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Building integrated photovoltaic in heritage contexts award: an overview of best practices in Italy and Switzerland

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Abstract. The widespread of photovoltaic (PV) technology has led to high-performance products and systems during recent years. This allowed an expansion of PV application scope enormously, especially in listed buildings and natural landscapes subject to different forms of protection. Despite that, there are still many doubts and supposed limitations regarding their applicability by stakeholders involved in the construction process. Best practices and applications help to spread the applicability of the PV technology in historic buildings, conservation areas and cultural landscapes. For this purpose, the "*Special Award for Solar Architecture in Heritage Contexts*" developed within the framework of the Interreg project "BIPV meets history" aims at awarding the more significant Italian-Swiss BIPV case studies in historical buildings and heritage landscapes. This research work offers an overview of the 85 projects nominated for the award. The best projects are described and analysed to define the state of the art and criteria and technologies used for PV integration in architecturally sensitive areas to raise awareness to all stakeholders involved. The trade-off between cutting-edge technology and design expertise can lead to the perfect balance between historic buildings or high-value contexts preservation and contemporary needs and lifestyles.

Keywords – Building integrated photovoltaic (BIPV); Building applied photovoltaic (BAPV); Historic building; Protected landscape; Award.

1. Introduction

Photovoltaic (PV) field development with innovative and performing products makes it possible for new product applications in the building sector. The balance between technical and aesthetic issues, such as visual appearance (*e.g.* visual impact, colour palette, reflectance), architectural multifunctionalities (*e.g.* thermal insulation, energy productions), and construction requirements (*e.g.* safety, fire security, performance stability, climate and hazard resistance, maintenance, and durability), is a priority for PV systems. "Architecturally pleasing" systems have been produced, ranging from crystalline silicon modules, thin films, glazing integrated photovoltaics [1], hidden coloured cells, printed PV glasses with high-resolution images, dye-sensitised, to organic solar cells [2].

The field of historic buildings and protected sites offers a great opportunity for the application and development of PV systems [1,3]. Despite that, many barriers still exist for their acceptability in heritage contexts, mainly due to heritage constraints, legislative framework, costs, and lack of case studies and guidelines [4]. Several countries defined national guidelines to address PV systems' installation in sensitive buildings and landscapes, offering common and agreed indications for PV integration and assessment in these areas. These indications are based on the maximum conservative attitude, which allows PV systems where historic matters and materials are irremediably damaged or lost, or on the high architectural quality of the new interventions [3]. Also, material conservation, minimisation of impacts (*i.e.* aesthetic, chemical, physical, and so on), protection of the landscape are crucial objectives for any intervention. In a few cases, old pilot projects are presented to lead the design of PV systems [5].



Similarly, some pilot projects have shown the possible integration of PV elements in old buildings and heritage landscapes [6,7] and there are various online platforms [8,9,10] that help disseminate PV case studies and best practices. However, many examples are contextualised in areas other than the historical or protected landscape. Therefore, case studies and examples of best practices to be adopted are needed for promoting and guiding the PV technology revolution in heritage contexts areas [11]. Also, the dissemination of case studies and best practices for PV integration in historic buildings or in protected areas appears of high importance.

2. Aims and methodology

This work aims at offering an overview about the recent state of the art on PV implementation in heritage buildings, historic structures and protected landscapes through the analysis of a series of case studies submitted to the "*Special Award for Solar Architecture in Heritage Contexts*" 2020 edition [12]. This award refers to the Italian (IT) and Swiss (CH) territories, given their common peculiarities, and high cultural values. Within this framework, some tendencies for PV application in heritage and sensitive areas have been delineated. The study also highlights the most relevant evaluation criteria and compatibility issues for balancing heritage conservation and energy production from renewable energy sources (RES). The paper is structured in the following parts: (i) description of the award; (ii) overview of the submitted projects; (iii) tendencies for PV application.

3. Solar Architecture in Heritage Contexts Award

The National Institute of Architecture (In/Architecture) with the National Association of Building Constructors (ANCE), promoted a special recognition for exceptional people and projects in the architectural field, namely IN/Architecture Awards. Within this framework, a "*Special Award for Solar Architecture in Heritage Contexts*" was promoted by Eurac within the Interreg Project IT-CH "*BIPV Meets History*" [6]. The Prize was awarded to an intervention that would demonstrate a successful dialogue between the reduction of the ecological footprint for buildings, the conservation of heritage building and landscapes, and the improvement of energy efficiency and internal environmental comfort.

The Award was focused on energy renovation projects of historic buildings (villa, palace, castles, rural building, industrial archaeology) or buildings located in prestigious architectural landscape or naturalistic contexts (e.g. historic centre, park or nature reserve, mountain or marine environment, etc.) integrating PV systems. The Prize was awarded to buildings located in IT or CH renovated or built between 2014 and 2020. To participate in this Prize, candidates had to document their projects and submit a general description and technical and photographic documentation of the building along with details of contractors and any bibliography relating to the work. The winning project was selected by a panel of international experts, taking into consideration the architectural result of the case study as a whole. A preliminary check of the submitted project data and descriptions was made to evaluate their eligibility. Then, the relevance of the projects to the criteria of the call was assessed. Subsequently, these projects were evaluated according to:

- Integration criteria, subdivided into technologic, aesthetic and energy integration,
- Innovation criterion that considers interventions with innovative PV technologies or projects not disclosed through scientific publications,
- Replicability criterion that refers to solutions that could be applied easily to the most common and widespread building types in a reference area.

The international scientific community has not reached a univocal consensus yet about the concept of integrating PV systems in buildings. The international standard EN 50583-1:2016 [13] considers building integrated photovoltaic (BIPV) as an element that also acts as a constructive or technologic component. International Energy Agency (IEA) Task 7, [14] and Task 41 [15] add the shape and aesthetic concepts to multifunctionality [11]. In most recent years, another aspect of integration arose, that is the energy integration, meaning the ability of PV of being integrated into the envelope of the building and also integrated into the overall energy system of the building [16]. In support of the definitions discussed, the concept of integration used to evaluate the projects dealt with three aspects: technological integration, aesthetic integration, and energy integration [17]. For "*technological integration*", the concept of multifunctionality was applied considering different elements [17]. By

"*aesthetic integration*" is meant the characteristic of a PV intervention that uses a typical architectural composition language. The aesthetically integrated intervention should demonstrate a successful interaction between shape and function. The sub-criteria explicitly used for the evaluation of the aesthetic integration of the projects were taken and then adapted among [2,3,18] (i) "*chromatic integration*" when colour and texture of PV components harmonise with the other architectural element; (ii) "*morphological integration*" when the size and arrangement of PV harmonise with those of the building or elements of the surrounding landscape; (iii) "*accurate design*" when all details are carefully designed and distributed, and the number of materials used is the minimum possible; (iv) "*overall appearance*" that follows the aesthetics of the building context; and (v) "*respect for the historical value of the building*" when the integration intervention does not alter peculiarities of the architectural element and does not vary its historical memory. "Energy integration refers to the ability of a PV system to interact with the building's energy system [16] or the neighbourhoods in which it is included for maximisation of energy produced on-site. The aim is to increase the interconnection of cities looking at centralised national systems for electricity production and management [17].

For each of the identified criteria, a score from 0 to 2 was assigned where 0 indicated "Poor", 1 indicated "Medium" and 2 indicated "High". For criteria with sub-categories, each sub-category was treated according to the same principle. Weighted averages were then considered to ensure that all items had the same weight within the evaluation. Finally, the best projects were evaluated by the panel of experts for the final selection.

4. Overview of the submitted projects

An overview of the submitted projects is shown below. The eligible projects are mainly located in Italy (95%); 40% in the northern area, 27% in the central area and 28% in the southern area and the islands. The remaining 5% are located in Switzerland, in the northern east and southern cantons. Figure 1 shows the number of projects for each region of the Italian and Swiss territories.

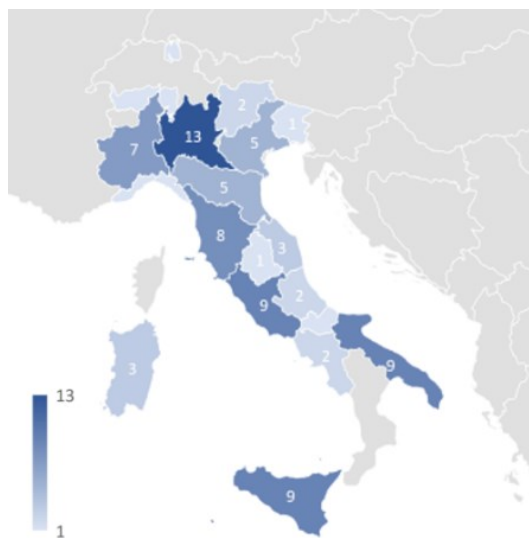


Figure 1. Case studies' location within Italian and Swiss regions

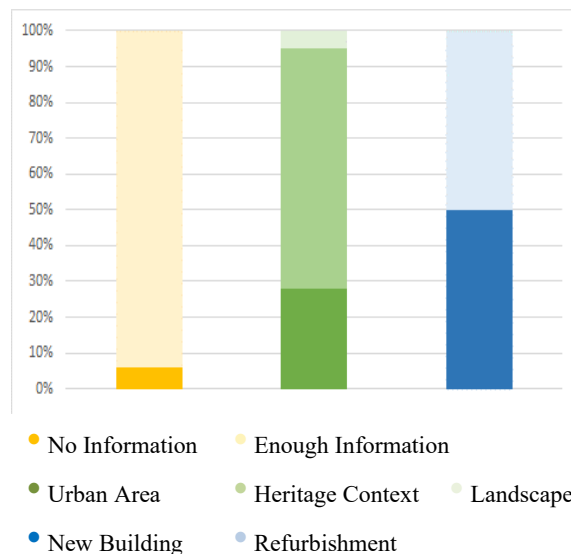


Figure 2. Case studies' analysis overview

28% of the case studies with PV systems relates to historic buildings in consolidated urban or peri-urban contexts. 67% refers to PV systems integrated into a prestigious natural context, of which 27% in prestigious countrysides protected by law, 3% in woods or historic gardens, 5% are close to lakes or lagune or sea. 5% of cases refers to PV systems integrated into the landscape or self-standing systems. Of those with a PV system, 50% are new buildings or buildings rebuilt after demolishing it. The remaining part is buildings with interventions of energy refurbishment and conservation, as shown in figure 2. For the vast majority of projects, PV elements were roof-mounted. Only a few examples of

façade applications were found. The projects with PV systems are grouped into two main groups in relation to the characteristics that the ensemble "Building + PV system" assumed following the intervention: building applied photovoltaic (BAPV) and building integrated photovoltaics (BIPV). The first category includes buildings where PV elements are applied to the building envelope. Therefore, they do not perform additional functions other than producing energy [17]. Interventions belonging to the second category are PV systems that became part of the architecture itself according to aesthetic, technological and energy integration principles. Hence, PV modules perform other functions in addition to the primary function of energy production, that offer, for example, protection from bad weather, thermal insulation, acoustic insulation, natural light control, safety, becoming part of the building from an architectural point of view [15,17].

According to this distinction, 55% of the projects are equipped with BAPV and 39% with BIPV systems. It was not possible for 6% of projects to determine what type of intervention was envisaged due to lack of information. From the PV technological point of view, conventional mono and polycrystalline PV and coloured flat PV panels were used. In a few cases, hybrid panels obtained by combining PV and solar thermal modules for domestic hot water production or flexible modules were used. A more in-depth analysis of these case studies allowed a further grouping according to some tendencies relating the way PV systems were characterised:

- *Applications where there is no particular attention to the context:* no dialogue is sought between the PV systems and the historic building or landscape.
- *Attempts to PV integration:* the integration does not take into consideration aesthetics, technological, and energy integration at the same time, but only some of those aspects are considered.
- *Attempts to BIPV integration:* all the three aspects of integration are addressed.
- *Integration with the surrounding landscape:* direct or indirect dialogue with the surrounding is created.

The last two tendencies are of particular interest in the following analysis.

5. Approaches to PV integration

PV integration in historical buildings and preserved landscapes is possible, but its effective applicability is highly influenced by the surroundings.







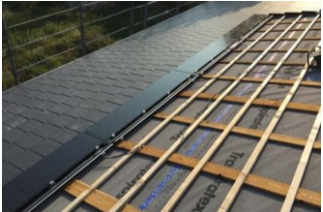











Case studies have been grouped according to similar features. Six main groups have been identified according to the location of the PV system in relation to the historic building, the position of the modules on the building, the type and level of technological, aesthetic and energy integration and the PV technology used, as shown in table 1. These groups synthesise the main approaches to PV integration of the case studies from the Award and can serve as a suggestion for best practices. A few cases have been extrapolated from some of the groups and described for their successful PV integration.

5.1. Location of the PV system

According to the location of the PV system with respect to the historic building, three main tendencies have been identified. The most common tendencies deal with the application or integration of PV modules directly on the historic building. That is envisaged mainly with ruined, damaged, reconstructed, or replaced structures.

A good example is offered by the refurbishment of the Doragno Castle, located in Rovio (CH) and its PV system integration. The castle was probably built in the early Twelfth Century. In the early Nineties, it was transformed and expanded to create a private residence. A recent intervention aimed at restoring and preserving the ancient part and showing the difference between the original medieval part and the recent interventions – figure 3. The parts added to the complex were made of steel and glass and were recognisable as a contemporary addition. The building's dialogue with the surrounding landscape was of great importance through the design stage.

Table 1. Approaches identified for photovoltaic system integration in historic buildings and protected landscapes.

		Approaches		
		On the historic building ^(a)	Decentralised power production in the nearby ^(b)	Stand-alone modules ^(c)
Location of the PV system				
		Roof-mounted ^(d)	Façade-mounted ^(e)	Solar blinds ^(f)
Position of the modules				
		Reversibility ^(g)	Protection from rain and natural light control ^(h)	Solar tiles ⁽ⁱ⁾
Technological Integration				
		Morphological integration ^(j)	Chromatic integration ^(k)	Accurate design ^(l)
Aesthetic Integration				
		^(m)	⁽ⁿ⁾	^(o)
Energy Integration				
		Conventional modules ^(p)	Hidden coloured modules ^(q)	Flexible, thin modules ^(r)
Technology				

^(a,n) Doragno Castle, Rovio CH, ^(b) La Capanna, Capannori (LU) IT, ^(c) Casino Cappuccilli, Ripabottoni (CB) IT, ^(d) Spazi pastorali Parrocchia de La Vergine, Pistoia (PT) IT, ^(e,f) ACCA Software, Bagnoli Irpino (AV) IT, ^(g) Casa B, Alemanno San Salvatore (BG) IT, ^(h) Rural building, Seegräben CH, ^(i,k) Parco Urbano, Isola della Certosa (VE) IT, ^(j) Ruralia, Arzago D'Adda (BG) IT, ^(l,q) Kohlesilo/Gundeldinger Feld, Basel CH, ^(m) Prysmian Headquarters, Milano (MI) IT, ^(o) Casa Canale, Vasto (CH) IT, ^(p) Abitazione MK, Gubbio (PG) IT, ^(r) Fondazione Museo Pino Pascali, Polignano a Mare (BA) IT. Source Archilovers [19]

The opaque black roof disappears into the forest's dark vegetation, respecting and protecting the historic and values of the original building and transmitting the collective memory as well as producing green energy. The PV system and the solar-thermal system have been fully integrated into the roof pitches. The PV system comprises 67 glass to glass modules with an opaque external surface with the same aesthetic finish as the roofing panels that do not produce energy. The PV and solar-thermal installations cover the castle's annual heating and cooling needs. In this way, the PV system is not a foreign element to the building, but it integrates perfectly with the roof from aesthetic, energy and technological integration perspectives.

Another approach that has been identified is the position of the PV system on an annexe building or an existing building close to the historic one, namely decentralised power production in the nearby. When integration on the main building is not possible, this solution helps reducing the visual impact on the landscape and preserving its traditional aesthetic while maintaining the historic value of the main building unchanged even though some limitation about allowed shapes and colours exist.

La Capanna, a traditional eighteenth-century building in the province of Lucca (IT), is a remarkable example of this approach – figure 4. Initially, it was used for tobacco production and re-adapted to residential use in 2017 with a complete refurbishment. PV and solar-thermal systems were applied on the roof of a pavilion structure close to the main building and part of the historic complex. The appearance of the historic building was preserved. The original shape was maintained; attention to detail as the use of specific features and colours, matching those of the local natural stone, was vital for aesthetic and technological integration.

A further approach identified is the stand-alone PV system. When there is no chance of installing the PV system attached to the building, it is sometimes installed near the main building on *ad hoc* structures; this type of intervention results in a highly reversible solution.



Figure 3. Doragno Castle, Rovio CH



Figure 4. La Capanna, Capannori – Lucca IT

5.2. Position of the modules

Usually, PV modules are roof-integrated or façade-integrated. When dealing with historic building, roof-integration is the most common; the visual impact that PV modules integration on façade might cause is reduced. This is the trend that emerged from the case studies that were analysed, where a remarkable number of projects considered PV modules applied exclusively on the roof. Only on industrial buildings, PV modules are inserted as façade-mounted systems or integrated in venetian-blinds, to emphasise the idea of transformation and innovation.

5.3. Integration

The concept behind integration has been extensively discussed in the present work. Technological integration is also quite widespread and sometimes together with chromatic integration, especially for PV panels integrated into the roof. Approaches of technological integration found amongst the examined projects deal with PV elements that replace roof tiles. This solution offers a high degree of reversibility.

Among the submitted projects, a recurring trend is that of morphological integration, attention to alignments and panels' arrangement. Morphological integration, in a few cases, has been accompanied by chromatic integration. The latter is taken into greatest attention dealing with historic buildings at the expenses of the other aesthetic integration criteria that are not often applied all together. An application

of this approach is offered by the Isola della Certosa Park, a protected archaeological and natural area in the northern Venetian Lagoon (IT), where coloured PV panels were used to mimic terracotta tiles, as shown in figure 5.

This territory acts as laboratory and showcase hub for projects of energy production from RES in historic areas. In fact, some buildings for boatyard were refurbished, transforming over 1110 m² of opaque surfaces into an active roof using the BIPV system with coloured PV tiles. The unique PV tiles were of double laminated glass, making them more resistant than single glass panels. Visual continuity was obtained by adding some tiles of the same colour and material of the others where PV modules were not needed. Thanks to the colouring of the front glass of the tiles that simulates the terracotta effect, and the usage of custom tiles, the roof refurbishment resulted in a valuable example of PV integration.

Despite some exceptions, the case studies presented for the award show that an integration that contemplates the application of technological, aesthetic and energy criteria together is still rare. This is probably due to the number of variables considered in dealing with historic buildings and preserved landscapes. Nevertheless, satisfactory integration is possible.

5.4. Technology

Conventional silicon monocrystalline or polycrystalline panels are still prevalent, probably because of their efficiency, affordability, and durability, even if they are not of easy integration, especially with historic buildings because of their colour. An interesting approach that resulted as very successful amongst the projects presented for the Solar Architecture Award is the adoption PV panels used for replacing tiles. These products allow for both aesthetic and technological integration.

An application of this approach is offered by a building located in Seegräben (CH), a small town in the north of the country, where an old building in the countryside was renovated without losing its characteristics – figure 6. Customised coloured PV modules glass to glass type, without frame, were mounted on the existing canopy facing the main road for replacing tiles. Because of their colour and material that matched with the other colours of the building, the modules resulted perfectly integrated with the building and its surrounding. The colouring process, based on ceramic colours incorporated into the glass during the hardening process, ensures colour stability over time.



Figure 5. Parco Urbano, Isola della Certosa – Venezia IT



Figure 6. Rural building, Seegräben CH

6. Conclusion

This paper discussed PV integration best practices in historical artefacts, listed buildings or buildings included in protected areas. The Special Prize in Solar Architecture in Prestigious Contexts offered an exciting starting point to test the sensitivity of designers, local authorities, and end-users towards PV integration in historic buildings in IT and CH territories. Given the state of the art regarding PV products available on the market, designers' skills and knowledge and peculiarities of the historic buildings in these contexts, it is suggested that the PV integration criteria, recommended by existing regulations and standards for new buildings, might be not appropriate for application to historic buildings or landscapes. It is envisaged that a proper design methodology within appropriate regulation schemes will lead to the correct and conscious integration of photovoltaic systems in historic buildings.

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