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Criteria for building types selection in preserved areas to pre-assess the Building Integrated Photovoltaics solar potential - The case study of Como land area

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Abstract. The implementation of RES technologies in preserved areas encounters specific challenges and barriers due to the pre-existence of valuable heritage and natural values. This research aims at identifying a clear methodology to evaluate the potential application of Building Integrated Photovoltaics systems (BIPV) in heritage buildings and protected land areas. The study, realized in the framework of the Interreg V-A Italy-Switzerland project "BIPV meets history", presents the methodology for analyzing the best BIPV exploitation possibilities to validate their applicability in a preserved land area in the province of Como (Italy). This methodology considered several characteristics such as the predisposition, limits, suitable BIPV technologies and so forth. After the identification of the most recurrent building types and the related relevant characteristics for the solar potential exploitation have been identified, the analysis focused on the historical buildings that despite the high energy retrofitting potential encounter the major technical and heritage constraints for BIPV. The study resulted into a building classification database, which lists a series of parameters and identifies the main architectural elements and compatible criteria with the BIPV application. This study creates the base for the evaluation of effective energy savings related to the use of BIPV technology on heritage buildings and landscapes and demonstrate their potential for improving the energy efficiency of historic buildings and sites, safeguarding their heritage values.

Keywords – Building Integrated Photovoltaic; Renewable energy; Energy efficiency; Heritage building; Protected landscape

1. Introduction

The regulatory framework of the European Union (EU) boosts the transition from fossil fuels to cleaner energy production, especially in the construction sector. Existing buildings, particularly, are responsible for 39% of final energy consumption [1], 30% of solid waste production, and for 36% of total emission of carbon dioxide (CO_2) emission in atmosphere [2]; [3]. They have a high renovation potential [4], as more than 110 million European buildings require renovation and approximately 35% of them are over 50 years old [2]. Old buildings built before 1945 worthy to be preserved represent 30-40% of the whole EU stock [5]. The recent EU policies for the building sector provide specific measures to improve the energy efficiency of buildings, to reduce the energy use, and to enhance the decarbonization to transform the existing building stock into nearly zero-energy buildings (nZEB) [6]; [7]. Additionally, the achievement of the European target for Climate change mitigation requires the increase of low-carbon buildings and, consequently, the diffusion of Renewable Energy Sources (RES) applications [8]; [9]. The recast Renewable Energy Directive sets the target for RES penetration in the European energy mix to 32% by 2030 [10]. In this context, solar energy systems, particularly photovoltaic (PV) and building integrated photovoltaics (BIPV) technologies, can support the transition of existing and historical buildings towards a low-carbon energy system [11]. The "integration" of BIPV systems implies the substitution of the traditional constructive element with PV technologies, combining electricity generation with weather and noise preservation, thermal insulation, and sun shadow [12]. Nowadays, "*architecturally pleasing*" and "*less visually intrusive*" BIPV solutions renovate the visual appearance of standard PV modules to favor their integration in heritage and sensitive environments [11]; [13]; [14]. Notwithstanding, the acceptability of PV systems and building components is very critical in heritage contexts, especially for the preservation of their aesthetical, material, and historic values and appearance [13]; [14]. The analysis of the compatibility between traditional building types and BIPV technologies is crucial for the deep renovation of heritage and historical towns and landscapes, to boost their applicability and acceptability at territorial level. This topic is studied in the framework of the Interreg V-A Italy-Switzerland Project "*BIPV meets history*" that aims at creating a value chain for the use of BIPV in architecturally sensitive areas by showing to the main stakeholders the aesthetic, economic and energy benefits of these technologies [15].

2. Methods

Scope of this study is to evaluate the compatibility between BIPV systems and the most diffused building types in a specific area. The area considered to map and assess the most prevalent building types is the Como province, as representative of the cross-border between Italy (IT) and Switzerland (CH). The methodology followed for the buildings classification and assessment can be summarized in the following steps: (i) selection of the study area with the presence of a variety of building types, landscapes, and territorial specificities representative of the area; (ii) building types mapping to define recurrent building characteristics and (iii) database creation to collect all the building types.

2.1. Study area selection

The research area identified as most suitable for the landscape and buildings similarities between Italy and Switzerland was the cross-border territory. From a preliminary analysis, the province of Como revealed to contain a variety of buildings types and landscape characteristics fully representative of the specificities of the IT-CH cross-border area. Therefore, the analysis focused mainly on the city of Como, given here the presence of all the most representative typologies of areas and the large number of documentary sources. The main types of areas present have been identified according to preservation constrains, population density, and prevalent presence of building types. The followings areas have been identified (**Figure 1**):

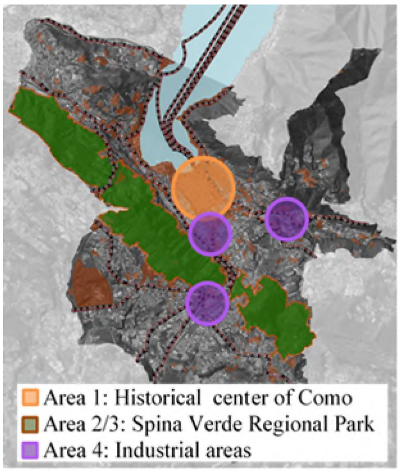

Figure 1. Areas identified.

- **Area 1 –historical centers:** ancient historical centers are parts of the territory constituted by dense urban fabrics with historical identity, morphological and typological characteristics recognizable by the stratification of the processes of their formation. These areas are rich of buildings with historical, monumental or landscape values and, therefore, subject to heritage preservation. The historical center analyzed is in the town of Como.
- **Area 2 – regional parks**: the regional park area for the municipality of Como is well represented by the "Spina Verde Regional Park", which extends on the hilly strip northwest of Como, straddling the IT-CH border. It is an area of considerable public interest, subject to landscape preservation. There are no listed buildings, but all the buildings are subject to landscape preservation.

- **Area 3 – rural areas**: the "Spina Verde Regional Park" includes also areas classified as agricultural. It was decided to select Spina Verde park, rather than other bigger rural areas, as representative for this category since it is subject to landscape preservation. This choice is supported by the Territory Government Plan (PGT), of the municipality of Como [17], according to which most of the places with symbolic value of the rural civilization, are located within the regional park "Spina Verde" (about 63%) [18]. It can therefore be said that this Park is representative not only of the Regional Park area, but also of the Rural Areas.
- **Area 4 – industrial areas**: industrial areas are generally not subject to monumental or landscape preservation, but buildings that insist on them offer a very high potential for BIPV applications due to both their envelope characters and the contribute they can give to urban regeneration of degraded areas. In the municipality of Como, several industrial areas have been identified, such as "disused industrial areas" subject or not to preservation, areas with historical evidence of industrial settlements and industrial areas with productive buildings without any historical value. In these different industrial areas, there are both buildings subject to landscape preservation and buildings subject to monumental preservation.

2.2. Building types mapping

Once identified the main four area typologies, the research focused on the building types mapping with the objective of identifying the most relevant and recurring buildings subjected to heritage or landscape constrains. Therefore, the analysis consisted in the following steps: (i) identification of the relevant building types within each typology of identified area (from SIRBEC cards on the study area [19], TABULA web Tool [20], municipal landscape plan); (ii) analysis of the characteristics of the identified building types (historical period, materials, height, housing density, etc.) through consultation data (PGT [17], cadastral maps [21]); and (iii) creation of the database of the building types with the data extrapolated from the analyzed sources. For the analysis of the housing stock and residential building types in the study area, a preliminary research of the available sources was carried out. This process has shown that the municipality of Como has far more documentary sources than the other municipalities identified for this analysis. The large amount of the different sources analyzed, both official documents (e.g. PTC of Spina Verde regional park [18], SIRBEC Cards [19], Como's PGT etc. [17].) and Webtools (e.g. DBTR [22], SIBA [23], DUSAF [24], Viewer 3D [25], cadastral maps [21], Vincoli in rete [26], Google Maps [27] etc.), ensure the quality of information extrapolated for the different areas identified. A deep analysis of the available sources was conducted to evaluate the different buildings located in the preserved Areas in the territory of Como. The main building types identified are: (a) Palaces; (b) Villas; (c) Rural buildings and farmhouses; (d) Industrial buildings (e.g. mills and production buildings); (e) Public buildings (e.g. kindergarten, church, etc.); (f) Single and Multi-family houses (SFH, MFH) and apartment blocks. Palaces are characteristics of the historical core area, which is rich of buildings subject to heritage and landscape constrains (**Figure 2.1**). Two main shapes are present: courtyard buildings distributed on densely built closed lots and buildings on a Gothic lot, narrow and elongated, with the short side facing the street, the commercial functions located on the ground floors and the residences on the upper floors. This typology, as well as the villas, embodies the historic places of residence within the city and represents the two most common types of historic buildings within the territory. Villas represent a highly widespread type of historic building within the territory. In addition to the villas located in historical center area (**Figure 2.2**), the building type (b) is also widespread over the territory with the dual aspect of agricultural residence and residence of panoramic value (**Figure 2.3**). These suburban villas are located in areas subject to landscape constraints (parks, lake shores, etc.), and are characterized by the presence of large parks and gardens. Rural building refers to farmhouses and cottages widespread in the past, albeit most of them have lost their original function and, in general, have been incorporated into the urbanized (**Figure 2.5** and **Figure 2.6**). Despite this, their original characters are still noticeable, i.e. the courtyard typology, the presence of loggias and the tiled roof. Industrial buildings category includes both those historical evidence of the industrial settlements of the past, and the productive buildings particularly suitable to the application of BIPV (**Figure 2.7**). Public buildings refer to all the public construction not included in the previous categories, with a special function (**Figure 2.4**). Finally, residential buildings with no particular historical-artistic or landscape values, are identified by the categories SHF, MFH and Apartment blocks.

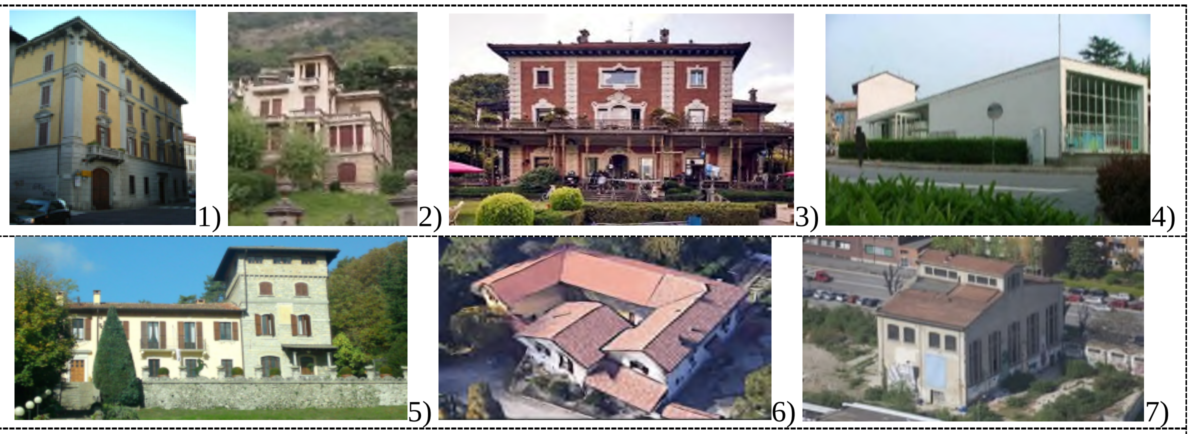

Figure 2. Some examples of building types identified in the area of Como: 1. Palace (a) in Area 1 [17]; 2. Villa (b) in Area 1 [17]; 3. Villa Noseda (b) in Area 2 [18]; 4. Asilo Sant'Elia (e) in Area 1 [19]; 5. Cascina Bronno (c) in Area 2 [17]; 6. Cascina Terramara (c) in Area 3 [27]; 7. Ex Ticosa (d) in Area 4 [17].

2.3. Database definition

Having identified the different types of buildings placed in the analysis areas, a sample number of buildings for each category have been analyzed to identify morphological and typological recurrences. The parameters examined and associated with each type are the following: building type, building use, year class, heritage and landscape constrains, conservation state, construction density, number of stories, features of the building envelope (e.g. roof typology and materials). Despite a large number of information is available for the constructions placed in the historical town, a lower amount of data was found for the other typologies, especially about conservation state, building use and year class. Finally, a database was created with all the information collected for all the building types identified, except the SFH, MFH and apartment blocks typology, which present already an existing database named "TABULA web tool" [20]. A total number of 65 buildings placed in Como have been analyzed, classified, and included in the database, as summarized in **Table 1**. **Figure 3** represents an example of the analysis conducted and the information collected for all the buildings selected for the database, including images, architectural element and the presence of heritage and landscape constrain.

Table 1. Summary of the building types analyzed

Area type	Building type	Case studies analyzed
Historical centers	Palace	12
	Villa	11
	Public buildings (e.g. kindergarten, church)	1
	SFH, MFH and apartment blocks	Tabula web tool
Regional parks	Villa	13
	Rural building and farmhouses	10
	SFH, MFH and apartment blocks	Tabula web tool
Rural areas	Rural building and farmhouses	5
	SFH, MFH and apartment blocks	Tabula web tool
Industrial areas	Industrial buildings	13

Villa

Villa 021 Sant Agostino				
	Constrain	Heritage Art. 10	Natural Art. 136	Natural Art. 142
	Year Class	1760-1860		
	Conservation state	Bad	Mediocre	Good
	Number of stories	1 story	2/3 stories	>3 stories
	Roof	Tile	Bitumen	Other
		Flat	Pitched	Other
	Building use	Residential	Public	Commercial
		Productive	Farm	Tourist
	References	PGT Como, DBTR, Google Earth, SIBA, DUSAF		

Figure 3. Urban villa (b) in Area 1, located in the "Sant'agostino district [17].

The analysis revealed that although data and tools describing different aspects of buildings are widely diffuse for the Lombardia area, they are not integrated together and give a fragmentary view of state of art of the existing heritage buildings. The database created compensate this lack, successfully including and describing all the information collected from those different sources. Indeed, besides giving detailed, complete, reliable view of the state of art with easy-to-read information, it includes the critical analyses of the compatibility of BIPV and the architectural element, such as roofs and façade. Hence, this study creates the basis for a tool that can help in identifying the BIPV applicability and energy retrofitting potential of historical buildings subject to heritage and landscape constraints.

3. Analysis of BIPV application case studies in the transnational cooperation area of the project

To assess the potential application of BIPV systems on the typologies identified in the previous part of this research, different best-case studies located in IT-CH have been analyzed, considering multiple factors, from the point of view of aesthetic, conservation, energy, and technology related to BIPV systems [13]; [14]. The selected CH buildings are best-practices on energy rehabilitation of historic buildings and of the integration of solar energy, mostly recognized by the Swiss Solar Award. The information were mostly collected from the Interreg Alpine Space ATLAS [16] research project, the collaboration with IEA-SHC Task59 / IEA EBC Annex 76 [28] and the Swiss BIPV and solar architecture digital platforms [29]; [30]. Before matching the best CH cases with the building types identified in Como area, a specific analysis on swiss recurring building schemes have been carried out, outlining five typological archetypes: 1) Court: type of building closed to the outside developed around the a free central space, the courtyard; 2) Block: isolated building type, with a vertical development with a maximum of three floors above ground; 3) Tower: typology whose spatial development occurs mainly vertically 4) Terraced: several building units that share a load-bearing wall; 5) Line: mainly horizontal spatial development. In addition to this, five categories of BIPV integrations have been identified: A) tilted BIPV on the roof (mounted at an angle between 0° and 75°), not accessible from inside the building; B) tilted BIPV on the roof (0° and 75°), accessible from inside the building; C) vertical BIPV (mounted at an angle from 75° to 90°) not accessible; D) vertical installation, accessible from inside the building; E) externally integrated as an additional layer to the building envelope (e.g., balconies, shutters, awning, louvers, etc.). Finally, the best cases studies have been assessed to verify the matching with the building types previously identified (palaces, SFH and villas, public buildings, rural buildings, industrial buildings and MFH) and included in the typological schemes and BIPV categories previously listed, as shown in **Table 2** and **Figure 4**. Results evidence that most of the examples correspond to rural buildings or farmhouses (28%), where BIPV is integrated in the roof (category A) with an average nominal power installed of 53 kWp. The other most repeating building type corresponds to multi-family houses (MFH) and apartment blocks (28%) where BIPV is mainly in the roof (category A), but in some cases in façades or integrated externally (category E). The average nominal power installed is 24 kWp varying between 5 kWp, installed where only the best orientation or visual aspects are taken into account due to preservation constrains, to 53 kWp when multiple surfaces (e.g. roof, facades or balconies) and orientations are used.

Table 2. Cross-check comparison with the archetypes identified in the land Como area to identify solar systems options and BIPV technologies to be best implemented.

	Category BIPV									
Case studies in Switzerland	**A**					**C**		**E**		
Building types	**1**	**2**	**3**	**4**	**5**	**2**	**3**	**3**	*Total*	*kWp mean*
Palace or unusual building		4%							*1*	*16*
Villa, single-family houses SFH		8%							*2*	*27*
Public building	4%	8%							*3*	*55*
Rural building		24%			4%				*7*	*53*
Industrial building		4%				4%			*2*	*12*
Multi-family houses MFH	4%	4%	8%	8%	4%		8%	4%	*10*	*24*
Total Category BIPV	*8%*	*52%*	*8%*	*8%*	*8%*	*4%*	*8%*	*4%*	***25***	

Figure 4. Some CH examples studied in correspondent to building types and BIPV categories:
1. a) Doragno Castle: A-2, © L. Carugo [16] [30]; b) Villa and SFH Hutterli R.: A-2, © C. Martig [16]; c) Doppelkindergarten: A-1, © R. F. Malans [16]; d) Glaserhaus rural building: A-2, © C. Martig [16] [29].
2. e) Industrial Solar Silo: A-2 and C-2, © M. Zeller [16] [29] [30]; f) Hôtel des Associations: A-3, © C. Martig [28]; g) MFH Kettner: A-5, © C. Martig [28]; h) MFH Sanierung Viriden: A-2 and E-3, © Viridén + Partner AG [29] [30].

In IT some significant examples related to the building types identified have been highlighted from the IN/Arch Awards 2020 [32] and other databases [28]; [34]. Only building types (b), (c) and (d) have been found in IT, due to the strictly heritage constrains in this territory (**Figure 5**). In the IT cases studies a special attention is given to the integration of PV and BIPV systems in architecturally and naturally sensitive areas. In all the building types the main goal is the protection of the heritage values, obtained through the preservation of original and traditional features, proportions, construction techniques, and materials. Also, the minimization of the visual impact is an important criterion. Inconspicuous locations (e.g. less visible areas, internal gardens, not visible streets, or internal courtyards) have been preferred. PV systems are installed mainly on new constructions, non-historic buildings (**Figure 5.4**), outbuildings (**Figure 5.2**), or damaged building elements (**Figure 5.1, Figure 5.3**), matching the original geometries, visual appearances, and colors. Visual impact reduction on building types (b) and (c) is more strictly than in (d), where PV technologies express the idea of "material innovation" of industrial buildings (**Figure 5.5, Figure 5.6**).

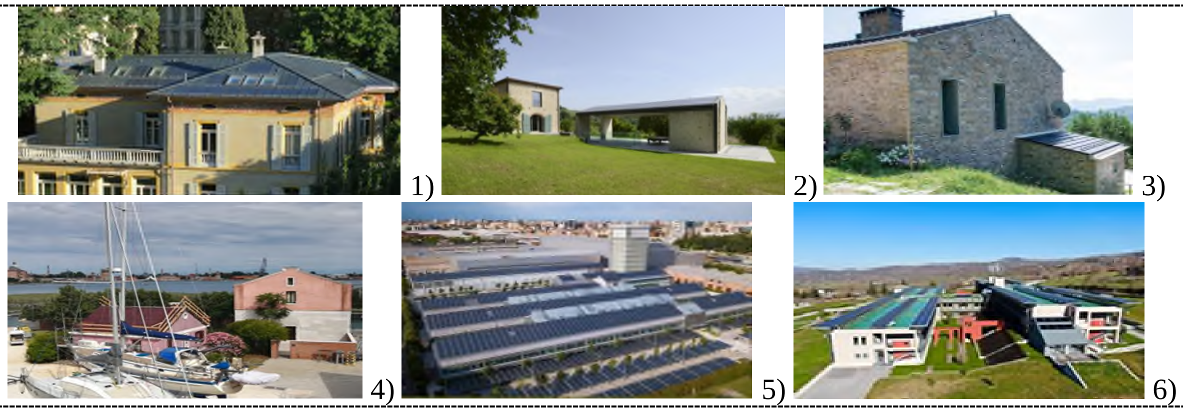

Figure 5. IT case studies correspondent to Como building types: 1-2. (b) Villa Castelli in Bellano (LC) [28] [34] and La Capanna in Capannori (LU) [32] [34]; 3-4 (c) Podere del Tiglio in Palazzuolo sul Senio (FI) [32] and Parco Urbano Isola della Certosa [32] [34]; 5-6. (d) Prysmian Headquarters Milano [32] and Sede ACCA software in Bagnoli Irpino (AV) [32].

In all cases, the impact of PV systems on the historic and natural values is evaluated by Heritage and Public local Authorities with a long process. In all the IT cases, the PV system are inserted on roofs, using both PV and BIPV technologies. Geometrical uniformity and colors of the cells are the most important parameters considered in the projects. Geometrical uniformity means the coverage of the roof surface with PV systems, to guarantee a uniform appearance whit 100% of coverage, grouping of panels, or reduction of the spaces among the panels. Also, in many cases, the colors match the colors of traditional materials at local level (i.e. terra-cotta cells for clay roof tiles, or anthracite cells for stone tiles). Also, the design is very accurate, and in many cases is an *ad hoc* design (**Figure 5.1, Figure 5.2, Figure 5.4**), to respect the appearance of the original roofs. Finally, reversibility is adopted in few cases for removing the PV panels without affecting the integrity and the materiality of the original structure.

4. Conclusion

The integration of RES in urban contexts and existing building stock opens a high potential to improve the architectural quality of the buildings in terms of economic and environmental sustainability. EU legislation imposes obligations to include RES in the renovation of the building stock, however, PV solutions that can be integrated into traditional building systems are still little known by designers and Public Authorities and, therefore, not widespread. The research aims at defining a specific methodology for identifying the potential for BIPV applications to encourage their diffusion in buildings renovation. The study focuses on a heritage in protected area in the cross-border territory of the province of Como. It starts from the analysis of the most representative areas and then identifies and classifies the recurring building types. The results of the analysis lay the basis to identify the degree of integrability of BIPV technologies in the different building types present on the territory, facilitating greater integration of these technologies in protected areas, respecting the historical and artistic characteristics of the heritage and landscape. For this purpose, real examples of solar systems already installed in historic buildings were analyzed through best practice IT and CH examples.

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