

	<p>SOLUTIONS FOR DIGITALIZATION AND PREFABRICATION IN BUILDING'S ENERGY REHABILITATION</p>	<p>ENERGETIC TECHNOLOGY</p>
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SOLUTIONS FOR DIGITALIZATION AND PREFABRICATION IN BUILDING'S ENERGY REHABILITATION

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SOLUTIONS FOR DIGITALIZATION AND PREFABRICATION IN THE ENERGY REHABILITATION OF BUILDINGS

1 INTRODUCTION

The construction sector has a great impact on our environment, both in terms of energy consumption and CO₂ emissions into the atmosphere. In Europe more than 70% of the buildings were built before the first energy crisis (decade of the 70s) [1]. Most of these buildings were built without any energy consideration, in fact, the energy aspects were not included in the Building Technical Codes until the transposition of Directive 2002/91 / EC (EPBD Directive) to the member states.

In order to meet the objectives of the Kyoto Protocol [2], it is necessary to focus on improving the energy efficiency of the existing built stock. However, despite the fact that the building energy rehabilitation sector is a great potential market for the construction sector, it has not just taken off. The reasons are several, but mainly they are the cost of the intervention and the high period of return on investment due to the low cost of energy [3].

The digitalization of the construction sector incorporating new technologies that improve the efficiency of processes and mass manufacturing of rehabilitation solutions, could reduce intervention costs and facilitate an economy of scale that will boost the market for energy rehabilitation of buildings.

There are numerous technologies to be applied in construction processes (BIM, laser scanner, drones, etc.) and numerous solutions for rehabilitation with prefabricated modules. However, unlike in other industrial sectors, the practical adoption of these technologies has been minimal, because despite the fact that the technology is fully developed, the difficulties in its use and implementation are not yet resolved.

This article shows the results obtained in the framework of the BERTIM project [4] where a digital process of energy rehabilitation of buildings has been implemented, from the capture of data to the installation of the modules, carried out with prefabricated modules in timber. The use of timber is gaining relevance due to its low demand for primary energy and its carbon footprint [5]. Nevertheless, the presence in the southern Europe countries is still much lower compared to Northern Europe countries where its employment in new buildings is very widespread [6]. The process has served to identify and solve the difficulties of bringing theoretical propositions into practice. Three critical points have been identified in the project:

- The capture of adequate building data for the creation of an accurate BIM model.

- The difficulty of rehabilitating the building HVAC systems from the inside due to the requirements of interior space and the disruption to residents during the execution.
- The installation of prefabricated modules of flat geometry on a building facade that is neither flat nor regular.

2 MATERIALS AND METHODS

2.1 BUILDINGS' DATA CAPTURING FOR THE CREATION OF A BIM MODEL

Buildings data collection for the design of the rehabilitation project is currently done manually. In many cases data are written down on paper, and then it is necessary to translate them to a digital format. Moreover, each professional participating in the rehabilitation makes its own data collection, in many cases duplicating the efforts unnecessarily. To improve the efficiency of this process, a single digital data collection and the creation of a single BIM model for all involved professionals is proposed.

Three different data capture techniques were compared, using three different tools with the objective of assessing the accuracy they provide and their cost-benefit in creating the building's BIM model:

- The 3D laser scanner with terrestrial Lidar technology
- Drone with camera for photogrammetry technology
- Total station for point to point topography of the building.
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Two of the technologies, terrestrial Lidar technology and photogrammetry, support the concept of point cloud, while the third technology uses a point-by-point analysis. This tool is very common in topography where the usual precision required is of the order of the centimeter, while for the manufacturing of prefabricated modules for rehabilitation the precision must be of the order of the millimeter, specifically a maximum of 10mm is recommended.

The building that was taken for comparison was a three-story building with an irregular geometry due to its architectural design and which also presented a lack of planarity on the facades of up to 5 cm.

Data collection with the laser scanner was performed by placing the device in different positions around the building. Special precaution was taken in the data collection of the windows, since from some positions the points of the windowsills could not be taken precisely. Therefore, the scanning positions were chosen in detail, with 13 positions around the building (28,106 density of points per rotation; 7.67mm between points in a range of 10 m) supplemented with 43 scans from inside the building in front of each of the windows (44,106 density of points per rotation; 6.14mm between points in a range of 10m). The post-processing of the points was done with Trimble RealWorks, being this post-processing quite automatic today. The points are joined in a single cloud and unwanted objects such as passers-by or street furniture are eliminated. In addition, with the laser scanner, 360 degrees panoramic photographs were also taken from each position, resulting in a very realistic image of the building, thus facilitating the interpretation of the architectural details of the building.

The photogrammetry was performed with flying a drone over the same building at several heights to be able to take multiple angles. The camera does not measure distances, so it is necessary to adjust the point cloud obtained to the appropriate scale by calibrating points taken with a total station from different angles. 30 calibration points were taken. These points were joined with Pix4D and imported to RealWorks where the point cloud was calibrated. Then point cleaning was carried out by removing unnecessary ones.

With both methods the data collection was done in one day, the post-processing of the points required between two and three days. 3D models from point clouds were created with Revit. This part of the process is not yet automated, but it is a manual job. It is the most time consuming, requiring 5 to 6 days.

Finally, the scanning of the building was carried out with a LEICA total station with an accuracy of 2mm + 2 ppm. The time required to obtain the points with the total station is greater than with the other two methods. In addition the cost in personnel is increased because it takes between 3 and 4 people to carry out the measurement campaign, while with the other two methods with 2 people is enough.

In the measurements made with the total station, resulted that the 20% of the points obtained were erratic. Mainly these errors were close to the limits of the windows and irregularities, being necessary to repeat the measures. To address this

difficulty, a very simple procedure was devised. A target drawn on a small cardboard (Fig. 1) placed in the façade would allow the technician to ensure that he is measuring the appropriate points.

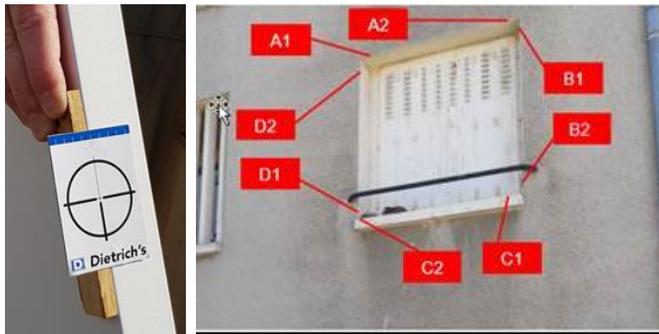


Fig. 1. Left: target that allows identifying the measurement points with a total station; Right: measurement points around the window [Source: BERTIM project]

2.2 PREFABRICATED MODULES INTEGRATING HVAC INSTALLATIONS

2.2.1. Design of prefabricated timber modules

The prefabricated modules that have been proposed for the buildings energy rehabilitation of are made of timber frame. The timber frame has inner slats, an OSB (Oriented Strand Board) layer on the back, is insulated and then protected with a waterproofing layer.

However, this proposal is incomplete since it does not consider the rehabilitation of obsolete HVAC installations (heating, cooling and ventilation) of the building.

The project worked on the design of some installation modules, which could house the distribution networks (ducts and pipes) of HVAC system and allow the rehabilitation of the system without having to intervene inside the house. For this, the timber frame modules are not an adequate solution since the frames prevent the pipes and the air ducts from having continuity. To solve this problem, it was decided to design the installation modules with CLT (Cross laminated timber) self-supporting modules.

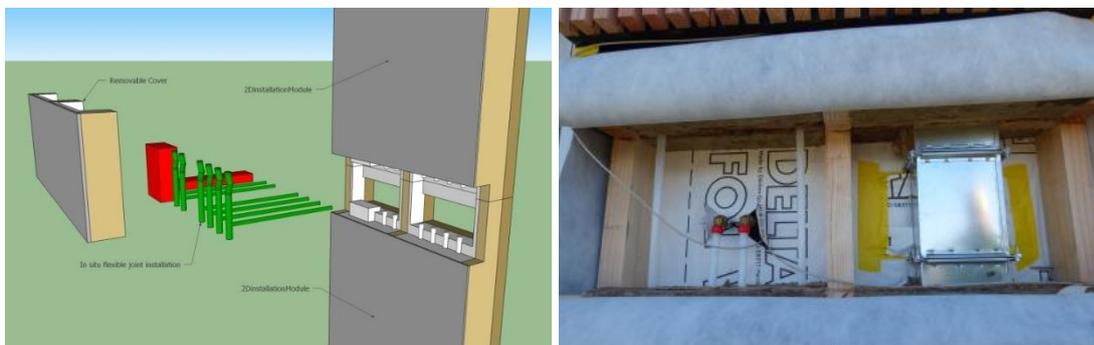


Fig. 2. BERTIM installation module. The T-shaped pieces couple pipes and ducts of two modules and penetrate in the dwellings [Source: BERTIM project]

2.2.2 Viability of the dimensions of the installation modules

A barrier was the thickness of the installation modules outside the façade line, both due to the dimensions of the HVAC distribution ducts, and due to the necessary insulation thickness to avoid energy losses.

To evaluate the dimensions of the distribution conduits, a residential building located in Madrid was taken as a case study. The building has north-south orientation. On the north facade kitchen and bathrooms are placed and on the south facade the bedrooms and the living room. The building in its current state has individual heating systems powered by gas boiler and radiators as terminal units. The proposed intervention was to centralize the generation system (the boiler) taking advantage of existing emitters and provide the building with centralized mechanical ventilation and air

conditioning. The generators would be placed on the building roof and the distribution would be carried out through the façade, integrating the pipes and ducts in the BERTIM installation modules.

Two scenarios were analyzed, one where the building was five stories with two dwellings per floor and a second where the building would have 11 stories, also with two homes per floor.

To analyze the necessary insulation thickness, the same case study was used: the residential building in Madrid. The proposed installation module was designed by the timber manufacturer EGOIN (<https://egoin.com/>). The module is made of has rock wool insulation (thickness = 140 mm). The reference conductivity of the insulation is 0.038 W / (m K). The minimum thicknesses for the ducts are established by the Regulation of Thermal Installations in Buildings (hereinafter RITE) [7]. Based on these values, an energy loss calculation was carried out by means of a two-dimensional heat flux analysis performed with a dynamic analysis software.

In Spain, according to the RITE, the maximum value of the instantaneous loss of energy in the distribution networks must be a maximum of 4% of the energy generated. Therefore, the developed concept of integrated façade distribution would only be viable if the design can ensure that the distribution losses are similar to this value.

2.3 INTEGRATION OF THE MODULE WITH THE EXISTING FAÇADE: NEW INSTALLATION METHODS

Rehabilitation with prefabricated modules has the benefit of a quick on-site installation. However, the lack of planimetry of the existing facade could make the use of prefabricated modules unfeasible. To solve this difficulty when installing the modules, two solutions were proposed that aimed to achieve tolerances less than 2mm in the relative position.

The two solutions were demonstrated in a test wall of about 5x10 meters. In the first place, a 3D scan of the wall was carried out generating a cloud of points that allowed measuring the deviations of the facade. The maximum deviation was 20mm.



Fig. 3. Left: Identification of the zones for the distribution of the modules in the wall; Center: Strategy 1: traditional installation system; Right: Strategy 2: installation with the Matching Kit system [Source: BERTIM project]

In order to install the modules two strategies were tested, as shown in Figure 3:

- **Strategy 1:** They were carried out in Zones 1 and 2. It is the “most traditional” way to place a module. The modules places in Zone 2 were supported on two steel profiles (in red) that aligned them properly. The upper modules in Zone 1 were placed on the lower ones that acted as a guide.
- **Strategy 2:** They were carried out in Zones 3 and 4. Timber plates were placed on the wall, four per module, (in blue). The precise coordinates of each of the plates were measured by means of a digital theodolite. Being the irregular wall, the plates were not in the same plane perpendicular to the floor. An interface was generated (called Matching Kit or MK). The MK interface is a new development of BERTIM project. It was made of timber in a CNC machine and placed on the plates on the wall. MK interface is the one who absorbs the irregularities of the wall and achieves the necessary verticality. Depending on the “lack of verticality” of the wall, the thickness of the interface will vary and all interfaces can be different from each other on highly irregular walls. 4 connectors per module were placed on the MK interface, which now respected the necessary planimetry.

Then, on the BERTIM module, another 4 connectors were placed that matched those already placed on the MK interface

3 RESULTS AND DISCUSSION

3.1 BUILDINGS' DATA CAPTURING FOR THE CREATION OF A BIM MODEL

Once the BIM model of the building was generated with the three data capturing methods described above, the obtained results were compared. First, the results from the point clouds were compared. The following image superimposes the results obtained with the laser scanner (grey) against those obtained with photogrammetry (brown).

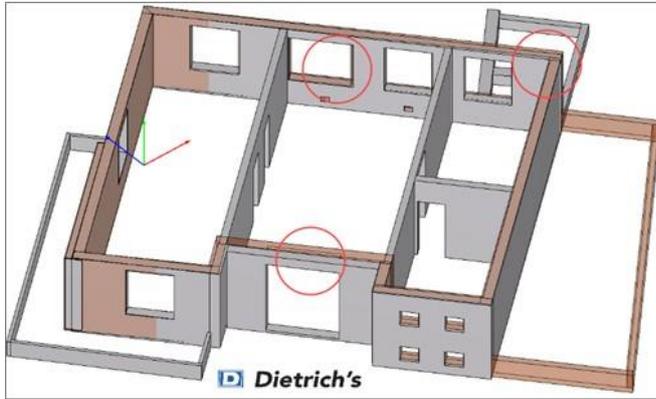


Fig.4. Comparison of BIM models built from point clouds obtained with laser scanner and photogrammetry. [Source: BERTIM project]

Figure 4 shows that:

- On the front wall there is a difference of 9 cm in position
- In the windows there are discrepancies of up to 5 cm
- In the rear facade the difference is even greater than the thickness of the facade itself

As literature already anticipated, modeling from the point cloud does not provide sufficient accuracy for the design of prefabricated modules.

Next, the data obtained with the total station were analyzed. For our experiment, four columns were extracted in txt format: the point number and the three Cartesian coordinates x, y, z. The point number facilitates the connection of the points to create lines and planes. The result obtained after post-processing resulted in adequate precision for prefabrication of the modules, offering a precise and error-free plan.

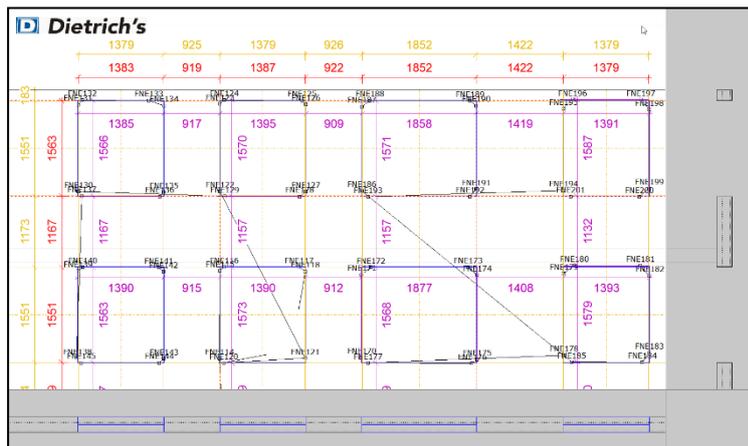


Fig.5. CAD / CAM manufacturing drawing from the total station points. [Source: BERTIM project]

The modules obtained by this method were manufactured and installed in a building in Charité sur Loire (France) by the manufacturer of timber houses POBI (www.pobi.fr). Great accuracy was obtained in the position of the openings (windows and doors) and the execution was a success, really demonstrating that the total station is the most appropriate technique today for data capturing.

3.2 PREFABRICATED MODULES INTEGRATING HVAC INSTALLATIONS

3.2.1 Design of prefabricated timber modules

The design is technically viable. The price of the modules with a timber cladding is € 130 / m² once installed. Considering the current energy prices in Spain, the estimated return period is between 15-20 years. Buildings that allow increasing one story with a residential apartment (it can be a prefabricated module in timber) can use the selling of the apartment to cover the required investment.

The price of the installation modules varies depending on the HVAC generation equipment installed.

3.2.2 Viability of the dimensions of the installation modules

The viability of the CLT facade modules to house the HVAC ducts depends on the fact that they do not overhang in excess the building's facade.

After the analysis carried out on the distribution of the ducts in the two scenarios of five and eleven floor building, it is established that the most convenient distribution is:

- The north façade (kitchen and bathrooms) must contain the extraction of ventilation, pipes for domestic hot water and heating circuits.
- The south façade (bedrooms and living room) must contain the ventilation drive and the cooling circuit pipes.

By geometry it is convenient to have two independent installation modules for each hand. That is, two similar modules on the north facade and two other similar ones on the south.

The duct that establishes the total dimension of the module is the ventilation duct:

- For the building of five heights it is obtained that for each of the hands of the building a ventilation duct with a minimum section of 400 cm² is necessary.
- For the building of eleven heights it is obtained that for each of the hands a ventilation duct a minimum section of 1,100 cm² is necessary.

This last section is established as a maximum application of the BERTIM installation module. In fact, if it were necessary to use ducts larger than 1100 cm², there could not be a single point of entry and exit per house, but there should be several points in each of them. Other unique solutions could be to increase the air velocity inside the air ducts with adequate sound insulation or use ducts that gradually become narrower, although this would make installation difficult.

The insulation needs of the facilities module were obtained based on the insulation values established by the RITE. The following starting values were considered: D1 minimum insulation thickness for an outer duct: 50mm; D2 minimum insulation thickness for an external pipe with hot fluids and DHW: 35mm and 40mm respectively; and D3 minimum insulation thickness for an external pipe with cold fluids: 45mm (Fig. 6)

Considering these values and the climatic conditions of Madrid the following figure shows the result of the calculation of energy losses: the losses in the hot water pipes for heating and DHW were of the order of 7.18 W/m, while the limit established by the regulation is 3.40 W/m regulation. The losses in the cold-water pipes for cooling were 2.97 W/m, while the normative value is 2.01 W/m.

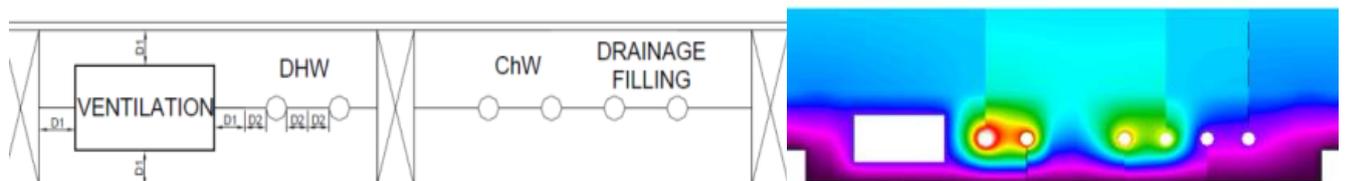


Fig. 6. Heat flows to evaluate the thermal losses in the installation module. [Source: BERTIM project]

To overcome this difficulty, it was decided to place an insulator with a conductivity of 0.032 W/mK and to increase the thickness of the D1 insulation by 80mm, reaching a total insulation of 130mm. With these changes the losses were reduced to a value of 3.59 W/m in hot water and 0.93 W/m in cold water, orders of magnitude of the normative values.

Considering the increase of the insulation on the outside of the ventilation pipes, the section of the installation module would have a thickness of 303mm, plus the thickness of the CLT panel (75mm). That is, the installation module would have an approximate thickness of 40 cm plus the cladding

These results have been obtained considering the climatic conditions of Madrid. The colder the weather, the more heat losses will be in the hot water pipes, and more insulation will be required. Therefore, in extremely cold climates, heating and DHW installation modules would not be feasible.

3.3 INTEGRATION OF THE MODULE WITH THE EXISTING FACADE: NEW INSTALLATION METHODS

The results obtained with the two installation systems were satisfactory with respect to the assembly time, where on average, about 0.10 hours of work per square meter were executed. If compared with traditional manual methods (between 1.3 and 1.6 h / m²), a significant decrease is observed. In terms of accuracy, relative deviations of 2mm were achieved. So this objective was also achieved

The reduced on-site installation time is the greatest competitive advantage of the BERTIM solution.

4 CONCLUSIONS

- The digitalization of buildings' rehabilitation process with prefabricated modules has an impact mainly on the reduction of on-site installation times, being reduced by 90% compared to ETICS. The approximate installed cost is € 130/m², the order of magnitude of the ventilated façade, but still much higher than ETICS.
- The capture of building geometric data for the realization of a BIM model requires precision of order of magnitude of the millimeter.
 - The capture of data with laser scanner and photogrammetry, requires 2 people during one day, but it doesn't have sufficient resolution.
 - The data capturing with the total station is more time consuming and requires 3 to 4 people to carry it out. However, it is the only technique that offers adequate accuracy. To ensure that the correct points are measured, the need to place targets on the facade has been demonstrated.
- The feasibility of the rehabilitation of the air conditioning systems of a building integrating the distribution networks in the modules has two limitations:
 - In Northern Europe, the insulation thicknesses necessary to limit energy losses in the ducts can make these interventions unfeasible.
 - A maximum of 10 story-building is established. Beyond, the thickness of the module would make its integration into the building unfeasible.
- The lack of verticality of the building's façade could make the use of flat modules unfeasible. Two installation techniques have been demonstrated to absorb these irregularities and to install the modules in very short times.

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