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Historic buildings in Mediterranean area and solar thermal technologies: architectural integration vs preservation criteria

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Abstract

Architectural integration of plants in historic buildings has always been a much debated topic. Nowadays it is enriched with an ethical connotation linked to sustainability/environmental responsibility (reduction of energy consumption, using renewable energy sources, reduction of CO2 emission, etc.).
This paper deals with the theme of integration of solar technologies in buildings and focuses on difficult and problematic relationship between the physical conformation of the plant and the cultural values of the building itself (especially on the cultural value of the image of built heritage). It wants to highlight how the satisfaction of requirements linked to the protection of these buildings, cultural resources of every city and nation, could constitute as an promoter of technological innovation.
After making an investigation on major existing products on the solar technology, through a case study of residential historical building, we present the preservation criteria and guidelines that laying down principles for the validation of each existing technology on the market.

Selection and peer-review under responsibility of KES International

Keywords: built heritage, energy performance, multidisciplinary approach, building constructive technology

1. Introduction

We know that the power from sun intercepted by the earth is about 1.8×10^{11} MW, which is many times larger than the present rate of all the energy consumption [1]. Therefore countries of Mediterranean basin would have to use this free, clean and climate-friendly energy thanks to their latitude. The use of renewable energy sources and the reduction of energy consumption by humans are now the challenges of the future. From a specialist point of view (disciplines of building physics and electric engineering) we

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witness to technological innovations of interesting application: by building attached photovoltaic systems (BAPV) to those integrated into constructive element (BIPV and BIST) up to hybrid systems (BIPV-T). Recently, however, in addition to the engineering aspect, researchers are examining the fallout of these systems on the architectural quality of the building in which they are located. The attention to architectural quality of the proposed solutions is interesting historic buildings both in Europe [2, 3] and internationally [4]: we refer to buildings which cannot be treated in the same way as modern and contemporary ones because they characterize the city with their cultural value. These buildings are stone documentations of architectural culture of pre-modern communities and they need bonds or preservation criteria (to be considered also opportunities) for the purpose of keeping intact the identity of cities in which they are inserted. This study was conducted by an interdisciplinary team (Building Construction, Building Physics, Restoration) in order to analyze the existing solutions on the market from different points of view, according to a systemic approach.

2. Built heritage as cultural resource: the need to define criteria for saving the urban image

The urgency of studies and research to address the application of captation systems for renewable energy sources (photovoltaic, solar, wind, geothermal, biomass etc.) has given for years new input to the research in the field of architectural restoration to establish a balance between the need of conservation versus innovation and energy saving.

Certainly a theoretical premise is necessary to every reasoning that concerns in the context of intervention on built heritage: innovation and re-use should be evaluated as a mean and not as the end of the intervention. According to the more general theory of restoration, in the case of architectural heritage, the primary purpose is the preservation and transmission to future generations, under the best possible conditions. Built heritage, in fact, since the 19th century have been recognized as still defined documents, as materials evidence of civilization, precious, unique and unreproducible memories. Their reuse and/or innovation is the correct way to favour its conservation [5].

Every need, from economic to functional and technological ones, in built heritage must therefore submit the historical and conservative instances. The cultural reasons should not be understood as an obstacle to that technological innovation aimed to energy saving or renewable sources exploitation, but rather an opportunity to design, industry and research for the economic recovery. Humanistic competences and creativity, together with the research on innovative technologies and materials should contribute towards policy-based design of minimum intervention, potential reversibility (or, better, removability without subtracting of material) and compatibility according to an aesthetic and technological point of view. The architecture with artistic value is not only the monumental "emergency", but also a large percentage of man-made territory (historical centres, towns, villages etc.). The inclusion of technological systems for the exploitation of renewable energy sources in sites like these, certainly requires expertise from various sectors. Adding technological elements, such as the first generation of BAPV, though not involve important transformations of materials, could compromise the correct perception of historical artifact [6].

For these reasons, we believed that the introduction of systems for the exploitation of renewable energy sources in built heritage, or in the consolidated city, should be assessed according to a well-established practice, which involves a series of preliminary investigations to the operational phase for professionals (architects, engineers, physicists, designers), which can identify the correct design solutions respecting the pre-existing buildings. In addition, scientific research should choose materials and technologies to make the impact of the systems with the context as minimal as possible, without tending to the easier but also more commonplace, concealment attempt or clumsy camouflaged. A sensitive and cultured creativity becomes a prerequisite for the success of the intervention, therefore [7] (Fig. 1).

Fig. 1 (a) Architectural integration of BIPV into historic buildings: Nervi's auditorium in Rome; (b) Reichstag in Berlin.

The strategy that best fits to the critic conservative method, the latter advocated one in the context of the interventions on cultural heritage, is to evaluate, case by case, the most effective solutions responsive to the needs of each case, both in terms of aesthetics that in technological terms. Any methodological inconsistencies (performance requirements versus conservative requirements) could be happily resolved with the creation of criteria, unfortunately still absent, which can direct the system designers on built heritage. In fact, the guidelines are needed to cope with the current disorientation among the actors in this context that, in recent years, generated an anthropic degradation process spread throughout national and international territory with the explosion in demand for renewable energy. The system design must fall within the project of restoration (reuse) either when we intervene on single monumental building or on urban contexts. The exploitation of the gaps (in buildings and towns) to make place for new creative structures for systems, could lead to consistent solutions with the conservation and, at the same time, which respect the requirements for *recognition* of intervention, always having the *potential image unit* as main objective [8].

3. Solar technologies: the contemporary scenery

Building Integrated Photovoltaic (BIPV) systems and Building Integrated Solar Thermal (BIST) systems are photovoltaic modules integrated into elements of building envelope, such as the roof or the façade. These systems are very important because they serve the dual function of building skin, replacing conventional materials, and energy generator. They modify the architectural appearance of the construction. Buildings which produce power using renewable energy sources reduce the demands of traditional energy generators and, often, the overall emissions of climate-altering gases. Generally, it is necessary to combine more than one system to maximize the utilization of resources; this need has led to the realization of a new technology that combines photovoltaic with solar thermal: BIPV/T. Before their application, the site and the orientation of the building must be carefully considered because the impact of shading on an array of photovoltaic or solar thermal panels could influence the energy harvesting. In this paper BAPV hasn't been considered because they are overcome by these integrated technologies available today on the market.

3.1 BIPV products: foil, tile, module, solar cell glazing

There are different technologies of Building Integrated Photovoltaic (BIPV) systems. The four main options for architectural integration of PV in the building envelope are on sloped or flat roofs, facades and windows. BIPV systems can provide savings in materials and electricity costs. By avoiding the cost of conventional materials, the incremental cost of photovoltaic is reduced and its life-cycle cost is improved. Often, BIPV systems have overall costs lower than PV systems that require separated and dedicated mounting systems. BIPV systems can be interfaced with the available utility grid or they may be designed as stand-alone with off-grid systems. The advantages of power production during the utilization of this system include savings in the losses associated with transmission and distribution (known as 'grid support'), and savings for the consumer through lower electric bills because of peak shaving (matching peak production with periods of peak demand). There is a wide range of BIPV products which can be categorized in different ways. The classification is mainly based on how the manufacturer describes the product and how this product can be combined with other materials. The categories considered are foils, tiles, modules and solar cell glazing products. Modules can normally be used with different roofing materials. Solar cell glazing products can be integrated in the facade, roof or windows, providing various aesthetic solutions.

The valuation of different BIPV products considers the following parameters:

- Solar cell efficiency $\eta=P_{max}/(GA)$, where P_{max} is the maximum power in W, G is the input light irradiance in W/m^2 and A is the surface of solar cells in m^2;
- Open circuit potential or voltage, U_{OC};
- Short circuit electrical current, I_{SC} _ Maximum power point, $P_{max}= (UI)_{max}$;
- Fill factor FF is given by $FF=P_{max}/(U_{OC}I_{SC})= (UI)_{max}/(U_{OC}I_{SC})$.

The BIPV foil products are light and flexible; these properties are ideal for their easy installation and for the respect of the weight constraints of roofs. The photovoltaic cells are often made of thin-film to maintain the flexibility of the foil and the efficiency at high temperatures, so they can be used also for non-ventilated roofs.

The BIPV tile products replace the traditional tiles of the entire roof or a part of it. Normally they are arranged in modules. This is a good solution for the retrofit of roofs. The type and the shape of the cell varies. Some tile products look like curved ceramic tiles, which haven't an effective surface due to their curved shape.

The BIPV module products are similar to conventional PV modules. The difference is that they are made of weather skin solutions. These products can be used in the facades or in the roofs and sometime they replace only a part of these elements of building envelope. Besides, some products are default and isolated modules.

Solar cell glazing products provide a great variety of solutions for windows, glassed or tiled facades or facades and roofs. Different colors and transparencies permit the realization of different and possible products, which may be esthetically pleasing. The modules transmit daylight and serve as protection from the sun and the water. The technology involves the spraying of a coating in silicon nano-particles on windows, which works as solar cell. The distance between cells depends on transparency level wanted and criteria for electricity production. The space between cells transmits diffuse daylight. The transparency level varies from 16% to 41%.

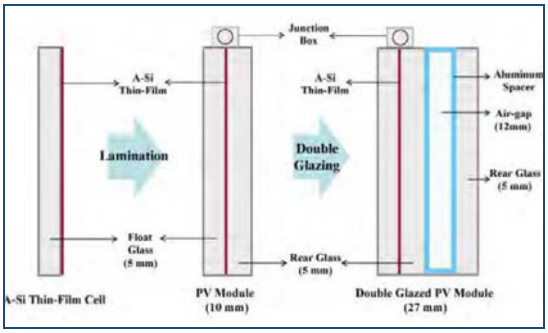
3.2 BIPV technologies: single and double glazed windows

Today, in the current market there are also new BIPV technologies:

- PV single-glazed windows;
- PV double-glazed windows and same with ventilation gap.

The PV single-glazing windows are constituted by a single glazing with or a thin-film or that includes opaque solar cells. Considering the structure of the semi-transparent BIPV module, part of the module is covered by opaque solar cells while the remaining part is transparent. The part covered with opaque solar

cells is composed by three layers: front glass, solar cells and back glass. The front glass is directly in contact with the outdoor environment while the back glass with the indoor. The solar radiation is absorbed by solar cells; a part of heat is also absorbed by the front glass and then released gradually toward both indoor and outdoor sides [9]. Instead, in the transparent part solar radiation enters directly to the indoor environment, passing through the glass. Referring to both surfaces of the modules, absorbed heat is exchanged by convection and radiation with the surrounding environment.
The PV double-glazing windows are constituted typically by an amorphous silicon (a-Si) PV panel and a clear glazing behind. Some of these systems presents ventilation gap behind. A single flat PV module presents a thickness of 10 mm; so, the total thickness of a PV double-glazing windows is 27 mm, where there are 12 mm of air space and 5 mm of common transparent glass [10]. (Fig. 2)



Item	Specification
Module thickness (mm)	10
Module efficiency (%)	7
Maximum power output (W)	44.0
Maximum voltage (V)	59.6
Maximum electric current (A)	0.74
Open circuit voltage (V)	91.8
Short circuit current (A)	0.972

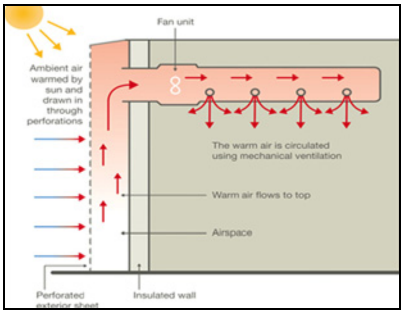
Fig 2. (a) Preparation for single plate of double-glazed PV module using transparent amorphous silicon (A-Si) thin-film cell; (b) specification property of thin film PV module.

Optical and thermal characteristics of double-glazed PV module are: the solar transmittance (T_sol) is 0,068, the transmittance of visible radiation (T_vis) is 0,075, the solar heat gain coefficient (SHGC) is 0,18, and the thermal transmittance of PV module (U_value) is 2,66 W/m^{2}K. The PV double-glazing window can reduce significantly the indoor heat gain and the cooling load through the air gap behind PV modules; this happens because the inner surface temperature of PV double-glazing windows is lower than PV single-glazing windows. Besides, these technologies improve the predicted mean vote index (PMV) of the zone. There are also ventilated openings at the top and bottom of the semi-transparent a-Si PV glazing which provide shading and electricity for the indoor ambient. Part of solar energy absorbed is converted into electrical energy while the other is converted into thermal energy and heats the air in the ventilation gap behind the PV panel. The electrical efficiency is 3.65% .

3.3 BIST products: glazed collectors, transpired solar collectors (TSC)

The utilization of solar radiation to heat air for various purposes, for istance ventilation, pre heat, process air heat and their applications, has attracted many interests. BIST systems can provide savings in energy both for heating and for the production of domestic hot water. There are so many uses for solar energy and one of the most potential applications of it is the solar air heaters. Many designs for solar air heated have been reported and discussed in the literature e.g. bare plate, back-pass, glazed, unglazed, covered, uncovered, perforated, unperforated, single pass, double pass and triples pass. The glazed collectors are flat and they are constituted by glazing and solar absorber plate mounted on insulated back surface.

The transpired solar collectors (TSC) are unglazed and present a perforated absorber layer. TSCs use solar energy to heat the absorber surface, which transmits thermal energy to the ambient air. The absorber surface is generally a metallic sheet (usually steel or aluminum), which can be integrated to the building façade (Fig. 3a). The contact surface between the metal skin and air is increased by drawing air through the multiple small perforations into the cavity between the skin and facade. Finally heated air is drawn into the building to provide to the heating of the space. During summer season the warm air in the cavity can be released using a by-pass damper to avoid the inside over heating of the building or can be used for water heating in order to maximize the utilization of TSCs. The space between the absorber (perforated sheet) and back plate is sealed to create an air channel also known as a plenum. The perforations generally cover a very small fraction of total area of TSC (also known as porosity). In the top of the back sheet, there is an outlet which leads to the canalization of the system where there is the fan. The fan sucks the air through the collector, which draws the air to pass through the holes and collects heat from the absorber surface and the boundary layer of the heated surface. The literature has shown that the most critical factors affecting TSC efficiency are wind velocity, flow rate, porosity, absorbition and porosity [11]. There are stand alone transpired solar collectors. In a stand-alone TSC perforated absorber and back plate are exposed to environmental conditions.



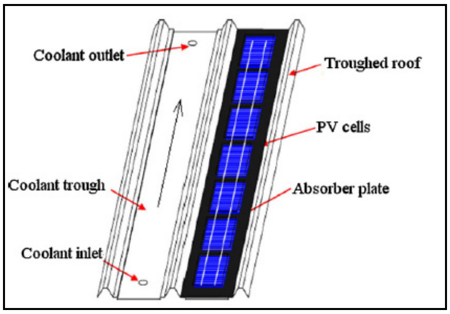


Fig. 3. (a) Building integrated transpired solar collector; (b) Roof mounted integrated BIVT collector.

3.4 Hybrid and building integrated (BIPV/T)

The combination of TSC and PV panels on facades is promising for the realization of systems that can be applied where there is a significant need to heat ventilation air in winter. BIPV/T systems use air as cooling fluid. A potential advantage of BIPV/T systems is that during summer months heating is not required, so the production of electricity may be an added bonus. There is a system directly integrated into the roof of a building and it is made of standing seam or troughed sheet (Fig. 3b).

Roofs with standing seam and troughed sheet are typically made of aluminum or coated steel, although other metals can be used. This system also utilities high thermal conductivity materials. The drilled passages in the trough are subsequently enclosed by the cover, thus forming a tube to which heat can be transferred. The flow has an input and an output and they are placed at opposite ends of the trough [12]. The stored heat can be released to the building during the night, extending the effective operation time of the hybrid system. The thermal performance of transpired solar collectors is very complex because it is necessary to consider different parameters.

4. Architectural integration of solar energy technology in traditional buildings of Catania historical district

4.1. Short description of urban image

The perception of urban image is based on a sequence of streets, squares, facades and roofs. All of these elements have got colors, materials and forms that, in historical centre, are an harmonious mixture of human and nature. The presence of Etna volcan (the nature) conditions the built environment of Catania downtown (the human). Here we can find materials deriving from the volcan activity: basalt stone and various inerts always coming from eruptions. These inerts are mixed with lime to produce mortars that are used in the masonries and also in the plasters, often characterized by a light gray color that dialogues with architectural elements of facade equipment (crowning, string-course, pilaster strips and basement), made by white limestone. Other kinds of plasters are the render float and colored set, the stucco plasters and false ashlars. The most common traditional colorings are ochre, both light and dark, sometimes red and green ones. In Catania the buildings use the pilaster strips that divide façades in a peculiar way, determining a giant order from Roman origin, usually made of compact lime stone and mortar. Crownings are made using both stone materials and plasters. In the first case formal solution provides for the use of stone elements and brackets; in the second case a mortar and an inert matter equal to one to imitate have to be used. Stone materials come from the quarries of South-Eastern, easily connected by sea. The traditional roof tiles are pitched and made by flat slabs of burnt clay (laconian roofing) laid on a wooden structures. The introduction of iron profiles (post 1850) justifies the presence of floors and tiled terraces in the upper levels. We can find four standards of frames and all of them are wooden, mostly chestnut from Etna: main doors, street doors, door-windows and windows. The most common door-windows and windows have got an upper rectilinear shaping and two internal shutters [13].

4.2 Evaluation of applicability of solar technology vs preservation criteria

In general, the application of solar technologies (photovoltaic and solar thermal) concerns specific technical elements of the external building envelope: opaque vertical components (facades, railing balconies…) and transparent (frames, railing balconies) or roof (slooped or flat). The development of technologies such as BIPV or BIST, which forecast the integration with these technical elements, made more complex their application on buildings, especially when they have a historical character.

Considering the technical literature [14] and existing products on the market, we hypothesized the possible application of BIPV or BIST on historic buildings. These evaluations have undertaken a reflection on their problematic integration with specific technical elements of traditional buildings. Therefore, we excluded some technologies considered incompatible with the aesthetic and technical aspect of a building, for instance the application of solar cell glazing on facades or on roofs or of transpired solar collectors on secondary facades. Later, considering only the selected technologies, we thought some criteria for their correct and non-invasive integration on facades, frames or roofs of a historic building. Therefore, the application of BIPV or BIST is advisable:

- on main facades without openings;
- on secondary facades overlooking not-value courtyards;
- if it is necessary the replacement of skylights or windows/french-windows/velux situated on internal facades;
- on limited surfaces of roofs (slooped or flat);
- on attic walls as protection element or along the inner vertical surface.

Besides, for a better integration, all solar technologies should be made of colors or materials compatible with those of tradition. The analysis of products currently on the market has shown that these aspects have not been carefully considered by various manufacturers. An obvious example is represented by photovoltaic tiles produced by some companies: the application of these grey-blue elements can influence the aesthetic appearance of the roof of a historic building.

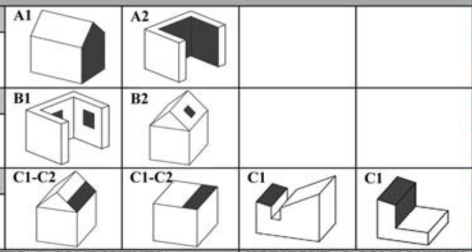
Finally, we created an evaluation grid (Fig. 4), elaborated to visualize immediately technologies selected and criteria of application suggested. This proposed grid can be considered such as a fundamental tool to consult within the energy retrofit of historic buildings.

POSSIBLE APPLICATIONS AND CRITERIA

A) Facades
A1 - only on main facades without openings
A2 - only on secondary facades overlooking not-value courtyards

B) Frames
B1- only when it is necessary the replacement of windows/ french-windows/velux situated on secondarv facades
B2 - only when it is necessary the replacement of skylights

C) Roofs
C1- it is advisable the application on limited surfaces or on attic
C2- it is advisable the application on limited surfaces



CATEGORIES		VERTICAL COMPONENTS			HORIZONTAL COMPONENTS	
		Secondary Facades	Main Facades	Frames: Glasses	Sloped Roofs	Flat Roofs
BIPV	Foil products					C1
	Tile products				C2	
	Module products	A2	A1		C1	C1
	Solar cell glazing products			B2		
	Thin-film			B1		
BIST	Glazed collectors	A2	A1		C2	
	Unglazed collectors	A2	A1		C2	

Fig. 4. (a) Evaluation grid of existing solar technologies: possible applications and suggested criteria; (b) Historical centre of Catania and an example of use of photovoltaic tiles.

5. Case study: methodological approach and results

Historic building, chosen as case study, is representative of buildings and construction types present in Catania downtown. This choice was made considering:

- location into the block: it is located between two adjacent buildings;
- type of roof :plain and pitched;
- façade orientation: we have chosen a problematic one (West - East);
- number of elevation floors (equal to 4);

The study was organized into the following phases: building survey from historical- typological, geometrical-formal and technical-constructive point of view; energy analysis; retrofit energy according to building cultural value; proposal for architectural integration of solar technology system.

This traditional building shows on a main facade facing up to public street and a secondary one on private space. The first one is enriched by a formal composition representative of nineteenth-century architecture, the second one doesn’t have got any particular architectural value. The vertical components are masonries made of basalt stone blocks and lime mortar; external frames cover about 10% of envelope dispersing surface and are made by wood with internal shutters. The horizontal structures are floors made by in iron profiles with a casting in lime and basalt pumice. Energy analysis has produced the following results: during the winter we have a need for energy equal to 117.85 kWh/m^2 and 35.70 kWh/m^2 in the summer. According to Italian rule, during winter season this building fall in energy class F (very low); while in summer season the quality performance index takes a more comforting intermediate value. Then we have defined the energy retrofit interventions, respecting the cultural value of case study: thermal covering on secondary facade; insulation of the roof and replacing of frames glaze with selective ones. So we have reduced the energy consumption of 19% during winter period and of 32% during the summer one. For the application of the BIPV and BIST systems on the considered case study, it has been evaluated carefully on what technical elements could intervene (Fig. 5).

DATA IMPUT			
	Longitude	15°5'	
	Latitude	37°30'	
	η BIPV	5%	
		Pitched	
	Orientation	East	South
	Azimuth	90°	0°
	Inclination respect to the horizontal plane	32°	16°
	Reflection coefficent of the soil	0,20	0,20
	Surface	31,77	12,77
ANNUAL GLOBAL SOLAR RADIATION [kWh/m^2]		1559	1743
MAXIMUM ENERGY ABSORBED BY BIPV TILE PRODUCT [kWh]		2476	1113
	Without BIPV tile products	With BIPV tile products	Percent Energy savings (%)
SPECIFIC ENERGY FACTOR OF ILLUMINANCE [kWh/m^2]	15,00	7,20	52
PRIMARY ENERGY FACTOR OF HEATING (HEAT PUMP) [kWh/m^2]	154,21	147,21	4,54
GLOBAL PRIMARY ENERGY FACTOR [kWh/m^2]	169,21	154,21	8,86

Fig. 5. (a) Calculation of maximum energy absorbed by BIPV and percentage of energy saving using BIPV; (b) the radiance during 17th July in the analyzed block, using Autodesk Ecotect Analysis 2011 ®, and architectural integration of BIPV in the case study.

Given their orientation, using the analyses derived from software Autodesk Ecotect Analysis 2011 [15] and criteria of application set out above, we established to integrate photovoltaic systems only on the roof. The solution could be the application of BIPV tile products on the south pitch (12,77 m^2)and on the east pitch (31,77 m^2). We proceeded to the calculation of annual total solar incident on these surfaces. Using thin films of amorphous silicon with an efficiency of 5%, we calculated the maximum energy absorbed by the BIPV technologies applied. Subtracting this value with the electricity needs of the state of art, it has been calculated energy savings. The percentage of savings relative to the contribution of illumination is 52%. By these calculations, we obtained a global savings equal to 8.86%; therefore the needs required for the operation of the heat pump have not satisfied. All the results are reported in the fig.5.

6. Conclusions

Historic buildings are recognized as documents and defined as material evidence of civilization, precious, unique and irreproducible memories. The integration of systems that use solar energy needs multidisciplinary design that is characterized by the main requirements of any intervention on built heritage: minimum intervention and its reversibility. According to minimal intervention and the preservation criteria, we have defined a scenery of solar systems which are applicable into traditional buildings belong to historic centre. Finally we have considered a case study in Catania historical centre where we propose an architectural integration. As regard the BIPV integration into the pitched roof, we have considered a problematic aspect to be evaluated very carefully: if we place ourselves in a perspective of application to an entire city block, such as roofs of adjacent buildings, we will have to evaluate the aesthetic impact on the city from the top.

This foreseeable situation, which we require the overcoming, could lead us to study photovoltaic tiles with very close colors to the existing shingles (ochre from light to dark) with the aim to avoid a grating chromatic effect and to make visible the integration nearly but not away. We consider the BIST and BIPV as an interesting technology for the its energy performances and the architectural solutions quality; these technologies could be applied on the facades on the interior common spaces, where to declare the presence of a system integration (with a case-by-case approach). For each historic building we think that architectural and plant design should be conducted by proposals and mutual feedback between cultural, architectural, constructive and plant aspects. We believe that this design process could lead new technological innovations and, in particular, to advanced engineering solutions respectful of historic buildings cultural value.

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