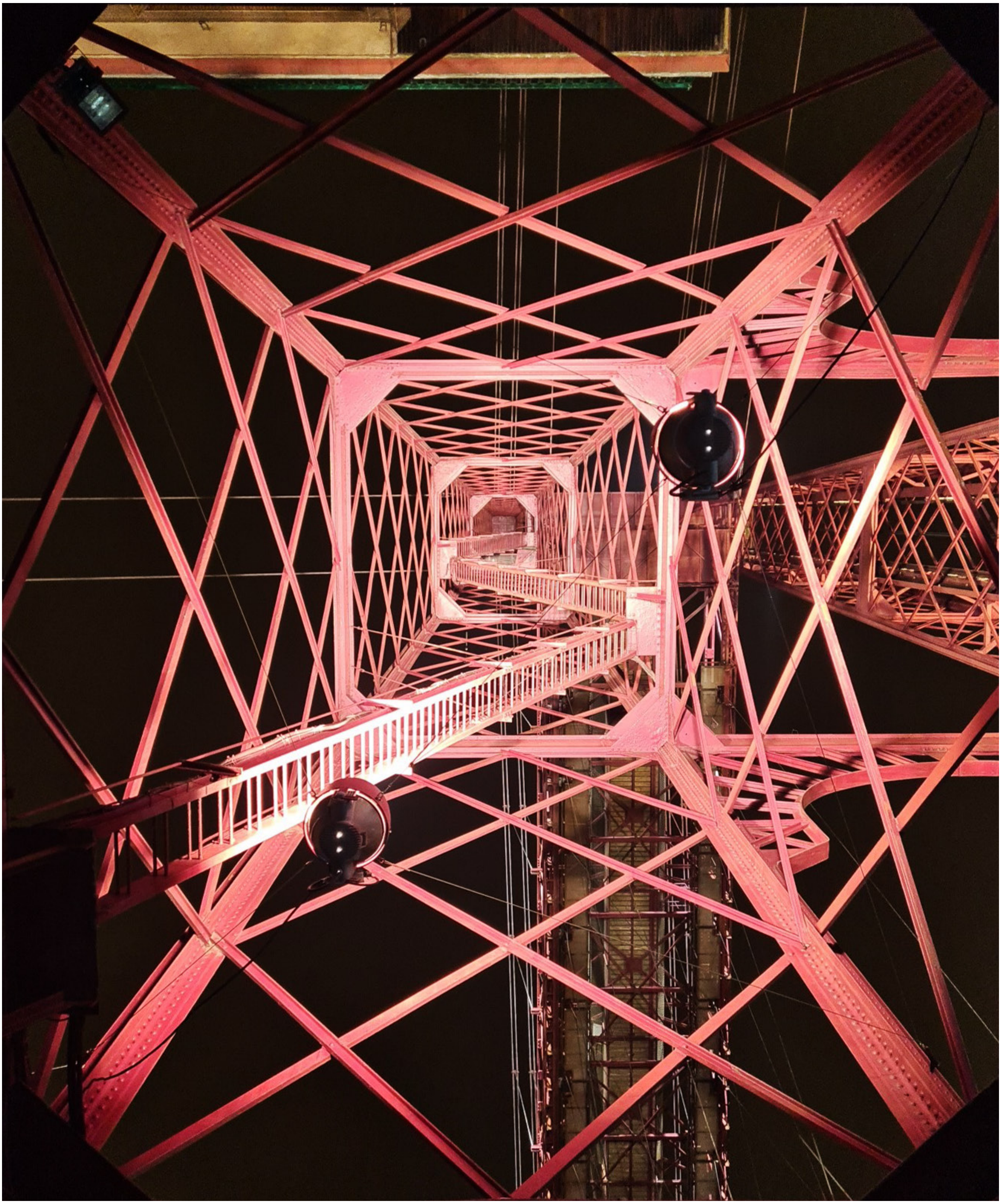

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IMPACT OF MODELLING ON THE ASSESSMENT OF ENERGY PERFORMANCE IN EXISTING BUILDINGS: THE CASE OF CONCORDIA SAGITTARIA

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Lorna Dragonetti, Davide Prati, Annarita Ferrante

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Abstract

Energy efficiency in existing building stock is a priority for achieving the decarbonization objectives imposed by the European Union. Several European projects have addressed the issue and suggested strategies. In particular, the TripleA-reno project has among its objectives the development of a web tool for the energy assessment of buildings so that users can simulate the economic and energy benefits of the renovation process.
The paper aims to assess the impact of simplification in geometric, energetic and modelling input on the calculation of the energy performance of buildings. The study was conducted on a case study of the TripleA-reno project, located in Concordia Sagittaria (Venice).
The architectural configuration, the structural typology and the stratigraphies of the building and the interventions foreseen by the redevelopment project are described.
After defining the energy modelling software intended to be used, a detailed energy assessment was carried out, which was subsequently approximated by maintaining unchanged only the gross heated volume and the characteristics of the opaque and transparent elements. The different energy assessments were then analyzed to compare and evaluate the parameters most influenced by the simplification introduced and the variation of the S/V ratio.
Finally, the TripleA-reno platform was used to compare the results with both the detailed and the simplified model.

Keywords

Sustainability, Energy efficiency, Energy modelling, Deep Renovation.

Lorna Dragonetti*
DA - Dipartimento di Architettura, Università degli Studi di Bologna, Bologna (Italy)

Davide Prati
DISA - Dipartimento di Ingegneria e Scienze Applicate, Università di Bergamo, Bergamo (Italy)

Annarita Ferrante
DA - Dipartimento di Architettura, Università degli Studi di Bologna, Bologna (Italy)

** Corresponding author: e-mail: lorna.dragonetti2@unibo.it*

1. INTRODUCTION

TripleA-reno [1] is a European project funded by the Horizon 2020 programme whose aim is to increase the awareness of users and experts of energy renovation by providing tools to simplify and accelerate this process.

During the initial phase of the project, several case studies were analyzed in different European countries. Thanks to the results of these analyses, the processes of energy renovation and their activation were investigated. The project then focused on the actors involved in this process, the end-users and the professionals [2]. In-the-field ethnographic analyses have been carried out to illustrate how the context defines and influences the renovation process [3], highlighting its complexity and variability [4, 5]. In order to achieve the objectives set, the TripleA-reno project exploits the dynamics and mechanisms of gamification through various tools and a gamified platform where users can simulate and understand the process of renovation by using easy-to-use tools.

To carry out these simulations, it is also necessary to quickly and easily estimate the energy consumption of the buildings in pre and post renovation scenarios. However, before using these results, it is necessary to validate the process of energy modelling simplification through the phases described in this article, particularly in one of the case studies of the project.

The case study analyzed in this article concerns a multi-apartment building located in the province of Venice and managed by ATER Venezia. A renovation project has been approved for this property that includes interventions to improve the facade insulation, internal comfort, and static safety. After a general description of the building, in terms of geometry, materials used, and stratigraphies, the plant systems will also be described in the current state and the renovation project state.

Once the modelling software to be used was defined, a detailed assessment of the energy performance was carried out and then went on through several simplifications to understand if the margin of error due to the simplification could be considered acceptable. The study was conducted both for the current state and the project state in two different configurations; the first provides only the envelope improvement while the second also adds the replacement of the heating system.

Finally, energy performances have been compared to assess which parameters are most affected by the simplification introduced [6].

2. THE TRIPLEA-RENO GAMIFIED PLATFORM

One of the objectives of the TripleA-reno project is to provide the main actors of the renovation process with an easy-to-use tool conceived as a platform based on the principles of gamification [7], which can:

- connect directly with end-users, investors, manufacturers and professionals;
- give investors a tool from which to access the information entered by end-users, expanding the database of buildings that can be candidates for deep Renovation projects;
- provide professionals with a tool to make them enter the deep renovation process as mediators between end-users and investors.

One of the results of TripleA-reno is the creation of an open user-oriented platform based on solutions, experiences and methodologies applied in these recent projects. This tool will allow end-users to simulate the redevelopment of their homes, making guided choices on the various technological solutions available. It will also be possible to share experiences, solutions, and performances with a community of users of this tool to create a network that can further help users in their decisions through different means.

In particular, the Design Wizard Pro allows the user to evaluate different energy renovation actions using the measures stored in the TripleA-reno archive through a cost-benefit analysis.

To achieve this, the following steps are needed:

- input some data about the building; the needed data are simple, building dimensions and typology, through which the wizard will calculate the most likely thermophysical data;
- create a geometric model of the building; to simplify the input of data by the user, a module called Sketcher has been developed that allows the user to enter the geometric data of the building using a simplified CAD;
- input the thermophysical data of the building in the current state;
- choose the most suitable strategy for the renovation among the one proposed (maintenance, ecology, economical, lifespan, low energy, comfort);
- choose the measures that are proposed, ordered by performance according to the selected strategy;
- check the results, as improved energy class and CO_2 savings and investment payback time.

The Tabula approach has been followed for the insertion of thermophysical data (IEE Project Tabula 2009-2012 Typology approach for building stock energy assessment-funded by The Intelligent Energy Europe Program of the European Union, IEE/08/495 - IEEE Project Episcope 2013-2016, Energy Performance Indicator Tracking Schemes for the Continuous Optimization of Refurbishment Process in European Housing Stocks, co-founded by The Intelligent Energy Europe Program of the European Union, IEE/12/695/SI2.644739 - EPISCOPE). Based on a few input data (such as the country, the year of construction and the type of building), the data necessary to perform the energy calculation are extracted from the Tabula database to suggest the end-user plausible values for the energy assessment. A professional can adjust these values that, otherwise, would remain based on the end-user's skills.

3. THE CASE STUDY

The case study is located in Concordia Sagittaria (Venezia), owned by the social housing company ATER Venezia. It is a residential building with 21 apartments with tenants; the owner, ATER, is therefore responsible for the maintenance and conservation of the building. ATER has planned a restructuring to meet tenants' requests and access regional and national funding to reduce the investment cost.

3.1. ARCHITECTURAL DESCRIPTION

The building has a rectangular shape (80 m long and 12 m wide) along the east-west axis, with the most windowed facades to the north and south. It is divided into two blocks and comprises 21 apartments on four floors.

The ground floor is divided longitudinally into a garage area on the same side of the access from the road and a rear porch slightly raised connected to the park. The east block rises to four floors above ground and consists of semi-duplex specular apartments. Instead, the west block rises to three floors above ground and consists of one-storey flats on the first floor, while the upper floors consist of semi-triplex type apartments.

The flat roof is not accessible and is scattered longitudinally by half a floor. On the street side, the building has a height of 12.00 m above the ground, while on the park side, the west block has a height of 10.20 m and the east block of 13.50 m (Fig. 2).

Three staircases conceived as independent structures from the main blocks guarantee access to each dwelling. The main stairwell is located in the middle of the two blocks, while the other two staircases are situated in the eastern and western extremities of each block. The stairs lead directly to the external balconies, which extend the entire length of each main block. The east block has two balconies at two different heights, while the west block needs only a balcony to allow access to all apartments. Therefore, the architectural concept is based on similar or mirror-like apartments, arranged one above the other, and repeated several times along the central longitudinal axis. This arrangement favours a prefabrication logic, even if the construction is made of traditional reinforced concrete and prefabricated solutions are minimal.

3.2. STRUCTURAL DESCRIPTION

The supporting structures of the building consist of pillars and lowered reinforced concrete beams, weakly reinforced concrete partitions and slabs in prefabricated reinforced concrete panels with 20 cm high slabs. The structural typology of the flat roof is similar to that of the intermediate floors.

Fig. 1. *On the left, the north facade towards the road. On the right, the south facade overlooks the public park adjacent to the archaeological park side. (Photo © 2021, D. Prati).*

Fig. 2. *Structural design of the building. Identification of floor slabs, internal and external stairs. Schematic representation of the different transverse partitions of the east and west blocks. (Picture © 2021, D. Prati).*

Both the east and west blocks are marked longitudinally by seven 18 cm thick reinforced concrete walls with two outer layers of Heraclit (mineralized wood wool panels) 2.5 cm thick on each side. These walls give a peculiar characterization to the architectural organization and structure of the building. The concrete partition walls divide the dwellings into repetitive patterns, which are replicated, as in a mirror, and become the primary vertical supporting structure. They support the main beams and all internal stairs.

The internal structure of these partitions is not homogeneous: they are generally weakly reinforced, but on the inside, more reinforced vertical and horizontal parts are visible. These parts allow identifying an internal warp of beams and pillars. Given the horizontal offset of the floors of a half-plane, the internal structure of the partitions is particularly dense. Each septum contains four posts and beams of different thicknesses at the junction of the floor and above each gallery overhang. The foundations consist of reinforced concrete beams placed on underground poles (Fig. 3).

The main stairwells are not connected to the main structure and were built later: each stairwell has a reinforced concrete wall in the centre of the ramps, and all the loads of the landings are supported by a knee-high protrusion coming out of the slabs of the blocks. The foundations of the stairs (except for the central one) are not connected to those of the building but have their own reinforced concrete beams; as a result, the differential settling of the ground caused the sagging of the side stairs, causing vertical subsidence of 2-3 cm with respect to the building. The building has no seismic or expansion joints despite its considerable longitudinal length.

The walls along the north and south sides of the building have the following stratigraphy from the outside to the inside: 1 cm of plaster, 12 cm of brick, 2 cm of rock wool, 8 cm of perforated bricks, 1 cm of plaster, for a total thickness of 24 cm.

The windows are placed only on the long facades (the short sides are entirely blind), and the windows are still the original ones, made of single glass steel and without thermal break. Some tenants have installed double aluminium frames outside. There were also private balconies for each house on these elevations, which in many cases were closed with double aluminium windows. Additional aluminium windows were also installed on the end parts of the common balconies to limit the entrance of rainwater.

The heating system and domestic hot water production are centralized on the ground floor, where there is a boiler room with a diesel generator. Many residential units have individually installed an air conditioning system for summer cooling. Only one apartment in the west block was weakly insulated with a 4 cm thick outer coat.

3.3. THE RENOVATION PROJECT

The building is in a poor state of preservation due to the original construction imperfections and the lack of maintenance over time. Some residents who attended the construction site said that the project of the building was not well defined and that its construction was poorly managed and controlled. The building has certainly been designed in a short-sighted way, without considering the ageing of generations, the elderly and the disabled, and future changes in lifestyles. Beyond the possible reasons for the current situation, the fact is that the occupants face these problems in their daily lives.

At first sight and even more after inspection, several technical deficiencies in the building can be reported. In addition to insufficient, or better none, insulation, the low drainage capacity of the roof and the formation of moisture patches in the most exposed walls have often been highlighted. The flat roof, protected only by a thin bituminous coating, has a compluvium that leads from the facades to the centre of the building and drains water into the internal open vertical shaft from the roof down to the ground. As a result, the apartments have considerable problems with rainwater infiltration on the upper floors: stains in the ceiling, blooming in the plaster or moisture penetration.

Another typical problem, due to the specific internal arrangement of dwellings on different floors, is related to cooling and heating. The interior stairwells act as air convectors and make it difficult to maintain an optimal temperature both in winter and summer. Other general complaints concern the positioning of the glazed front to the north, which is often hit by heavy rains in cold seasons, causing water infiltration. Conversely, the southern front is unlivable in the summer due to a considerable heat accumulation caused by the lack of shielding elements. In addition, due to the foundation displacements, the original steel frames of the windows manifested significant air seepage over time. All this, together with the poor stratigraphy of the walls and the entrance doors made of honeycomb sandwich wood, lead to a level of insulation of the apartments that is not adequate to current standards [8] (Fig. 4).

The maintenance status of the facades is not particularly good, with damage and detachments of plaster. In particular, the detachment of portions of plaster on the northern façade, more exposed to the weather, the detachment of the concrete cover in the walls of the stairwells and the lower outer corners of the longitudinal beams. Evident cracks are visible in the connection where the external infill walls rest on the concrete beams. Where steel armour emerges to the eye, it causes the inhabitants a particular concern which, although excessive, is not entirely unfounded in non-expert people. No elevator system is available in the building, and people with disabilities also have to deal with a few stairs inside the apartments (Fig. 4).

For the reasons explained, ATER has planned for this building a retrofitting project promoted in collaboration with the Veneto Region, aimed at improving its energy performance, which consists of several interventions aimed at reducing or removing the main energy criticalities:

- thermal insulation (12 cm fibreglass panels) of the entire external envelope of the building, including the roofing and the lower surface of the garages and porch;
- replacement of window frames and glazing and renovation of the heat generation system by integrating energy from renewable sources.

At the same time, during the thermal retrofitting intervention, some actions will be taken to improve the seismic performance of the building:

- in the outermost parts of the two blocks, the thermal insulation will be stiffened by the construction of a 15 cm thick reinforced concrete wall filled inside the insulation, which will be divided into two layers of 8 cm (externally) and 4 cm (internally);
- installation of an eccentric bracing system along the longitudinal axis of the building to support the seismic mantle and transfer the horizontal actions to the ground;
- realization of a series of reinforced concrete diaphragms at the north facade, built between the foundations and the first floor so as not to block the entrance of the garages but able to act as an effective structural reinforcement.

4. SIMPLIFIED ENERGY MODELLING

Implementing the TripleA-reno platform has necessitated a simplified architectural and energy modelling of buildings, both for data management by the algorithm and to simplify user input. This study aims to verify that simplification does not lead to a significant error and reduces the reliability of the results.

The building has been studied in three conditions: current state, envelope-only project (scenario of intervention on the only envelope), envelope-and-plants project (scenario of intervention with replacement of the heat generator and installation of photovoltaic panels). These three conditions were then analyzed through a detailed energy model and a simplified one, having the same heated volume but regular geometric shape. The simplified model was then used for analysis through the TripleA-reno platform.

4.1. THE CHOICE OF THE SOFTWARE

For the first analysis, it was decided to use Logical Soft's Termolog software for the calculation of energy performance. The software in the Epix 10 version is updated with the dynamic hourly assessment in accordance with the Italian legislation, the UNI EN ISO 52016, and the new UNI TS 11300-2:2019 [9].

On Termolog, the user can create the BEM (Building Energy Model) energy model of the building from scratch, using the integrated modeller, or import an existing BIM model from files in the IFC standard format. The program has broad flexibility for modelling; it recognizes, in fact, .dwg/.dwf file, .pdf and gives the opportunity of tabular data entry, thus allowing the geometry of the envelope to be mirrored by automatically obtaining orientation and shading from the outline of the building. Termolog quickly models the various types of plants and implements any energy efficiency measures. The software has a database containing all the materials required by the technical standards and the stratigraphies pre-calculated provided by the UNI TR 1152 standard. Still, it also provides the opportunity for manual input by the user. It also allows for the automatic creation of windows through a wizard.

4.2. THE DETAILED MODEL

The detailed model fully reflects the case study building in its volume, which was created by importing in Termolog the plans of the various floors. Since these are at scattered heights, 8 levels have been modeled based on the dispersion characteristics, and 21 thermal zones corresponding to the apartments have been identified and created. No unnecessary elements for energy modelling

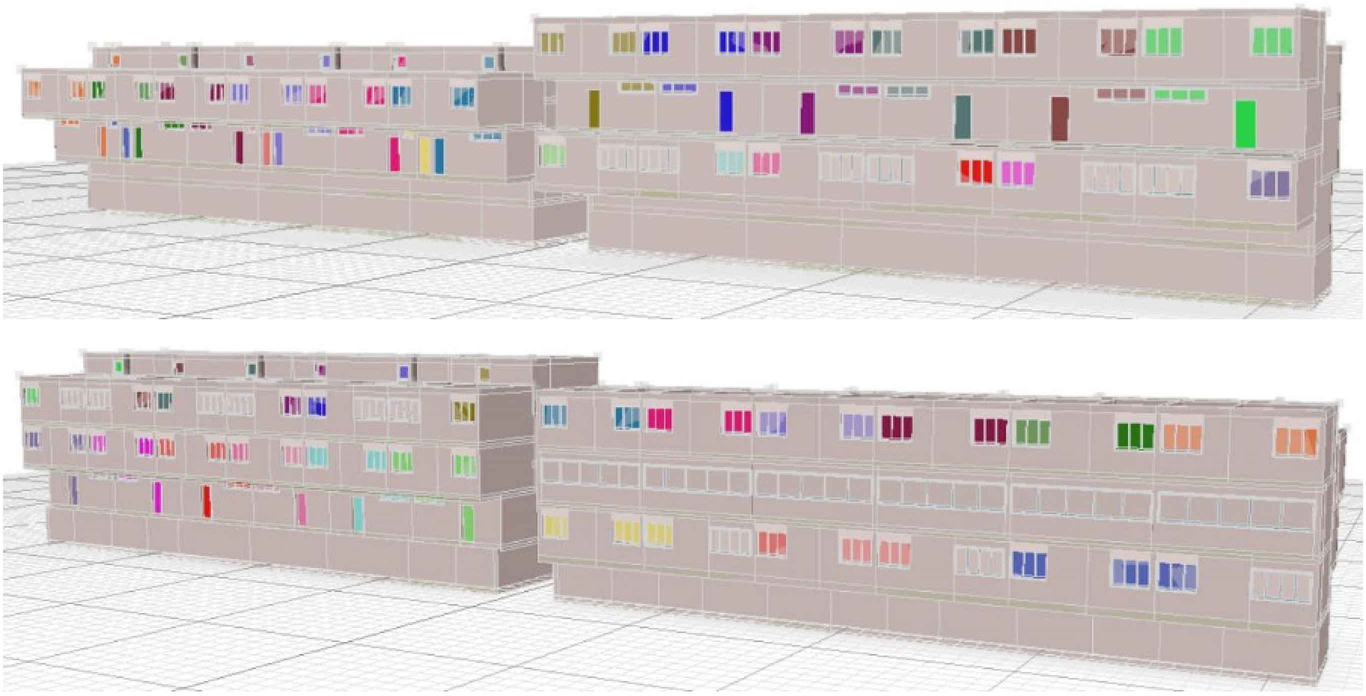

Fig. 3. *3D views of the detailed energy model. Above, South-East view. Below, North-West view. (Picture © 2021, D. Prati).*

have been added, such as the internal stairs of the flats, the pillars in the portico and the balcony parapets.

4.3. THE SIMPLIFIED MODEL

The simplified model was created from the heated gross volume resulting from the detailed model, dividing the building into east and west blocks. The value was then divided by the actual length and height, obtaining in this way the width of each block. This procedure led to a model that respected the distribution of the heated volumes. The building is, in both blocks, divided longitudinally with the volumes scattered half a floor from the opposite side.

With the method used for simplification, given the differences in the heated gross volumes, the two blocks now result in two different floor heights and floor numbers. In particular, the east block was modelled with three floors (from 6 scattered half-floors), lowering the half-planes of the south side to the height of those of the north side. In the simplified model, the west block is transformed from 5 scattered half-floors to 2.5 floors. On the ground floor, the garage boxes on the north side and the porch on the south side were preserved in the model to keep the same dispersant surface as much as possible. However, the dispersant surface is smaller in the simplified model because the balconies have been eliminated by incorporating those volumes in the main building body.

The volumetric simplification is evident looking at how the east and west elevations change; the scattered trend is no longer visible and is replaced by a regular shape. No internal partitions have been added to the simplified model. In contrast, the original design has not been heavily modified as far as windows and doors are concerned. Only the doors to access the terraces have been eliminated, while in correspondence with the windows of the terraces, a “double window” has been created, replacing the two single glass windows present on the line of the external wall and the inside wall of the terrace. At the plant systems level, however, trying to make the energy estimations as close as possible, the same number of terminals was inserted in the detailed model, even if the two blocks were not divided into thermal zones.

4.4. THE MODEL FOR THE TRIPLEA-RENO PLATFORM

The TripleA-reno platform is designed to allow end-users to simulate how a renovation process can improve their building. Because of that, the input needed is more straightforward than the one required by energy simulation software.

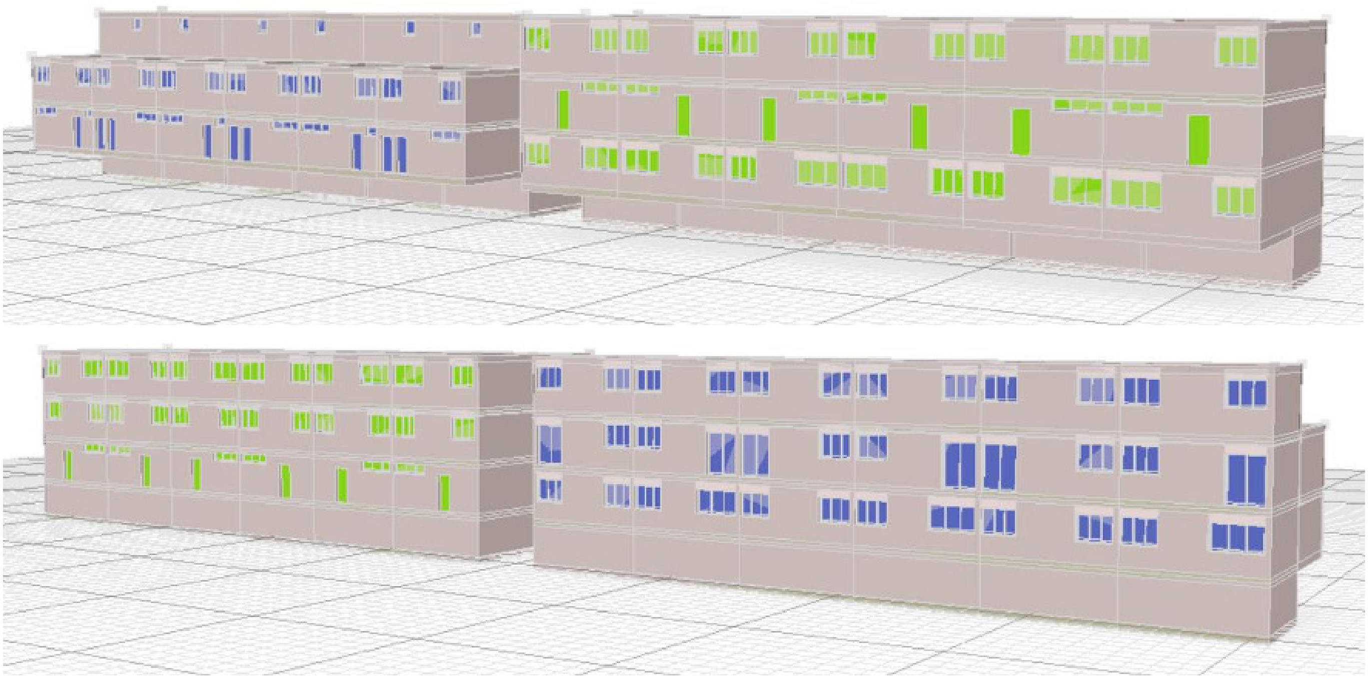

Fig. 4. *Three-dimensional views of the simplified energy model. Above, South-East view. Below, North-West view. (Picture © 2021, D. Prati).*

The calculation is then performed through the UNI/TS 11300 standard based on the parameters entered by the user, which are mainly geographical and typological. Based on these types of input, the main thermal and performance parameters of the structures are deduced according to the approach developed in the Tabula project mentioned in par. 2.

As for geometric input, the user can choose whether to enter it in a tabular way or via CAD (Sketcher). In the latter case, the detail is not as precise as the one of a traditional CAD because the average user needs to simplify the building. For example, the balconies and garages were not modelled in the present case study.

5. RESULTS

There are no shape variations between the current state and the post-renovation scenario while the heated gross volume slightly increases. The modelling process of the simplified model has been described in the previous paragraphs, and from the results, it is evident that it has not led to significant errors; in fact, the two models are very similar, and the most important difference is in the total dispersant surface that is slightly underestimated with 3917.51 m^2 for the detailed model and 3749.88 m^2 for the simplified one.

When the post-renovation scenario is concerned, which involves changes in the stratigraphy of the outer walls, there are changes in the dispersant surfaces and the heated gross volumes. However, the simplification process entails a difference that is constantly below 1% compared to the detailed model. In both cases passing from the current state to the post-renovation state produces a variation of about 10% of the heated volume, as seen in Table 1.

The energy analyses of the six scenarios were carried out using Termolog® software in a semi-dynamic monthly regime. The overall performance index is underestimated in the simplified model for the current state, while it is overestimated in the renovation scenario with the plant systems replacement. The energy requirement for heating in the current state scenario is remarkably accurate in the simplified model; in fact, the needs are respectively 511917 kWh for the detailed model and 505885,9 kWh for the simplified one. While for the renovation scenario, the detailed and simplified models present much more different values, as shown in Table 2.

The current state and post-renovation scenarios energy assessments were also carried out using the TripleA-reno platform. The first one differs from the detailed model by about 16%, while in the post-renovation scenario, the difference is more significant and is about 31%. The simplified model is accurate for the current state (around 1% difference), while the post-renovation differs by 55%, as seen from the following table.

	Detailed model		**Simplified model**	
	Current State	Renovation (envelope+system)	Current State	Renovation (envelope+system)
Net heated Area	2135.57	2135.57	2266.53	2266.53
Gross Heated Volume	7961.28	8751.79	7995.8	8803.82
Dispersant Surface	3917.51	4280.97	3749.88	3989.16

Tab. 1. *Geometrical data of the models.*

	Detailed model		**Simplified model**		**TripleA-reno model**	
Primary energy demand for heating (kWh)	Current State	Renovation (envelope+system)	Current State	Renovation (envelope+system)	Current State	Renovation (envelope+system)
Primary energy heating non-renewable	511643.10	145388.30	505615.20	224647.90	431899.80	190152.60
Primary energy heating renewable	273.90	0.00	270.70	0.00	44.50	280.50
Primary energy total	511917.00	145388.30	505885.90	224647.90	431944.30	190433.10

Tab. 2. *Primary energy demand for heating.*

	Difference Simplified Model - Detailed Model		Difference TAR Model - Detailed Model	
	Current State	Renovation (envelope+system)	Current State	Renovation (envelope+system)
Primary energy heating non-renewable	-1%	55%	-16%	31%
Primary energy heating renewable	-1%	N/A	-84%	N/A
Primary energy total	-1%	55%	-16%	31%

Tab. 3. *Primary energy comparison between models.*

6. CONCLUSION

From the analysis of the results, it is possible to make some considerations about the use of simplified models for the energy assessment of buildings. First, the procedure chosen to simplify the building model correctly maintains the geometric conditions, with almost unchanged values of heated gross surface area, dispersant surface and heated gross volume.

It is necessary to distinguish discrepancies according to the scenarios concerning energy results. There are inconsistent trends between the various scenarios when comparing the results obtained for winter heating. The simplified model results, related to primary energy demand for heating, differ from the detailed model by a maximum underestimation of -1% and a maximum overestimation of +55%, and from the TAR model from -16% to +31%, the first values for the current state and the second for the renovation (envelope+system).

The second scenario, which involves the replacement of the generator of the heating system, presents a converse behaviour. In this case, not only are the results overestimated, but the differences with the previous scenario are not consistent with those obtained in the detailed model. The simplification of the plants is a critical point, as well as the modelling of particular areas such as lodges or greenhouses, and must be improved.

In the TripleA-reno platform, the energy demand of the current state was 15% underestimated, while the one of the post-renovation state was overestimated by 30%. This variability could mean that the simulation with the TripleA-reno platform could make renovation action less convenient than it actually is, but also ensures that the user “acts in safety” and continuing with more in-depth estimations, the scenario will only improve, and this will not discourage end-users from undertaking a real redevelopment.

Therefore, it turns out to be fundamental to analyze further case studies to refine the method. On the one hand, the case study of Concordia Sagittaria was hard to model in detail since it consisted of a multiapartment building with scattered floor dwellings. This complexity resulted in difficult management of the thermal zones within the software. On the other hand, a higher number of case studies will minimize the differences between the detailed model and the simplified one, giving a better simulation for the user. As already said, the case under consideration is a rather complex building, which has been reduced to a sum of simple shapes and spaces during the modelling process. As a consequence, it creates a scattering of the error. Therefore, it is suggested to choose geometrically simpler cases to refine the method with simple shapes.

Furthermore, it is utterly necessary to test the platform with several case studies, to understand better the threshold values for which the geometric, energetic and input simplification can work and how to refine the simulations to have results that deviate less from detailed energy simulations while making the use of the tool accessible to non-expert users.

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