MORE-CONNECT

Development and advanced prefabrication of innovative, multifunctional building envelope elements for MOdular REtrofitting and CONNECTions

(No. 633477)

D5.9 Analyses of the total renovation processes in the pilots

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Executive summary

This report presents and summarises the experiences from the MORE-CONNECT energy renovation pilot projects. These projects demonstrate the implementation of new prefab technologies to lower the renovation cost and reduce the working time at the building site in 6 countries: Czechia, Denmark, Estonia, Latvia, The Netherlands and Portugal. As these projects are demonstrating the technologies for the first time they are referred to as pilot projects. The project comprises 5 pilot projects and 2 so-called real life learning lab (RLLL) environments.

The experiences cover the complete working chain from the design, via the production of the prototypes of the first prefabricated elements, the realization at the building sites - and includes the evaluation of the whole process. The compilation of experiences have been documented in four reports – also called deliverables - from the project, which in addition to the pilots themselves represent the results of the MORE-CONNECT pilot projects. Especially one of these reports (D5.6) form the basis for this fourth report. The reports/deliverables can be downloaded in full from the MORE-CONNECT website: www.more.connect.eu.

Below the experiences has been organised in two main parts – one for the pilot projects and one for the Real Life Learning projects. For each pilot and RLLL the experiences in the form of conclusions and recommendations are presented. At the end is a paragraph with a summary of the overall findings of the MORE-CONNECT pilots and the RLLLs.

Experiences and conclusions from the five pilot projects

In the country specific chapters of this report the actual renovation of the pilot buildings using the prefab construction elements and other energy renovation measures has been described. The renovation in some cases included the partial or total removal of existing structures (facades, roofs, installations), depending on the renovation methodology (total replacement, partial replacement or addition of elements). For each country, the pilot project documentation covers the total process from design over production of elements to implementation, including recordings of the essential steps on photos and videos (can be found on the MORE-CONNECT website.

The Danish Pilot

In Denmark the products of the two Danish industry partners of MORE-CONNECT - Invela and Innogie – were piloted/tested on a quite large apartment block of 170 apartments in the main town of Fyen – Odense. This pilot project, called Korsløkken 34.6, also comprises an overall renovation including energy renovation with for example new windows, thermal bridge breaking and new ventilations systems with heat recovery. Invela has through its work with developing a new solution for prefab manufacturing of façade elements gone from thoughts around the traditional factory prefab solutions using different types of materials herein to use of robots, which can be pre-programmed to the work on the building site. Innogie is a company specialized in innovative use of solar energy with special attention to power adequacy, design and profitability for the consumer. In the context of the MORE-CONNECT project they have developed a PV-roofing element, which at the same time is photovoltaic (PV) and roof elements. The implementation of these two technologies on the Danish pilot is shown on Figure 1.

Figure 1: The finished PV-roof (left) and gable wall with the robot-made decoration.

Below the final conclusions and recommendations based on the experiences from the Danish Pilot from the two Industry partners.

<u>Invela:</u>

Our recommendations for the future are the focus on optimizing materials and tools to be used together with the robot on specific tasks. All materials today have been developed to be handled by the hands of the craftsman, and when we use our robot that is fast and precise, we have seen that the stability and continuity of the material is often not good enough. The same goes for the tools for different kinds of tasks. Here we have seen that the tools made for hand work has difficulty in handling the fast and precise work of the robot. So, in both cases there is a big potential in optimization hereof in gaining even better performance of the robot doing work on-site.

<u>Innogie:</u>

Innogie has based on their experiences chosen to use micro-inverters for their PV-installation. These have many advantages – easy installation, low heat generation and long durability being a couple of important ones. Usually the inverters are installed in the bottom of the roof but because the building is so tall in this project it was decided to place the inverters inside at the loft. This way they can be easily reached if necessary. Figure 2 shows the penetration of the cable through the underlay roof to the inside of the loft, where the inverters are placed.

Figure 2: The cable is led through the underlying roof to the inside loft before the last PV-modules are mounted.

The Estonian Pilot

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.

A number of lessons were learned from the whole renovation process:
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 hydrothermal 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.

The photos on figure 3 shows different stages of the installation of the prefabricated elements in Estonia.

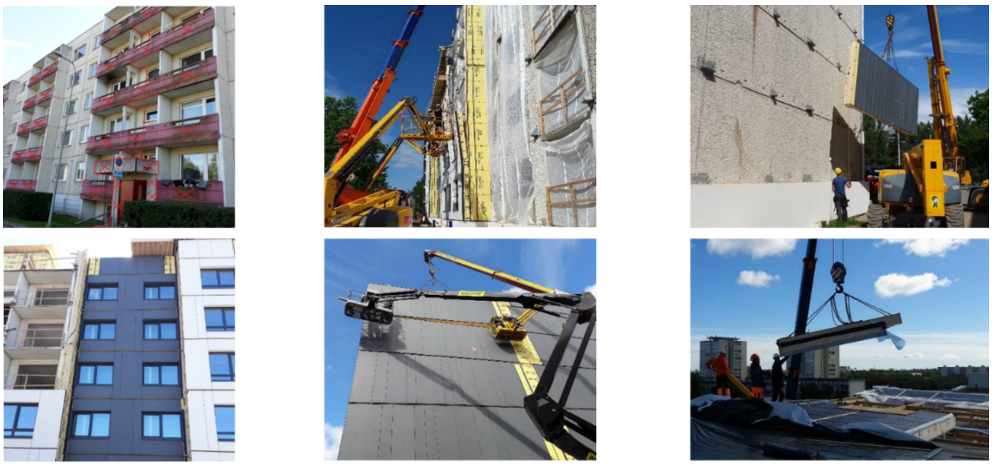


Figure 3 Installation of modular elements at the Estonian pilot building - summer 2017

The Latvian Pilot

The Latvian pilot building represents typical brick building built in 1950 – 60ies. Such type of building is typical for rural areas in Latvia. Similar building types are typical also for Estonia and Lithuania. The prefabricated wall and modular elements was carried out in 2016-2017. Taking into account the poor technical conditions of the building it was decided to focus modular retrofitting on improvements of external building envelope. The general strategy included development and installation of prefabricated modular thermal insulation panels. See the completed Latvian pilot on figure 4.

Figure 4 The Latvian pilot building after renovation

The experience gathered deals mainly with the mounting of the prefabricated panels. In total the panel mounting took 5 working days for 6 workers. The 5 days included also some delay in oversized panel replacement. Taking into account gained experience the panel mounting time can be reduced with up to 3 working days for similar buildings.

The proposed modular retrofitting thus allow significant reduction of on-site construction work. Other construction works took 9 days.

The Dutch Pilot

One of the Dutch pilots - Presikhaaf - is shown on figure 5.

Figure 5. The improved architectural appearance of the Dutch pilot project (Presikhaaf, Arnhem)

Four main conclusion can be drawn from the Dutch pilot / demonstration project:

- First, supported by theory about modular construction, the project organization need to mirror the modular design of the deep-renovation solution. Traditional project practices hinder the application of modular renovation due to the required close network ties between stakeholders in order to manage the complex interfaces between modules.
- Second, the conversion from point clouds derived from laser scanning to a digital building model and subsequent design is done manually so far, which is time-consuming. Further advancements of related ICT could benefit this conversion, but has not been solved yet.

- Third, it have been concluded that significant cost reductions are possible when production of the façade elements are further industrialized and automated. However, this requires high investments in advance production technology and in order to legitimize these investments some guarantees are required about production scale and continuity. Today, suppliers are reluctant to invest due to uncertainties about market demand.
- Fourth, the project showcased that transport and mounting have been optimized and is done in an efficient way in terms of quality, time, cost and hindrance experienced by occupants of the housing unit being renovated. Since the introduction of modular renovation in 2007 the demonstration project benefits of the advancements related to transport an installation of the building envelope modules.

The Portuguese Pilot

The overall process has faced several challenges. Consideration of 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 the stakeholders in the process.

Unfortunately, due to insuperable administrative reasons that arose in the Portuguese consortium, it was not possible to comply with the proposed deadlines and the Portuguese pilot building will not be renovated within the MORE-CONNECT project framework. However, DarkGlobe and University of Minho are still very interested in the façade renovation solution developed under this project and are deeply committed to finding an alternative building where it can be incorporated and tested. Unfortunately, this will be possible only after the project end date.

The two Real Life Learning Lab Environments

The RLLL situations are more suitable for the in deep testing of specific solutions like the smart plug & play connections, advanced controls, building physics, moisture behaviour, zero energy solutions and testing of special and specific materials like super insulation, biobased composites and 3D printed materials in a small scale semi-lab setting. RLLL settings were organized in Czechia and in The Netherlands.

The Czech RLLL

In focus at the Czech RLLL were:

- Testing of connections among modules and of advanced control systems
- Provision of a showcase for dissemination

Lessons learned from the RLLL in the Czech Republic:

- For the assembly is better for manipulation to take the HVAC connectors from prepared in the lower module and fit them from bellow to the upper module. Thus, for the fine manipulation of the hanging panel the workers can grip the module by the connectors in order to level it with the lower panel and to aim precisely on the HVAC tubes' positions to fit them together.
- When the HVAC tubes are fixed properly in the structure of the panels, their connectors provide quite good routing for setting the module in the proper position. So once the connectors are prepared in the inline position, and the module is lowered by several centimetres, the connectors are able to keep the module on its track so that the workers have enough time to focus on connection the pipes and pull through the cables. Therefore, it is critical to have the

HVAC tubes placed very precisely and properly fastened in the structure, as they more or less define the relative positions of modules when assembled.

- At some point, there is hung panel and the workers need to put their hands between two modules, of which one is hung on crane. This step is dangerous, because there is risk that the hanger belts fail or wind could blow and tilt the modules and cause a serious injury. So perhaps there will be needed to have some prepared sticks, wedges or other distance keepers that would be inserted between the modules before the hand works between the panels start.
- It is quite important to calculate the position of the centre of mass of each module and locate the hanger belts evenly relative to centre of mass. Otherwise there are needed significant side forces, which might complicate the installation on site from the mobile platforms (would require more workers and would be more dangerous for them to make such operations.
- It is rather impractical to have free cables hanging from the upper module and let the workers to push them through the conduits. Better solution is to have all the cables in tight conduits and push just steer them into one conduit of a larger dimension in the lower module.
- System of thermal insulation around the water piping connections need further elaboration to prevent gaps in the thermal insulation.

The Dutch RLLL

In focus at the Dutch RLLL were:

- Testing of prefab multifunctional facades and roofs
- Creation and testing of a first compact 'engine' (installation platforms)
- Monitoring on energy use and in deep monitoring on thermal comfort and health in relation with energy use in renovated homes under semi-lab conditions.

Lessons learned from the Dutch RLLL:

- From this first experiment with a full renovation by prefabricated integrated façade and roof elements for deep renovation it was proven that the renovation of the envelope and building services can be achieved within three days, including the total removal of the existing facades, placing and mounting of the new prefab façade elements, roof with integrated PV elements and finishing. As this was the first test with some 'trial and errors' it is expected that the renovation works can be further optimised and the renovation time can be further limited to 1 to 2 days.

Although the façade elements had a very good airtightness, the total airtightness of the dwelling, after the renovation was poor due to the connections between elements, the cellar and roof joints and leaks around pipes and ducts.

<u>Overall lessons learned and conclusions from both pilots and RLLL projects</u>

In the conclusions chapter at the end of the report the lessons learned and conclusions from all the pilots and RLLL projects have been compiled. The following is an extract thereof. The most important lesson learnt in MORE-CONNECT are:

1. Technological developments are not so much a problem, but traditional market is still dominated by traditional (large) construction companies. This results in:
    - There are still too many layers in the renovation process.
    - Clients are in general still reluctant for innovations.
    - 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.
- 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 able to develop blue prints for new production processes and factories in MORE-CONNECT, but due to lack of market still on hold. A step to make is the connection between advanced geomatics 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.

During the actual execution of the demonstration projects, many experiences were gained on the construction and the operational level. These are accounted for in detail in the conclusions chapter.

2. On the prefabrication production process the most important lessons learned 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 in prefabrication are:
     - Step 3: industrializing
     - Step 4: automizing
     - Step 5: roboting

At this moment, the average construction process is not much further than step 2. In MORE-CONNECT we have started work on steps 3 – 5.

<u>Next generation</u>

The Dutch participants has compiled their experiences in a number of observations concerning the next generation of prefab developments. See the table below (figure 6) for the differences between the first generation and the second generation.

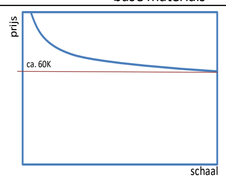
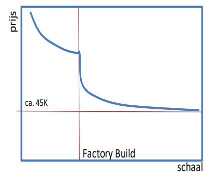
Characteristics	Generation 1; 2018	Generation2; 2022
reference	H2020 2014 -2018	H2020 2018 -2022
Quality level	wide variance in quality of models	minmal standards defined and applied
Depth of use	wide variance, still growing	deep use and integration with all building aspects
Design	integral approaches, 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		

Figure 6. Comparison of 1st and 2nd generation of pre-fabricated façade elements.

Further comments to this development from the first generation to the next:

Technological (product) innovation - several technical innovations contribute to the improvement of the cost-benefit ratio of Dutch modular deep-renovation concepts:

- Advanced geometrics contributed to the accuracy of how the dimensions of a building are determined and contributed to a more efficient design and engineering process. Further improvements are expected in the upcoming years with respect to on-site assessment of the building (hardware) as well as processing the – point cloud – data into a building model (software).
- The design of the modules, in particular the connection between elements, have been optimized in order to improve the airtightness of the building envelope. Standard connections have been developed to ensure the airtightness in every project. However, ducts and piping among other components, integrated in the module are considered as risks to the airtightness of the building envelope.
- Re-engineering of the module is required to improve the level of industrialization. To further improve the production efficiency (line production) new challenges will emerge. More precisely, prefab elements are now finished on 'tables' and in order to include finishing into a full production line requires different techniques.

- In order to improve the mounting process on-site plug and play connectors have been developed which no longer requires scaffolding on-site. However, still about 30% of the costs link to on-site labour and substantial cost reductions can be achieved if on-site labour can be reduced.
- “Housing engines”, which include several energy efficient indoor climate installations, have been developed. However, these engines are developed as additional, spatial elements which are connected to the dwellings. Today, these modules are too large and suppliers attempt to miniaturize these modules such that they better fit into a dwelling. Due to a lack of upscaling the housing engines are too expensive.
- One of the next major steps forward if redeveloping the deep-renovation concept according circular building principles. This will be further investigated and elaborated in a new H2020 project ‘DRIVE 0: Driving de-carbonization of the EU building stock by enhancing a consumer centric and locally based circular renovation process’.

Process innovation – it needs to be emphasized that in contrast to product innovation, process innovation is key to further advancement of modular deep-renovation, including:

- Minimal hindrance, dwellings remain occupied during the project: retrofitting within a single day;
- Improvement of design and engineering (in-office) processes: supply chain average administrative cost in chain is approximately 30%;
- Reduction of the number of stakeholders involved in the supply chain, an reduction of approximately 10%, including profit & marketing costs, per stakeholder is possible;
- Optimization of administrative, design and engineering processes across the supply chain based on Lean management and supply chain integration;
- Upscaling production from 500 housing units annually to 10,000 housing units annually could result in production cost reduction of approximately 30%. To achieve this design and materials innovations for production are mandatory.

1 Introduction

1.1 Overall objectives and tasks

The objectives of work package 5 is the testing, pilot implementations and demonstration in real settings, as well as in industrial settings (demonstration of production), as in practice (demonstration and testing of the developed modular renovation elements both in real settings as in real life learning lab (RLLL) settings.

The work package comprises 6 tasks of which this report deals with Task 5.6: Total evaluation of the renovation process. In this task the total renovation process as described in the tasks 5.1 to 5.5 has been analysed and evaluated and the results are presented in three deliverables D5.7 – Monitoring, D5.8 - The inhabitants involvement and experience and in the present report: D5.9: Analyses of the total renovation processes in the pilots. This report is at the same time a final update of the report D5.6 Evaluation of the quality of construction works presenting at the beginning the general MORE-CONNECT approach and at the end the conclusions from the evaluations of the total renovation processes in the pilots.

Task leader: Cenergia

Other participants knowledge: Zuyd, RTU, TUT

Other participants industry: BJW, LWCC

1.2 The MORE Connect pilot projects - the MORE-Connect approach

The testing and demonstration in practice was carried out in six countries:

- Czech Republic (RLLL setting for in deep testing)
- Denmark (full real setting)
- Estonia (full real setting)
- Latvia (full real setting)
- The Netherlands (full reals setting and RLLL setting for in deep testing)
- Portugal (partial real setting) (not completed)

This report has been structured country-wise according to this subdivision of the testing and demonstration work.

The MORE-CONNECT approach focuses on refurbishment with prefab facade and roof panels and standard procedures applicable for full house or partial house retrofit. The focus is mainly made on the technical aspects, considering how several solutions can be introduced staying insightful of the client needs. The approach aims to develop a set of solutions for several housing types in several climate zones.

The work was carried out observing the following main criteria within three areas:

- Technically, it should be feasible and work for different housing types and different combinations of heating and ventilation technologies.
- In terms of energy supply, it should aim for zero energy in the design phase, although in execution it might be nearly zero energy with low embodied energy: solutions should be optimized to prevent a large rebound effect in materials related (fossil) energy consumption.
- Economically, it should be viable.

2 CZECH REPUBLIC

2.1 Housing type chosen 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 2.1). Technical or housing facilities and cellars were put in the basement, which is partially situated underground. 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 2.1 Typical representative of the typology in question in Czechia

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 wall, 0.76–1.22 W/(m^2K) for 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 remaining 88 % is accounted to heat flow by transmission. The annual energy consumed by one reference building is around 1050 GJ.

2.2 General strategy to renovate chosen 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).

2.3 Technical concept chosen for renovation:

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 is made plaster finishing on wood fiberboards (see Figure 2.2).

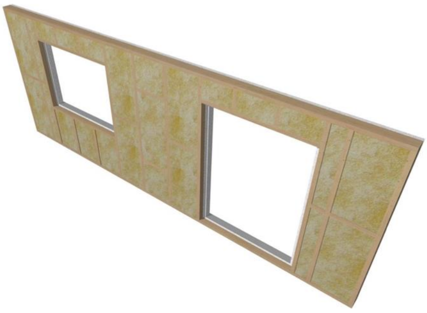


Figure 2.2 Structural core of a wall panel made of timber elements, fire-resistant boards from both sides and filled with mineral wool.

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 Figure 2.3). In the same layer outlets of the ventilation air are also integrated, which are attached to the frame adjacent to windows.

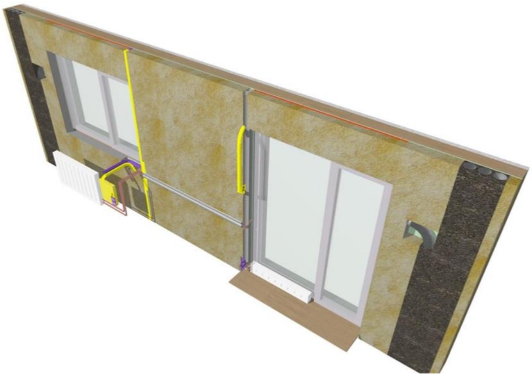


Figure 2.3 Soft layer from the back of the core, which will be in contact with the wall of existing building.

The prefab wall panels are attached to the existing masonry wall, usually 450 mm wide. Additional extension of openings (after dismantling the old windows) for larger windows is possible and the finishing. The window sills and jambs are finished by caldding from furniture boards. The wiring and piping is accessible through small doors in the window jambs; the design of all technological boxes is airtigt. The final setting is presented in Figure 2.4.

Figure 2.4 Final setting of the external wall module on the existing wall structure.

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.

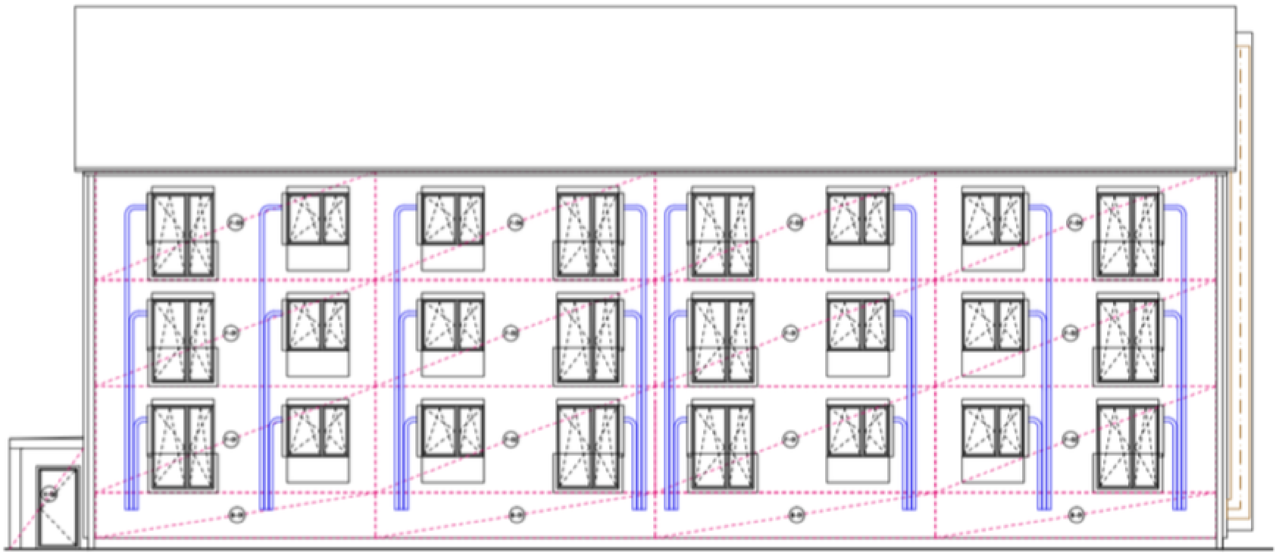


Figure 2.5 Set of 12 standard panels and 4 plinth panels on the east façade. New prefabricated entrance on the left, new "chimney" encapsulating new HVAC ducts on the right.

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, see Figure 2.5.

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.

2.4 Design

In Czechia the target building typology for which the modules were developed is a block of flats built between 1950's. However, within the MORE-CONNECT project we did not have a real case, but we have built a small mock-up building, on which the critical details of modules will be tested.

Figure 2.6 Typical representation of target typology and architectural and technical options enabled by the modular design.

Figure 2.7 Visualisation of key elements to be tested at the mock-up building.

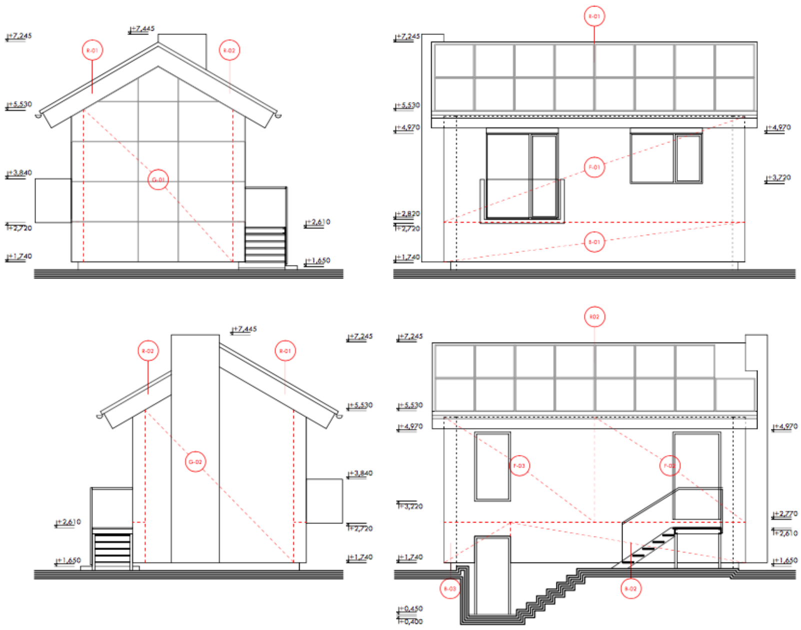


Figure 2.8 Elevations showing modules that were included in the testing. In addition to that a HVAC system was mounted in the semi-underground floor.

The design led from the general wall modules developed to testing of selected details and production of full scale samples on which technology of connections and fire resistance was tested to production of modules for the RLLL setting on building mock-up.

We have used the samples for design of the details of all the elements that can in various settings be located around windows (air inlets, cabling, switchbox, WiFi router, piping etc.) to ensure the air tightness and at the same moment fast installation.

Figure 2.9 A "wall-simulator" attached to the sample of wall module that was used to simulate the critical details of connections between the module and existing building with integration of building services elements (left). The third version of switchbox designed to fit the gap between the hard part of the module and the existing building (right).

Figure 2.10 Development of air tight detail of electrical box installation.

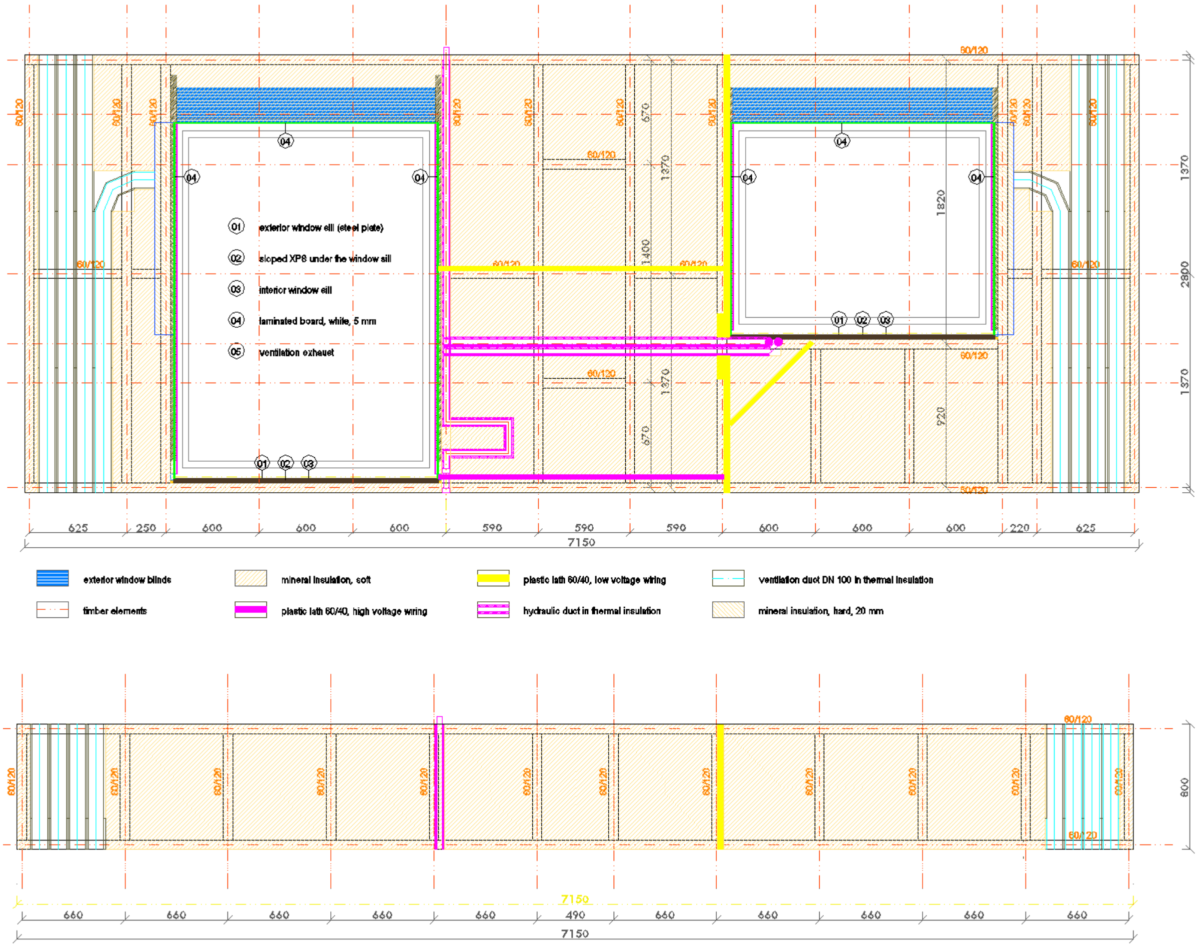


Figure 2.11 A schematic drawing of set of the basic elements in the modules – the standard wall module in the top and the base module in the bottom.

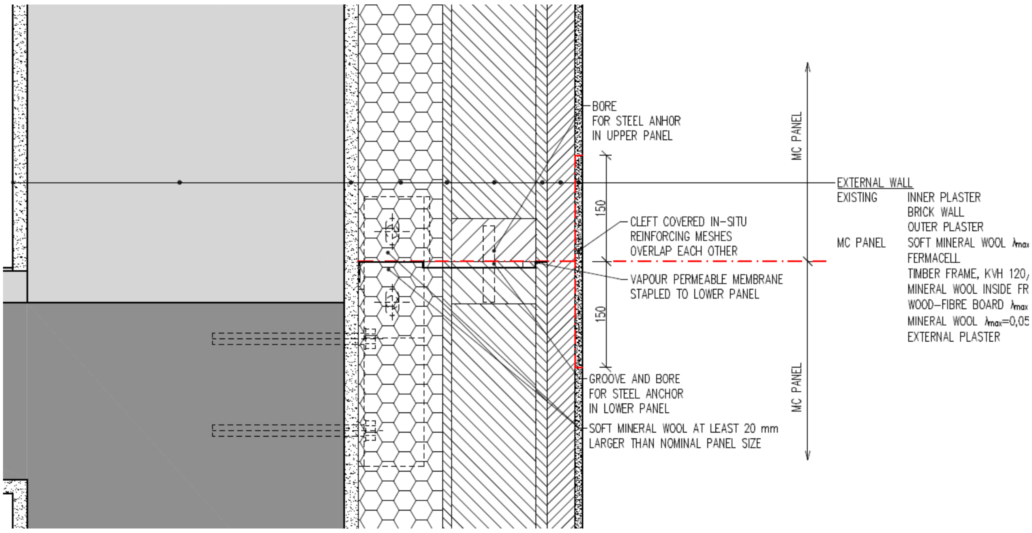


Figure 2.12 Detailed drawing of horizontal inter-modular connection

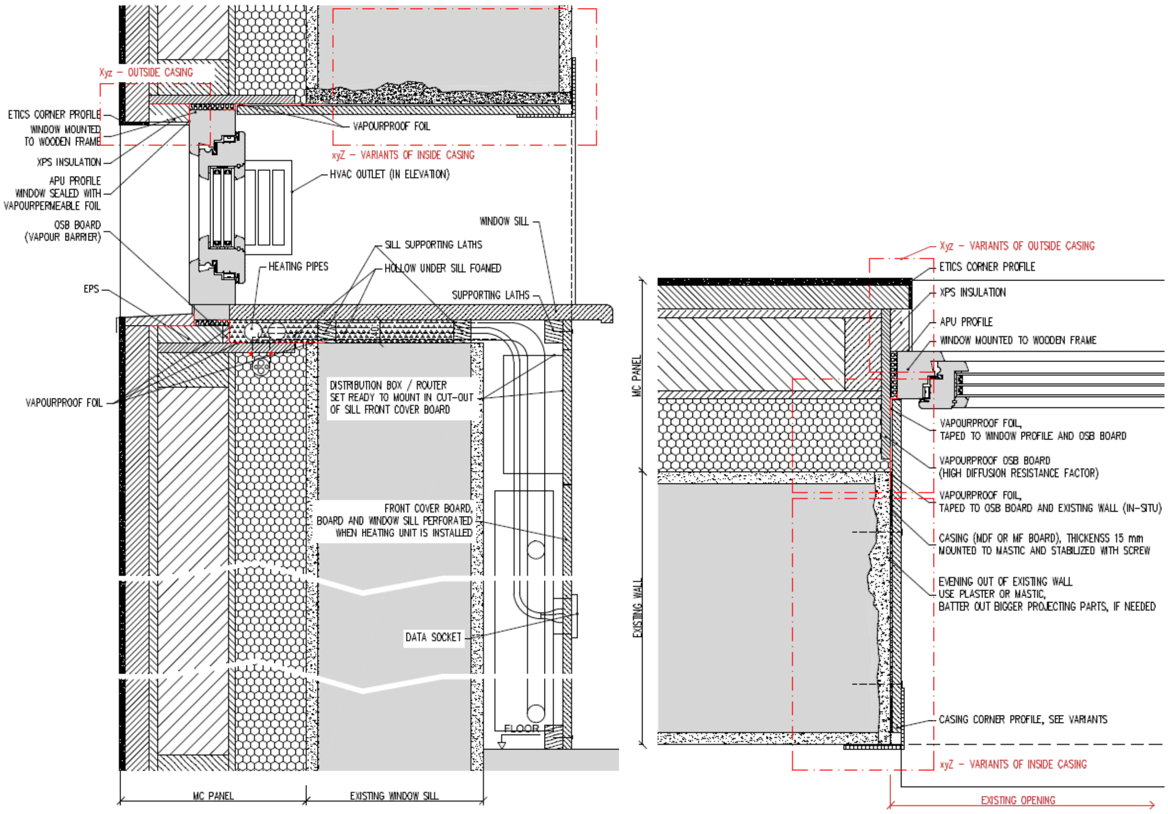


Figure 2.13 A detailed cross-section (left) and floor plan (right) of the window siding. The alternatives of different casing and integrated elements were considered and designed.

2.5 Production

Figure 2.14 Prepared modules (standard wall, gable and base modules) for the Czech RLLL in RDR factory before final production stage of integrated devices installation.

2.6 Installation/implementation

In the Czech case, there are two sources of experience from installation:

- From the test installation of modules in the testing hall
- Installation of the modules on a mock-up building.

2.6.1 Technology of installation of the modules (full scale experiment in testing hall)

Test installation of two panels to test the technology of connecting panels onsite including connections of HVAC tubes that lead fresh air from the HVAC system located typically cellar or attic space, piping for heat distribution (when needed) and wiring for sensors, power from integrated PV panels and WiFi routers built in the panels to distribute internet connection to each flat.

The test installation of took place indoors on laboratory stands that simulated the load bearing structure. On the stands were mounted typical anchors that will be used for the Czech version of the modules. There were produced one full standard module with one standard window and one French window and one top part of module that goes bellow the full panel. First of all, the top part of module was fixed to the stands using the typical anchors and the HVAC tubes' connectors and connectors of heat distribution system pipes were prepared in the proper positions (see figures below).

Figure 2.15 Preparing of the HVAC tubes' connectors in proper positions (first variant of setting, left) and preparation of click-on connectors onto the pipes of heat distribution system (middle). The moving of the pipes to enable connection is made by bends on the pipes (right).

After that the full module was hung on a portal crane (simulation of standard crane onsite) and carried over above the lower module and slowly lowered down to distance similar to the length of HVAC tubes connectors.

Onsite, we have found that it is more practical to have the connectors prepares in the tubes of the upper panel and use them for navigation onto the holes in the lower panel rather than the opposite setting. Also, we were fighting with the tilt of the hung module caused by uneven mass distribution relative to location of hanger belts (it took one or two people pushing the module from the side, which would be unacceptable and dangerous to make in height from mobile platform). However, it turned out that once the HVAC connectors were in line with the pipes, it is possible to lower the module down and the connectors would fix the panel in the right position and the pushing from side is then not needed any more and so the workers can focus on connection of piping and cabling.

Figure 2.16 Connecting the HVAC tubes with inserted elements (left) and installation of cables (right). This might be quite dangerous manoeuvre in windy conditions on site, perhaps some kind of provisional wedges or other kind of distance keeper shall be inserted between the panels before the workers work with their hands between the modules. This way turned out to be impractical and delaying the installation works. Would be better to have the cables in tight conduits so that they are stiff and slide easily into the slightly wider conduit in the lower panel.

After finishing connections, we lowered the module down so it sat on the lower module, rectified it (as much as the HVAC tubes' connections enabled) and fastened the module by steel anchor inserts and their screwing to the "wall"-mounted parts of the anchors.

2.6.2 Installation of the modules on a mock-up building.

The originally planned experiment was changed from partial façade mock-up installation to a complete small experimental house. Such a house provides all representative details and connections that can be found on a typical residential building. The main aim of the change was to test all the possible system elements and the control system of the complete solution. This helps to get the real information on feasibility of the system.

All the main details of the original pilot building were transformed into experimental Real Life Learning Lab (RLLL) setup (Figure 2.18), that has been created at University Centre of Energy Efficient Buildings of Czech Technical University in Prague (UCEEB) during spring 2018 by UCEEB together with RD Rýmařov, a.s.

The building has a simple rectangular shape with external dimensions of 7.18 x 3.89 m. There is one room in the cellar used as a technical room for testing the connections of the HVAC system. Single room in the first floor simulates the apartment room in a residential building. An opening for the ventilation ducts were created in the gable wall.

The mock-up building was built up to the stage of the real building before refurbishment (e.g. after removal of windows and parapet walls). The next step was a creation of the 3D digital point cloud for the production of the modules and installation of the anchors. The refurbishment modules were prepared in the factory of project partner RD Rýmařov and equipped with ventilation ducts, external window blinds with electrical control, and hydronic heating pipes. Already in the factory, the wall panels were completed up with the final layer of the plaster. The modules were then transported from the production factory to the construction site.

The installation of the modules was performed during one working day (see Figures 2.18 – 2.23). All the walls (e.g. foundation wall modules; standard wall modules; and gable pitched modules) and roof modules were mounted to pre-prepared anchors. Interior, surfaces and other finishings were finished in one further week.

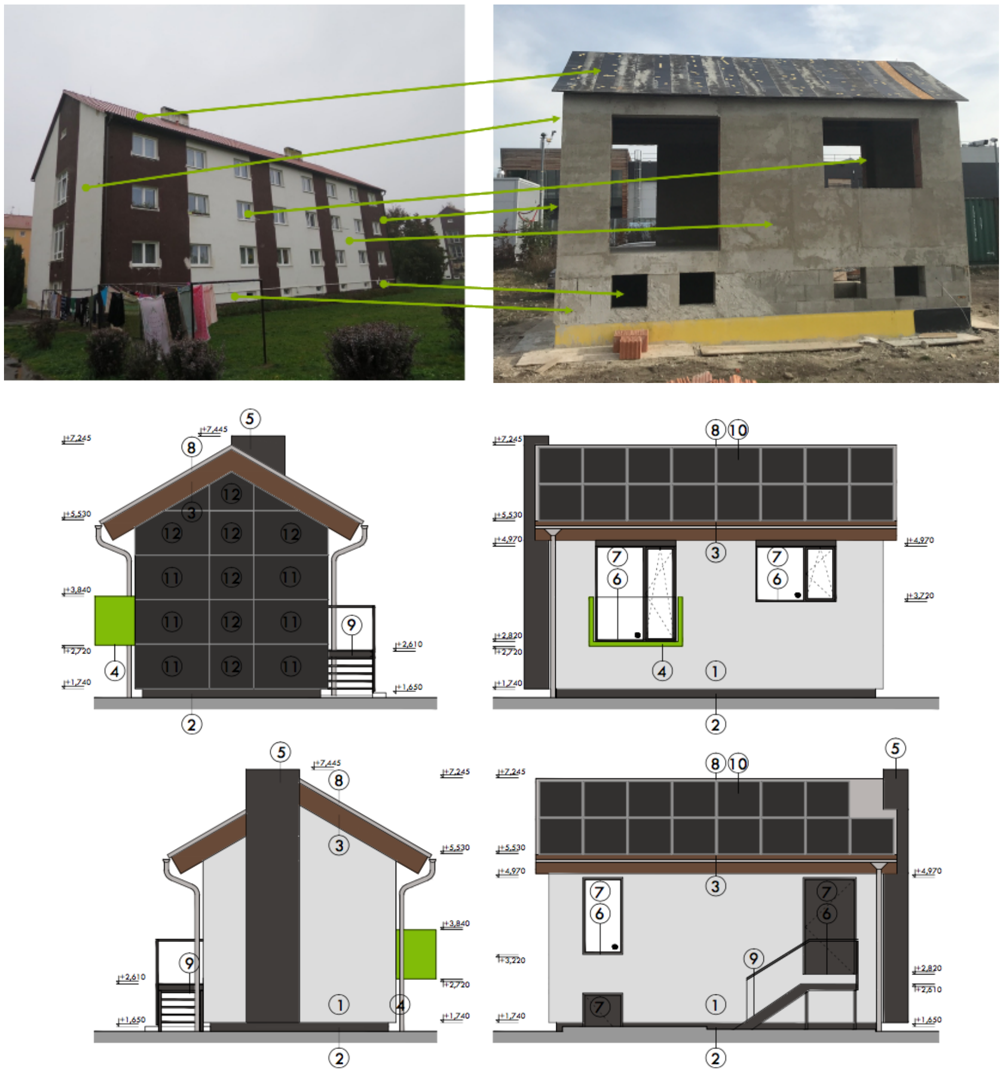


Figure 2.17 Original pilot building in the left and the mock-up house built up for the RLLL setup and Planned final form of installation

Figure 2.18 Installation: 6 a.m.: Prepared anchors on the simulated original building's façade. Unloading the first modules.

Figure 2.19 Installation of modules (8 a.m.-11 a.m.) and HVAC connections between the modules

Figure 2.20 Integrated wall module placement (noon)

Figure 2.21 Placement of roof modules (4 p.m.)

Figure 2.22 Montage of additional balcony (7 p.m.)

Figure 2.23 End of installation (8 p.m.)

The building is operated as a demonstration building for occasional visits or meetings. The visitors and other users of the building can be questioned about their sense of thermal comfort etc. Therefore, a questionnaire was prepared and the collection of the data from the users is performed.

The monitoring system for timber structures originally developed by UCEEB was installed in the wall modules creating smart connections. The system was further adjusted for the application within MORE-CONNECT project, especially within the connections. The monitoring is fully autonomous and a web interface provides the real-time overview of the measured data. The following parameters are measured in the experimental building: temperature and relative humidity of exterior air; relative humidity, moisture content and resistance of timber elements; roof irradiance parameters and average temperature above the roof; electrical measurement (voltages, power); and indoor air quality (air temperature; humidity; pressure and VOC index). All the measurements started with finishing the experimental building.

2.6.3 Lessons the team learned from the installation

- The system is workable in full-scale, in total the process is sufficiently fast. The real installation revealed heat bridges in specific positions (around the steel anchors, around HVAC starting connection etc.) These details have to be improved.
- The system is very complex which should not mean complicated. The integration of all necessary structural layers and all the technologies brought new requirements to the factory staff. The production of the system showed the need of incorporating more professionals

with specific experience to be able to obtain sufficient quality on-site. This touches electrical and HVAC installations as well as final interior coverings. Interior finishing should be prepared in a different way so that even construction workers without any special qualification are able to create indoor lining of sufficient quality.

- Ventilation system is working, connections of the elements was fast and solid. After starting the ventilation system operation, the noise from interior exhaust appeared. This shall be improved by integration of a silencer before releasing the system to the market.
- Pipes of the hydronic heating systems were connected easily. However, this type of heating is considered rather risky and vulnerable due to uncomfortable access to the connections.
- The installation of the metal anchors on the external walls was very time-consuming. There were four main montage holes needed to be drilled for each anchor; drilling one hole took more than 90 seconds. Even with the small dimensions of the mock-up building, the installation of the anchors took 2 days.
- Although the finished external plaster survived the transportation successfully, the connections had to be done in-situ that took additional time after installation. The under-roof covers were not transported mounted to the modules; their installation also took additional time.

Figure 2.24 Finished interior of the RLLL building with information arrows for the demonstration purposes.

Figure 2.25 Information arrows for the demonstration purposes: hydronic heating preparation and window blinds' control element (left); window siding with electrical switchbox (right)

Figure 2.26 Engine room in the underground floor with ventilation unit.

Figure 2.27 Finished building

3 DENMARK

3.1 The housing type chosen and the underlying rationale.

In Denmark, housing generally consists of single-family houses and apartment blocks. Both prefabricated elements and use of a robot for façade 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 in the MORE-CONNECT project. The majority of apartment blocks are own and administered by social housing companies. Many of these apartment blocks have been constructed in the 1950-ies to 1970-ies in 3-5 stories. This is the background for choosing an apartment block for the Danish pilot project. The chosen block is one of 7 blocks of a neighborhood area called “Korsløkkeparken afd. 34” administered by Fyens Almennyttige Boligselskab – FAB. The block selected for the pilot building is referred to as building 34.6. It has 170 apartments, which after the renovation was changed to 166 apartments. The building is 205 m long and 13,6 m broad and has 5 stories. The total living area is 13,685 m² and the basement area is 2,737 m². The photos below in Fig. 3.1 show the Danish pilot building before and during renovation.

Figure 3.1 The Danish pilot building before (left) and during (right) renovation.

3.2 General strategy chosen to renovate the housing type

Generally this type of buildings are energy renovated as part of a total renovation plan for the area in consideration, which means all the blocks of the department and the outdoor areas around the blocks. The energy renovation part of this total makeover typically includes the following activities:
-replacement of windows,
-installation of mechanical ventilation system with heat recovery
-additional roof insulation
-insulation of facades and gable walls. Depending on the current conditions of the existing external wall this additional insulation will be partly or complete.
The exchange of windows and insulation of façade typically requires the use of scaffolding.

Considerations

External insulation of façades and gable walls is costly and normally only carried through when the conditions of the existing wall is rather poor and the wall is in need for repair for example with a new external climate protection layer. In this situation adding a layer of insulation becomes marginal costs and the costs will be manageable by the housing association.

3.3 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 and
- Robot finishing of two 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 system with heat recovery
- additional roof insulation
- additional wall insulation at selected areas

Considerations

The overall energy renovation concept is well known in Denmark, so no special considerations from that. Of the two MORE-CONNECT technologies especially the robot finishing was completely new and special care was needed to integrate that into the overall construction process.

3.4 Two Danish industry partners

For each of the three following phases – design, production and installation - the work of the two Danish industry partners of MORE-CONNECT - Invela and Innogie is presented in separate chapters below. The two MORE-CONNECT products are different from the other prefab solutions developed in the MORE-CONNECT project. Therefore the presentation of the design, production and implementation are structured a bit different from the others.

3.5 Invela - the robot concept

3.5.1 Development of the robot solution

Invela has through its work with developing a new solution for prefab manufacturing of façade elements gone from thoughts around the traditional factory prefab solutions using different types of materials herein to use of robots, which can be pre-programmed to the work on the building site. The company started out with the general concept idea of making the whole facade renovation onsite with the robot solution. But through the first tests with the called Fixit 222, it was found out that the hardware pump and spraying tools on the market could not easily be modified to work with the precision required by the robot. Also this Fixit 222 was a new product on the market and the prize was way too high - 3-4 times compared to traditional materials.

The robot was then tested onsite to investigate the work process, when moving the robot out of its traditional working environment in the factories. Invela explains: “This gave us the insight to create small working areas for a robot to work onsite as a co-worker to the craftsman. The test showed that it wouldn't be a good idea to bring bigger robots onsite as co-workers, but better to make the robots easy to use and flexible for any kind of work needed. We then decided to test and develop the best workflow and user interface for the future robots working alongside the craftsmen onsite.

This we have tested in different setups and with different materials. We now have a direct workflow from the architect’s specific designs in Revit or any other 3D designs, into the Autodesk program called Fusion 360. From this we can generate a specific script and with our software (our black box Linux based program) we can execute any design/work package chosen by the craftsmen onsite on our Tablet Guided User Interface (GUI). This elements of this workflow are shown in the diagram from Robot At Work. On figure 3.2.

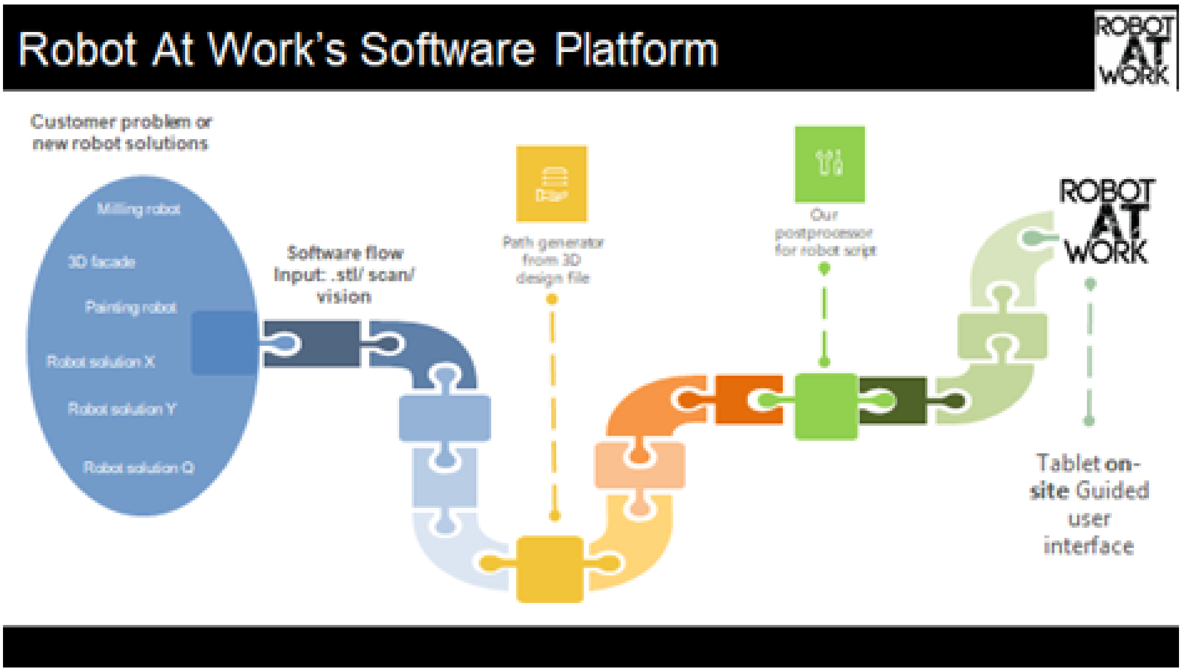


Figure 3.2 Robot at works workflow diagram."

3.5.2 Design and production

Invela programmed the specific artistic design for the two gable-walls on the apartment block - Korsløkken 34.6. They made the work packages and tested the output through their software. See the design by a local artist on figure 3.3.

Fig. 3.3 The logo design of the building association FAB to be painted on the concrete plaster of the vertical gable walls onsite by the robot.

For the robot solution no products as such are produced before the actual installation on the building. However, the programming of the work packages to be used for the actual implementation in combination with the robot itself can be considered as parallel to a pre-production of building elements. Once onsite the robot is mounted and the craftsman only have to press a button.

3.5.3 On site implementation and testing

The insulation of the gable walls and actual testing of the robot work had to follow the time-schedule of the general renovation of the apartment block – Korsløkken 34.6 and as the concrete finishing is weather dependent it can not be done when the weather is too cold and humid. Therefore, the first part of the actual implementation was carried out separate – the insulation of the gable walls as illustrated on figure 3.4.

Figure 3.4 The insulated gable wall (25 cm Rockwool) ready for the concrete finishing and robot decoration painting.

The final test with the totally new type of scalable robot solution onsite developed for this test is shown below in the pictures – figure 3.5. Invela managed to install a robot onsite with a total working area of 120m² and it performed a precision work on-site painting the building clients logo directly on the gable in 25 minutes. The final result is shown on fig. 3.6 for the other gable wall (in blue).

Fig 3.5 The scalable report mounted and working – and in parts for transportation (outmost right)

Figure 3.6 The insulated gable wall (25 cm rockwool) made with concrete finishing and robot-made decoration.

The robot work process was programmed in Fusion360 (Autodesk drawing programme) and then the robot onsite was started by the push of one button on the smartphone interface. This was a 100% success of the new technology and scalable robot solution ready for integration into many different types of working areas and proved that the new technology could be programmed directly via an already known and well used programme: Fusion360. It also proved that the robot hardware could execute on-site in very large scale. The scalability is shown in the last picture on fig. 3.5, where the robot, which can cover an area of 120m^2 is packed for transport in a van - the small size is very visible.

3.5.4 Lessons learned

Invela has throughout the More Connect project engaged in creating a robot solution for the building sector. This solution is focused on a diverse robot platform to perform several tasks in a renovation of a façade.

Regarding the design issues towards engaging the robot solution for on-site façade work, we have integrated the possibility to program the robot's actual movements in the on-site task directly from an already existing drawing in Autodesk for example dxf. and dwg files. This has made it possible for the architects and engineers to program the robot for on-site work.

Instead of traditional prefab elements our robot solution can now do the work on-site performing many different tasks in the future. Our goals where to perform one specific task with the robot on-site in large scale. In the pilot case we performed on-site painting and decoration with a robot solution on a 5-floor building which made it possible for the robot to have a workspace of 120m².

The work in the pilot case was performed by installing the robot framework on the façade in an approximately one-hour installation time. Hereafter the robot was started with the interface on a smartphone doing the painting of the façade in 25 min. The disassembling of the robot took 40 min.

The totally new developed robot platform has gone from a TRL 1 to TRL 9/10 making it ready for implementation in many different tasks in the future. The main asset of this robot platform is the capability to work on large surfaces in harsh environment mainly performing tasks that are heavy and repetitive.

Our recommendations for the future are the focus on optimizing materials and tools to be used together with the robot on specific tasks. All materials today have been developed to be handled by the hands of the craftsman, and when we use our robot that is fast and precise, we have seen that the stability and continuity of the material is often not good enough. The same goes for the tools for different kinds of tasks. Here we have seen that the tools made for hand work has difficulty in handling the fast and precise work of the robot. So, in both cases there is a big potential in optimization hereof in gaining even better performance of the robot doing work on-site.

3.6 Innogie solar cell roof

Innogie is a company specializing in innovative use of solar energy with special attention to power adequacy, design and profitability for the consumer.

3.6.1 Design

Considerations:

For the installation of the PV-roof panels the size and architectural integration are important issues that has been considered. 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.

The PV-solar roof from Innogie was implemented on the Korsløkken 34.6 building in Odense. The building is quite long but to match the electricity consumption for the operation of the building the area was fixed to app. 400 m². Its location is illustrated on figure 3.7

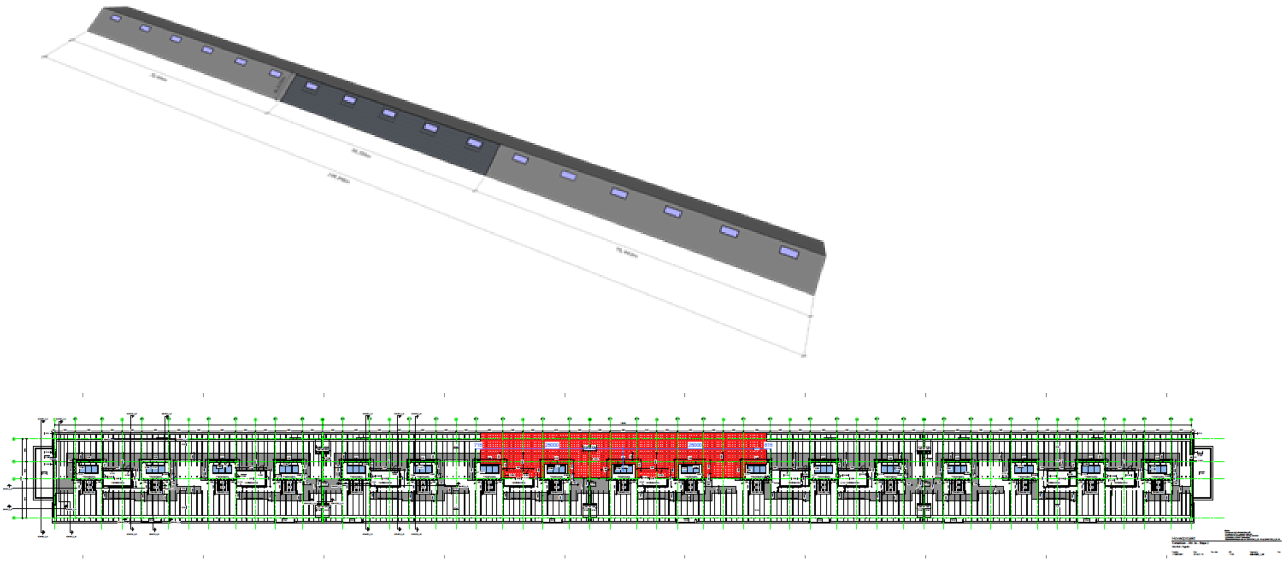


Figure 3.7: Design drawings showing the placement of the PV-roof on the roof of Korsløkken 34.6.

The design details of this implementation is shown on figures 3..8 and 3.9 below.

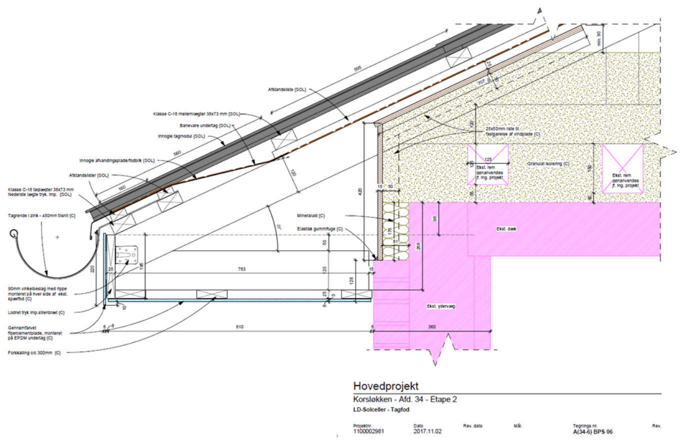


Figure 3.8: Detail showing mounting of the PV roof at the lowest part of the roof.

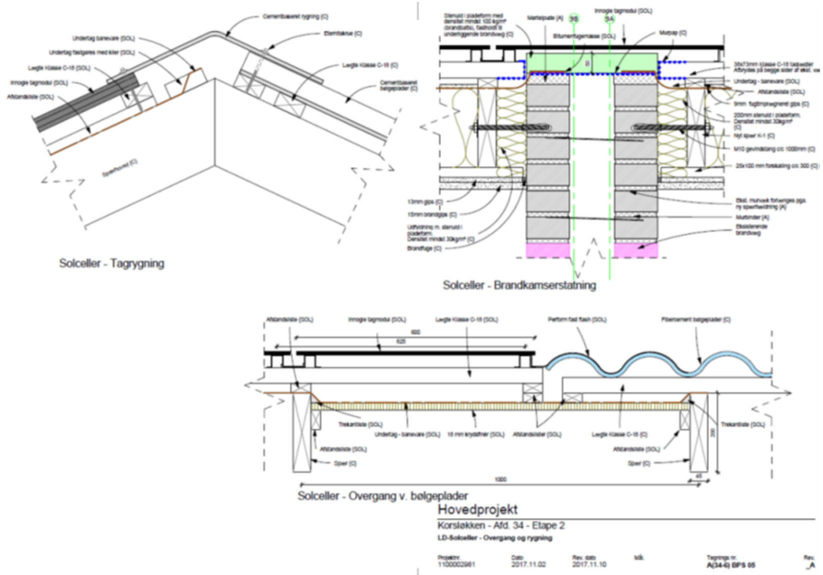


Figure 3.9: Details showing mounting of the PV roof at the highest part of the roof and the connection to the cement wave tiles.

3.6.2 Product prototype development and testing

Within the More-Connect project Innogie 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 Danish MORE-CONNECT pilot building Innogie completed two prototype installations. These are shown on figures 3.10 and 3.11.

Learning from the experience about installation methods and workmanship Innogie changed the way cables are being assembled and packed which led to an increase in efficiency in on-site installation time - about 10% faster installation was gained.

Figure 3.10: Prototype 1 – PV roof on single-family dwelling on Funen.

Figure 3.11: Prototype 2 – PV roof on an industry building in Haderslev, Jutland.

3.6.3 Implementation on pilot project

The implementation/installation of the PV-roofing elements has several steps of which the two major are illustrated on figure 3.12 – preparing the roof and 3.13 – mounting the PV roof elements. Thanks to the experiences gained from the two prototype installations the mounting of the PV-solar roof on the pilot project in Korsløkken 34.6 went generally smooth. Due to the large size of the renovation Innogie was more dependant on other entrepreneurs on site and the experience is that coordination is an important task. i.e. when other workers can not warn in good time that the scaffolding is being moved ahead of schedule it was lucky that Innogie has an installation partner that could react fast and finish the affected roof area(!)

Figure 3.12: Preparing the roof for installation

Figure 3.13: The Innogie PV solar roof mounted.

Innogie has based on their experiences chosen to use micro-inverters for their PV-installation. These have many advantages – easy installation, low heat generation and long durability being a couple of important ones. Usually the inverters are installed in the bottom of the roof but because the building is so tall in this project it was decided to place the inverters inside at the loft. This way they can be easily reached if necessary. Figure 3.14 shows the penetration of the cable through the underlay roof to the inside of the loft, where the inverters are placed.

Figure 3.14: The cable is led through the underlying roof to the inside loft before the last PV-modules are mounted.

The finished PV-roof is shown on fig. 3.15.

Figure 3.15: The solar roof is finished and fits well with the renovated façade.

4 ESTONIA

4.1 Housing type chosen and the underlying rationale

Building type chosen represents a typical multi-storey 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. See fig. 4.1.

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 $W/m^2 \cdot K$.

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 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.

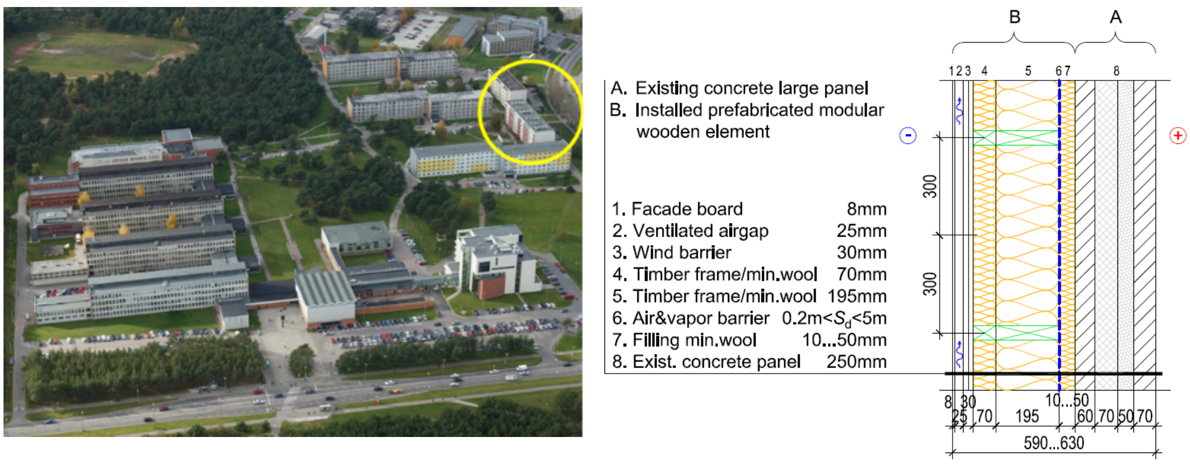


Figure 4.1 Location of pilot building at TUT campus in Tallinn, Estonia (left) and basic design of wall insulation modules, placed onto the existing concrete wall (right)

4.2 General strategy chosen, to renovate 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 to be insulated in-situ with an external thermal insulation composite system.

Figure 4.2 Pilot building at the renovation stage in summer 2017

4.3 Technical concepts chosen for renovation:

In the pilot project, the building envelope was supposed to be insulated and finished 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 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).

4.4 Design

The architectural and structural design of the Estonian pilot project was drafted and formed out by Estonian architectural design company Sirkel&Mall in 2016. The prefabricated wall and roof modular elements structural and detailed design was carried out in 2016-2017 by Estonian company Matek.

The pre-renovation aesthetic state was not very requiring as it represents widely used soviet-time concrete multi-storied house building traditions from last century 70’s and 80’s.. Nevertheless, the compatibility with surrounding architecture was relevant to be considered.

The value of a property was expected be raised via renovation with prefabricated roof and wall modular elements according to the MORE-CONNECT principles and with help of sustainable and hygrothermal design of all parts of building, its envelope, technical equipment, openings, etc.

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 the region in question 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.

The design was divided into 3 common traditional steps:

- Preliminary design: with help of input data from archives, in-situ inspections and geodesy 3D scanning model the basic ideas of the building owner and architectural propositions from design company were formed
- Basic design: in addition to aforesaid, the basic structural and architectural solutions were worked out, with help of in-situ and laboratory hygrothermal measurements the solutions for hygrothermal performance of modular elements was investigated and worked out
- Working project: in addition to aforesaid, the detailed working and installation solutions for whole building were finalized

Figure 4.3 Overview of the Estonian pilot building before renovation (above) and architectural initial design (below)

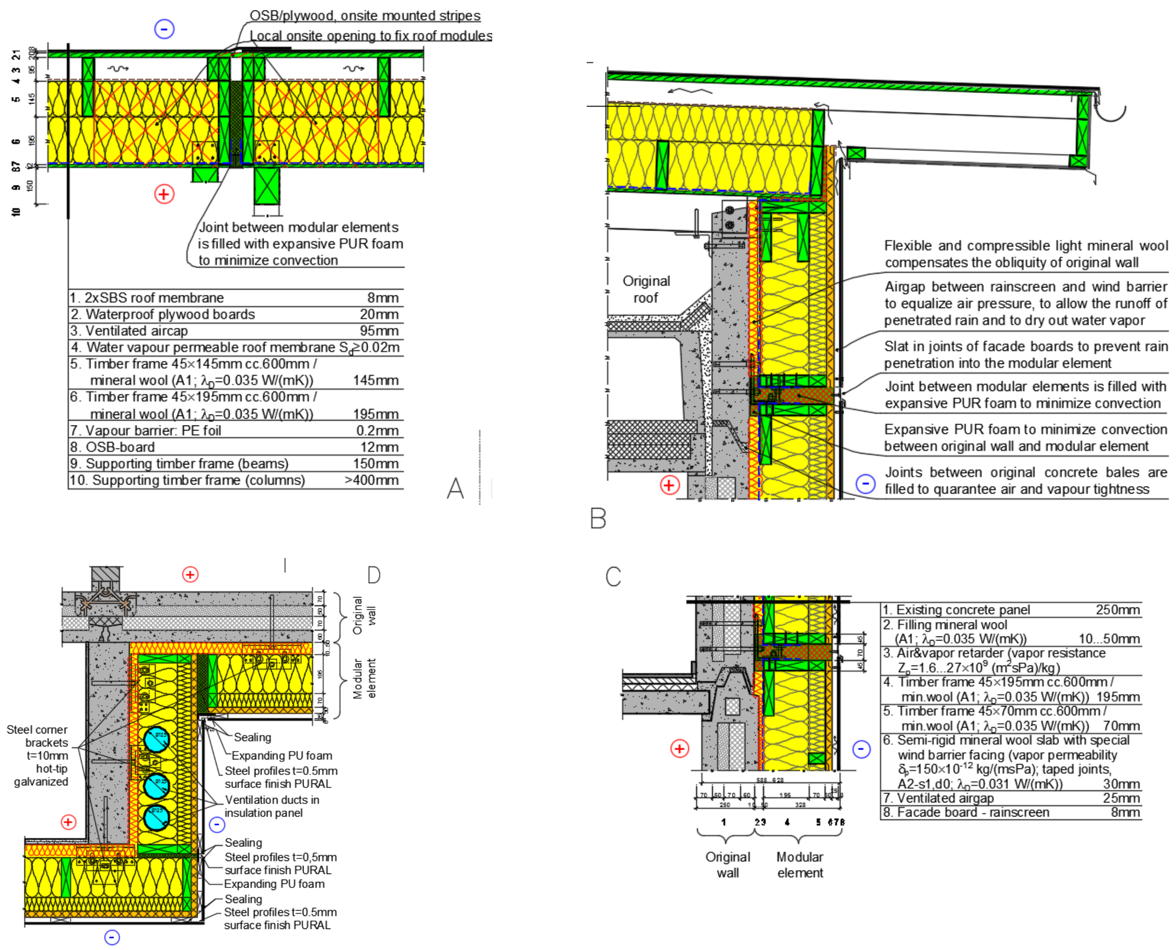


Figure 4.4 Designed solutions at the different structural points of Estonian pilot building wall modules (above and centre) and roof loadbearing structure (below)

4.5 Production of elements

Prefabricated modular elements final structural design was worked out and elements were produced in factory of Estonian prefabricated elements producer Matek facilities in spring 2017.

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 Uwall=0.11 W/(m2·K) and the airtightness of the entire building envelope is q50<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.

Matek got starting task from main design contractor Sirkel&Mall. Very helpful was 3D geodesy scanning (point cloud) of the house. As existing house had very poor quality (measures were off to approx. +/-50mm), it was challenge to fit elements around the envelope and also fit existing window openings with new windows. 3D adjustable metal brackets were designed to level the inequality of vkjk6ymeasures. Matek designed wall elements which were almost typical timber frame elements with wooden frame step c/c 600mm. New solutions for the producer in that project were:

- no stiffening board on inner side of the element – it was replaced with soft mineral wool layer to fill the unevenness and roughness of the existing surfaces
- quite thick and big elements – the elements were with dimensions (HxW) up to 2700x10000 mm and with total thickness 475 mm for roof and 380 mm for walls
- embedded into the wall modular elements ventilation ducts

In conclusion: Expectation was to produce the prefabricated elements, assembled and ready as possible but enough open at the same time to be possible to finalize necessary sealing and tightening of the joints etc on the building site after the installation. In the element design there were challenges to deal with existing house measures (fluctuation of sizes and evenness) which slowed down the conventional production process at the factory.

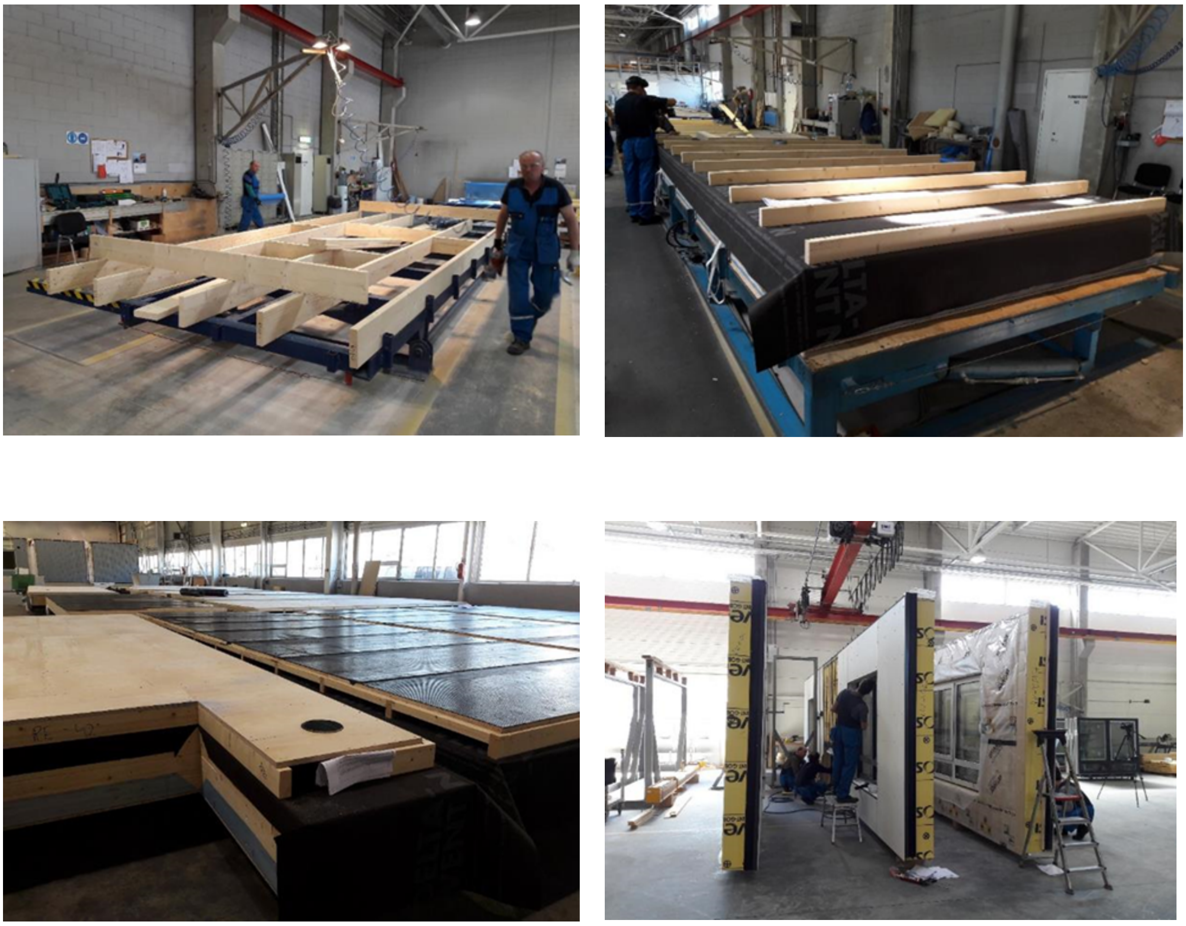


Figure 4.5 Production of modular elements at the factory of Matek (spring 2017)

4.6 Installation

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, Uroof=0.10 W/(m2·K).

Prefabricated modular elements installation at the pilot building was carried out by producer of prefabricated elements Matek in May-June 2017. Installation works were divided into 3 stages:

1. Mounting of metal brackets on the concrete wall.
2. Mounting of wall and roof modular elements
3. Sealing of the joints between elements and finishing of external cladding

1. The 3D adjustable design of metal brackets is quite ingenious for this type of house with initial poor building quality of soviet period. Because of the unevenness of the existing structure, the designed adjustable distance of brackets was not enough. Therefore, actual mounting works proved that the brackets should be even more adjustable. Also the brackets connection (anchor size, location) to concrete should be revised as this proved to be very difficult work (to drill) because of a lot of steel reinforcement inside of concrete slabs of external envelope.

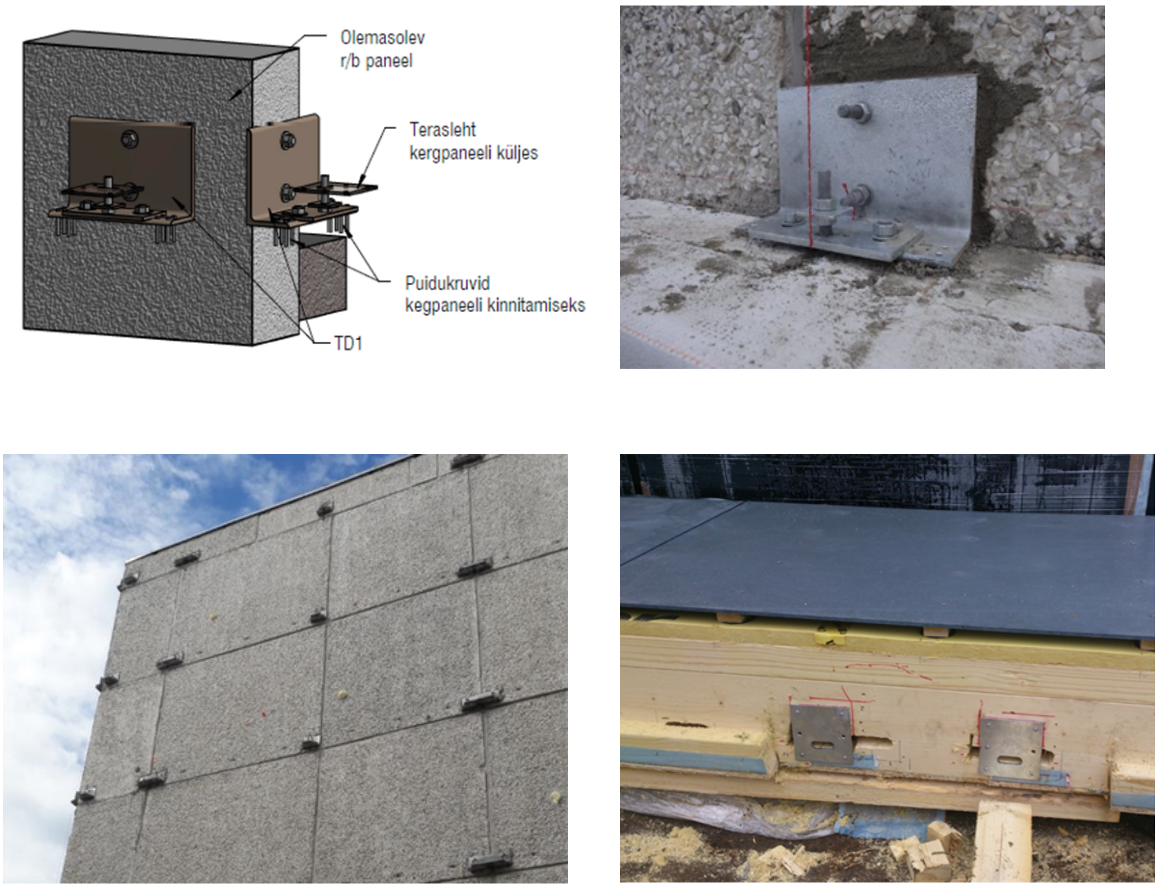


Figure 4.6 Steel brackets, 3D adjustable, for wall modular elements: designed solution (above left); brackets installed onto the wall (above right and below left); brackets support adjustment on the element before mounting at the pilot building site (below right)

2. Mounting of wall elements turned out to be slower than expected. Wall support/connection design with adjustable brackets proved to be possible but there were difficulties to fit long and heavy wall elements into many support brackets simultaneously as the elements bent during lift

under their own weight. These issues could be avoided with different way of lifting, fine tuning of brackets design, smaller and/or stiffer wall modular elements. Roof modular elements were mounted almost as predicted and there were no specific surprises.

Figure 4.7 Mounting of wall (above and centre) and roof (below) modular elements at the building site (May-June 2017)

3. Initial structural design of joints between the wall and roof modular elements was intended to be tightened only with PU-foam as an insulation, vapour barrier and wind barrier seal of the joints. It was reconsidered during the working design of the wall and roof modular elements to use light mineral wool and tape instead of PU-foam without significant update in joint size/design. Therefore,

the joints sealing works turned out to be quite difficult, uncomfortable and time consuming. Biggest challenge was the way to insulate horizontal external wall joints as its depth was up to 380 mm. However, the joint sealing works could be easier and faster to perform if the design of joints would be from the beginning intended to accomplish with mineral wool and tape.

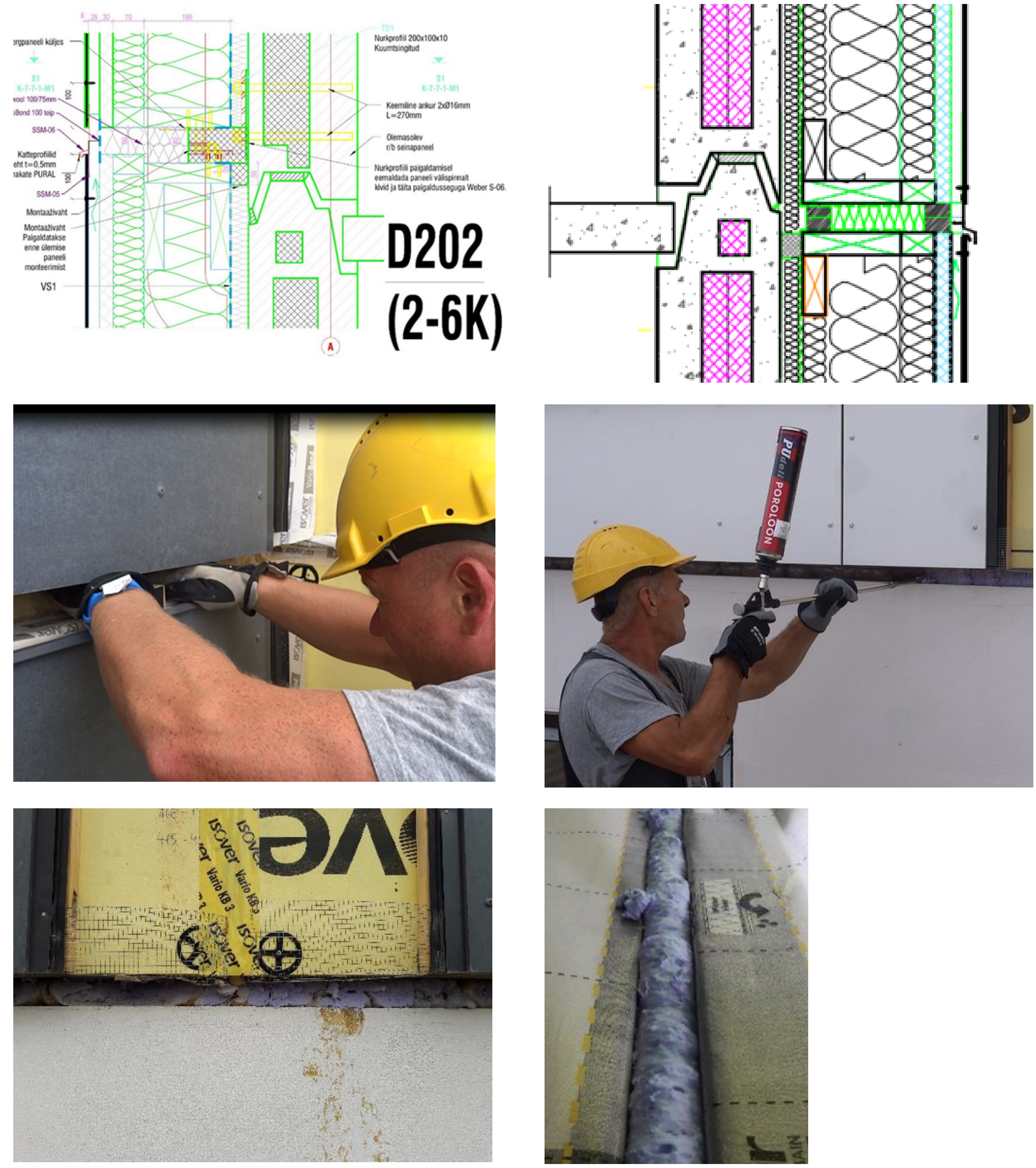


Figure 4.8 Designed solution (above) and sealing of joints (centre and below) at the pilot building site (June 2017)

Figure 4.9 Building process at the pilot building site (spring-autumn 2017)

Figure 4.10 Some examples of challenging points at the pilot building site (spring-autumn 2017)

Figure 4.11 Estonian pilot building after renovation (autumn 2017)

5 LATVIA

5.1 Housing type chosen, and why.

Latvian pilot building is typical brick multi apartment building built in 1967. The building represents typical building constructed in 1950-ies and 1960-ies. This type of building is very common in rural areas and small cities in Latvia. Similar building types are typical also for Estonia and Lithuania. Thus the selected building type has a high replication potential.

The pilot building is 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 are replaced by PVC windows 7 – 10 year ago.

Buildings located in rural areas usually has a higher cost for design and construction in comparison to buildings located in cities.

Figure 5.1. Demo Building before renovation.

5.2 General strategy chosen, to renovate housing type

Pilot building has a 380mm thick load bearing wall. External walls as well as roof coating was in bad technical conditions with cracks and gaps. Quality of construction work was very poor. Windows/walls connections were not insulated and sealed properly. The extra ceiling thermal insulation has a lot of air gaps between mineral wool mats and was partly damaged by water leakage.

Taking into account building poor technical conditions it was decided to focus modular retrofitting on improvements of external building envelope. The general strategy included development and installation of prefabricated modular thermal insulation panels.

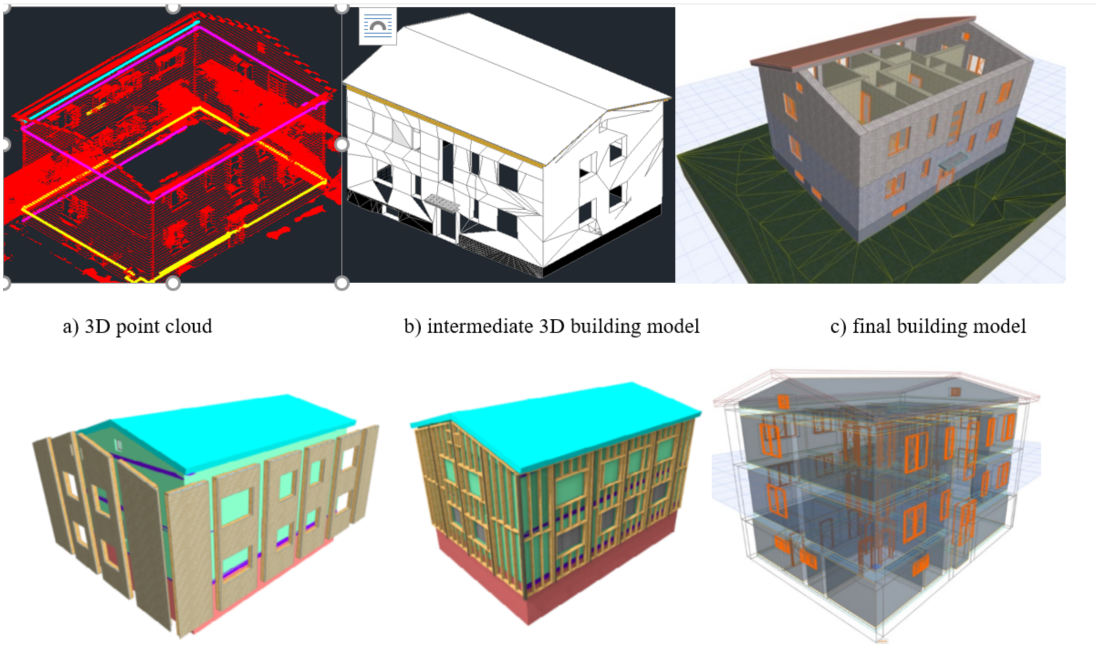
Figure 5.2. Demo Building technical conditions

5.3 Technical concept chosen for renovation:

Modular solution is based on wooden frame. Extra attention is paid to air-tightness of panel joints. The main target was to get wall below 0.18 W/(m^2·K), windows below 1,1 W/(m^2·K) and ceilings below 0.11 W/(m^2·K).

5.4 Design

All initial data for technical project development was gathered during the first part of work package. At the early beginning, the agreement between homeowners, housing company and Riga Technical University was signed. Before the preparation of the technical project the IAQ measurements, thermography and Blower-door test were performed. According to the measurements air tightness of building envelope was 4.5 m^3/m^{2}h. U-values of external building envelopes were around 0.3 W/(m^2·K) for ceiling, 0.95 W/(m^2·K) for walls and 1.9 W/(m^2·K) for windows. The architectural project was developed by RTU spin-off company PLACIS LTD in January 2017.



a) 3D point cloud b) intermediate 3D building model c) final building model

d) development of panel layout e) Thermal blocks for energy simulation

Figure 5.3. Pilot building design process

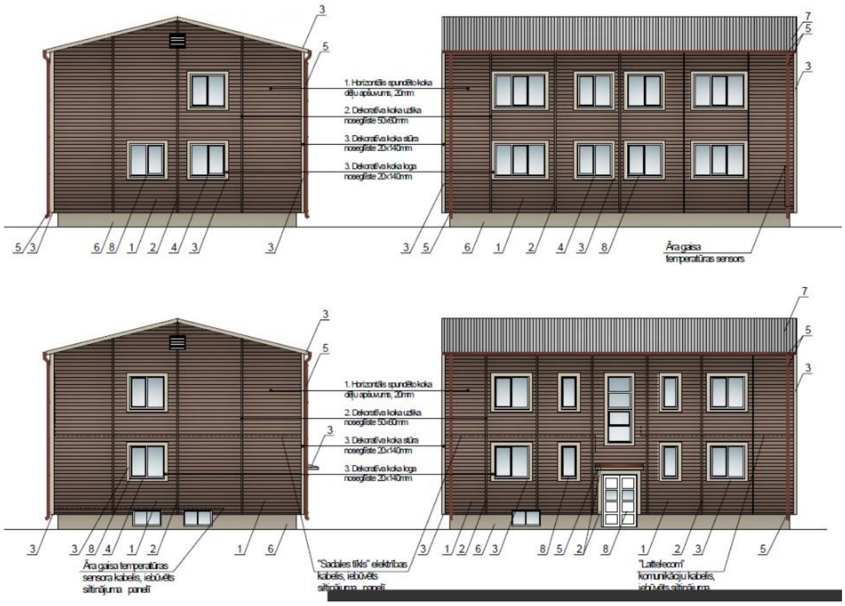
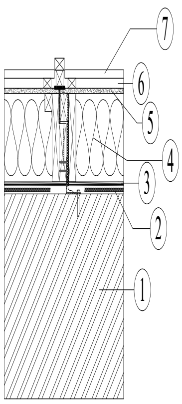


Figure 5.4 Façade layout

5.4.1 Design of prefab panels:



1 – existing wall;

2 - Connection layer between 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;

7 - External finishing - wood planks;

Figure 5.5. Final layout of modular prefabricated thermal insulation panel

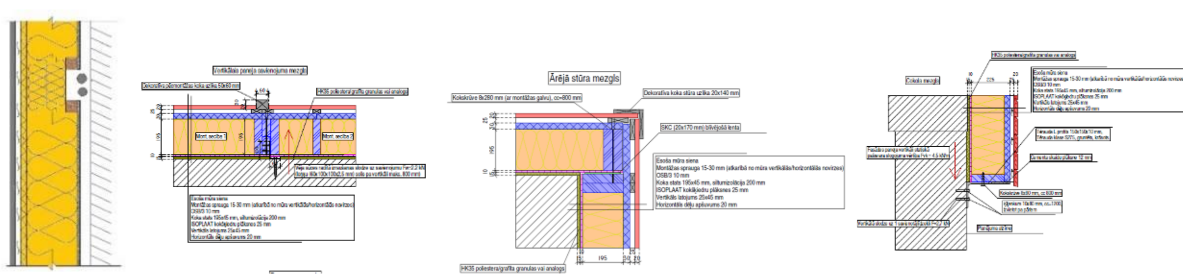


Figure 5.6 Initial design for panels' connections

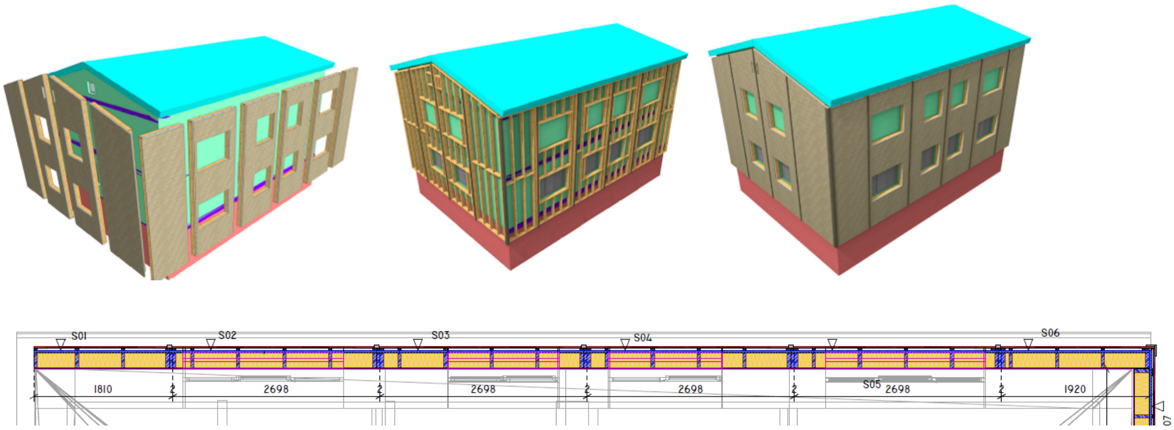


Figure 5.7 Panel layout

After the architectural project was approved by local authorities the open tender procedure was launched. After the tender was closed, the negotiation process on panel solution was initiated by the construction company.

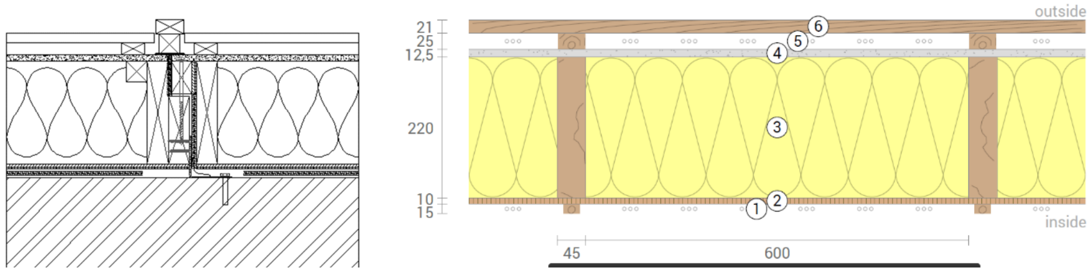


Figure 5.8 Modified panel solution, proposed by construction company

5.5 Production of elements

Panels were produced by local company Silver Standard Plant LTD. During production minor changes in panel layout were performed taking into account transportation specifics as well as available space at the construction site.

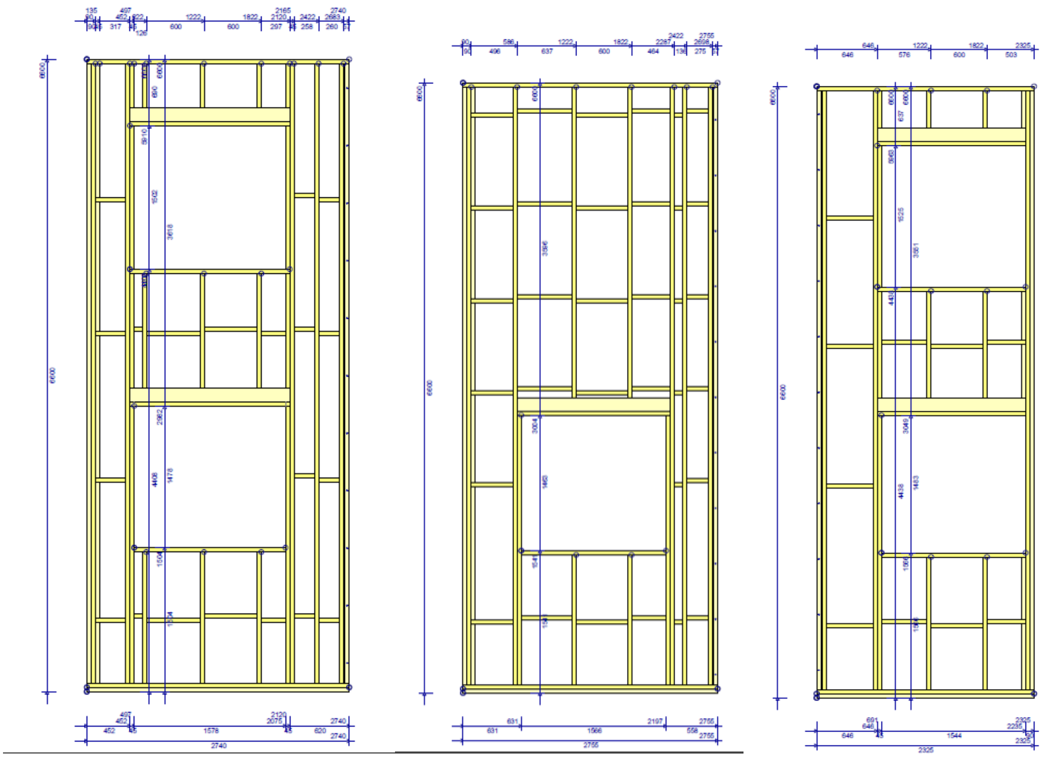


Figure 5.9 Final layout of prefabricated modular panels

Figure 5.10 Front façades view

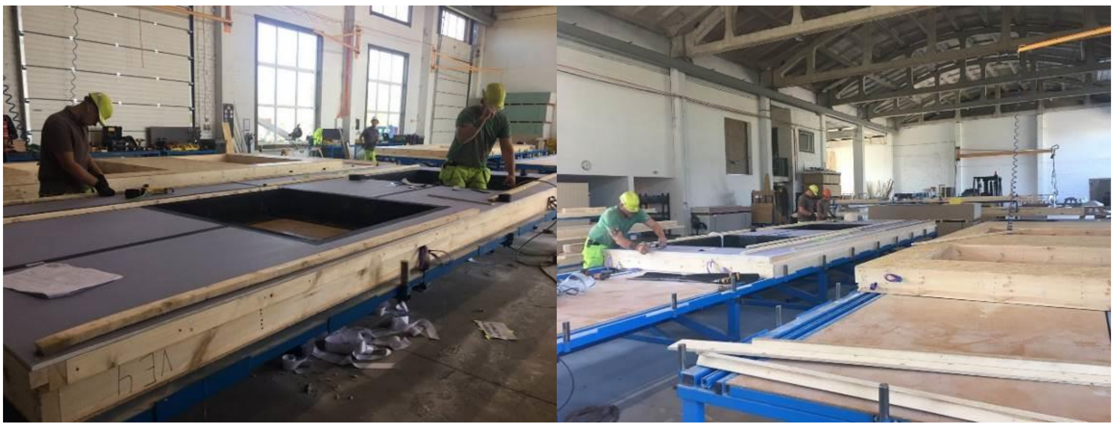


Figure 5.11 Real production process

5.6 Mounting of wall and roof modular elements

Mounting was started in July 2017. The moveable scaffolding was used to prepare the building for panel installation and crane lifting was used for panel mounting (Figure 5.12).

Figure 5.12 Use of scaffolding and crane lifting for the retrofitting work process

In total the panel mounting took 5 working days for 6 workers. The 5 days included also some delay in oversized panel replacement. Taking into account gained experience the panel mounting time can be reduced with up to 3 working days for similar buildings. The proposed modular retrofitting thus allow significant reduction of on-site construction work. Other construction works took 9 days. The mounting process is illustrated on Figure 5.13.

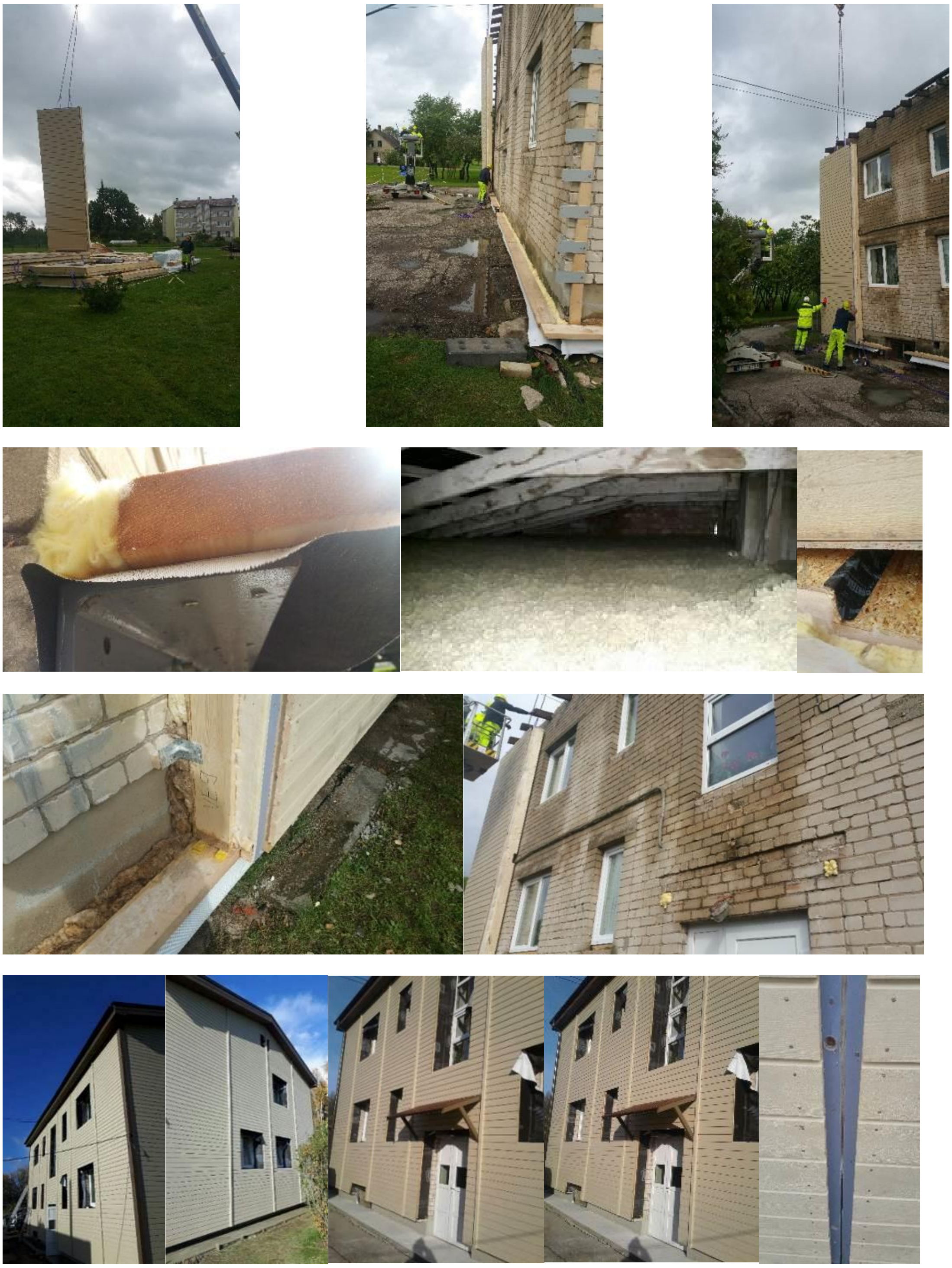


Figure 5.13 Illustrations of the mounting and completion process

Installation of renewables wasn’t taken into consideration due to bad condition of roof supporting structure and absence of central hot water supply system. Installation of PV also was limited by home ownership specifications. There are four owners. Thus calculation of supplied electricity to the grid and received/used electricity would require an extra effort to implement a complicated metering system.

Figure 5.14 The Latvian pilot building after renovation

6 THE NETHERLANDS

6.1 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 include the substantial energy efficient improvement of the building envelope. Therefore, the building envelope is replaced by prefabricated elements and micro energy generation technologies is installed (like heat pumps and photovoltaics). The repetitive aspect of building construction makes these buildings very suitable for an industrialized renovation approach.

Figure 6.1 Overview first generation of deep-renovation applying prefabricated building envelope elements (since 2006).

More recently the application of this approach also have been demonstrated in apartment buildings as showcased by the Dutch demonstrator project, see figure 6.2. Within the Netherlands this housing type (multi-family housing with common staircase) encompass about 254,000 housing units.

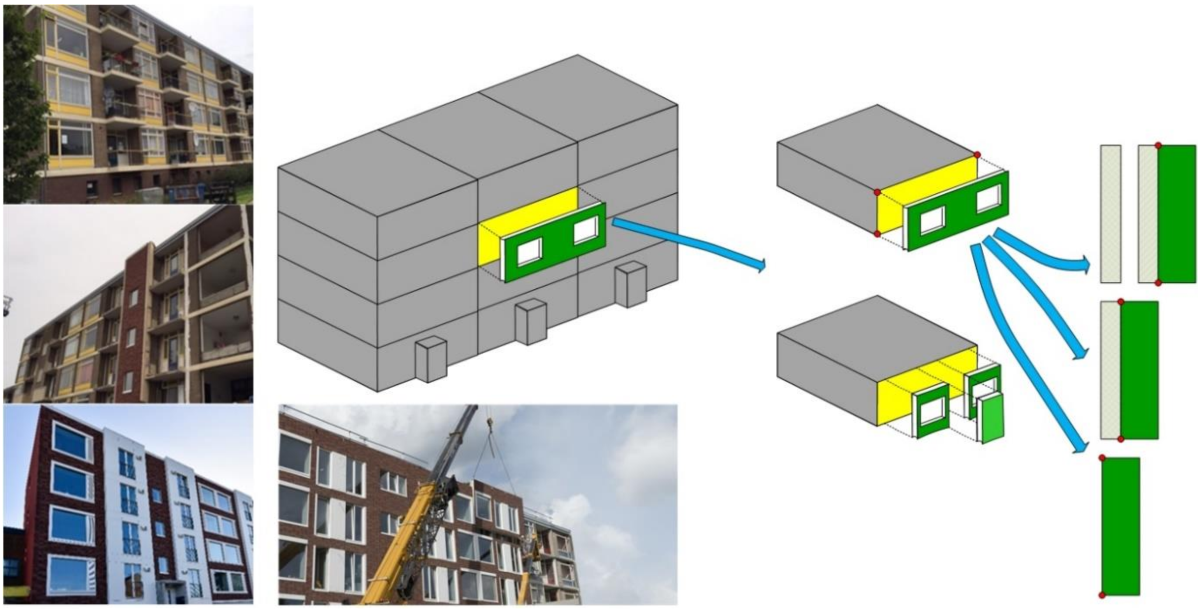


Figure 6.2: Underlying rationale deep-renovation approach Dutch demonstration project

6.2 General strategy chosen to renovate the housing type

It was learned that in particular single family dwellings and apartment buildings constructed in the sixties and seventies have the potential to upscale deep renovation solutions. These housing types are constructed at a large scale and share several commonalities which enables the prefabrication and replication of deep renovation solutions for this building typology.

The key performance indicators:

1. The installation of off-site produced prefab panels is more quickly than an on-site solution
2. It is less complex to ensure airtightness of the building façade.

After closing the covenant ‘De Stroomversnelling’ in 2013, the application of prefab façade and roof element became the dominant design for deep renovation projects in the Netherlands. The building blocks of Zero-on-the-Meter renovations according ‘De Stroomversnelling’ standard are included in figure 6.3.

The Dutch demonstration project includes four apartment buildings encompassing 64 housing units, constructed in 1963, located in the city of Arnhem. These outdated and energy consuming housing units were renovated towards ‘Zero-on-the-Meter’, i.e. by adding PV in the near future the apartments can be upgraded to zero energy. The renovation is based on the (favourable) concept which include the improvement of the insulation of the building envelope (with prefabricated façade panels) and installing mechanical ventilation with heat recovery.

6.3 Technical concept chosen for renovation:

In sum, 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 exchange (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.

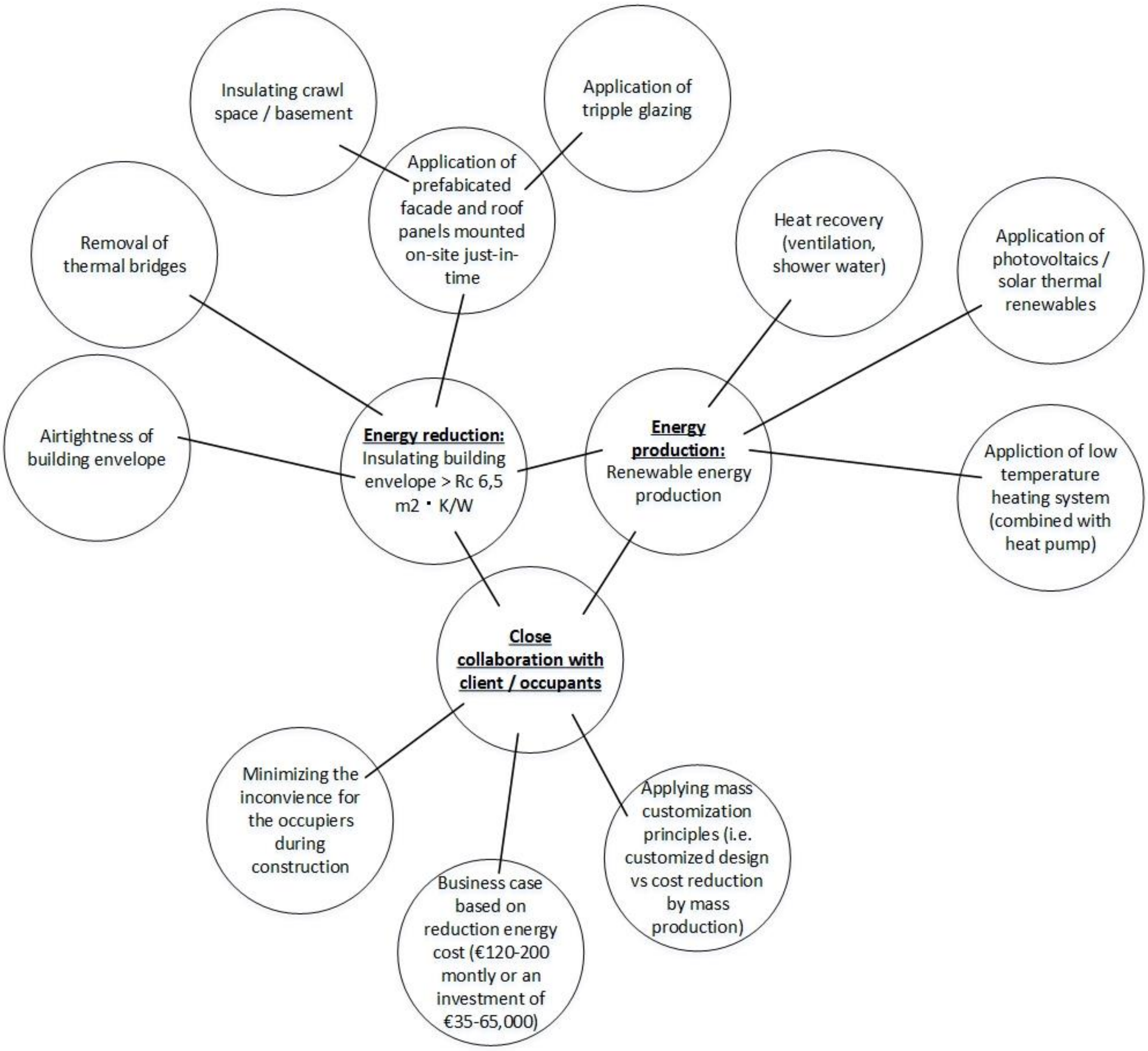


Figure 6.3: Key aspects of the deep-renovation concept

6.4 Design - lessons learned

In the Netherlands the experiences and lessons learned have been gathered for the pilot project Presikhaaf. 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 6.4 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. See figure 6.5.

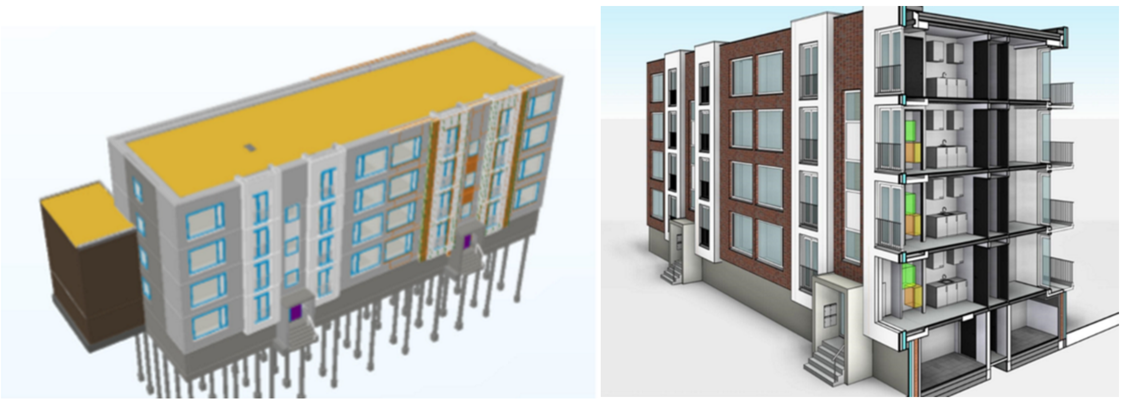


Figure 6.5 Cloud representation in the BIM system (left) and final design (right)

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), see figure 6.4

Modular façade consists of several fixed design rules. Nevertheless some unique, project specific, detailed solutions need to be developed (design flexibility). Fixed design rule contribute 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).

6.5 Production of elements - lessons learned

Structural Insulated Panels (SIPS) have been improved after its application in the Presikhaaf project: the EPS on which the brick slips are glued is replaced by battens and cement-fiber board (see figure 6.6). This has some advantages with respect to:

- Guarantee on wind- and waterproofing in the long term in case of mechanical damage
- Improved fire protection. It appeared that the construction layers with EPS or PIR where from a fire safety point of view technically not viable. This has been improved by using a ventilated layer (WEBO also had to change this for the Germany market as > 23 mm EPS is not allowed there).
- Production efficiency (simplification)
- Improved production efficiency: ‘in line’ process developed
- Improvement quality management system: every single wall element checked and marked with a 'approved' sticker, according to the quality management system

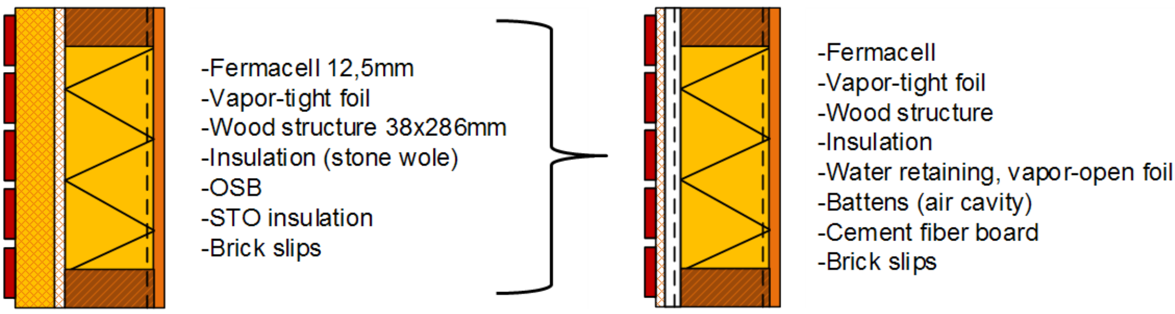


Figure 6.6 Change of wall element based on the lessons learned at the Presikhaaf project.

There were some problems with the sagging of thermal insulation in the cavities of the façade elements. This problem was simply solved with strips in the facade elements, keeping the thermal insulation in place.

Integration of ventilation ducts is typically project bound and sometimes difficult or not meaningful. However, the supplier, WEBO, noticed that installation technology is advancing rapidly, coming up with new innovative solutions.

Further, evaluating the production process it has been suggested to further industrialize and automate the production of the façade elements. Nowadays the panels are moved from position A to B and during each step building components are added by craftsman until the façade element is fully produced and ready for transport to the construction site (see figure 6.7). Preliminary designs have been developed to build a fully automated production line. This step is considered necessary to further reduce the production cost of the façade elements.

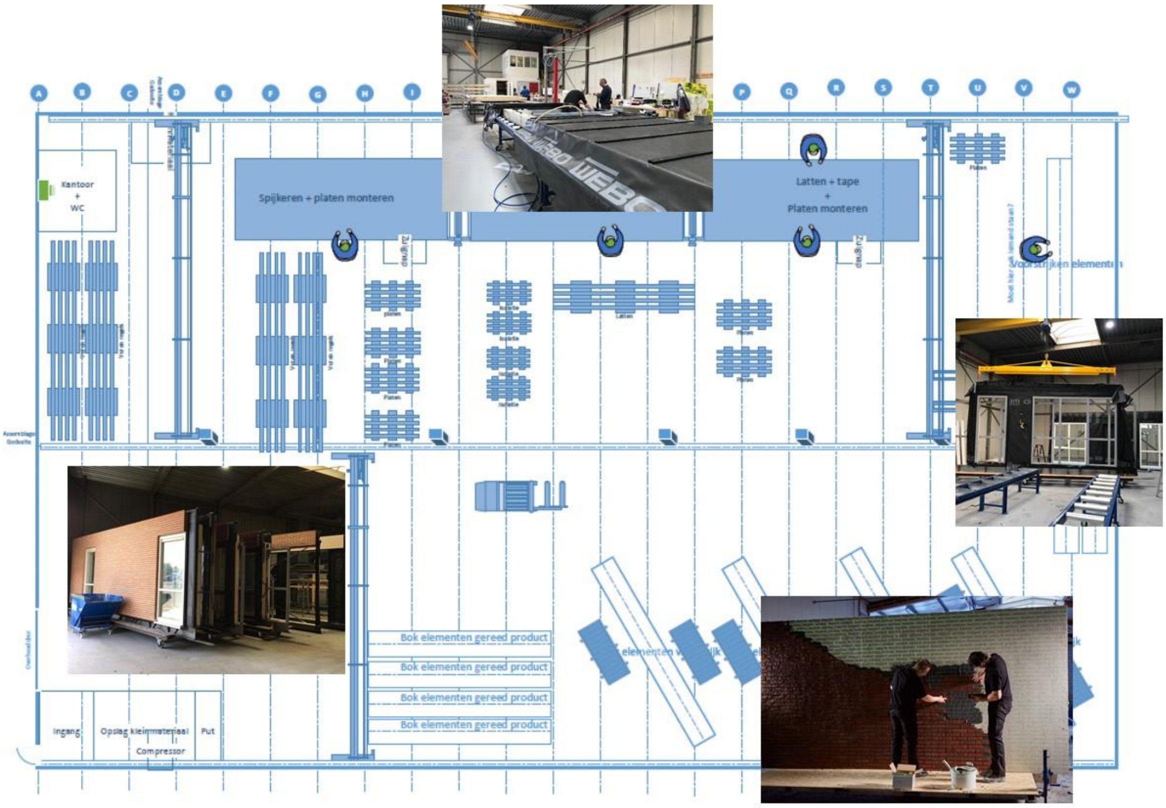


Figure 6.7 Schematics of the current production of the façade elements.

6.6 Installation - lessons learned

6.6.1 Change of project organisation structure

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.

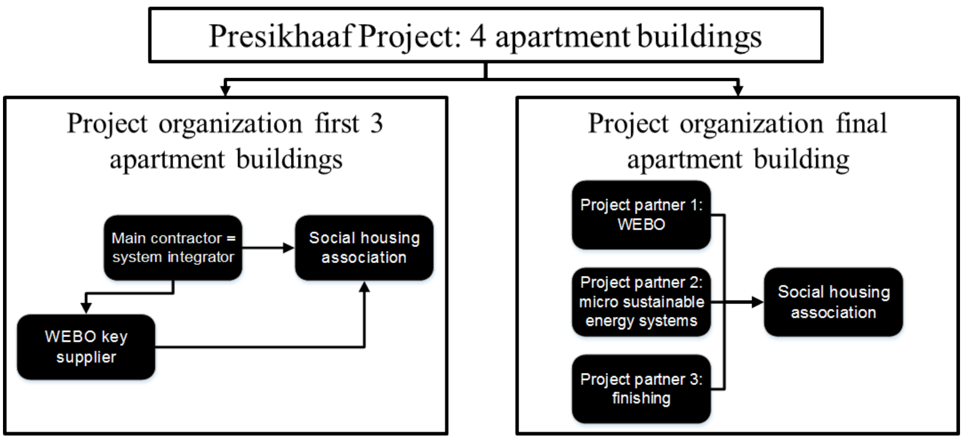


Figure 6.8 The change in project organisation after the first apartment buildings had been completed.

Webo comments on this:

“if you are under a third party who is responsible but does not understand the whole system, and does not believe in it, you should not allow that and reject the project. The client was unsatisfied with how the three first apartment buildings were completed, and with respect to the fourth apartment building, they emphasized ‘you learned a lot from the previous buildings’. That is of course not the case. We have not learned much at all. Of course we have a continued improvement process in our system, but the poor performance of the third party had a negative effect on (the perception of) our performance.” - W. Haase

“WEBO has now made over 5000 wall elements. What we still struggle with, the product is so innovative, and simple, that people do not believe in it. Then we are inclined, and the problem lies with us, then we adapt to our customer demands. So we make concessions on our own product. What we should do: we have developed a product, this is it, this is what you get, this is how it works. The modular system must be applied as such, and we must not adapt to the traditional process of the contractor.” - W. Haase

6.6.2 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 (figure 6.9) 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 6.9 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 preconditions is not met it could result in performance issues as was confirmed by the Dutch demonstration project[1].

[1] COLFER, L. J. & BALDWIN, C. Y. 2016. The mirroring hypothesis: theory, evidence, and exceptions. *Industrial and Corporate Change,* 25**,** 709-738, SANCHEZ, R. & MAHONEY, J. T. 1996. Modularity, flexibility and knowledge management in product and organization design. *Strategic Management Journal,* 17**,** 63-76.

7 The Dutch RLLL

In focus at the Dutch RLLL were:

- Testing of prefab multifunctional facades and roofs
- Creation and testing of a first compact ‘engine’ (installation platforms)
- Monitoring on energy use and in deep monitoring on thermal comfort and health in relation with energy use in renovated homes under semi-lab conditions.

Lessons learned from the Dutch RLLL:

- From this first experiment with a full renovation by prefabricated integrated façade and roof elements for deep renovation it was proven that the renovation of the envelope and building services can be achieved within three days, including the total removal of the existing facades, placing and mounting of the new prefab façade elements, roof with integrated PV elements and finishing. As this was the first test with some ‘trial and errors’ it is expected that the renovation works can be further optimised and the renovation time can be further limited to 1 to 2 days.
- Although the façade elements had a very good airtightness, the total airtightness of the dwelling, after the renovation was poor (the initial n_{50} value was ~ 6.5 after renovation!). This was mainly due to:
    1. The connections/joints between the existing structures (partition walls, floors, with very rough ‘endings’) with the new elements – figure 7.1.

Figure 7.1 Connection between existing structures and new elements

    2. The fact that the dwellings have a storage cellar; therefor the floor between the cellar and the first floor has to be fully airtight (on a level of the Dutch Building Decree for new dwellings)
    3. Major air leakages between the connections and joints between the new roof and the existing partition walls
    4. The transits for ducts, pipes, cables, in the roof to the ‘engine’ placed in a space, integrated within a cavity in the roof.

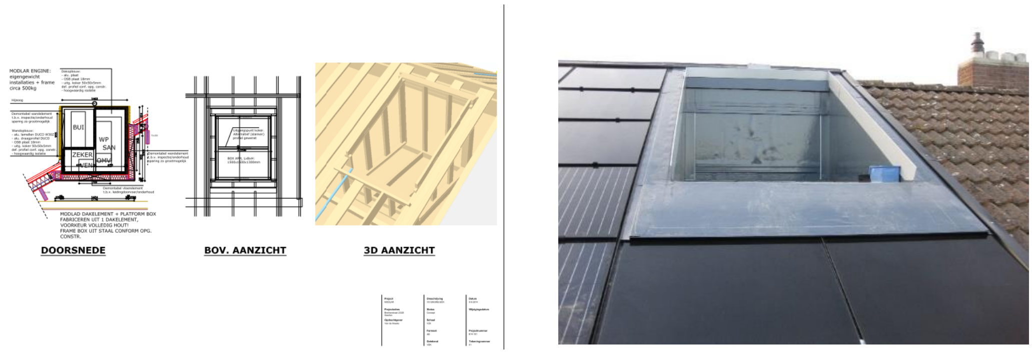


Fig. 7.2 Roof space for integrating the roof engine.

The leakages, mentioned under 2, is not intrinsic to this way of renovation. The leakages, mentioned under 1 and more specifically 3 are a common problem with envelope renovation in the Netherlands. These leakages do not have serious consequences in terms of energy use due to infiltration losses (as it is infiltration to another dwelling with most likely the same temperature) but it has severe consequences in terms of acoustics (noise transfer between the dwellings) and fire safety. There are two ways to handle this:

- Airtight finishing of the joints on site (however, this is not prefab and implies extra time)
- A prefab construction where airtight joints are realized by a special connection, which can be shoved over the partition walls and floors.

In the Dutch Real Life Living Lab in Heerlen, the so called Thermo-Neutral-Zone (TNZ) model (developed by Maastricht University in collaboration with Huygen IA) was tested and validated for the first time in practice. What has been observed is that occupants behave naturally in such a way (indoor temperature, clothing, type of activity) that they are tended to 'move' their thermal balance to the center of the TNZ. (However, in this pilot the exact limits in the TNZ could not be determined). In practice, it is therefore difficult to determine this TNZ for every person and is therefore not yet a practical tool for large scale application. (Follow-up research is taking place now in the Dutch demonstration cases in the H2020 MOBISTYLE project and TKI-DYNKA project, were people are offered a dynamic temperature profile, followed by an assessment of its acceptance).

8 PORTUGAL

8.1 Housing type chosen and the underlying rationale

The Portuguese pilot building is a building located in Vila Nova de Gaia, Porto Metropolitan Area, in the North 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-bedrooms apartment and a three-bedrooms apartment per floor). In total, eighteen apartments constitute the building (Figure 7.1), which has a gross heated floor area of 1265 m^{2}.

Figure 7.1 - Portuguese Pilot Building before renovation

The building, in terms of typology and building characteristics, is representative of about 40% of the Portuguese multifamily buildings, which justified being chosen as a pilot for this project. 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, the building envelope presents some signs of deterioration, although in 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 in some of the ceilings of the rooms and bathrooms. All these issues highlight the need for renovation.

8.2 General strategy chosen to renovate the housing type

The general renovation strategy is based on a modular approach to improve the overall performance of the façade. In that way, prefabricated modules will be added to the existing façade, using crane lifting as a working method. Calculations indicate that an estimated 25% reduction in primary energy use is possible with the application of the prefabricated modules alone. However, as the project has as main objective the reduction of at least 80% of the primary energy use, other measures had to be considered in addition to the application of the prefabricated modules. In this context, additional layers of insulation are planned to be placed in the roof and in the cellar. Existing windows are already double glazed and therefore, their replacement is not being considered at this stage.

Additionally, the building manager chose not to implement solar panels for domestic hot water (DHW), but after the renovation, as part of a second phase, a biomass boiler is planned to be installed, improving significantly the building systems performance for both heating and DHW preparation.

Considerations:

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

8.3 Technical concept chosen for renovation:

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

8.4 Design

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 7.2). The renovation solution includes the application of an additional insulation layer of mineral wool to be put between the existing façade and the prefabricated modular system. The modules will be vertically oriented (10 m height) and will use standard metal connectors to be assembled to the exterior wall (figure 7.3 and figure 7.4).

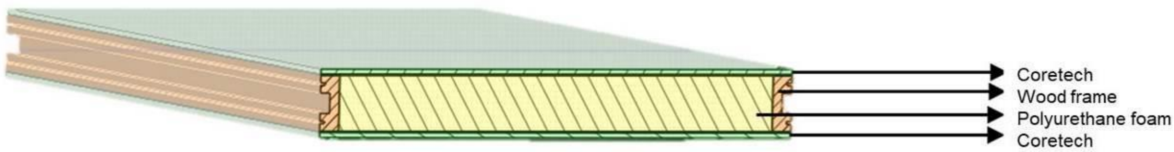


Figure 7.2 Illustration of prefabricated module

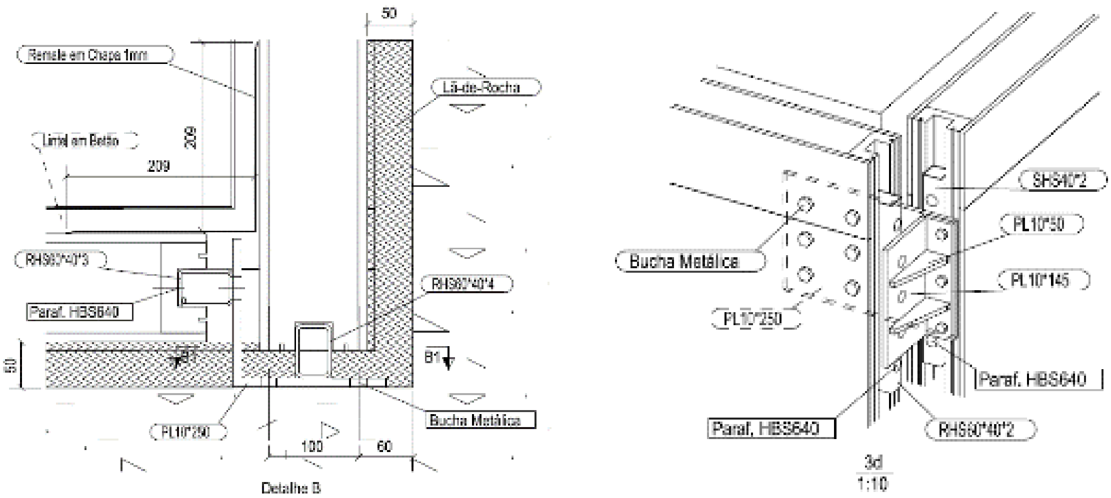


Figure 7.3 Examples of designed connections (between modules in interior and exterior corners)

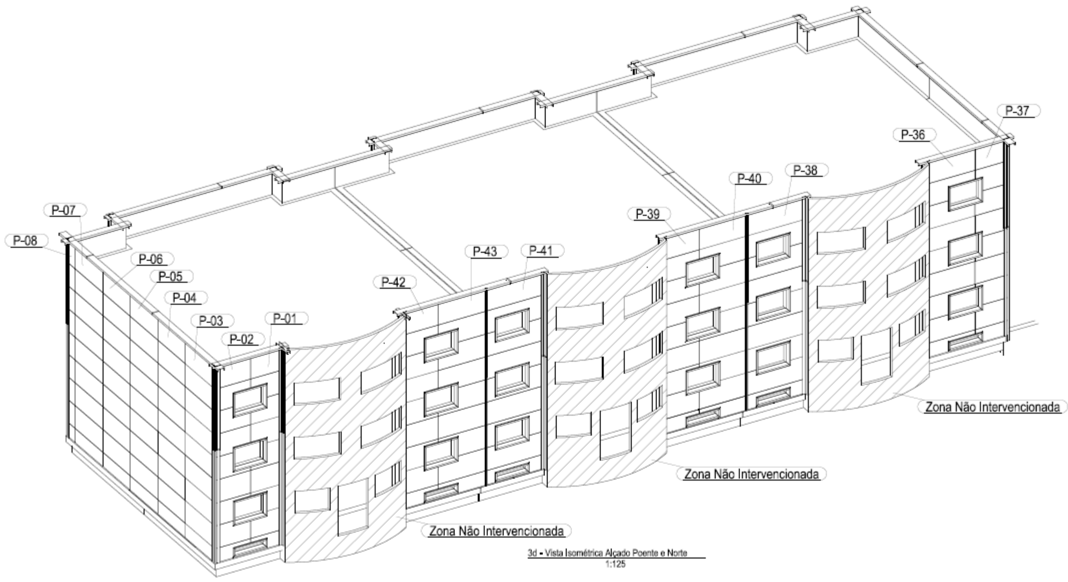


Figure 7.4 - Detail of panel fixation and planning of prefabricated façade module installation

8.5 Production of the façade elements

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 presents 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 cellulosic paper, polyurethane foam, fabrics and fiberglass. It presents attractive characteristics such 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 filling material of the prefabricated elements given its high thermal performance and high durability.

In order to be tested in laboratory facilities, the prefabricated modules were produced with 2.55 m of height and 1.00 m width (figure 7.5). 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 panel are 10.0 m high and 2.4 m width.

Due to the stiffness of the prefabricated element, there was the 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 will efficiently avoid the occurrence 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.

Figure 7.5 Prototype production (Frame detail and assembly process)

8.6 Installation

Prefabricated modular elements installation were planned to be carried out according to table 7.1

Table 7.1 Planned renovation process

Activities	Time schedule
Start of panels production	First trimester of 2018
Preparatory works on site	First trimester of 2018
Panels transport and mounting	First trimester of 2018
Delivery of completed renovated site	First trimester of 2018

Unfortunately, due to insuperable administrative reasons that arose in the Portuguese consortium, it was not possible to comply with the proposed deadlines and the Portuguese pilot building will not be renovated within the project timeline.

However, DarkGlobe and University of Minho are still very interested in the façade renovation solution developed under this project and are deeply committed to finding an alternative building where it can be incorporated and tested. Unfortunately, this will be possible only after the project end date.

9 CONCLUSIONS

The evaluations documented in this report was carried out for each of the pilots and the RLLL projects covering the phases: Design, production of elements and installation as well as 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, ProGETonE, P2Endure, BERTIM, IMPRESS, STUNNING and many others) we can indeed conclude that we were able to make a step forward by combining these four pillars:

Product innovation

Modular façade elements
Modular roof elements
Modular 'HVAC engines'

Process innovation

Advanced geomatics
Web-based and/or digital decision tools to link building characteristics, building (energy) potentials, end-users demands
BIM for controlling industrial processes and for enhanced quality assurance.

Optimization between costs, environmental aspects and quality

Integration of components and systems
Re-design
Smart connectors

From a end-users perception

Development of one stop shop concepts
Development of systems of performance guarantees
Development of energy cost guarantee proposition to end-users ('zero on the meter')

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

3. There are still too many layers in the renovation process.
4. Clients are in general still reluctant for innovations.
5. 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.

6. 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 able to develop blue prints for new production processes and factories in MORE-CONNECT but due to lack of market still on hold. A step to make is the connection between advanced geomatics 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 (as discussed during SP2019, 5 – 7 June 2019, Cagliari).

During the actual execution of the demonstration projects, 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.

The most important lessons 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 in 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.

As more general conclusions:
- A generalized lack of knowledge on innovative deep retrofit design methodologies including the adoption of prefabricated systems is hindering the wider market adoption of such highly promising technological solution

- Enhancing user's experience of the retrofit process, by means of ICT/BMS-supported improved comfort, while ensuring low intrusiveness and allowing aesthetic flexibility in design, and accommodating future performance uncertainty
- Make complexity manageable, ensuring and enhancing product and process quality during the whole life cycle
- Integration of RES is included as solution for achieving energy efficiency, but has alone limited relevance
- Learning from previous experiences and best practices of technological solutions and optimization objectives for deep retrofit and pre-fab systems could be further developed in further (EU) projects, thus successfully meeting the expected 2020 energy targets
- More holistic approaches and user-centric design are needed

10 REFERENCES

Kalamees, T., Lupišek, A., Mørck, O.C., Borodiņecs, A., Aalmeida, M., Rovers, R., Veld, P.O. ’t, Kuusk, K., Silva, S., 2016. What kind of heat loss requirements nZEB and deep renovation sets for building envelope?, in: Central Europe Towards Sustainable Building 2016: Innovations for Sustainable Future, CESB 2016. University Centre for Energy Efficient Buildings Czech Technical University in Prague, Prague, Czech Republic, pp. 137–144.

Kuusk, K., Kalamees, T., Pihelo, P., 2016. Experiences from Design Process of Renovation of Existing Apartment Building to nZEB, in: Heiselberg, P.K. (Ed.), Proceedings of the 12th REHVA World Congress, CLIMA 2016, 22-25 May 2016, Aalborg, Denmark. Aalborg University, Department of Civil Engineering, Aalborg, Denmark.

Pihelo, P., Kalamees, T., Kuusk, K., 2017. nZEB Renovation with Prefabricated Modular Panels, in: Geving, S., Time, B. (Eds.), Proceedings of the 11th Nordic Symposium on Building Physics in Energy Procedia, NSB2017, 11-14 June 2017, Trondheim, Norway. Elsevier B.V., pp. 1006–1011. https://doi.org/10.1016/j.egypro.2017.09.708

Pihelo, P., Lelumees, M., Kalamees, T., 2016a. Influence of Moisture Dry-out on Hygrothermal Performance of Prefabricated Modular Renovation Elements, in: Kurnitski, J. (Ed.), Proceedings of the SBE16 Tallinn and Helsinki Conference “Build Green and Renovate Deep” in Energy Procedia, SBE2016, 5-7 October 2016, Tallinn and Helsinki. Elsevier B.V., pp. 745–755. https://doi.org/10.1016/j.egypro.2016.09.137

Pihelo, P., Lelumees, M., Kalamees, T., 2016b. Potential of Moisture Dry-out from Concrete Wall in Estonian Climate, in: Hansen, K.K., Rode, C., Nilsson, L.-O. (Eds.), International RILEM Conference on Materials, Systems and Structures in Civil Engineering. Conference Segment on Moisture in Materials and Structures, MSSCE2016, 22-24 August 2016, Technical University of Denmark, Lyngby, Denmark. RILEM Publications S.A.R.L., Lyngby, Denmark, pp. 289–298.

Rose, J., Thomsen, K.E., Mørck, O.C., Kuusk, K., Kalamees, T., 2016. The Economic Challenges of Deep Energy Renovation-Differences, Similarities, and Possible Solutions in Northern Europe: Estonia and Denmark. ASHRAE Trans. 122, 58–68.

COLFER, L. J. & BALDWIN, C. Y. 2016. The mirroring hypothesis: theory, evidence, and exceptions. *Industrial and Corporate Change,* 25**,** 709-738.

SANCHEZ, R. & MAHONEY, J. T. 1996. Modularity, flexibility and knowledge management in product and organization design. *Strategic Management Journal,* 17**,** 63-76.