Prefabrication for the building energy renovation, BERTIM methodology

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1. Industrialization of the building energy renovation

About 40% of the overall energy consumption in Europe is related to the building sector and represents about 1/3 of Europe's CO2 emissions[1]. So, in order to meet the objectives of the Kyoto Protocol we have to concentrate on improving the energy-inefficient building stock. Thus, renovation is envisaged as a key strategy[2,3] to reduce the energy impact of the building sector.

The construction sector remains very traditional and with a low industrialization in the processes and products. The common way of renovation is based on crafts-oriented processes with high personal efforts. The traditionally chosen methods mostly are based on on-site works and they are subjected to climatic conditions and unexpected delays. The industrialization of the manufacturing process based on optimized technology use and the use of prefabricated modules for renovation offers a big potential for the optimization of the construction sector and in particular of the building energy renovation. In various European countries first frontrunner projects using industrialized renovation methods have already been realized, but there is still further need for the implementation into more projects.

Even if the technology developing fast, in order to industrialize the building energy renovation process the current collaboration models, planning routines and process chains have yet to be changed. The information flow, the communication among stakeholders and the information sharing must improve to really enable the industrialization of the process.

BERTIM proposes a Holistic renovation process with prefabricated timber modules that enables high quality and efficient building renovation in terms of energy, costs and time while providing added values for all stakeholders:

- **The innovative holistic renovation process** methodology from data gathering to installation will improve the current processes of the wood manufacturing and installation industry. A digital workflow for the whole process will be defined to improve efficiency and accuracy of the mass manufacturing process.
- In order to support the renovation process, a **Renovation project design tool** RenoBIM integrating BIM with CAD/CAM tools and assuring the interoperability with CNC machines for mass manufacturing processes has been be developed.
- **High energy performance prefabricated modules** for deep renovation, integrating windows, insulation materials, collective HVAC systems, renewable energy systems and energy supply systems. The modules will be based in timber and recyclable materials for a low carbon foot print. The assembly system with the existing building will guarantee a very little time in the installation and low disturbance to tenants

The Holistic renovation process has the following steps:

- Building data gathering: Building materials, systems, structure and façade geometry (by means of laser scanner, total station or photogrammetry).
- Creation of the building BIM model from the scanning data
- RenoBIM tool for the design of the renovation project:
  - Calculation of energy savings due to the implementation of the renovation façade (exporting IFC model to Energy+ software). Different insulation thicknesses and materials can be compared in terms of energy performance to select the most suitable timber modules for the building renovation.
  - Calculation of ROI: the cost of the renovation project and the expected returns are assessed in order to provide the investor information for decision taking.
  - Configuration of the façade timber modules: the tool has a configurator that allows defining the dimension of the timber modules according to the stablished requirements and restrictions. First approach to the timber modules design is

1 European Union Directive on the Energy Performance of Buildings (EPBD2002/91/EC)

2 http://ec.europa.eu/research/industrial_technologies/pdf/ppp-energy-efficient-building-strategic-multiannual-roadmap-info-day_en.pdf

3 Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012

developed by means of RenoBIM. The results of the tool are exported to IFC format and can be imported by most of the CAD/CAM software such as Dietrich's, Cadwork, etc.
- Manufacturing process: Detailed design of the modules in CAD/CAM software and manufacturing of the modules.
- Installation of the modules: innovative modules installation procedure for reducing on-site works.

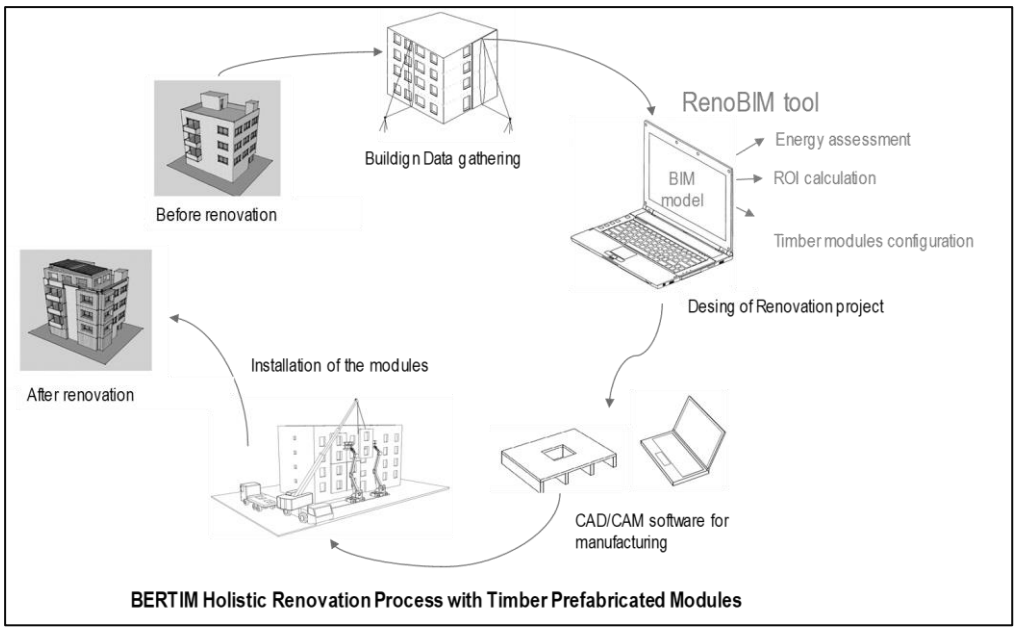

Figure 1 : BERTIM Holistic Renovation Process

Target buildings for the BERTIM methodology are energy inefficient buildings in the need of improving the thermal performance of their envelop and could be also in the need of renovating the building systems.

In Europe more than the 70% of the building stock was built before the first energy crisis (1970's decade) 4. The majority of these buildings were constructed without consideration of the energy efficiency criteria due to the poor performance of the insulation systems and lack of affordable innovative active and passive technologies. In fact, no consideration of the energy issues was included in the Building Codes until the transposition of the Energy Performance of Buildings Directive 2002/91/EC (Directive EPBD)[5], to the Member States.

So, in general buildings built between 1950 and 1970 are target building for energy efficient renovation. Among them in order to use prefabricated modules, buildings with regular geometry must be selected in order to assure that mass manufacturing methods are applicable for renovation.

2. Design of timber prefabricated modules

BERTIM proposes prefabricated timber modules to renovate buildings with the Holistic methodology.

Two type of modules are developed i) standard modules: modules with insulation for façade renovation; ii) modules with embedded installations: modules integrate installations in order to renovate building systems.

4 http://infohouse.p2ric.org/ref/17/16352.pdf

5 Directive 2002/91/EC of the European parliament and of the council of 16 December 2002 on the energy performance of buildings

Standard modules: the modules are based on timber frame. The layers of the modules and the insulation thicknesses depend on the timber manufacturer and the climatic zone. The finishing can vary from wooden slats, fibrocement boards, render, etc. The module will include the windows when necessary.

Figure 2 : Standard timber prefabricated modules' scheme

Modules with installations: centralized Ventilation, heating, cooling and domestic hot water distribution systems are integrated in the modules. The equipment are located in the building roof. A CLT 3D module to allocate the systems has been designed: The equipment needed is: A:Condensing boiler and chimney or heat pump; B:DHW tank; C:Equipment (manifolds, pumps, accessories); D:External weather louvre; E: Heat recovery unit.

The façade modules integrate the pipes to distribute water for the DHW, for heating and for cooling and the ducts distribute air for the ventilation. The thickness of the installation module depends in the dimension of the ventilation duct.

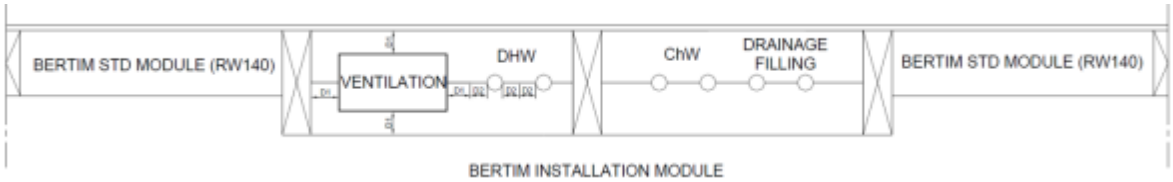

Figure 3 : Scheme of the Façade Installation modules

The pipes and ducts are connected between modules. It is necessary to make some cuts to the mullions to form the manhole cover to execute the installations joints and for its maintenance.

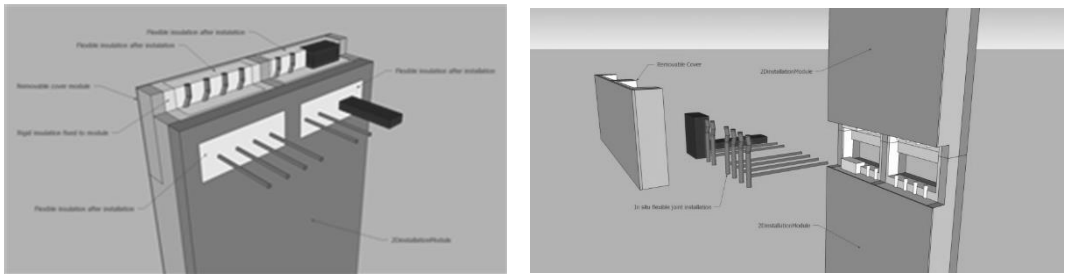

Figure 4 : Scheme of the façade installation modules

The pipes and ducts must be insulated in order to reduce the thermal losses. In north European countries insulation thicknesses are greater than in South or Central Europe. An assessment of thermal losses has to be performed taking into account the external minimum temperature values.

Figure 5 : Assessment of thermal losses in pipes and ducts in the climate of Bilbao (North of Spain)

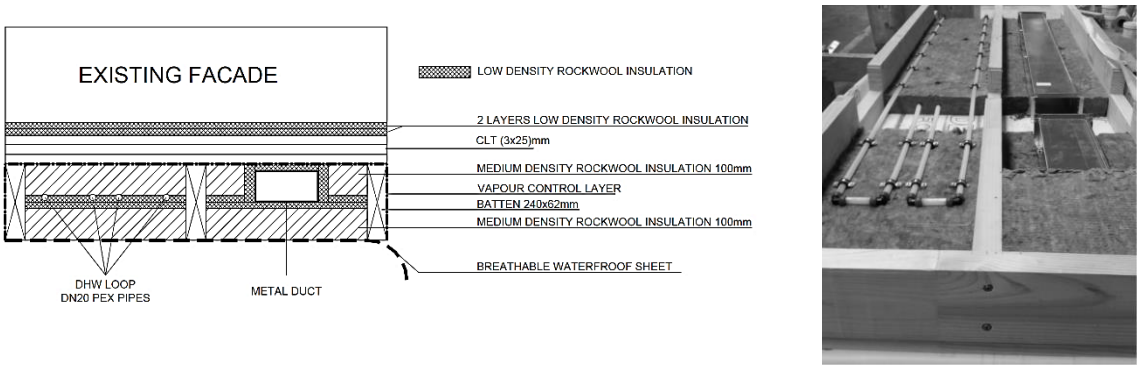

Figure 6 : Integration of pipes and ducts in the module

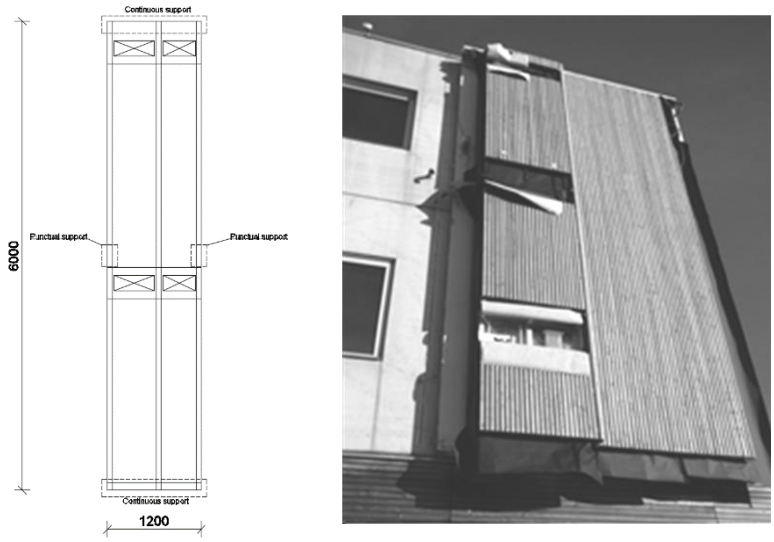

Figure 7 : Manhole to execute the installations joints and maintenance.

After having concluded the pipes and duct assembly between modules in the infrastructure KUBIK by Tecnalia, some conclusions could be depicted:

Using regular connectors to attach the BERTIM module to the existing façade produces some tolerance in the positions of the ducts embedded in it. Depending on the needed accuracy, two different joint accessories have been used: one of them allows to couple ducts where the axes positions has big tolerances. This joint is not a regular accessory for the duct manufactures, so it has to be used when it is really needed. The second one is used for low tolerance needs, being a common joint in a duct net.
Concerning water pipes connection: two different joint accessories are tested in KUBIK. The first one is more rigid and it would be used to couple pipes from consecutive modules. The second type used is a typical flexible hose, commonly used for connecting component as toilets, basins, etc. This type has been used in KUBIK to connect the embedded pipes to the system placed in the cell.

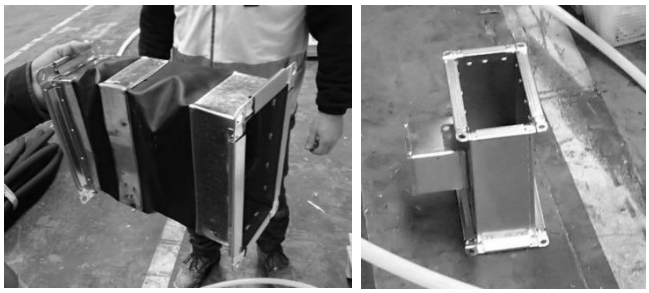

Figure 8 : Rectangular duct joint for coupling distribution ducts with big tolerances (left); b) T-branch accessory to connect consecutive modules and with the duct net in the dwelling (right)

3. RenoBIM tool for design of the renovation project

The Holistic renovation process is supported by the novel decision support (RenoBIM) tool that will cover the whole process. RenoBIM will allow seamless integration of the design and manufacturing processes through the IFC-BIM[6] of the renovation project. It has two main components: Renovation Project DST that will guide the designer in the selection of most cost-effective prefabricated modules Renovation Project Configurator will allow a geometrical definition of the prefabricated modules, taking into account the Building 3D Template that has been developed.

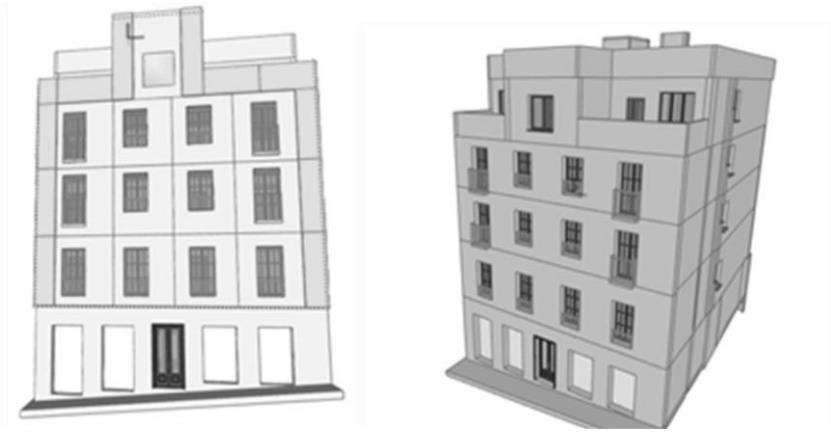

Figure 9 : Building BIM model and configuration of the timber modules with RenoBIM

4. Demonstration of BERTIM Holistic Renovation Process

The process has been demonstrated in four different demonstrators, two in Spain, one in France and another one in Sweden. The objectives of the demonstration are mainly threefold:

- To test de seamless digital data flow from building survey up to the modules' installation.
- To test the building energy performance after renovation.
- To test the reduction in prefabricated modules' installation time comparing to the traditional building renovation process: two different connection systems are tested: one based on the accurate positioning of four individual connectors for each module, and the other one locating a horizontal beam to level the modules.

Figure 10 : BERTIM modules installed in two demo buildings in Spain

6 The Industry Foundation Classes (IFC) data model developed by buildingSMART is an **open, international and standardized specification for Building Information Modelling (BIM) data** that is exchanged and shared among software applications used by the various participants in a building, construction or facilities management project. http://www.buildingsmart.org/standards/ifc

Figure 11 : Demonstration building in Sweden (left) and demonstration building in France (right)

5. Innovative business models

A greater challenge in energy efficient building renovation is how to finance the necessary investments. BERTIM has developed a system to increase one floor to the renovated building, by means of 3D residential prefabricated modules. The addition of one floor with a residential 3D module, provides the opportunity to drastically reduce the ROI of the renovation action. A business model of the solution considering the technical constraints, the cost of additional works versus the incomes due to the selling of the residential modules is carried out in order to allow defining in which cases it is profitable to increase one floor, and when it is not profitable.

Figure 12 : Natibox residential apartment developed by POBI

6. Conclusions

In order to cope with the building stock energy renovation needs in Europe, construction industry must adopt industrialized methods, to speed up the process and to reduce the costs in time and effort.

Prefabrication is a good opportunity to reduce works on-site, save installation time, reduce wastes in the renovation works and reduce intrusiveness during renovation works. In order to move to prefabrication processes planning and design phases are crucial. The better the preparation and planning is, the shorter the work on-site.

The design of timber prefabricated modules for renovation without the adoption of digital procedures would not have effect. New procedures are necessary. The use of digital tools for the design and collaborative tools to improve the communication and cooperation among stakeholders are necessary in the industrialization of the construction sector.

7. Acknowledgements

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