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Research Article

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Deep renovation methodology for 20th-century masterpieces: the case of Palazzo Affari by Carlo Mollino

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Abstract. This paper proposes a methodological approach to energy renovation in valuable buildings, encompassing architectural, historical, and energy analyses. The research tests its application on a case study: a retrofit proposal for Palazzo Affari in Turin, an office building designed by Carlo Mollino for the Chamber of Commerce (1964–1974). The building, still in use, has never been thermally renovated yet. Palazzo Affari gathers structural, technological, and spatial experimentation worth to be preserved. The core of Mollino's design is a versatile plan, clear from any structural encumbrances, which was made possible thanks to an innovative structural technique. Façades are cladded with finely designed concrete prefabricated panels. As a 20th-century masterpiece, it must be recognized as culturally valuable but also shows enormous energy improvement potential, as many buildings of its age. Based on a deep understanding of the building, the paper proposes a combination of traditional and innovative ad hoc solutions for its renovation, mediated by the need for material and iconic preservation. Both the substitution of the façade panels and the insulation from the outside are excluded. The opaque parts of the façade are insulated from the inside using high-performance Vacuum-Insulation-Panels, and cladded by a new counter-facade conceived to be produced in panels through digital fabrication. On the other hand, windows are fully replaced by choosing glass which is both high-performing and respectful of the original chromaticity and transparency. The new window frames with thermal break are specially designed to respect the original external thickness. The design is configured as an add-in intervention, coherent with the pre-existence. Substitutions are carefully weighted and respect the original architectural features. FEM analysis demonstrates the reduction of the thermal flux through the opaque walls by 80% and through the windows by 65%. The solar factor is reduced by 35%, thus improving the summer internal thermal comfort.

Keywords: Innovative retrofit / preservation of modern architecture / high-performance insulation / FEM thermal simulation / digital fabrication

1 Introduction

To achieve the decarbonisation goals envisaged in the 2015 Paris Climate Agreement, all sectors of society (transport, buildings, industry, agriculture) are required to reduce greenhouse gas emissions drastically. Through their life-cycle (construction, usage, renovation and demolition), European buildings are responsible for 40% of energy consumption and 36% of greenhouse gas emissions [1]. Thus, energy retrofitting of existing buildings represents one of the opportunities with the highest potential to achieve carbon neutrality by 2050, as the European Green Deal sets out.

When intervening on buildings credited with a testimony value, it is necessary to study ad hoc solutions, which should represent a reasonable balance between heritage preservation and energy performance. In fact, both energy efficiency and cultural heritage preservation are needs following the same aim: the protection of irreplaceable resources, whether they are natural or cultural [2]. Even assets in which a historic or cultural value may be recognised risk being radically transformed in the name of energy retrofit. In particular, many valuable buildings built between the Second World War and the energy crisis appear to be vulnerable since they are obsolete from the energy point of view, but often too recent to be listed [3–9].

This paper proposes a methodological approach to energy renovation in valuable buildings and tests its application on a case study. It concerns Palazzo Affari in Turin, an office building still in use, conceived for the

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Chamber of Commerce by Carlo Mollino together with Carlo Graffi, Alberto Galardi and Antonio Migliasso. The construction resulted from a design competition announced in 1963, calling for a building with "architectural features appropriate to the importance of a public building" so that it could meet "the most modern and advanced requirements for office organization" [10–15]. The resulting construction gathers architectural, structural, and technological experimentations that deserve to be considered cultural heritage and preserved.

2 Methodology

The structure of the paper reflects the process followed in applying the proposed methodology on the case study. Firstly, when intervening on a valuable building, getting to know it thoroughly is highly necessary. The first part of the paper illustrates the history of the building and the reasons for its construction. Detailed studies were made, besides those on the work itself, on the cultural context, the materials and the technologies which made its conception and achievement possible. This process is based on documentation work: bibliographical research, archive research, and interviews with direct witnesses.

Secondly, the process of the virtual reconstruction of the building is described; it is based on the archive drawings and measurement campaigns. The virtual model is useful for producing an accurate design solution that can be realized through digital fabrication processes.

Finally, the development and outcomes of the retrofit project are illustrated. In the case of the Palazzo Affari, the façades are considered an element to be preserved. All the design choices, in fact, do not derive from the desire to obtain the maximum possible energy and comfort performances today, but are made by weighing up criteria of perception, enhanced energy performance and impact on heritage preservation.

3 Knowledge of Palazzo Affari

3.1 Conception and construction

Palazzo Affari was built on the site of Palazzo Morozzo della Rocca, a sixteenth-century building and former headquarters of the Turin Chamber of Commerce, destroyed during the Second World War. Building new headquarters for the Chamber was considered during the economic boom period. In such a context, the Chamber of Commerce needed more space and decided to build a "Business Palace" (Palazzo degli Affari), which would become the new headquarters for its services. From the point of view of its image, too, the organisation needed to reflect the importance possessed by the body co-ordinating the various economic initiatives and forces operating in the region. Palazzo Affari was conceived as a tool for information, documentation, meeting, and knowledge for the economic players in contact with the local economy. The call for entries to the competition was published in January 1964 and produced responses from 29 groups of designers, with all the proposals judged to be of high quality [16–18].

The team of designers directed by Carlo Mollino, and formed together with Alberto Galardi, Carlo Graffi and Antonio Migliasso, presented the competition's winning design, considered innovative from several points of view: architectural, technical, and technological. Although this was not required, the group delivered a research report on the evolution of contemporary office buildings and on the relative organisational needs. The basis of the design was precisely, as called for by the competition, a building which could respond to the "most modern and advanced needs in terms of office organisation". The fundamental consideration at the base of the proposal was that rigid internal layouts suffered the invariable fate of rapid ageing. The research, therefore, went in the direction of the greatest possibility of change of the building plan in harmony with the changing needs and criteria for use and organisation of offices. This design criterion was a significant factor which not only conditioned but powered the constructive synthesis of the building and was followed by putting forward a structure which would allow the maximum area free from internal pillars [10–13,19].

Between July 1964, when the competition winner was announced, and May 1967 when the Municipality of Turin released permission to build, several events occurred. Migliasso and Galardi left the design group, and the preliminary design was noticeably modified and reshaped throughout the executive project and during construction. The execution of the works was awarded to a qualified firm headed by the engineer Felice Bertone, who also assumed the role of structural designer. In 1971 Mollino was given the additional responsibility of interior design. In the same year, the structures were tested and in 1973 the building workshop finally finished its work. In May 1974 moving in began and extended for about a year; however, Carlo Mollino didn't see his building begin to be used as he died in August 1973 [15,20–23].

3.2 Architectural features

The choice of an isolated volume rather than a traditional layout allowed the cost of the façades to be reduced by about half, having a front perimeter of around 150 metres, compared with a traditional winged or H-block layout which would have required around 300. Moreover, from the layout point of view, the desired freedom was obtained and, with simple changes, several configurations of both pedestrian and vehicular access and walkways were also possible [19].

In the design for the Chamber of Commerce, the ground floor becomes a pedestal base which retraces the perimeter of the original block, but its volume is completely glassed, so that it looks like a vanished base. This choice lightens the perception of the ground floor and allows it to frame unusual views of the city from inside. The floor is slightly raised and hosts two main environments: the atrium and the public counters, separated from the vertical distribution nuclei which contain the helical staircase and the lifts. The vertical limit of the glassed pedestal is the first floor, characterised by completely open space, crossed only by

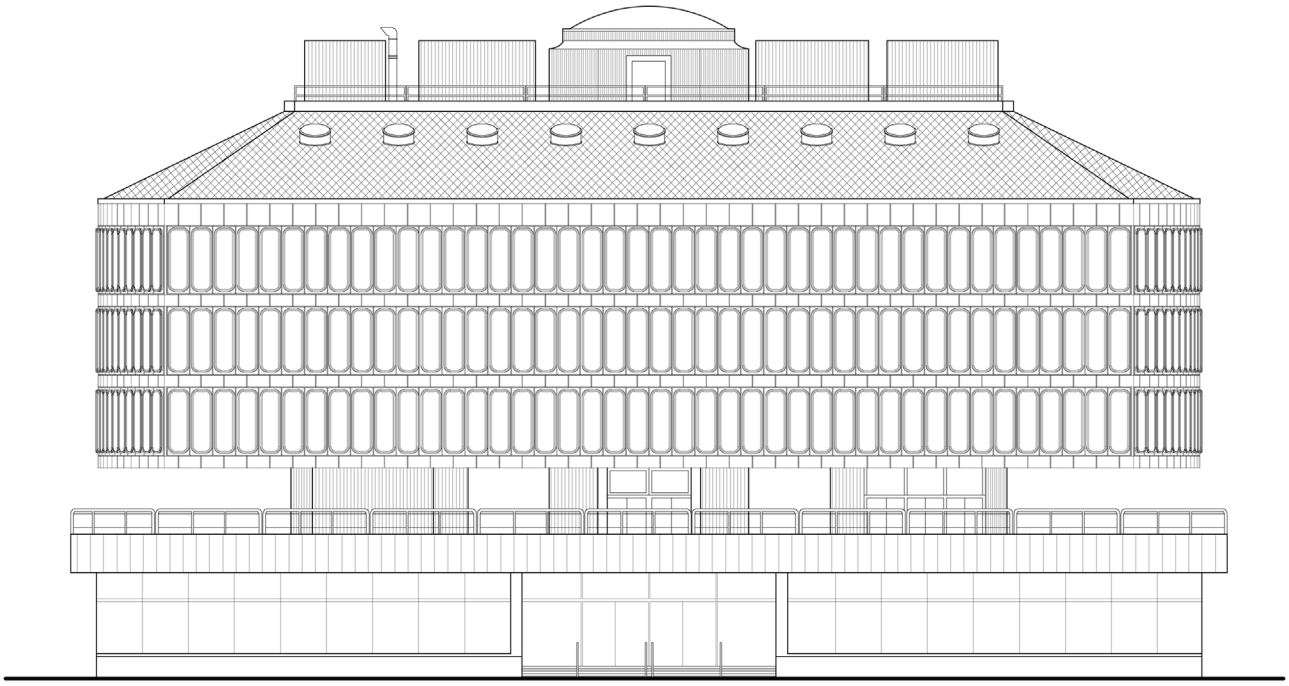

Fig. 1. South elevation of Palazzo Affari. Drawing by Alessandro Di Renzo.

the reinforced concrete structural nuclei. It is a free aerial platform, which allows us to perceive the suspension of the volume of the offices above it. This floor is designated as parking and is reached by cars using a ramp. The choice to bring the cars to the first floor of the building represents an effort to integrate vehicular traffic into architectural design, responding to the problem posed at the time by the spread of cars in cities. From the third floor above ground, the main structure rises. Its volume is supported only by the central nuclei thanks to the structural technique of suspension and consists of three floors of free-plan offices and an attic floor. The central area of the three floors is occupied by the structural nuclei, whilst all the surrounding area, free of structural encumbrances, hosts offices or meeting rooms and is sometimes open space, sometimes subdivided using mobile partitions (Fig. 1).

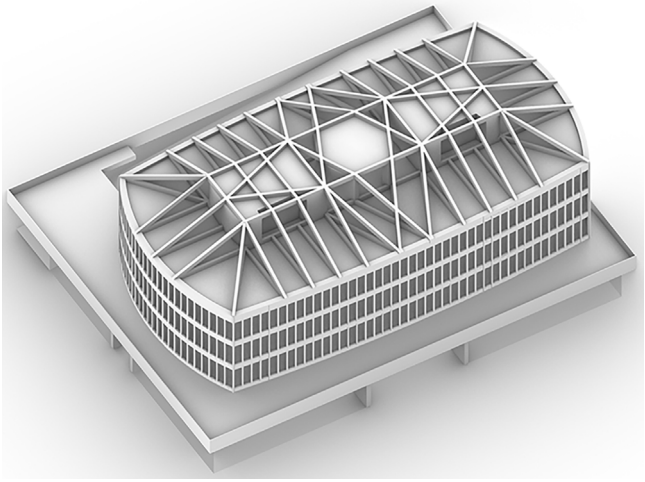

Fig. 2. 3D reconstruction of the structural system at the roof level. Drawing by Alessandro Di Renzo.

3.3 Structural features

The structural conception of Palazzo Affari should be attributed to Antonio Migliasso who proposed a "mushroom" solution for Palazzo Affari, laying the foundations for the achievement of a highly innovative building from the structural and architectural point of view. Migliasso put into action for the first time in 1962 the technique of suspension to solve construction difficulties for the building of the municipality of Saint-Vincent (Aosta Valley): compared with a solution of overhanging shelves, at each floor he managed to reduce the quantity of reinforcing steel by 15% and of pre-stressed steel by 80% [17].

The structure of Palazzo Affari is composed of three reinforced concrete hollow cores which assume the role of the building's service hub and head its internal distribution system, circulation system and services. These cores support a superstructure composed of a radial system of shelves which overhang by around 9 metres, placed at the level of the roof, and linked together by a perimeter girder ring to which are attached the tie rods in pre-stressed reinforced concrete which, in turn, carry the load of the three office floors (Fig. 2). The choice to use reinforced concrete, a material well understood by the Italian workforce, in place of steel, guaranteed traditional management of the building site. The construction of the floor slabs actually happened in the usual sequence, from low to high thanks to temporary props [17,24].

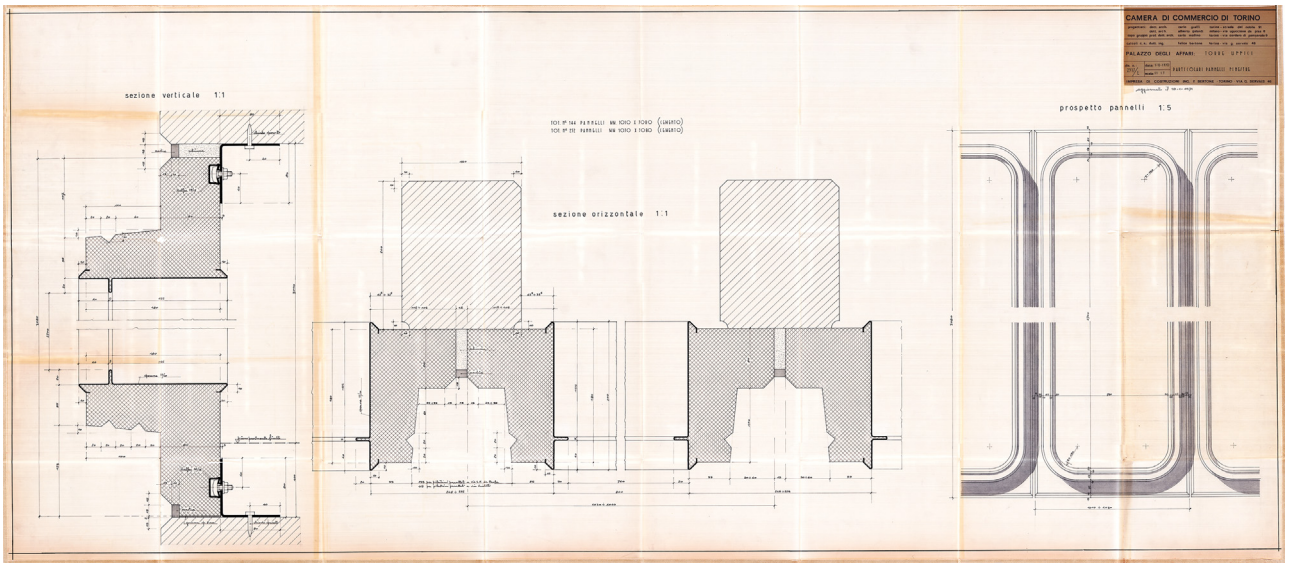

Fig. 3. Archive board of the executive project of the concrete façade panels. © Felice Bertone Archive, "Roberto Gabetti" Library, Politecnico di Torino.

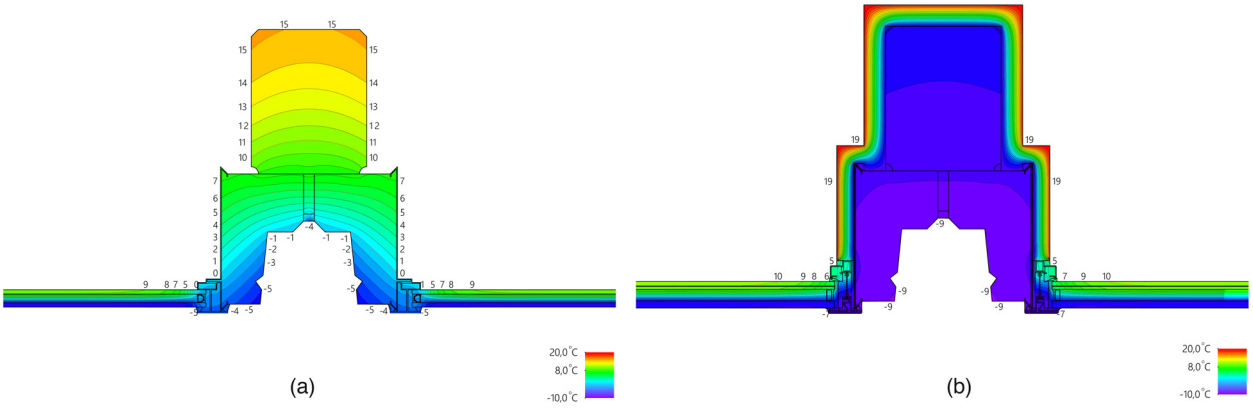

Fig. 4. FEM simulation: on the left the existing thermal precondition, on the right design thermal condition. Simulation by Alessandro Di Renzo.

3.4 Envelope features

For the infilling of the façades of the suspended volume of Palazzo Affari an alternative system to the usual curtain wall was chosen; it consisted of the repetition of façade modules (about 3×1 meters), placed inside the structural grid formed by the slabs of the floors and the vertical ties. The façades consist of around 400 reinforced concrete prefabricated panels. They were lowered from above with the crane, the lower base of the panel was laid on a rubber cushion, finally the panel was made to rotate in order to assume its final vertical position. The attachment to the slabs is assured through two metal L-profiles, anchored below and above to the slabs through Halfen profiles embedded in the concrete. The joints were filled with foam and finished on the outside with a mastic sealing (Fig. 3). The insulated glazing is composed of Saint-Gobain double glazing with an air cavity and is mounted from the outside, after the prefabricated modules are in place, in the calendared metal sheet slot incorporated in the façade module. The design of the metallic frame, visible from the outside, is simple and clean. The design of the glass with curved corners is declared to be inspired by aeronautics; the choice is motivated by a better efficiency of the frame whilst being in the air, made possible thanks to the use of a single continuous seal with curved corners [19].

3.5 Archive research, onsite surveys, and virtual reconstruction

The approach taken requires an exhaustive knowledge of the building to be worked on. Before setting out a design solution, an exhaustive search of the archives was made to collect all the useful documentation available. From the Chamber of Commerce Archive, the Felice Bertone Archive, the Riccardo Moncalvo Archive and the Carlo Mollino Archive, many documents were found that were

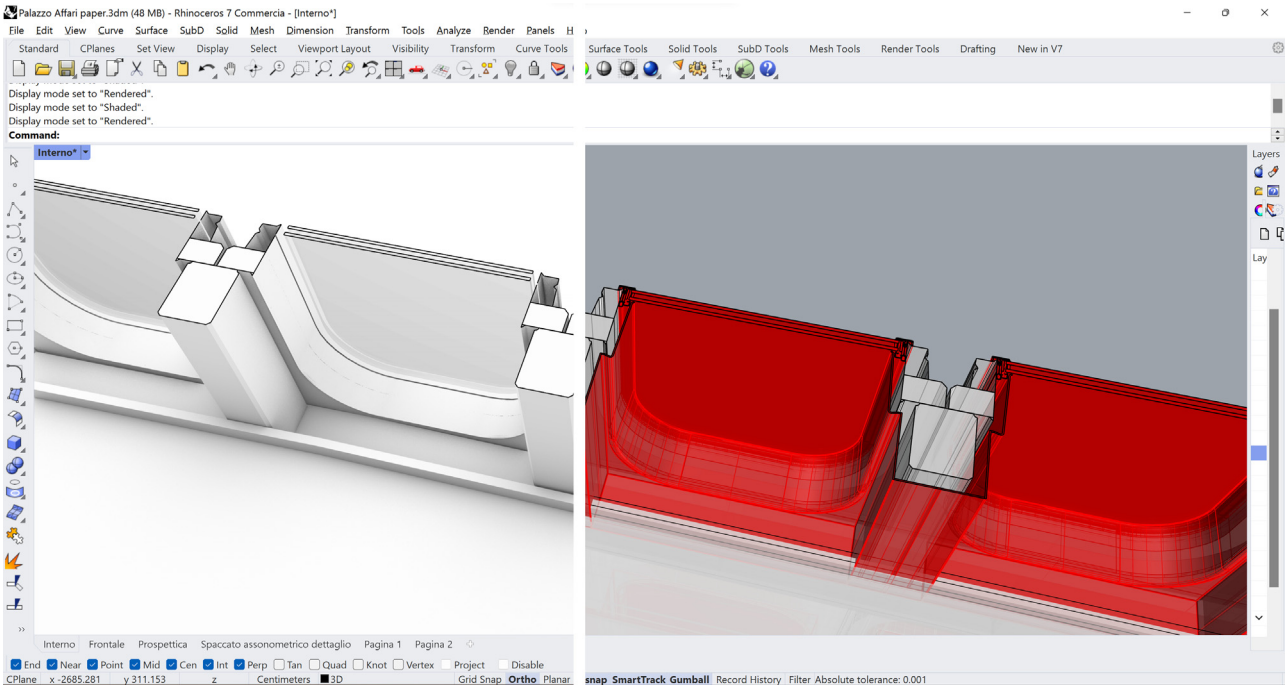

Fig. 5. 3D model: on the left the existing precondition, on the right the internal counter-façade. 3D models by Alessandro Di Renzo.

useful for an understanding of the building. In particular, the Felice Bertone collection contains drawings in scales of 1:5 and 1:1 which show the detail design for the façade panels.

Based on archive documents and on some measurement programmes carried out on site, the modelling and detailed reconstruction of the current state of the building was carried out (Fig. 5a). Almost fifty years on, Palazzo Affari has shown excellent resistance to ageing. The building was subject to a series of restructuring interventions and upgrades to security, accessibility, and layout. All the partitions and all the furnishings have been replaced. The three-dimensional model has allowed very precise design for the solution of insulating the façades, with tolerances in the millimetre range.

3.6 FEM analysis: performance of the current envelope

The building envelope appears to be in a good state of preservation, both externally and internally. Regular maintenance is carried out; the façade panels and the window frames appear to be undamaged. Until now, there have never been any improvements to the energy efficiency of the building envelope, except for the application of reflective coatings to the outside of the windows of some façades of the building.

The analyses carried out show that the windows currently in place are composed of two single sheets of 6-millimetre-thick body-tinted float glass, with a 12-millimetre air cavity. It is assumed that the thermal characteristics of this type of glass would be: transmittance $U = 3.0\,\mathrm{W/m^2 \cdot K}$; solar factor $g = 0.49$ and light transmittance $T = 45\%$. Finite Element Method analysis of the façade sections shows a very high potential of thermal improvement. The simulation was carried out with $\Delta T = 30\,°\mathrm{C}$, the boundary conditions were the internal temperature $T_i = 20\,°\mathrm{C}$ and the external temperature $T_e = -10\,°\mathrm{C}$. The surface temperatures recorded varied from 0 °C close to the glass to 7 °C on the internal edge of the façade panel. The pillar showed temperatures varying from 8 °C to 15 °C (Fig. 4a).

4 Retrofit design

4.1 Design strategy

The design strategy put into practice for the façades of Palazzo Affari is intended to be a reasonable compromise between conservation and energy improvement. The intervention proposal concentrates on the façades of the suspended volume of Palazzo Affari, which represent 40% of all the surfaces of its envelope. These façades are unique, so they require a more detailed study and the proposal of an ad hoc solution, unlike the roof and the first slab, to which it is possible to apply more conventional solutions. The façade panel of Palazzo Affari is considered a unique work, an irreplaceable element which expresses what was culturally conceivable and technologically possible during the era in which it was made. In the case of Palazzo Affari, in fact, the replacement of the façade panels is ruled out. For the opaque parts, an "add-in" [25] intervention is planned, this approach allows the material conservation of the original façade panel [6].

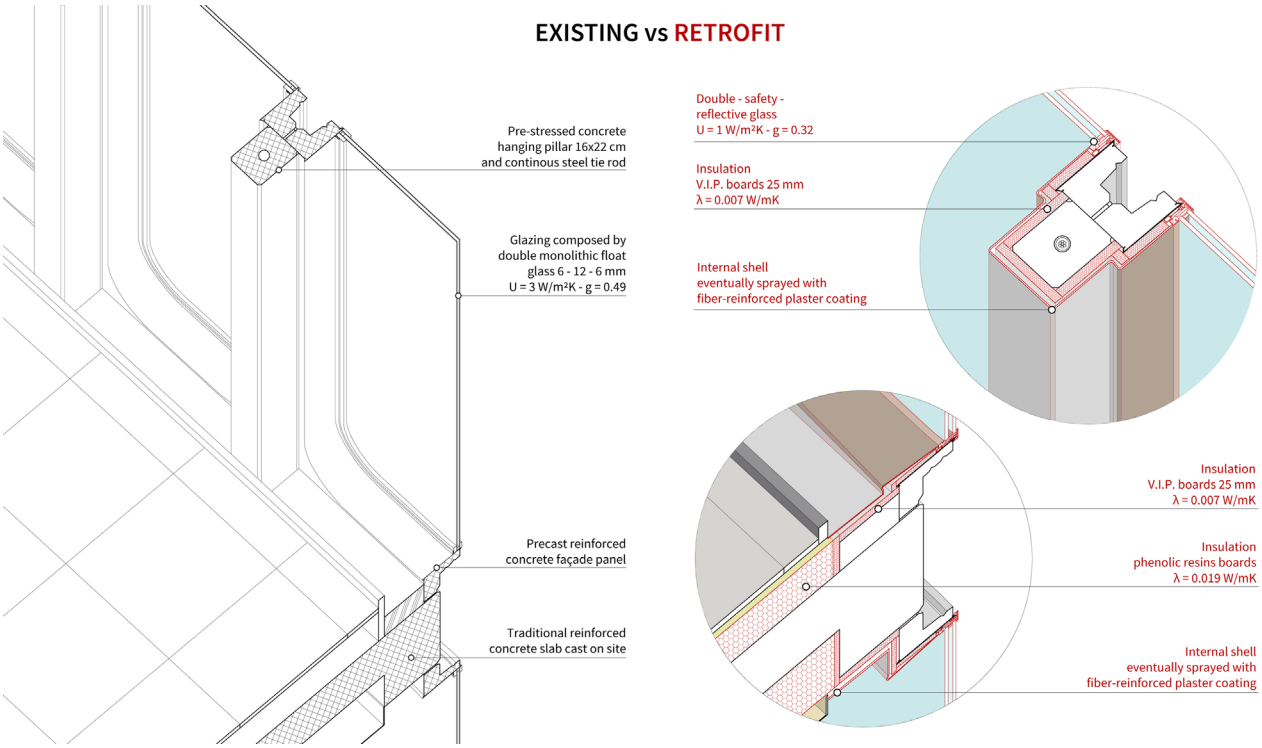

Fig. 6. Current state and retrofit design compared. Drawings by Alessandro Di Renzo.

4.2 Design of the new glazing

As regards the transparent envelope, it is proposed to replace them with more recent glass, having the same tint and transparency characteristics, but with improved thermal and security characteristics to meet today's needs. Although the act of removal should be considered an exception to be evaluated with extreme caution [5,6], the current glazing, an industrial product from the Saint Gobain factory, does not have irreplaceable features. The glass represents an enormous potential for energy conservation. In this case it is held that the current glass may be replaced with a more recent product with very much better performance, keeping however the current colour and perception characteristics [8,26,27].

The double glazing in the design is composed on the outside of 10 millimetres tempered glass with a reflective solar control magnetronic coating, and on the inside of a low emissive coated glass. The transmittance of the glass is equivalent to $U = 1.0\,\mathrm{W/m^2 \cdot K}$ compared with the current $U = 3.0\,\mathrm{W/m^2 \cdot K}$. The argon chamber and the low emissive deposit allow striking reductions in heat loss towards the outside in winter weather. Moreover, the very low solar transmission factor ($g = 0.32$) allows improved solar control compared with the current one ($g = 0.49$), thus reducing energy demand in summer weather. A selective rather than reflective glass, with comparable thermal performance, would have involved a higher visible light transmission factor, but would have radically altered the view of the building from the outside, making it much more transparent than it is today. Moreover, a choice was made to use double glazing rather than higher performing triple glazing, in that its thickness better fits the existing façade panel.

For the new insulating glass, a painted steel frame with thermal break was selected from a broad range of products. Its design was adapted to faithfully reflect the dimensions and the neat, clean design shown by the outside of the current system.

4.3 High-performance insulation of the opaque envelope

The proposed solution plans for the use of a very high-performing material which, in the case of Palazzo Affari, is able to work with only 25 millimetres (Fig. 4b), a thickness around five times less than traditional insulation, so without distorting the original proportions of the construction elements. This product is V.I.P. (Vacuum Insulation Panel), panels composed of a pressed microporous silica powder core, to which is added an opacifier to minimise the passage of thermal radiation and cellulose fibres to improve mechanical stability. The core is vacuum packed and sealed with a covering of aluminium which makes the panel impermeable to gas and vapour. Effective thermal conductivity which takes into consideration the thermal bridge generated by the juxtaposing of the individual panels is $\lambda = 0.007\,\mathrm{W/m \cdot K}$ The risk attached to this type of insulation relates to the state of its vacuum. The loss of this characteristic would cause the thermal conductivity to increase to $\lambda \approx 0.025\,\mathrm{W/m \cdot K}$ which would mean the loss of

any benefit from its use. For this reason, they must be installed with extreme caution, by a specialised workforce, without causing any damage to the covering. The panels must be attached with polyurethane glue and can be sealed with polyurethane foam [28,29].

4.4 Design of the internal shell

To clad the insulated parts of the façade an interior counter-façade has been modelled (Fig. 5b), inspired by the profiles of the existing internal façade; the splays are shaped in such a way as to hint at the load-bearing structure behind it, and they take up the design and the original colour of the intrados of the window frames. The plane of the structure, the windows intrados and the plane of the façade panels can still be perceived (Fig. 6). The task of giving form to the expected project outcome is entrusted to a panel whose technical feasibility is highly regarded, in collaboration with some businesses operating in the sector.

4.5 Digital fabrication of the internal shell

Two options have been evaluated to produce the internal counter-façade. Because of the modular repetitiveness of the façade, one option evaluated was serial production, through vacuum thermoforming of ABS (Acrylonitrile butadiene styrene) sheets. The choice fell on this method since it allows the generation of bodies of relatively complex forms at a contained cost. The technique requires first of all the fabrication, using numerical control machines, of a wooden model from which, once it is refined and tested for feasibility, an aluminium mould descends. On the latter, the sheets of softened ABS are laid, to be then placed in a vacuum which makes them assume the exact form. Once they have hardened, the products are cut and refined by five-axis numerical control machines.

The second fabrication option evaluated is additive manufacturing. This method has been considered as the objective is to generalise a methodology which could also be applied to other buildings. Through 3D printing, it is possible to produce each panel potentially of different forms. The design of the panel was optimised in such a way as to reduce the hours necessary for the printing, and evaluations were made of a wide range of materials, including recycled ones, and various 3D printing techniques [30–33].

In both cases, it is expected that the panels will be coated with a thin layer of 0.5 millimetre grain plaster. This is an organic product, cement-free, non-toxic, obtained by mixing an acrylic resin solution with quartz sands, and additives to improve its workability and oxidising pigment. This type of plaster has extremely good characteristics for adhesion to polymer materials, guarantees stability in fluctuations of humidity and temperature, and has good vapour permeability and water repellence. Lastly, the final finishing is planned to be painted according to the original colours of the internal façade.

5 Results

The proposed project matches the need for cultural resources conservation together with decarbonisation demands.

The architectural design responds to the "add-in" strategy [25]: opaque parts of the façade are insulated through the addition of layers from the inside of the building, and the replacement of original components is limited only to window frames and glass panes, with the caution not to alter their original design, transparency, and colours.

From the energy point of view, the Finite Element Method simulations and other performance analyses show that:

- it is possible to achieve internal surface temperatures of up to 19 °C, comparable to those achieved by a new building;
- thermal flux across the opaque parts of the façade can be reduced by as much as 80%;
- thermal flux across the transparent envelope can be reduced by as much as 65%;
- the solar factor is reduced from 49% to 32%.

6 Conclusions

This paper proposes a methodological approach to energy renovation in valuable 20th-century buildings. The proposed methodology encompasses architectural, historical, and energy analyses and considers both aspects of heritage conservation and energy-related issues, attempting to balance them and finding a reasonable compromise.

The application of the methodology on Palazzo Affari case study shows excellent results from the architectural, heritage and energy point of view. Combining traditional and innovative methods, it can be considered as a best practice, with the understanding that each building of such value needs appropriate and specific architectural and technological solutions.

Further studies are needed to assess the impact of the overall retrofit measures on the energy balance of the whole building and the economic sustainability of the operation which, from initial analyses, appears to be in line with the average cost of intervention on buildings of cultural value.

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