BERTIM – innovative wood prefabrication for energy efficient renovations

PROJECT RESULTS BOOKLET

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Building energy renovation through timber prefabricated modules
Foreword

The European building sector has enormous impacts on our environment and the influence of building performance on broader sustainability is widely acknowledged. 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. More than 50% of all materials extracted from earth and 25% of all virgin wood are transformed into construction materials and products. If the building sector is to significantly contribute to the 90% GHG reduction target for 2050, each building, on average, will have to demonstrate very low carbon emission levels and consume very low energy in the context of a decarbonised power sector. For most of Europe’s buildings, this probably means improving the current average energy consumption by the installation of renewables. In order to achieve those improvements deep renovation scenarios are needed, among which BERTIM solutions can be found.

The following booklet presents the main results achieved in the BERTIM project which was funded by the European Union’s Horizon 2020 research and innovation programme under grant agreement No 636984. The booklet is comprised of five articles corresponding to the papers presented during the BERTIM Final Conference held in the framework of 9th International Wood Construction Forum (Forum Bois Construction), 5th April 2019.

In the first article, Nagore Tellado – BERTIM project coordinator – describes 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 footprint. The assembly system with the existing building will guarantee a very little time in the installation and low disturbance to tenants. Tellado also presents the most important assumptions of the BERTIM innovative holistic renovation process from data gathering to installation, with strong emphasis on the improvements made in the wood manufacturing and installation industry.

In the next article, Thomas Bock and Kepa Iturralde from Technische Universität München review the different aspects of robotics and automation in the field of prefabricated modules, including classification
of the different technologies that are applied to this field. They place particular emphasis on the renovation of buildings due to the high importance of the renovation market in Europe and its impact on building energy efficiency. Authors of the article consider several issues related to the automated prefabrication, such as design of prefabricated module systems for robotic and automation processes, manufacturing process and installation of the modules on the building. In the conclusions, Bock and Iturralde define the most important challenges for the building prefabrication industry, some of which were solved by the BERTIM project.

The third article, written by Yvon Sebesi from Dietrich’s, pays close attention to the issues regarding data gathering from building selected to the renovation. Author of the paper describes several different technologies allowing the engineers to scan structure of the building, including 3D laser scanning methodology and photogrammetry. Before any design of the BERTIM modules by the manufacturers, the architect will need a 3D model to obtain the geometry of the existing building, define the dimensions of the modules and manage all the aesthetic aspects of the renovation job. Taking this into account, the paper highlights the very specific requirements with regard to the accuracy of the process aimed at surveying and modelling the building structure. It also explains the need to integrate the model with the data necessary for energy analysis, concluding with a presentation of the various devices and associated software tools allowing the architect to survey an existing building.

In the fourth text, Asier Mediavilla from TECNALIA, presents the most important advantages of renovation project design tool RenoBIM which integrates BIM with CAD/CAM tools and assures the interoperability with CNC machines for mass manufacturing. Mediavilla describes the most important functionalities of RenoBIM allowing the architects and engineers to analyse the data gathered during the scanning phase, speed-up the early decision-making and identify the most efficient façade renovation alternative. Moreover, the paper pays close attention to the digital renovation methodology created in BERTIM project, starting from checking the project feasibility and structure of building geometry, going through the 3D BIM model creation, energy simulation of renovation alternatives and identification of the most suitable product to use from the manufacturer’s catalogue, ending with quickly design the façade splitting layout and export to CAD/CAM tools for final design for fabrication.
The final part of the booklet, prepared by Hervé COPERET from POBI and Zaratiana MANDRARA from FCBA, is focused on the production of the BERTIM modules. The authors consider different aspects of the manufacturing process, including architectural modelling and mechanical, energy, and environmental dimensioning. They provide many interesting details related to the prefabrication stages and installation of the modules on site. Due to this fact, the paper pays close attention to the demo building which is located in France. Thanks to that, one can see how the prefabrication process goes in practice, starting from the design of the panels, going through the production process and ending with its implementation in the real case.

We hope this booklet may provide many interesting details related to the industrial prefabrication with strong attention to the wood technologies. We believe that the BERTIM solutions presented in all papers not only contribute to the reduction of energy consumption in the European building sector, but also offer attractive renovations schemes for all investors who care about environment, ecology, low intrusiveness of the renovation process and aesthetic aspects of their building. To find more about the project, please also visit www.bertim.eu or contact with our partners who contributed to this innovative BERTIM renovation solutions.

BERTIM project team
Prefabrication for the building energy renovation. BERTIM methodology, Nagore Tellado, project coordinator, Tecnalia

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 CO\(^2\) 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:

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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 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 footprint. 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 established requirements and restrictions. First approach to the timber modules design is 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.
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.

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.

Modules with installations: centralized Ventilation, heating, cooling and domestic hot water distribution systems are integrated in the modules. The equipments 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 on the dimension of the ventilation duct.

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.

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 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.a) 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 designing 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 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 the 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.
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.
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.
Robotization for the prefabrication and installation of building renovation, Thomas Bock and Kepa Iturralde, Technische Universität München

1. Introduction

This article reviews the different aspects of robotics and automation in the field of prefabricated modules. It also classifies the different technologies that are applied to this field. In this document, particular emphasis is placed on the renovation of buildings, because in the European context, the renovation of buildings is as important as new construction. A holistic view is needed [1] to examine the entire life cycle of the process. Consideration must be given to the safety, ageing, workforce, productivity, flow and accuracy of information and finally material.

2. Design of prefabricated module systems for robotic and automation processes

The concept of Robot Oriented Design (ROD) was developed in 1988[2]. The main idea is to facilitate the manufacturing, assembly and installation processes using robots. To do this, it is necessary to develop connection systems that facilitate an intelligent connection. The main objective is to create a design that facilitates the assembly and installation processes (Figure 1). Overlap is generally used to ensure water and airtightness conditions [3].
The prefabrication of modules with robots requires multiple measurements during the process. Data acquisition refers to the understanding of the physical conditions of an environment. In the field of robotics and prefabricated facade automation, data acquisition covers several aspects. There are attempts to integrate all these phases into a synchronized, fully automated and robotized workflow [4]. But there is still a need to create a more robust solution.
Complexity of prefabricated modules.

The prefabricated module shown includes services and requires the definition of each element to be assembled. This definition, if not automated, takes a long time, up to 0.43 hours per m² as already verified in a previous study [5] of the BERTIM project.

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<td>BERTIM project.</td>
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Manual design of the layout.

Currently, it is possible to directly design the layout of the facade, including the point cloud, from the 3D laser scanner. However, as was the case in the BERTIM project, several decisions must be made, such as the definition of the average plane and reference coordinates of the wall. This decision-making process does not prevent the collision of objects. In addition, due to blind spots, the necessary information may be missing.

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Automated design and layout definition.

As mentioned above, the manual definition of all the elements of the prefabricated facade takes a long time. This is why, as part of the BERTIM project, an algorithm is being developed to define the design of each of the prefabricated modules using only the data from a total station and the 3D laser scanner as inputs. It is a tool to avoid arbitrary decisions.

Image of the authors.

3. Manufacturing of the prefabricated modules

The primary structure of a prefabricated facade can be manufactured by robotic or at least automated systems. The examples and techniques are varied [6]. These automated production lines and machines are already on the market. However, two aspects need to be improved. On the one hand, the accuracy of these primary structures remains a challenge. On the other hand, the assembly of different materials on the primary structure is a rather manual process.

www.bertim.eu
4. **Installation of prefabricated modules**

Once the modules are manufactured off-site, they are transported to the site with special carriers on top of the trucks. On site, there are examples of automated logistics [7] that manage the prefabricated module. Then, the tasks are divided into several phases:

- Installation of the modules.
- Maintenance of the modules.
- Renovation.
- Uninstallation and disassembly.
To accomplish these tasks, the prefabricated module and the tooling system or end-effector must reach the required location. This location cannot be reached by common industrial robots, therefore, other bodies must be used, as explained in the next chapter.

**4.1 Classification of robotic bodies for working on facades**

This chapter is a classification of robotic bodies that can work on facades. The bodies themselves are not new, nor are the tasks that are performed with them. But it was necessary to classify them. For example, in Figure 4 robotic bodies are shown.

**Figure 4: Systems using cables**

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<th>Suspended robotic system.</th>
<th>Cable driven parallel robot.</th>
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<td>The hanging system is built on the &quot;gondolas&quot;. On the platform, robotic devices are placed as shown in the image on the right. Image of Matteo Carotta under the direction of the authors.</td>
<td>These types of robots are not yet fully commercialized and are still under development. This system is currently being developed as part of the Hephaestus project [8]. Image of Marcel Schlandt under the direction of the authors.</td>
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The use of a mobile external platform is a common technique in manual procedures and these can be transformed to robotic systems.

**Figure 5: Mobile platforms with robotic tools.**

One of the first experiments using a robotic crane was developed at the University of Ljubljana for TRIMO [9] facades. The accuracy of the system has reached deviations of less than 20 mm.

Image of Karl Greschner and the authors.

There are examples of the use of a rail system for handling the facade, as shown in **Figure 6**.

**Figure 6: Cartesian systems**

Vertical overhead crane type robotic system. This system is based on automated storage and retrieval systems.

Image of the authors.

In addition to the option presented in the previous tables, there are other robotic bodies that must be taken into account, as shown in **Figure 7**.
Unmanned aerial vehicles

UAVs or drones can be used for the assembly of structures, as described in the Arcas project [10].

The placement of connectors can be a task developed for such a robotic system. Stability is necessary during the execution of operations.

Image of Alice Cluzeau-Tomatis, Ilaria Giacomini, Florian Hirschel, Leyang Zhang under the direction of the authors.

5. Conclusions

The concepts presented in this document are still challenges for the building industry. The life cycle of prefabricated facades with robotic systems still needs to be improved. Several topics were addressed in two ongoing research projects, BERTIM and Hephaestus, conducted at the BR2 TUM laboratory. Several points are being developed currently:

- Improved workflow from data acquisition to manufacturing and assembly processes. Definition of a precise flow for each project taking into account each step.
- Precision in product assembly
- Improvement of the assembly of the product variety with robots.
- Development and testing of a robotic body on site.
- Placing the connector in its exact location
- Development of strategies to facilitate the installation of the prefabricated panel.
- A solution to address the irregularity in the geometry of the building structure (existing buildings).
  The adaptation of these two geometries and tolerances requires specific solutions.
- Creation of a valid equation or feasibility method to assess technological performance.

The development and marketing of new robotic facade systems are currently adapted to simple geometric building typologies. In the future, it will be necessary to develop different robotic bodies to ensure the most complicated types of facades.
References


[8] Site Web consulté sur le site Web du 31/01/2019: http://www.hephaestus-project.eu/


Capturing building data: point-cloud or theodolite?, Yvon Sebesi, Dietrich’s

1. Introduction

Capturing data from an existing building in order to build a 3D digital model for subsequent design work is now almost a mainstream feature of BIM processes. The study on which this paper is based stands out because data capture was applied to a particular field of external wall insulation using prefabricated modules. It is even more unusual in so far as the precision of surveying required in the present case was far greater – by a factor of five to ten – than the surveys carried out by specialists in this field. It consequently obliged us to question and adapt the methods usually employed.

![Comparison of 3 devices and technologies](image)

Figure 1. Comparison of 3 devices and technologies

Over the past four years the BERTIM European research project (talk during Workshop B5 at 11.00) has provided many opportunities to deploy various technologies and gradually improve the methods used. It has involved three timber construction firms: EGOIN, Spain; SETRA, Sweden; and POBI, France. At the time of writing SETRA’s results have not yet been used.

For simplicity’s sake the title of the present paper cites two technologies, but in fact it compares three. Two capture techniques, using different tools, underpin the point-cloud concept. The first one, laser scanning, is associated with the 3D laser scanner or terrestrial Lidar (laser-imaging detection and ranging).
The second one, photogrammetry, is generated by cameras, in the present case carried by a drone. The third technology used is point-by-point surveying with a theodolite and tacheometer – referred to as a total station since the introduction of laser beams. This measuring instrument is habitually used by land surveyors. Often referred to simply as a ‘laser’ on building sites, set on a tripod much as a fixed 3D laser scanner, this device measures points, selected one by one, and should not be confused with tools for generating point-clouds, which comprise millions of points.

Our comparison of the three technologies takes into account the key technical constraint associated with prefabricated EWI (External Wall Insulation) modules, namely the unusually high precision required. It also makes allowance for the economic and organizational aspects of obtaining tools, software and skills, the direct costs of thermal renovation work, and lastly the pros and cons of outsourcing all or part of the workflows described here.

2. **Stakes for modelling prefabricated EWI**

2.1 **Adapting an industrial product to the irregularity of a building**

The new facades, consisting of BERTIM modules fixed to the existing structure, form a new vertical plane in front of a surface that is only approximately vertical or even. On the four-floor masonry building renovated at La Charité sur Loire, France, dating from the 1960s, deviations of about 5cm from the vertical plane and surface regularity, invisible to the naked eye, were revealed by surveying. The overall geometry turned out to be more of an arc than a plane. Compressible mineral wool was used to prevent any air from circulating between the existing structure and the cladding modules, regardless of whether CLT or timber-frame modules were fitted. So the first challenge for surveying and subsequent modelling was to ensure that the wool was sufficiently compressed, to prevent any air gaps, but within the limits set by the material itself. Given that the new plane is by definition vertical, to allow easy assembly of the various modules at the corners of the building, the aim is to determine the right horizontal axis for each new façade and the optimal distance from the existing wall.

The BERTIM modules include new windows, of standard dimensions. These windows must fit the existing openings without the need for any masonry work. The existing openings are not properly aligned vertically or horizontally. Furthermore, the regularity of the rendered sills is very variable. So the opening
in the wall never forms a rectangle; the volume of the hole is never that of a right-angled parallelepiped. The outer cladding of Bertim modules is such that it may accentuate the need for re-aligning the openings (e.g. panels with hollow joints) or alternatively help conceal discrepancies (conventional wood slats). The second big challenge for surveying and modelling is to allow analysis of all the dimensional variations of the existing structure in order to properly size the new windows and position them correctly in the models, while allowing for the constraints specific to cladding.

The final challenge is to adapt module geometry to suit all the singular features. Even on projects previously selected by the RenoBIM web platform (talk during Workshop C6 at 15.20) as being well suited to BERTIM prefabricated modules, there may be many details of this sort, such as cut-outs round plinths, joints with original stone facing, or porticos over entrance doors.

![Figure 2. Adaptation of windows to rectangular shapes](image)

### 2.2 Coping with all the necessary gaps and tolerances

The first tolerance to be taken into account concerns the accuracy of surveying. To begin with this was arbitrarily set at 5mm, on the basis of interviews with the specialists we met. Ultimately it was precisely estimated to be 10mm, at the most, on the POBI demonstration job. This estimate was obtained through a series of three surveys, on two separate days, with the same 12 targets, carried out by the same professional surveyor using the same total station operating at three locations. The various parameters
allowed the inaccuracies of the total station and the surveyor’s eye to be combined, yielding an average of 7mm. The 10mm value ultimately determined corresponds to the greatest 3D discrepancy observed on only one of the 12 measurements.

The second tolerance relates to manufacturing. POBI manufactures and assembles timber-frame walls for Natilia, a network of contractors building detached houses. In the course of regular quality control on its production line it reports a tolerance of under 3mm on the length or height of a prefabricated module, and for the size and position of a window. Some of these tolerances must be aggregated during the design process.

The third tolerance concerns installation: the overall length or height of two modules, once assembled, is not equal to the sum of their respective dimensions, given the imperfections in the contact plane. A tolerance of 2mm must be allowed for each of these joints.

Finally, as is the case for any mechanical assembly, some leeway must be left for fitting windows into their lodging.

3. Data capture and 3D modelling

3.1 Point-cloud: laser scanning and photogrammetry

Point-clouds provide increasingly realistic 3D digital images. What is more they do it increasingly fast. Photogrammetry, which is based on the colour pixels in images, is in colour from the outset. For laser scanning, on the other hand, colour is now an option available by adding a photographic sensor to the 3D scanner. A word of caution though: these point-clouds, which all have the appealing appearance of digital models are not in fact what they seem as far as 3D modelling tools are concerned. The latter, present in the CAD software used in the building industry, use volumes to define a building. Indeed the longest and trickiest part of the process is to use a point-cloud to produce an accurate digital model of an existing building ... to which BERTIM prefabricated modules can then be fitted.
Fixed 3D laser scanners (Trimble, Faro and Leica Geosystems are the main suppliers) produce a point-cloud for each position of the device. Parts of the various cloud points are common, enabling them to be joined up, or ‘registered’, to create a single cloud, using special software (Trimble RealWorks, Faro Scene, Leica Geosystems Cyclone, Autodesk ReCap, etc.). This initial phase of post-processing is increasingly automated. Indeed some systems do it in real time while data capture is underway. The same software is also used to clean up point-clouds, eliminating unwanted objects (passers-by, street furniture, etc.), but this lies outside the scope of the present study. In addition to point-clouds, 3D laser scanners also take 360° panoramic photographs, at each location, constituting a record for subsequent viewing of all the building’s architectural details.

Photogrammetry, carried out by flying a drone over a building at various elevations in order to catch multiple angles and points of view, does not require registration because the data for the entire building can be captured in a single flight. But a camera does not measure distances, so the cloud must be adjusted to scale by post-processing based on a survey using a total station, operating at several locations. Given the relevant locations and distances, the point-cloud can be calibrated.

The point-clouds obtained by one or other of these two capture technologies are generally reprocessed to obtain a mesh model. This is not yet a volumetric model, simply a surface model built up from a series of triangular planes. Computer processing of this sort is often used to reduce the number of points in a cloud, when surveying terrain, representing the architecture of old buildings, or approximating complex sculpted shapes in archaeology. But it is not thought to be of any significant use in 3D modelling.
A large number of software tools are available to facilitate (plug-ins for Revit, with Faro Point Sense or Indoor Intelligence ScanToBIM) or automate (ClearEdge3D EdgeWise or the Snapkin service platform) the creation of the standard objects used by construction industry CAD tools, primarily walls, openings and floors corresponding to the IfcWallStandardCase, IfcOpeningElement and IfcSlab[Floor] classes of the open BIM .ifc format. But the interface does not allow the user to parameterize the algorithms underpinning such software. So, although such tools are useful for creating architectural models, they currently seem ill suited to the demands of models for prefabrication. Take for example the Snapkin platform, which displays almost 500,000 square metres of processed model and offers to process up 200 square metres of built space an hour. The parameters available here allow the user to obtain an average position — but without accessing the relevant parameters — or keep close track of the cloud which may produce walls that do not quite line up from one storey to the next. But neither of these approaches was really suited to our needs.

So, in the course of our studies, we did not use either a surface mesh model, or any assistance or automation software, in order to produce 3D models, drawing exclusively on the analytical skills of the design engineer. We should stress that five to ten times more time was spent modelling from cloud points than capturing data on-site, then cleaning and registering the cloud, though the difference in time varied depending on the detail of the model — whether or not it represented window sills, gutters and down-pipes, inside partitions, radiators — and on the contractors involved.

### 3.2 Capturing useful points, one by one, with a total station

For each point it captures, a total station, or theodolite-tacheometer, records a horizontal angle, a vertical angle and a distance — calculated from the time it takes for the laser beam to make the round trip — then converts these spherical coordinates into Cartesian (x, y, z) coordinates. Some of these devices (Leica Builder and 3D Disto, Hilti) may be connected to a PC, directly inputting points into the Dietrich’s CAD-CAM system. This may be useful for surveys with a small number of points, also for precisely repositioning structures in the CAD tool. But the sort of project we are dealing with here soon accumulates hundreds of points. So, after a preliminary test to determine the speed of the two methods, we opted for the more conventional approach of recording files from the total station, then importing surveyed points into the CAD system.
Although the time spent on-site may seem greater than the time required for a 3D scan or drone survey, it was nevertheless increased by the fact that at least three people were needed to do the survey, whereas a single operator may be enough for the other two methods. On the other hand, 3D modelling work was made easier by the fact that the points surveyed were selected from the outset to define the edges of the volumes that needed to be created. If, as is the case when building a model from a point-cloud, it starts with a preliminary stage of 2D drawing, it is nevertheless easier and quicker due to the limited number of relevant points.

4. Outsourcing or not

4.1 Subcontracting point-cloud capture and modelling

With the rapid development of consumer 3D-printing systems, there is now a wide choice of 3D scanners, ranging from €300 to over €100,000. The price of professional tools for the construction industry varies from €40,000 to €60,000. Leica is now marketing a product that costs about €15,000, but the rated precision (perhaps 10 times less) would not be suitable for the specific needs of prefabrication projects. In the field of photogrammetry, the necessary investments have become much more affordable. Although there are still professional solutions at comparable prices (in the region of €40,000), many of them — combining a drone and a camera — cost between €3,000 and €10,000 before tax. However, in France at least, a drone pilot must obtain a specific licence before offering professional services. The level of investments and the rising number of service providers naturally encouraged the various firms taking part in the Bertim project to subcontract data capture for the buildings undergoing renovation.

Given the specific skills point-cloud modelling entails, most of the firms providing such services include a complete package comprising the capture and processing of point-clouds, then modelling using a CAD tool, generally Revit or ArchiCAD. Here again the three companies involved in the BERTIM project did not own licences for these software tools, lacked basic skills in their use, less still the specific techniques required for point-cloud modelling. So the obvious solution was to subcontract the whole work package.

The demonstration job done by the EGOIN works, near Bilbao, was a special case. Here scanning work was contracted directly to Leica Geosystems. This only involved capturing point-clouds, but not production of a 3D model. The possibility of processing the cloud point directly with Cadwork was
considered, because the firm’s design office uses this timber-oriented CAD tool. It can import point-clouds, but Egoin lacked the necessary Lexocad module and had no experience in this field, so it tried, without success, to obtain help from the Cadwork support team in Spain. Ultimately only the results of a total-station survey were used.

For the demonstration job at La Charité sur Loire (talk during Workshop B6 at 14.20), POBI organized a tender to find a specialist to provide scanning and modelling services. A 5mm precision target was set at this point, in order to prepare bidding contractors for the unusual methods ahead. The tender was awarded to the best, not the cheapest bid. We met them before modelling started to agree on a specific approach to work under Revit.

As the surface area of both floors and outside walls was more or less the same (c. 550m2), the cost per square metre of this work package was about €10/m2 before tax, lasting an estimated 8.5 days. This fab-oriented work package originally only included the point-cloud, a 3D geo-referenced (LOD 300) model of the building’s structure, outside walls, load-bearing walls, slabs and stairs, and production of 2D drawings of the four floors. The project architect subsequently asked for details of inside walls, radiators, windows and doors. The first 3D scan, completed in one day, was supplemented by another day to position targets on the building, which were then surveyed using the total station and added to the point-cloud for purposes of cross-checking. The various additions raised the overall cost to about €17/m2 before tax.

On this same demonstration job the French Institute of Technology for Forest-based and Furniture Sectors (FCBA) carried out a second survey, using photogrammetry this time, carried out by a specialist in drone capture. This data was then modelled by a firm of chartered surveyors, also under Revit. The photogrammetry option had initially been set aside, given the degree of accuracy predicted by various experts, but we nevertheless seized the opportunity to compare methods and results.

4.2 Surveying outsourced, then in-house modelling

Many timber construction companies are now equipped with total stations, but for the three firms involved in the BERTIM project this is not yet the case. A total station suitable for construction work costs at the very least €6,000 before tax. The price depends mainly on the quality of the lenses — which
determine the precision – so a land-surveying device could cost up to five times as much. For our present need it is best to allow about €9,000, before tax.

EGOIN sub-contracted this service to a surveyor it works with and POBI turned to a surveyor, employed by its parent company AST. It is perhaps worth pointing out that land surveying generally concerns the layout of buildings or utility networks. Surveying buildings, and more specifically with a view to prefabricated additions, requires surveyors to learn new skills in order to improve overall precision. The survey carried out for Egoïn is a case in point. Plywood blocks, measuring 150 x 150 x 20mm, were fixed to the wall and surveyed, measuring four points at their respective corners. It took three surveys (and three changes in position) for the resulting points all to register on the same plane. We shall look at a second example below, regarding the surveys done for POBI. Unless it is possible to establish a long-term partnership, outsourcing such survey work does not seem an ideal solution, particularly as the process also involves the skills of the timber-design team and its CAD input. Furthermore any omissions or the need to cross-check often makes it necessary to return to the site and do more surveying. Such flexibility is much easier to achieve if surveying is done in-house.

5. Specific methods to achieve greater precision

5.1 Point-clouds and modelling under Revit

The methods used for drone-surveying and photogrammetry were those habitually used by service providers, with a 30-point survey by a total station for calibration purposes. All the pictures were assembled under Pix4D, then imported into Real Works to calibrate and clean up the point-cloud, removing pixel noise, mainly in the sky. The survey of the site was completed in a day; post-processing required a further two to three days’ work. Here again, subsequent modelling under Revit, which took about five to six days (for a detailed LOD 300 model), was the largest part of the job.

With regard to laser scanning, the process of adapting methods of work to meet the specific precision targets started with the capture phase, using 3D laser scanning. On POBI’s demo site it was necessary to capture all the details of the window openings, but to a large extent the sills did not register in the ground-based surveys. So the scanning positions had to be specially located, with 13 ground-based scans (28 million point density per rotation; 7.67mm between points at a range of 10m; noise-reduction setting
Building energy renovation through timber prefabricated modules

3; no colour; scanning time 3 hours and 17 minutes), supplemented by 56 scans from inside the building, in front of each window (44 million point density per rotation; 6.14mm between points at a range of 10m; noise-reduction setting 4; no colour; scanning time 8 hours and 9 minutes). Similarly, although point-clouds can now be registered without the need for targets, POBI opted to insert spherical or flat checkerboard targets to achieve the necessary precision. Lastly six points were surveyed on a total station and a GPS device to geo-reference the model.

Figure 4. Targets for registering point-clouds, seen here on a 360° photograph from the 3D laser scanner

It took just over a day to register all the scans. But this work, which required access to all the dwellings in the building, could be made easier by using a stable, scissor-lift, for work on the outside of the building, or, on low structures, by fixing the 3D scanner to a steady mast.

The modelling process also required methods to be adapted to achieve the necessary accuracy. The Bertim consortium set aside mesh models and existing automated modelling tools, and opted to explore ways of improving the techniques for analyzing point-clouds in order to obtain the mean planes of existing outside walls, in line with the demands of renovation work. One research action was carried out by the Technical University of Munich, using the Autodesk Dynamo programming environment. Another action, conducted by Sogexfo, a firm of surveyors, included a preliminary phase colouring planes to heighten contrast. This development work is still underway and had not made sufficient progress to be used on the
BERTIM demonstration jobs. So our 3D models were built up step by step, wall by wall, slab by slab, opening by opening on the basis of the two point-clouds, obtained respectively by laser scanning and photogrammetry.

We had planned to produce a coloured map of each façade in order to measure the defects in its regularity, but the functions available in Trimble for analysing floors in this way did not deliver the expected results when applied to walls. In addition, following our initial visual observations, we no longer expected curvature of as much as 5cm. So we positioned all the walls on the basis of a cross-section of the point-cloud just above the first-floor slab. The groundfloor might seem to be a more natural starting point for all the cladding modules, but it was discarded due to the atypical nature of this storey, featuring shops with projecting fronts and terraces. However this choice of baseline subsequently proved difficult, given the substantial curvature.

Much as for the alignment of the outside walls, we adopted specific methods to define the windows, based on additional cross-sections of the point-cloud, the aim being to obtain in each case the largest possible right-angled parallelepiped that could fit into the geometry of the opening. Grouped together under Revit, in families of similar dimensions, we only set about rationalizing their size and exact position much later, using a production-oriented CAD tool.

Figure 5. Modelling a window in a point-cloud under Revit: two cross-sections to limit the visible field
5.2 Surveying points and modelling with a production-oriented CAD tool

In keeping with usual practice, all the points surveyed by the total station were marked, with a series of sketches added to an old drawing of the outside walls. But the usual surveying procedures for topography had to be adapted to suit the goal of 5mm precision. In the course of an initial test, at the POBI demonstration site, using three total stations, including a land-surveying station operated by a professional surveyor, the positions of 20% of the points obtained were erratic. The attempt to target points located as close as possible to the edge of openings often resulted in capturing a point further back, on the window itself rather than on the outside wall, an error that went unnoticed during the survey process. A very simple tool was subsequently used to avoid this pitfall. Moreover the target, mounted on a 12cm gauge, made it much easier to characterize the position of the edge being surveyed. This simple tool gave rise to several other improvised instruments, using scraps of metal panel or profiles, which proved very handy for surveying singular points, such as the uneven masonry facing.

On the four-storey POBI demonstration job we also had to use a scissor lift, in addition to the tools discussed above. So four people in all were deployed to produce a worthwhile survey: a surveyor to operate a total station; an assistant to make sketches of the surveyed points; a qualified lift operator; and a fourth person to position the surveying targets (one person could fulfil the last two functions). These operations kept four people busy for three half-days, on two separate occasions due to a change in project design. On the POBI demonstration job they only focused on the relevant parts of the building, for example, the windows of the stairwell were not surveyed as this part was not scheduled for outside insulation.
The survey focused on the eaves and edges of outside walls, capturing one point per 1.5m, approximately, with greater frequency for singular points such as roof plinths. Slabs and their respective depth were surveyed with four points on each of the loggias. Each window was surveyed with eight points close to the corners, rather than the corner itself, never particularly precise due to the render. The number was increased for doors (10) and large french-windows (12).

The data captured by the total stations may be delivered in various formats that can be imported into construction-industry CAD tools, of which .txt or .dxf and .dwg (3D), possibly 2D planned for some stations such as Leica’s Geosystems Disto 3D.

We preferred the .txt format, comprising four columns: point number with an alphanumerical prefix, then x, y, z Cartesian coordinates. It allows more information to be imported into the Dietrich’s CAD-CAM system. Unlike .dwg files, the label indicating the point number stays attached and is displayed. Thanks to this numbering system points can be connected up with lines which form a really useful thread, enabling a point to be located quickly in a small cloud of several 100 points. Furthermore, the number suffixes serve to automatically generate layers with the same name, which is useful for subsequently filtering points under the CAD system. POBI, which uses the Dietrich’s system, took advantage of this functionality. EGOIN did too, despite the fact that it uses CADwork, enabling it to provide a design engineer with a drawing to help identify points in their .dwg format import.
Projected onto a horizontal plane these points allow the Dietrich’s system to measure and analyse graphically the defects in the regularity of each of the outside walls. The north-east wall, which is the largest, is noticeably curved. Our analysis led to the definition of an optimal median plane, in order to obtain compression values for the 12cm layer of flexible insulation (fitted between the wall and the BERTIM modules), ranging from 6 to 11 cm.

For the windows, automated projection of surveyed points onto the vertical plane of walls enables the definition of a vertical rectangle within the surveyed four-sided space. Then other plots and 2D measurements enable vertical and horizontal re-alignment of openings, if need be, and finally definition of standard dimensions for the new windows, allowing for survey tolerance and the play necessary for fixing.

The division of the facades to create the various modules — horizontally, starting from the slabs necessary to anchor them, and vertically, starting from the maximum length of a production module — is also entered, with 2D plots, before dividing up the modules themselves.

Having reached this point, the subsequent 3D design and production processes — drawing on all the details of how to assemble BERTIM modules already studied in two dimensions — is just as straightforward and automated (despite these modules being braced on the inside, not on the outside as is usual practice) as for the walls of the 565 homes that POBI produced in 2018.
6. Surprising comparisons

The D-Ref BIM module in the Dietrich’s system can be used to make comparisons, juxtaposing digital models, with various display and automated research functions, and subsequent processing of any discrepancies. We used this tool to compare the first two models produced from the two point-clouds, obtained respectively by photogrammetry and laser scanning. Although the two service-providers ‘guaranteed’ a certain level of accuracy, our comparison revealed some surprising, indeed worrying, results. After a series of tests to determine the best common point and the best direction along which to superimpose the two models, a difference of about 1° on one wall resulted in a 9cm discrepancy at its end. Discrepancies of as much as 5cm affected the windows. The wall at the back of the loggias was offset by a distance greater than its own thickness.

![Figure 8. Superimposing models in the D-Ref BIM module to highlight discrepancies](image)

Despite all the precautions taken, this finding confirmed what the scientific literature has already stated on the topic: automated modelling does not achieve the requisite precision, but even ‘manual’ modelling on the basis of point-clouds requires specific skills and also leaves quite a lot of scope for subjectivity. And of course, ‘to err is human’. This wholly unsatisfactory result prompted the production of a third model, which in so far as it approximated — hopefully — to one of the previous two, would enable us to complete the prefabrication project, already well advanced. It was decided to produce the third model using data captured on a total station, as described above. This tool was chosen because of our determination...
to master all the necessary processes in-house. On the one hand the survey could be done by a surveyor seconded by POBI’s parent company. On the other all the modelling could be done directly under the Dietrich’s system by a member of the POBI design office. Furthermore, the experience gained from this initial project — with support from Dietrich’s for specific features of the new venture — would constitute a reserve of skills for subsequent outside-insulation jobs.

The model produced using the same rules for positioning the walls as with the point-clouds proved much closer to the one produced by laser scanning. This confirmed preliminary data on the accuracy of photogrammetry. The discrepancies observed on eight significant points in plan view indicated an average discrepancy of 7mm and a maximum discrepancy of 12mm.

It was also surprising to find incomprehensible discrepancies, between 30mm and 50mm, on three of the 14 targets surveyed successively using two different total stations, in the course of the 3D laser scan and then with the full total-station survey. So the AST surveyor carried out a check, surveying 12 target points three times, on two different days and moving the survey station. The maximum discrepancy on this survey was less than 10mm, with an average of 7mm. This value, which is quite acceptable for our purposes, nevertheless falls short of the rated performance of the Leica TRCP 1205 station that was used. The age of the device may explain this discrepancy, particularly as it had not been serviced for several years. The quality of surveys might be improved in two ways, by using polygonation, instead of the conventional triangulation method of surveying, or by carrying out a Helmert resection. So it seems that the 50mm discrepancy, which prompted the check, can only be attributed to operator error.

7. Conclusion

Having initially set a 5mm target for precision, we ultimately succeeded in securing a value better than 10mm. This tolerance was integrated in all the design details, particularly the dimensions of windows to avoid the need for any work on the masonry when finishing the joints between the modules and the existing structure.

3D laser scan and total-station surveys yielded comparable results in technical terms at a fairly similar cost. Confirming the information obtained during our preliminary inquiry, drone surveying did not achieve the necessary degree of accuracy.
The total-station survey that enabled both POBI and EGOIN to use the timber-construction CAD tool for which they already have most of the necessary skills was preferred to point-cloud modelling. The latter technique either entails the development of additional skills or the acquisition of new software licences and/or the extension of existing ones, or outsourcing of the entire process. It is difficult to keep complete control over this solution, reaching from on-site surveying to modelling. As things stand doing as much as possible in-house seems to be the right choice for small or medium-sized companies, but this may only be a temporary conclusion, given the rapid changes in the cost of capture, processing and cloud-point modelling tools.

A continuous BIM process, all the way through the design flow — as initially planned for the BERTIM project — seems to an ambitious goal. A preliminary, affordable survey using drones and photogrammetry could be quite adequate for the early phases of a renovation project, launched by an architect and the necessary contracting team. This workflow could include the use of the RenoBIM tool to assess energy savings and the return on investment of projected work. But the working drawings and, to an even greater extent, prefabrication would probably entail production of a second, much more accurate digital model, generated of necessity by the firm manufacturing and fitting the BERTIM modules.
RenoBIM: New tools for the competitiveness of timber construction, Asier Mediavilla, Tecnalia

1. Context: why RenoBIM

During the last century most industries have been deeply transformed by technological progress, leading to a noticeable increase in productivity. However, this has not been the case in the construction industry, which remains as one of the least productive and digitalized, mainly due to the fact of its fragmentation. A huge number of companies with different skills and roles are involved throughout the life-cycle of a building, mainly (>90%) Small & Medium Enterprises (SMEs). This leads to a lot of manual and poorly coordinated processes, which lack industrialisation and automation. Many processes are not replicable and predictable.

The adoption of BIM (Building Information Modelling) offers an opportunity to reverse this situation. A digital model of the building guarantees more accurate data and better decisions, with significant time and cost savings. Together with prefabrication and robotization it is the basis for the Construction 4.0 paradigm. However, BIM is still mainly applied to new designs and less adopted for fabrication and construction phases and for retrofitting processes. Additionally, BIM software is still perceived as expensive, which requires investment in training and skills, only affordable by big companies.

RenoBIM tool, developed in H2020 funded BERTIM project, aims to overcome these barriers and demonstrate that BIM can be tailored to small companies’ needs and enhance their competitiveness by optimizing their processes and enabling efficient collaboration with other companies. It has been applied to the energy renovation using prefabricated timber panels.

The main goal is to speed-up the early decision-making, identifying the most efficient façade renovation alternative, following the methodology created in BERTIM project:

Check the project feasibility considering legislation, structure or building geometry.

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7 Annual Report on European SMEs 2016/2017 (European Commission)
Laser scanning and BIM model creation (in-house or subcontracted, depending on the skills and resources).

Energy simulation of renovation alternatives and identification of the most suitable product to use from the manufacturer’s catalogue.

Quickly design the façade splitting layout and export to CAD/CAM tools for final design for fabrication.

This can only be achieved through Open BIM formats like IFC, the main standard for data exchange between BIM software tools. It makes the solution independent from any specific commercial software, thus with higher market potential. Additionally, the use of IFC has made possible to implement very innovate features, such as automatic running of energy simulations using Energy Plus, web visualization of BIM models, properly geo-referenced and a 2D drawing module, which produces a design exported to IFC.

RenoBIM can be used in different collaboration workflows between clients and manufacturing companies, based on IFC file exchanges. Depending on the project type, objectives and available data different usage scenarios are possible following the previous steps. The functionalities are grouped into two modules: Decision Support Tool (DST) and Configurator.

2. RenoBIM DST module

DST module supports the early decision making, by providing a cost-benefit analysis of potential renovation alternatives from an energy savings perspective. It is targeted as a marketing tool of the manufacturer to attract potential clients’ interest by enabling them to estimate the savings using the
timber panels of the catalogue. But it could also be used by manufacturers themselves to estimate the potential of their products.

Step 1: project context

The user specifies the context of the building: location, typology and use (single-family house or apartment block), age and other aspects. Currently, RenoBIM is only customized for residential buildings, since this is the targeted market in BERTIM project, but it can be extended to other buildings, adapting the database and the simulation templates.

Step 2: feasibility analysis

The user can check if the renovation of the building is technically or legally feasible with the manufacturer’s technologies, considering the project context. Two types of restrictions are implemented. Generic BERTIM constraints include legislation (possibility to extend the building, to modify the façade or use timber for instance), type of structure or the status of the building, among others. They are always applicable. Specific constraints from manufacturers may include aspects like geometry complexity, free distance around, etc. Once the values for the building under analysis are entered, a feasibility check is run, and results displayed in a colour code indicating the fulfilment degree.

Figure 2. Checking project constraints and running feasibility check
Although this functionality could be used by both the manufacturer and the building owner, feedbacks obtained during the validation of the tool suggest leaving it as an internal feature for the manufacturer because a building owner has no knowledge about manufacturers’ products and processes, thus manufacturer should double-check clients’ answers and review the results. Additionally, instead of filtering too early potential market opportunities, it is better if manufacturers double-check by themselves the feasibility of the project.

**Step 3: building model creation or import**

RenoBIM relies on a building model to carry out its cost/benefit analysis. At this point, similarly to previous steps, it is flexible enough to adapt to different starting situations. For example, when no more data is available, the user can manually define the basic parameters of the building (such as number of storeys, orientation, glazing ratio, shape type and basic dimensions, as well as shadowing or adjoining buildings’ position and height) and a virtual building geometry is automatically created. This can be done by the building owner even before contacting the manufacturer or when the project feasibility is still unclear.

In a more advanced case, RenoBIM can automatically import a full BIM model in IFC format and process the geometry. This can happen when a contract is already done or when the owner has already a BIM model (not frequent for residential buildings). In any case (simplified virtual or detailed BIM) the model is converted to a web 3D format (using Cesium libraries) and displayed in RenoBIM.
The principle which should always be followed is to be able to reuse the same BIM model for different purposes. In this case of BERTIM the two main uses are: first, to serve as a detailed reference for CAD/CAM tools where to install the prefabricated panels and second, to serve for energy simulation.

For the first case, a guideline was produced on how to properly scan and model the building envelope and how to deal with aspects like openings, salient, etc. For the second case the guidelines include recommendations on how to create the internal spatial partitioning of the building. Only dwellings and common spaces have been modelled, not individual rooms inside each dwelling.

Figure 4. Point clouds (left), modelling of envelope (centre) and creation of spaces (right)

Step 4: conceptual energy and cost analysis

The final step in the DST is the simulation of different renovation alternatives and a comparison with each other and with the current situation of the building. The user indicates the type of envelope components (external walls, roof, windows and floors) in the building, if they have any insulation and inertia. Usually these aspects depend on the construction year, building typology and location. Then, the façades to be renovated must be selected.

Each renovation alternative consists on adding to the current façades an extra layer, which corresponds to each of the timber panels in the manufacturer’s catalogue (or variations in thickness and finishing of the same panel). Physical properties of the panels must be defined in the RenoBIM database, especially the thermal transmittance, as well as the unitary cost.
Based on the geometry and the thermal properties of both the existing building and the timber panels, RenoBIM automatically creates an input file for Energy+, one of the most popular and reliable energy simulation engines. The two main innovations offered by RenoBIM DST are:

- Use Energy Plus for both detailed approach (imported from IFC) and simplified approach (parametrically created geometry).
- Automatically run parallel simulations for each alternative, with no user interaction.

The first point provides a very flexible and robust simulation approach, using the same engine for all phases, adapting it to different levels of detail of the inputs (real geometry vs procedurally created). Since the same engine is used, the results are comparable. The second point allows using powerful dynamic engines by non-experts.

The Energy+ generation algorithms are based on previous research activities of Tecnalia in several EU projects.

Finally, an approximate cost and return on investment is calculated considering the total area covered by timber panels and the unitary cost of each, plus some possible correction factors, and transforming the yearly energy savings to saving in money, depending on the energy tariffs.

When the simulation is performed by the manufacturer, some filters can be applied, e.g. select different product combinations for different façades.

![Figure 5. Defining current envelope characteristics (left) and simulation options (right)](http://dsp.tecnalia.com/handle/11556/362)
For each simulated alternative energy consumption, energy savings compared to the baseline (current situation), investment in euros and return on investment (in years) are given. The description of the scenarios shows which panel is applied to each façade.

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Figure 6. Simulation results

3. RenoBIM Configurator

Once the most appropriate panel type is selected in the DST and the potential savings estimated, the next step is to make a first sketch using the RenoBIM Configurator module. The objective is not to produce a detailed design with all the constructive details of the system to be installed. Instead, it is intended for creating, quickly and easily, an optimized first predesign of the prefabricated panels, by saving a lot of time and quickly selecting the best configuration.

It is especially useful to facilitate the communication between the commercial department of the timber manufacturing company and the clients and architects who will develop the project. Nowadays, commercials often have problems understanding customers’ needs and RenoBIM offers a way to collaborate and share through the web a 3D visual model of the predesign, which can be exported to IFC to be used in external design and engineering tools.

This final IFC contains the original building plus the extra layer of building elements corresponding to the prefabricated timber modules. For the façade splitting layout, a Web 2D drawing functionality is offered.

The configuration process consists of 5 steps:
Step 1: Building configuration and panel type selection

Initially, the user uploads the IFC file of the current situation of the building, together with a DWG with the elevation view of the target façade. The timber panel selected in the DST is used here, and the configurator reads the panel properties from the database (thickness, maximum dimensions, etc.) and adapts to it. For example, the initial grid size will be adjusted according to the optimal size of the panel, as defined by the manufacturer. In addition, the user will have to define the distance between panels.

Step 2: Define sections and splitting

In this step, the wall section for the prefabricated elements will be defined. One or more sections can be defined. Within each area only a homogeneous group of panels can be placed. Then, openings can be created inside the section, which usually represent windows in the real building. Finally, the section is split into several panels using the grid. If a panel’s dimensions exceed the maximum sizes, the configurator marks them in red as a warning to the end user.

Step 3: Select installation panels

The solutions developed in BERTIM project include two types of timber panels. The simple ones are just insulation panels with different finishing options and the most complex ones include an extra space for carrying all the piping needed for installation systems. These allows a deeper renovation of the building, including HVAC installations, with no need to enter the building. The user has the option to indicate which of the created panels will contain piping for HVAC, as it is the case in the corner panel of the example below.
Step 4: Export to IFC

Once the configuration of the full façade has finished, the final step consists on the creation of the IFC file and download it to the local computer. The IFC export process creates additional `IfcBuildingStorey` entities, since the panels’ position may not respect the actual storeys of the building. Then, each panel is exported as an `IfcWallStandardCase`, which will contain `IfcOpeningElements`, when they contain an opening, mainly doors or windows.
Building energy renovation through timber prefabricated modules

Previous pictures show the result in the two test cases from the BERTIM project. On the left, a virtual demo building in Madrid, where the renovation contains HVAC installations (thicker). The result is visualized in an external tool (a free IFC viewer). On the right, a demo building in France, which is being renovated with BERTIM products. RenoBIM output has been imported in a CAD/CAM tool (Dietrich’s), where additional design details have been added to some of the panels.

4. Conclusions and impact

This paper shows an example of integration of actors and tools in complex processes like building energy renovation with prefabrication, using Open BIM as the main driver, but at the same time flexible by supporting alternative simplified approaches. Several technical challenges have been faced during the development: create a BIM model adapted to renovation with prefabrication and energy simulation, automatic conversion from BIM to Energy Plus and Web 3D technologies and automatic generation of IFC files from web drawing interfaces, among others. By means of these automations, RenoBIM is ready to be used by non-expert users.

The focus in BERTIM project is the renovation of residential buildings with prefabricated timber panels and this use case has been successfully tested in RenoBIM. However, it offers a great extension potential to other contexts (other types of buildings or other types of products and processes apart from prefabrication).

The main benefits for a manufacturing company can be summarized as follows:

- The companies can optimize their processes, digitalizing and automating data flows.
- They can collaborate more efficiently with other companies and with building owners by sharing the information through the web using a BIM model.
- It gives them the opportunity to digitalize their product catalogues and integrate them in design and simulation tools. This allows easily reaching new markets.

In parallel, new challenges arise for the companies: they must develop new skills for adapting to this new digital context. Sometimes they can be developed in-house, sometimes they can be subcontracted outside, which means they must create new relationships and business models with external collaborators.
Prefabrication of renovation modules for the "L'étape" building in La-Charité-sur-Loire: demonstrator of the Bertim project, Hervé Coperet, POBI and Zaratiana Mandrara, FCBA

1. Description of « l'Etape » building

The building "L'Etape" was built in the early 1960s. This building belongs to the city of Charity sur Loire. The ground floor is occupied by "les restos du coeurs" (humanitarian restaurant) and the other floors are between emergency housing and social housing. The total habitable floor area is 502m².

The city aims to rehabililate the building in order to host specific temporary housing related to a training activity, temporary contract or other short-term activities.

“L'Etape” building has a rectangular form on 4 levels and the main façade is oriented to the south overlooking to “Place de l'Europe”:

- South facade: main façade, entrance to the building, staircase with double frame, balconies on living room with access through French windows with doors, a bedroom with one window,
- North facade: Windows on the left and on the right give on rooms, central window gives on the kitchen and a system of logias with vertical concrete amount,
West facade: Window overlooks a room, presence of external stone decoration on the right of the facade,

East facade: 2 frames on the facade overlooking the bathroom.

1.1 Description of walls and equipments

1.1.1 Structure of the building

The exterior walls are made of blocks masonry, with two rows of load-bearing walls.

The floor are made of joists, hollow concrete slabs and concrete slabs. The beams carry the first gable wall to the second with two intermediate walls. The building does not have significant structural disturbances.

Roofing: with one slope. Insulation necessary above the roof slab.

Insulation: no insulation on external vertical walls and on the ground floor.

Exterior joinery: wood joinery with single glazing.

Ventilation: Static ventilation of dwellings by grids in facades and vertical sheath in the kitchen. Lack of grid maintenance makes the system ineffective. Studios are not ventilated.

Heating: The collective heating is connected to the boiler room of the city. Each floor is then supplied with hot water radiators, the same heating circuit feeding all the rooms superimposed from one floor to another (a circuit for all the stays, a circuit for all the clearances, a circuit for each room bath, etc).

Electricity: Presence of several electrical control panels per dwelling

Floor covering: majority in tiled, presence of soft linoleum coating in some rooms.

Wall and ceiling coverings: the first floor housing has been completely repainted, all the other units are in a state of variable degradation. Poor ventilation is a major source of deterioration (traces of fat in kitchens, taking off by humidity in the bathrooms).
2. Retrofitting design

2.1 Certification procedures

A repository for certification of renovation solutions has been developed within the framework of the BERTIM project including performance evaluation procedures based on a technical file, on file and photo tracking methods, on factory and on-site measurements and Implementation. The "L'Etape" building served as the first certification example for POBI.

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<tr>
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<td>Connection between the vertical and horizontal walls, between two vertical walls...</td>
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<td>Connection of joinery and vertical and horizontal walls</td>
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<td>All the particular details specific to the constructive system studied</td>
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Figure 2. Technical description for certification

The certification carried out by FCBA in BERTIM on the modules planned for the renovation of this building takes into account the characterization of the existing envelope (mechanical, energetic, acoustic performances), going through the manufacturing and up to the renovated envelope made at the end of the demonstrator.
2.2 Existing building performances

2.2.1 Geometric statement

The BERTIM project has enabled the application of several methods of surveying building facades in Charité sur Loire. We tested the method by 3D scanner, photogrammetry with drone and total station method.

Figure 3. Differences between SCAN 3D laser surveys and photogrammetry to obtain the digital model
The digital models obtained by 3D laser scanner, and by photogrammetry and drone are difficult to exploit by business software without significant additional processing. Indeed the precision required in the specifications (5mm) can not yet be satisfied for current market technologies despite the extensive effort made by the BERTIM team and the chosen professional providers.

![Building energy renovation through timber prefabricated modules](www.bertim.eu)

Figure 4. Survey of the building by total station (theodolite)

In the end, the readings obtained by a total LEICA station, in two times (520 measurement points), made it possible to redesign the building on DIETRICH’S as close as possible to the real dimensions of the building.

This demonstration has thus made it possible to note the lack of precision that market techniques could generate in geometrical survey of the building if the operation is not studied in advance, with defined methods, with an important numerical treatment and an on-site verification after modeling.
2.2.2 Energy performance

A diagnosis of the envelopes was made with the help of a thermal camera and measurements of temperature and heat flow through the walls.

Figure 5. Identification of the thermal bridges on the existing building by infrared camera: external floor and wall connections, balcony, contour of the openings (T ext = 7 °C and T int = 18 °C)

Figure 6. Extract recording measurements over 24h (15/12/2018)
The theoretical thermal transmission coefficients $U \ [\text{W/ m}^2\text{K}]$ based on the thermal conductivities of the components are greater than those measured.

![Figure 7. Temperature, relative humidity and heat flow recording instruments](image)

The current performance of the building corresponds to an annual consumption of $200\text{KWh/m}^2\text{year}$: class D according to french regulation RT2012. The aim of the project is to reduce this consumption by at least 50% by renovating the enclosures: insulation and replacement of joinery, integrated ventilation in joinery.
2.3 Choix des murs à rénover

Figure 8. Plan presenting the renovation choice on the building on R + 1 to R + 3
Red: exterior renovation with BERTIM modules
Green: Insulation operation from the inside: project in phase 2 by city authority

2.4 Performances énergétiques après rénovation

As part of BERTIM project, we applied the decision support tool RENOBIM with alternative solutions proposed for the demonstrator, along with existing RT2012 regulatory calculations.

The simulation results on several variants of outdoor insulation solution pre-see up to 72% of saved energy. The simulations make it possible to pass from a consumption of 220KWh / m²an (DPE class D) to between 60 and 90KWH / m²an (DPE class B). The solution chosen by the town hall corresponds to an approximate consumption of 85 KWh / m²an with the solution that offers a better quality / price
ratio and thus the best ROI. The main insulation thickness of 120mm is standard for the factory and does not result in modification or creation of article on the production line in POBI factory.

Figure 9. Composition of prefabricated modules

Détail 1 : LIAISON ANGLE avec Parement PIERRE

Figure 10. Example of details on singular points with a simulation of thermal bridges

The technical study file validates the theoretical design and will be completed by verifications in the factory and in the field after construction.
3. Préfabrication des modules de préfabrication en usine

3.1 Présentation de l’usine de fabrication POBI

POBI is a family business created in 1929, in Charité-sur-Loire, in the Nièvre, near Nevers. Over the years, POBI develops different activities: Manufacturer of industrial and traditional structures, manufacturer of wood frame panels, global offer for building owners.

AST Groupe (corporate headquarters in Décine Charpieu, Rhône), builder, developer and developer since 1993, market leader in Rhône-Alpes and Burgundy, listed on the stock market, acquires the industrial factory POBI to make it the wood frame production unit for its new timber frame house construction network (the Natilia brand).

3.2 Les étapes de préparation et études de la préfabrication

- Execution technical study: calculation notes, execution plan,
- Production scheduling:
  - Synchronous flow manufacturing of joinery
  - Preparation of specific flows: wood, insulation, ...
  - Preparation / reception of material orders
- Manufacturing

Duration of the step: (Experimental Indication) 10 Days

3.3 Les étapes de fabrication POBI : LEAN Manufacturing

The plant operates according to the LEAN MANUFACTURING (Operational Excellence), a production management system modeled on that of the automotive industry, based on three fundamental elements: the reduction of costs by the elimination of wastes, the production in just in time, the quality.

In Image 11: 1-Flow Opening Dies, 2-Mounted Trimmer, 3-Mount trimmer, 4-Pose Vapor Barrier - Laying Two Sides, 5-Pose Lifting Strap, 4-Pose Insulation Glass Wool, 5-Pose working sails, 6-Staple and cutting working sail, 7-Call Swing and recovery rods, 6 & 7-Gluing working sail, 6 & 7-Pose Polyester, 7-Supporting wall by conveyor, 8-Staple of the rain barrier, 8-Cutting Rain-barrier + Waterproofing, 9-Pose
bottom and top drip, 9-Pose MYRAL cladding, 10 & 11-Cutting openings, 10 & 11-laying and waterproofing PVC joinery, 13-Panel Verification.

![BERTIM Organisation Production](image)

**Figure 11. Organization of factory production**

### 3.4 Time-line of timber frame panel manufacture

The following graph shows the manufacturing time-line simulator for an example panel: 8 line operators. The production of a 6,60m * 2,70m wall is 23minutes.
The number of walls planned for the renovation of the "L'étape" building is 15 prefabricated panels in the factory on 284m² and a site adaptation of 118m². Joinery is integrated into factory walls, as well as exterior cladding. In total, the surface of the renovation is 402m² of wall.

4. Mise en œuvre sur chantier

The estimated duration of the project is 5 days.

Means of lifting:

- Mobile crane PPM 30m of arrow
- Platform

Installation team: 3 persons and 1 crane operator

Mounting steps:

Implantation of the fixing brackets according to the plan defined by the design office and by the reference lines defined in the geometrical statements at the Total Station. Then assembly of the prefabricated panels from level R+1, R+2, R+3.
Figure 13. Installation of the panels by level: the first panels correspond to the 1st floor

Figure 14. Façades of the building "l'Etape" after renovation
5. CONCLUSION

The BERTIM (Building Energy Renovation through Timber Prefabricated Modules) project benefited from a real demonstrator thanks to the achievement of a renovation operation on three levels of the "L’Etape" building belonging to the city of Charité sur Loire. As part of the BERTIM project, the demonstration task involves the characterization of existing walls and geometric measurements. Then, the design of prefabricated modules: architectural modeling, mechanical, energetic and environmental dimensioning, economic study. Subsequently, we were able to experiment with the prefabrication stages at the POBI plant and finally the realization on site. Apart from the experiments and studies carried out for the BERTIM project, the actual operations of study, supply, prefabrication and implementation took a total of 1 month: this short time is one of the appreciable advantages in favor of prefabricated reinforcement solutions based on wood framing, in addition to recognized performance.