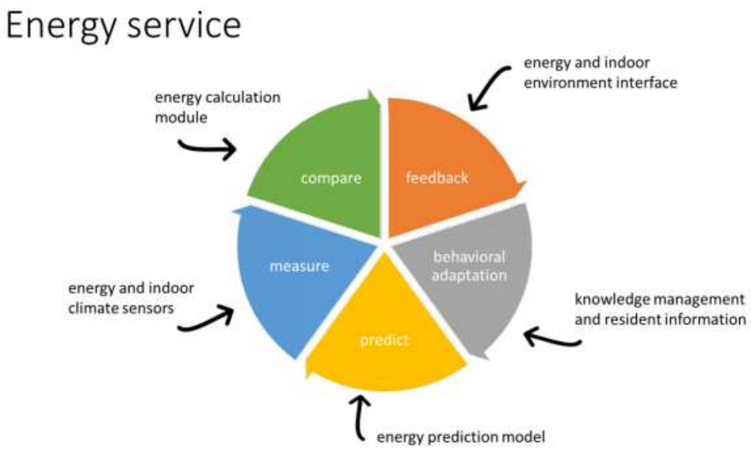


Figure 6.5 The cycle of predicting until behavioral change adapted by MORE-CONNECT

6.6 Valorisation models for each geo-cluster

The valorisation models describes in more detail how the business plans are going to be implemented and through the involvement of which market actors the products, concepts and services linked to the MORE-CONNECT solution will be brought to the market.

The development of the valorisation models and related considerations regarding supporting framework conditions and energy services as well as pointing out favourable marketing partners build on the results of previous work carried out within the MORE-CONNECT project: In particular on the pre-selected favourable concepts, the insights obtained by developing the final favourable concepts, the business plans related to this favourable concept and on the findings regarding favourable energy services, based on a one-stop-shop concept.

Valorisation models and implementation plans were developed for each geo-cluster through cooperation between the knowledge partners and the industry partners. The same project partners responsible for the business plan of a geo-cluster were also responsible for the valorisation model and implementation plan for that geo-cluster: For Czechia Czech Technical University in Prague and RD Rýmařov, for Estonia Tallinn University of Technology and AS MATEK, for Latvia the Latvian wood construction cluster in cooperation with Riga Technical University, for the Netherlands Zuyd University of Applied Sciences in cooperation with WEBO, and for Portugal University of Minho in cooperation with Dark Globe. For Denmark, two valorisation models/implementation plans were developed, as two different types of MORE-CONNECT solutions were developed by two project partners, Ennogie and Invela.

The valorisation models/the implementation plans for the favourable concepts consist of the following elements:

- A brief description of the unique selling points of the favourable MORE-CONNECT solution to be brought to the market according to the business plan
- The main customer groups targeted by the favourable MORE-CONNECT solution according to the business plan with a description of the specific offers to the particular target groups, as well as the key arguments and selling points for addressing the target groups, and the favourable trigger points for addressing the targeted customer groups
- Channels, multipliers and market actors to market the MORE-CONNECT solution and indication of channels which are planned to be established
- Subsidiary financing offers or strategies to boost demand for the MORE-CONNECT solution as well as subsidiary energy services or other supporting services planned to be established
- Indication of necessary regulatory and supporting framework conditions which could help to increase demand for the MORE-CONNECT solution

- Conclusions pointing out the main elements for a promising valorisation and implementation strategy and indicating the need for establishing new energy services or amending existing framework conditions in favour of a successful marketing of the MORE-CONNECT solution.

The valorisation models and implementation plans in part summarize information which is already provided in the business plans. They go beyond the business plans in particular by specifying the channels, multipliers and market actors for bringing the MORE-CONNECT solution to the market, by mentioning subsidiary financing offers or strategies or other supporting services, as well as by identifying potentially necessary regulatory and supporting framework conditions.

7 KEY CORNERSTONES OF THE MORE-CONNECT BUSINESS CASE

7.1 Introduction

Except the demonstration in the Netherlands, all other demonstrators involved technologies applied for the first time at this scale. From a technological perspective, encompassing the design, engineering, pre-production, production and installation of modular components constituting the MORE-CONNECT deep-renovation system, proof-of-concept has been provided by the demonstrators. This provided valuable insights about the business case for modular deep-renovation systems.

7.2 Coping with high investment costs

From the Dutch deep-renovation market it have been learned that since the first deep-renovation projects have been conducted (2007), this approach resulted in severe cost reductions from €120,000,- (excluding VAT) towards 65 - 85,000,- (excluding VAT) per single-family dwelling. About €25,000,- to €30.000,- is spent on the building envelope. Equally, about the same amount is spent on installation and finishing respectively. In comparison, from this it can be derived that the relative cost advantage of deep-renovation over new-build is limited, while the cost of new-build fall in the same range (excluding demolition and land costs). In both cases the return of investment is about 40 - 50 years within the social housing market. However, to come to this price reduction and moreover, to make further steps in price reduction, larger amounts of deep renovation projects are necessary, leading to a further market uptake, upscaling and mass production. In figure 7.1 the recent steps in price reduction of renovation projects in the Netherlands are shown.

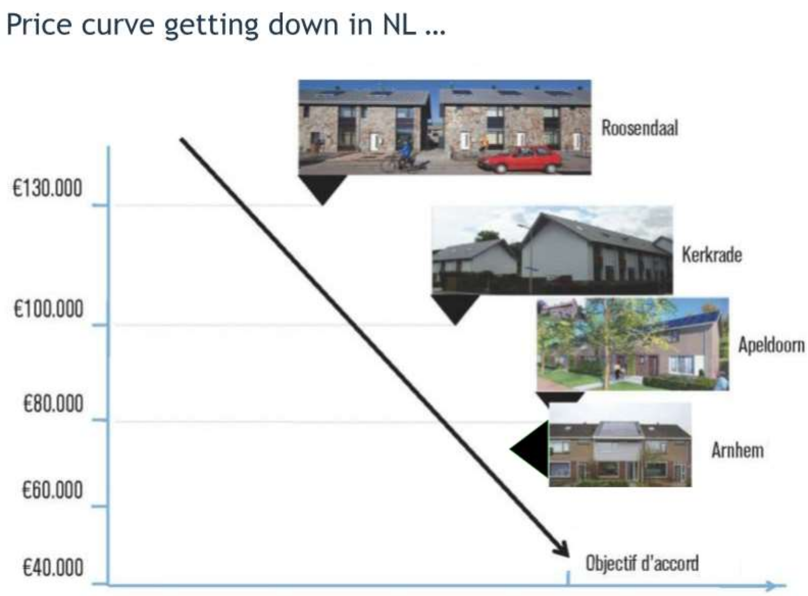


Figure 7.1 Price reduction of deep renovation in the Netherlands since 2010

Next, it was also learned that the MORE-CONNECT deep-renovation solution competes with alternative investment decisions, building owners could:

1. suspend investment in favour of the status quo;
2. invest to preserve the property for a shorter period of time up to 10 years);

3. invest to renovate the property (as built) with minor energy efficiency improvements (for a period up to 25 years);
4. invest to transform the property according the principles of a near energy zero build environment (for a period up to 50 years);
5. invest to replace the property, or;
6. to sell the property.

More precisely, it is expected that deep-renovation solutions compete with less radical investment decisions, like upgrading dwellings to label B; replacing dwellings (demolition and rebuilding) or selling properties (transferring responsibilities to another owner). There is also important to take in consideration, within a social housing context, for example, like the one addressed in the Portuguese business case, that there is a significant mismatch between the investor and the beneficiary of the improvements which can constraint ROI considerations and consequently, discourage decisions on investment.

Nevertheless, a study conducted by Kortman et al. (2016)[1] shows that the narrow business case (without taxes) already yields a positive return for the investing stakeholder (in the Netherlands often a social housing association). In this study the costs and benefits of deep-renovation projects, for the lifetime extension, have been broadly illustrated, i.e. the indirect costs, such as income tax, employment, rent subsidy, comfort increase, health and nuisance during renovation are included. See also the studies conducted by the RentalCal project[2], Financial Ideas[3], and the Energiesprong/Energielinq[4]. Taken together, during the MORE-CONNECT project (see chapter 6) it was learned, from the demonstrators as well as other research initiatives, that a viable business case is possible, but requires high investments which tend the be recovered over a relative long period of time. Nevertheless, Return on Investment (ROI) covers 40-50 years for the full deep-renovation. In contrast, it was learned that single modules part of the deep-renovation solution fall within the range of a ROI of 8-10 years like for example photovoltaics.

Moreover, it is expected that the investment cost of some other modules, like 'housing engines', will be reduced substantially due to economies of scale and eventually have a ROI of less than 10 years.

Table 7.1 Deep-renovation investments versus new-build investments (demolition cost; land cost not included)

Concept characteristics	First generation deep-retrofitting projects in The Netherlands (2007)	Second generation deep-retrofitting projects in The Netherlands; cost optimization (2017)	New-build
Energy label (improvement)	G/F --> A++	G/F --> ZEB	A++
€/dwelling * (case study)	€90,000-120.000,-	€65,000-85.000,-	€115,000,-
€/dwelling * (reference)	€65,000-85,000,-	€45,000-65,000,-	€82,000 (social housing) - €300/m3 (Fakton, 2014)

[1] Kortman, J., Vis, A. & Moret, E. (2016). Winst en waardecreatie bij energie renovaties: Eindrapport Waardecreatie bij energie renovatieprojecten in de woningbouw. Den Haag (NL): Rapport VNG

[2] H2020-EE-2014-2015: H2020-EE-2014-3-MarketUptake - European Rental Housing Framework for the Profitability Calculation of Energetic Retrofitting Investments, http://www.rentalcal.eu/rentalcal-reports

[3] Heijdendael, T., Buruma, J.M. & Van Vulpen, D. (2015). Financierbaarheid NOM renovaties: De impct van NOM renovaties op het financial risk volgens het WSW. Utrecht (NL): Report Finance Ideas.

[4] Coen, M. & Stutvoet, E. (2015). Nieuw Businessmodel voor corporaties. Retrieved from: https://www.energielinq.nl/wp-content/uploads/2016/08/03-Nieuw-businessmodel-voor-corporaties.pdf

Also the high investment costs seems also to complicate upscaling modular deep-renovation in other countries across Europe. More in detail, the total construction cost of the full renovation of Estonian pilot was € 822/m^2 (VAT included) that can be decomposed to:

- € 251/m^2: interior finishing (31%)
- € 121/m^2: general structures and public space in basement (15%)
- € 334/m^2: improving energy performance and indoor climate (41%)
- € 116/m^2: nZEB and scientific measurements (in addition to MORE-CONNECT) (14%)

From the experiences in Latvia and Denmark the remark is made that MORE-CONNECT aims to address mass retrofitting of similar buildings built by typical design. If a 'MORE-CONNECT renovation' is done as a one-off event it is much more expensive than regular traditional retrofitting. However, the modular approach is very attractive for ESCO's, municipalities and big housing associations. These companies are very interested in a solution which offers quality assurance and minimizes risks related to construction quality.

As extensively explored during the MORE-CONNECT project, innovation could substantially reduce the investment cost and subsequently contribute to a viable business case:

- Marketing and social innovations are suggested which increase demand such that the price per unit decreases;
- Product (component) innovation which lower the production and mounting costs;
- Process innovation in order to reduce overhead (design and engineering) costs;
- Optimization of the (pre-)production process which lower the production costs (increasing industrialization and automatization of production, upscaling production);
- Systemic innovation with revaluation of the deep-renovation concept as a whole. The façade element for example could be optimized on material consumption, which means reducing the amount of materials used in the elements: a slim element with minimum insulation thickness, facade openings, frameless, integrated ventilation and installations, and finished on the outside with thin film solar cells. The minimum use of insulation is compensated (with regard to energy) by extra energy yield. The facade element as a whole has a minimal embodied energy by applying bio-based materials.

7.3 How to capitalize the added value?

Having said that, the MORE-CONNECT project showed that the modular deep-renovation approach are transforming outdated and energy consuming housing into (near) energy zero buildings of new build quality and thus depend on both a retrofit cost part (restoring building quality) and an investment cost part (improving building quality). Improving a dwelling accordingly the MORE-CONNECT approach is considered to add value to the property in terms of overall building quality including energy performance and indoor climate. In sum, given the relative low (operational) energy costs in contrast to the high investment costs it cannot be guaranteed that just the decreased energy cost can compensate the investments to:

- Improved indoor climate
- Improved thermal comfort
- Extending the service life of building
- Improving the general living quality (including safety, accessibility etc.)
- Increasing the real estate value
- Less disturbance of occupants
- Etcetera.

These findings are supported by other research projects like Rentalcal[5]. The question is, can we take these aspects also into account in calculation of return of investment? And if so, how should we capitalize the added value of this? As also learned from the Netherlands, for the Estonian demonstrator, the building owner could calculate a simple payback period on single component level and as it was much shorter than service life of renovated building (which was enough for the owner). In addition, from the Dutch demonstrator it became clear that a decision to invest in deep-renovation also depends on the book and operational value of the property. Property on the balance sheet with a high book and/or operational value will not be considered because the investment could threaten the financial position of the building owner. In particular previous investments, for example the replacement of the HVAC system, could hamper adoption for the same reason.
An overview of costs parameters involved in the assessment of the business case of a deep-renovation project (adopted from Rentalcal, http://rentalcal.eu) is given in table 7.2.

Table 7.2 Overview of costs parameters involved in the assessment of the business case of a deep-renovation project

#	Parameter	#	Parameter
1	Depreciation base	**12**	Interest level on cash
2	(Linear) depreciation system	**13**	Credit limit
3	Depreciation rate	**14**	Holding period
4	Depreciation cash effective	**15**	Return expectations
5	Marginal tax rate	**16**	Loan-to-value expectations
6	Direct subsidies	**17**	Preferred amortisation method
7	Subsidised credit conditions	**18**	Equity
8	Interest levels of loans	**19**	Liquid assets at disposal
9	Reclaim ability of investment costs	**20**	Administrative and maintenance costs before renovation
10	Accounting side green value	**21**	Administrative and maintenance costs after renovation
11	VAT deduction	**22**	Development costs

[5] http://rentalcal.eu

8 CONCLUSIONS, LEARNINGS AND RECOMMENDATIONS

8.1 What can we conclude after four years of MORE-CONNECT?

The MORE-CONNECT pilots and Real Life Learning Labs are covering the phases: Design, production of the prefab elements and installation and were based on the four pillars that were the basis for the MORE-CONNECT project:

- Product Innovation
- Process Innovation
- Optimization between costs, environmental aspects and quality
- From the perception of the end-user

MORE-CONNECT started with as main idea that prefabricated multifunctional renovation elements are expected to have the potential to:

- reduce costs
- reduce the renovation time and disturbance for occupants (less intrusive)
- enhance quality and performances:
  - of the products/elements by better Quality Control in factory
  - of the renovation works (less labour on site, less failures)
- energy efficiency, indoor climate and environmental quality in use

This assumption was based on the first studies and experiences that have been done in IEA EBC Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (2006 – 2011).

After four years of MORE-CONNECT and the sharing of the experiences of the MORE-CONNECT 'sister projects' (like 4RinEU http://4rineu.eu/, ProGETonE www.progetone.eu , P2Endure www.p2endure-project.eu, BERTIM www.bertim.eu, IMPRESS www.project-impress.eu/, STUNNING www.stunning-project.eu , TripleA-reno http://triplea-reno.eu and many others) we can indeed conclude that we were able to make a step forward by combining these four pillars.

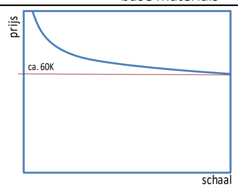
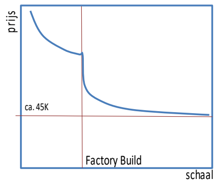
Important lessons, learned in MORE-CONNECT are:
Technological developments are not so much a problem, but the traditional market is still dominated by traditional (large) construction companies. This results in following observations:

1. There are still too many layers in the renovation process.
2. Clients are in general still reluctant for innovations.
3. Major traditional construction companies have a total other 'earning model' than new innovative companies, i.e., traditional companies often bring out low very and competitive bids and do the actual earning on extra work and failure costs. An 'all in offer', as proposed by the MORE-CONNECT companies, cannot compete with that.
4. One of the major constraints of further market implementation is the (much) higher quality of the MORE-CONNECT solutions, compared to traditional solutions, so in fact, prices cannot be compared one-on-one.

As a result, the production companies in MORE-CONNECT were indeed able to develop blue prints for new production processes and factories in MORE-CONNECT but due to lack of market the implementation of most of them are still on hold. A step to make to overcome this deadlock is the connection between advanced geomatics (point clouds) and BIM for production as transferring point clouds in BIM is still hand work. If we can make this step, it should be possible to come to a disruptive

price reduction, without limiting the quality. Concerning this point, MORE-CONNECT explored some new projects, funded under the EeB2-2019 call (BIM adapted to efficient renovation). It seems that for example the BIM4REN project can offer solutions for this.
Table 8.1 shows an overview of steps made in MORE-CONNECT (and its sister projects) from 2014 till 2018 (MORE-CONNECT 1.0) and the steps that can be made from 2019 till 2022 (MORE-CONNECT 2.0).

Table 8.1 Overview of steps and developments in MORE-CONNECT from 2014 till 2018 and steps to make till 2022.

Characteristics	**Generation 1; 2018**	**Generation2; 2022**
reference	**H2020 2014 -2018**	**H2020 2018 -2022**
Quality level	wide variance in quality of models	minmal standards defined and applied
Depth of use	wide variance, still growing	deep use and integration with all building aspects
Design	integral approaches, weak tool support	Multidiciplinary approach
Applicability (business type factor)	Larger buildings and installations	All buildings and installations
Business approach	Project by project	Product by product
Supply chain penetration	Weak	deep
Supply chain integration	Low	High
P/P curve	too expensive; only larger projects, only larger suppliers	affordable for all
Satisfaction	still resistence from traditional workforce	happy users and end users
Decision support	On physical building design errors	On all building aspects
Parametric design	upcoming	widely used
Partnering model	dictation model	Multidiciplinary approach
Excisting build support	low, much manual effort	highly sofisticated f.i. automated Pointcloud2BIM
Maintenance support	almost non excisting	ranging from remote support to predictive maintanance
Technology supported (1)	non integral, vendor based, upcoming exchange standards for Bim	integral seamless between vendors
Technology supported (2)	almost no solution for on-site realization, process management and quality control support	Integrated solutions for on-site realization, process management and quality control support
Technology supported (3)	Industry 4.0 principles early state	Industry 4.0 principles applied; f.i machine learning for optimising next product, oit/algorithms for distance management, flexible production assemblys part of the design proces
Office effort	30% of cost	10% of cost
Marketing effort	1 % of cost	10% of cost
Assemblage time on-site	3 to 10 days	< 1 day
Scale	small assembly suppliers dictated by builders	Large assembly suppliers organised/supported by OEM's
Focus	Projects	Products
Mass customization priciples	somewhat in new home projects	full scale including one-off buildings
Production preperation in design	limited	full scale including one-off buildings
Production automation support	single machine based (mostly)	line production based (multi assembly) including flow/routing optimization
Design for onsite work (craftsmen versus factory)	mixed approach	only assembly
Design for circularity	base materials	refurbishment included in original design
Cost reduction for single family dwelling		

The next generation will be aiming at price reduction due to profound use of new technology, industrialisation, implementation of robotics and high possibilities of modification. Also there will be the focus on the creation of 'building streams' instead of building projects. The next generation anticipates an upscale up to 8 fold.

8.2 Collaboration and experiences gained from other H2020 deep renovation projects

From the start of the project, MORE-CONNECT has aimed for strong collaboration and sharing of experiences with other H2020 project on deep renovation. This led to the idea to establish the so called 'Project Cluster', http://4rineu.eu/project-cluster/, initiated by MORE-CONNECT's sister project 4RinEU. In the framework of this project Cluster workshops were organized during Sustainable Places

2018 and 2019 and the SBE Retrofit Europe Conference 2018. These events were joined by 4RinEU, ABRACADABRA, P2Endure, ProGETonE, STUNNING, TransitionZero, TripleA-reno, Turnkey Retrofit. This strong collaboration with MORE-CONNECT's sister projects was very important as a learning process and to gather feedback on the MORE-CONNECT technology and concept developments. Moreover, this collaboration also gave the change to have an effective common promotion of all the c outcomes and the numerous benefits, working together in the H2020 programme.

MORE-CONNECT is one of the first H2020 projects on deep renovation and many H2020 projects started after that, focusing on several technical developments. Table 8.2 categorizes 32 EU-funded projects (mostly H2020) based on 10 key state of the art solutions, as follow:

- Prefabricated systems
- Smart Building Management Systems (BMS) and ICT integrated solutions
- Heating Ventilation and Air Conditioning (HVAC) integrated solutions
- Renewable Energy Source (RES) integrated solutions
- Building Information Modeling (BIM) and Building Performance Simulation Model (BPSM)
- Advanced Geomatics
- 3D printing
- Super Insulation Materials
- Smart Connectors
- Multi-benefit approaches

The majority of the revised EU-funded project included pre-fab systems in deep renovation processes (ABRACADABRA, ADAPTIWALL, BERTIM, BRESAER, E2EVENT, EASEE, Eensulate, IMPRESS, INSPiRe, MeeFS, MORE-CONNECT, P2ENDURE, REnnovates, RetroKit).

Since one of the main barriers to adopting deep renovation measures is the guaranteed high efficient performance, against the high capital investment cost and complex operation, pre-fab system are oftentimes supplemented by smart building management systems (BMS) and ICT, as in the case of the A2PBEER, BRESAER, CETIEB, E2EVENT, MeeFS, MORE-CONNECT, REFURB, REnnovates, and RetroKit projects.

The modular nature of pre-fab system allows seamless integration with active system for production from renewable energy sources (RES) such as solar panels and photovoltaic (PV) systems, as for the ABRACADABRA, BRESAER, E2EVENT, INSPiRe, MeeFS, MORE-CONNECT, REFURB, REnnovates, and RetroKit projects.

Building Information Modeling (BIM) and the exchange information with building performance simulation models (BPSM) emerged significant enabling technologies in state of the art solutions for deep renovation towards nZEB oftentimes in combination with advanced geomatics (3D scanning), as for the case of the BERTIM, EASEE, MORE-CONNECT, NewTREND, REnnovates, and projects, and 3D printing techniques (MORE-CONNECT, P2ENDURE, IMPRESS, TransitionZero).

Several projects focus on innovative optimized HVAC packages integrated with pre-fab deep renovation packages that allow for easier, less intrusive and more efficient improvement of the existing HVAC installations, as for the case of the E2EVENT, MORE-CONNECT, REFURB, REnnovates, and RetroKit projects. One of the latest trend in deep renovation solutions for nZEBs emerge the coupling of multi-benefit strategies with state of the art technologies, overcoming technology adoption barriers and addressing the faceted needs of customers of the renovation market at the EU scale, for example the ABRACADABRA, MORE-CONNECT, NeZeR, REFURB, REnnovates, TransitionZero and ZEBRA 2020 Projects.

Table 8.2: Key state of the art technologies for the reviewed EU-funded projects that deal with pre-fab systems for deep renovations (source: H2020 ProGETonE, D2.1 'Report on the state of the art of deep renovation to nZEB and pre-fab system in EU').

Project	Pre-fab	BMS - ICT	RES	BIM - BPSM	Multi-benefit	HVAC	Advanced geomatics	3D printing	Smart connectors	Advanced materials
A2PBEER		√								
ABRACADABRA	√		√		√					
ADAPTIWALL	√									
BERTIM	√			√			√			
BRESAER	√	√	√							
BuildHEAT	√	√	√		√	√				
CETIEB		√	√							
E2ReBuild	√									
E2EVENT	√	√	√			√				
EASEE	√			√			√			
Eensulate	√									
HERB	√		√			√				√
IMPRESS	√							√		
INSITER							√			
INSPiRe	√		√							
MeeFS	√	√	√							
MORE-CONNECT	√	√	√	√	√	√	√	√	√	√
NewTREND				√						
NeZeR				√	√					
P2ENDURE	√			√			√	√		
OptEEmal	√	√		√	√		√			
REFURB		√	√	√	√	√				
REnnovates	√	√	√	√	√	√				
RetroKit	√	√	√			√				
RE4	√	√		√			√		√	√
smartTES	√		√			√				
TES	√		√			√			√	√
TransitionZero				√	√		√	√		
VEEP	√						√		√	√
ZEBRA 2020					√					
4RInEU	√	√	√	√	√	√				

As illustrated in figure 8.1, most of the projects included pre-fab systems in deep renovation processes.

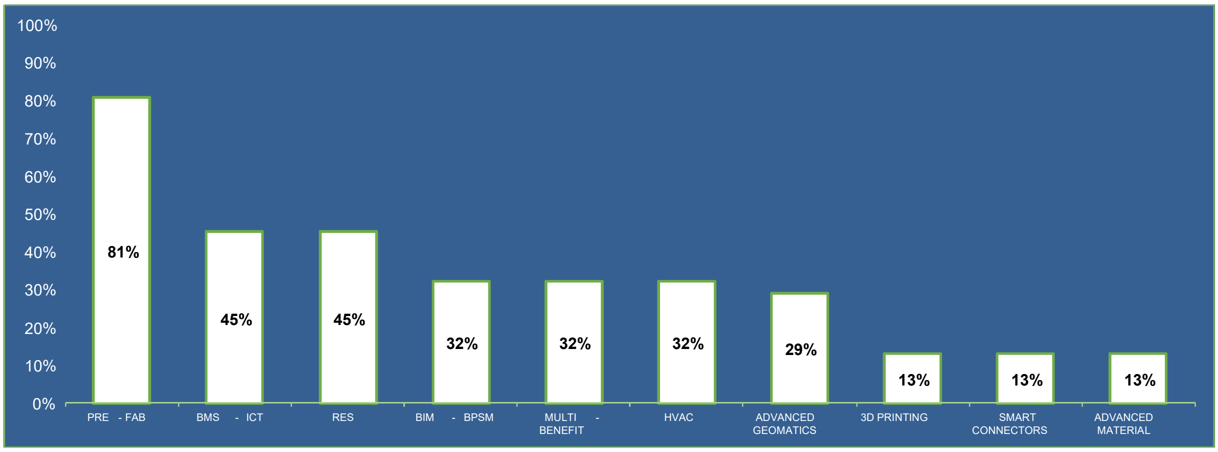


Figure 8.1: Analysis of key state of the art solutions for deep retrofit emerged from EU-funded projects (2011-2020)

MORE-CONNECT emerges as the only H2020 project moving one step forward a full integration of the most advanced state of the art technologies combined with prefabricated modular systems for deep renovation. Significantly, fully integrated adoption of prefab principles (platforms, modularity) and its correlated state of the art technologies has some advantages:

- Development of an assessment approach, towards development and testing of technical progress of state of the art technologies, developed;
- Development of guidelines, including transfer of knowledge and skills, to be delivered and disseminated among all the EU community (researchers, practitioners, building industry, technology vendors, and producers, etc.)
- Better knowledge understating for the building industry on properties and duration of advanced materials, to enhance the performance of their products/concepts, as well as calculation methodologies, assessments, and testing procedures. Benefits for the industry sector include the validation of integrated solutions enabling better collaboration and utilization of each other’s competencies, products, and experiences.

All combined, these advantages are foreseen as enabling factors for a deeper market (and user) acceptance of the highly promising state of the art solutions for deep renovation at the EU level.

8.3 What did we learned from our MORE-CONNECT pilots?

During the actual execution of the pilot projects, also many experiences were gained on the construction and the operational level.

For example from the Estonian pilot following lessons were learned:

- It appeared to be very difficult to insulate horizontal joints in practice.
- In practice, different gap sizes appeared in vertical joints.
- These two problems can be fixed by a better fine tuning of the production design.
- The prefab façade elements were quite large and heavy and were very demanding to install.
- Too accurate design details.

Another example of the lessons learned is here presented from the Danish PV-roof manufacturer Ennogie, Within More-Connect Ennogie has developed several prototypes of its Solar Energy Roof - in particular concerning methods of mounting and flashing details to create a customer and installer driven plug-and-play solution. Before starting the installation on the pilot building Ennogie completed two prototype installations. Learning from these experiences about installation methods and workmanship Ennogie changed the way cables are to be assembled and packed, which led to an increase in a 10% efficiency in onsite installation.

A special feature in MORE-Connect is the robot developed by Invela. Invela has throughout the MORE-CONNECT project worked to test and find suitable robots for the building industry. After numerous tests using traditional 6 axes robots, Invela found that these types of robots are not fit for use in the building industry. The main raison is due to their high price and high technology level for implementation, and their limitation concerning their actual capacity to only work on a very small working area. The biggest of these types of robots weighs more than 1.5 ton, which makes it very hard to maneuver around the building site. Even when using a smaller robot on-site, like the model UR-10 (Universal Robot), the working area is not more than 1m^2, which means it should be moved many times when working on a big building. This would destroy the business case for the hole solution, due to the manual workers time spend on moving the robot around.
Due to these learnings, Invela has developed a new modular robot lightweight platform, which is scalable in size and ready for programming and implementation directly from the original *Autodesk* drawings of the building and tested in Invela's pilot case in Korsløkkeparken. This new robot type makes it possible to mount many kinds of tools to be used for the on-site tasks. The tasks can vary from mounting, painting, milling, drilling, moving and lifting. The new robot solution provided by the spin-out company: Robot At Work, has been well received and is already being commercially implemented into 3 different tasks for 3 different clients:

1. A solution where the robot is mounted directly on the façade. A small milling tool and *Vision* controlling of the robots movement on the fly is applied, and this makes it possible for the robot to mill out the old mortar joints between the bricks.
2. A solution where a big grinder tool is mounted on the robot. This makes it possible for the client to grind of dangerous lead and toxic PCB paints of the walls on the building.
3. A solution that is being implemented in a prefab wall element factory, where the robot makes it possible to (1) render with plaster on an interior wall, (2) polish the wall plaster evenly and (3) making the finishing painting layer on the element. All 3 tasks performed with only one robot solution

So basically, Invela has achieved to develop a modular robot lightweight platform fit for the building industry, making it possible to work faster and more efficient in many different tasks with and improved quality. A secondary output of this technology, will be minimizing hazards for the craftsmen performing heavy lifting and unilateral repetitive work - securing a safer future of craftsmen in the building industry.

8.4 Learnings from the prefabrication production process

At the start of MORE-CONNECT, 2015, the building industry was not or hardly industrialized. Raw materials and half fabricates were not suited for automated production lines. Details (assemblies) were typically designed for implementation on the job, i.e. on the building site. The European building industry stood for a real challenge as it was one of the few industries that did not innovate and develop integrated products and solutions. Facts as that:

- a systemic approach is not implemented;
- an interdisciplinary approach is not implemented;
- the 'chain' is a chain of fighters, not cooperators;

- a *project* approach instead of *product* approach with no mass customization;
- a lack of power building industry suppliers of assembled components as:
    - they are mostly too small (the larger are 10 to 20 millions in revenues);
    - are stuck in their old routines;
    - are stuck in the builders old routines;
    - are stuck in the buyers old routines;

has led to the situation that the building industry was the only industry that succeeded in generating worse price/performance ratios overall last 30 years.

In MORE-CONNECT the industrial partners worked on improving this situation during the project by developing and improving prefabrication of renovation elements.
The most important lessons that the MORE-CONNECT industries have learned in general on the prefabrication production process are:
- Industrialization of the construction process is in fact the decomposition of a building in different elements (step1).
- These elements can be produced and pre-fabricated off site (step 2).

The next steps to make in further industrialization and prefabrication are:
- Step 3: industrializing
- Step 4: automizing
- Step 5: roboting

At this moment, the average construction process is not much further the step 2. In MORE-CONNECT we started with steps 3 – 5. The question however to which extend can we establish now a further *market uptake* for the steps 3 – 5.
Once these steps are made it is expected that the majority of building and renovation projects will be industrialized, leading to:
- Better products
- Lower pricing
- Maximum value to customer and companies
- Guaranteed performances

On the short time it is expected that 60% of the renovation market (as well as new construction) will be fully industrialized. However, still 20% of the renovations will be done in a traditional way (i.e., not interested in making the transition). The other remaining 20% are the so called special projects, i.e. project for which no solutions are (yet) available.

Figure 8.2. The future of the building industry

8.5 Our recommendations

After four years of MORE-CONNECT following more general conclusions and recommendations can be made:

- There still is a generalized lack of knowledge on innovative deep renovation design methodologies including the adoption of prefabricated systems. This is hindering the wider market adoption of such highly promising technological solutions.
- It is crucial to enhance user's experience of the renovation process, by means of ICT/BMS-supported improved comfort, while ensuring low intrusiveness and allowing aesthetic flexibility in design, and accommodating future performance uncertainty.
- It is important to make complexity manageable, ensuring and enhancing product and process quality during the whole life cycle.
- Integration of RES is included and necessary as a solution for achieving energy efficiency and as a necessary step towards nearly zero energy renovation, but has as a single measure just a limited relevance.
- Learning from previous experiences and best practices of technological solutions and optimization objectives for deep renovation and pre-fab systems could be further developed in further (EU) projects, thus successfully meeting the expected 2020 energy targets. For example, the Sustainable Places conference series appeared to be a successful platform for knowledge exchange.
- More holistic approaches and specially user-centric design for deep renovation are needed.
- The most important step to come to further automation, industrialization and hence price reduction is the connection between advanced geomatics (point clouds) and BIM for production as transferring point clouds in BIM is still hand work. If this step can be made, it should be possible to come to a disruptive price reduction, without limiting the quality.

COLOFON

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION'S H2020 FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION UNDER GRANT AGREEMENT NO 633477

WWW.MORE-CONNECT.EU