MORE-CONNECT
Development and advanced prefabrication of innovative, multifunctional building envelope elements for MOdular REtrofitting and CONNECTions
(No. 633477)

D5.6 Evaluation report of quality of construction works

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Executive summary

Within the MORE-CONNECT project testing, pilot implementations and demonstration in real settings, as well as in industrial settings (including demonstration of production), of the modular renovation elements developed within the project has been organised at six locations:

- Czech Republic (RLLL setting for in deep testing)
- Denmark (full real setting)
- Estonia (full real setting)
- Latvia (full real setting)
- The Netherlands (full real settings and RLLL setting for in deep testing)
- Portugal (partial real setting)

To gather experiences from these pilots in six different countries an evaluation and analysis of the total renovation process was carried out. This has been done in two steps:
A first evaluation documented in this report (Deliverable 5.6), which has been further elaborated in the final report summarizing the experiences from the pilot projects (Deliverable 5.9): "Analyses of the total renovation processes in the pilots", May 2019.
To structure the analysis and documentation of the renovation process of the MORE-CONNECT pilots the work was subdivided in the following phases:

- Design
- Production of elements
- Installation/implementation

The analysis was carried out for each of the above pilots country by country. The results are summarised here. For the complete result of the analysis, the different chapters for each country need to be studied.

<u>Experiences and conclusions from the five pilot projects</u>

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

Invela:

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.

Innogie:

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:
1. 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. 2.. 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. 3. 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.

4. 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.

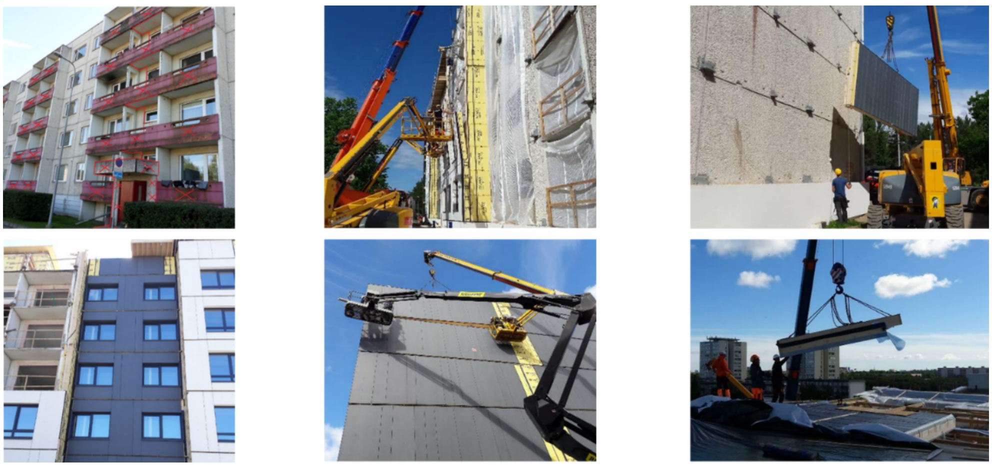


Figure 3 Installation of modular elements at the Estonian pilot building - summer 2017

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 below 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 conclusions from this first analysis of the lessons learned.</u>

Summarizing what has been learned from the different pilots and RLLL projects - the most important lesson from each pilot and RLLL:

- Focus must be on optimizing materials and tools to be used together with robots on specific tasks (Denmark).
- 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 (Estonia).
- Extreme care should be taken not to oversize elements (Latvia).
- The project organization need to mirror the modular design of the deep-renovation solution (The Netherlands)
- Aa more integrated perspective from all the stakeholders in the process is needed to avoid that consideration of life cycle and embodied energy in the choice of materials lead to non-consensual discussions regarding the need for balance between technical and structural features and sustainability concerns (Portugal),
- Security precautions should be taken when assembling modules by crane to avoid damage to the hands of the workers on-site (Czech RLLL).
- The renovation of the envelope and building services was proven to 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 (Dutch RLLL).

1 Introduction

The objective of work package 5 is the testing, pilot implementations and demonstration (and demonstration of production) of the developed modular renovation elements both in real settings as well as in real life learning lab (RLLL) settings. The testing and demonstration in practice has been organised on six locations:

- Czech Republic (RLLL setting for in deep testing)
- Denmark (full real setting)
- Estonia (full real setting)
- Latvia (full real setting)
- The Netherlands (full real settings and RLLL setting for in deep testing)
- Portugal (partial real setting)

The work package comprised 6 tasks of which this deliverable presents the results of **Task 5.6 Total evaluation of the renovation process.** In this task the total renovation process has been evaluated and analysed.

This has been done in two steps:
A first evaluation at the end of the third year with the possibility to make some modifications if necessary by the finalisation of the project at the end of the project.
The Task leader was Cenergia with contributions from other knowledge partners: Zuyd, RTU, TUT and industry partners: BJW and LWCC.

The work within this task carried out for each of the above pilots are described below, country by country. The renovation process of the MORE-CONNECT pilots is for this purpose subdivided in the following phases:

- Design
- Production of elements
- Installation/implementation

2 Czech Republic

2.1 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 are not having a real case, but we have built a small mock-up building, on which the critical details of modules will be tested.

Fig. 2.1: Typical representative of target typology and architectural and technical options enabled by the modular design.

Fig. 2.2: Visualisation of key elements that will be tested at the mock-up building.

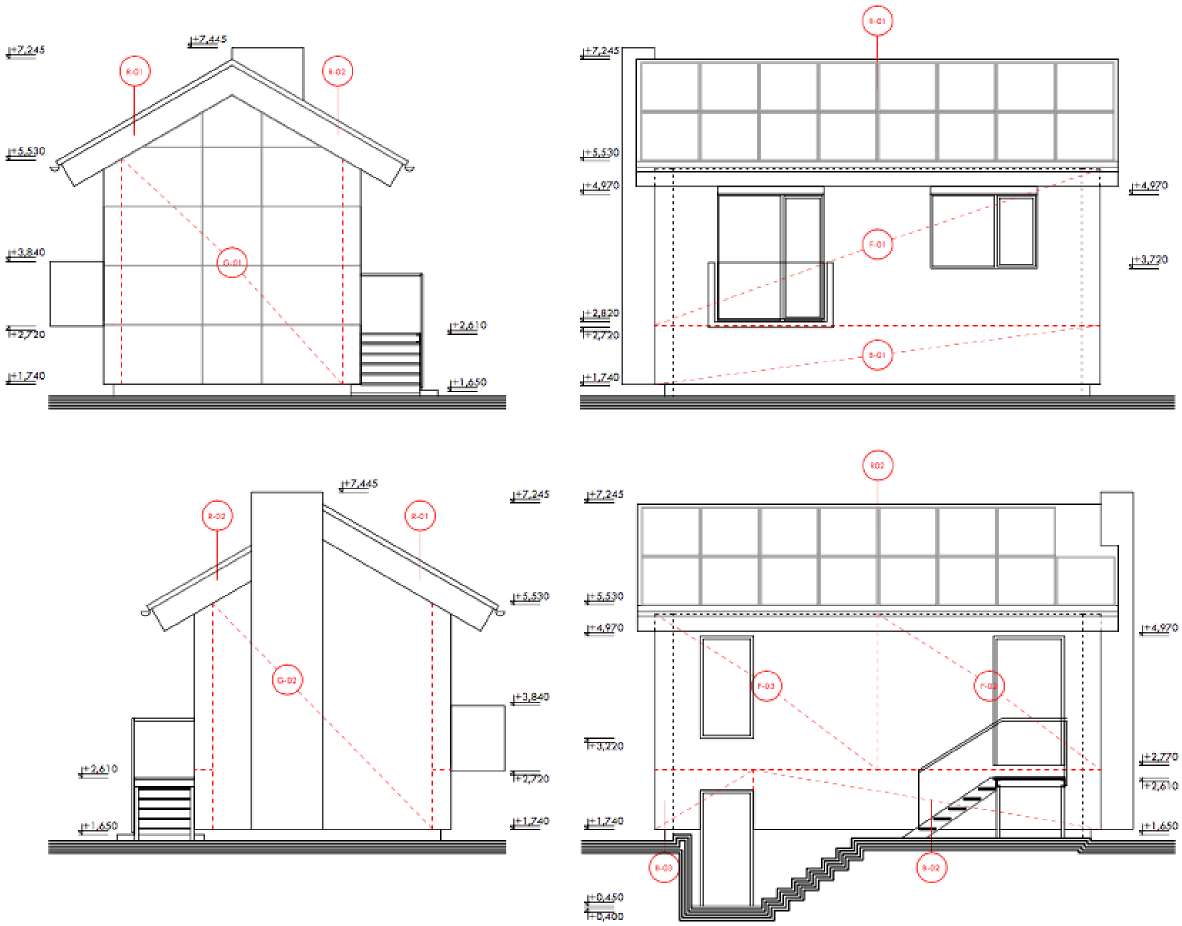


Fig. 2.3: Elevations showing modules that will be included in the testing. In addition to that HVAC system will be mounted in the semi-underground floor.

The design led from the general wall modules developed in WP2 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.

Fig. 2.4: 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).

Fig. 2.5: Development of air tight detail of electrical box installation.

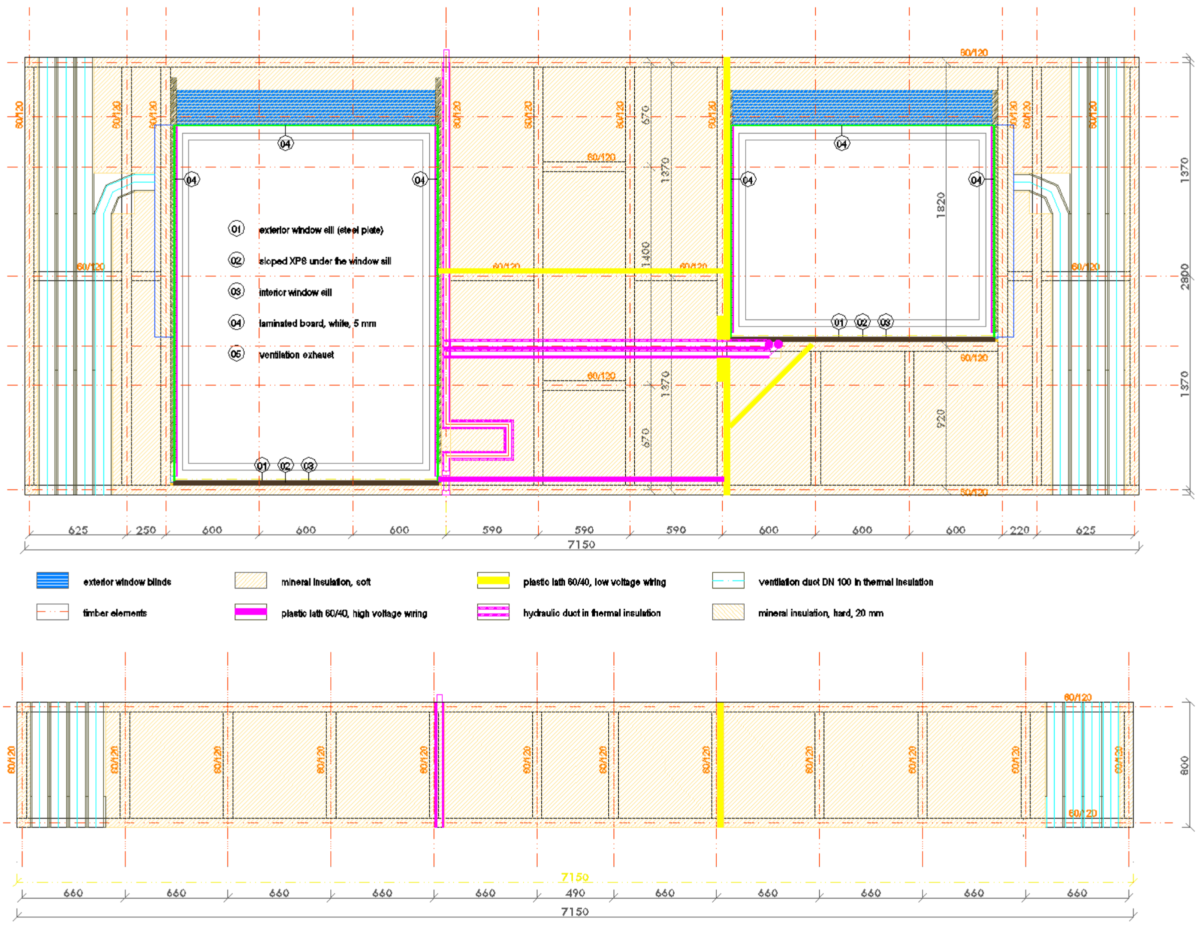


Fig. 2.6: A schematic drawing of set of the basic elements in the modules – the standard wall module in the top and the base module in the bottom.

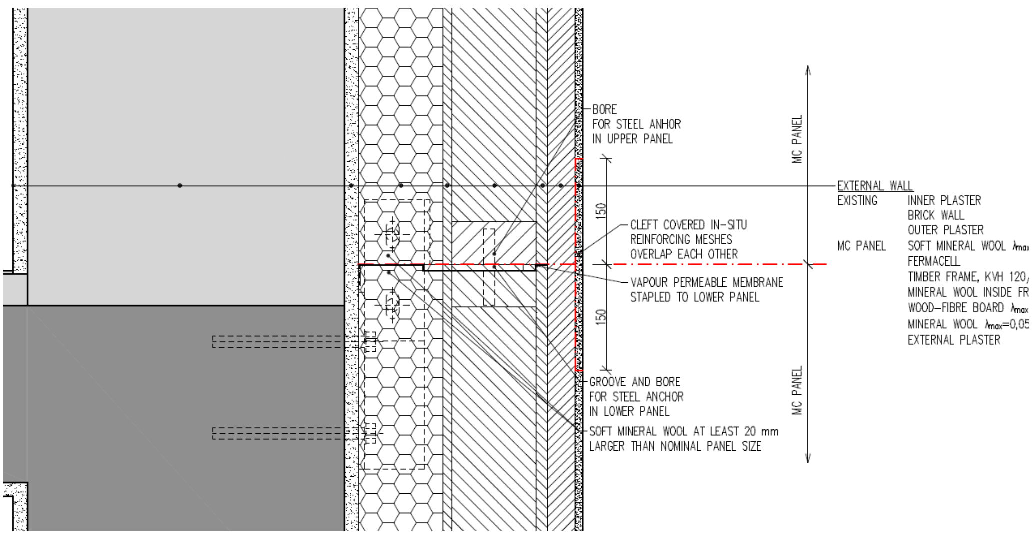


Fig. 2.7: Detailed drawing of horizontal inter-modular connection

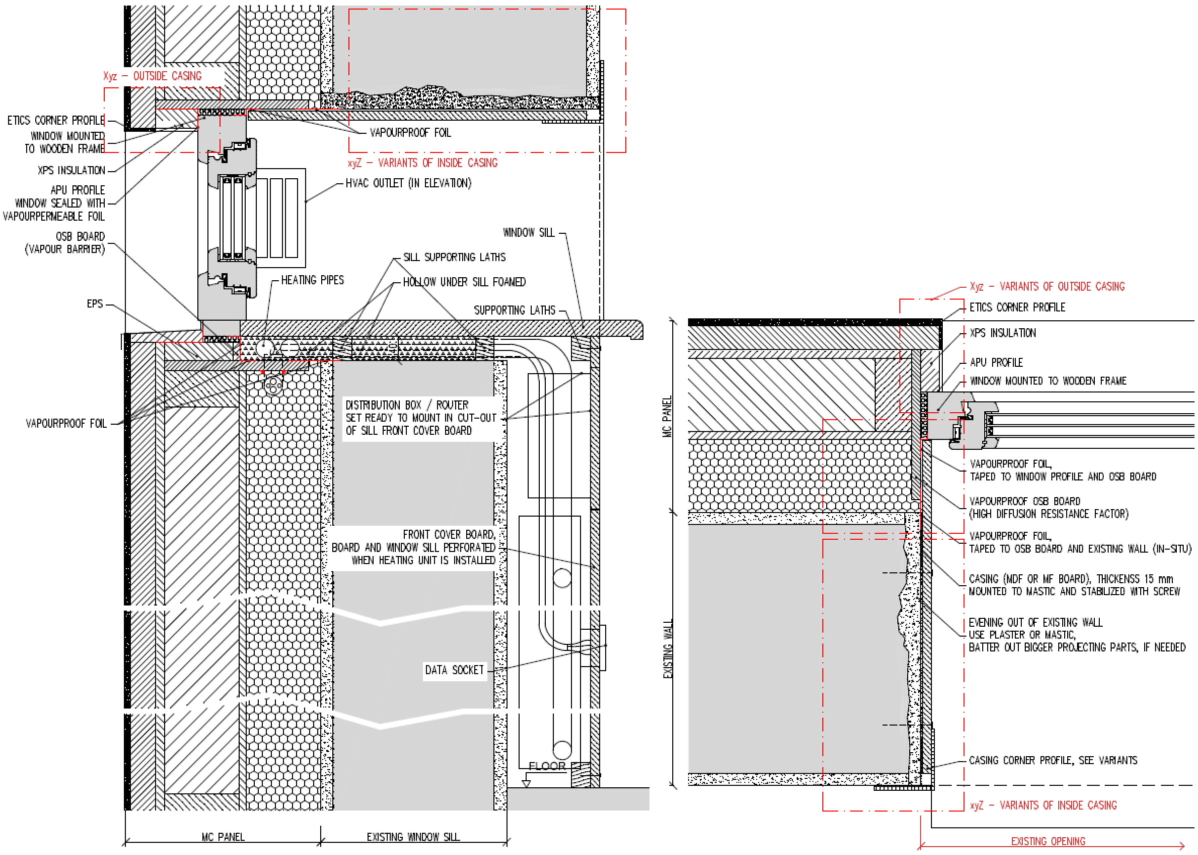


Fig. 2.8: A detailed cross-section (left) and floor plan (right) of the window siding. The alternatives of different casing and integrated elements were considered and designed.

2.2 Production

Fig. 2.9: Prepared modules (standard wall, gable and base modules) for the Czech RLLL in RDR factory before final production stage of integrated devices installation.

The report with the experience from the production of the elements and integrated parts will be provided after the production finishes (after December 2017).

2.3 Installation/implementation

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

- From the test installation of modules in the testing hall (finished)
- Installation of the modules on a mock-up building. The modules are in production by the time of writing this deliverable. Installation of the modules on the mock-up building will take place after the submission of this report and the experience will be described in future updates or annexes after the works are finished and evaluated.

Technology of installation of the modules (full scale experiment in resting 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).

Fig. 2.10: The lower panel fixed to the stands by typical anchors.

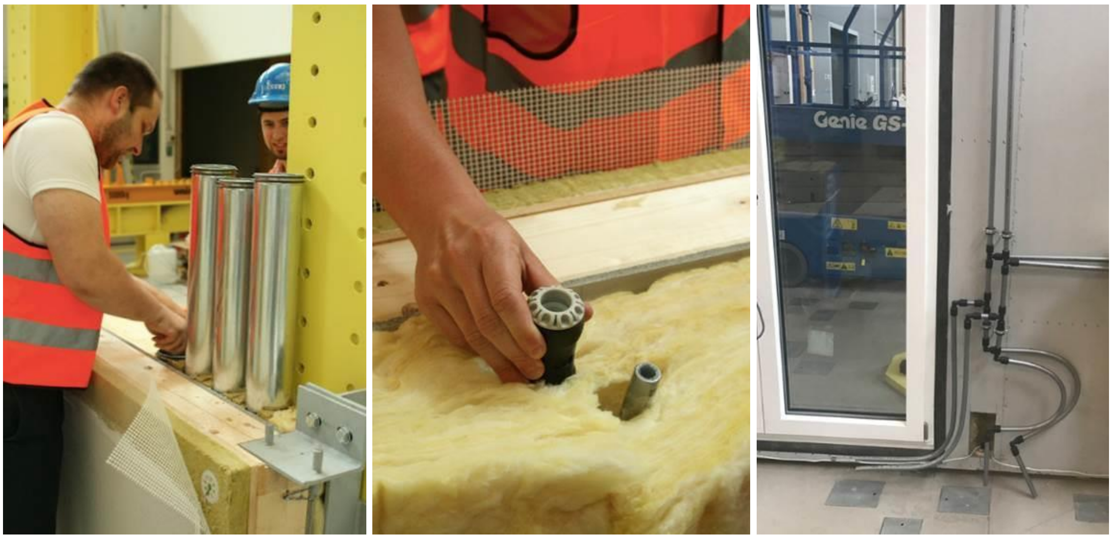


Fig. 2.11: Preparing of the HVAC tubes' connectors in proper positions (first variant of setting, left) and preparation of click-on connectors onto the pipes of heat distribution system (middle). The moving of the pipes to enable connection is made by bends on the pipes (right).

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.

Fig. 2.12: Standard wall module hung on crane. Note the tilt caused by uneven mass distribution relative to location of hanger belts.

Fig. 2.13: Lowering the module and alignment of the HVAC tubes.

Fig. 2.14: Connecting the HVAC tubes with inserted elements. 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.

Fig. 2.15: Installation of cables. 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.

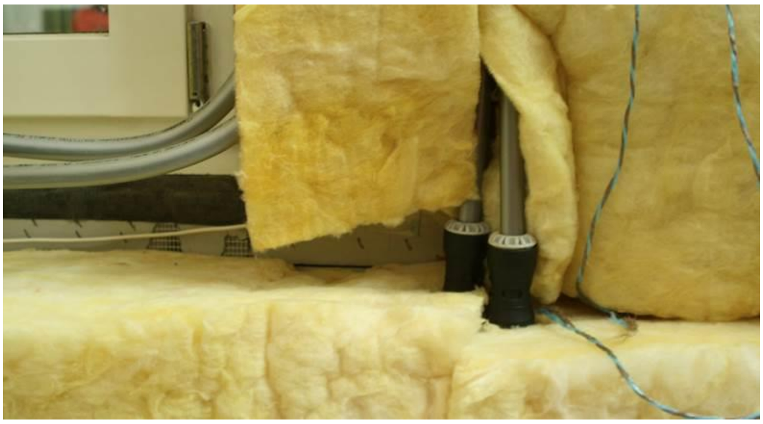


Fig. 2.16: Connected heat distribution system pipes. Note the gaps and bent thermal insulation. In real case, this side would be facing the existing wall, so there will be no easy way to unbent it easily (there is access from the window, but the gap is 12 cm wide, so it would be challenging and at least time consuming to make the smoothing). So perhaps there will be need to be some cuts in the thermal insulation or used specially shaped pieces of harder thermal insulation. Another (recommended option) is to simplify the whole system and design the thermal insulation thickness in a way that water-based heat distribution system can be abandoned and heating provided just by the warm air.

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.

Fig. 2.17: The module in its final position.

Fig. 2.18: Fixing the anchor: provisional fixation (left); screwing to the two parts of anchor together (middle); fixed anchor (right).

Lessons learned:

- 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.

3 Denmark

In Denmark the products of the two Danish industry partners of MORE-CONNECT - Invela and Innogie – are 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, On figure 3.1 is an illustration of the façade of this building after renovation with new windows and façade cladding.

Fig. 3.1: Architectural sketch of the façade after renovation

For each of the phases the work of both Invela and Innogie is presented below. The two MORE-CONNECT products are different from the other prefab solutions developed in the MORE-CONNECT project. Therefore the presentation of the development work, design and implementation lessons learned are structured a bit different from the others.

3.1 Invela

3.1.1 The robot concept – lessons learned and improvements

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 25% better insulating material (compared to Rockwool) called Fixit 222, it 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 see 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 small 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.

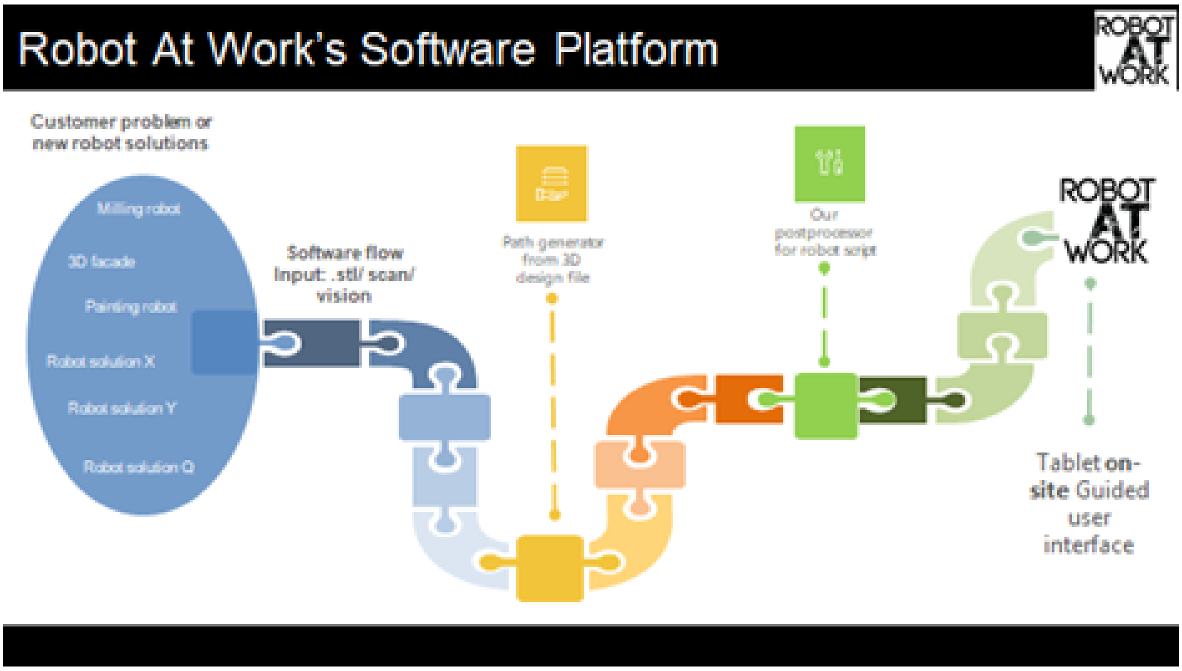


Fig. 3.2 Robot at works workflow diagram.

3.1.2 Design

Invela are at the moment working on the programming of the specific design for the 3D design of the first gable-wall on Korsløkken 34.6. We are making the work packages and testing the output through our 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 3D printed in concrete on the vertical gable walls onsite by the robot.

3.1.3 On site implementation and testing

The actual testing of the robot work has 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 cannot be done when the weather is too cold and humid. Therefore, only the first part of the actual implementation has been carried out – the insulation of the first gable wall as illustrated on figure 3.4. The insulation of the second gable wall and the actual implementation of the robot onsite painting of the decoration design wasl therefore carried out in the autumn of 2018.

Fig. 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. We 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.

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

This process was programmed in 20minutes 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. e proved that our technology could be programmed directly via an already known and well used programme Fusion360, and that the robot hardware could execute on-site in very large scale only by the push of a button on a smartphone. The scalability is shown in the last picture where the robot with the size of 120m2 is packed for transport in a van, and the small size is very visible.

Fig. 3.6 The insulated gable wall (25 cm rockwool) made with concrete finishing and robot-made decoration painting performed in the autumn of 2018.

3.2 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.

3.2.1 Design

The PV-solar roof from Innogie will also be implemented on the Korsløkken 34.6 building in Odense. The building is very long and to completely cover one side of the roof would result in an over-production of electricity that in the current situation for PV on dwellings in Denmark would not make sense as overproduction would have to be unpaid to the grid. The chosen area is app. 400 m² - and its location is illustrated on figure 3.7

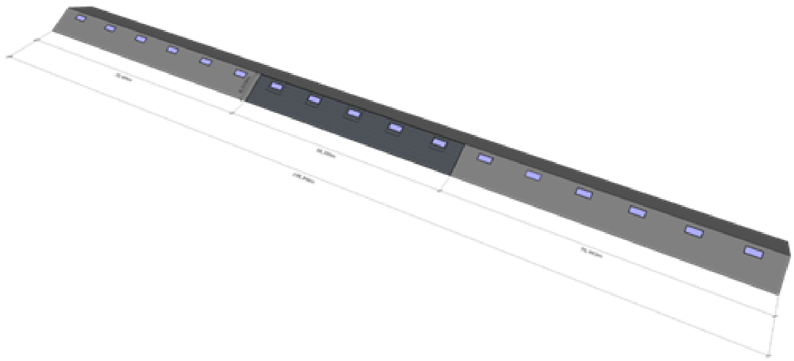


Fig. 3.7: Design drawing showing the placement of the PV-roof on the roof of Korsløkken 34.6

The design details of this implementation is shown on figures 3.8 and 3.9 below.

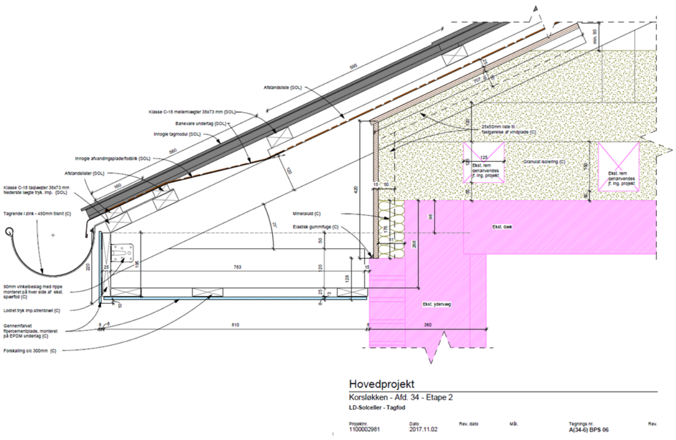


Fig 3.8: Detail showing mounting of the PV roof at the lowest part of the roof.

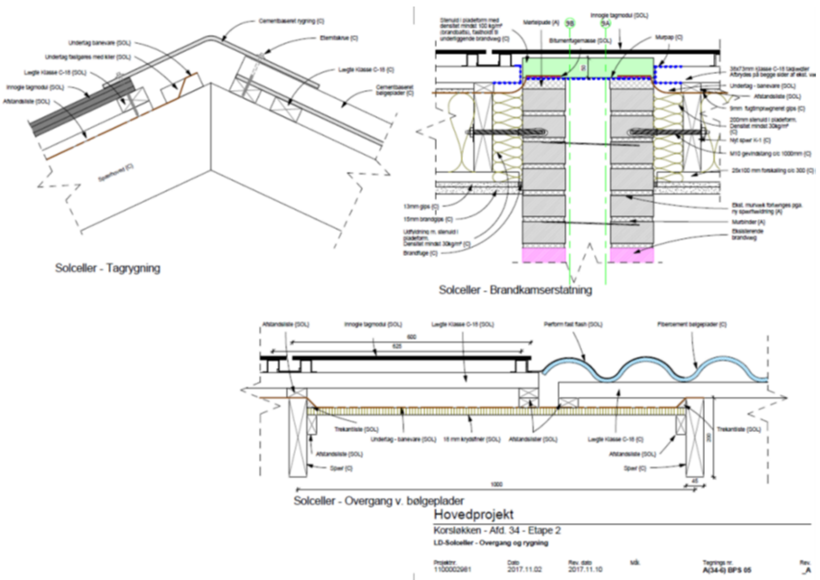


Fig 3.9: Details showing mounting of the PV roof at the highest part of the roof and the connection to the cement wave tiles.

3.2.2 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.

Fig. 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.

3.2.3 Implementation on pilot project

Innogie began the actual installation of the PV solar roof on the pilot project in October 2017 and by the end of November 2017 the installation was 80% complete.

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(!)

Fig.3.12: Preparing the roof for installation

Fig.3.13: The Innogie PV solar roof mounted - 80% finished on the Danish pilot building.

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 the loft. This way they can be easily reached if necessary. Figure 3.14 shows the penetration of the cable through ventilation covers to the inside of the loft where inverters are placed.

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

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

4 Estonia

4.1 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 and with help of sustainable and hygrothermal design of all parts of building, its envelope, technical equipment, openings etc.

Fig. 4.1 Overview of the Estonian pilot building before renovation (above) and architectural initial design (below)

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

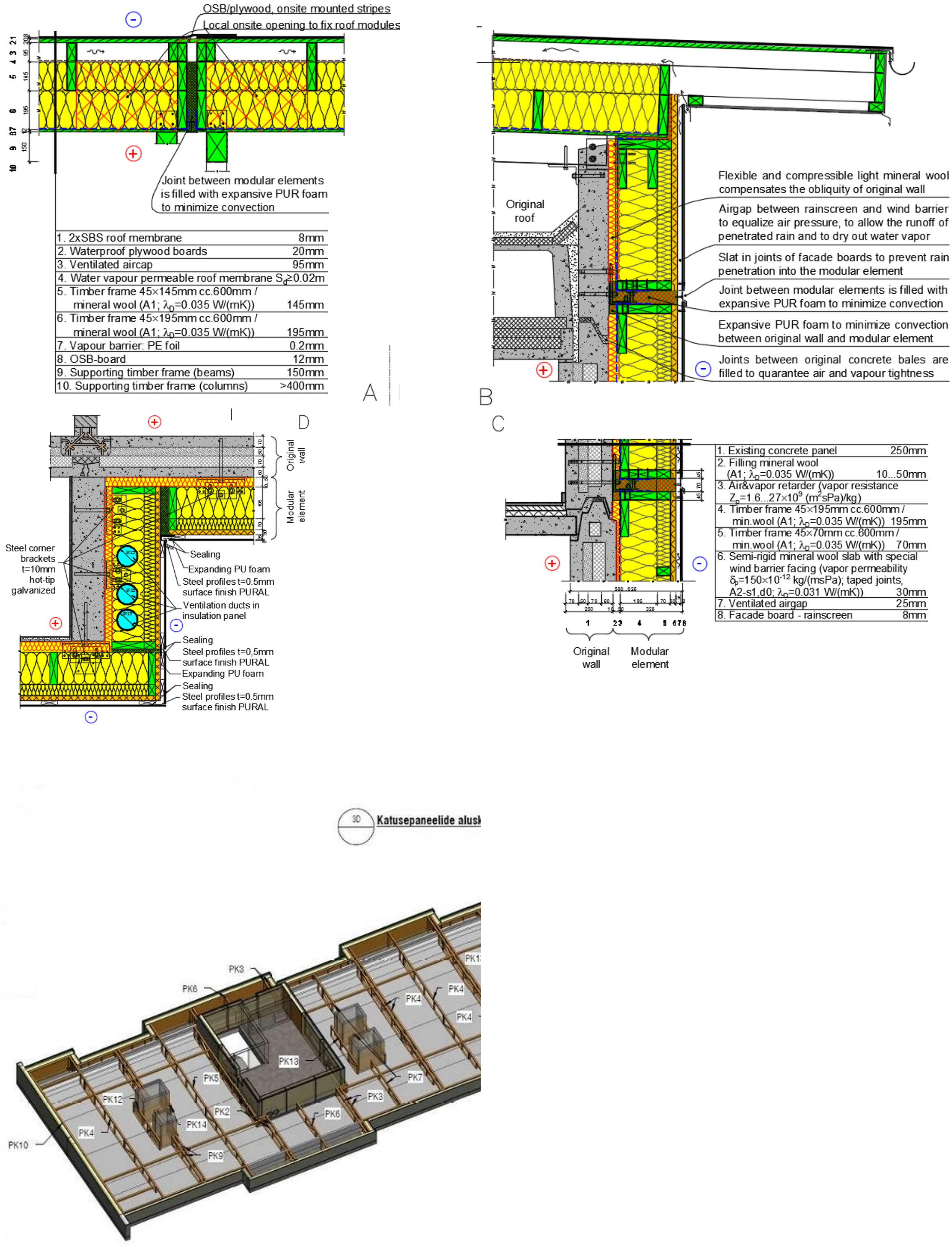


Fig. 4.2 Designed solutions at the different structural points of Estonian pilot building wall modules (above and centre) and roof loadbearing structure (below)

4.2 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.

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 measures. 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.

Fig. 4.3 Production of modular elements at the factory of Matek (spring 2017)

4.3 Installation

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:

- Mounting of metal brackets on the concrete wall.

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.

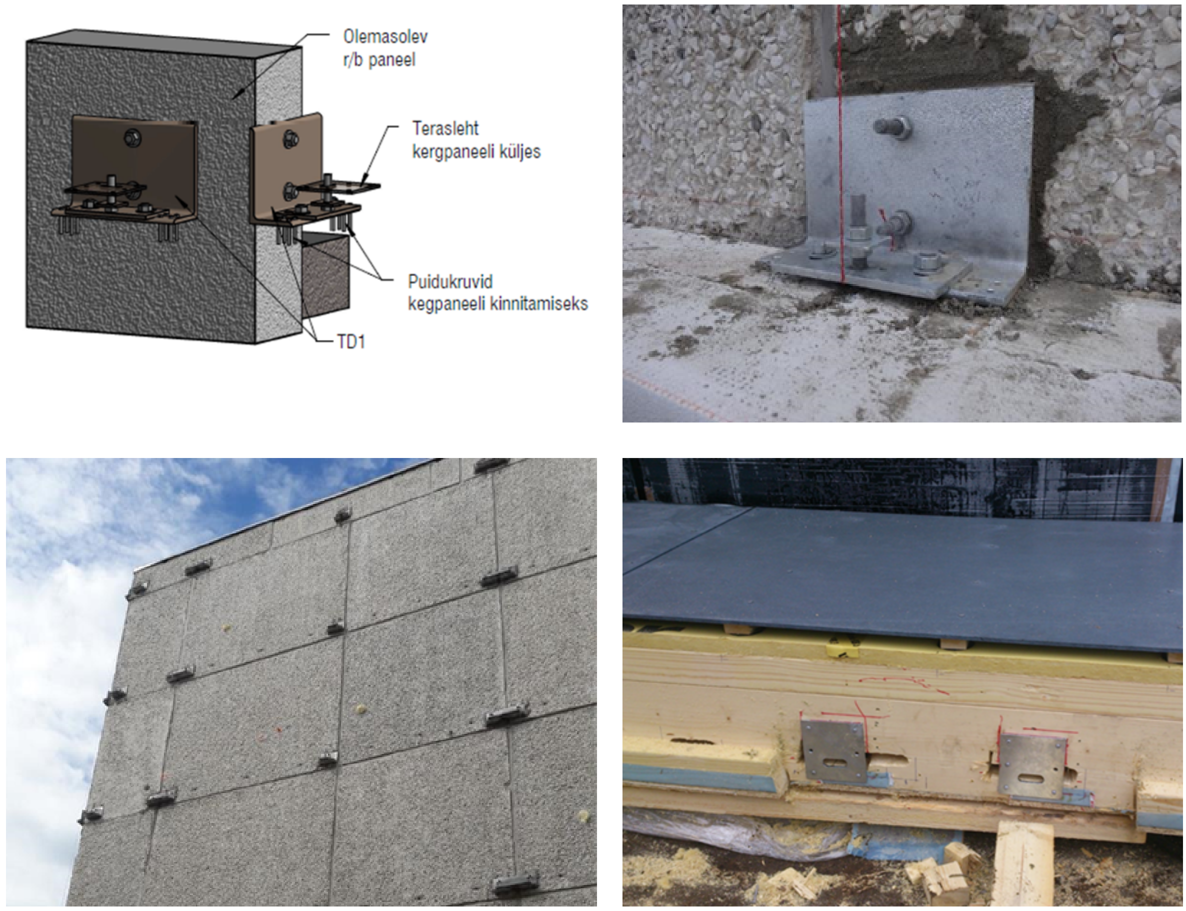


Fig. 4.4 Steel brackets, 3D adjustable, for wall modular elements: designed solution (above left); brackets installed onto the wall (above right and below left); brackets support adjustment on the element before mounting at the pilot building site (below right)

- Mounting of wall and roof modular elements

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.

Fig. 4.5 Mounting of wall (above and centre) and roof (below) modular elements at the building site (May-June 2017)

- Sealing of the joints between elements and finishing of external cladding

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.

Fig. 4.6 Designed solution (above) and sealing of joints (centre and below) at the pilot building site (June 2017)

Fig. 4.7 Building process at the pilot building site (spring-autumn 2017)

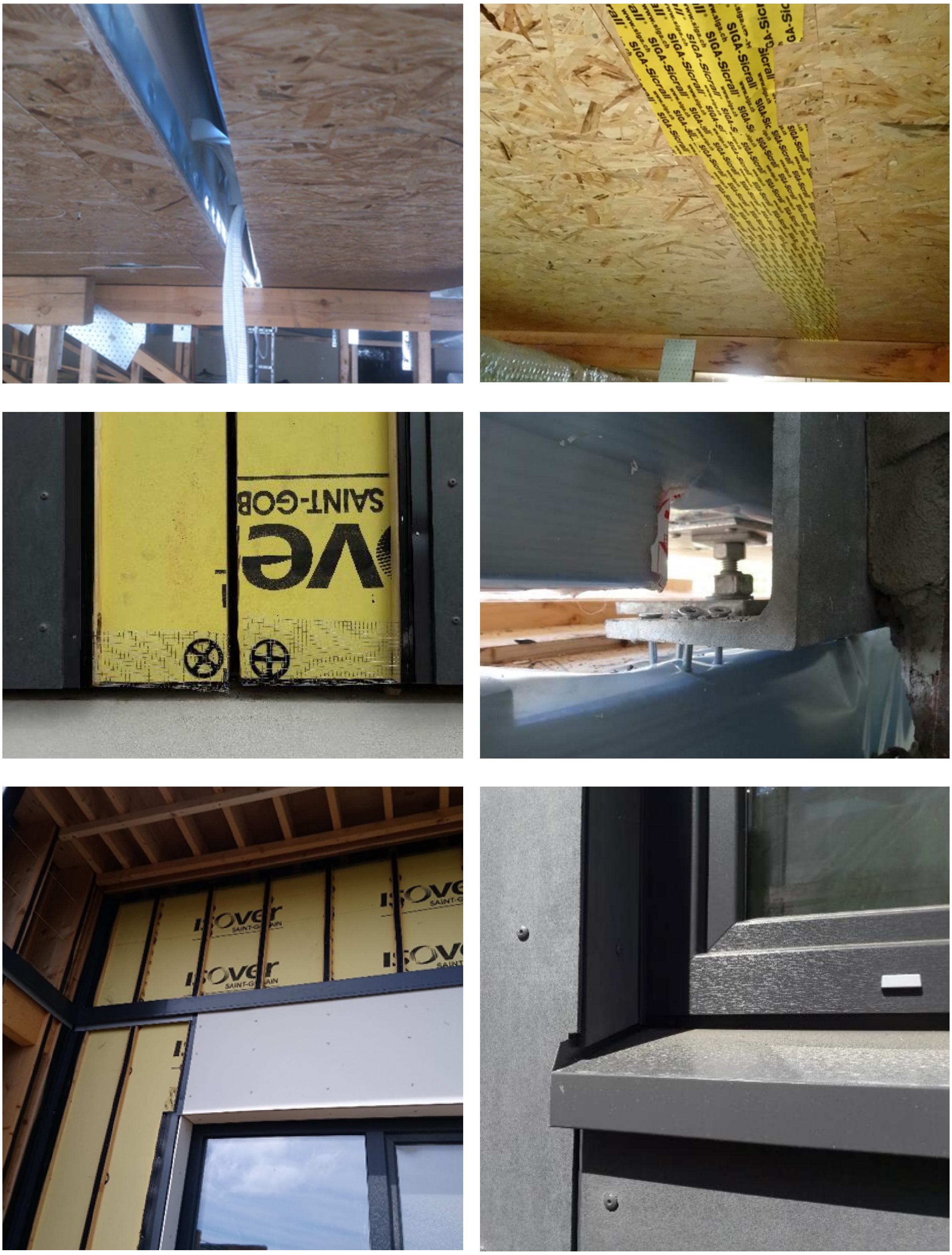


Fig. 4.8 Some examples of challenging points at the pilot building site (spring-autumn 2017)

Fig. 4.9 Estonian pilot building after renovation (autumn 2017)

5 Latvia

5.1 Design

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.

Fig. 5. 1 Latvian pilot building after renovation

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. Ceiling thermal insulation layer partly damaged by water leakage.
Architectural project was developed by RTU spin-off company PLACIS LTD in January 2017.

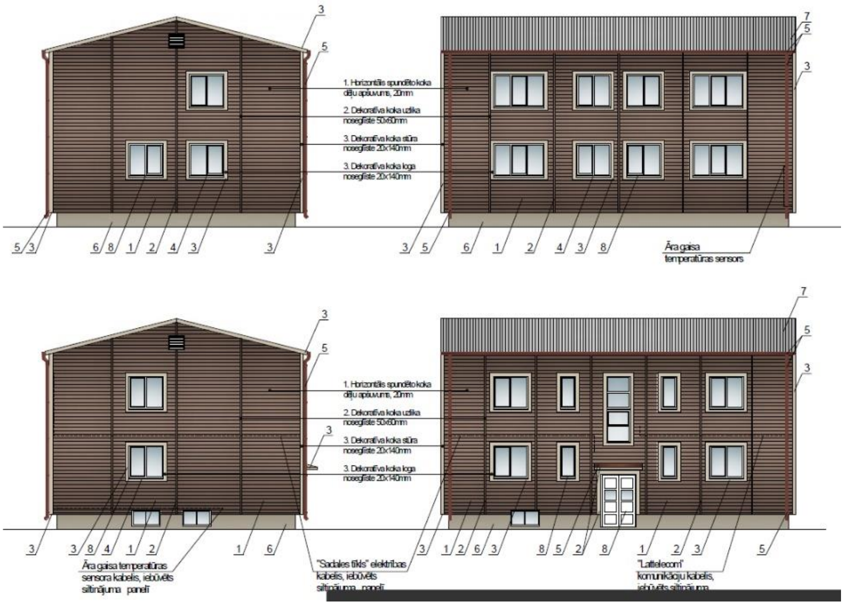


Fig. 5.2 Façade layout

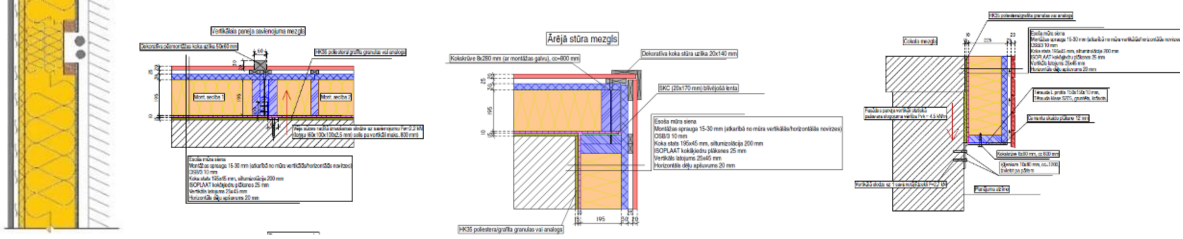


Fig. 5.3 Initial design for panels connection

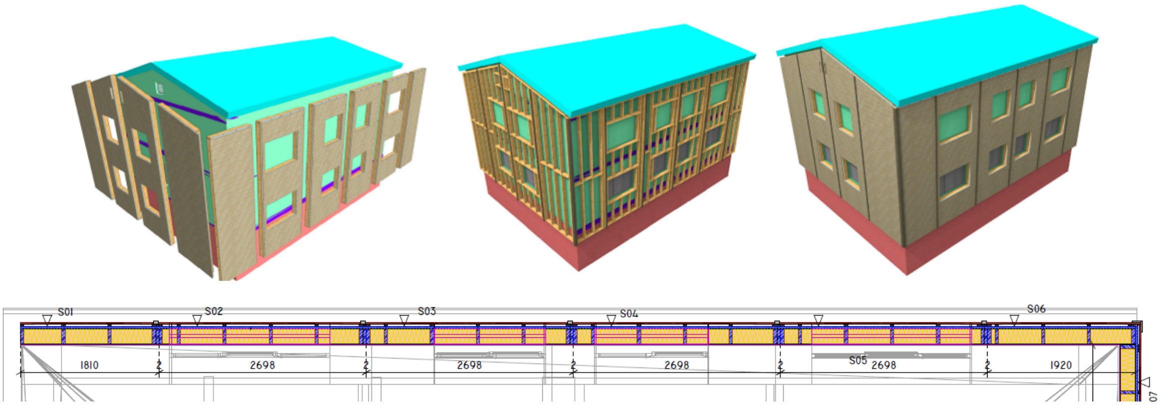


Fig. 5.4 Panel layout

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

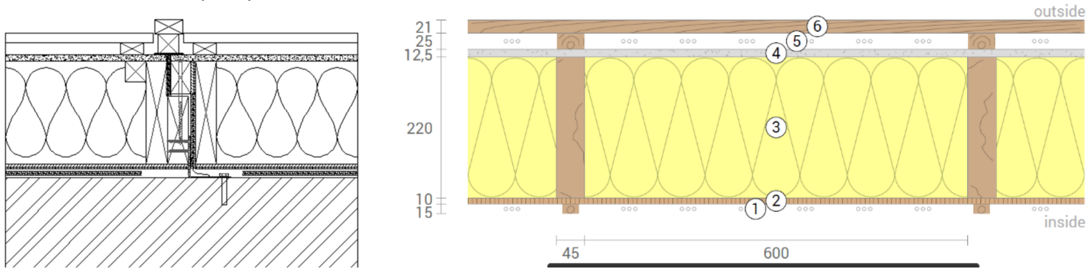


Fig. 5.5 Modified panel solution, proposed by construction company

5.2 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.

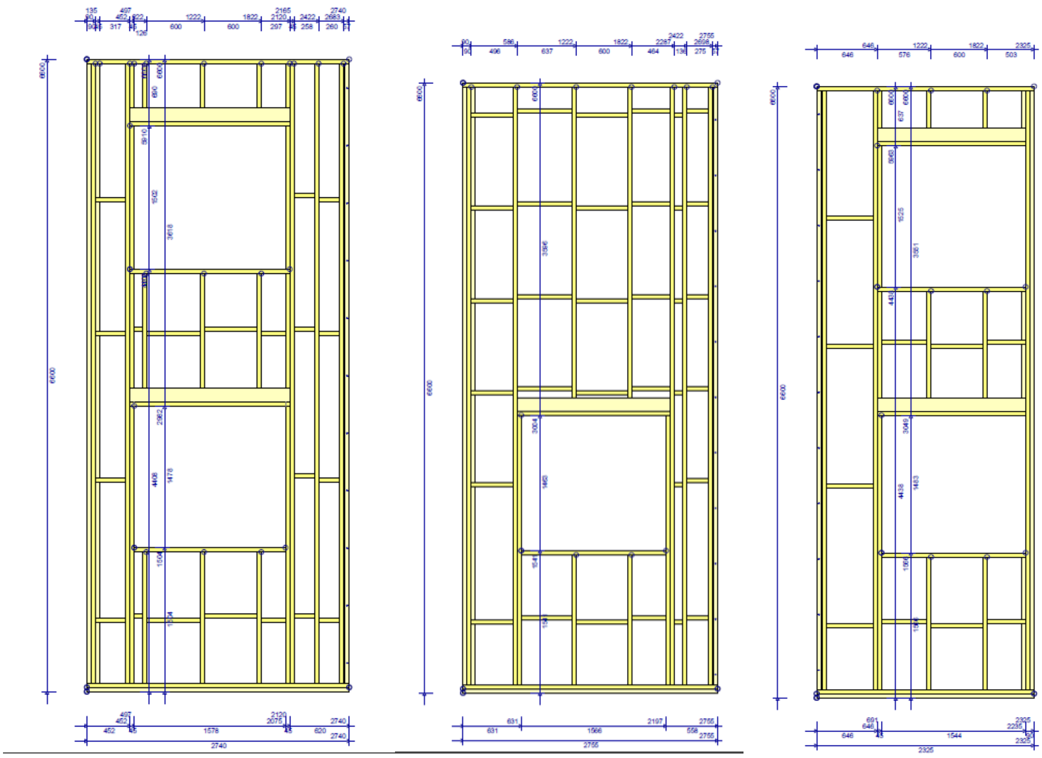


Fig. 5.6 Final layout of refabricated modular panels

Fig. 5.7 Front façades view

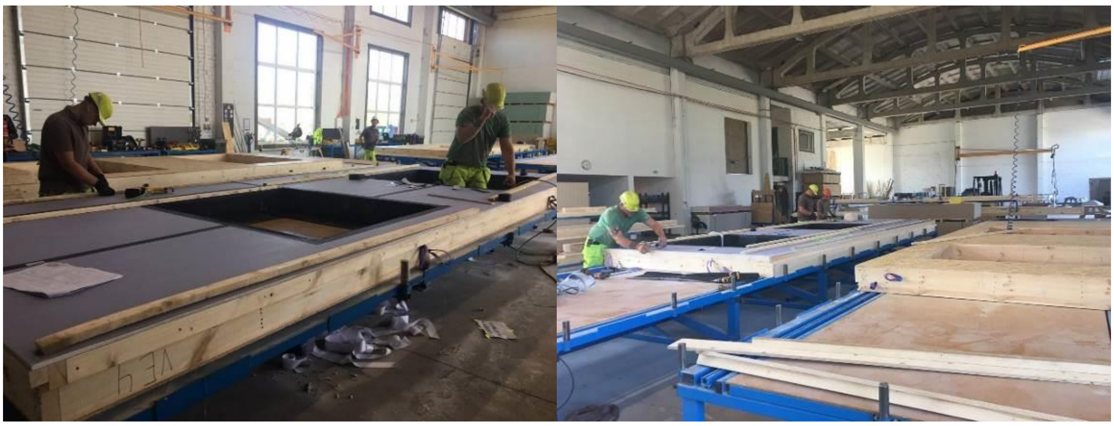


Fig. 5.8 Real production process

5.3 Mounting of wall and roof modular elements

Mounting was started in July 2017. Panel mounting took 5 days including some delay in oversized panel replacement. Other construction works took 9 days.

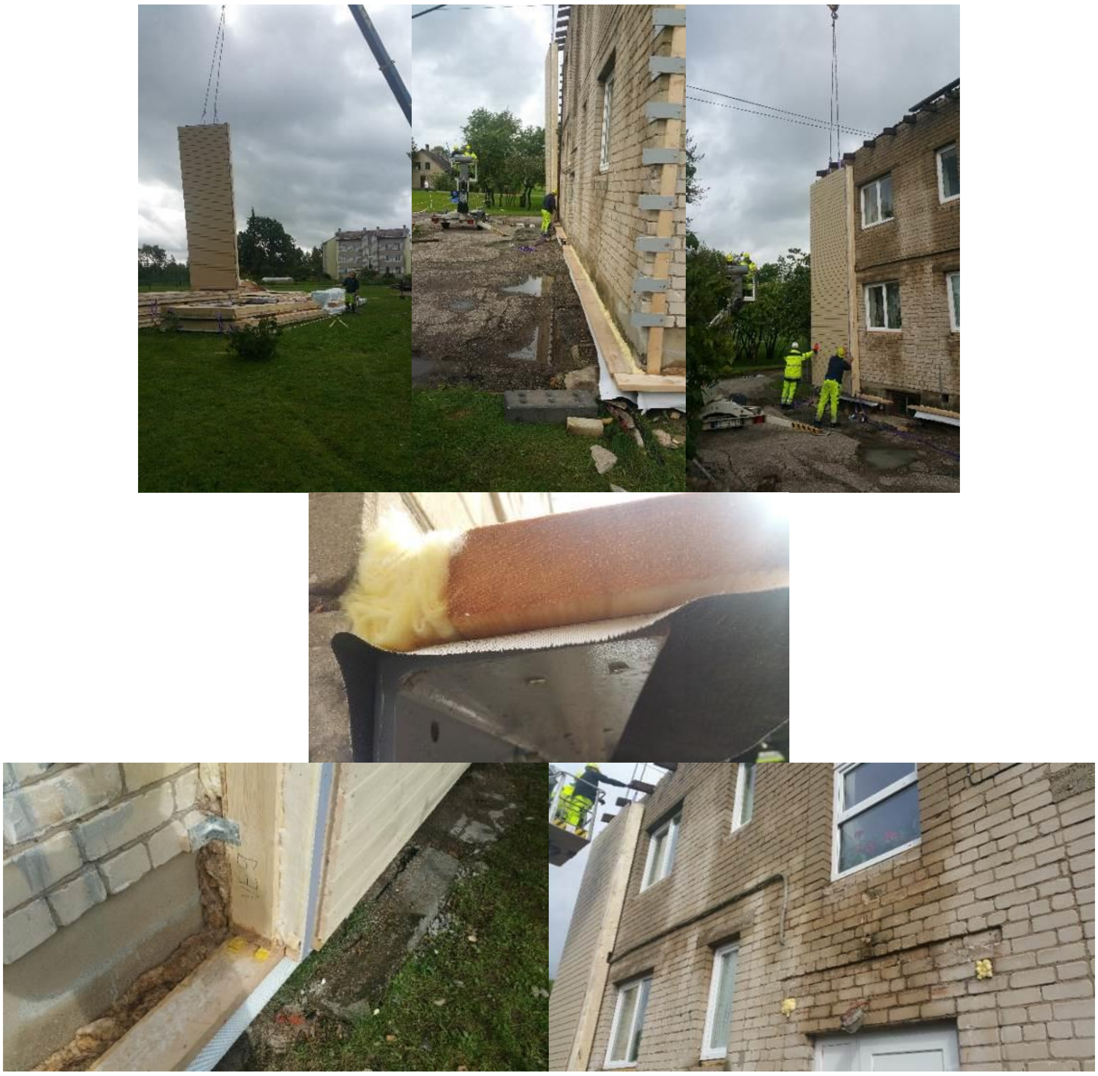


Fig. 5.9 Final process

6 The Netherlands

In the Netherlands the experiences and lessons learned have been gathered for the pilot project Presikhaaf:

Fig. 6.1 The Presikhaaf project

6.1 Design

For this project this paragraph deals with design, pre-production and also with acquisition. For the latter point Webo presented the façade solution itself to the client: that was decisive and the client prescribed WEBO as preferred supplier.

Few competitors taking into account: high insulation, airtightness, certified industrial production, integrated ducts, finishing included, geometrics (laser scanning, pointcloud), 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.

Fig 6.2 The Presikhaaf design process and outcome

First 3 apartment buildings (out of 4) subcontracting; for the final apartment building the project organization form was changed to a side-by-side contract while the client was not satisfied with the performance of the contractor; project did not benefit from the modular deep-renovation approach offered by WEBO:

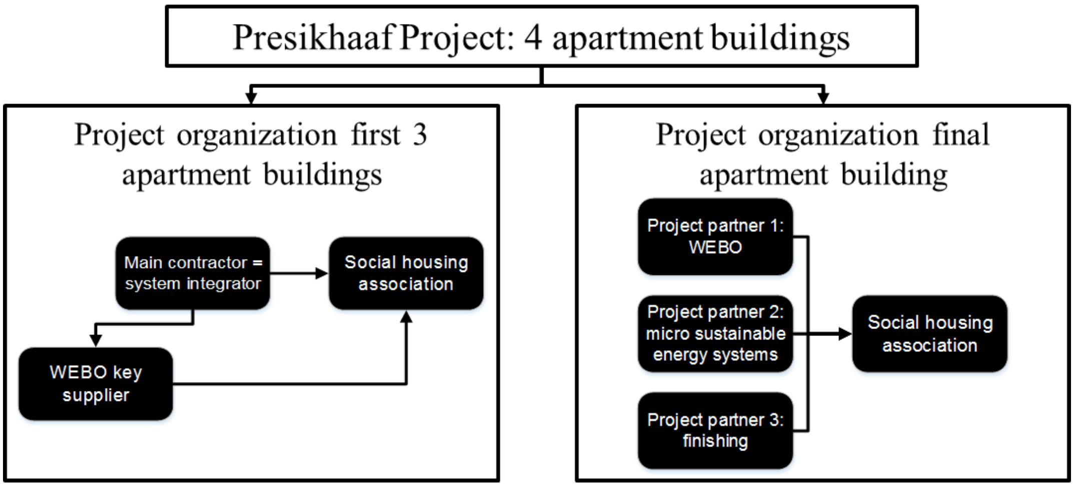
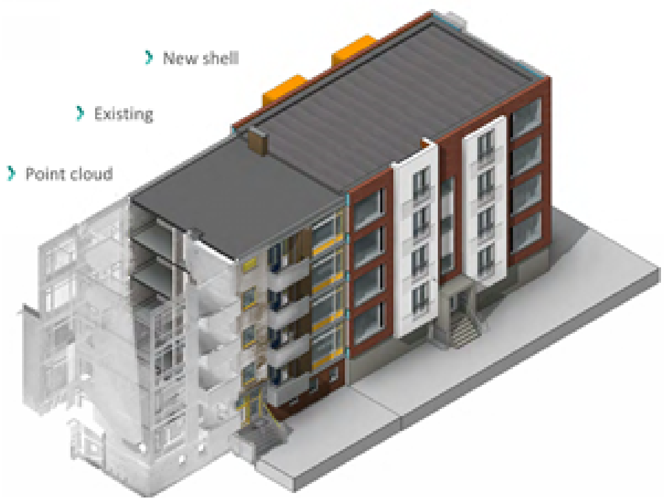
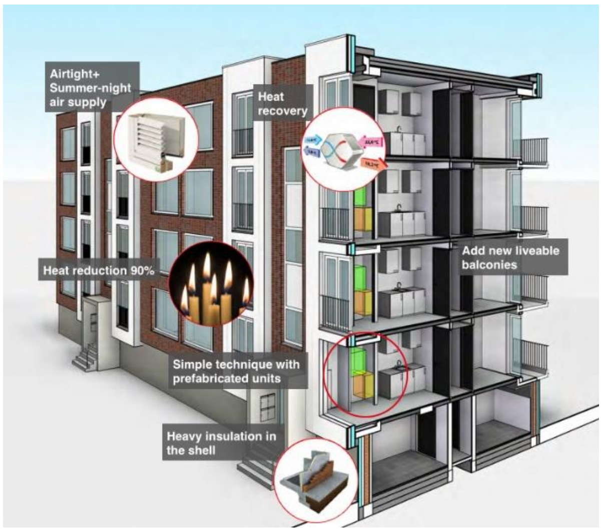


Fig. 6.3 The change in project organisation after the first apartment buildings had been completed.

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 continue 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
Design and engineering: lower project risks – i.e. lower failure costs - due to accurate data acquired by laser scanning of the existing property.
Pointcloud is manually turned into building design which is problematic while it is time consuming and error-prone. This is not yet solved.

Fig. 6.4 Cloud representation in the BIM system (left) and final design (right)

Initial (architectural) design adjusted according predetermined design rules related to the modular façade system. In the Presikhaaf project building extension like balconies were removed.
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 is responsible for the quality of the (integrated) design of the façade. Within tradition construction projects several stakeholders share the responsibility of design like precast penal floor systems.
For the architecture and integral design process the morphological design approach was followed as developed in D3.6.

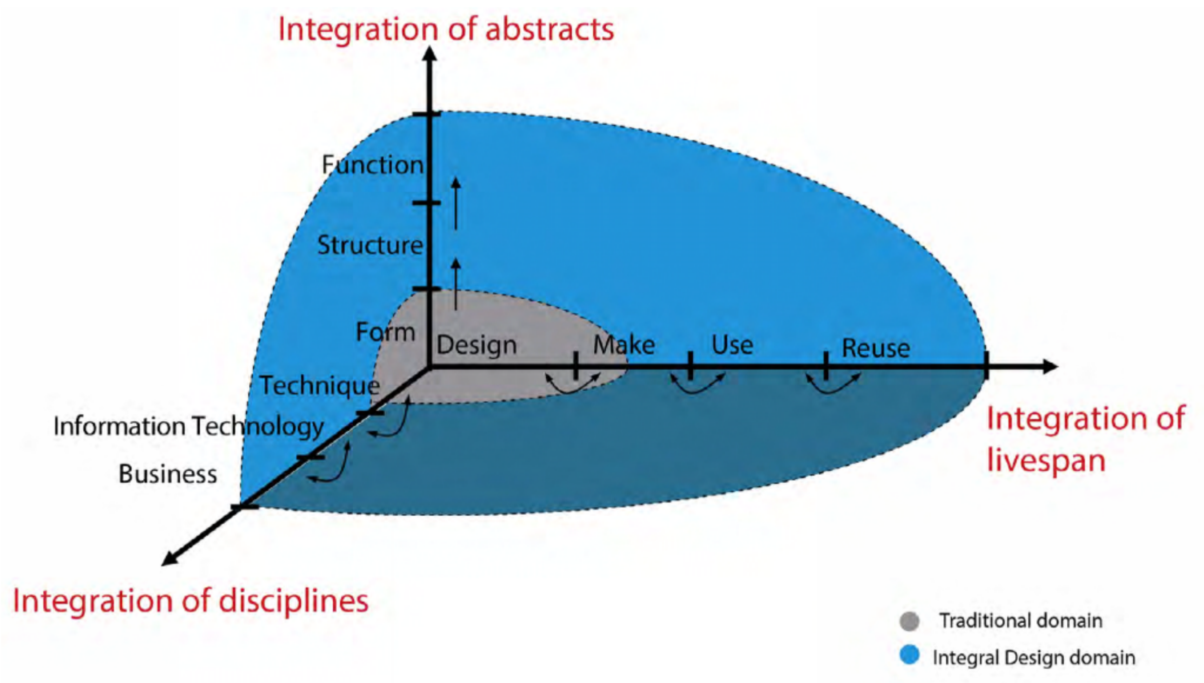


Fig 6.5 Scheme of the integrated design approach used in Presikhaaf

The following three steps can be distinguished in every approach:

- Conceptualization
- Opinion forming
- Decision making

These steps are not always taken sequentially, but can be employed iteratively as the requirements change.

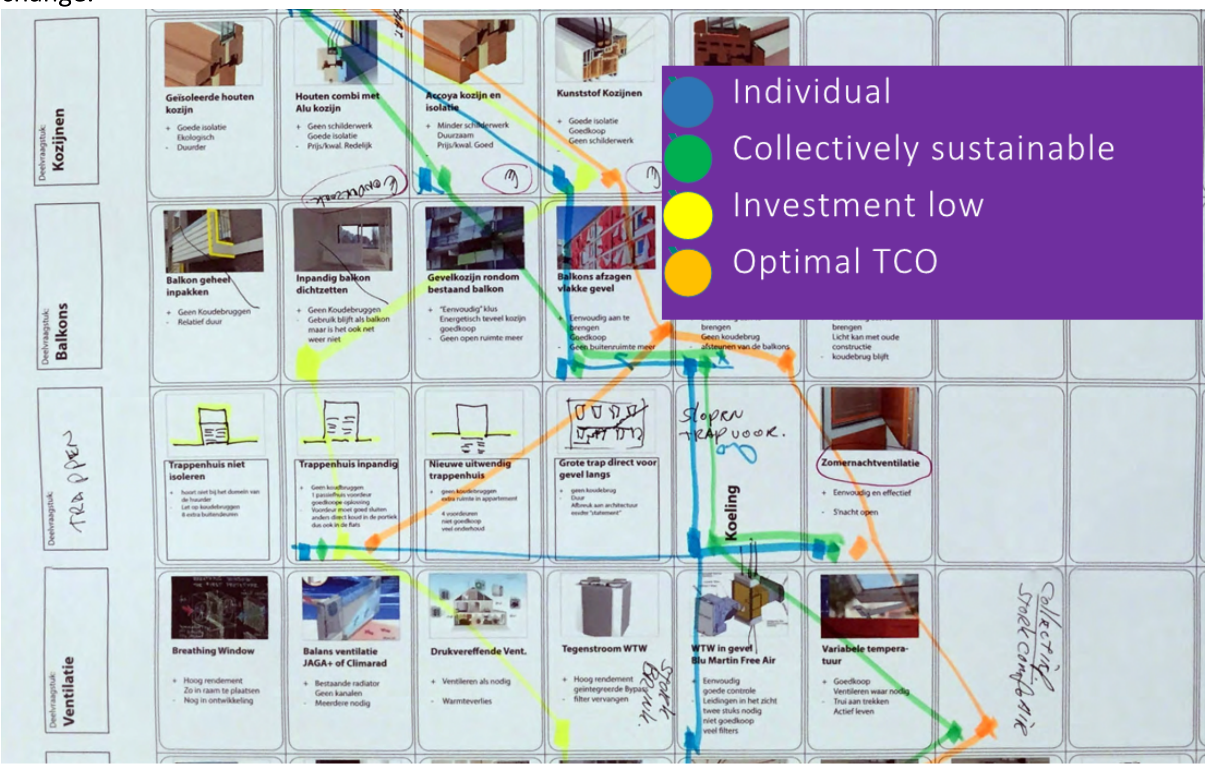


Fig 6.6 Scheme of the morphological design process used in Presikhaaf

6.2 Production of elements

SIPs elements 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. This has some advantages with respect to:

- Guarantee on wind and waterproofing in the long term in case of mechanical damage
- Improvement fire protection
- Production efficiency (simplification)
- Improvement 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

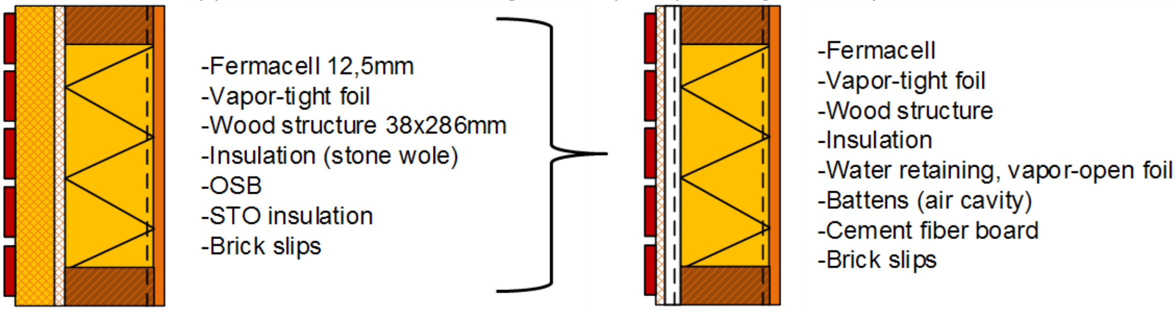


Fig. 6.7 Change of wall element based on the lessons learned at the Presikhaaf project.

6.3 Implementation/Installation

Experiences:

- No problems encountered during transport and installation of the facade elements: plug-and-play connectors, no scaffolding required
- Installation on-site by ‘dedicated teams’
- 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 to reduce costs.
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Fig. 6.8 Installation of pre-fabricated wall elements at the Presikhaaf project.



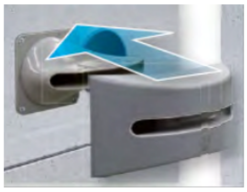
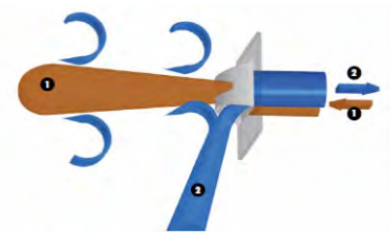




Fig 6.9 Fast installation of the prefab elements by the Click and Span system

Fig 6.10 Renovation of the building services

6.4 Next generation

Innovation constitutes the next generation of modular deep renovation approaches. See the table bellows for the differences between the first generation and the second generation.

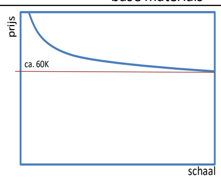
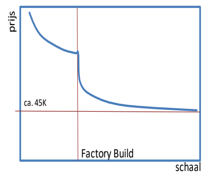
Characteristics	Generation 1; 2018	Generation2; 2022
reference	**H2020 2014 -2018**	**H2020 2018 -2022**
Quality level	wide variance in quality of models	minmal standards defined and applied
Depth of use	wide variance, still growing	deep use and integration with all building aspects
Design	integral approaches,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

Fig. 6.11 Comparison of 1st and 2nd generation of pre-fabricated façade elements.

7 Portugal

7.1 Design

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-bedroom apartment and a three-bedroom apartment per floor). In total, eighteen apartments constitute the building, which has a gross heated floor area of 1265 m2 (
Fig. 7.1).

Fig. 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 its choice.

The general 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.

The module 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. 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 (Fig. 7.2).

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.

The modules will be vertical oriented (10 m height) and will use standard metal connectors to be assembled to the exterior wall (Fig. 7.3). 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.

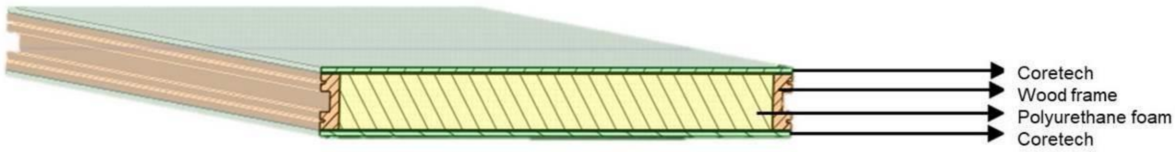


Fig. 7.2 - Illustration of prefabricated module

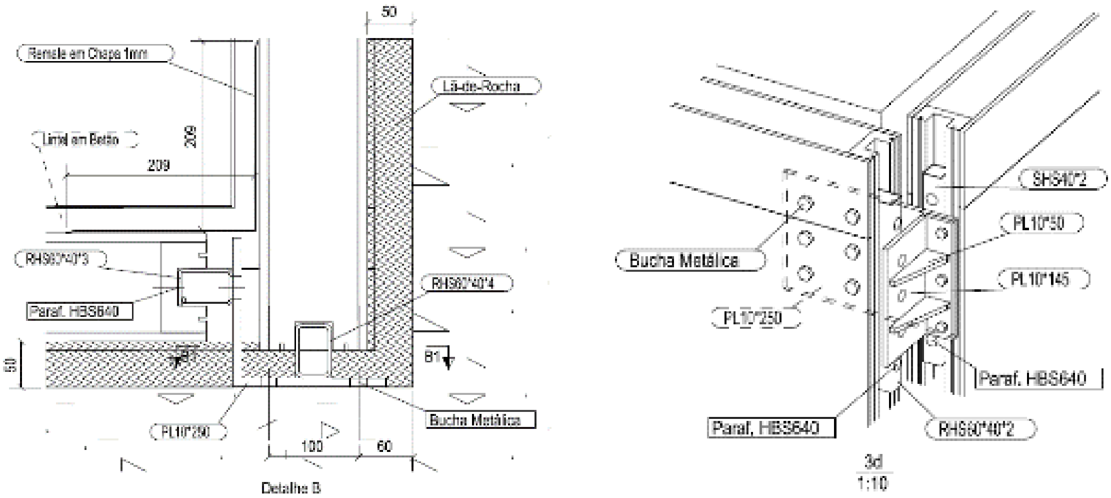


Fig. 7.3 - Examples of designed connections (between modules in interior and exterior corners)

7.2 Production of elements

In order to be tested in laboratory facilities, the prefabricated modules were produced with 2.55 m in height and 1.00 m width (
Fig. 7.4). 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.

Fig. 7.4 - Prototype production (Frame detail and assembly process)

7.3 Installation

Prefabricated modular elements installation are planned to be carried out according to

Table 7.1 and following planning defined in previous project phases (
Fig. 7.5)

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

Table 7.1 – Planned renovation process

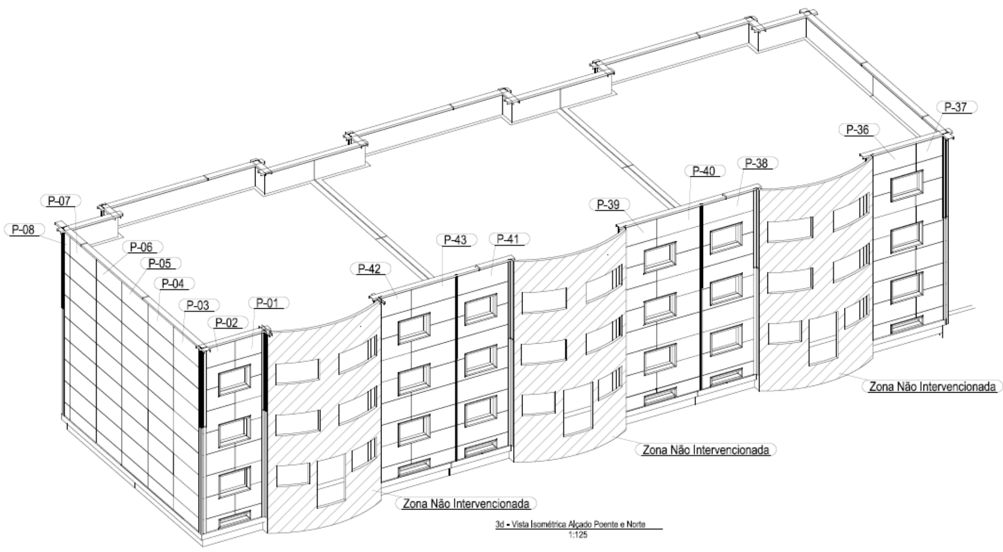


Fig. 7.5 - Planning of prefabricated façade module installations