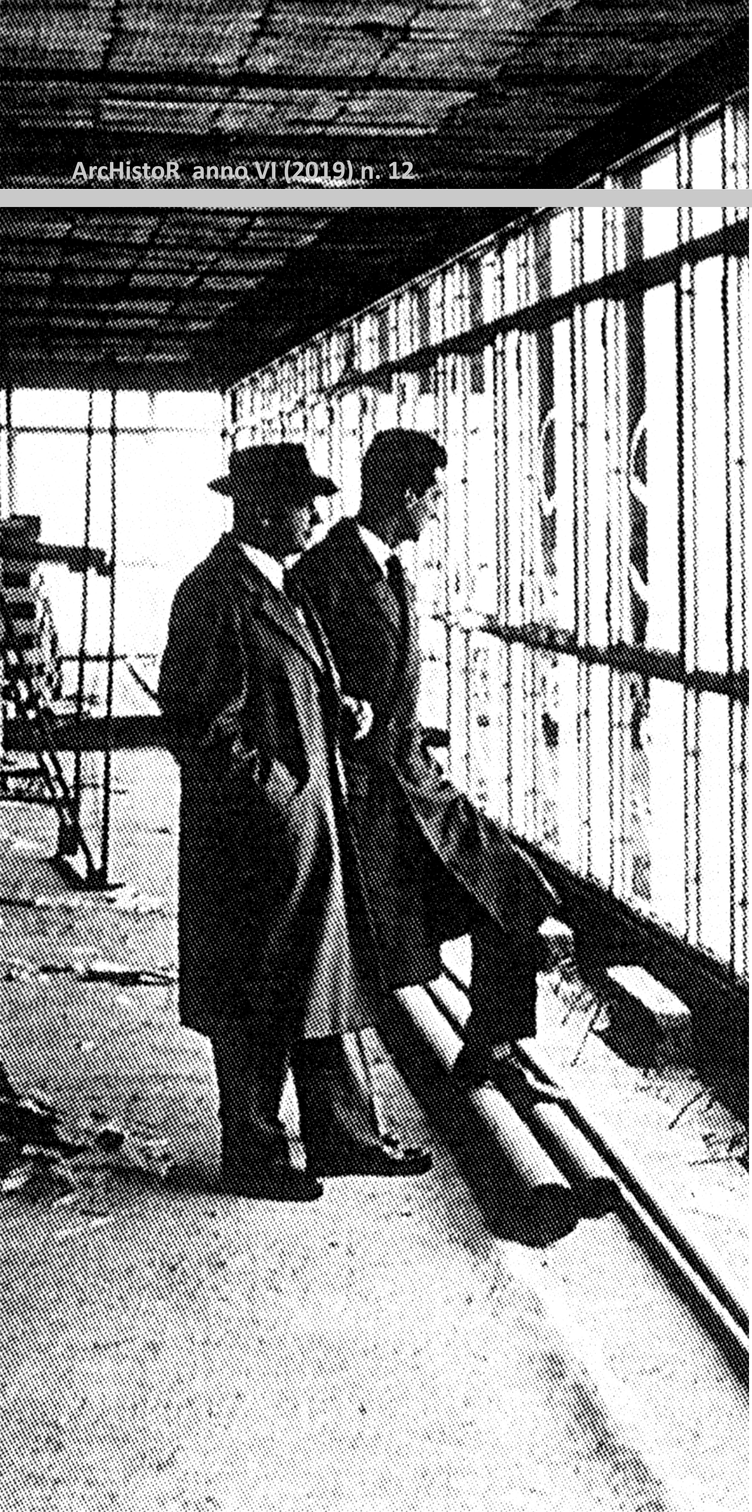

Quando la conservazione incontra un edificio con curtain wall. Il caso di Torre Galfa in Milano

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Il testo discute se il processo di rinnovamento funzionale di un edificio degli anni Cinquanta sia compatibile con il proposito di conservare un curtain wall di riconosciuto valore architettonico.
L'attenzione si concentra sugli edifici moderni del secondo Novecento, già identificati come capolavori architettonici, ma non ancora tutelati. Gli autori si interrogano su come mantenere in uso queste facciate, sulla base di una valutazione multicriteria che esamina comparativamente diversi scenari di intervento, valutando l'incremento dell'efficienza energetica, il costo d'esecuzione e il grado di conservazione materiale della facciata originale.
Dopo un esame della letteratura internazionale, l'articolo presenta i risultati ottenuti analizzando la facciata della Torre Galfa in Milano. L'analisi è stata condotta seguendo il metodo già impiegato per la conservazione delle finestre storiche e adattato con successo alla conservazione delle facciate continue dal riconosciuto valore architettonico.
I risultati dimostrano che un'analisi approfondita è determinante per valutare consapevolmente diverse strategie, contemperando istanze funzionali, tutela e sostenibilità. In conclusione, considerando il grande numero di edifici che nel prossimo futuro saranno coinvolti da questo processo, e la varietà di questioni tecniche e teoriche coinvolte, si sottolinea la necessità di affrontare il tema in modo sempre più interdisciplinare.

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When Preservation Meets a 20th-Century Building with Curtain Wall. The Case of the Torre Galfa in Milan

Davide Del Curto, Chiara Stanga

This paper discusses if the renewal of a 1950s building is compatible with the purpose of preserving a curtain wall of architectural value.

In the first half of the 20th century, iron and glass were distinctive features of modern architecture, since they allow architects in designing wide openings, thus passing from the concept of window to the curtain wall[1]. Curtain walls widespread in the second half of the century, when they were made of aluminum alloys and special glazing. The curtain walls made in the 1950s and 1960s have presented signs of physical decay since the last decades and risk being replaced with new façades. As this process involves buildings of historical interest, the experts in conservation raised their attention to save the most iconic cases. Curtain walls have been described as a latest step within the window's history and therefore considered as a heritage, by both the history of architecture and construction[2]. Thanks to a debate developed since the 1980s, some were preserved and restored in the last two decades, according to the same methodological path that was already applied to the conservation of historic windows and based on preliminary studies and surveys[3].

1. Conte 2010.
2. Romanelli, Scapaccino 1979.
3. De Jonge 1997b; Albani 2012, pp. 165-192.

The authors investigated Galfa Tower in Milan, a 106-meter-high office tower built in the 1950s, with a curtain wall made of aluminum and glass. Although it is unlisted, this façade was studied by the experts in conservation, as an early example of pre-assembled system in Italy. After years of neglect, a restoration process started in 2016. The authors wonder if the original 1950s curtain wall is able to meet the new functional requirements and thus kept in use. To answer this question, the façade was analysed to draft an as-built drawings based on the direct survey, and to design tailored scenarios of intervention. Each scenario was then assessed according to a multi-criteria approach taking into account: i) the improvement of the energy efficiency; ii) the cost for maintaining, repairing or substituting; iii) the preservation of the building components and materials.

The results consist into an accurate description of the as-built façade and into a comparative tool, supporting the decision-making process. By comparing different scenarios, tailored and more effective solutions can be developed. The conclusions confirm as such relevant interventions needs a real multidisciplinary approach and strongly benefits of an in-dept analysis of each case study.

Energy efficiency and preservation. The issue of historic windows

The conservation of historic windows is a standing issue for the preservation of the built heritage that binds together energy efficiency and cultural significance, under the main topic of sustainability.

Windows are often considered to be the weakest point of a building, in terms of energy efficiency. Owners and tenants often claim their poor hygro-thermal performances and the market tends to replace them. Nevertheless, several studies have demonstrated that windows are only one of the aspects we should take into account when assessing the energy efficiency of a historic building, together with the cooling/heating system, the insulation of walls and floors, the way a building has been inhabited and kept in use over the time.

The legislation does not even promote a comprehensive assessment of the energy behaviour of the historic buildings. Over the last 20 years, the EU incentives on energy saving resulted into national regulations encouraging the homeowners to improve the energy performances of each part of the building in order to reach specific U-values for walls, windows, roofs, etc. Since the old windows usually do not match the current standards, this approach stimulated the homeowners to substitute the old windows, instead of repairing and keeping them in use. By replacing a single building element, the homeowners are successful in matching the standards required for that specific component, and thus to have access to the economic benefits for the energy efficiency. As a consequence, when a historic building has come to a phase of renovation, new windows very often replace the old ones. According to some authors, windows represent almost half of the components replaced in the existing buildings[4]. Moreover, buildings of any kind, age and typology are supposed to guarantee the same energetic performance and derogation normally applies to listed buildings only[5].

On the contrary, the sustainability issue implies a more comprehensive approach to assess a number of issues, beside the energy consumption, e.g. the overall life-cycle of the old and new frames, including the cost/impact for the extraction, transport, production of raw material, and disposal of the old windows. In fact, adopting a long-term perspective, the average annual saving achieved by different kind of intervention upon the historic windows (maintenance, restoration, replacement) proves that replacement results in a lowest saving[6]. According to some recent studies, replacing historic windows would not result in any payback at all[7].

The interest for matching energy efficiency and preservation of historic windows dates back to the 1990s[8]. Scholars have investigated a number of situations, including the case of historic but unlisted buildings, mostly privately owned. English Heritage proposed an integrated approach based on a deep analysis of the existing building and the client objectives. In order to o avoids one-size-fits-all solutions, and to find a good balance between historic values and performances, English Heritage recommends to addressing this topic in five stages[9]: 1) assessment and understanding of the building and its context; 2) setting objectives and planning improvements; 3) detailed design and specification; 4) installation; 5) use and maintenance.

The decision of preserving or renovating should be thus taken hand in hand with an analysis of the state of conservation of the windows, together with other aspects. E.g. historic frames are usually thinner than the current ones and replacing them may result in a major alteration of both the indoor lightening and the façade layout. English Heritage also assessed the pros and cons of different strategies for retrofitting a single-glazed historic window, in terms of energy efficiency, economic benefits and building significance. The benefits obtained by adding textile curtains, well-fitting shutters, roller blinds, honeycomb blinds, were compared with the results obtained by adding a low-emission secondary glazing[10].

Similar studies were developed outside the English-speaking area, by applying the same comparative approach to a wide range of windows that date back to the 18th, 19th and 20th centuries and still in use.

4. Della Torre 2010.

5. Pracchi, Rat, Verzeroli 2014, p. 435.

6. See CRESME Report July 2010, pp. 435-436, www.cresme.it/it/rapporti/ (access December 20th 2019).

7. *Ibidem*.

8. Caterina 1995; Fossdal 1996.

9. English Heritage 2018.

10. English Heritage 2008, p. 51.

The results often confirm that replacing a historic window is not always the best solution to meet the expected requirements, and it is rather one of the possible solutions among a number of options[11]. Experimental research proves as the gap of energy performance between an old and new window is not as wide as one could expect[12], and therefore stresses the importance of adopting tailored strategies of conservation/renovation for any kind of historic windows[13].

Energy efficiency and building management: two tasks for a 20th-century curtain wall

When dealing with the question of preserving or renovating a 20th-century curtain wall, a number of issues enters the debate beside energy efficiency and building performance.

Trabucco and Fava analysed the curtain wall performances as one of the parameters to evaluate the possibility of demolishing or renovating tall buildings, together with other points, such as the obsolescence/inadequacy of vertical connection systems (lifts and staircases do not match current safety standards), the presence of contaminants, like asbestos or PCB, and architectural limitation due to the original design (e.g. a limited ceiling height). These authors focused their attention on the unlisted and tall buildings, by discussing the alterative between demolition or renovation. The demolition of a building can cost 50-90% more than its renovation and takes more time[14]. Despite they did not consider the conservation issue, they stressed that demolishing a building (or part of it) always implies the waste of construction materials since most of them cannot be effectively recycled and therefore demolition means losing the energy embedded during the construction.

David Artigas, Sean O'Brien and Arfa Aijazi in 2018 pointed out that the façade is not the main issue to be considered when dealing with the energy-efficiency of a tall building[15]. They argued that the poor thermal performance of the façade impacts the overall energy performances of a tall building less than mechanical systems and lighting. As a consequence, there are not relevant differences in the energy performance of a tall building with an old or a renovated curtain wall. Nevertheless, tall buildings are often located in business districts and frequently change tenants. Replacing the curtain wall is therefore a way to affirm the corporate identity by renewing the look of the headquarter. According to the authors, the replacement of a curtain wall is normally based on a quick judgment that the older

11. Caterina 1995.
12. Ortelli *et alii* 2014.
13. *Ibidem*.
14. Trabucco, Fava 2013.
15. Artigas, O'Brien, Aijazi 2018.

is always worse and cannot be improved, while the newer is better, not considering that a tailored analysis would easily demonstrate the real pros and cons of each possible intervention[16].

Patterson and Vaglio focused on the waste of glass due to the replacement of curtain walls. In fact, while aluminum profiles can be recycled, glass (particularly the one with surface treatments) can be reused only for asphalt or embankments fill, and most of it ends in the landfills. This energy loss is normally not included in the life-cycle assessment and payback estimations that motivate the need to replace a curtain wall[17].

In addition, glass has not commonly been considered as a construction material to be preserved, despite it drove the new aesthetic in the 19th and 20th-century architecture[18]. Literature has only recently focused on glass as an item for architectural conservation, by investigating how it was historically produced, its material decay and the possible strategies of preservation[19]. Glass manufacturing knew a sudden growth in the 19th century, when products with specific features of transparency, dimensions and thickness began available to the building construction sector[20]. This was evident within the renovation of the pharmaceutical factory Boots Wets at Beeston in England. The factory was designed by the English modernist Architect Evan Owen Williams around the 1930s. In the 1990s, the metal and glass façade was replaced with a new one. The new curtain wall was designed by the same company that realised the previous one, by following the same layout but using more performant profiles and double-reflective glazing. Some scholars praised it as a good result, because the new façade respects the original architectural layout. Others argued that the personality of Williams' building is lost forever due to the different colour of the new reflective glazing[21]. The case of Boots Wets at Beeston confirms that nowadays glass needs to have good thermal performances, but at the same time it is asked to be as transparent as possible, particularly when dealing with the restoration of a curtain wall of historical interest[22].

Following what happened to the historic windows, the increasing requirements of energy efficiency risk making 20th-century curtain walls obsolete. Energy efficiency is not the only issue to be considered when wondering if preserving or substituting a façade, together with building performances, the ageing of the installations and waste management. Some experiences have looked for a balance

16. Artigas, O'Brien, Aijazi 2018.

17. Patterson, Vaglio 2011.

18. Reichlin 2011.

19. Pender, Godfraind 2011.

20. Albani 2012.

21. *Ivi*, p. 168.

22. Graf 2014, p. 266.

between performances and preservation needs for more than a decade. A deep phase of analysis confirms being an opportunity to assess different scenarios of intervention, thus transforming a mere technical question into a cultural issue.

20th-century curtain walls meet preservation

20th-century curtain walls can be divided in two groups: i) the proto-industrial façades with thin iron frames and single glaze (1920-30s); ii) the façades dating back to the 1950s and 1960s made by assembling extruded aluminum alloy frames and improved glass. This second type became very common after the Second World War and nowadays represents a major challenge for the preservation and management of 20th-century architecture. Both types present poor thermal performances compared to the current standards. Improving the energy efficiency of such façades poses a number of challenges[23]. In fact: 1) insulation can be improved thanks to double glazing and thermal break steel profile. Nevertheless, these elements increase the weight and might affect the stability of the window; 2) the improvement of the overall sealing might increase the indoor humidity and the risk of condensation; 3) the substitution of single with double glazing might result into cold bridges and condensation along the original frames; 4) of tra use a glazing with sun reflective coatings substantially alters the appearance of the building.

A comprehensive understanding of how a curtain wall was designed and realised is thus essential to properly manage a renovation process. This objective can be achieved by following the same methodological path already described the preservation of historic windows. This way, a number of curtain walls dating back to the first half of the 20th century have already been restored with positive results.

Sanatorium Zonnestraal was built around 1925-1931 by architect Jan Duiker and it is one of the most important building of the Modern Movement in the Netherlands. A comprehensive restoration was carried out in the 2000s and included the question of how to preserve the curtain wall. Sanatorium Zoneestraal was originally designed to perform a programmatically limited therapeutic function, in the expectation that drugs would quickly made long hospitalisations unnecessary. The building construction process followed this view, by using cheap and intentionally short-lasting materials[24]. The main issue for the restoration project was therefore "how to prolong the limited lifespan"[25] of the original building,

23. De Jonge 1997b, p. 28.
24. De Jonge 1997a.
25. De Jonge 1995.

and it led to the need of identifying new functions and new performances for each building component, including the curtain wall[26]. A specific decision-making tool helped the designers to balance the conservation issues and the energy requirements, by comparing different scenarios. The replacement of single glazing with double glazing usually implies to insulate the building structure (façade columns, floor edges, etc.) to avoid thermal bridges. To avoid this risk, in the case of Zonnestraal, single glazing was replaced with a special insulating glass, that was specifically designed to be similar to the original one[27]. Single glazing was kept whenever it was possible, e.g. in corridors and staircases where a lower temperature is acceptable. According to the authors, the case of Zonnestraal proves as a cheap solution can sometimes result into an immediate benefit, when it is properly designed. On the other hand, a comprehensive works, e.g. replacing the whole façade, might result into a moderate benefit, on both preservation and cost-saving perspective, since the payback period could be more than 30-year[28].

The ICO Centrale building (named after Ingegnere Camillo Olivetti) was built from 1939 to 1942 as an expansion of the Olivetti factory in Ivrea. The pioneering double façade designed by Architects Luigi Figini and Gino Pollini is made of a full-height external curtain wall hanging to the concrete slabs, plus a second layer of windows aligned with the pillars. A 50 cm gap results between the two façades thus foreseeing the contemporary idea of a ventilated façade. The façade was restored within a comprehensive renovation (2004-2006) since the building was turned into the Vodafone Italia call centre. The internal windows were replaced to improve the thermal behaviour, while the external façade was maintained to preserve its iconic appearance. The iron profiles were dismantled, sandblasted and re-assembled. A small percentage (15%) was replaced with new zinc-plated profiles. However, the single glazing was not preserved, but substituted with float-laminated glazing[29]. The building was listed in 2016.

Specific challenges nowadays affect the curtain walls dating back to the second half of the 20th century[30]. As reinforced concrete nowadays has come to a critical age and results into an unexpected fragility[31], similarly 1950s-curtain walls highlight specific issues in conservation due to the ageing of their components[32]. This issue has often been faced according to a building-performance approach:

26. De Jonge 2010.

27. *Ivi*, pp. 179-201.

28. De Jonge 1997b, p. 26.

29. Albani 2012.

30. Mornati 2012; Mornati 2017.

31. Mornati 2006, p. 874; Greco 2012, p. 441; Graf 2014, pp. 12-13, 265-271.

32. Cupelloni 2017, p. 39.

the whole system or even single components were dismantled and substituted, since both material and technology were considered to the end of their life cycle[33]. As a result, several façades were therefore substituted, but some others demonstrated as the performances of a 1950s-curtain wall can be improved together with its conservation.

The Pirelli Tower in Milan was designed by Architect Gio Ponti and Engineer Pierluigi Nervi in 1956-60 and was restored in 2002-2004 after a little plane crashed against the main façade. The accident gave the occasion for opening a debate about the preservation/restoration of the entire building and to promote a wider discussion about the legal framework of safeguard for this kind of buildings. In fact, Pirelli Tower was not yet come to the age to be automatically listed by the Italian protection law (70 years old for any public building), while the restoration project needed to respect the authorship of Architect Gio Ponti, which is legally recognized as a form of copyright[34]. As usual for a heritage building, the restoration of the Pirelli Tower was thus based on a deep investigation of the façade, revealing unexpected details linked to the construction phase, e.g. the pioneering assembling that makes this façade one of the most outstanding examples in Italy dating back to the 1950s[35]. The restoration work was therefore carried with the purpose to maintain most of the original parts, and to replace only the heavily damaged elements. The façade was therefore dismantled and subjected to a re-anodising treatment to renew the resistance to the corrosion. A "microsurgery" treatment also improved the energy and acoustic performance of the profiles[36].

A similar approach was developed for the curtain wall of the Cité du Lignon, a huge residential complex in Geneva, realized in the 1960s-1970s by Architect Georges Addor. Despite the huge dimension of this building, and the low degree of legal protection, if compared to the Pirelli Tower, a very detailed analysis was promoted by the École Polytechnique Fédérale de Lausanne. A multidisciplinary research analysed the state of conservation of the façade components (aluminum frame, glass, gaskets, etc.)[37]. This survey was integrated with a research on the construction history of the complex, focusing on the materials and techniques employed within the building site. The architectural research resulted into a very effective as-built model that made the results of the subsequent analyses (i.e. energy demand, pollutants, etc.) more precise and effective. Following this path, four hypotheses of intervention have been developed and translated into technical documents. They span from a complete replacement of

33. Graf 2014, p. 265.

34. Salvo 2014.

35. Greco 2012, p. 443.

36. Crippa 2007, pp. 80-89.

37. Graf 2012b; Graf 2014.

the existing curtain wall, up to the keeping of the existing façade, by reducing major defects through a minimum maintenance[38].

A last example of restoration based on the comparison of different technical solutions concerns the curtain wall of the Neue Nationalgalerie in Berlin designed by Ludwig Mies van der Rohe and completed in 1968. The 5-years restoration was designed by David Chipperfield Architects with the supervision of the Federal Building and Regional Planning Office (BBR). Since its construction, the glass envelope had to deal with two main issues: breakage of glass and surface condensation. For this reason, the panes have undergone several restorations and replacements. The large glass panes (360 x 500h) were no longer commercially available and were therefore replaced with smaller panes connected with silicone joints since 1972. In 1969 it was necessary to install small gutters in front of the windows to overcome the problem of surface condensation. The recent restoration decided to replace the glass panes in order to improve the thermal performances of the curtain wall. Three technical solutions have been designed: (i) the substitution of the glass panes with new safety glazing, maintaining the metal structure; (ii) the substitution of the glass panes with double glazing, changing the existing metal frames; (iii) the complete replacement of the curtain wall, including glass, frames, structural profiles. The first solution has been chosen, together with a structural consolidation of the envelope. This follows Mies van der Rohe's vision as he designed a not thermally insulated building, thus not using metal profiles with thermal break, although he had already tested them for the buildings in Chicago[39].

The case of Galfa Tower

Galfa Tower was built (1956-59) to be the headquarter of the S.A.R.O.M. oil company and it was designed by Architect Melchiorre Bega and Engineer Arturo Danusso[40]. The site is near the Central Railway Station, at the crossroads between Luigi Galvani and Fara streets, hence the tower was named after these two streets (Gal-Fa). A secondary two-storey building sides the tower at south-west. Galfa is a a 31-storeys tower of 37x14x106 mt. (fig. 1) made of a reinforced concrete structure supporting a glass and aluminium façade. The aluminum silver frames results into a chromatic contrast with the glass surface and the full-height black duralumin profiles. A set of indoor curtains were added to shade

38. Graf 2012a

39. Jaspers 2017; Danesi, Di Resta 2019.

40. Cervini 1996; Greco, Mornati 2012.

the interiors from the solar radiation (fig. 2). The HVAC channels occupied a limited thickness at the edge of the slab, thus opaque parapets were not needed to hide fan coils, as it was for the nearby Pirelli Tower (figg. 3-4). The overall design of the façade is therefore dominated by transparent surfaces (fig. 5). The façade was produced with techniques on the edge between craftmanship and industry, thus testifying the fragmentation of the manufacturing sector in the 1950s, where most Italian companies had small-medium dimensions[41].

After having changed use and ownership several times, the Galfa Tower fell in ruin in 2002. After fourteen years of neglect, a rehabilitation project has been developed since 2016, and the works will be completed by the end of 2019. BG&K Associate, Architect Maurice Kanah, is in charge for the architectural design, Ramboll UK Limited, Engineer Alberto Ferrari, is responsible of the curtain wall engineering[42]. The reinforced concrete structure will be preserved and a new safety staircase will be added to the tower along the secondary façade. The interiors will be entirely renovated. The curtain wall will be replaced with a new one following the original design.

The possibility of preserving the existing curtain wall, by adapting it to current safety standards, was not considered, differently from what happened to other buildings of the same period, e.g. the nearby Pirelli Tower. This is linked to the delicate issue of the legal protection of the modern architecture, in Italy. Public buildings are protected since they are older than 70 years (Code of the Cultural and Landscape Heritage - Decree law 42/2004, art. 10). This does not apply to private buildings, as they can benefit of a legal protection just on the basis of a specific statement of cultural interest. Nevertheless, the masterpieces of modern architecture can be protected thanks to the Italian law on copyright (Law 633/42). This applies since a certain building has been recognised to be a relevant example of special creativity and originality[43.] The law does not directly protect the building, but the designer and gives him the possibility to legally oppose to anyone who intends modifying the building and risks threatening these qualities. The author can also ask to be appointed to design the required transformations. However, Galfa Tower is not protected by any law, neither for the building itself, nor for the author's copyright.

The following paragraphs present the results of an experimental research developed at Politecnico di Milano, School of Architecture and Society, MSc program[44]. Students were asked to analyse the

41. Cupelloni 2017.

42. Bolognesi 2017.

43. Carughi 2012.

44. Politecnico di Milano, School of Architecture and Society, Thematic Design Studio, Professors Davide Del Curto (Architectural preservation), Massimiliano Nocchi (Interior design), Gianpaolo Rosati (Structural analysis), A.Y. 2013/2014.

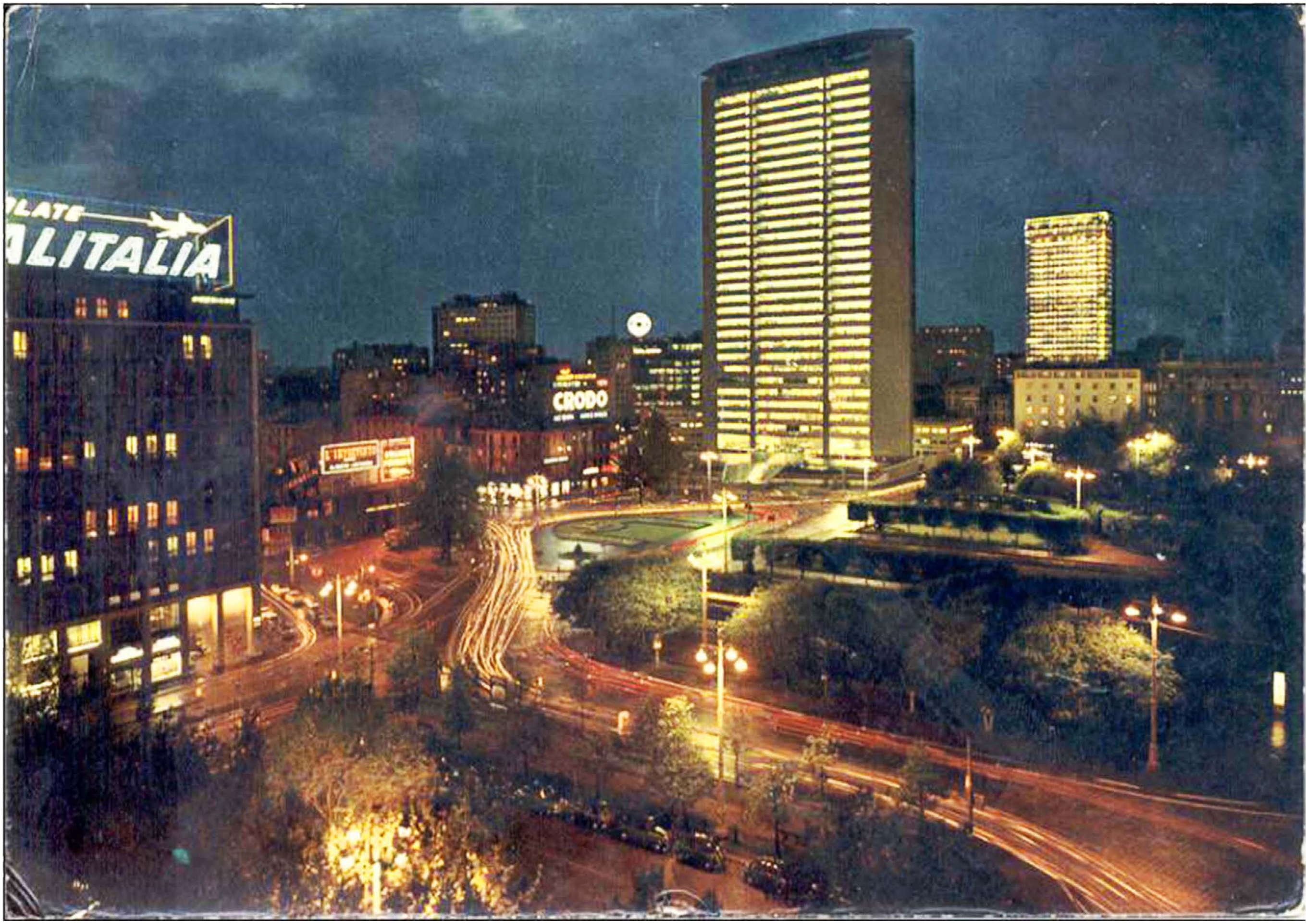


Figure 1. Milan, Pirelli Tower and Galfa Tower
(1960s-postcard, collection of the authors).

Figure 2. Mlan, Galfa Tower façade with curtains, view from Pirelli Tower rooftop (1960s-postcard, collection of the authors).

current state of Galfa Tower and to design a restoration and possible reuse. Student needed to take into account the energy and structural performance of the building, together with the issue of keeping its architectural significance. In particular, they were asked to analyse the possibility of preserving the curtain wall, rather than replacing it. The project had to be feasible in terms of adaptability of the existing structure to the new functions.

Despite the lack of instrumental tests to evaluate the thermal behaviour of each building components, an in-dept analysis of the as-built was carried out. It followed the methodology already applied to the case of Citè du Lignon and based on a comparative and multi-criteria analysis. The aim was to verify: a) if the method proves to be effective when applied to the façade of a tall and unlisted building; b) the possibility of obtaining reliable data, from a didactic application of the same methodology, thus from non-specialized operators, such as MSc students of architecture; c) the possibility of applying the results to the discussion about if preserving or replacing the curtain wall.

Surveying the as-built

The original executive drawings of the Tower are well preserved in the private archive of Architect Melchiorre Bega and they have been partially published[45]. An on-site survey was done to draft the as-built drawings of the curtain wall. 37 students operated by using simple tools as metric tape, laser distance meter, optical level, callipers. This significantly clarified both the construction process of the façade and the current state of conservation[46].

A 24 mm (6/12/6) glass pane was used, named Thermopane by the Italian company VIS. Two single glazed are weld together with a patented metallic joint (Bondermetic) filled with dehydrated air[47]. The frames were made of an aluminum alloy named Duralumin, containing copper, manganese, and magnesium[48]. It is highly suitable for extrusion, despite it was still being under testing at that time[49]. The curtain wall presents a combination of full-height black mullions and silver-coloured aluminium window frames. Each mullion is connected to the concrete slab by steel brackets placed in the 30-cm gap between mullion and concrete. The mullion of each storey is hanged to the slab of the storey

45. Greco, Mornati 2012.

46. The authors want to thank Chiara Spinelli for her support during the survey on field and for the implementation of the as-built drawings.

47. Albani 2012, pp. 122-127.

48. Conte 2010.

49. Greco, Mornati 2012.

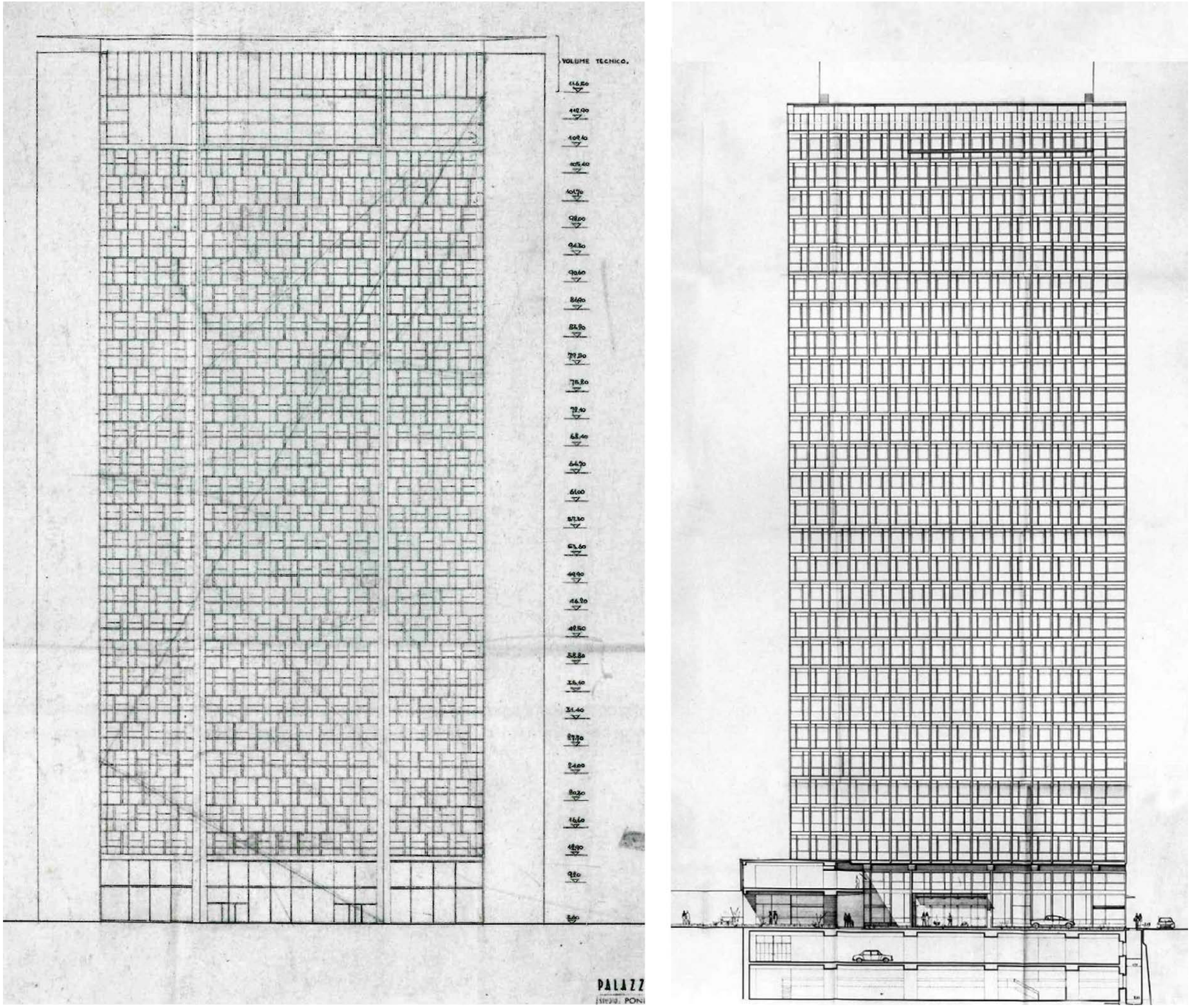


Figure 3. Comparison between the curtain wall of Pirelli Tower and Galfa Tower: design state. Pirelli tower first design in 1954 with full-glass windows (Cevini 1996, p. 46, left). Galfa Tower technical drawing (courtesy of Architect Bega Archive, right).

Figure 4. Comparison between the curtain wall of Pirelli Tower and Galfa Tower: as-built. Pirelli tower curtain wall includes opaque parapets and fanlights to hide fan coil units and countertops (Crippa 2007, left). Thanks to the limited thickness of the air-ducts, Galfa Tower has a fully transparent curtain wall (courtesy of Architect Bega Archive, right).

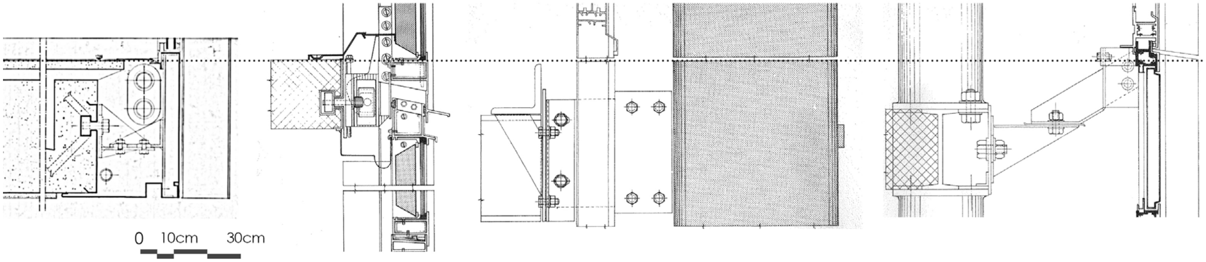


Figure 5. Comparison among 1950-60s curtain wall-slab connections. Dot line represents the floor level. From left to right: Galfa Tower, Milan, 1956-59 (courtesy of Architect Bega Archive); Pirelli Tower, Milan, 1956-60 (Romanelli, Scapaccino 1979); Esso Standard headquarters, Rome, 1963-1964 (Romanelli, Scapaccino 1979); RAI-TV headquarters, Rome, 1967 (Romanelli, Scapaccino 1979).

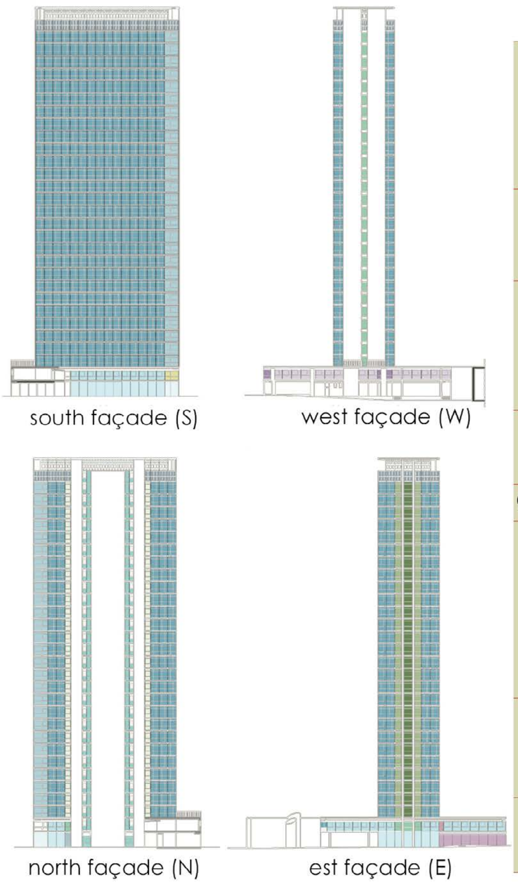
above. This connection shows that the curtain wall was probably installed from the inside rather than the outside, thus accelerating the construction process. The curtain wall was totally assembled on-site in less than three months, after the concrete structure was finished. The easy-to-handle metal profiles allowed this rapid construction. The making of mullions and frames took one month, the glass panes were then installed[50].

Despite years of neglect, nowadays both the metal and glass components are mostly well preserved. On the other hand, the iron elements connecting the curtain wall to the slab are affected by corrosion and the rubber gaskets are mostly vulcanized (fig. 6).

Despite the uniform appearance, the façade is composed of eight different windows modules (fig. 7). Each module was measured and drawn at 1:20 scale. Some details, e.g. the joint between mullion and transom, were drawn at 1:5-1:2 scale. The ground floor presents a window type (Single Module) as tall as the storey. Single Module can be subdivided in four sub-typologies: Basic, Small, Large, and Longitudinal. The first floor has a Tripartite Module (sub-typologies: Basic, Small, Horizontal) and a Bipartite Module (Basic, Small, Large, Horizontal). The Basic sub-type (225x246 cm) was employed both for the first storey of the Tower and for the East façade of the minor building parallel to Galvani street. It is made of a parapet (102 cm height) and two panes on the upper side: a fixed pane 75 x 145 cm and a single casement 145x150 cm. The Tripartite Module (sub-type: horizontal) dominates the West façade of the minor building parallel to Galvani street. It differs from the others because it lacks

50. *Ibidem*.

Figure 6. Galfa Tower curtain wall. Comparison among building site (Greco, Mornati 2012, p. 93, left), interiors in 1959 (Greco, Mornati 2012, p. 122, middle), interiors in 2015 (Photo D. Del Curto, right).



MODULES	SUB TYPE	BUILDING	STOREY	FAÇADE	N. MOD.	MQ MOD.	MQ TYPE	MQ tot MOD.
Single	BASIC	T	GF	N E S	17	8.92	151.64	311.63
	SMALL	T	GF	N E	3	6.13	18.39	
	LARGE	T	GF	N S	2	14.66	29.32	
	HORIZ.	L	GF	E	14	8.02	112.28	
Bipartite	BASIC	T	1°	W	27	3.77	101.79	129.26
	SMALL	L	1°	E	1	2.75	2.75	
	LARGE	T	1° 1°	N E	3	4.62	13.86	
	HORIZ.	L	1°	W	3	3.62	10.86	
Tripartite	BASIC	T	1°	N E S	35	5.61	196.35	294.86
		L	1°	N E				
	SMALL	L	1°	W	1	4.31	4.31	
	HORIZ.	L	1°	W	15	6.28	94.20	
Tripartite Single	BASIC	T	2°-28°	N E	108	4.41	476.28	663.66
	LARGE	T	2°-28°	E	27	6.94	187.38	
Quadripartite	BASIC	T	1°	N S	2	9.23	18.46	18.46
Six-party	BASIC	T	2°-28°	N E S W	702	6.66	4675.32	5659.38
	LARGE	T	2°-28°	N S	54	11.29	609.66	
	VENTIL.	T	2°-28°	N	60	6.24	374.40	
Parapet	BASIC	T	29°	N E S W	104	1.94	201.76	201.76
Horizontal	BASIC	T	29°-30°	N/S/W/E	*	*	*	*
	SMALL	T	29°-30°	N/S/W/E	*	*	*	*
	OPEN	T	29°-30°	N/S/W/E	*	*	*	*

Figure 7. Curtain wall-windows typological analysis, comparison among the different modules. In the third column building T is Galfa Tower, building L is via Galvani wing (elaboration by the authors, together with arch. Chiara Spinelli).

the full-height black mullions. This sub-type (245x247 cm) has a fixed pane (54x134 cm), an openable one (170x134 cm) and a single-slab parapet (height 102 cm). The Tripartite Single Module was then adopted to adjust the layout of the curtain wall to the concrete structure on the eastern and western façades of the Tower: at the level of the staircases (sub-type: Basic) and at the level of the corridor (sub-type: Large).

The Six-Party Module covers the Tower from the 3rd to the 28th storey (sub-types: Basic, Large, Ventilation system). The Basic sub-type (figg. 8-10) is the most used. This sub-type can be divided into six sectors, two vertically, and three horizontally. The parapet height is 102 cm, like the one of the other sub-types. The pane height is 134 cm. The fanlight height is 48 cm. The fixed pane width is 45 cm. The casement width is 139 cm. The vertical mullion therefore divides this module into two sides of different width (one fixed and the other openable). These modules were installed as vertically mirrored from one storey to the other. This way, the vertical mullions of the even and odd floors are not aligned, and the overall design of the aluminum façade is more dynamic. The Six-Party (subtype: Large) is employed to adjust the Six-Party Module to the overall layout of the curtain wall at the northern and southern corners, where a special module is needed, since the space is wider comparing to the Six-Party Module (sub-type: basic). The same happens for the northern and southern corners of the first storey, where a Quadripartite Module was thus used. The Six-Party (sub-type: Ventilation system) is applied to the northern façade from the ground floor to the 29th storey. It has the left pane filled with a ventilation grid instead of a glass. A Bipartite Module (sub-type: Basic) made the parapet of the 30th storey (terrace).

The on-site survey made it possible to evaluate the building materials assembling and the current state of degradation. Moreover, by making a detailed re-drawing of each element, this apparently uniform façade turned out to be made of a number of components that were industrially produced in a standardized way (aluminum profiles, glass plates, steel brackets) and were then tailored and assembled on site. This work of artisanal tuning was crucial to make an industrial product compatible with the characteristics of a construction site of the 1950s, as the poor control of tolerances in the reinforced concrete structure, and the frequent changes during project execution[51]. However, this phase is not documented nor by the historical archive that refers to the project, nor by the information related to the construction site, and it was therefore a positive outcome of the on-site survey.

51. Poretti 2009.

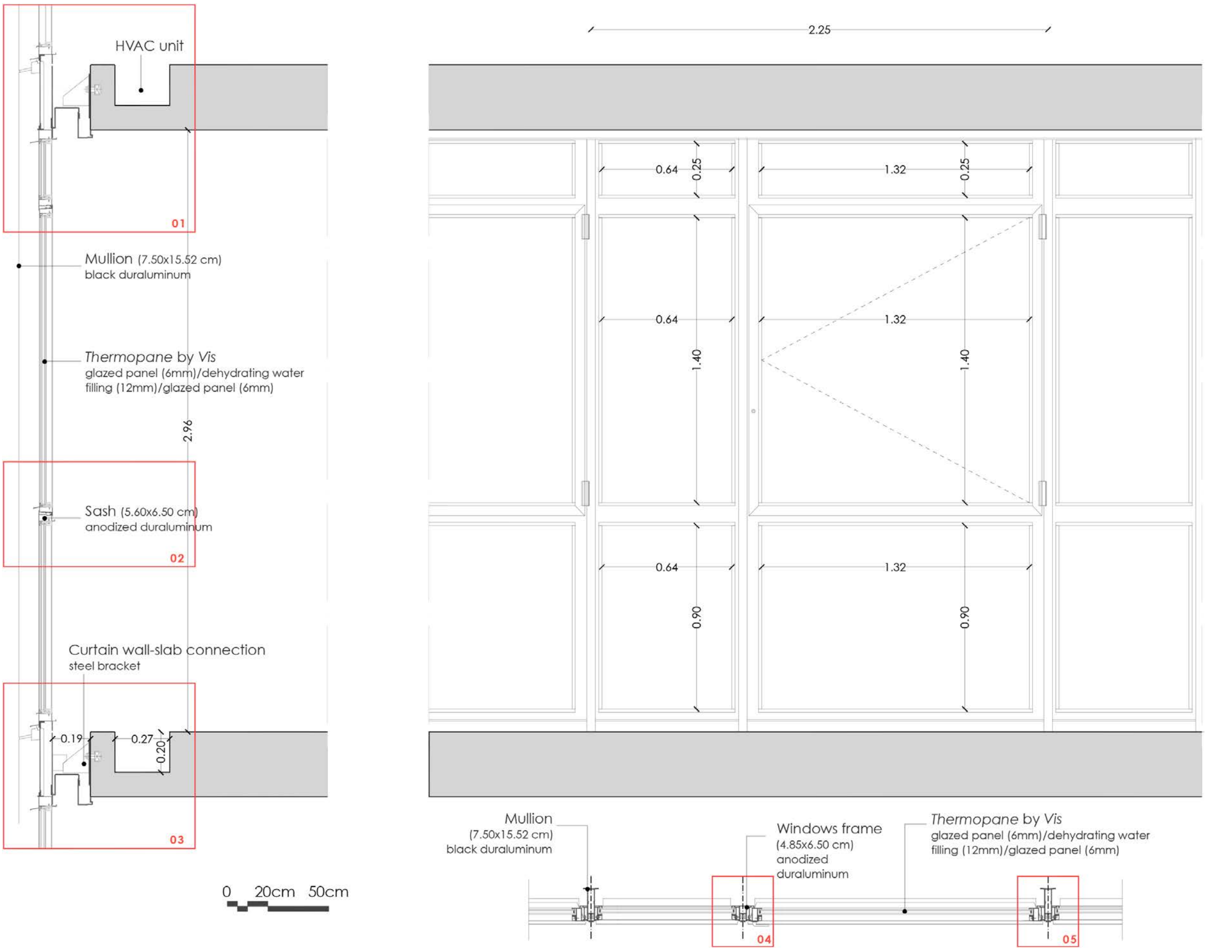
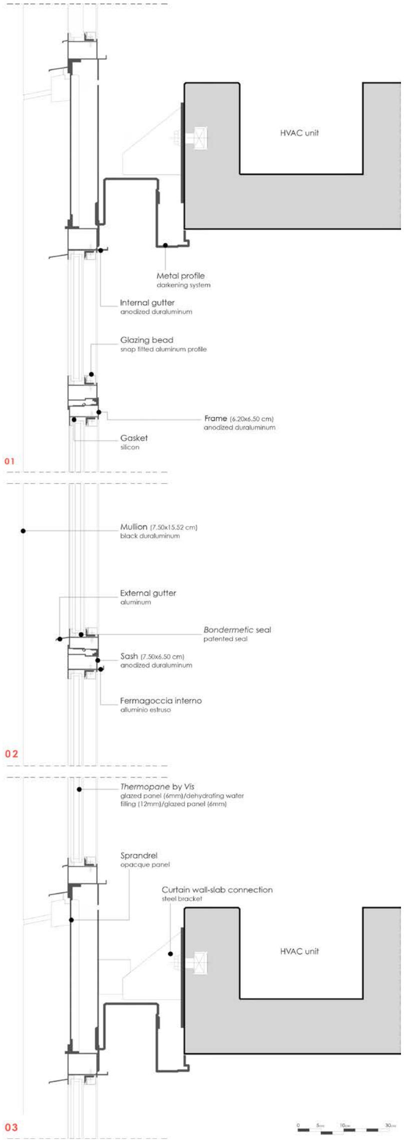
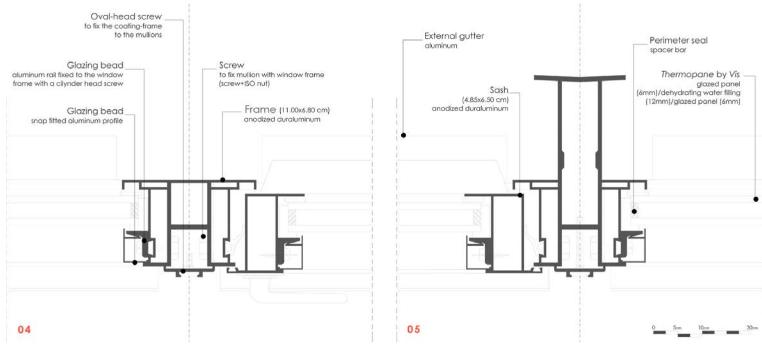


Figure 8. As-built drawing of the Six-party Module (elaboration by the authors, together with arch. Chiara Spinelli).





On the left, figure 9. As-built drawing of the Six-party Module, detail (plan) (elaboration by the authors, together with arch. Chiara Spinelli).
Above, figure 10. As-built drawing of the Six-party Module, detail (cross section) (elaboration by the authors, together with arch. Chiara Spinelli).

Energy assessment and retrofit design

Based on the above described analysis, the second part of this exercise consisted in designing a range of possible intervention, in the aim of matching preservation and energy efficiency of the curtain wall. Following the case studies described in paragraph 4, the options spanned from the maintenance to the replacement of the existing façade. Four scenarios were designed: 1. Maintenance; 2. Refurbishment (of the glass panes); 3. Addition (of a secondary casement); 4. Replacement.

1. Maintenance provides a minimum intervention on the existing curtain wall and consists with the application of a reflectivity safety film on the inner side of the glass panes. This improves the energy efficiency and safety performances. Decayed gaskets are replaced with new ones and if necessary new gaskets are added. Duralumin components are cleaned and re-anodized. Curtains will be re-installed according to the original design.

Scenarios 2, 3 and 4 were divided into sub-categories, depending on the different design approach and architectural concept, thus resulting into seven sub-scenarios (fig. 11).

2. Refurbishment aims at replacing the double glazing with a new and more performant one. The first sub-category (2.A) keeps the existing spacer, while double glazing is replaced by a new one, but the original width is maintained (24 mm). In the second sub-category (2.B) the double glazing is replaced by a thicker one, and thus a wider spacer. Due to this increase in width (29,6 mm), also the internal glazing bead is changed with a smaller one. The third sub-category (2.C) replaces the existing windows with thermal break aluminum profile and third glazing (41,6 mm) and replaces the glazing beads with new ones.

3. Addition keeps the existing curtain wall (same interventions for Maintenance) and introduces a second double glazing casement with thermal break aluminum profile, placed on the backward of the existing curtain wall, in order not to change the envelope materials, constructive techniques and external aspect. The two sub-categories present differences in the distance between the existing curtain wall and the new windows: 20 cm in the first case (3.A) and 150 cm in the second one (3.B). The choice between those two depends on the way the architectural space is conceived: the first solution can be considered as a ventilated façade with airing grills and darkening integrated system. The second implies the creation of a glazed loggia, thus a new interior to be designed, e.g. in form of a greenhouse.

4. Replacement presents two sub-options: the first one (4.A) consists in replacing the existing curtain wall with a new and more performant one. The new façade has a triple glazing and aluminum profile with thermal break, being characterised by the same architectural layout. The second one (4.B) replaces the existing curtain wall with new double-skin façade. This is made of: (i) a new curtain wall, with the same characteristics of the previous solution, and (ii) a new single-glazed window with

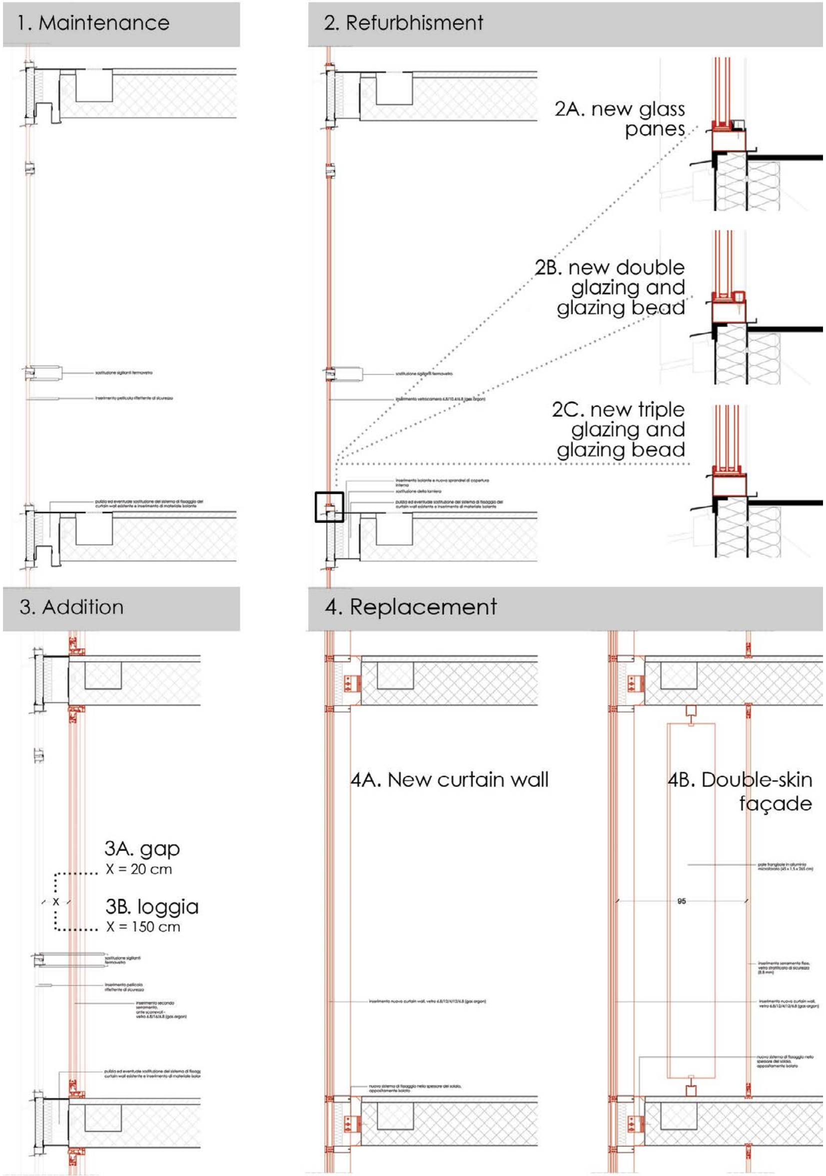


Figure 11. Scenarios of intervention. Comparative table: 1. Maintenance, 2. Refurbishment, 3. Addition, 4A. New curtain wall, 4B. Double-skin façade (elaboration by the authors).

aluminum frame, installed 95 cm from the curtain wall. A solar shading system (micro-perforated aluminum elements) takes place between the two glass-walls.

Each scenario was compared to the existing situation by using the following parameters:

- the expected improvement of the U-value,
- the cost of the intervention,
- the preservation of the building components and materials.

The improvement in thermal transmittance was evaluated as a percentage increase of the U-value of the existing curtain wall. UE Directive 2018/44 stresses the importance of improving U-values within a comprehensive approach when retrofitting the energy performance of a building, by considering the façade together with the HVAC and lighting system, and whether the building is in use or abandoned [52]. Following the guidelines prepared by the HVAC engineering field, also the Italian Ministry of Cultural Heritage recommends a tailored diagnosis for the historic buildings[53,54]. However, nor UE Directive nor Italian recommendations indicate a specific method to calculate the U-value[55]. The U-value of a curtain wall depends on the thermal resistances of each component (frame, glazing, linear thermal transmittance) and their surface. The issue of how to assess the U-value of a building component has long been the subject of research and international discussion[56]. The use of a heat flux sensor proved to be effective for many structures, e.g. masonry[57]. In the case of Galfa Tower, each component of the current façade was analyzed on site, and in view of a comparative discussion of the outcomes, the U-value of both the current curtain wall and the ones expected after each scenario of transformation were calculated according to UNI EN ISO 10077-1: 2007 (updated in 2018)[58], UNI TS 11300-1: 2014[59] and UNI EN ISO 12631:2012 (updated in 2018)[60]. Since both the frame and glazing were well preserved, it was not necessary to correct the values obtained by applying this procedure. The U-value of the curtain wall resulted 1,70 W/m^{2}K (fig. 12).

52. Directive (EU) 2018/44, see point 15, p. 77.

53. De Santoli *et alii* 2014.

54. MiBACT 2015, see chapter 3.1.

55. Mazzarella 2015.

56. Cho, Kim 2019.

57. Lucchi 2017.

58. UNI EN ISO 10077-1: 2007, see D.3 (frame) and E1 (linear thermal transmittance).

59. UNI TS 11300-1: 2014, see C.1 (glazing). Since the current double glazing (6/12/6) is not mentioned, the U-value of a 4/12/4 glazing was considered.

60. UNI EN ISO 12631: 2012 (updated in 2018) refers to UNI EN ISO 10077, in particular UNI EN ISO 10077-1 (glazing) and 10077-2 (frame and spacer).

The cost analysis was based on the public price list of building works in the Municipality of Milano[61]. The price per square meters of the four scenarios is the sum of the cost required for each single intervention, e.g. in case of Maintenance (option 1) it includes: the cost of dismantle, transport, re-anodize and re-assemble the existing aluminum frame. In case of Replacement (option 4) it includes: the cost of dismantle and disposal of the existing curtain wall, the installation of the new one.

The preservation of the building components and materials measures how much each scenario would keep the components and materials of the façade and therefore the significance of the architectural design. While the first two parameters (U-value improvement and cost) were estimated by means of a parametric calculation, this third parameter was calculated on a qualitative-quantitative basis, in particular by assessing if the proposed intervention would satisfy a number of questions, according to two categories: (i) how much would each scenario keep the original design? (ii) how much the building components and materials? For both questions, three sub-questions were defined, respectively focused on keeping the window frame (inside and outside aspect), the casement (inside and outside aspect) and the glass panes. Every specific feature of each scenario was evaluated by weighting up the positive / negative answer to these ten questions. Each positive answer results in 1 point, for a maximum of 10 points (100%). For example, for both 1-Maintenance and 2-Addition, the original building components and materials are preserved. Glass is improved by adding a reflectivity safety film. On the other hand, this film changes the original color of the glass, and the overall aspect of the building. 4-Replacement has the lowest score in preservation, since it replaces the existing curtain wall, even if by following the same layout of the original one (fig. 13).

Results

The results obtained with each scenario are compared in figs. 14, 15. In fig. 15, the different scenarios are indicated on the X axis. The cost is indicated on the Y axis, right side and represented by the green line. The energy improvement is indicated on the Y axis, left side and represented by green columns. The preservation of the building components and materials is represented by the red line. The preservation of the building components and materials trend is highest for Scenario 1-Maintenance, and it decrease for Scenario 4-Replacement. On the contrary, costs are minimum for Scenario 1 and maximum for Scenario 4.

61. Comune di Milano, 2011.

U-value of the existing curtain wall (U_w) UNI EN ISO 10077: 2007 - UNI TS 11300: 2014		Sources	Data	Unit of measure
A_w	area of the casement	on-site survey	62,14	m^2
A_g	area of the glass panes	on-site survey	23,61	m^2
U_g	thermal transmittance of the glazing	6-12-6 (dehydrated air); thickness 24 mm	2,80	W/m^2K
A_f	area of the aluminum frame	on-site survey	5,63	m^2
U_f	thermal transmittance of the frame	aluminum frame without thermal break	7,00	W/m^2K
l_g	perimeter of the glass	on-site survey	11,22	m
Ψ_g	linear thermal transmittance		0,02	W/mK
U_w	$\frac{A_g U_g + A_f U_f + l_g \Psi_g}{A_w}$		1,70	W/m^2K

Figure 12. U-value calculation of the existing façade, according to UNI EN ISO 10077-1: 2007 and UNI TS 11300-1: 2014.

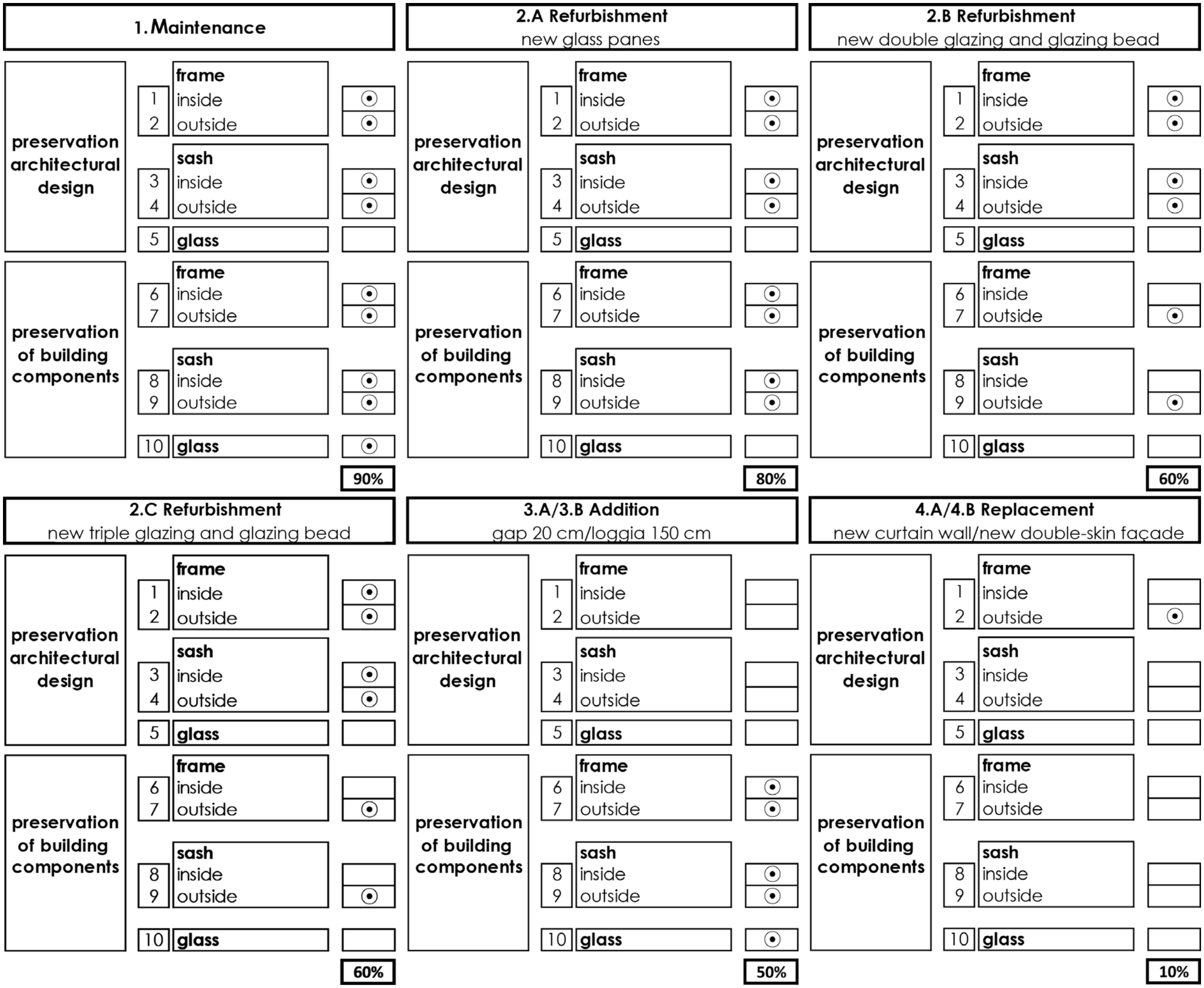


Figure 13. Preservation of building components. Comparison among different scenarios (elaboration by the authors).

According to Scenario 1-Maintenance, each component of the curtain wall (window frame, casement and glass panes, glazing beads) is kept. However, the reflectivity safety film will affect the color of the glass panes, thus the score in preservation is equal to 90%. On the other side, maintenance results in the lowest improvement of the energy performance (3%, equal to 1,65 W/m^{2}K). The cost of the intervention is not cheap as one might expect. In fact, most of the windows components have to be dismantled, classified and cleaned. The aluminum elements have to be re-anodized and every part need to be re-assembled. This results in a relevant demand of skilled manpower thus resulting in a high rise in cost (€/m^2 255).

Scenario 2-Refurbishment needs to change the glazing beads both inside and outside, in order to introduce double or triple glazing. It therefore affects both the inside and outside aspect of the overall façade. Refurbishment 2.A gets a good score in preservation (80%), but it results in a less satisfactory U-value improvement (+31%, 1,17 W/m^{2}K) and intervention cost comparing to 2.B and 2.C (€/m^2 403). Refurbishment 2.B is based on the replacement of the current glass with a double glazing more performant than 2.A. It results in a +40% improvement of the U-value (1,02 W/m^{2}K) with an estimated cost of 420€/m^2 and 60% of preservation of the original materials. Refurbishment 2.C results into a +65% improvement of the U-value improvement (0,60 W/m^{2}K), with an estimated cost of 507€/m^2, and 60% score in preservation of the original materials. It consists in replacing the current glass with a triple glazing and improving the aluminum frame in order to avoid thermal bridges. For 2.A and 2.B this was not considered since the two sub-categories have a less performant glazing. Indeed, thermal break aluminum profiles could reduce the energy performance of the overall curtain wall. In fact, while they contribute to limit thermal bridges in the windows frames, this could otherwise favour surface condensation on the glass panes, as it was discussed above, about the Neue Nationalgalerie in Berlin.

Addition (3.A and 3.B) aims at introducing a new performing window. Since the difference between the two sub-category depends on the distance of the new casement from the curtain wall (respectively 20 cm and 150 cm), they get the same score: a high improvement of the U-value (+71%, equal to 0,50 W/m^{2}K), a medium score in preservation of the original materials (50%), a relevant cost (€/m^2 620).

Replacement results into a major increase of the U-value, even if comparable to Addition. 4.A results in a +71% (0,50 W/m^{2}K), 4.B. in a +73% (0,46 W/m^{2}K), thanks to the double-skin technology of the façade. They are otherwise poorly satisfying in preserving the original materials (10%), since the original façade would be entirely replaced with a new one. They are both costly since they consist in making a new façade. 4.B is the most expensive due to the introduction of two high performant windows (€/m^2 817).

In conclusion, scenario 2.C-Refurbishment is the best compromise, as it allows preserving the original building components and materials with a reasonable cost and improving the U-value. This

	1. Maintenance	2. Refurbishment			3. Addition		4. Replacement	
		2.A double glazing new glass panes	2.B double glazing glazing bead replacement	2.C triple glazing glazing bead replacement	3.A new windows gap 20 cm	3.B new windows loggia 150 cm	4.A new curtain wall	4.B new double skin façade
improvement of the U-value	3% (1,65 W/m^{2}K)	31% (1,17 W/m^{2}K)	40% (1,02 W/m^{2}K)	65% (0,60 W/m^{2}K)	71% (0,50 W/m^{2}K)	71% (0,50 W/m^{2}K)	71% (0,50 W/m^{2}K)	73% (0,46 W/m^{2}K)
cost	255 €/m^2	403 €/m^2	420 €/m^2	507 €/m^2	620 €/m^2	620 €/m^2	573 €/m^2	817 €/m^2
preservation of building components	90%	80%	60%	60%	50%	50%	10%	10%

Figure 14. Comparison among different scenarios (U-value improvement, cost, preservation of building components) (elaboration by the authors).

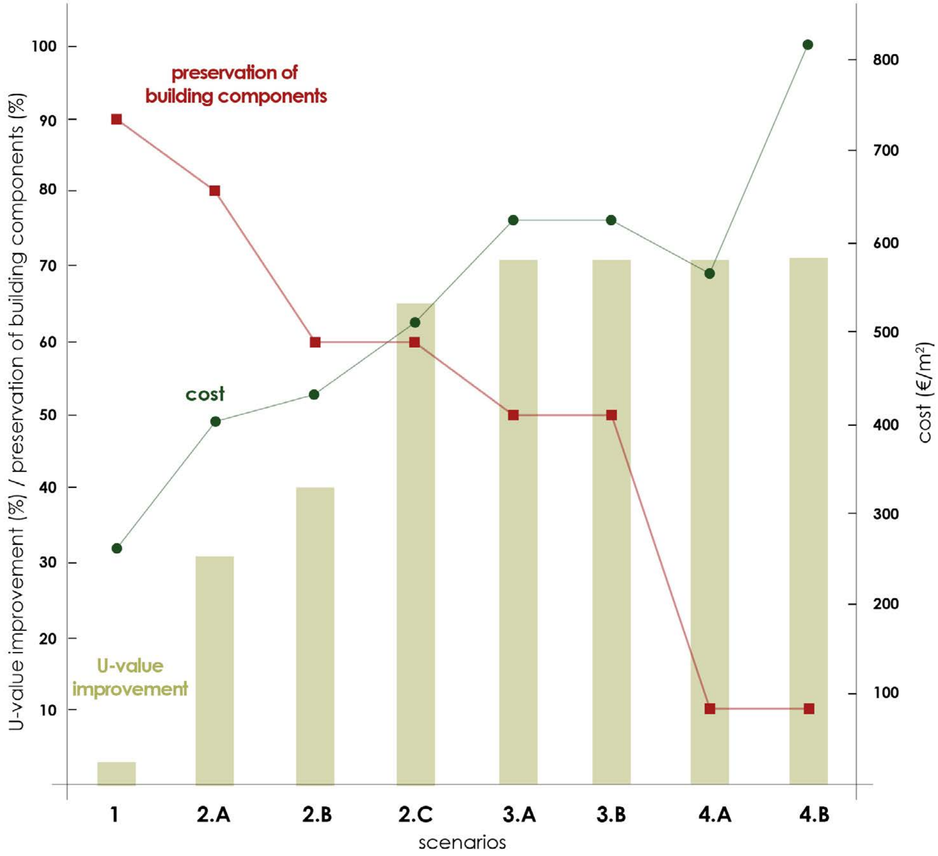


Figure 15. Comparative chart among different scenarios (elaboration by the authors).

scenario permits keeping the aluminum frame, although the glass panes would be replaced. In fact, the replacement of the glazing bead with a smaller profile would be enough to install a triple glazing. Scenario 2C. Refurbishment therefore prolongs the lifespan of this façade, by avoiding a full and expensive replacement. It results in a good improvement of the energy performance, and most the original components would be conserved.

Conclusions

The results consist in a comparative tool as a support for the decision-making process, based on an accurate description of the present state of the façade. The conclusions confirm as an in-dept analysis of each case study results into a great benefit to the design phase of such relevant interventions. By comparing different scenarios, tailored and effective solutions can be achieved. This method was developed for the preservation of historic windows in the 1990s. In the 2000s, it was then applied to few iconic façades dating back to the 20th century. The results presented in this paper prove it to be successful even when applied to the case of an unlisted tall building. The effectiveness of such a methodological path was verified by applying the same operative approach within an academic exercise, thus involving non-specialized operators, such as the students of an architecture MSc. Such positive outcomes lead to the chance of applying the same approach to the wider issue of conserving and managing the vast heritage of the 20th century. However, to make this analysis more effective for both historic windows and contemporary curtain walls, a wider range of disciplines needs being involved. Many issues are involved indeed: value assessment, conservation, energy efficiency, cost-saving, safety and the overall building management.

Moreover, according to a contemporary perspective of environmental sustainability, it is necessary to further expand the range of techniques involved, by including a life-cycle assessment aimed at prolonging the lifespan of a contemporary material (high-performance glass, aluminum alloys, polymers, etc.) and the issue of disposal/recycling within the production process. In view of a tight approach to the issue of sustainability, the question of glass remains unresolved. In fact, keeping old glasses in use is strongly discouraged both for safety and energy efficiency. Conservation has not been successful so far in supporting the will to keep in use the glass panes of the curtain walls dating back to sixty or seventy years ago. For many contemporary buildings, it represents a paradox, both in terms of conservation and sustainability, since glass is the most widely used material for curtain walls, as well as the most representative of their architectural value.

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