Evaluation report of the quality of construction works

- feedback from the pilot projects

- Deliverable 5.6

of the

MOdular REtrofitting and CONNECTions (MORE-CONNECT) project

H2020-EE-2014-1-PPP (EE-01-2014)

This project has received funding from the European Union's H2020 framework programme for research and innovation under grant agreement no 633477.

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1 Introduction

The objective 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 testing and demonstration in practice will be 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 comprises 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 will be evaluated and analysed.

This will be 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 fourth year,

The Task leader is Cenergia at Kuben Management with contributions from other knowledge partners: Zuyd, RTU, TUT and industry partners: BJW and LW CC.

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.

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

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

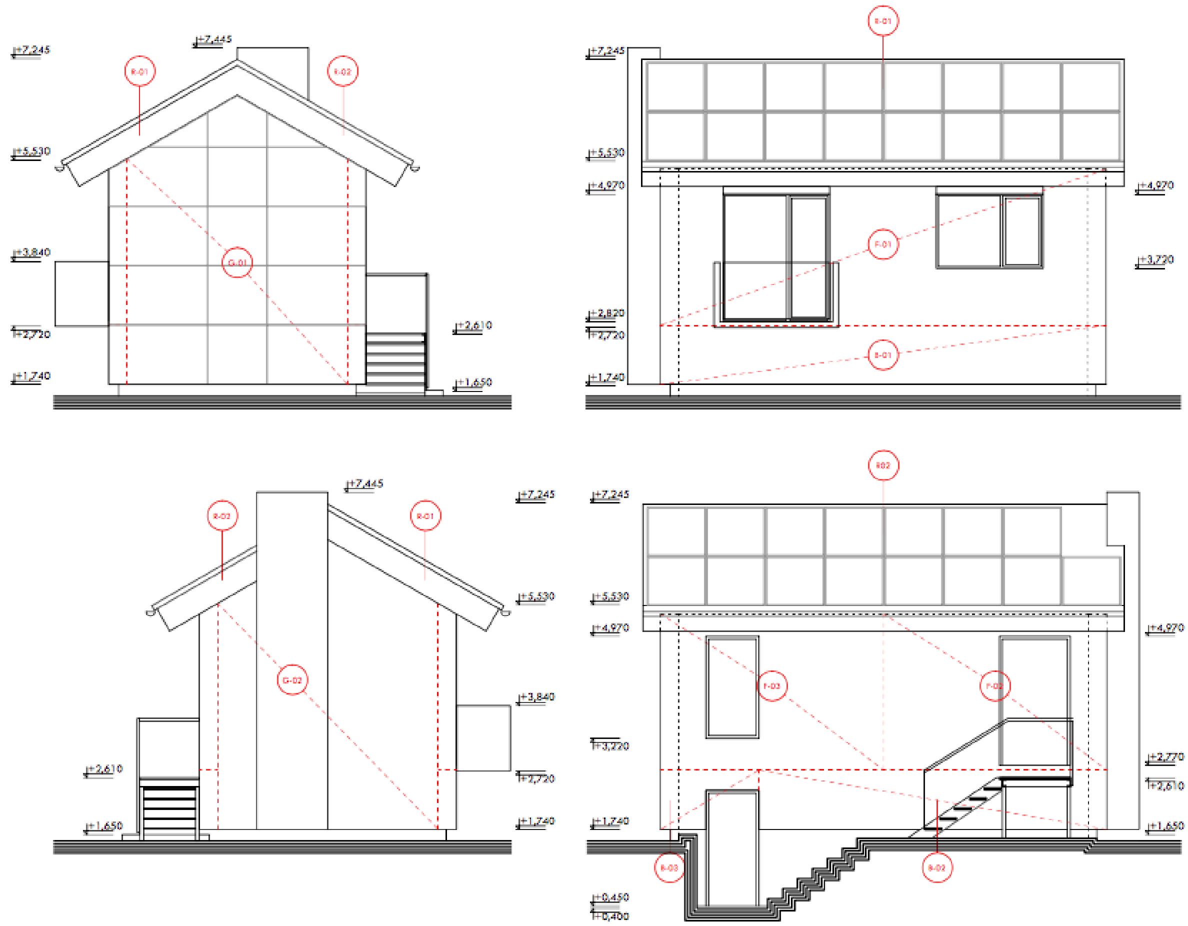


Figure 2.3: Elevations showing modules that will be included in the testing. In addition to that HVAC system will be mounted in the semi-underground floor.

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.

Figure 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).

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

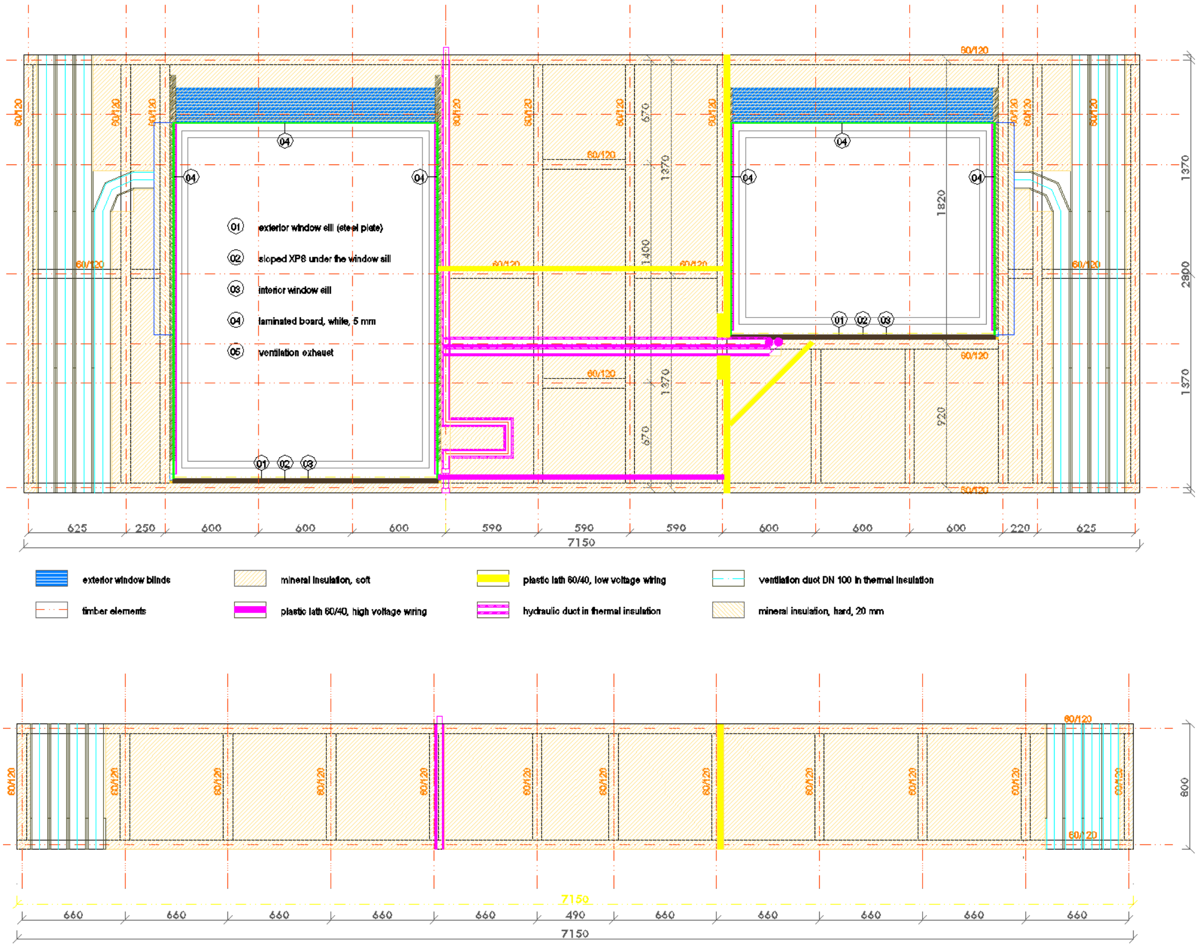


Figure 2.6: A schematic drawing of set of the basic elements in the modules – the standard wall module in the top and the base module in the bottom.

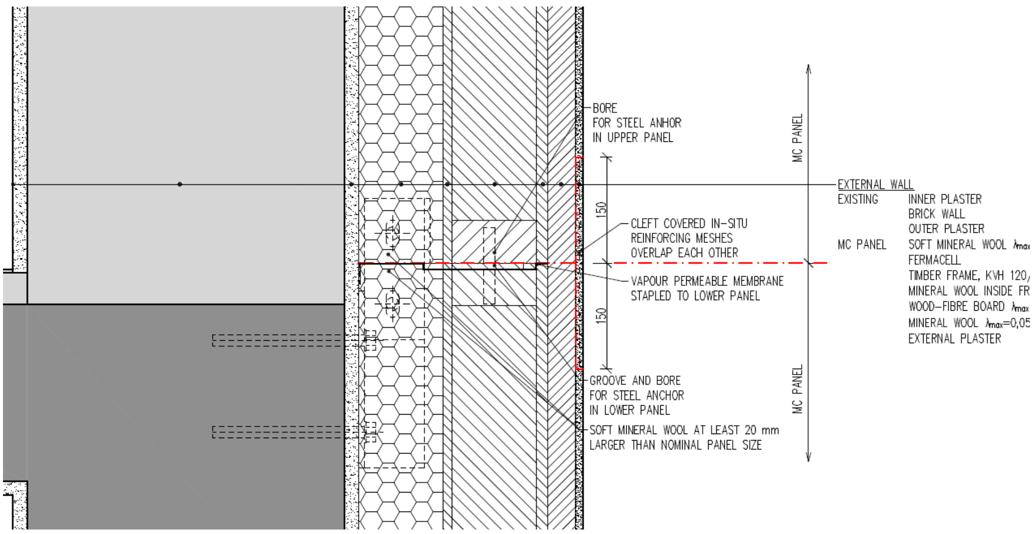


Figure 2.7: Detailed drawing of horizontal inter-modular connection

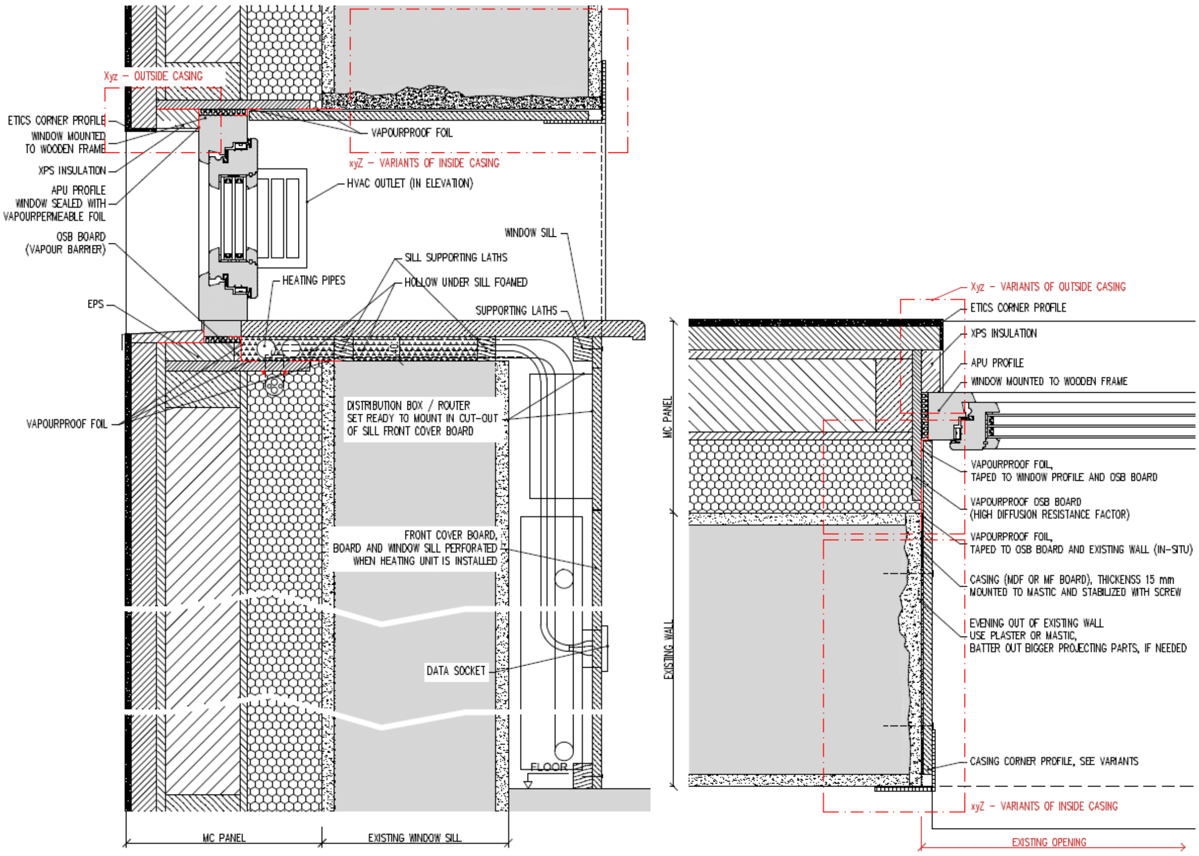


Figure 2.8: A detailed cross-section (left) and floor plan (right) of the window siding. The alternatives of different casing and integrated elements were considered and designed.

2.2 Production

Figure 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 v ersion 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 bellow).

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

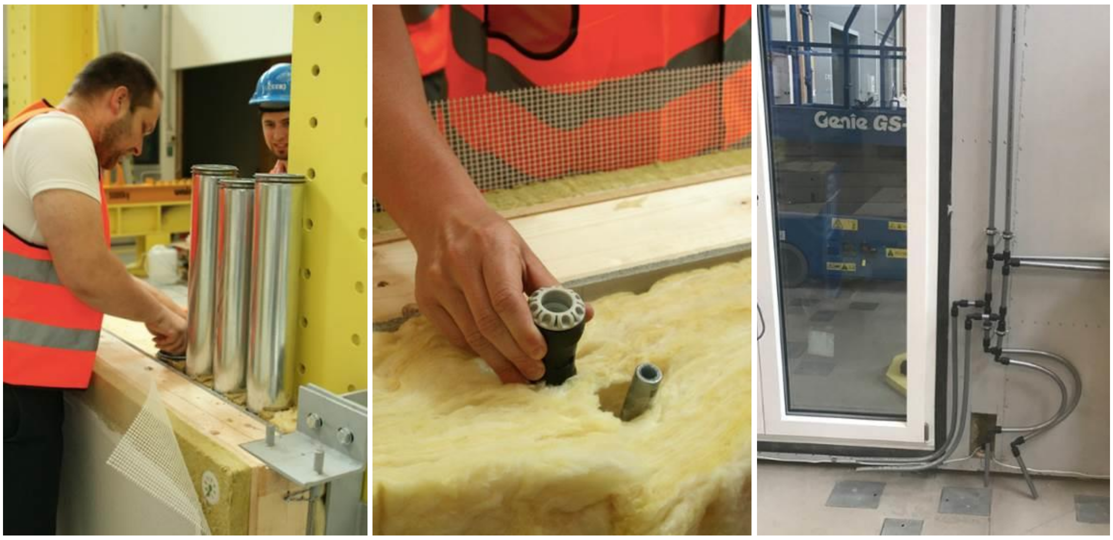


Figure 2.11: Preparing of the HVAC tubes' connectors in proper positions (first variant of setting, left) and preparation of click-on connectors onto the pipes of heat distribution system (middle). The moving of the pipes to enable connection is made by bends on the pipes (right).

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.

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

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

Figure 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.

Figure 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.

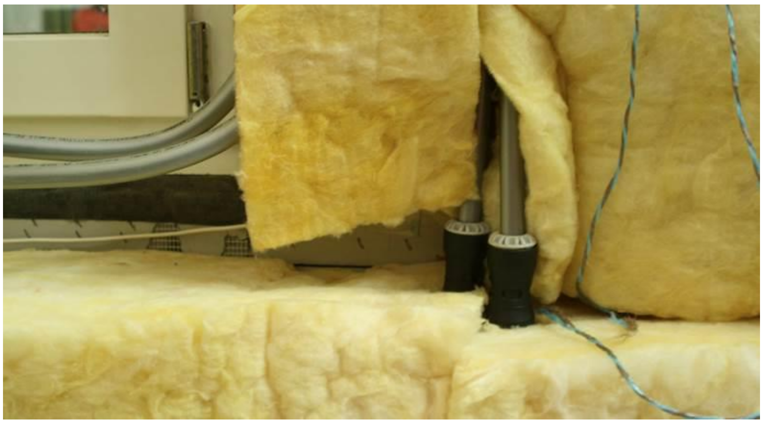


Figure 2.16: Connected heat distribution system pipes. Note the gaps and bent thermal insulation. In real case, this side would be facing the existing wall, so there will be no easy way to unbent it easily (there is access from the window, but the gap is 12 cm wide, so it would be challenging and at 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.

Figure 2.17: The module in its final position.

Figure 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,

Figure 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 our first test with the 25% better insulating material (compared to Rockwool) called Fixit 222, we 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.

We then tested the robot onsite to see the work process, when moving the robot out of its traditional working environment in the factories. 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.

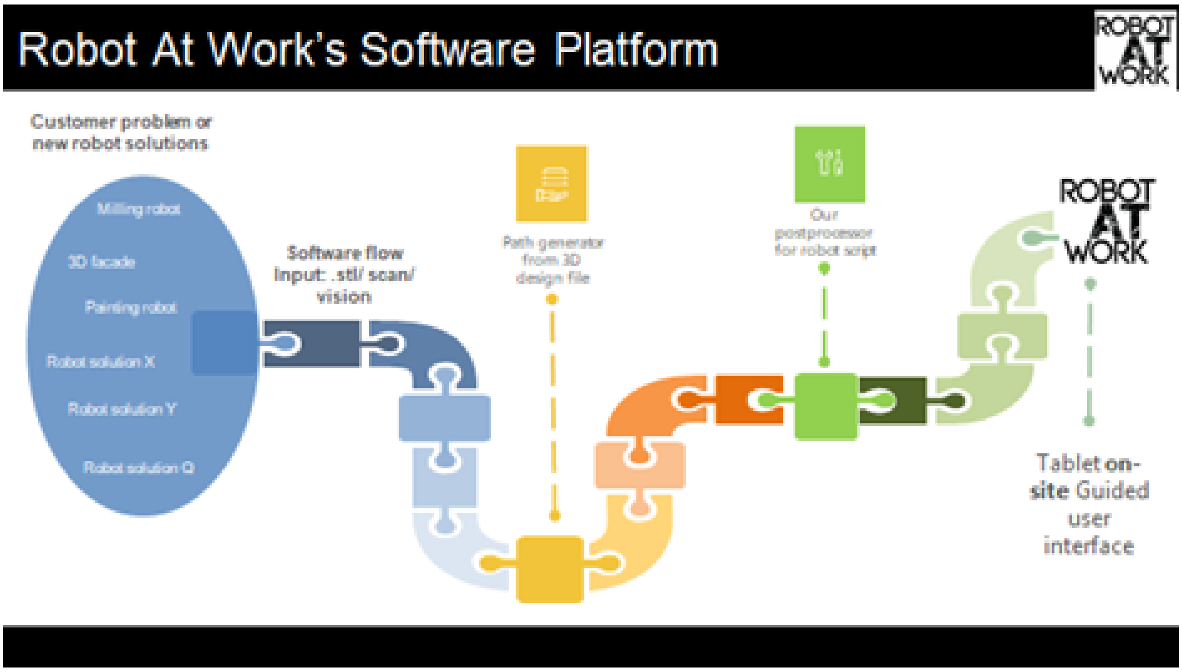


Fig. 3.2 Robot at works workflow diagram.

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 applied concrete layer and 3D-printing of the decoration design will therefore be carried out in the early spring of 2018.

Fig. 3.4 The insulated gable wall (25 cm rockwool) made by Invela – ready for the concrete finishing and 3D-decoration printing to be performed in the spring 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 3.5

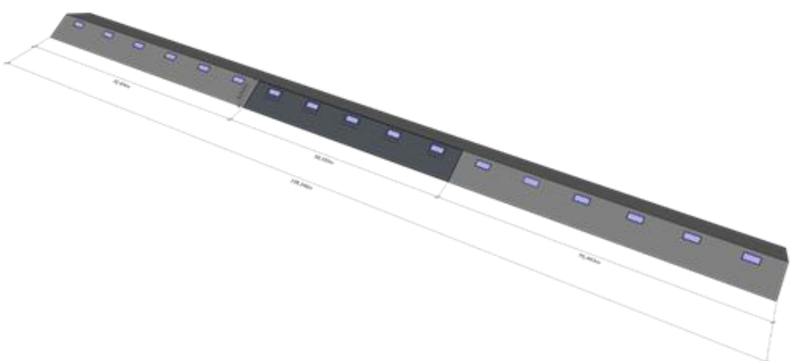


Figure 3.5: Design drawing showing the placement of the PV-roof on the roof of Korsløkken 34.6

The design details of this implementation is shown on figures 3..6 and 3.7 below.

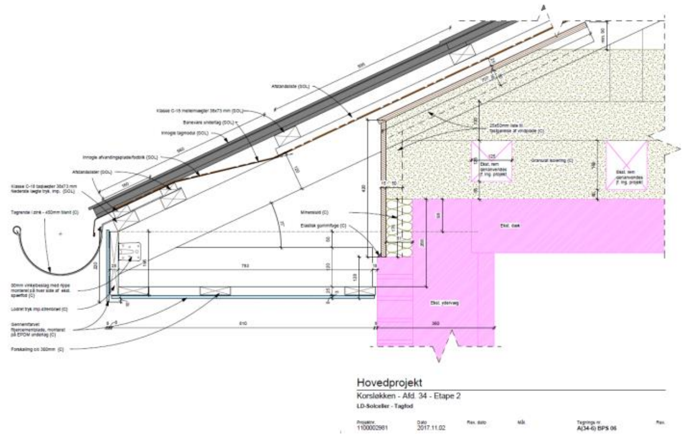


Figure 3.6: Detail showing mounting of the PV roof at the lowest part of the roof.

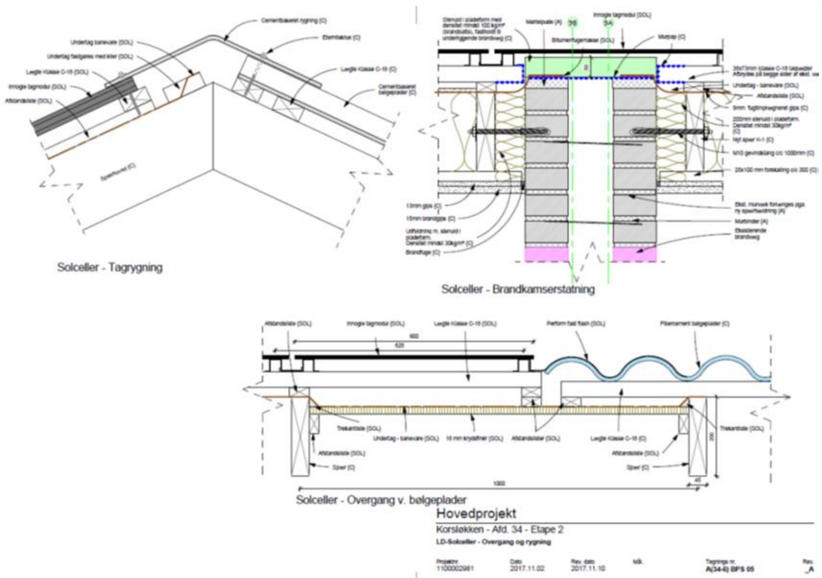


Figure 3.7: Details showing mounting of the PV roof at the highest part of the roof and the connection to the cement wave tiles.

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 3.8 and 3.9.

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

Figure 3.9: 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 3.10 – preparing the roof and 3.11 – 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 3.10: Preparing the roof for installation

Figure 3.11: 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 3.12 shows the penetration of the cable through ventilation covers to the inside of the loft where inverters are placed.

Figure 3.12: The cable is led through the underlaying roof to the inside loft before the last PV - modules are mounted.

4 Estonia

4.1 Design

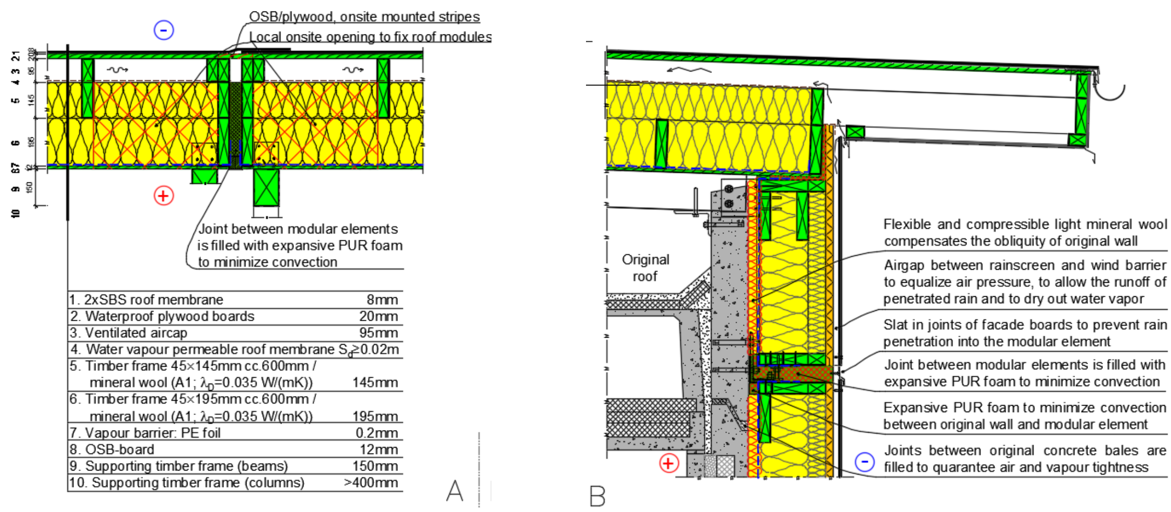
The architectural and structural design of the Estonian pilot project was drafted and formed out by Estonian architectural design company Sirkel&Mall in 2016. The prefabricated wall and roof modular elements structural and detailed design was carried out in 2016-2017 by Estonian company Matek.

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



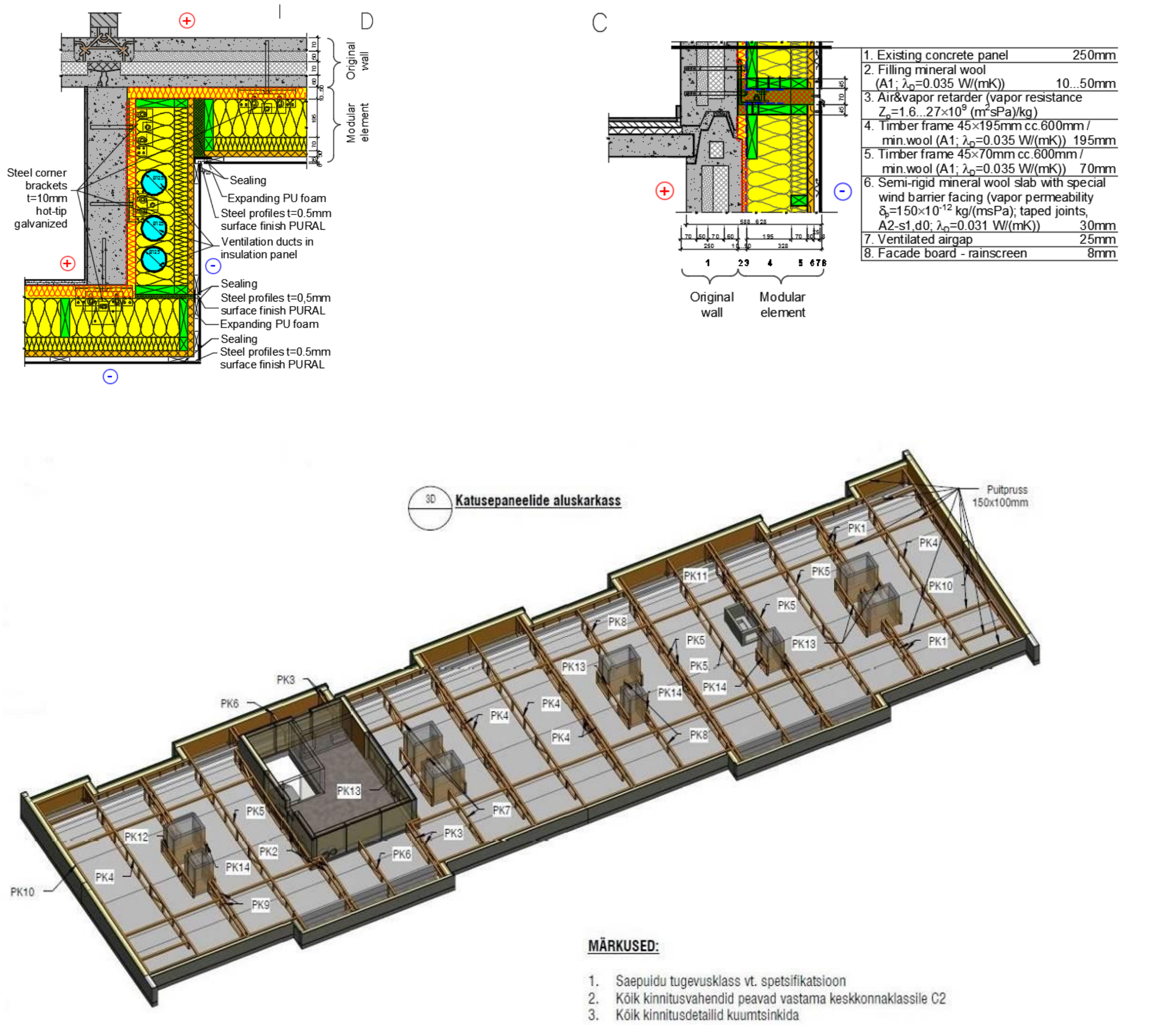


Fig. 4.2 Designed solutions at the different structural points of Estonian pilot building wall modules (above and centre) and roof loadbearing structure (below)

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.

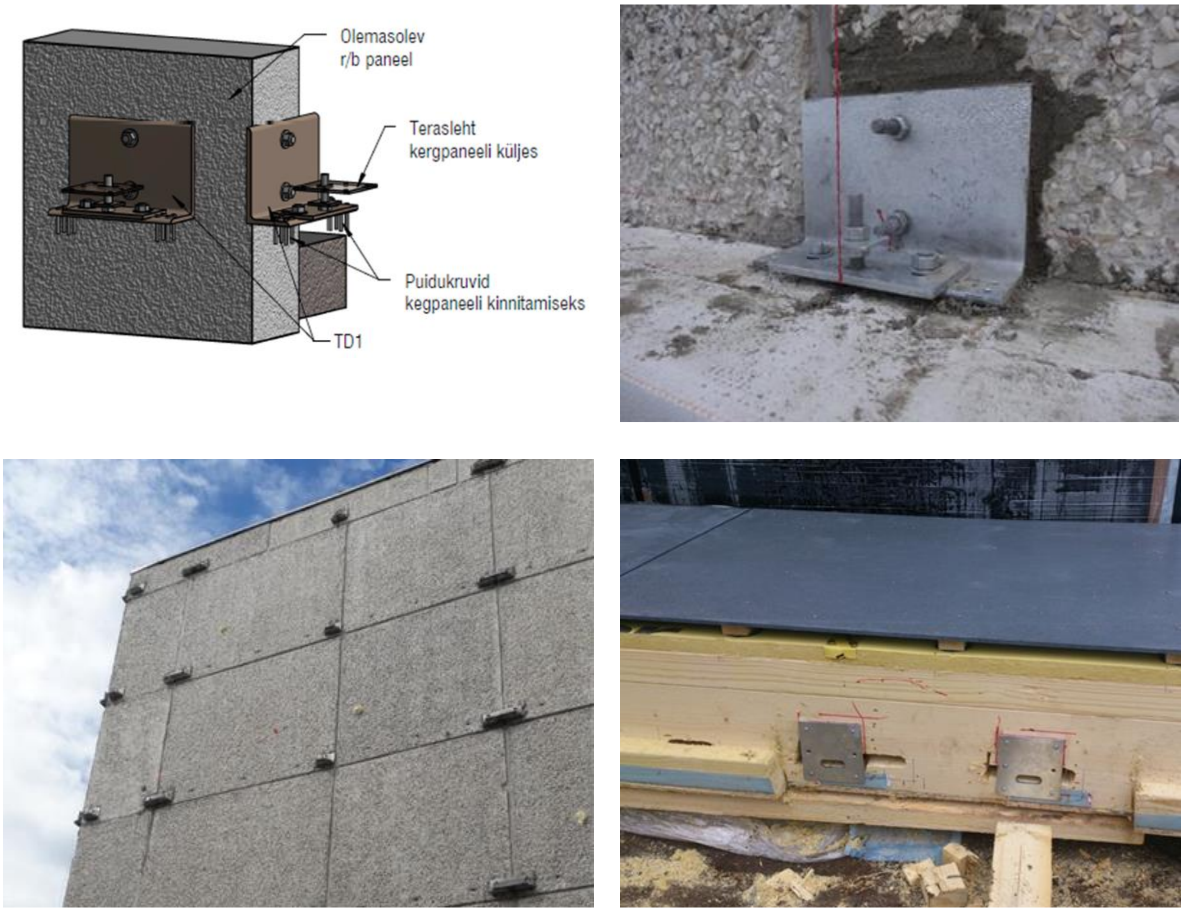


Fig. 4.4 Steel brackets, 3D adjustable, for wall modular elements: designed solution (above left); brackets installed onto the wall (above right and below left); brackets support adjustment on the element before mounting at the pilot building site (below right)

- 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.

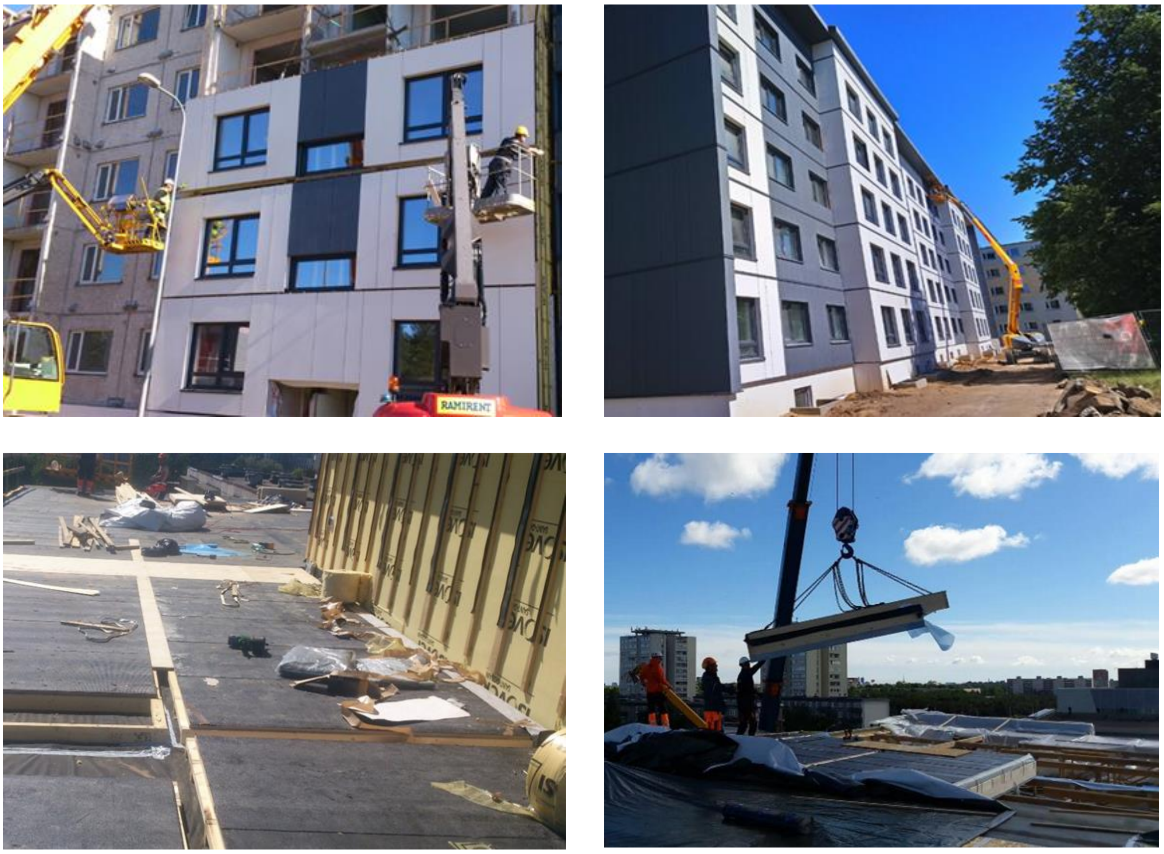



Fig. 4.5 Mounting of wall (above and centre) and roof (below) modular elements at the building site (May-June 2017)

- 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.

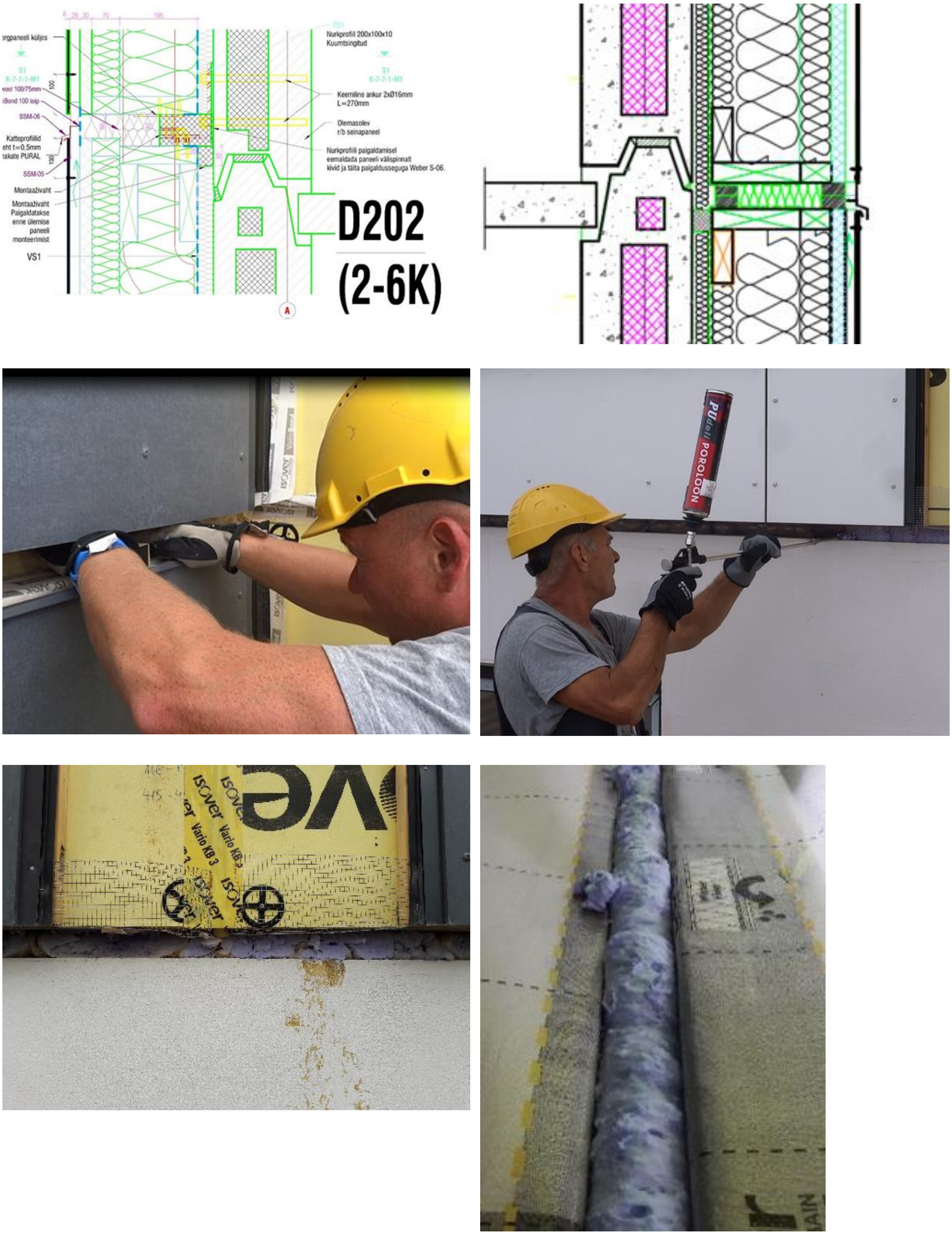


Fig. 4.6 Designed solution (above) and sealing of joints (centre and below) at the pilot building site (June 2017)

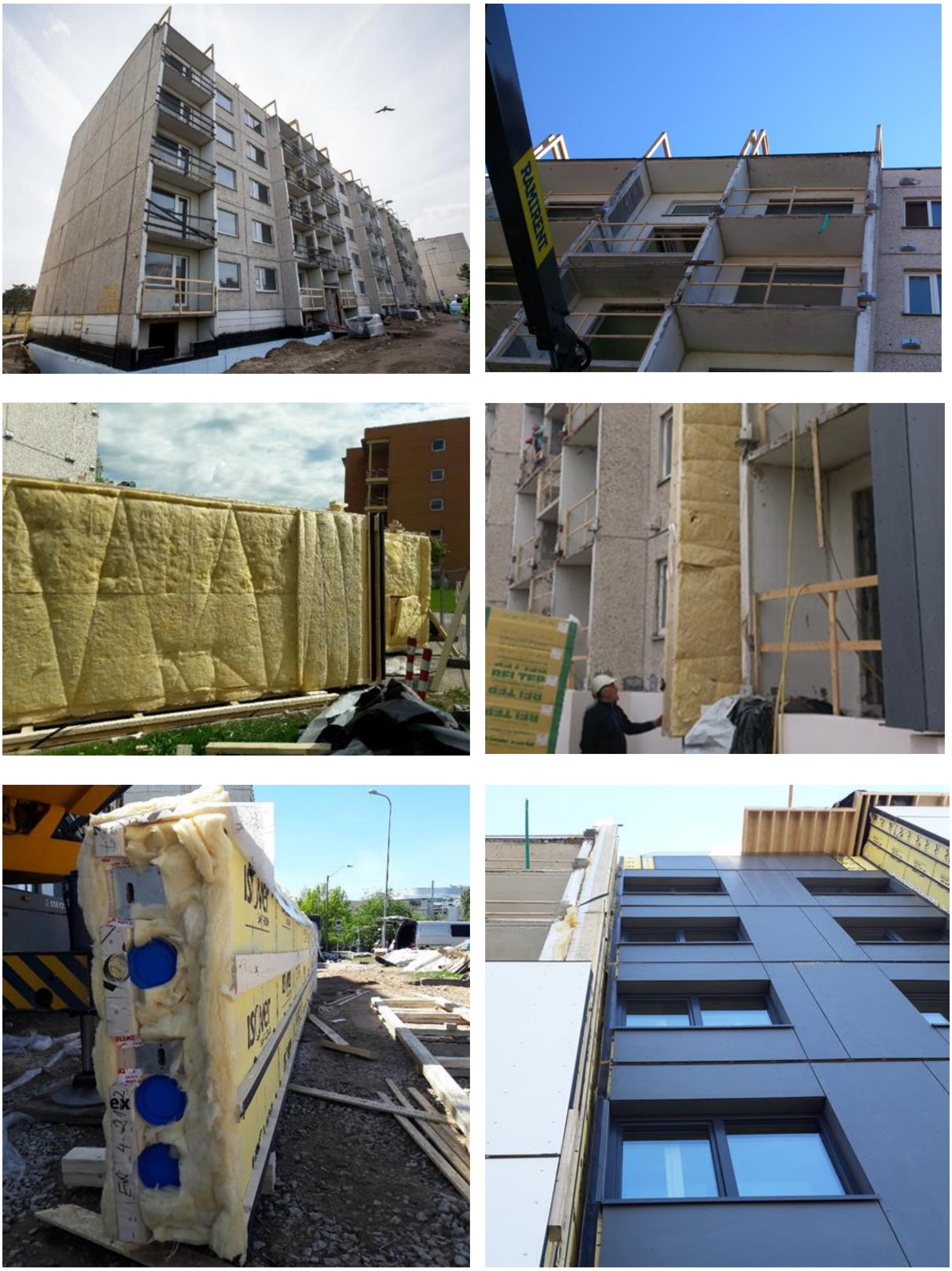


Fig. 4.7 Building process at the pilot building site (spring-autumn 2017)

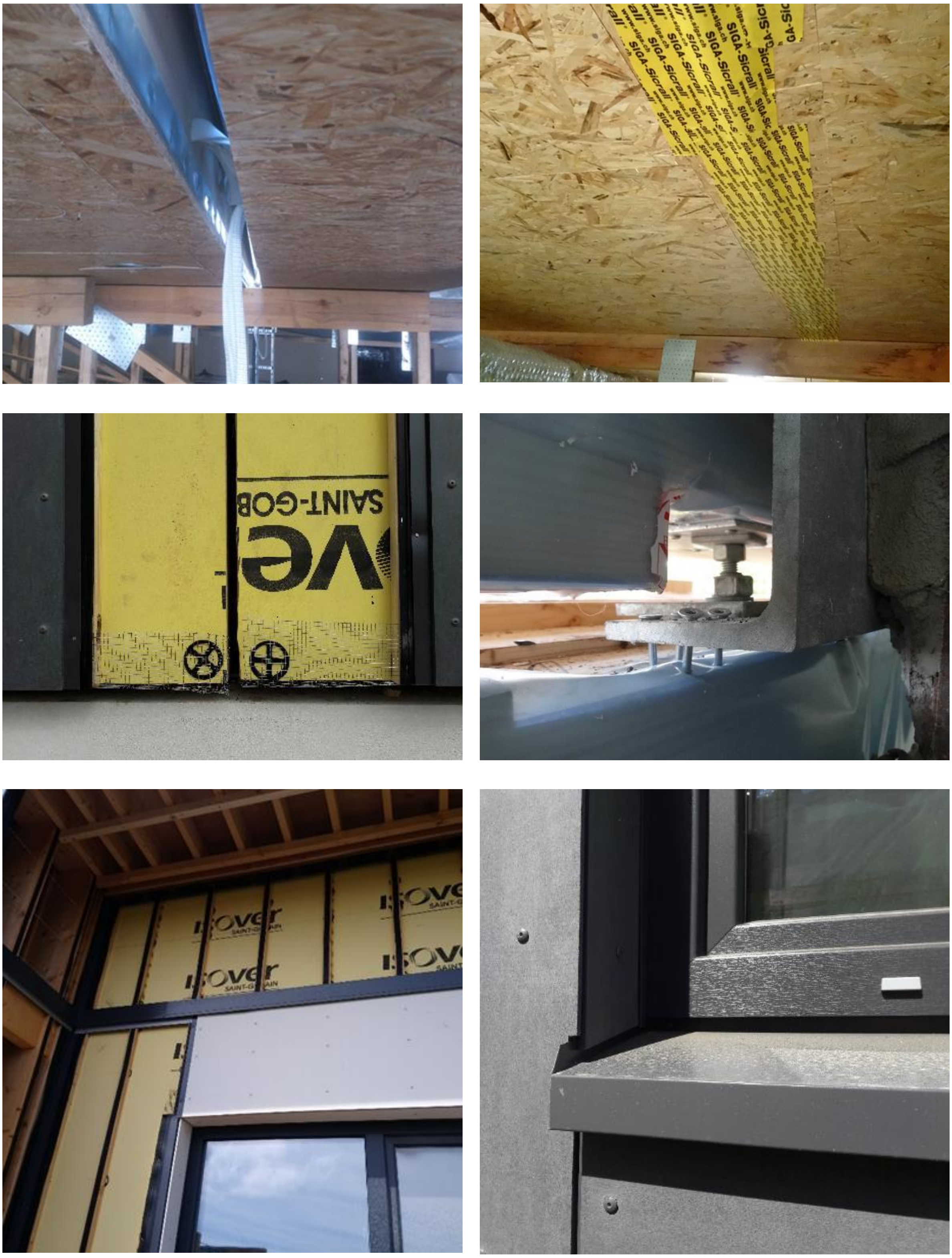


Fig. 4.8 Some examples of challenging points at the pilot building site (spring-autumn 2017)

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

5 Latvia

5.1 Design

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.

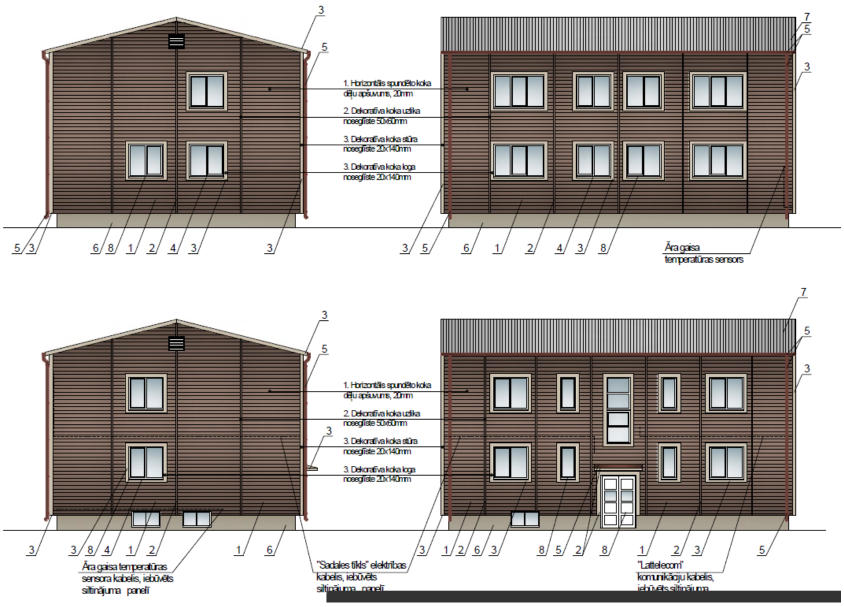


Fig. 5.2 Façade layout

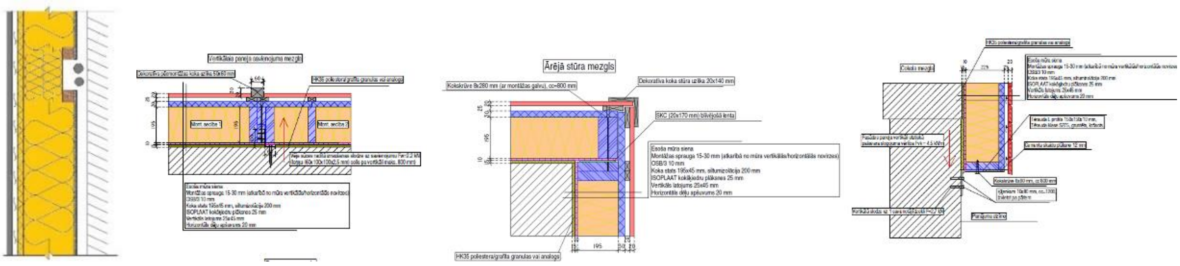


Fig. 5.3 Initial design for panels connection

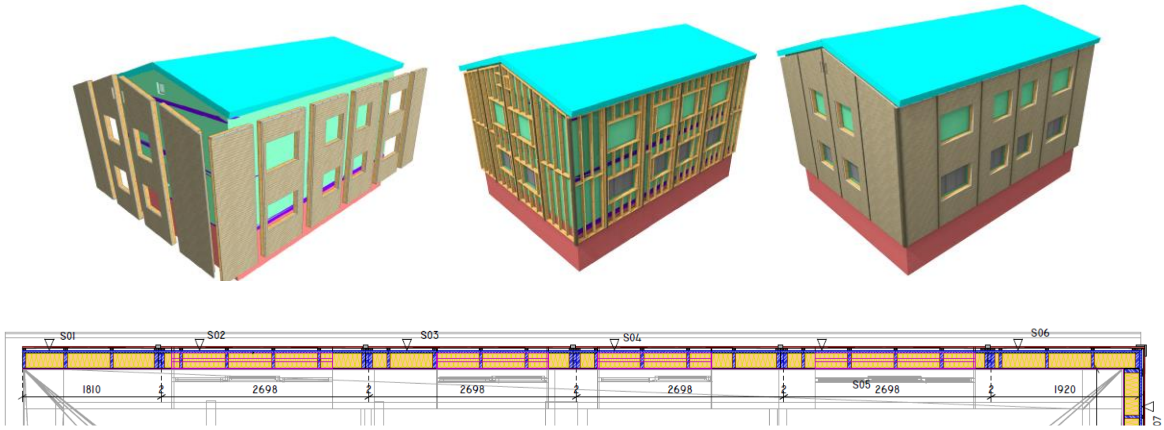


Fig. 5.4 Panel layout

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.

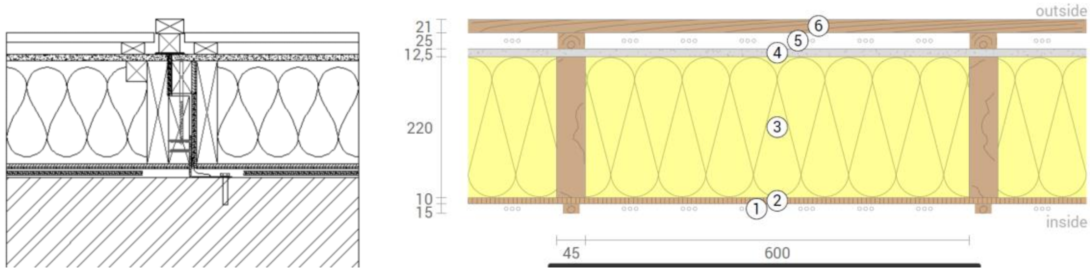


Fig. 5.6 Modified panel solution, proposed by construction company

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.

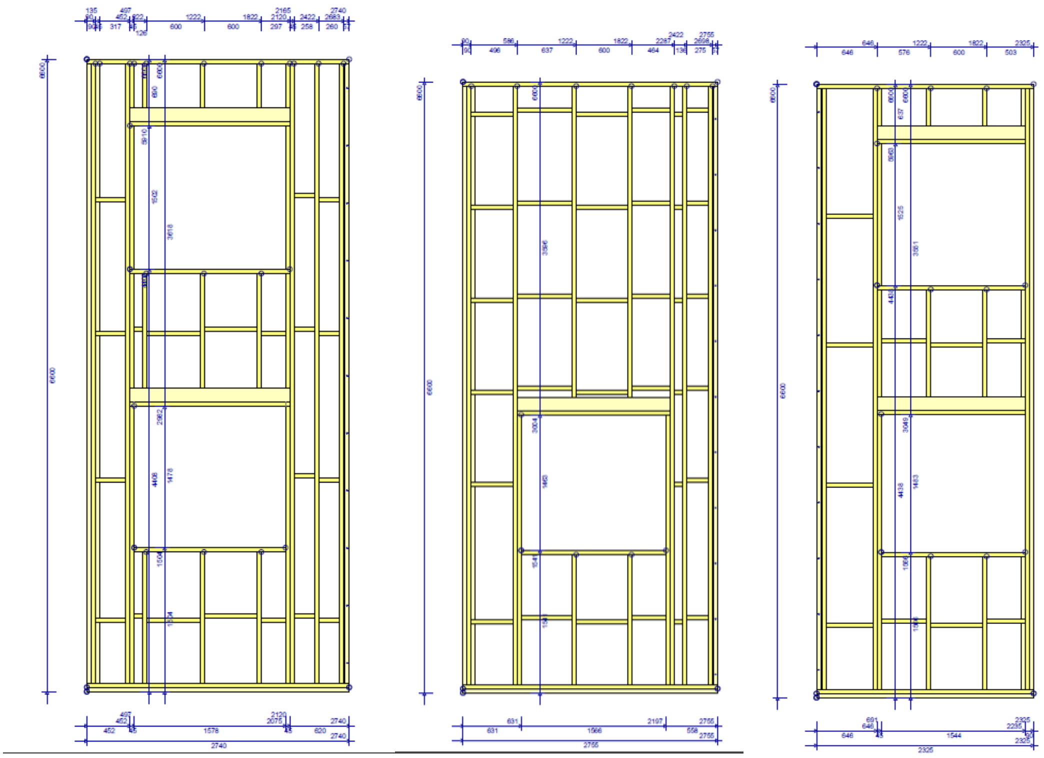


Fig. 5.7 Final layout of refabricated modular panels

Fig. 5.8 Front façades view

Fig. 5.9 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.

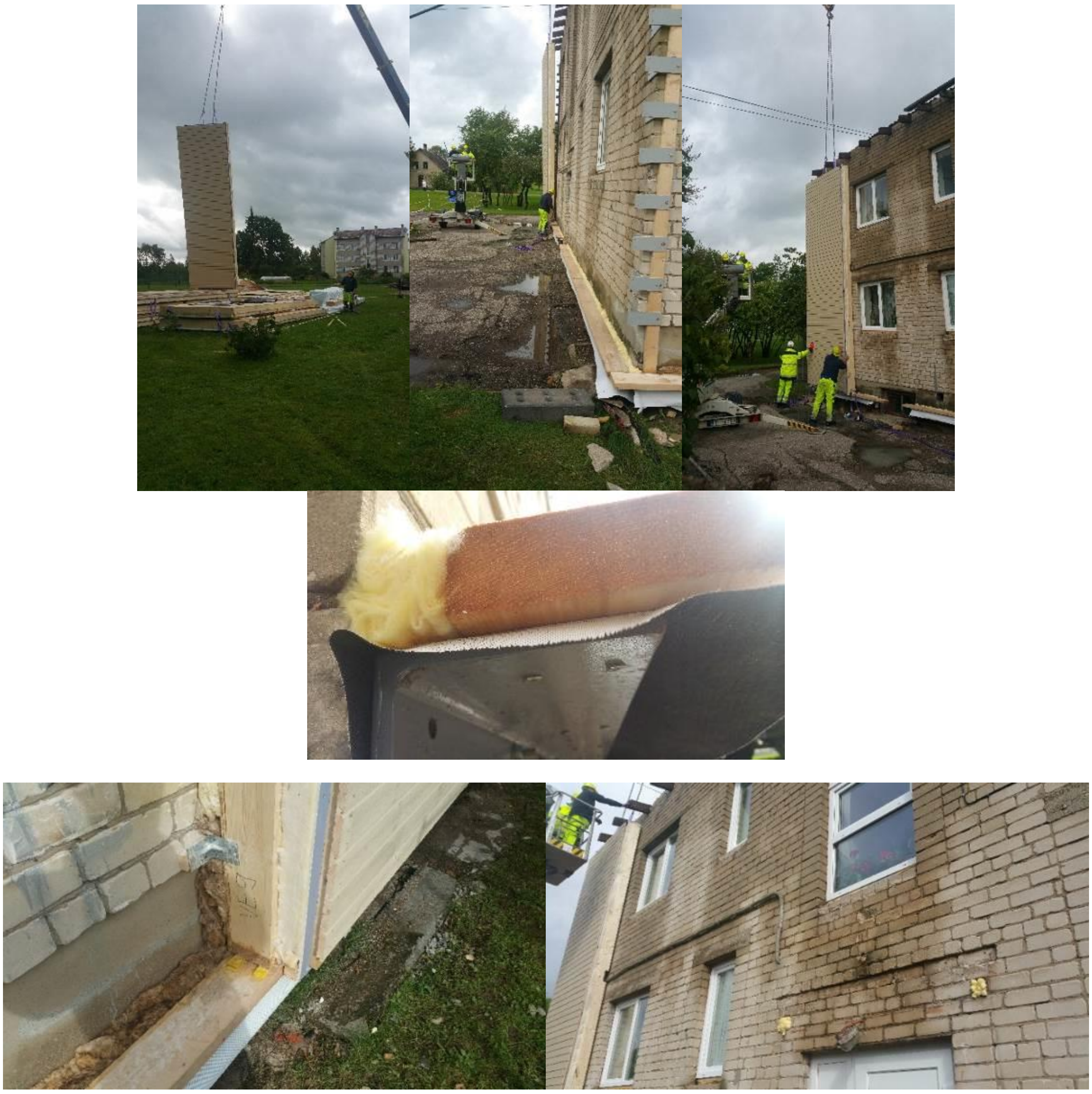


Fig. 5.10 Final process

6 The Netherlands

In the Netherlands three pilot projects will be implemented:

- Zoetermeer
- Presikhaaf
- Kruiskamp

6.1 Zoetermeer project (Webo and BJW)

6.2 Presikhaaf project (Webo and BJW)

6.3 Breda Kruiskamp project (BJW)

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 (Figure 7-1).

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 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 (Figure 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 (Figure 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.

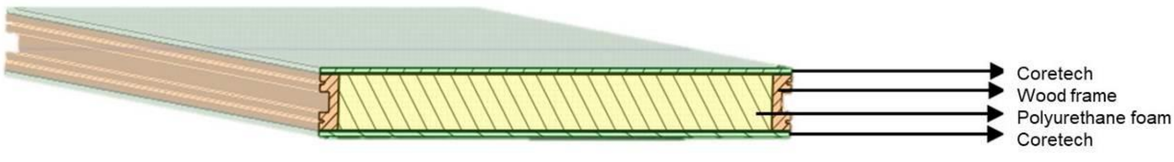


Figure 7-2 - Illustration of prefabricated module

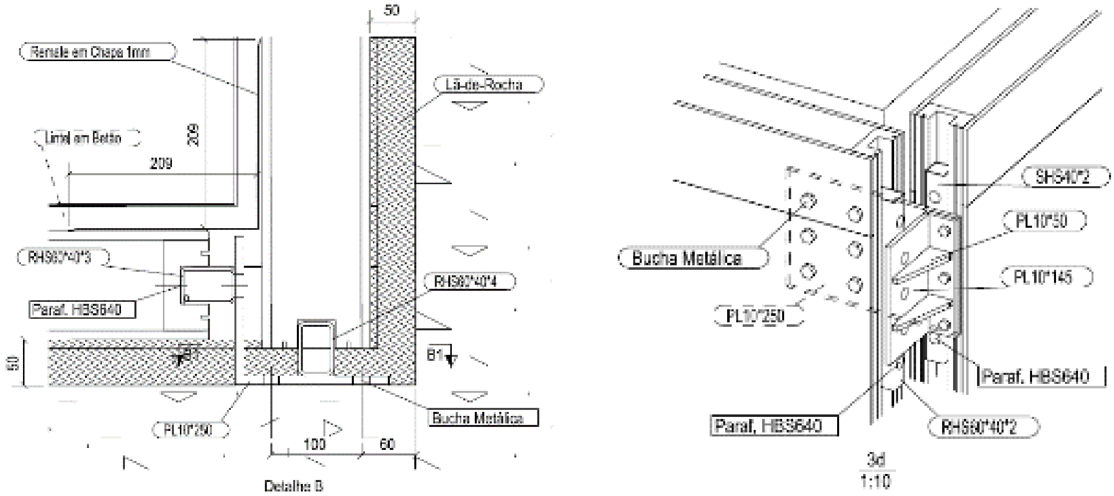


Figure 7-3 - Examples of designed connections (between modules in interior and exterior corners)

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 (Figure 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.

Figure 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 (Figure 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

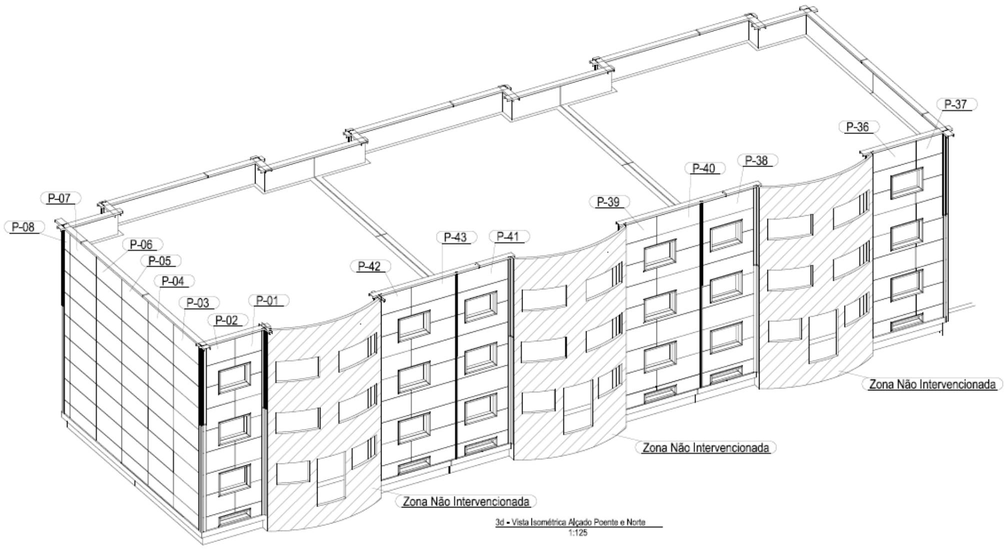


Figure 7-5 - Planning of prefabricated façade module installation