EXPERIMENTAL ENVELOPES AND THEIR INTEGRATION IN THE BUILDING INFORMATION MODELING ENERGY SIMULATION PROCESS

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ABSTRACT

The present contribution deals with an ongoing Italian research which includes several steps and it is approaching to its final stage. The main goal is analysing and testing the feasibility of municipal waste reuse for designing building envelopes for Near Zero Energy Buildings (NZEB), so as to contribute to the decreasing demand for energy and improve eco-friendly waste management in urban areas. First, prefab building components have been designed using selected waste and their thermal and acoustic behaviours have been calculated, according to the European rules; then the economic costs of the obtained building envelopes have been assessed and compared to common building structures to verify their possible appeal on the Italian market, and finally the components have been assembled in the project for a small NZEB building: a didactic classroom for the Mira Porte Primary School (Venice, Italy).

This paper refers to the in-depth elaboration of the project, mainly concerning fire and pollutant protection, and it focuses on the reliability check of the Building Information Modeling (BIM) parametric model, especially as concerns non-conventional materials and components. The relative building energy behaviour has been obtained exporting the BIM energy simulation model using the EC770 Integrated Design for Revit plug-in. Finally, a comparison between the results obtained with the traditional energy assessment (according to D.M. 26/06/2015) and those using the BIM model has been made to evaluate the interoperability between architectural modeling software and the energy simulation one.

Keywords: BIM, energy behaviour assessment, energy simulation, high performance components, municipal waste reuse, parametric modelling, Zero Energy Buildings.

1 INTRODUCTION

In view of the European Union's regulatory framework, the latest legislation directly encourages and boostes reuse and up-cycling of waste [1]. The average quantity of household waste thrown away in EU every year is around half a tonne per person, in addition to industrial waste coming from activities such as manufacturing (360 million tonnes) and construction (900 million tonnes) with water and energy supplies accounting for a further 95 million tonnes. Altogether, the European Union produces up to 3 billion tonnes of waste every year. The consequent pollution and greenhouse gas emissions have a huge impact on the environment and contribute to climate changes [2].

The long-term goal of EU's waste management policies is to turn Europe into a recycling society, trying to avoid unnecessary waste and convert it into a resource, with the prospective of reaching higher levels of recycling while minimizing the extraction of natural resources. Proper waste management is considered a key element in ensuring resource efficiency and the sustainable growth of European economies [3]. The Waste Framework Directive, the backbone of the EU waste policy, was revised after the introduction of the 2005 Thematic Strategy on Waste Prevention and Recycling. Under the revision, a modernized approach to

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waste management was introduced, leading to a change from considering waste as an unwanted burden to considering it as a valuable resource. New targets have been set under the Directive 2008/98/EC on waste. By 2020, EU member states aim to recycle 50% of municipal waste and 70% of construction waste. In the Directive's five-step waste hierarchy, prevention is at the top as the best option, followed by re-use, recycling and other forms of recovery, with disposal such as landfill as the last resort [4].

In December 2015 the European Commission adopted the Circular Economy Package, which includes revised legislative proposals on waste to stimulate Europe's transition towards a circular economy which will boost global competitiveness, foster sustainable economic growth and generate new jobs [5].An EU Action Plan has been established under a Circular Economy Package which covers the complete cycle of waste, from production, consumption, and waste management, under a series of ambitious programs of actions, the aim of which is to complete the life-cycle of products and encourage recycling and re-use to protect the environment and boost the economy [6].

Waste and water are also special priorities in the challenge *Climate Action, Environment, Resource Efficiency and Raw Materials* in Horizon 2020, the most important EU program for research and innovation. Horizon 2020 calls for eco-innovative solutions and resource-efficient products, processes and services, promotes the use of waste as a valuable resource, in line with the EU Resource Efficiency Roadmap and the Waste Framework Directive.

EU strategies are combined with the voluntary initiatives of European cities in Europe, such as Covenant of Majors and the Smart Cities network, promoted by the SET-Plan, the technology pillar of the EU's energy and climate policy [7].

The present research deals with the reuse of solid urban waste for the designing of building envelopes for Near Zero Energy Buildings, introduced by Directive 2010/31/EU "*Energy Performance Building Directive"* (EPBD) [8]. In order to achieve the level of performance requested for a NZEB, specific design strategies and technological and engineering solutions must be developed, applied and tested, so as to identify the most effective in terms of efficiency, sustainability and costs [9]. The research aims at analyzing the feasibility of innovative components in the project of a small NZEB building: the enlargement of the Mira Porte Primary School, in the province of Venice, Italy [10]. The development and demonstration of technological solutions based on reuse and up-cycling of waste, boosting eco-innovative solutions and testing them in real-life environments, will enhance their market uptake and contribute to sustainable global urbanization [11]. The research agreement between the Interdepartmental Centre for Territory, Building, Conservation and Environment of the Sapienza University of Rome (CITERA) and the Municipality of Mira includes the designing, carrying out and *post operam* monitoring of a classroom of about 100 total sq m, divided into a didactic area and a winter garden.

The present stage is the development of the detailed project, investigating and solving the residual critical aspects, especially those linked to the use of unconventional materials, and is aimed at obtaining the authorization to build, in compliance with all the Italian and local government rules on the environment and construction. In particular, the requirements in terms of energy consumption, fire protection, safety, indoor well-being and comfort, seismic hazard, use of soil, are respected. Moreover, the building respects the Italian technical legislation concerning planning and restoration of school buildings [12]. A BIM 3D model (Building Information Modeling) has been built and used to test the energy behavior.

2 COMPONENTS FOR EFFICIENT ENVELOPES MADE FROM TYRES AND PALLETS REUSE

The municipal wastes considered in this research for designing energy efficient envelops are: tyres, wood pallets, cardboard tubes, glass and plastic bottles [13]. The present paper deals only with the components made from reused tyres and wood pallets, selected for the classroom building project. The thermal transmittance of the components (U), has been calculated according to UNI EN ISO 13790 "Thermal performance of building components. Dynamic characteristics. Calculation methods". The reached value allows the use of assembled building envelope structures in all the Italian climatic zones in compliance with the legal limits of the Italian building regulation also for years to come (D.P.R. 26/08/1993, n. 41). In consideration the thermal resistance of indoor and outdoor air film surfaces, this value has been estimated considering the reciprocals of indoor and outdoor adduction coefficients taking into account convective and radiative heat transfer [14]. Additionally, the thermal conductivity for all the selected materials has been obtained by consulting the database of the Italian Heating Engineering Committee—Energy and the Environment (CTI) of the Italian National Unification (UNI).

All the municipal waste considered in this research is used as infill in assembled modules and needs a complementary primary structure. A wooden structure of beams and pillars with metal joints has been selected as the most compatible and flexible. Moreover, it allows further reuses after the building is decommissioned.

2.1 Deepening step of the design of the components and the building envelope: fire and pollution protection

After the architectural design of the classroom and the envelope design have been integrated with the plants design, an in-depth technical analysis of the components was necessary in order to comply with Italian rules on fire and pollution protection. To be accepted by the market and have the opportunity for real use in the building construction sector, a demonstration of the non-harmfulness of the components and an evaluation of fire risks are necessary. The building hosts a classroom and an annexed winter garden of about 100 mq in total, with an expected presence of 28 people, so it does not fall within the activities subject to Fire Prevention included in the D.P.R. 151/2011 but, because of its particularly delicate didactic destination, the D.M. 10 march 1998 "General criteria for fire safety and emergency management in the workplace" has been applied.

According to the Attached 1 to the D.M. 10 march 1998 "Guidelines for the assessment of fire risks in workplaces", combustible materials, such as gas, paint and flammable solvents, paper, packaging and plastic materials must be identified, possibly isolated and stored in security. Fire prevention and protection measures must reduce the possibility of a fire and limit its consequences if it occurs. In general, the adoption of the following measures can be considered as compensatory in case the elimination of all the risks is not achievable: escape routes, tools and systems for extinguishing, detection and fire alarm systems, information and training for the users of the spaces.

In the experimental building designed for the Mira school, the most critical element under the fire risk point of view, is the presence of tyres and straw in the envelope components placed mainly in the north facing wall. Consequently, the project of the classroom includes the provision of fire-fighting measures: 2 opposite escape routes with REI 60 doors, 3 powdered type fire extinguishers placed near the escape routes, a program of evacuation from the building. Nevertheless, as the component can be used in other contexts, in bigger and more complex buildings that may need a careful and in-depth fire risks evaluation, the research defined in detail the stratigraphy of both the tyres and pallet components, selecting the complementary elements and materials included, in order to guarantee the protection and isolation of flammable materials in any condition of use.

The so conceived external layers are able to answer also to concerns over tyre particles pollution [15].

The ultrafine particles that detach from the surface of tyres during their use and constitute one of the most dangerous elements of urban pollution, are only produced by friction, so dismissed tyres do not release pollutants [16]. Any possible residuals are neutralized enclosing the tyres in the OSB shell.

2.1.1 Component made from reused wood pallets

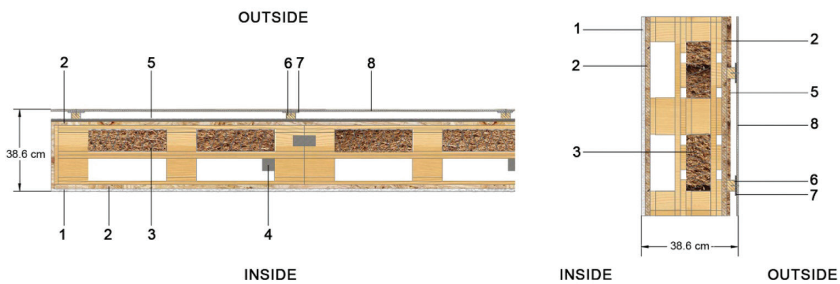

Figure 1: Horizontal and vertical sections of the component made from 2 reused pallet. Placing in the building envelope of the classroom: West and South facing walls, part of East facing wall.

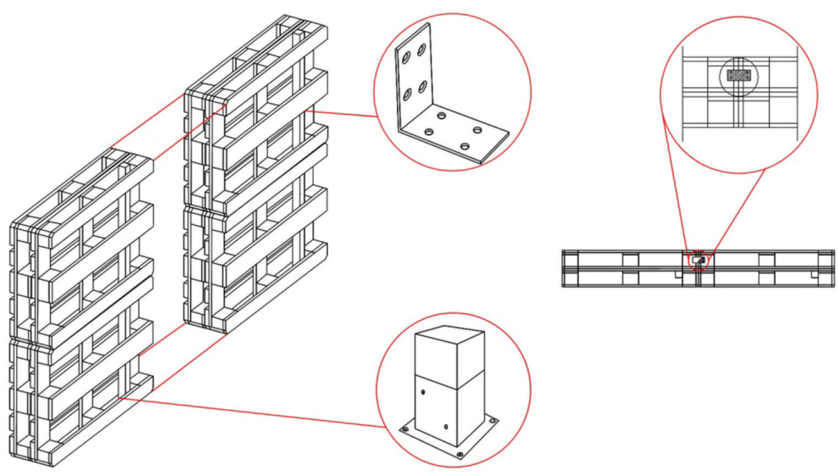

Figure 2: The pallet components are fastened together using 4-hole smooth metal plates positioned at the contact points in the internal part of the pallets. The two overlapping pallets that form the component are fixed to each other by means of inclined bolts.

Table 1: Legend of the horizontal and vertical sections of the component in Figure 1.

Legend of horizontal and vertical sections of the pallet component	
1. Porotherm Heavy fireproof plaster, based on anhydrous gypsum and perlite (cm1.5)	Protective fireproofing plaster, based on anhydrous gypsum and perlite, applicable by hand or machine. In conformity with DM 16/02/2007.
2. KronospanFirestopOSB3 Panel (cm2)	Coating consisting of flame retardant materials based on magnesium oxide, reinforced with fiberglass. This coating provides the OSB panel with a strong cohesion and a high resistance to combustion. Furthermore, it increases shear and bending strength. EN 300: OSB3 type; EN 13501-1: class B-s1, d0.
3. Pavatherm panel in wood fiber (cm12)	The insulation provides protection against cold and heat and sound insulation thanks to the porous structure of the slabs. Fire behaviour (EN 13501-1): class E.
4. Wooden upright (cm 6 x 6)	Walls made with pallets are stiffened and stabilized by the insertion of a lamellar wood pillar that vertically crosses the components, hooking them to the foundation slab with a bearer and to the covering beam with angular plates or riveting.
5. DuPont Tyvek protective membrane	Breathable monostrate membrane for ventilated walls. It allows the passage of water vapor while offering a barrier to water and resistance to UV rays.
6. Wooden upright for ventilation (cm 3.4 x 7)	Lamellar wood uprights for the support of ventilation external finishing panels.
7. Metal joint	Metal joint for covering panels.
8. Rockpanel for microventilated walls (cm 0.8)	Prefabricated panels in compressed mineral wool with an organic thermosetting layer. The surface of the panels is treated on one side with four-layer water-based polymers, and has the protective Protect Plus treatment. Fire behaviour (EN 13501-1): B-s2, d0.

2.1.2 Component made from reused tyres.

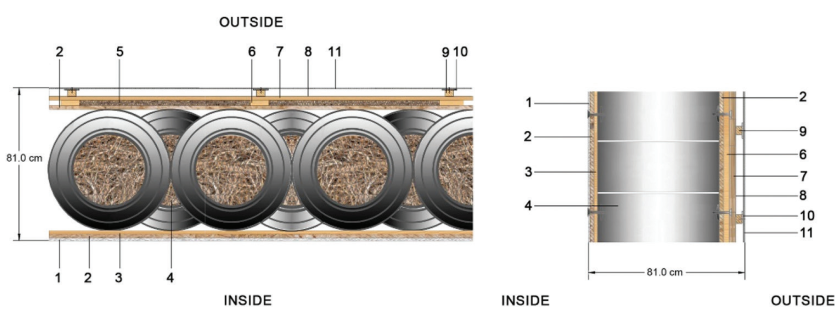

Figure 3: Horizontal and vertical sections of the component made from tyres. Placing in the building envelope of the classroom: North facing wall and part of East facing wall.

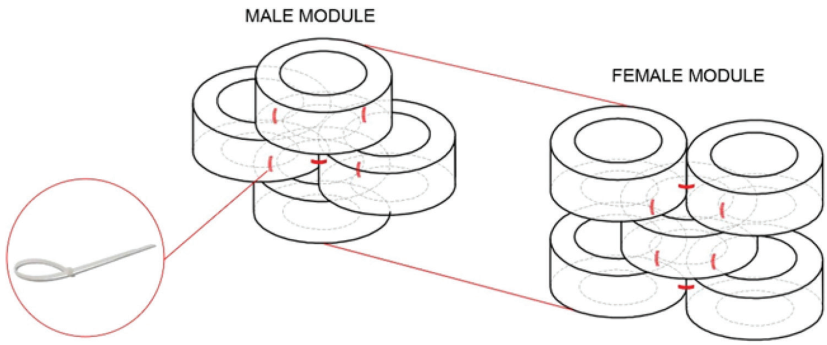

Figure 4: The tyres are assembled in male-female modules and positioned in place by interlocking. These modules are fixed by means of nylon self-locking clamps with teeth, inserted in prepared holes.

3 BUILDING ENERGY SIMULATION USING THE BIM MODEL

In compliance with the European Directive 2014/24/EU on public procurement [17], in Italy, the D.L. 01/12/ 2017, art. 23, Code of Contracts, provides a progressive introduction of electronic modeling methods and tools for construction and infrastructure. The BIM (Building Information Modeling) will be mandatory from 2019, but only for works of the value of over 100 million euro. Then, a series of progressive deadlines will be scheduled, and the system will be fully operational in 2022, when the BIM will become mandatory for all procurements. However, the contracting authorities may already require the use of specific electronic methods and tools for new constructions and renovation interventions.

The introduction of the BIM within the new Code of Contracts, will therefore increase its diffusion also in Italy; the integrated design carried out using electronic methods and tools for building and infrastructure modeling, has yet to be experienced on a large scale in the Italian reality, strongly characterized by small construction companies and medium-small contracts.

The BIM can provide an important contribution to "green" design, allowing to make the most of the integrated processes among the different disciplinary fields in order to achieve the best sustainable design results [18]. Being able to incorporate many aspects into a single multidisciplinary information model, has made it possible to make performance analyzes in the early stages of the process in order to have a feedback on different initial design options. The most important decisions on sustainable issues of the building can be taken from the beginning of design while in a traditional process, the analysis of the building's energy performance is generally conducted after the architectural project has been completed. A separate performance evaluation requires much longer time and higher costs. Furthermore, the lack of continuous monitoring of sustainability aspects within the project creates inefficiencies in the process and causes subsequent changes and updates. With this methodology, on the other hand, not only is it possible to carry out accurate simulations of the thermal and visual comfort of buildings with consumption and energy saving assessments, but also the energy aspects, incorporated from the first design decisions, can be followed during the whole life cycle of the building [19].

The just illustrated BIM characteristics have made significant the modelling of the experimental classroom through a BIM software and the use of the obtained 3D model as a basis for carrying out an energy assessment, in order to test the methodology and to bring out

Table 2: Legend of the horizontal and vertical sections of the component in Figure 3.

Legend of horizontal and vertical sections of tyres component	
1. Porotherm Heavy fireproof plaster, based on anhydrous gypsum and perlite (cm1.5)	Protective fireproofing plaster, based on anhydrous gypsum and perlite, applicable by hand or machine. In conformity with DM 16/02/2007.
2. KronospanFirestopOSB3 Panel (cm2)	Coating consisting of flame retardant materials based on magnesium oxide, reinforced with fiber glass. This coating provides the OSB panel with a strong cohesion and a high resistance to combustion.
3. Wooden anchor traverses	The wooden traverses make it possible to connect the OSB panels to the load-bearing structure, consisting of lamellar fir wood pillars.
4. Compressed straw	Insulation in compressed straw, inserted inside the tyre. It allows an excellent thermal insulation and a high sound-absorbing power, ensuring noise reduction up to 55 db.
5. Pavatherm panel in wood fiber (cm 4)	The insulation provides protection against cold and heat and sound insulation thanks to the porous structure of the slabs. Fire behaviour (EN 13501-1): class E.
6. Wooden stiffening structure	Set of wooden planks arranged horizontally which allow the structure to be stiffened to guarantee a major stability of the components and the whole wall.
7. Wooden boards	Wooden boards arranged horizontally that allow you to stiffen the component and ensure complete stability of the entire wall.
8. DuPont Tyvek protective membrane	Breathable monostrate membrane for ventilated walls. It allows the passage of water vapor while offering a barrier to water and resistance to UV rays.
9. Wooden upright for ventilation (cm 3,4 x 7)	Lamellar wood uprights for the support of ventilation external finishing panels.
10. Metal joint	Metal joint for covering panels.
11. Rockpanel for microventilated walls (cm 0.8)	Prefabricated panels in compressed mineral wool with an organic thermosetting layer. The surface is treated on one side with four-layer water-based polymers, and has the protective Protect Plus treatment. Fire behaviour (EN 13501-1): B-s2, d0.

advantages, critical aspects and reliability of the process in a small building, characterized by unconventional technologies.

3.1 Comparison between the energy simulation carried out with BIM and with the traditional method

Many BIM modeling software packages contain several functions for energy analysis, but it is necessary to export the model into interoperable software, specifically designed to simulate energy behavior, to obtain a more detailed assessment.

However, there are various applications and different plug-ins that generate dissimilar results for the same case study, a problem that must necessarily lead the user to evaluate the reliability and the calculation method of the chosen simulation program [20].

The described experimentation involved a comparison between the BIM parametric energy model of Mira's classroom and a traditional energy model realized with Edilclima EC700 software (according to D.M. 26/06/2015). The data were compared to verify the correspondence or any discrepancies.

The virtual BIM model of the classroom and the adjoining winter garden was built using Autodesk Revit Architecture [21]. Subsequently, this model was used to carry out an energy simulation with the Edilclima Engineering & Software EC700. To make data between Revit and Edilclima interoperable, the EC770 Integrated Design for Revit plug-in was used. In this way, it was possible to refer to the only 3D model developed with Revit, without the need to model another one through energy simulation software. The main advantages of this operation are the time saving, due to the use of a single model, and, above all, the possibility to update the energy simulation in case of project variations. For example, it is possible to carry out more simulations by varying the materials and the thickness of the elements until the expected performances are achieved.

The first criticality is that not all the data about the systems used within the Revit model are automatically imported: information about the used materials and technologies, as well as the envelope performance characteristics, essential for the purposes of energy analysis, must be entered manually into the software used for the simulations [22].

This operation requires subsequent updates in the eventuality of changes in materials or their characteristics; moreover, it is not always possible to find effective combinations between the Revit materials library and the energy simulation software library. Therefore, this operation must be carried out with great awareness, especially in the case where the design includes innovative components, not present on the market and not codified, as in the present case study.

An emblematic example of this difficulty concerns the components made with tyres and pallets. In the parametric architectural model built with Revit, it is possible to realistically draw the outer envelope made up of these components (Figs 5 and 6), formed from the reuse of the two types of waste and a series of complementary layers. When these elements are imported into the energy simulation software, however, it is not possible to evaluate their energy performance because tyres and pallets are interpreted as individual objects and not as part of the wall's stratigraphy.

Therefore, the separate calculation of the thermal transmittance of the combined double pallet, one of which is insulated with wood fiber, is necessary and the same occurs for the tyre element insulated with straw: the traditional method (UNI EN ISO 13790) has been used and the resulting data have been manually entered in Edilclima (Table 3 and 4). The complementary layers (plaster, OSB, ventilation, etc.) can be added in Edilclima in order to finally obtain the entire envelope package data (Fig. 7). The definition of the rooms and the insertion of geographical information, climatic data, occupancy density, time of use of the building, temperatures, information on the environments, surrounding buildings and shadings, are simple and effective.

The Global Energy Performance Index of the building, calculated according to D.M. 26/06/2015, is 92.50 kWh/m² year and the value obtained using the 3D Revit model in combination with the EC770 Integrated Design for Revit plug-in is 92.20 kWh/m² year. The difference between the two results is very close so the BIM method applied to the energy simulation can be considered reliable. However, the advantage of its use is partially limited

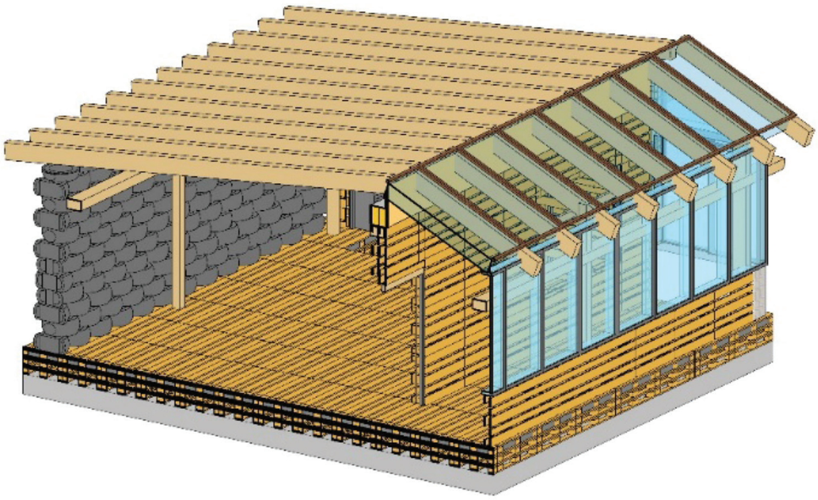

Figure 5: BIM model without covering internal and external layers and without the West wall. (Source: Spiridigliozzi, 2017).

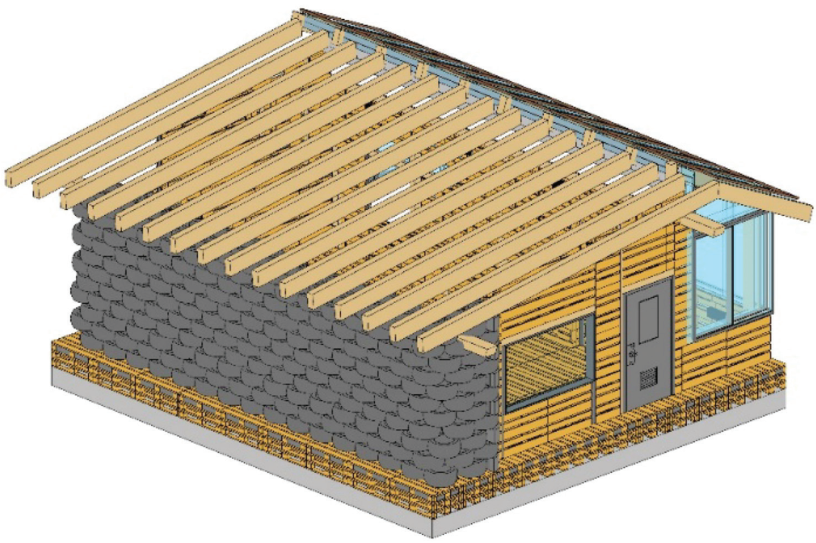

Figure 6: BIM model without covering external layers: North and West walls. (Source: Spiridigliozzi, 2017).

by the manual insertion of the values relating to the materials from the solid urban waste reuse.

At this stage of the BIM software evolution, the interoperability of data between the architectural model and the energy model needs to be implemented: an omni-comprehensive parametric model does not exist but, globally, information models improve efficiency and cooperation within the integration process [23].

Table 3: Insulated pallet transmittance calculation, according to UNI EN ISO 13790 (U = 1.78 W/m²K).

Layer	Thickness (m)	Thermal Conductivity κ (W/mK)	Thermal Resistance R (m²K/W)
Indoor air film surface			0.125
Pavatherm panel (wood fiber)	0.12	0.038	3.158
Wood pallet	0.03	0.14	0.214
Outdoor air film surface			0.043

Table 4: Simple pallet transmittance calculation, according to UNI EN ISO 13790(U = 0.28 W/m²K).

Layer	Thickness (m)	Thermal Conductivity κ (W/mK)	Thermal Resistance R (m²K/W)
Indoor air film surface			0.125
Air gap	0.13	-	0.18
Wood pallet	0.03	0.14	0.214
Outdoor air film surface			0.043

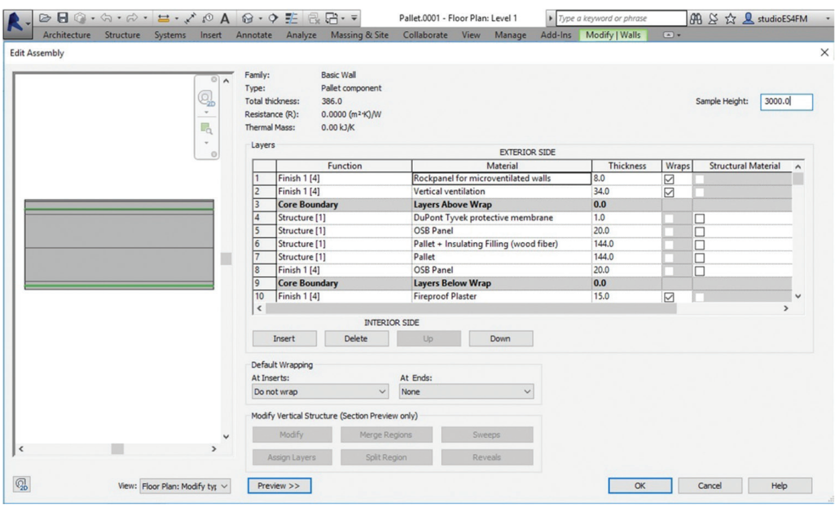

Figure 7: Screenshot of Autodesk Revit Architecture software: definition of the stratigraphy of pallet component, made from an empty pallet, a pallet filled with insulation and additional layers (covering, ventilation, internal finishing, etc.). Pallets are included as simplified layers and not with their real geometric features. Total transmittance: 0.22 W/m²K.

4 CONCLUSIONS

The last step of the research involves the construction of the building and its *ex-post* monitoring, aimed at the verification of energy behavior and indoor comfort. At this stage, the Mira classroom design and the development of each envelope and partitions component can be considered as concluded. The resulting building is in compliance with the building, safety, hygiene and energy saving laws that regulate construction in Italy. Therefore, the project is suitable for submitting to the competent State and Municipal bodies for its acceptance and approval before proceeding to the construction phase in the identified site (courtyard of the Mira Porte school). The cost of the building has been estimated at € 95,000, thus staying within the budget established in the agreement between the Municipality of Mira and the CITERA of Sapienza University of Rome. The budgeted amount must be approved and financed by the Municipality and the expired convention with the Sapienza University must be renewed.

The project has been developed in BIM with the adjunctive aim of testing the evolution of information design processes using this real case study. The main focus regards the integration of energy aspects into the design process, in particular the collaboration between the architectural and energy fields, essential to achieve building sustainability.

The level of interoperability between architectural modeling software and energy simulation software has been verified, finding some criticalities and trying to find solutions that guarantee the most reliable results. It emerges that information models can improve efficiency and cooperation within the integrative process even though, at present, the level of technological maturity of BIM does not allow complete interoperability, thus denoting the need for further development of its potential. In particular, the lack of flexibility and adaptability of BIM has been highlighted in the case of building components that cannot be easily assimilated to simple masonry layers, if not using alternative and hybrid procedures. However, the use of such procedures partially reduces the advantages of parametric models.

Before starting a 3D BIM modeling of an unconventional building, identification of the main final objective is advisable: if it mainly resides in the management of energy aspects, it is necessary to evaluate whether it is more convenient to model realistically the various technological components or to assimilate them right away to stratified wall elements.

The energy analysis of the whole building, conducted through the use of the Bim EC770 Integrated Design for Revit plug-in and through the traditional method, has led to substantially coincident thermal performance results. This evidence, albeit positive, is not to be considered sufficient to evaluate the reliability of the BIM integrated energy calculation in the case of buildings characterized by more complicated geometries, larger dimensions and greater technological-plant complexity.

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