The “Filigrana” system for a fair look in facades solar-panel embedded

(Article begins on next page)

The “Filigrana” system for a fair look in facades solar-panel embedded

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Abstract. Solar energy is the most available and easy to use of the renewables available for buildings. Retrofitting the building stock goes through a designed, non-emergency placement of solar panels. In some cases, rooftops are not the best option: for example, in residential buildings they are not equally available to all owners or in commercial centers they are cluttered with chillers, AHUs, and so on. In contrast, the integration of solar collectors into the vertical envelope raises some visual issues related to the image of the urban environment, which has to deal with dark, shiny surfaces that are, moreover, suboptimally oriented with respect to the sun’s rays and therefore inefficient. This paper focuses focused on the new design of a thermal insulation system that incorporates photovoltaic or thermal solar collectors and allows for dimensional flexibility, scalability, and custom finishes. Retracing the development of the optimal shape of thermal insulation cladding, devices that enable the application of photovoltaic strings or solar thermal panels are also illustrated and visual results in different contexts are proposed. The project result, originally named Filigrana and covered by an Italian patent, has been brought to the level of pre-feasibility by Dreamet S.r.l. (Modena, Italy) under the name “Aster”: it allows the free choice of color of cladding, the replacement of all or part of the solar collectors over time depending on their technological evolution, and, most importantly, it is designed to improve the orientation of solar collectors on the vertical walls of buildings. Shopping malls and warehouses may be the main target, but the system also allows for managing access to photovoltaic energy for each of the individual tenants, avoiding impromptu and random additions to facades and improving the passive thermal performance of the building envelope.

Keywords: BIPV, photovoltaic envelope embedded, patented PV façade, green building, envelope refurbishing.

1 Context outline

The process of de-carbonization of the European continent, or the so-called Green Deal, aims to reduce the net emission of greenhouse gases into the atmosphere by 55 percent by 2030 compared to the 1990 situation. Approximately three-quarters of Europe's CO_2 emissions come from energy production and use, so the deployment of renewables plays a key role. In this regard, the building sector is critical mainly because of weakness in recycling and reuse of materials and because it contributes 14% of the EU's total direct GHG emissions for its own operations (2021 data), due to the use of fossil fuels for HVAC and DHW production [1]. Extensive replacement of the building stock has unfavorable environmental and social impacts, due to the aforementioned limited opportunities for recycling or reuse of materials and the complexity of inhabitant relocation, while widespread envelope efficiency and energy retrofit of the building stock seems to be a more feasible strategy [2], and today is already responsible for an annual reduction of about 1.4 percent of greenhouse gas emissions from the building sector, as noted by Eurostat.

Of the renewable sources available for integration into the building system, solar energy is the quietest and usable almost regardless of the scale of the system, at least during warm periods; however, it carries the greatest constraints visually (footprint and appearance of receptors) and spatially (location and shading).

Besides roofs, opaque parts of favorably exposed facades are surfaces where it is conceptually possible to place solar collectors. This is demonstrated, for example, by the loggia of the “Sasso Rosso” hostel (Mario Botta, 2001 [3]), in the National Youth Sports Center in Tenero (CH), which integrates solar thermal panels into the parapets (Fig. 1), and by the widespread commercial offerings of photovoltaic kits.

The latter usually have a peak power within 800 W (a threshold above which photovoltaic installation in Italy requires a formal authorization process) and come with a set of balcony railing anchors for easy DIY installation. But in this way, everyone's legitimate need to be able to self-supply with an individual, autonomous source of green electricity can clash with the right to use the roofs of buildings on the one hand and respect for the formal unity of the elevations on the other. This is somewhat what happened thirty years ago with the spread of satellite broadcasting and the related “spontaneous” proliferation of satellite dishes, at least in the early years.

In the context outlined, research has explored the possibility of integrating a solar collector system into the opaque part of vertical facades so that the potential right of access to the solar resource does not deaden the regular appearance of building elevations. Thus, even in the case of fragmented properties such as those of multi-story condominium buildings (Fig. 2), the adoption of a single insulation and finishing system can expand over time by gradually incorporating photovoltaic or solar panels. In addition, the system studied and patented by the authors can also be used extensively without scale limitations on blind facades and the envelope of commercial, sports, entertainment, etc. buildings.

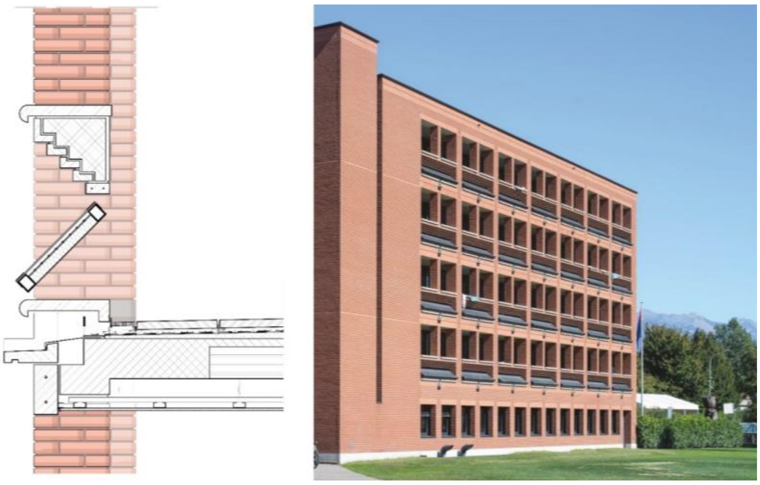

Fig. 1. National Youth Sports Centre, "Sasso Rosso" building, Tenero, Switzerland, Mario Botta Architects, 2001 © 2024, Paolo Piantanida, Antonio Vottari (drawing); © 2023 https://www.espazium.ch/it/attualita/alla-scala-del-paesaggio (photo)

Fig. 2. Visual interference of balcony photovoltaic kits © 2022 https://progetti.habitissimo.it/progetto/consigli-per-posizionare-il-fotovoltaico-sul-balcone-di-casa

2 Research targets

The focus on solar energy is generally accepted and appreciated in newly constructed buildings, where the design can also fully integrate it, such as in the Copenhagen International School (Fig. 3). In contrast, solar integration on the existing, which accounts for the majority of the Italian building stock, is of a different and more complex management, partly because of the necessary mediation between the different needs of individual owners and users and interventions on common parts such as, for example, facades or roofs.

The products available for integration into the technological envelope system are generally designed to serve a single user and to provide a color palette through pigmentation of the glazing alone (e.g., with films) in order to mask the underlying dark-colored layer. These components are classified by the IEA (International Energy Agency) as BIPV (Building Integrated Photo Voltaic), i.e., as entities that are simultaneously photovoltaic modules and building products and that, if disassembled, should be replaced by other building products [4].

Fig. 3. Copenhagen International School (C.F. Moller Architects). Detail of the facade with BIPV solar modules © https://integratedpv.eurac.edu/en/case-studies/copenhagen-international-school.html

The adoption of façade systems of this type, even without solar thermal integration, has important implications on the image of the building, which has to relate to shiny and partially reflective surfaces, very different from the common textures of Italian building tradition. In any case, these changes require careful and reasonable design of the building's new look and may be less easily handled and accepted in energy retrofit contexts on buildings with an established image.

Even after overcoming the issues of appearance and integration mentioned above, in solar facades the issue of durability and replaceability of cladding elements remains important, because each solar element is simultaneously a finishing and protective element of the facade, and determines its appearance. Just as it has proved complex to replace deteriorated klinker or exposed brick elements decades later, for example, it may be very difficult to find panels with similar electrical performance and finish and with a footprint compatible with the surrounding elements: the uncertainty about replaceability and restorability over time, due to the possible absence of spare parts, must be considered in the investment evaluation, given the high financial commitment involved in a BIPV façade system. In fact, the building could also depreciate due to the uneven patchwork that would result from the impromptu replacement of façade panels or due to the diminishing effectiveness of the façade photovoltaic system due to the inability to repair it.

In fact, the IEA considers the integration (BIPV) or Building Added PV (BAPV) of solar cells as one of the main possibilities for wide penetration of PV in the building market, provided that "aesthetic", reliability and financial requirements, among others, are met.

That said, and considering that the application on conveniently exposed façades of solar panels, whether thermal or photovoltaic, is a driving opportunity in the deployment of renewables, as evidenced by several product offerings on the market, the technological research conducted by the authors has been geared toward conceptualizing a solar captor integration system that promotes:

1. dimensional flexibility;
2. multiplicity and customization of finishes, including the texture of foreground surfaces and their maintainability over time;
3. replaceability of active components, with particular reference to photovoltaic cells, reducing as much as possible the constraints for spare parts availability in the market, also to encourage subsequent upgrades to gradually more efficient components;
4. scalability of the system, e.g., from the balcony parapet to the facade of sports or commercial centers;
5. integrability of the system into various building and technological contexts.

3 System design

The design research work was conducted by changing the objective for the adoption of the collectors in the façade system: not a technological trophy to be exhibited as in many BAPVs (and like the fluorescent tubes of the luminaires of the 1930s and 1940s), and not already an element to be faked by finishing, and for this reason acceptable only because it is artifactual (like the televisions hidden behind the mirrors), but rather a set of parts that are declared in their explicit technical consistency and are put into system by the technological design that constitutes their control.

The choice was therefore made not to intervene in the coloring of the active elements, because it would have been difficult to guarantee their identical availability over time and because the market already offers a range of proposals in this regard, but instead it was studied how to metabolize the visual impact of the captors in the appearance of the façade from a real point of view, that of proximity to the building, at street level.

Based on these assumptions, the research activity reasoned to hybridize the categories of BIPV and BAPV: the conceptualized system is integrated (BIPV) as far as the functional and conceptual scheme is concerned, while it is not in the strict sense for the technological solution. Indeed, one can eliminate or replace all or part of the active elements with only the conditioning of the dimensional compatibility of any additions, without the need to replace the corresponding façade finish.

However, the proposed system is not even "added" to the facade (as in BAPVs), because the system determines the form and construction rule of the facade itself.

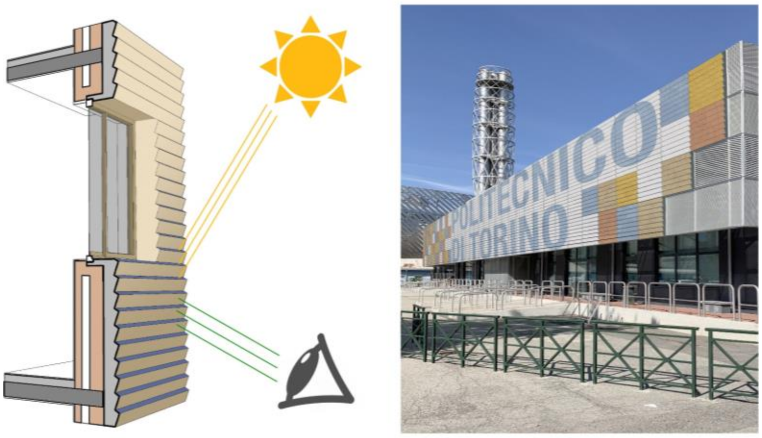

Fig. 4. *Filigrana* pattern (authors' elaboration) © 2020, Paolo Piantanida, Antonio Vottari

The developed solution is based on a thermal insulation façade panel with a special shaping of the outer side (Fig. 4), so as to offer an alternation of support strips, for the integration of thin thermal and/or photovoltaic strips, and corresponding undercut strips, the latter with the possibility that the coloring and finishing as desired build the image of the building.

The pitch, which can also be very small depending on the "string" of solar elements available, alternates between passive and active undercut strips facing the sun. It generates a rather dense horizontal pattern on the façade that favors the view, especially from below, of the undercut strips alone, while almost nullifying the visual impact of the solar collection strings, usually dark blue or black in color, which also have a better orientation for solar collection. The visual prevalence of the undercut strips, with the desired color or finish, helps to generate (or regenerate in the case of existing properties) the image of the building and integrate renewable energy into it, without the color of the collectors overriding the perception of the color of the façade.

4 System components

The system, which in Fig. 4 has been depicted with photovoltaic cells, consists of a shaped layer that forms the thermal insulation of the vertical closure, a finishing layer (cladding), strings of solar thermal or photovoltaic collectors, and a set of connections and anchors, as described in more detail below.

Undercut areas can be drilled with all the holes necessary for facade tooling (e.g., flag signs, tensioners for public grid cables, various brackets, etc.), which in facades with integrated, continuous PV cladding is a critical task even if already foreseen at the design stage. Undercut areas can also reproduce trademarks or logos, for example in the blind facades of shopping malls, or be equipped with videos for synchronous playback of images or notices, for example on cinema or theater programming, current initiatives and offers, etc.

In the case of using wood, the proposed system can even integrate into high-mountain buildings and provide an off-grid energy source with good continuity for high-altitude shelters and bivouacs, being less prone to snow accumulation (Fig. 5).

Fig. 5. High mountain shelter rendering (authors' elaboration) © 2020, Paolo Piantanida, Antonio Vottari

4.1 Thermal insulation

It consists of thermal insulation in the form of an external coat, laid with the techniques usually used in this type of intervention depending on the type of substrate (e.g., doweling) and with the usual care prescribed in the joint execution.

It is made with an appropriate predefined outline so that the strips intended to accommodate the collectors have an inclination toward the sun suitable for improving the efficiency of the system: this can be achieved, for example, by orienting the PV perpendicular to the direction of the sun's rays at the summer solstice. The undercut strips should not cause shadows carried on the active strips: for example, a right angle between the undercut and the collectors (oriented perpendicular to the summer solstice) can be adopted, or the undercut tilt can be maintained as in the previous case, but the tilt of the capturing strip is increased so as to maximize its annual yield.

With the same outline, the layer thus conformed can be made, according to the performance determined at the design stage (mechanical, biological, fire resistance, etc.), with the materials normally available for thermal insulation, for example, by means of glass or rock wool panels, in expanded polystyrene sheets with graphite added, in panels of wood agglomerates, etc.. In any case, the minimum panel thickness (at the "grooves") must still meet the regulatory requirements on verification of the maximum U-value for opaque building components.

In the research conducted by the authors, the geometry-dependent performance of the system was evaluated in two cases, according to UNI/TS 11300-4:2012 [5], with reference to the irradiance values of UNI 10349 [6] and the reflectance values of the surrounding surfaces according to UNI/TR 11328-1 (Table 3) [7], assuming a light or medium color (brick lath or paint) of the cladding.

In the first case, the reference is the direction of the sun's rays at noon on the summer solstice; in the second case, the inclination that maximized annual energy production was used. Table 1 summarizes the geometric data of the façade profile for two widths of the absorbers (20-cm band and 7-cm band) at solar noon on June 21 in some Italian locations (Fig. 6).

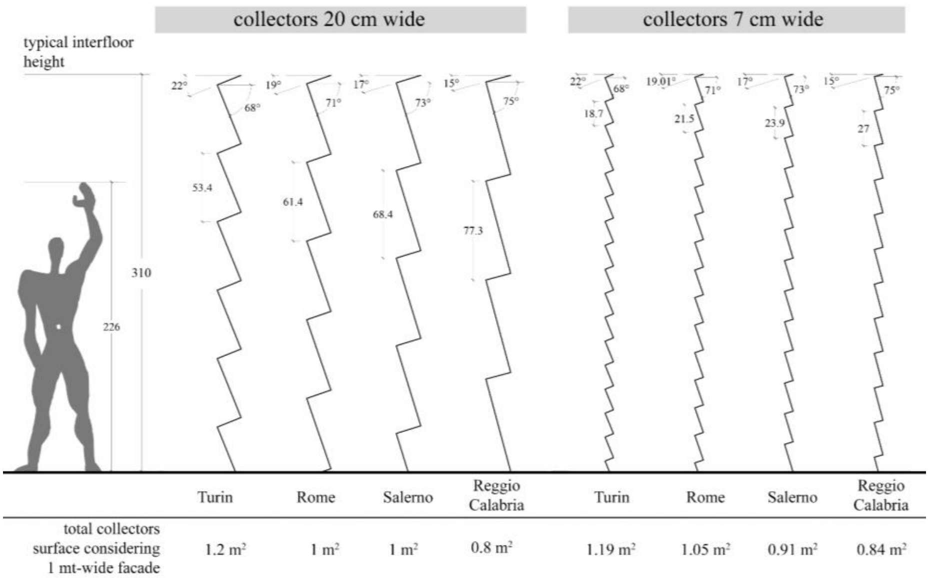

Fig. 6. Geometric data of the façade profile for two widths of the absorbers (20-cm band and 7-cm band) and best-option profile (i. e. no shadows at solar noon on June 21) in some Italian locations (authors' elaboration) © 2024, Paolo Piantanida, Antonio Vottari

The silhouette that maintains orthogonality between the bands (solar and undercut) is the most favorable for concealment of collectors, whether photovoltaic or thermal, but may penalize somewhat the seasonal performance. In the winter period, in fact, the hours of sunshine decrease and also the inclination of the rays decreases, resulting far from perpendicularity to the panels. The aforementioned Table 1 shows the annual producibility in kWh/m^2 with photovoltaic elements of 141 Wp/m^2 (the gross area of the photovoltaic string is considered, not the façade frontal area), in the case of panel orientation perpendicular to the direction of the sun's rays at the summer solstice.

For comparison, panel geometry was calculated again by increasing the PV tilt to that which maximizes annual producibility: the data are shown in Table 2 (as in Table 1, the gross area of the PV string is considered, not the frontal area of the facade). If annual productivity per sq m of frontal façade area is considered, the more the latitude increases, the more the annual energy per sq m of PV decreases, but this is offset by the increase in the area of the receptors due to the different tilt of the active strip.

Table 1. Example of orthogonal profile characteristics of the *Filigrana* panel with variable outline depending on latitude

	latitude	annual energy by PV	captor tilt	undercut tilt	crest pass (collector 20 cm wide)	crest pass (collector 7 cm wide)
	[deg]	[kWh/m^2]	[deg]	[deg]	[cm]	[cm]
Turin	45	159.3	22	68	53.4	18.7
Rome	42	186.4	19	71	61.4	21.5
Salerno	40	178.4	17	73	68.4	23.9
Reggio Calabria	38	195.7	15	75	77.3	27.0

Table 2. Characteristics of the optimized profile of the *Filigrana* panel at different latitudes in the Northern Hemisphere. Data in the red box identify the geometric profile chosen for standardization.

	gain (compared to Tab. 1)	annual energy by PV	collector + undercut tilt	crest pass (collector 20 cm wide)	crest pass (collector 7 cm wide)
	[%]	[kWh/m^2]	[deg]	[cm]	[cm]
Turin	4.72	166.8	**42.5+68**	**50.0**	**17.5**
Rome	5.50	196.7	42.0+71	56.5	19.8
Salerno	4.33	186.1	40.0+73	63.0	22.0
Reggio Calabria	5.88	207.2	40.5+75	69.7	24.4

Finally, the profile was assumed to be standardized at a ridge pitch of 50 cm (for 20 cm wide collectors) and 17.5 cm (for 7 cm wide collectors): the values obtained are highlighted in the box in Tab. 2.

In this case, each square meter of façade accommodates about 0.35 m^2 of solar panels (thermal or photovoltaic), in both collector widths: in the case of photovoltaics, there is about 50 Wp of installed power per square meter of opaque façade, and the annual

production is shown in Table 3 with reference to the gross PV active area and façade area.
This is almost identical to that of the optimized profile in Table 2 (the calculated loss is within 0.35 per thousand, largely within the uncertainties of the numerical model), demonstrating the industrial convenience of producing a single template. In addition, at locations further south, annual PV energy production per sq m of façade is favored by the larger active area compared to the profile optimized for that location (see Table 3).

Table 3. Estimated annual productivity of the standardized *Filigrana* panel profile at different latitudes in Italy (collector tilt: 42.5°; undercut tilt: 68°; ridge pitch 50 cm with 20 cm collectors; ridge pitch 17.5 cm with 7 cm collectors; 141 Wp/m^2 PV cells)

	latitude	annual energy production per sq m of façade	annual energy production per sq m of PV	gain compared to Tab. 1	loss compared to Tab. 2
	[deg]	[kWh/m^2]	[kWh/m^2]	[‰]	[‰]
Turin	45	58.9	166.8	45.06	0.00
Rome	42	69.4	196.6	52.08	0.04
Salerno	40	65.7	186.1	41.54	0.00
Reggio Calabria	38	73.1	207.1	55.20	0.34

4.2 Finish

The system's shaped panels are compatible with different types of coatings. For example, they can be shaved with a multilayer plastering cycle on a plaster-holding mesh, similar to traditional overcoat systems, and subsequent painting: this would reintroduce the usual, reassuring grain size and texture of the plastered surfaces, without the shine of the panels overpowering the image of the building. In addition, the possibility of decoupling the PV panels (or disconnecting the thermal collectors from the hydraulic circuit) would allow, when necessary, interventions to restore or modify the paintwork in the same manner as traditional facades.

The application, for example, by means of adhesive on appropriate skim coats, of a finish with klinker or brick laths is possible and brings back to the building tradition, but bearing in mind the added value represented by the segmentation in bands, useful to recover and mitigate application inaccuracies as well as to manage thermal expansion to a greater extent than traditional large planes.

The system can also receive the installation of drywall finishes, such as shaped metal sheets or wooden slats, allowing the creation of deconstructible facade systems and thus containing their long-term environmental impact.

4.3 Solar collectors

The commercial availability of stringed solar elements determines the appropriate geometry for the shaped panel.

In the case of solar thermal, the use of opaque black elements of the “roll-bond” type [8], a technology typical of refrigerator evaporators (mass-produced according to the specifications of the appliance for which they are intended), coupled with synthetic glass can follow specific dimensional requirements, while in the case of photovoltaic cells, reference must be made to current industrial production.

In the latter case, the best-selling photovoltaic cell of normalized size (monocrystalline silicon type) is growing in size, partly due to cost compression in producing countries [9]: from about 156 mm on a side, which was the widespread size until 2018 (M0 and M2 wafers), today’s production is between 166 and 182 mm on a side (M6 and M10 wafers). Therefore, it is reasonable to assume that the Filigrana system can be designed to have at most a capture band of about 200 mm in case of low-cost cell procurement. Leaving aside the scope of organic PV, which is still scarce in the market, a higher cost for PV string integration can reduce the bandwidth to less than one-third, i.e., to about 70 mm (Fig. 6): in the latter case, the pitch of the façade “ridging”, i.e., the pitch of the crests, is comparable to that of the stone courses in masonry with facing apparatus (see Tab. 1). The performance of this kind of system should be further investigated, given its specific intended use and focusing on the expected lifetime, due to a wide range in the characterization of small-size photovoltaic cells.

Fig. 7. *Filigrana* pattern on a residential multi-storey building (authors’ elaboration) © 2020, Paolo Piantanida, Antonio Vottari

Referring to the solar situation in Rome, as an example, 10 square meters of the façade system so designed would accommodate about 3.5 m^2 of photovoltaic cells with a power rating that can be estimated around 500 ÷ 600 Wp (within the free-standing limit) and an energy annual production around 700 ÷ 840 kWh, depending on the type of semiconductor chosen. The placement of solar thermal strips instead of photovoltaics in the same façade situation (10 m^2) would lead to the possibility of heating a domestic hot water cylinder of about 250÷300 liters at 40÷50°C, which could be advantageous, for example, to articulate the use of solar-equipped façades in sports or industrial facilities.

4.4 Anchors and connections

The solar collectors, both photovoltaic and thermal, are anchored to the façade panels after they have been coated, so as to avoid dirt or damage from the construction site as much as possible; by doing so, the façade finishing can be done more evenly and easily.

For anchoring the active elements, a pair of comb-shaped metal profiles with an L-formed cross section, obtained by cold-bending a stainless steel sheet metal, was designed (Fig. 8). The comb shape of the "rail" ridges allows for the drainage of rainwater, their fastening to the thermal insulation by means of screws or bolts with variable pitch depending on the substrate, and eventual cutting to size (shearing) on site. The presence of closely spaced holes (of the comb) also allows microventilation for cooling the photovoltaic cells, which increases their performance [10]; in the case of solar thermal elements, the cavity formed between the intrados of the solar ribbon and the extrados of the facade finish is intended to accommodate the piping network (e.g., PEX pipes similar to those used in radiant plasterboard) and the corresponding connection fittings.

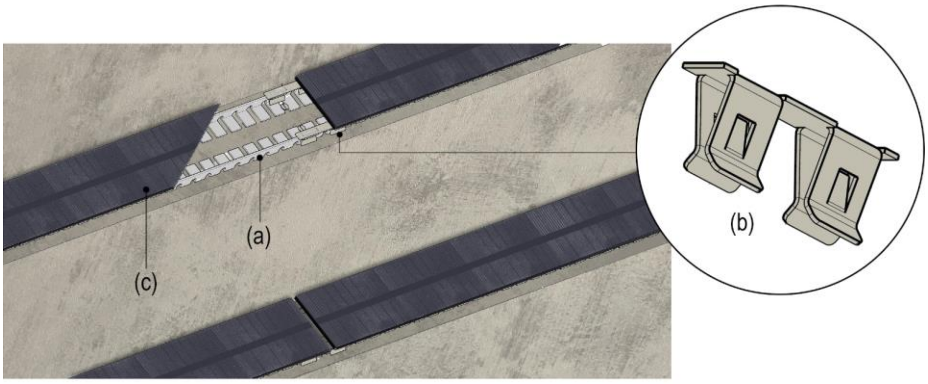

Fig. 8. Anchors and connections detail: (a) pair of comb-shaped metal profiles with an L-formed cross section; (b) bearing brackets; (c) solar strings (authors' elaboration) © 2024, Paolo Piantanida, Antonio Vottari

The comb openings also allow the mechanical anchoring of the solar string-bearing brackets “as needed”, by means of a pin that engages in the vertical holes of the upper profile of the rail and a screw that can be attached to the corresponding hole of the lower rail from the façade face: the attachment will always be hidden from view because it will be set back, like the comb profile itself, from the edge of the solar panel.

In this way, each photovoltaic or solar thermal element can be uncoupled independently of the others, for example to check their connections, repaint the facade, clean the rails, or replace degraded components.

In the case of photovoltaics, metal staples with snap fasteners have also been designed to ensure the electrical continuity of the rail profiles as well as the electrical connections from photovoltaic strings and rails (Fig. 7). Each of the L-shaped profiles, in fact, performs not only the function of anchorage, but also that of electrical conductor for the connection of photovoltaic panels: if necessary, a strip of synthetic material with the function of rail electrical insulation (e.g., Polytetrafluoroethylene, i.e., “Teflon”) and spacer bushings for the screw, in the shape of a cylinder with a protruding top ring, made of shaped synthetic material, can be interposed between the profiles and the facade cladding. In the event that the shaped thermal insulation panels had metal cladding, this could be used as one of the two conductors required for energy transport, limiting the components for electrical insulation to a single rail.

The anchoring system components are also recoverable in case of replacement of failed or out-of-date elements, and are therefore reusable for the installation of new elements, adapting the fastening to the new situation: it is a way to enhance the system lifespan and its sustainability; it also improves its over-time adaptability.

5 Patenting

The authors carried out the work as part of the free research activities of the Department of Structural, Building and Geotechnical Engineering within R3C (Responsible Risk Resilience Centre) of the Polytechnic University of Turin. The results obtained flowed into the “Facade cladding model for building upgrading”, Italian Patent No. 102020000021973 granted on Sept. 30, 2022 by the Ministry of Economic Development, Patent and Trademark Office. The system, brought to the level of pre-feasibility by Dreamet S.r.l. under the brand name “Aster”, was selected among the innovative products admitted by the organizing committee of the “Architect@Work Milano” fair for the November 2022 edition.

6 Conclusions

The achieved patent demonstrates the possibility of fostering the green transition of buildings by retrofitting their facades to transform favorably exposed ones into active elements for solar energy utilization. Considering, for example, a condominium building that has 700 m^2 of South facade (35 m front and 8 floors, with 4 dwellings per floor) that is assumed to be in full sun for about half, the facade can integrate about 18 kWp (i. e. 525 Wp per dwelling: in this case, the power is still compatible with the limit for a “debureaucratic” installation). These results are estimated using low-cost, low-efficiency photovoltaic elements: if the best cells available on the market were integrated (220 Wp/m^2), the available power would rise to around 30 kWp, with about 930 Wp per dwelling.

Further developments to be pursued include the study of integrating solar thermal and photovoltaics into a single product, so that the thermal system could be the cold source of a heat pump system powered by the electricity produced by photovoltaics. This would cool the photovoltaic cells increasing their efficiency of about 5 percent, and increase the efficiency of the water-to-water heat pump too, because it would work with a cold water loop at a more favorable (i.e., higher) temperature than the external air unlike the more common air-to-water operation.

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