

## Article

# Photovoltaic BIPV Systems and Architectural Heritage: New Balance between Conservation and Transformation. An Assessment Method for Heritage Values Compatibility and Energy Benefits of Interventions

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**Abstract:** This paper proposes to identify an approach methodology for the incorporation of building-integrated photovoltaic systems (BIPV) in existing architectural heritage, considering regulatory, conservation and energy aspects. The main objective is to provide information about guidance criteria related to the integration of BIPV in historical buildings and about intervention methods. That will be followed by the development of useful data to reorient and update the guidelines and guidance documents, both for the design approach and for the evaluation of potential future interventions. The research methodology includes a categorization and analysis of European and Swiss case studies, taking into account the state of preservation of the building before the intervention, the data of the applied photovoltaic technology and the aesthetic and energy contribution of the intervention. The result, in the form of graphic schedules, provides complete information for a real evaluation of the analyzed case studies and of the BIPV technological system used in historical contexts. This research promotes a conscious BIPV as a real opportunity to use technology and a contemporary architectural language capable of dialoguing with pre-existing buildings to significantly improve energy efficiency and determine a new value system for the historical building and its environment.

**Keywords:** solar energy; heritage buildings; energy efficiency; building integrated photovoltaic BIPV; renewable energy sources (RES)



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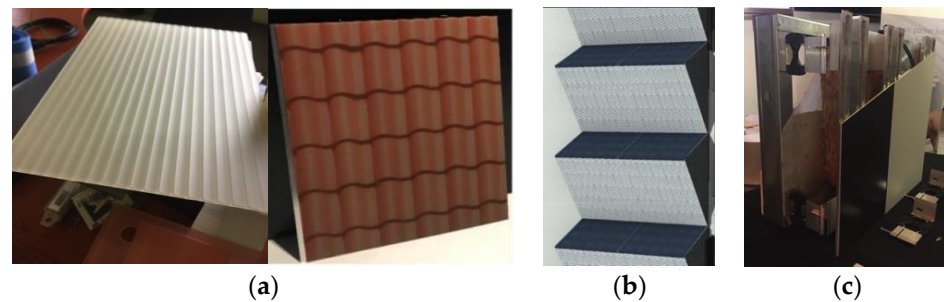
## 1. Introduction

The scope of the research on the right approach to the integration of new solar systems in historic buildings is based on two fundamental aspects: the preservation of the existing heritage and the need to align with provisions on the energy improvement of both new and existing buildings, using energy from renewable sources (hereinafter RES). The European Union (EU) is at the forefront of the global energy transformation and impressive progress has been achieved because of the ambition and vision of the EU to meet climate targets. To meet long-term decarbonization objectives, more effort will be needed, although this process is already underway and unstoppable due to the priorities and objectives set by an ambitious environmental policy that aims to achieve climate neutrality in 2050 [1]: the sustainable Green Deal [2]. Key points are focused on guaranteeing energy efficiency in the construction branch, research and investments in environmentally friendly technologies to create job opportunities by investing in low carbon and climate resistant companies and technologies, and solving the inequalities caused by the Covid-19 crisis as fundamental pillars of the European Just Transition Mechanism (JTM) [3,4]. The achievement of these

European targets for climate change mitigation requires the increase of energy efficiency in buildings and, more than ever before, a major penetration of RES applications which include solar energies. Consequently, implementation in the existing building stock becomes even more necessary and will be driven by the new EU strategy to trigger and boost renovation in the construction sector [5,6]. The revised Energy Efficiency Directive (EU) 2018/2002 sets a 2030 target of 32.5% [7,8] and recent EU policies establish a target for RES penetration to 32% by 2030, as stated in the recast Renewable Energy Directive [9]. The RES directive set framework conditions for renewable energies in the electricity sector (RES-E) and the requirements for the policy design of support mechanisms of renewable heating and cooling (RES-H/C). The EU could effectively double the renewable share in its energy mix, from 17% in 2015 to 34% in 2030, according to the International Renewable Energy Agency (IRENA) that also sees major potential for the share of renewable energy in the power sector to up to 50% until that date, as strong cost savings are expected mostly in solar energies [10]. IRENA's REmap programme and roadmap determine the potential in the world to scale up renewables, suggesting that they can make up 60% or more of many countries' total final energy consumption (TFEC) [11]. Beyond the pandemic crisis nowadays, their comprehensive analysis sets the outlines and path based on renewable energy to create a sustainable and safe future energy system for stability considering the necessary challenges that will be faced by different regions to bolster prosperity [12]. Due to the intermittent lockdowns and despite the fact that carbon dioxide (CO<sub>2</sub>) emissions have been slowed down as a result of the global situation today, any rebound of increased energy consumption in the future could restore the initial trend in the long run, and there is an urgent need of measures to face the consequences of COVID-19.

The issue of improving the energy efficiency of historic buildings is highly controversial and of great importance, considering that historic buildings constitute a large part of the European building stock. There is a need to preserve the values and characters of the heritage, as widely demonstrated by many funded research projects at the European level, with Italian [13–15] and Swiss participation [16–19]. Ongoing activities of the International Energy Agency (IEA), Solar Heating and Cooling Programme (SHC) Task 59 [20] and research conducted in the ATLAS project [21] are focused on finding efficient and conservation-friendly energy retrofit approaches and technologies for historic buildings (not necessarily protected). These studies take into account low levels of energy efficiency and comfort, also considering the integration of renewable solar resources. Building integrated Photovoltaic technology (hereinafter BIPV), as part of the building envelope, contributes to electricity needs but performs constructive functions, becoming part of the building envelope itself. In recent years, the integration of photovoltaic modules in architecture has been increasingly evolving, thanks to continuous research on competitive and innovative solutions for the global market to drive BIPV technology to a large market deployment [22,23]. New products, due to their size and characteristics (e.g., modularity, customization, new features and multi-functionality) are similar today to other traditional building elements [24,25]. The aesthetic and perceptive aspect is considered as a plus, in order to guarantee a building's efficiency, but it is also important to return a coherent and harmonious overall vision with the surrounding environment [26]. In recent years, the solar market is evolving much faster than the actual application of technology in architecture [27,28]. From an architect's perspective, a meaningful integration is only possible when PV is part of the design concept as well as part of the design process [29]. There is a willingness on the part of producers of PV cutting-edge technologies to reduce the impact of new products on buildings. In Switzerland, for example, the PV manufacturer industry is today at the forefront of product innovation and a move towards technical solar solutions, where the active part of the building skin is not even recognizable but camouflaged, (Figure 1) or it is even designed to be better integrated into the architecture and landscape [30,31]. Innovative design characteristics of solar technologies nowadays, already in the market (i.e., solar modules with patterns and colours, or that are geometri-

cally adaptable and economically feasible), can enable new possibilities of integration into old buildings, historical sites, the urban space and landscapes [31].



**Figure 1.** Innovative solar BIPV products developed by Swiss PV manufactures: (a) Solar prototypes with textures and colour patterns, source: Copyright [2021, Sunage SA] (<https://www.sunage.ch/>, accessed on 30 April 2021); (b) Solar system developed for retrofitting and landscape integration, source: Copyright [2021, Solar Retrofit Sgal] (<http://www.solar-retrofit.ch/>, accessed on 30 April 2021); (c) Multifunctional mate opaque BIPV solar component, source: Copyright [2021, Greenkey Sgal] (<https://www.greenkey.ch/it/>, accessed on 30 April 2021).

Moreover, the colouring of PV has recently been considered an essential requirement for market acceptance [32,33] and, for the rest, this aspect would allow a better integration in the landscape and in historical buildings and contexts [34]. Coloured glass, pattern coatings or printing on front glazing treatments or coverings are new solutions for solar BIPV or BAPV (Building Applied Photovoltaics) modules. However, this involves “shading” over the PV cells with a consequent reduction in the energy production [35]. Namely, the challenge to balance both the aesthetical quality with the energy, as well as the electrical efficiency, reliability and safety, is one of the drivers of innovation. Thus, a bigger acceptance of photovoltaics and solar thermal solutions would leave space for a greater expansion of solar technology in the near future, helping to improve the energy efficiency of the historic building stock (protected and not) [36,37]. The need to find the right approach to integrating new technological systems in valuable contexts could help to keep part of the architectural heritage active and alive over time, and respectful of new energy requirements and sustainability. Everything that possesses qualities of value and is the result of the constructive knowledge of past eras bears witness to a past that was, and is, the history of humanity, constituting its collective identity. Aware that architecture is the mirror of the civilization from which it is generated, in continuous relation with the surrounding environment and in evolution, change is inevitable as is the development of technology in response to the needs of the community. The surrounding environment changes and mutates its characteristics, and it is increasingly difficult to find the right way to preserve architectural organisms without uprooting them from their past, but also without making them alien to a new and modern context, condemning them to progressive abandonment. *“(Living) organisms are in balance with their environment, and when the environment changes, they too must change, otherwise they are condemned to disappear”* [38]. Charles Darwin’s reflection, if applied to architectural organisms, would also include all those retrofit interventions operating on the historical matter, which disfigure and destroy them finding shelter in a legislation that only partially succeeded in protecting and binding a limited portion of the building heritage. Only in recent years, the vision spectrum to a wider panorama is widening to those buildings equally worthy of protection, and questioning the correct methodology of investigation and attribution of values so far established. Architecture has always been considered the mirror of the civilization, which creates it, in continuous relation with the environment.

As with the change of technologies molded by the needs of a community, change is inevitable.

The research here presented is the result of collaboration between the Swiss BIPV Competence Centre within the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) and the University of Catania (UNICT) in Italy to develop an Architectural Master Thesis [39]. The research activity has been done with the support, and in the framework, of the Interreg V-A Italy-Switzerland Project “BIPV meets history” [40], a cross-border cooperation research project between Lombardy Region, South-Tyrol and Ticino Canton. Switzerland, even if outside the European Union, is the same as other EU countries in that it has always been in line with their medium and long-term development of common climate objectives to accelerate the shift to sustainable, decarbonized economies supported now by extra funding resources for this effort. The project “BIPV meets history” aims to create new business prospects in the cross-border areas between Italy and Switzerland for the integrated photovoltaic (BIPV) supply chain in the recovery of the historical building heritage and landscape, responding to European, national and local policies in terms of energy efficiency and protection of cultural heritage. Some of the products developed by Swiss companies in the BIPV sector participating at this research project have already been presented in the previous Figure 1. Even though solar photovoltaic technology is now mature, the technological and market development, and its application in the built environment, has been quite different in European countries, as shown in the previous literature. Besides, one of the main difficulties for the proliferation of PV systems within neighboring territories with a similar cultural and historical heritage is the different approach in legislative and regulatory framework in different countries, as well as the guide-criteria of possible intervention.

For this reason, focusing mainly on these cross-border territories (from the Italian and Swiss context) mentioned above as part of this research, this paper aims to analyze and compare the different approaches nowadays to the criteria for the integration of solar technologies and, in particular, photovoltaic systems in historic buildings. This study investigates the heritage value compatibility of solar photovoltaic integration interventions, on the basis of the criteria considered today in binding and not-binding documents in the area of study, and proposes a simple evaluation method based on assessing some energy retrofit interventions. Besides, the estimation of the solar potential, based on the analysis of real examples of application, will allow the identification of future development possibilities in the BIPV market, considering the BIPV technology used. The paper consists of five Sections: on the basis of the literature review, the methodological approach for the assessment of the heritage value compatibility of solar photovoltaic integration is introduced (Sections 1 and 2). Through an in-depth overview of European, Italian and Swiss policies and regulations on energy, landscape protection and conservation, reference criteria and recommendations have been identified (Section 3). The analysis of the legislation, regulation, implementation and procedure will allow highlighting differences and common approaches for solar integration criteria in historic and existing buildings, in order to preserve a landscape continuity in these geographical contexts. The criteria identified define the basis of an assessment method for the compatibility of heritage values with solar BIPV applied to case studies of real implementation, which have been realized in the last few years in Switzerland as in Italy or Europe (Section 4). The information is compressed and synthesized in a technical sheet concerning both the case study analyzed and the BIPV technology used, and serves to check also the energy benefits of the retrofit interventions (solar potential actually exploited) and the contribution of solar energy and BIPV to the overall energy needs of the building (Section 5).

## **2. Heritage Value Compatibility of Solar Photovoltaic Integration Assessment Method-Introduction**

The method of assessing energy retrofit interventions that includes building integrated solar renewable systems (BIPV) must take into account multiple knowledge areas, in line with the principle of the multidisciplinary, to be sought first in the legislative system and in the provisions of the guidelines that regulate the intervention. As thoroughly as possible, a guiding framework with the correct methodological approach has been established to

evaluate the integration of photovoltaic systems in historic buildings and its impact within a wide spectrum of other possible interventions aimed at improving their energy efficiency. Furthermore, it is in accordance with different degrees of protection and conservation, which is the starting point of the debate of multiple research projects, as indicated in the introduction. At the same time, criteria were identified for an integrated, coherent and harmonized approach to landscape, urban planning, architectural and procedural integration that respects the specificities of local governance, and the analysis of the cross-border context highlighted across clear common elements in the territories.

Moreover, it was considered to integrate further information, including new criteria for the assessment of interventions on historic buildings, not yet contemplated in the reference countries, but accepted at a European level, as specific international working groups review in the standard EN 16883:2017 [41], “Conservation of cultural heritage—Guidelines for the improvement of energy performance of historic buildings”. The EN 16883:2017 directive represents the first glue between the energy–environmental issue and the valorization of the existing heritage. The directive contains guidelines on the energy improvement of existing buildings based on surveys and analyses that take into account the cultural value of the building. The legislation is a turning point because it applies to all historic buildings, even those not directly protected by legislation. The standard EN 16883:2017 is a working procedure for selecting measures to improve energy performance, based on an investigation, analysis and documentation of the building. In essence, it provides a flowchart covering a suggested decision process, and brief information about how the different steps can be carried out. The guidelines are supposed to be applicable to all kinds of historic buildings, and to all renovation processes in such buildings. However, there is still a long process of implementation and adaptation. For this reason, experts from all over the world in the field of sustainability and heritage are working on reviewing the standard, in the collaborative research project by the International Energy Agency, IEA-SHC Task 59/IEA-EBC Annex 76. This action aims to investigate to what extent the standard can be improved in order to better meet the needs of the end users during the planning process. IEA-SHC Task 59 works to support the stakeholder in the planning of Assessment Criteria from the EN 16883:2017 content, looking specifically into the adoption of compatible solutions for historic buildings energy retrofitting. Specific focus will thereby be given to the following thematic areas or working groups: (i) windows, (ii) internal wall insulation, (iii) ventilation, (iv) HVAC, (v) solar active and (vi) retrofit strategies. By taking into consideration the recent activities of IEA-SHC Task 59, Subtask C working group on solar, the assessment criteria based on the Italian [42,43] and Swiss regulatory framework [44,45], as well as the respective country guidelines and not-binding documents [46,47], relevant criteria to be taken into account when integrating photovoltaic technology into historic buildings has been identified. It should be noted that the integration of solar technology is one of the possible energy retrofit interventions and therefore the principle of “derogation” applies in both countries, as an exemption from, or relaxation of, the law [48,49].

Besides, a very relevant aspect in this research to evaluate heritage value compatibility for solar BIPV integration with respect to the historical matter is the state of the building envelope before the intervention. This allows the identification of the parts of the building envelope to be involved or not in the integration intervention, following a process of prior analysis able to assign a value system from an energy and conservation point of view. The process of analysis of the intervention should involve, first, the reading of the work and the consequent judgment to recognize in it architectural values or the presence or absence of elements worthy of being preserved. If this is the case, the restoring of the building element to its original state as far as possible should be assumed. However, the possibility of applying even new technological solutions have considered, in this case solar photovoltaic BIPV solutions, and an effort to not exclude them in advance has been taken into account.

Another relevant aspect in this research to assess the compatibility of the asset value of BIPV solar integration with respect to the historical matter is the condition of the building

envelope prior to the intervention. As other authors have recently highlighted, the state of preservation of the building suggests the appropriate type of approach on a case-by-case basis [50,51]. This allows identifying the parts of the building envelope to be involved or not in the integration intervention by following a process of preventive analysis able to assign a value system by applying “critical judgment”. The process of analysis of the intervention of the BIPV should provide, first, the reading of the work and the consequent judgment to recognize in it architectural values or the presence or absence of elements worthy of being preserved. On this vision, we could hypothesize the methodology of integration of new technological solutions, as in this case the solar photovoltaic solutions BIPV, without excluding them a priori, but looking for a suitable approach supported by preventive analysis based on the recognition and respect of the work of both its historicity and aesthetics. This reflection takes its cue from the thought of one of the greatest exponents of the discipline of restoration, Cesare Brandi, leader of the so-called critical restoration [52]. Since the affirmation of critical restoration in the 1950s and 1960s, sanctioned in the Charters of Restoration (Charters of Restoration 1964 and 1972), an increasingly respectful practice of the artefact, of its history and of its peculiar aesthetic characteristics has made necessary an adequate historical–technical preparation of the operators. These documents and different authors have contributed to the definition of a clear and coherent methodology with the universally accepted theoretical dictate summarized in common principles of restoration [53] (pp. 70–71), [54] (p. 751), [55] (p. 169):

1. Distinguishable, as the addition must be easy to notice from the original material, without disturbing the vision of the work. If this criterion is not well-fulfilled, one runs the risk of practicing a not-proper restoration by making a wrong reading of the work;
2. Reversibility of the intervention that allows the removal of the intervention without altering or damaging the original parts;
3. Compatibility, those materials used must not bring any constructive or aesthetic alteration to the original materials with respect to chemical-physical and mechanical properties;
4. Minimum intervention, limiting the invasive actions on the historical material is preferable to respect all the information understood as historical stratifications;
5. Multidisciplinary, this principle underlies the importance of collaboration to engage and interface with different specialized professionals.

In addition, some authors, when considering the selection of energy efficiency measures for historic buildings, underline the importance of preserving the historical value and the adoption of compatible technological innovation solutions [55] (similar to values such as authenticity and contemporaneity [53,54]). Furthermore, it is necessary to distinguish the additions by enhancing the existing structure and, even if contemporary “signs” are added, verify that they are not intrusive to the pre-existence [55].

The interaction between the different disciplines and professions that collaborate together in research and in the exchange of knowledge must aim to obtain a work that is complete and respectful of the historical matter. Beyond the scope of architectural restoration, rehabilitation interventions also contribute to the regeneration of new values, providing for the reduction of urbanization processes and contributing to the reuse of part of the built heritage. Dealing with monuments and heritage protected buildings during the last decades has evolved and changed in different and not even similar approaches, but all still have an impact on subsequent theories and restoration charts (e.g., Venice Charter 1964, Washington Charter 1987 for the conservation of historic towns and urban area, Burra Charter revised in 1999, Nara Document 1994, Charter on the built vernacular heritage 1999) [56]. Among the many theories of restoration, it is possible to distinguish two extreme positions such as the ‘restoration movement’ in the nineteenth century (represented by Viollet-le-Duc, etc.) and the opposing ‘anti-restoration movement’ (e.g., theories of Ruskin, Boito) based on material authenticity and the documentary value of monuments. The critical restoration movement (represented by Brandi, Riegl, Bonelli, etc.) privileges the

aesthetic, historical and use values [57]. Brandi's theory considers that restoration can find various forms, ranging from "simple respect" to the most "radical operation". It aimed at re-establishing the potential unity of the work of art without infringing on historical falsehood and avoiding cancelling the traces of the work's passage through time.

In the spirit of the Charter of Venice, each community is responsible for the identification as well as the management of its heritage, regarding which values may change over time. From this process of change, each community develops an awareness and consciousness of a need to look after their own common heritage values. After the Venice Charter, experts reflected on how to develop a vision of conservation that does not exclude development to safeguard historical evidence [58], following Bellini's idea that conservation is the research of a regulation of transformation to give new interpretations without destruction, that maximizes permanency for the future [59]. This process requires continuous adjustments [60] and built heritage concepts evolve to extend the boundaries of protected heritage to new categories (e.g., rural settlements and industrial heritage) which are publicly recognized. Rehabilitation is not based on a static conception of the existing building providing only for its preservation, but adapts the existing buildings to new uses, allowing new relationships between the whole and the parts [61]. It is based also in the adoption of innovative techniques to support sustainability, industrialization and the consumer-oriented [62]. For this reason, the technological part related to the photovoltaic solar technical solution integrated in the historical building has been studied to better understand the aspects of feasibility and functionality, as well as the fundamental energy values that justified the solution used in each particular case.

Nevertheless, energy retrofit to historic buildings must be guided by indistinctive conservation principles intended to preserve their significance (building fabric and character) based on processes of managing changes [56,63,64] as delineated in several international charters by the International Council on Monuments and Sites (ICOMOS) and the United Nations Educational, Scientific and Cultural Organization (UNESCO). Keeping historic buildings alive, reuse or bringing them back to life, although if with a new use, is part of the contemporary sustainable approach to saving resources as key pieces highlighted by several institutions (e.g., ICOMOS, UNESCO, etc.). It is a significant challenge to preserve this historic heritage, most of the time no longer used or in decay, by enriching it with new content, and enhancing its modernity and attractiveness, which requires as well the pondering of economic processes and investments. The concept of "reuse" is then understood as the action or process by which it is possible to restore the building to a condition that makes possible a compatible use [65,66]. This is possible through maintenance, transformation or addition, preserving parts or characteristics of the asset that are significant for its historical, architectural and cultural value has also been considered in the evaluation [60,61,67]. Moreover, in the same way, ICOMOS terminology for "refurbishment" of existing buildings and systems implies the changing needs of the occupants recognizing main objectives in including greater energy efficiency and sustainability, and states that retrofitted buildings are often more sustainable than build up new buildings, depending on the percentage of embodied energy retained [66,68]. It could include building envelope enhancement and extensive maintenance or repair interventions to reach modern standards [69]. To remain within law/regulation requirements and, today, comfort and energy efficiency levels, sometimes a renovation upgrade of components, elements and systems is necessary [69,70]. Renovation does not always fully respect the significance of the heritage building. New materials or technical installations may not be compatible with the original finishes or with the historical features that characterize the construction [69] (p. 293).

Furthermore, as stated in the 1999 Charter on the built vernacular heritage [56], and the 2000 Krakow Charter [71,72], landscapes as cultural heritage integrating material and intangible values are testimony to the evolving relationship of communities, individuals and their environment. It is important to understand and respect the character of landscapes, and apply appropriate laws and norms to harmonize relevant territorial functions with essential values. Landscapes are historically related to urban territories and influences,

characterized by local architecture, the built environment of the metropolis, cities and towns. However, it is important to consider a harmonization in the sustainable development of adjoining regions and localities, especially in cross-border and neighboring territories, sometimes subject to different laws and ways of operating. Preservation of heritage can contribute to the sustainable, qualitative, economic and social developments of a community. For this reason, it needs to be considered in planning and management processes, and to include individuals and institutions in the decision-making process [72]. At the end, the management of changes to, and transformation and development of, the cultural heritage implies an appropriate regulation, making choices and monitoring results. When considering solar systems and PV integration in minor centers and historical contexts, parameters such as the “transformability ratio” need to be carefully weighted [73,74]. Adhering to the aesthetic, visual and distinctive features of historic buildings [75] could now be greatly facilitated by innovation in the BIPV market as mentioned in previous sections. However, the visual impacts of solar photovoltaic solutions are even the subject of controversy and continuous research [19,76–79]. Flexibility and versatility in development of custom BIPV products, and considering different BIPV integration schemes, are nowadays possible for roof or façade applications, considering that power output and performance reduction can occur based on design [80–82].

Findings of this research and the methodology proposed express some common issues that affect many areas of cultural heritage conservation, and reflect the current *Zeitgeist* approach or “spirit of the time” for the heritage conservation field [83] when considering their adaptive reuse and their energy efficiency improvement with contemporary technological compatible solutions (including solar energy integration). The *Zeitgeist* approach can be understood as a hypothesis for a pattern in meaningful practices that are specific to a particular historical time period that links different realms of social life, and extends across geographical contexts [84]. Spirit of time/age representing a specific time when the building was re-constructed or adaptively reused is considered, in this case when solar technology is implemented as part of an energy refurbishment improvement.

This research further investigates the importance of considering new approaches for renewable and solar integration in heritage buildings (protected and not protected), taking into account local and geographical specificities (in this case Ticino and the neighboring Italian areas), the specific regulations enforced and non-mandatory guidance documents in the geographical area focused on in this study (Section 3). Following these principles, the evaluation method (Section 4) was then used to assess the BIPV intervention in several case studies of real implementation in Switzerland and in Europe (Section 5). As stated in the 2000 Krakow [71,72], and previously mentioned, landscapes as cultural heritage integrating material and intangible values are testimony to the evolving relationship of communities, individuals and their environment. For this reason, it is important to understand and respect the character of landscapes, and apply appropriate laws and norms to harmonize relevant territorial functions with essential values. Landscapes are historically related to urban territories and influences, and characterized by local architecture. However, it is important to consider a harmonization in the sustainable development of adjoining regions and localities, especially in cross-border and neighboring territories, which are sometimes subject to different laws and ways of operating. The proposed methodology intends to support the stakeholders involved in the energy retrofit of historic buildings, and above all, the operators responsible for evaluating the interventions such as the cultural heritage offices responsible for landscape protection.

The research need is addressed through:

- An in-depth analysis of current criteria for the assessment of the integration of solar photovoltaic BIPV systems in historic buildings and conservation areas, based on the regulations and guidance documents in neighboring countries of a specific geographical area with similar cultural and architectonic historical heritage values;



- An assessment semi-quantitative method valuable for operators or cultural heritage offices to judge energy retrofit interventions and BIPV examples of integration, based on a common framework approach;
- A methodological approach to address some barriers that will allow a further dissemination of BIPV technology in existing buildings and further market development.

### 3. Comparison of Directives, Regulations and Consultation Documents with Regard Solar Photovoltaic Integration

#### 3.1. Part 1—Reference Legislation IT-CH Cross-Border Area, Binding Documents

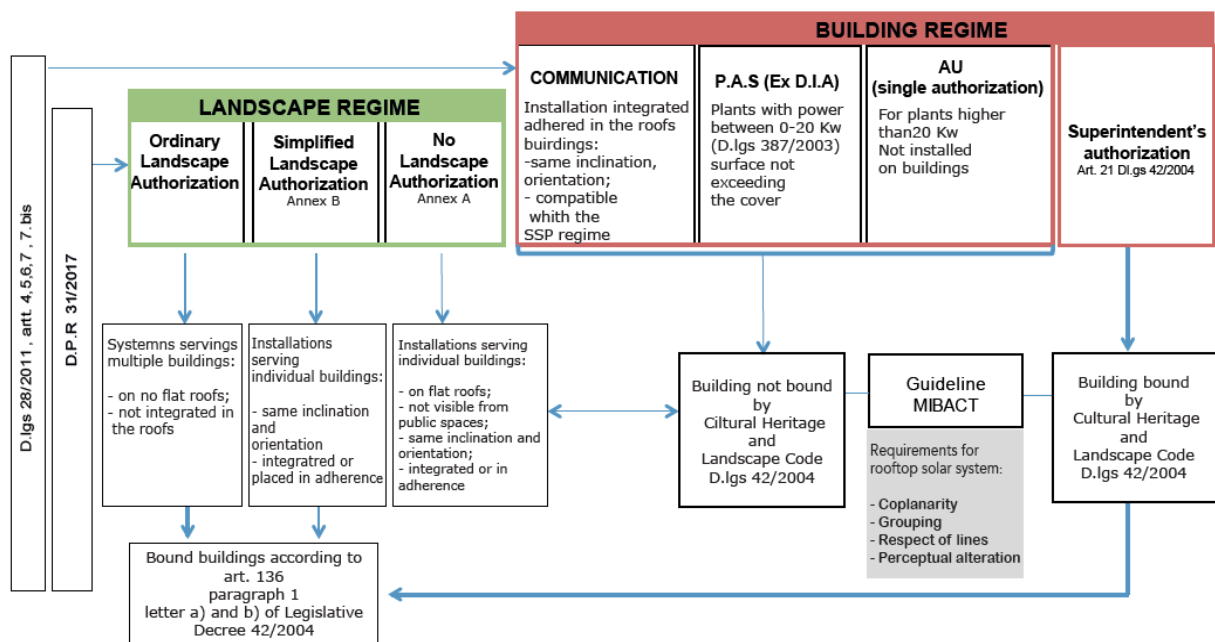
##### 3.1.1. Italy

The criteria governing the application of solar systems in Italy are reported in two main normative legislative texts, which were previously mentioned [42,43]. Solar systems must be in adherence to the roof of the building, with the same orientation and inclination of the slope (Annex three, point 4 of Legislative Decree 28/2011). The principle of derogation is also indicated, allowing not integrating solar systems if an alteration incompatible with the character or appearance of a cultural heritage protected by the Code of Cultural Heritage is shown (Part II, Legislative Decree 42/2004) [85]. Furthermore, the legislative decree also presents the authorization process, which submits the intervention of integration of photovoltaic systems according to the building regime. The GSE, Gestore Servizi Energetici [86], is the reference public holding for promotion and sustainable development in Italy through the provision of economic incentives for the production of electricity from renewable sources. Through a reference document [87], the same GSE classifies solar plants as a function of the architectural integration types (partial or total architectural integration) described by the Ministerial Decree D.M 19 February 2007(G.U. n 47, 26 February 2007) [88]. In addition, examples of photovoltaic systems applied to buildings, giving specifications of the technology used and the method of installation depending on the particular case, are provided [87]. The following criteria for correct installation have been gathered from the text:

- Coplanarity: photovoltaic modules installed on roofs, facades, balustrades and parapets of buildings must be installed coplanar to the supporting surface without substitution of material in the case of partial or total integration of the building;
- Respect of the eaves line: the module must not exceed the upper edge of the tiles by more than its thickness;
- Respect the geometry of the pitch: the position of the modules must respect the lines of the pitch;
- Compactness of the modules: limit as much as possible the separation space between the external perimeter of the modules and the residual portion of the existing roof.

The installation of photovoltaics always requires the authorization of the public administration. This can be a simple prior communication to the municipality in simple cases, or a Single Authorization (AU) in complex cases. Another solution is the “Procedura Abilitativa Semplificata” (PAS), a simplified authorization tool whose scope can be extended by individual regions, which replaces the previous procedure called “DIA”, which had its name changed in 2011. As a rule, for small systems installed on roofs, that are coplanar without changing their shape, a simple prior communication of the work to the municipal office is sufficient. The previous criteria are also identified by the GSE itself in accordance with the provisions of the Ministerial Decree of 28/2011 (it is referred to for all types of buildings, including heritage buildings). Depending on the specific case, the installation of photovoltaics requires specific authorizations for both the building and landscape regime. There is a need for specific authorizations in the building regime, in reference to buildings protected by the Code of Cultural Heritage. In this case, the photovoltaic installation is subject to a supervision commission evaluation by the Superintendence of Cultural Heritage. Besides, a landscape assessment is also required for those solar installations in areas or buildings constrained by the Code (Legislative Decree no. 42/2004 Code of Cultural Heritage [85]). For buildings explicitly protected by Article 136 of the Code, an

assessment from a landscape point of view is required to authorize the intervention. In this situation, a simplified (Annex B, D.P.R 31/2017 [43]) or ordinary (art. 146, Legislative Decree 42/2004 [85]) landscape authorization is required. For other types of interventions, a landscape authorization (Annex A) is not required if the solar system has the same orientation and tilt of the roof and if it is not visible from public spaces. In the figure below (Figure 2), the authorization procedure for solar systems in Italy has been summarized and refers to all buildings.



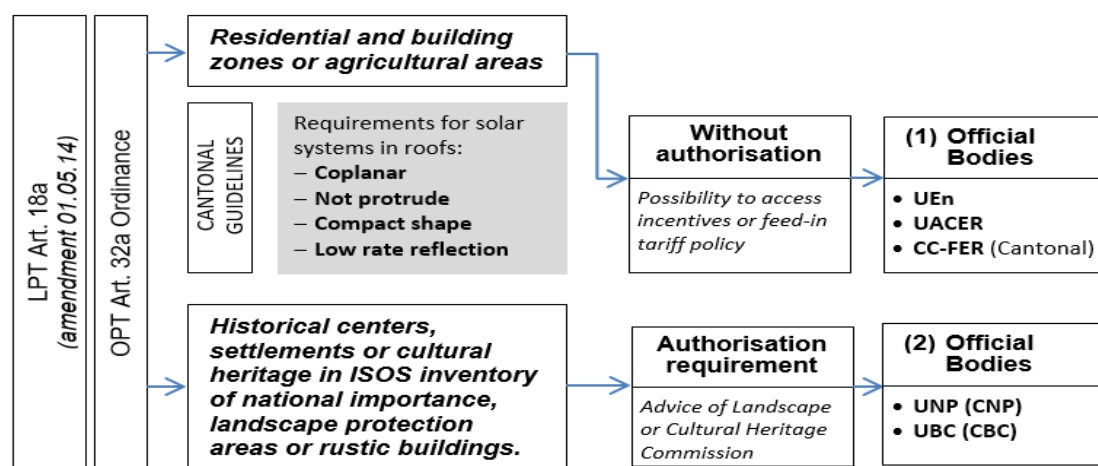
**Figure 2.** Authorization procedure for solar systems in Italy, referring to the two legislative regimes: building and landscape. The requirement criteria for rooftop solar systems extrapolated from the provisions and recommendations identified by MIBACT are also reported in the figure.

### 3.1.2. Switzerland

Following the energy transition, Swiss energy policy “Energy Strategy 2050”, since 2012, has aimed to encourage the integration of new technological systems and solar renewables in both new and existing buildings. It is part of the fundamental pillars to reduce the environmental impact produced by the building sector, recognized as one of the sectors most responsible for primary energy consumption [89,90]. Recently, the post-2020 climate policy of Switzerland’s government and parliament has considered revising the CO<sub>2</sub> Law (CO<sub>2</sub> Act, Act 641.71) to extend the key climate protection instruments. The version in force and the 2020 Ordinance 641.711 [91,92] have been amended to cover the period post 1.1.2020 to include extraordinary credits for: the energy efficiency incentive program, the production and distribution of energy from indigenous RES, the conversion of fossil fuels and the promotion of continuous training, awareness raising and consulting in the energy sector.

The amendment of the federal energy law LEn [93], at regional level Len [94], aims to adapt the legal basis of the Cantonal Energy Plan (PEC) [95]. The Spatial Planning Act (SPA) regulates the authorization of solar systems in construction and agricultural areas. According to Article 18 bis of the SPA -18a of the LPT [44] and the relative spatial planning ordinance OPT [45] for solar systems that are carefully integrated into the roof or facade of a building, a notification to the competent authorities is sufficient in place of a building permit. Monuments and historic buildings of cantonal or national importance remain subject to the authorization requirement, according to the amendment to the Building Act Implementing Regulations (RLE) [96].

Landscape assessment in historical centers and protected areas is referred to the advice of the Landscape Commission (CNP) of the Office of nature and landscape of the Department of the Territory (UNP). In protected buildings or cultural heritage listed in the Federal Inventory of Heritage Sites (ISOS), the Cultural Heritage Commission of the Cultural Heritage Office (UBC) gives the evaluation of restoration projects, solar plant integration and protection policy. A simple notification (art. 22 of the LPT [44]) is enough for installations in building zones designated by the cantonal law where the aesthetic aspect is less important, and it is the same in agricultural zones. Furthermore, article 32a of the Ordinance OPT [45] identifies the binding criteria for solar systems. It establishes a 20 cm limit on the allowed orthogonal projection with respect to the roof surface, while it does not allow any projection of the solar system in the frontal part of the elevation (main facade). It is therefore identified that some caution must be exercised regarding the maintenance of the lines of the building and the desire to preserve the original geometry of the architectural artifact, as well as the need to return a compact view of the surface involved. The ordinance considers appropriate a low reflection rate of the integrated panels, without providing specific reference percentages, but it is limited to considering the state of the art. Figure 3 summarizes the authorization procedure for solar systems in Switzerland (e.g., Ticino Canton).



#### EXAMPLE OF PROCEDURE FOR CANTON OF TICINO

(1) For the request of federal incentives, the reference bodies are the Office of Energy (UEn) and the Cantonal Office of Air, Climate and Renewable Energy (UACER) and for those at cantonal level it is the Advisory Commission of Renewable energy fund FER (CC-FER).

(2) For landscape assessment in historical centers and protected areas is referred to the advice of the Landscape Commission (CNP), of the Office of nature and landscape of the Department of the Territory (UNP). In protected buildings or cultural heritage listed in ISOS inventory, the Cultural Heritage Commission (CBC) of the Cultural Heritage Office (UBC) gives the evaluation on restoration projects, solar plants integration and protection policy.

**Figure 3.** Implementation scheme and authorization procedure for the installation of solar systems (example of Canton Ticino is presented).

The following table (Table 1) summarizes the main criteria applied to solar systems when integrated in buildings, extrapolated from the legislation in force both in Italy and in Switzerland, as previously indicated. The aspects linked to the authorization procedures by each country have been summarized in the table. Differences and main findings have been highlighted in the comments.

**Table 1.** Criteria identified by the individual provisions on regulatory documents in force (Italy and Switzerland) and evidence related to the authorization process.

Italy	Switzerland	Identified Criteria
Regulatory framework		<ul style="list-style-type: none"> <li>➤ <b>Coplanarity:</b> same orientation and inclination of the pitch.</li> <li>➤ <b>Visibility:</b> the solar system must not be visible from public spaces (no authorization).</li> <li>➤ <b>Respect of the eaves line:</b> the solar module must not exceed the upper edge of the tiles by more than its thickness.</li> <li>➤ <b>Respect the geometry of the pitch:</b> the position of the modules must respect the lines of the pitch.</li> <li>➤ <b>Compactness:</b> limiting as much as possible the space between the external perimeter of solar modules and the existing roof.</li> <li>➤ <b>Reflection rate:</b> low reflection from solar panels.</li> <li>➤ <b>Grouping/Compactness:</b> panels arranged in a sequence and by rows.</li> </ul>
D.lgs 28/2011 annex 3, Art. 11 [42] GSE [86]-D.P.R 31/2017 [43]	OPT, art.32a [45]	
Criteria identified		
- Coplanarity - Visibility - Respect of the eaves line - Respect the pitch geometry - Compactness of the modules	- Respect for lines/visibility - Low reflection rate - Grouping/compactness	
Authorization process		
D.lgs 28/2011-Art.4 [42] GSE [86]. - <i>Simplified Enabling Procedure (PAS)</i> - <i>Communication to the Municipality</i> D.P.R 31/2017 [43] Annex A: <i>Landscape authorization</i> Annex B: <i>No landscape authorization</i> Legislative Decree no. 42/2004 [85] Art. 146, <i>simplified landscape authorization</i>	LPT (SPA) [44] - Art.18a - Art. 22 - Art. 23 RLE [96] - Art. 4 par. h, <i>work subject to building license</i>	

Comments: the criteria identified agree to respect the figural integrity of the architectural feature. Only in the Ticino provisions is the criterion of low reflection rate of the solar panels taken into account in order to reduce the aesthetic impact on the building. The remaining criteria are identified in both legislations, although with different nomenclature. Regarding the authorization process, the Italian authorization system distinguishes two different regimes to which the integration of photovoltaic systems must be submitted, providing an assessment of the impact on the landscape, which is not found, on the other hand, in the Ticino authorization process. In fact, the Ticino building regulation (RLE) only specifies the obligation of a building permit. However, the Landscape Commission (CNP) is involved in the assessment.

### 3.2. Part 2—Reference IT-CH Not-Binding and Guidance Documents—Recommendations and Guidelines

In addition to the legislative system that has precise provisions regarding the integration of solar systems, the research further considers indications (voluntary) provided by national and regional guidelines. As mentioned previously, this paper focuses on the cross-border territories that are involved in the Interreg V-A Italy Switzerland project. The aim is to find a univocal approach in defining future guidelines for the integration of solar systems based on common criteria that operate to give a landscape cultural continuity. Other authors have already mentioned the importance of these guidelines and documents in their respective countries [50,54,97].

#### 3.2.1. Italy—MiBACT, Guidelines for the Improvement of Energy Efficiency in Cultural Heritage

The text provided by the Ministry of Heritage and Cultural Activities and Tourism, MiBACT “Guidelines for the improvement of energy efficiency in cultural heritage”, 2015 [46], expressly manifests the absence of a specific reflection either on the relationship between restoration and technological plants, or with reference to the comfort performance expected from ancient buildings. This is because, very often, technological systems and plans risk compromising the identity of the building and its context. Two key concepts are considered in the field of structural consolidation: “adaptation” and “improvement”. The concept “adaptation” is understood as compliance with the standards and prescriptions of current legislation, while “improvement” is interpreted as the adequate quality of performance in bringing modern standards of safety, accessibility and environmental comfort closer. In this guideline, expected “improvements” during a retrofit project are based on the following aspects: (1) operating principle; (2) applicability of the solution; (3) advantages and disadvantages (risks) and (4) synergies and interactions of the technical-functional

behavior of the individual elements in relation to the overall behavior from a systemic point of view.

Then, the type of intervention carried out is considered, referring to the geometric–spatial alteration that the elements of the intervention carry out with respect to the envelope that are mainly: (a) surface adaptation without altering the lines of the building (i.e., volumetric integration); (b) when volumetric changes are made to the building. Finally, each intervention is evaluated according to levels of feasibility (low, medium, high) based on the following criteria, which refer to the functional, aesthetic and constructive impacts:

- compatibility;
- reversibility;
- non-invasiveness.

MiBACT Guidelines proposed not-binding criteria in relation to energy retrofit intervention and the integration of solar energy, specifically photovoltaics. The first criteria identified are coplanarity and non-visibility. The document, when referring to solar photovoltaic energy in historical buildings, suggests the use of adjoining buildings if possible (i.e., it is always desirable to relocate the production of photovoltaic energy outside historic centers) [46] (pp. 148–149). Furthermore, the text underlines as visually critical aspects the chromatic alteration of the architectural surfaces and the possible alteration of the landscape. Now there are PV elements on the market that allow a better integration of photovoltaic elements with surrounding surfaces. Besides, the MiBACT text [46] (pp. 148–149) suggests the use of integrated solutions; above the eaves line, an arrangement of the panels in a continuous strip, along the entire length of the roof or possibly covering the entire pitch with the best exposure. The use of compatible colour solutions for the surface of the panels is encouraged. These aspects refer to compactness and non-invasiveness, and consider the perceptual alteration criteria (colour, material and shape). Other criteria such as reversibility and non-invasiveness are clearly specified in the MiBACT text, which explicitly invites reference to the subject of restoration and thus consideration of the two principles previously mentioned [46] (p. 147).

### 3.2.2. Switzerland—Ticino Cantonal Guidelines

The document “Interventions in historical cores. Criteria for landscape assessment within the framework of the building procedure” (2016) [47], drawn up by the Office for Nature and Landscape and the Landscape Commission, describes the value of historical assets and defines the assessment criteria for transformations and the methods of intervention. It aims to clarify the concepts considered fundamental within the framework of an intervention in a historic settlement, concepts that are translated into the criteria with which notifications and building applications are examined.

Similar criteria were found in different guidance documents in other regions of Switzerland (in-depth information can be found at the Swiss BIPV Competence Center web page [98]).

The following table (Table 2) summarizes the main recommendations applied to solar systems, when integrated in buildings in historical city cores or in historical buildings considered in non-binding reference documents used for guidance and consultation, in the countries being compared.

The document states that: “The solar system on the roof is considered admissible if it is coplanar, protrudes by a maximum of 20 cm, the shape is compact and rectangular, of an appropriate colour and appears without visible connections or pipes”. The assessment of the integration of interventions in the landscape must be based on clear and explicit criteria, which are an essential prerequisite to ensure coherence and unity of judgement, and guarantee a clear way forward for planners, developers and public bodies. The basic concept of the “case-by-case” approach remains, given the specificity that can be found in every project. This implies that it is impossible to set rigid criteria of judgement or design impositions. The installation of solar panels must be carefully evaluated, and it must be considered also if the roof is very visible and prominent from an external view,

in a privileged position in the landscape or if it is very visible from a public space which constitutes an important scenography.

**Table 2.** The panel summarizes the references cited in the text and makes explicit the recommendations identified in the reference guidelines. The five points of restoration are also given.

Italy	Switzerland	Identified Criteria
Recommendations		➤ <b>Coplanarity:</b> same orientation and inclination of the pitch.
MiBACT [46]	Ticino Guidelines [47]	➤ <b>Grouping:</b> panels arranged in sequence and by rows.
Criteria identified		➤ <b>Respect of lines:</b> no geometric alteration of the surface.
		➤ <b>Perceptual alteration:</b> no aesthetic alteration such as colour, material and shape.
- Coplanarity		➤ <b>Reversibility:</b> ability to restore the condition prior of the intervention.
- Grouping		➤ <b>Non-invasiveness:</b> not to alter the constructive, functional and aesthetic aspects of historic matter.
- Respect of the eaves line	- Coplanarity	➤ <b>No protrusion:</b> the same as respecting the lines.
- Perceptual alteration: colour, material and shape	- No protrusion	➤ <b>Compact shape:</b> the same as grouping.
- Reversibility	- Compact shape	➤ <b>Low reflection:</b> reflected light from solar panels.
- Non- invasiveness	- Low reflection	

Comments: The text provided by MIBACT offers an overview of examples and a graphic evaluation of the interventions through graphic cards. The reading of the text refers to the principles of restoration and minimum intervention, with a view to improving the energy performance of buildings. Some criteria were only found in Swiss guidelines (Ticino Guideline), for example low-reflection of solar panels. Differences will be evidenced with a text in different colour in the application of the method in following chapters. Common Restoration principles [53–55] are implied in the Italian text and, for this, they have been considered in the proposed valuation method. Ticino guidelines do not offer any method of evaluation, but share the need for a “case-by-case” approach, also identified in the Italian guidelines. The recommendations extrapolated from the guidelines will be used in the conservative assessment presented in the third part of the paper, using a unique nomenclature.

### 3.3. Part 3—European Guidance Documents—Standard EN 16883:2017

#### Europa

The ICOMOS International Scientific Committee on Energy and Sustainability [99] establishes the importance of considering a consensual and uniform approach to be implemented, given the different needs and aspects to be investigated, when intervening to improve the energy performance of historic buildings. This aims towards the preservation of cultural heritage, architectural and landscape values minimizing environmental impacts by decreasing primary energy consumption as much as possible and improving thermal, acoustic and indoor air quality and natural lighting conditions.

The procedure proposed by the European standard EN 16683/2017 [41], for the selection of measures to improve the energy performance in historic buildings, is based on the investigation, analysis and documentation of the building, including its importance as a cultural asset. This standard considers the application of some criteria identified based on this survey, not only to buildings officially recognized as “cultural heritage”, but extends to the entire historical heritage. A willingness by the EU is perceived to broaden its horizons, allowing major interventions on historical buildings aimed at the correct integration of technological elements; with a more aware and less discriminatory approach, even towards those buildings not directly protected by law, but that still participate in shaping urban identity. Retrofit interventions are evaluated in relation to the risk and as a function of the impact and compatibility of these measures on building conservation, following a colour criterion from red (high risk) to green (high benefit).

As mentioned before, the group of experts of the International Energy Agency IEA-SHC Task59 is currently in the process of adapting and reviewing the standard that benefits from a large international network of researchers and practitioners working in the field of sustainability and heritage. A collaborative group of experts verifies the assessment criteria for the various energy retrofit interventions possible (e.g., window interventions, HVAC systems, solar renewables, and retrofit strategies). Experts from the “solar energy” working group are focused on adapting the standard of compatible solar technical solutions in historic buildings. All assessment categories of the standard have been analyzed, defining a scheme for assessing risks and benefits related to the installation of solar energy

systems in historic buildings and conservation areas. For this reason, and in line with the study addressed by IEA-SHC Task59 solar group, the evaluation method presented in this paper then divided the identified criteria into three main categories, summarized in Table 3: (1) technical/constructive compatibility; (2) aesthetic compatibility; (3) energy/functional compatibility.

**Table 3.** Evaluation criteria identified and implicit in the study of the EN 16883/2017 standard.

EN 16883/2017 [41]	Identified Criteria
Recommendations	<p><b>Material:</b> the solar panels respect the historical material in their construction, functional and technological</p> <p><b>Fixing System:</b> mechanical structural requirements and safe operating conditions</p> <p><b>Reversibility:</b> the possibility of restoring the pre-intervention condition, considering anchoring and fixing materials</p> <p><b>Colour:</b> the colour of the photovoltaic surface in relation to the building and the context</p> <p><b>Texture/material:</b> referred the pattern and transparency of the photovoltaic cells</p> <p><b>Spatial geometry alteration:</b> it refers the size and the respectful the lines of the building</p> <p><b>Heating:</b> passive and active energy input compared to the initial performance levels of the building</p> <p><b>Shading:</b> the ability to contribute to cooling, both from the point of view of energy production and as shading element.</p> <p><b>Electricity/lighting:</b> provision of the solar system to the electricity and lighting of the building</p>
<p><b>(1) Technical/Constructive Compatibility</b></p> <ul style="list-style-type: none"> <li>- Material</li> <li>- Fixing System</li> <li>- Reversibility</li> <li>- Hygrothermal alteration</li> </ul> <p><b>(2) Aesthetic Compatibility</b></p> <ul style="list-style-type: none"> <li>- Colour</li> <li>- Texture/material</li> <li>- Spatial geometry alteration</li> </ul> <p><b>(3) Energy/functional Compatibility</b></p> <ul style="list-style-type: none"> <li>- Heating</li> <li>- Shading</li> <li>- Electricity/lighting</li> </ul>	

Most of the criteria considered in the two first categories are already considered in the analyzed documents. Indeed, the aspect of related energy/functional compatibility has been considered as a determining element in the evaluation, because these criteria are not currently observed in the analyzed regulations and guidance documents.

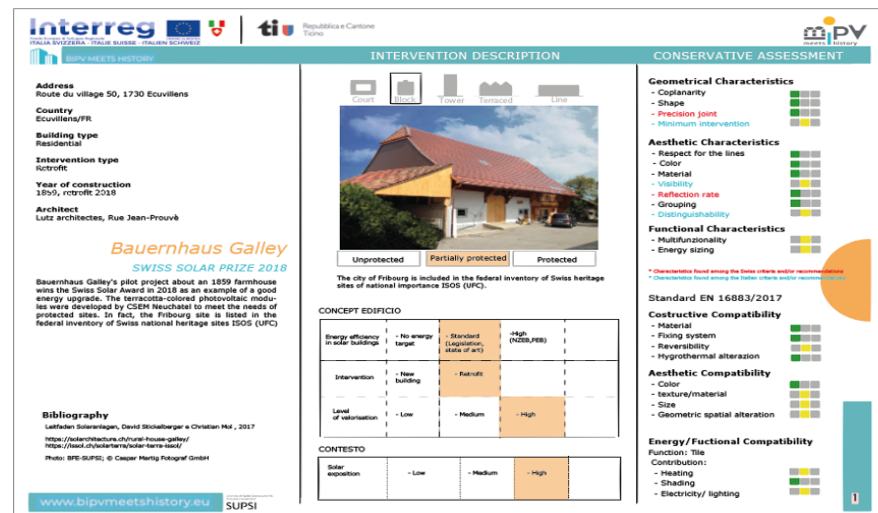
#### 4. Evaluation Schedules for BIPV Heritage Compatibility and Technical Assessment of Solar Photovoltaic Solutions of Real Case Studies

The importance of considering clear criteria in the evaluation of solar integration in historic buildings and historical settlements has already been highlighted in a recent study based on the research presented here [50]. As seen before, the exhaustive study of the rules and regulations in force and the not-binding reference documents in Italy, Switzerland and Europe just documented, show that it is possible to identify and select a certain number of criteria to evaluate the technical feasibility and compatibility of the intervention when integrating solar PV and BIPV in historical buildings. These criteria are part of the evaluation method, which will be explained in the following chapters in the evaluation of real implementation case studies. If a criterion was found only in one of the analyzed countries, it is coded with a different text colour (black, common criterion in both countries; red, criterion found only in Switzerland; blue, criterion found only in Italy).

The evaluation process starts consecutively, first from the analysis of the real case study and, thereafter, analyzing the technological system used by collecting the information in two technical schedules. Each one is divided into three fundamental parts described below and identified with an example in Figure 4 (technical assessment of case study) and Figure 5 (technical assessment of technological systems): **informative data** (building or solar technology information); **descriptive information** (solar retrofit intervention); **assessment** (criteria compatibility and energy assessment).

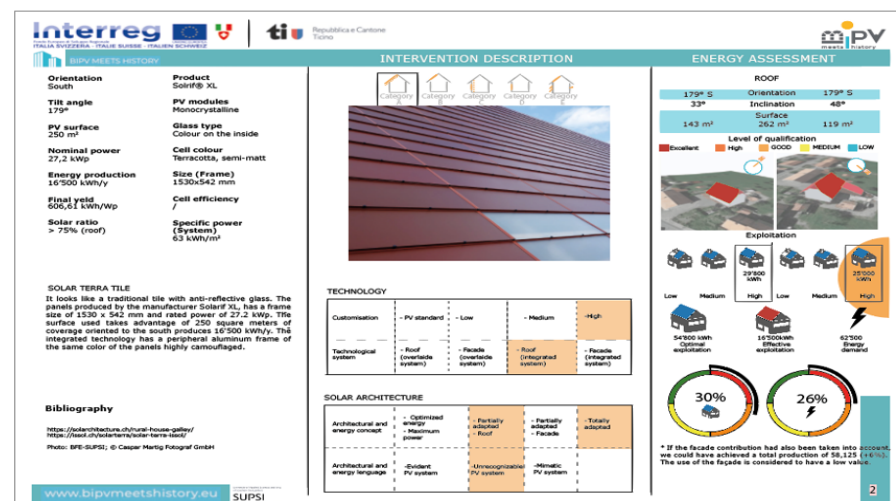
The technical schedules comprise overall information as follows:

1. Assessment of case studies—Building schedule: BIPV heritage compatibility;
2. Assessment of solar BIPV solutions—Technical schedule: BIPV functionality and energy benefits.



INFORMATION DATA	DESCRIPTION OF INTERVENTION	ASSESSMENT
Short information useful to describe the building is gathered by providing data on location, year of construction, year of retrofit and name of the designer. Furthermore, the main characteristics of the building and the context in which the intervention was carried out are described, with regard energy renovation and BIPV implementation.	This section identifies the building type according to the typological schemes of courtyard, block, row, line and the level of protection applied to the building or context with a photo of the building studied. The level of protection clarifies if there is a heritage protection regime referred to the building or the context (no protection, partial protection, under protection). The relationship between energy and conservation aspects are described in the tables describe.	This part present the proposed method for assessment of the intervention with the heritage historical values. The list presents all the criteria outlined in previous sections, through which the assessment is made. It is used a color-code scale assessment (green, yellow or red) that expresses how well the relevant criterion has been met.

Figure 4. Example of building schedule: Assessment of case studies and BIPV heritage compatibility.



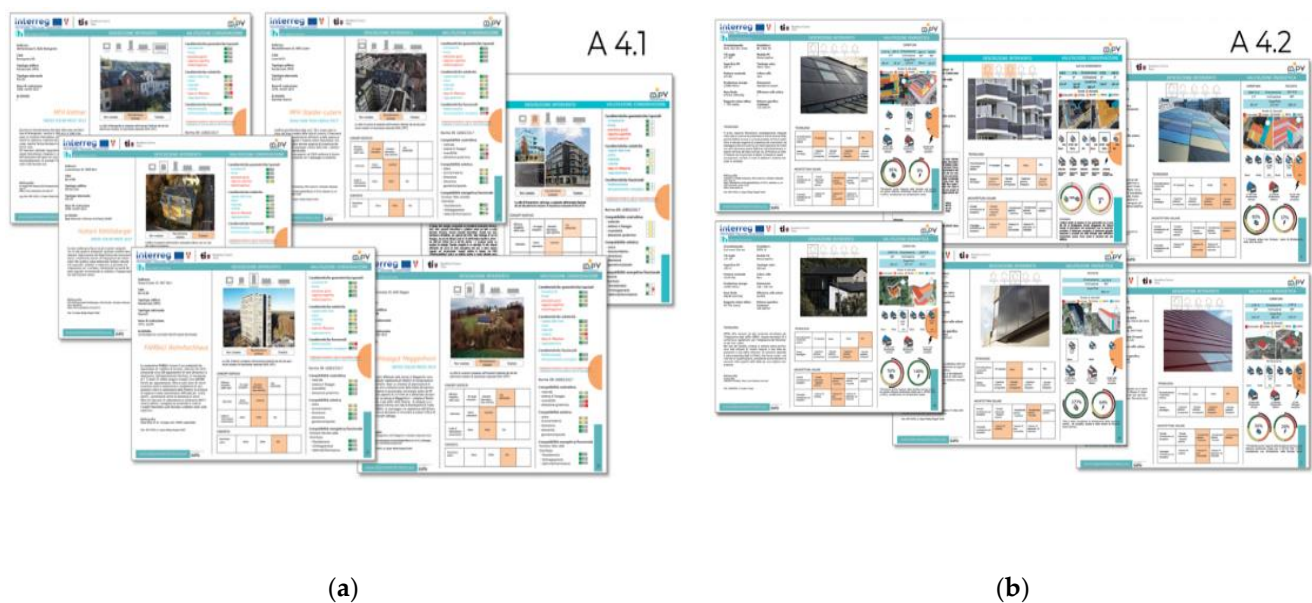
INFORMATION DATA	DESCRIPTION OF INTERVENTION	ASSESSMENT
Data concerning the energy retrofit intervention and the solar technology used are gathered. In particular, a description of the components of the integrated BIPV system is provided: information regarding the solar product installed the performance characteristics and energy yield in addition to reference data of PV manufacturer company.	The intervention description regarding solar technology and the BIPV product installed is made according to graphical icons that show the different categories of integration in the building envelope for solar systems in accordance with the definition of the specific standard for integrated photovoltaic BIPV systems, EN 50583:2016 "Photovoltaics in buildings, BIPV modules".	The energy assessment mainly concerns the BIPV solar photovoltaic system used. The assessment makes it possible to compare the energy data obtained from the retrofit intervention of the case study tackled, with the potentially solar exploitable data in the building and to verified the self-sufficient energy rate achieved after renovation.

Figure 5. Example of technical schedule: Assessment of solar BIPV solutions.



#### 4.1. Information and Description Data

The description of the intervention for each case study example studied shows the main characteristics related the solar system integration, referring respectively to the building and the BIPV technology, highlighting the level of protection applied to the building (not-protected, partially protected or listed). Many historic buildings have been studied following the methodology located in urban or rural contexts with landscape value, each with singularities and intrinsic characteristics that show different approaches to solar system integration and energy retrofits in existing buildings with historical value. The information of each historical building was gathered in the technical schedule previously explained in the building schedule (Figure 6a). Examples of different solar technologies implemented in the historical buildings analyzed were included in the BIPV technical sheet (Figure 6b) and consider different BIPV categories of possible intervention.



**Figure 6.** Collection assessment schedules elaborated applying the proposed methodology: (a) building sheet; (b) technical BIPV sheet.

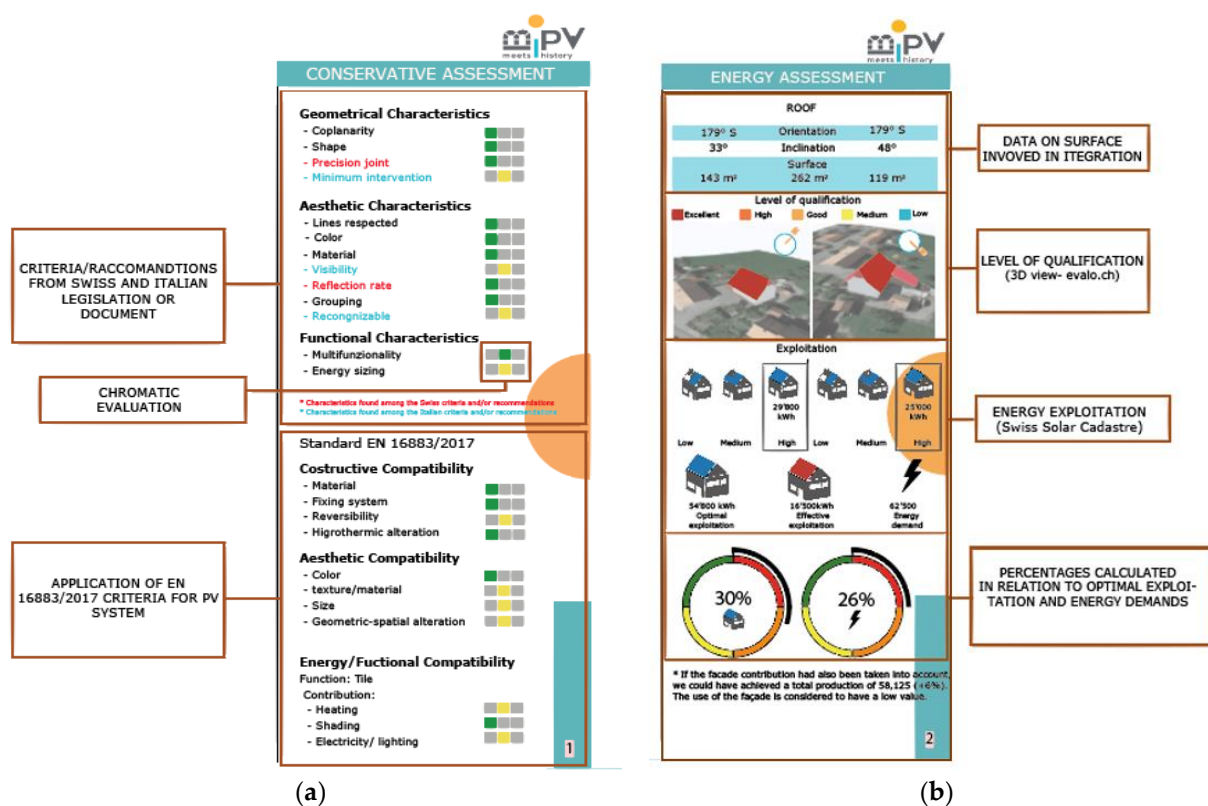
The buildings studied are representative of different architectural archetypes identified with five typological schemes: 1. Courtyard buildings: closed around a courtyard; 2. Block building: isolated multi-family or single buildings; 3. Tower buildings: with more than three floors; 4. Terraced buildings: referring to several buildings' units; 5. Line building: with a horizontal spatial development. The solar technologies are also representative of multiple integration options (e.g., roof, façade accessory elements such as shading devices, balconies, awnings or canopies). For this reason, solar technology and the BIPV product categorization, is made according to the definition of the specific standard for integrated photovoltaic BIPV systems, EN 50583:2016 "Photovoltaics in buildings, BIPV modules" [100]. This standard identifies five categories of possible intervention: (A) roof integration not accessible; (B) roof integration accessible from inside the building; (C) vertical installation not accessible; (D) vertical installation but accessible from inside the building and E) accessory elements, integrated externally.

#### 4.2. Assessment

In the structure of the technical sheets (building and technological), the third area in the cards contains the proposed assessment method with which to analyze the compatibility of the retrofit intervention carried out using the integrated solar systems.

#### 4.2.1. Assessment of Case Studies

The assessment of case studies, in the “building schedule” (Figure 7a), gathers first the criteria, previously identified in the area of study based on not-binding or guidance documents through an overview of European, Italian and Swiss regulations to check the quality of the intervention from the point of view of conservation, in a way that is respectful of the historical asset. The evaluation is based on a colour code scale which evaluates according to the worst (red) or best (green) compatibility with the analyzed criterion, in the same vein as the colour scale introduced in the standard EN 16883/2017 for the risk evaluation of interventions. The text in red refers to those criteria identified only in Swiss regulations or guidelines, those in blue belong to Italian regulations or guidelines, while black text refers to common criteria for both countries. The assessment of each criterion is based on a three-level colour scale (green, yellow and red) which identifies the degree of consistency met by the criterion/recommendation, according to its definition in the tables.



**Figure 7.** Assessment of case studies and solar BIPV solutions in technical schedules: (a) Building sheet, BIPV heritage compatibility; (b) Technical sheet: BIPV functionality and energy benefits.

In particular it is clarified that:

- Green colour: the criteria/recommendations respect the reference definition;
- Yellow colour: assigned if the reference criteria/recommendations have been partially fulfilled;
- Red colour: the reference criteria/recommendations do not meet any of the aspects of the provisions/guidelines.

This assessment method has been applied previously in other studies that deal with energy efficiency in historic buildings and that consider the integration of solar systems [17–19,79,101]. In particular, in the documents [17,18,101], the same colour scale refers to the level of feasibility of the intervention applied to general criteria and states the need to consider specific aspects of the case, identified by this research. Also, the LESO-QVS approach [19,79] to assess the visual impact of solar systems in urban environments uses

the same colour scale with three levels of coherence that evaluate the qualitative aspects of the photovoltaic integration intervention. The assessments have been done according to the level of coherence of the solar technology with respect to three global sets of integration criteria (system geometry, system materiality and modular pattern), using a three-level colour scale (green: fully coherent; yellow: partially coherent; red: not coherent).

#### 4.2.2. Assessment of Solar BIPV Solutions

The assessment of solar BIPV solutions in the “BIPV technical schedule” (Figure 7b) foresees an energy evaluation of solar technologies by using specific tools that provide the solar exploitation potentials compared to energy production data related the BIPV technology of the buildings analyzed (circle on the left, in Figure 7b, which represents the solar potential actually used). Furthermore, it is possible to know the actual contribution of the solar system to building energy needs (circle to the right in Figure 7b). In Switzerland, the data of exploitable solar potential in a building is provided by the solar cadaster. The Swiss solar cadaster [102] is one of the most advanced tools, covering the country to estimate the theoretical potential for solar energy applications on roofs and façades of buildings, and recent studies demonstrate the potentialities of this tool [103]. In the sheet, the data concerning the surfaces involved in the integration (façade/roof) are reported.

It includes a 3D view of the building under examination obtained through consultation of the evalo.ch website, an analysis tool for energetic renovation [104] and indicating the degree of suitability of the reference surfaces according to the solar cadaster data, as illustrated in Figure 7b. This analysis aims to make clear and intuitive the actual exploitation of the usable solar potential and the contribution of the solar system to the overall energy efficiency of the building. It considers the possible benefits from an energy point of view while respecting the historical and cultural character of the object of the intervention. The first circle in Figure 7b shows that usable solar potential, which in this case corresponds to 30% of the optimal value for the available surface area considered. Furthermore, the contribution of the solar system to the overall energy efficiency of the building corresponds to 26% of the energy demand (graphically shown in the second circle). In addition, further exploiting of other suitable surfaces is assumed to increase total yield and theoretically evaluate the feasibility of their use.

The percentages refer to the contribution of the calculation of the optimal exploitation offered by the Swiss solar cadaster and the percentage of the real energy demand of the building found in bibliographic texts and information gathered. The solar cadaster tool is only active in Switzerland. In order to allow a possible calculation method for other examples in other territories, the methodology proposed by the Swiss Solar Cadaster is summarized below, which calculates the solar potential using the following rule (BFE, 2016) [102]:

$$\text{Solar potential [kWh/y]} = \text{SL [m}^2\text{]} \times \text{IRR}_{\text{MED}} \cdot [\text{kWh/m}^2 \text{ y}] \varepsilon \times \text{PR [kWh/y]} \quad (1)$$

where:

SL: gross value of the façade/roof area obtained from swissBUILDINGS3D 2.0;

IRR<sub>MED</sub>: value of the annual average solar radiation on the façade/roof;

ε = module efficiency, taken as 17% [102];

PR = performance ratio, considered at 80% [102].

The solar cadaster tool appears to be a rather convenient tool for untrained users and makes it relatively simple to obtain data results. This kind of analysis is useful in those countries where a solar mapping system (solar cadaster) makes a complete and individualized building-by-building solar analysis possible [105,106]. A more accurate PV analysis requires tools for the calculation of PV systems [107–109] like PVGIS or PVsyst, developed by the University of Geneva.

An example of application in two real cases (historical buildings) of the assessment methodology proposed, both of the relative part of the integration of the solar system in the
















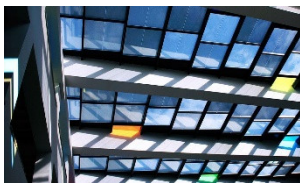
building (building schedule) and of the energetic evaluation of the solar system (technical schedule) is shown below in the results.

## 5. Results

### 5.1. Building Information and Description—Analysis of Results

The evaluation method proposed, as indicated in the introduction, served to assess the BIPV intervention in several case studies in Switzerland and in Europe (Table 4).

**Table 4.** Some examples of the case studies studied in Switzerland (lines 1–3) and Europe (lines 4–6). Correspondence with building types (1 to 5) and identification of BIPV solar system implemented (A to E) is shown from right to left.

Overview of Investigated Case Studies in Switzerland and Europe				
Switzerland				
				(a) Rural building Galley (FR, CH): A-2, photo © solaragentur.ch; (b) Rural building Glaserhaus (BE, CH): A-2, photo © C. Martig; (c) SFH Hütterli Rothlisberger (BE, CH): A-2, photo © C. Martig; (d) Industrial building Solar Silo (BS, CH): A-2 and C-2, photo M. Zeller.
				(e) Hôtel des Associations (NE, CH): A-3, photo © C. Martig; (f) Villa Carlotta (TI, CH): A-2, photo © 3S Solar Plus and BE Netz AG; (g) MFH Kettner (AG, CH): A-5, photo © C. Martig; (h) MFH Sanierung Viriden (TG, CH): A-2 and E-3, photo: © Viridén + Partner AG, Zürich.
Europe and Italy				
				(a) Multi-family house MFH Appiano (IT): A-4, photo: © EURAC; (b) Doria Castle, Porto Venere (IT): E-5, photo: © PVACCEPT; (c) Tourism Office, Alès (FR): C-2, photo: <a href="http://www.bipv.ch">www.bipv.ch</a> ; (d) Groenholf Castle (BE): E-2, photo: © Samyn and Partners;
				(a) Mayer Hospital, Florence (IT): D-5, photo: © CSPE (CSPE.net); (b) City Hall of Linares (ESP): B-2, photo: © Onix Solar; (c) Alzira Town Hall, Valencia (ESP): B-2, photo: © Onix Solar; (d) Béjar Market, Salamanca (ESP): B-2, © Onix Solar.

More than twenty best-case studies selected by the University of Applied Sciences and Arts of Southern Switzerland (SUPSI), located in Switzerland, and twenty-five BIPV technology solutions, were analyzed. Some of the projects present multiple integration solutions, for example, BIPV in roof or façade elements. The selected buildings are a model of best practices in energy rehabilitation of historic buildings and integration of renewable energy and solar energy, mostly recognized with the Swiss Solar Award, established by the association Solar 91 and the working group “Solar Agency Switzerland” (Solar

Agentur Schweiz). For the case studies' examples in Europe and Italy, for a total of thirteen historical buildings analyzed, further information has been gathered thanks the collaboration between the Interreg Alpine Space research project ATLAS [110] and the International Energy Agency's solar heating and cooling programs with the joint IEA-SHC Task59/IEA EBC Annex 76 projects [20]. Other information has been gathered from Swiss digital platforms on BIPV such as [www.bipv.ch](http://www.bipv.ch) (accessed on 30 April 2021) [111] and [www.solarchitecture.ch](http://www.solarchitecture.ch) (accessed on 30 April 2021) [112].

## Results

Most of the buildings analyzed date back to the period between 1800 and 1974. Some of the buildings analyzed are in a conservation-protected area (i.e., urban or rural landscape protection). There are historical buildings dating from the 1600s to the 1800s which are recently refurbished (e.g., Doragno Castle, SFH Hütterli in Switzerland, Doria Castle and Multi-family house MFH in Italy or Groenhof Castle in Belgium) and rural buildings not used or inhabited prior to being renovated (e.g., Glaserhaus or Schossgut Meggenhorn buildings). A few of the cases analyzed focused on industrial buildings or post-war buildings (for example, Solar Silo building or St. Franziskus Church). These are examples of buildings in protected areas with evidence of an industrial past or that are representative of a modern movement in architecture worthy of preservation. In these cases, the level of "transformability" could be higher, leaving room for more innovative photovoltaic solutions with coloured BIPV modules or using higher performing solar thermophotovoltaic PVT, for example. Single-family houses (SFH) with tilted roof integrated BIPV systems (category A) have proven to be the most common in the Swiss case studies analyzed (52%); examples are shown in Table 4 (e.g., rural building Galley and Glaserhaus, SFH Hütterli or Villa Carlotta building). More than half of these cases analyzed correspond to buildings with a certain degree of protection regarding both the building itself and the surrounding environment, with natural or rural landscape protection; for example, buildings classified ISOS (Swiss Heritage Sites of National Importance), as well as buildings or areas under Cantonal protection. Only few examples are representative of solar systems integrated in façade (category C, as for example Solar Silo) or accessory elements (category E, as in MFH Sanierung Viriden).

On the contrary, in Europe and Italy, there was a larger rate of BIPV technologies related to solar semitransparent solutions integrated both in façades (category C, as Mayer Hospital or Tourism Office Alès) or in skylights (category B, as in Linares or Alzira Town Halls or in the Béjar Market in Spain). However, there is a prevalence of solar integration in the roofs of single-family and multi-family houses (e.g., MFH Appiano in Italy). Almost all the cases analyzed correspond to listed or partially protected buildings. In some cases, the use of detached supports outside of the building, such as the BIPV wall in Groenhof Castle in Belgium, allows the solar system to be integrated without directly affecting the surface of the listed building. The same approach was found in the technology experimented with by the PVACCEPT research project [13], and installed in the Doria Castle, where self-lighting elements (Solar Flags) were integrated in the historical asset without altering the geometry of the building.

The comparison between buildings with different characteristics (building types, types of solar integration) and intervention approaches (e.g., in the different countries studied relating to heritage and landscape protection) on this specific topic helped the research by highlighting the need to consider the peculiarities of each case. In addition, it indicates the different ways in which it is possible to intervene in compliance with the criteria, established both in current legislation and in voluntary documents. As shown previously, in some cases, to assess the validity of the method, it was necessary to consider examples in other European countries because examples of real implementation in historic buildings for all categories were not always found in Italy or Switzerland. The methodology and criteria for determining the compatibility of the interventions would be equally useful in other countries or climate zones, but would require a deeper understanding of the specific

regulations and guiding criteria currently and, in the future, contemplated in these zones or countries.

### 5.2. Building and BIPV Assessment—Analysis of Results

An example is reported to explain how the assessment method is applied in two case studies analyzed in Switzerland: a rural building in Fribourg and a single-family house in Ticino (Tables 5 and 6). The main information gathered in the sheets regarding the description of the building (Building Description) and the solar technology used (BIPV System Description) is summarized below:

- (1) Rural building Galley, Encuivens/FR:
  - Building Description: Bauernhaus Galley's pilot project, an 1859 farmhouse, wins the Swiss Solar Award in 2018 as an example of a good energy upgrade. The terracotta-coloured photovoltaic modules were specially developed to meet the needs of protected sites. In fact, the Fribourg site is listed in the federal inventory of Swiss national heritage sites ISOS.
  - BIPV System Description: The solar technology looks like a traditional roof tile with anti-reflective glass. The panels produced by the manufacturer Solarif XL, have a nominal output of 27.2 kWp. The surface area uses 250 square meters of south-facing roofing and produces 16'500 kWh/a. A highly camouflaged aluminum frame in the same colour as the panels was used.
- (2) Single Family House, Villa Carlotta, Orselina/TI:
  - Building Description: Built in 1939, this historical villa stands on a slope above Locarno near Lake Maggiore. The retrofit interventions concern the replacement of the old heating system with a better-performing one, including a BIPV system on the roof and solar collectors with vacuum tubes in the garden to achieve a high-energy standard. The original roofing of red tiles, although in good condition, has been replaced entirely by blue photovoltaic panels with high reflection, as the building and the context are not bound by any protection by cantonal law.
  - BIPV System Description: The photovoltaic modules are blue in colour with a high reflection rate and standard size. Meyer Burger high efficiency crystalline solar cells are used with 18.2% efficiency in solar modules with maximum load capacity thanks to the tempered glass of 5 mm. The applied solution does not have supporting frames and uses three types of modules for a total of 117 active modules.

The two examples reported highlight differences between retrofit intervention and solar implementation. The first one tries to mediate between conservation and energy needs, while in the second example a higher energy contribution is preferred, which is also due to different protection levels. This type of analysis and method proposed allows for the evaluation of the BIPV technological solution used, but also considers the specific techno-functional characteristics of the solar system in relation to its integration into the historic building. The analysis considers the way in which the system is integrated (e.g., integrated roof, façade, accessory element) with reference to an internationally recognized classification.

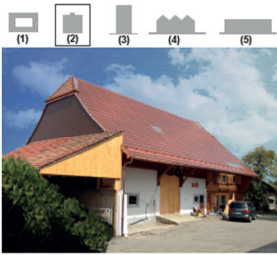
Furthermore, it shows whether high standards of energy efficiency are achieved and whether the intervention enhances the conservation of the building and its surroundings in order to maintain and preserve its character and significance. Besides, it highlights if the intervention uses an architectural language or an energetic concept that is in accordance with the unique characteristics of the building studied.

**Table 5.** Assessment method applied to two case studies in Switzerland. Common criteria in Switzerland and EU are indicated in black-text, while if found only in one of the countries under comparison (Switzerland, CH and Italy, IT) they are indicated in red (CH) or blue (IT), respectively.

**Intercomparison Results: Assessment of BIPV Heritage Compatibility—Building Sheet**

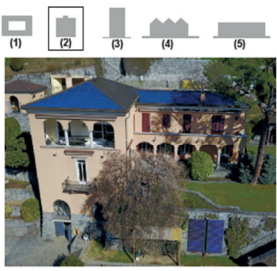
Rural Bauernhaus Galley:

The intervention meets many criteria required by current regulations and guide documents analyzed. Due to the BIPV tiles chosen, which echo the colour of the original tiles and, with a low-reflection rate, it was possible to meet the lines and the aesthetic characteristics of the building. Solar modules, although, if visible from public spaces, present a compact shape and are hardly recognizable due to the size, colour and shape chosen. However, the minimum intervention principle was not followed, as both roof pitches were used to optimize electricity production. Besides, solar technology performs constructional features, suitable to functional compatibility as a ventilation cavity underneath solar reduces steam condensation and optimizing energy yield.

INTERVENTION DESCRIPTION	ASSESSMENT	
<p>Rural Bauernhaus Galley, Ecuvullens/FR Route du Village 50, 1730</p>  <p>Unprotected <span style="border: 1px solid black; padding: 2px;">Partially protected</span> Protected</p> <p><a href="https://solararchitecture.ch/rural-house-galley/">https://solararchitecture.ch/rural-house-galley/</a></p>	<p><b>Legislation principles</b> (Legislation in force and not-bindi documents)</p> <p><b>Geometrical Characteristics</b></p> <ul style="list-style-type: none"> <li>- Coplanarity <span style="color: green;">■</span></li> <li>- Shape <span style="color: green;">■</span></li> <li>- Precision joint <span style="color: red;">■</span></li> <li>- Minimum intervention <span style="color: blue;">■</span></li> </ul> <p><b>Aesthetic Characteristics</b></p> <ul style="list-style-type: none"> <li>- Lines respected <span style="color: green;">■</span></li> <li>- Color <span style="color: green;">■</span></li> <li>- Material <span style="color: green;">■</span></li> <li>- Visibility <span style="color: blue;">■</span></li> <li>- Reflection rate <span style="color: red;">■</span></li> <li>- Grouping <span style="color: green;">■</span></li> <li>- Reconnizable <span style="color: blue;">■</span></li> </ul> <p><b>Functional Characteristics</b></p> <ul style="list-style-type: none"> <li>- Multifunctionality <span style="color: green;">■</span></li> <li>- Energy sizing <span style="color: blue;">■</span></li> </ul>	<p>Standard EN 16883-2017</p> <p><b>Costructive Compatibility</b></p> <ul style="list-style-type: none"> <li>- Material <span style="color: green;">■</span></li> <li>- Fixing System <span style="color: green;">■</span></li> <li>- Reversibility <span style="color: yellow;">■</span></li> <li>- Hygrothermal alteration <span style="color: green;">■</span></li> </ul> <p><b>Aesthetic Compatibility</b></p> <ul style="list-style-type: none"> <li>- Color <span style="color: green;">■</span></li> <li>- Texture/ material <span style="color: yellow;">■</span></li> <li>- Size <span style="color: yellow;">■</span></li> <li>- Spatial geometry alteration <span style="color: yellow;">■</span></li> </ul> <p><b>Energy/functional Compatibility</b></p> <p>Function: Tiles Contribution:</p> <ul style="list-style-type: none"> <li>- Heating <span style="color: yellow;">■</span></li> <li>- Shading <span style="color: green;">■</span></li> <li>- Electricity/lighting <span style="color: green;">■</span></li> </ul>

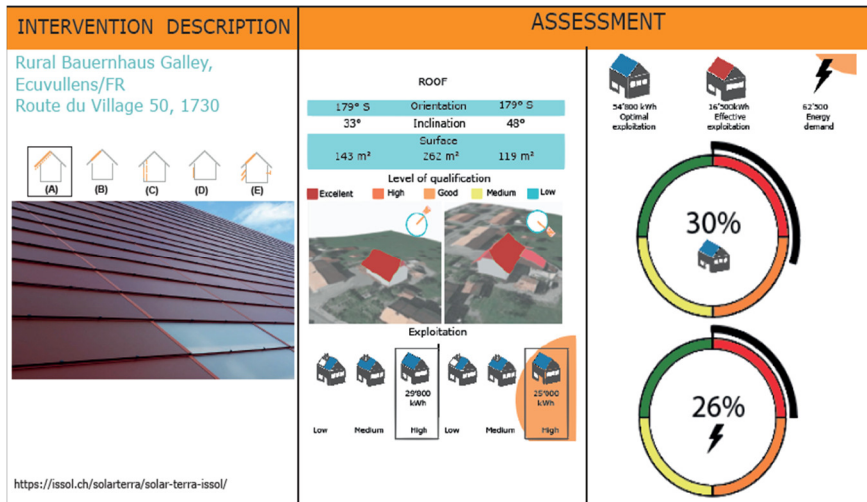
Villa Carlotta:

The evaluation indicates that not all criteria are met. The chosen solar modules have a very different colour compared to the original roof and a high reflection rate, which does not allow a good integration with the context. The principle of minimum intervention was not pursued, as all the pitches of the roof are used to optimize electricity production but maintain the roof lines. Moreover, the elements are visible from public spaces and are easily recognizable by their chosen colour and shape. On the other hand, the energy criteria are respected. Although the intervention is not suitable for conservation needs, it contributes significantly to building energy requirements.

INTERVENTION DESCRIPTION	ASSESSMENT	
<p>Villa Carlotta, Orselina/TI Via Caselle 40, 6644</p>  <p>Unprotected <span style="border: 1px solid black; padding: 2px;">Partially protected</span> Protected</p> <p><a href="https://www.swissolar.ch/">https://www.swissolar.ch/</a></p>	<p><b>Legislation principles</b> (Legislation in force and not-bindi documents)</p> <p><b>Geometrical Characteristics</b></p> <ul style="list-style-type: none"> <li>- Coplanarity <span style="color: green;">■</span></li> <li>- Shape <span style="color: green;">■</span></li> <li>- Precision joint <span style="color: red;">■</span></li> <li>- Minimum intervention <span style="color: red;">■</span></li> </ul> <p><b>Aesthetic Characteristics</b></p> <ul style="list-style-type: none"> <li>- Lines respected <span style="color: green;">■</span></li> <li>- Color <span style="color: red;">■</span></li> <li>- Material <span style="color: red;">■</span></li> <li>- Visibility <span style="color: blue;">■</span></li> <li>- Reflection rate <span style="color: red;">■</span></li> <li>- Grouping <span style="color: green;">■</span></li> <li>- Reconnizable <span style="color: red;">■</span></li> </ul> <p><b>Functional Characteristics</b></p> <ul style="list-style-type: none"> <li>- Multifunctionality <span style="color: green;">■</span></li> <li>- Energy sizing <span style="color: red;">■</span></li> </ul>	<p>Standard EN 16883-2017</p> <p><b>Costructive Compatibility</b></p> <ul style="list-style-type: none"> <li>- Material <span style="color: red;">■</span></li> <li>- Fixing System <span style="color: green;">■</span></li> <li>- Reversibility <span style="color: red;">■</span></li> <li>- Hygrothermal alteration <span style="color: green;">■</span></li> </ul> <p><b>Aesthetic Compatibility</b></p> <ul style="list-style-type: none"> <li>- Color <span style="color: red;">■</span></li> <li>- Texture/ material <span style="color: red;">■</span></li> <li>- Size <span style="color: yellow;">■</span></li> <li>- Spatial geometry alteration <span style="color: yellow;">■</span></li> </ul> <p><b>Energy/functional Compatibility</b></p> <p>Function: Tiles Contribution:</p> <ul style="list-style-type: none"> <li>- Heating <span style="color: green;">■</span></li> <li>- Shading <span style="color: green;">■</span></li> <li>- Electricity/lighting <span style="color: green;">■</span></li> </ul>

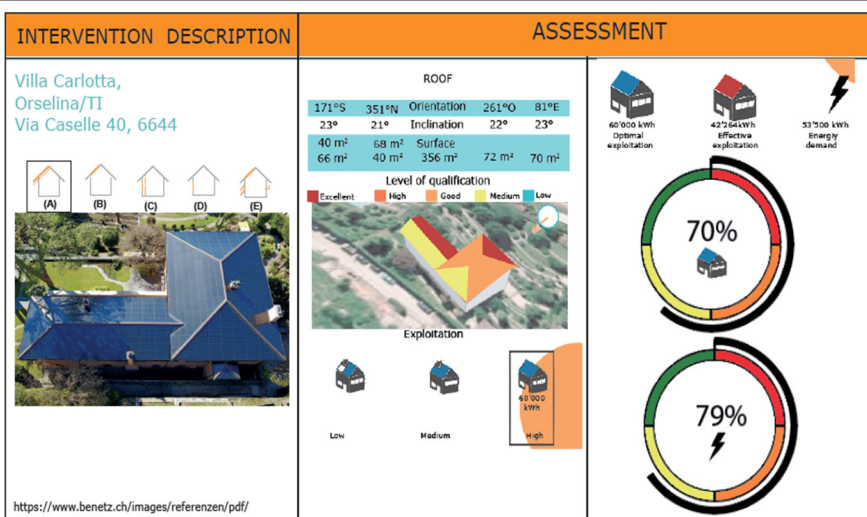
**Table 6.** Assessment evaluation related the BIPV technology used with regard to the energy performances of solar systems and the real contribution of the solar system to building energy needs.

### Intercomparison Results: Assessment of Solar BIPV Solutions—Technical Sheet



Rural Bauernhaus Galley:

The integrated BIPV system uses more than 75% of the total available roof area (262 m<sup>2</sup>). Thanks to the Swiss solar cadaster tool, it was possible to estimate a solar potential of 54,800 kWh/a. with an output of 16,500 kWh/a. Instead, the BIPV system produces only 30% of the calculated solar potential, while contributing 26% to the building's energy requirements. In this case, aesthetic and functional characteristics were prioritized with respect to the final energy performance considering a solution compatible with the historical values of the building. Due to the design and colours of the BIPV elements, it was possible to balance aesthetic and energy requirements.



Villa Carlotta:

The integrated BIPV system uses more than 75% of the total available roof area (350 m<sup>2</sup>). The Swiss solar cadaster estimated the optimum figure of 60,000 kWh/y of solar potential for the entire surface area involved. With a real energy yield output of 42,264 kWh/a, the system produces 70% of the calculated solar potential, contributing 79% of the building's energy needs. Exploiting all available roof surfaces of the building makes a significant energy contribution.

## 6. Discussion and Conclusions

The research addressed in the paper aims to select the appropriate criteria for the application of solar systems, such as BIPV technology, in historical buildings, responding to the European, national and local policies in terms of energy efficiency and protection of cultural heritage. The study focuses on the cross-border area between Switzerland and Italy, within the framework of a transborder cooperation research project between the Lombardy Region, South-Tyrol and Ticino Canton, with the aim of creating new business prospects for the integrated photovoltaic (BIPV) supply chain in the recovery of historical buildings and landscape heritage. In order to overcome the main difficulties in the diffusion of PV systems in neighboring territories with similar cultural and historical heritage, the different approaches in legislative and regulatory framework of the different countries, as well as the criteria guidelines for potential interventions, have been explored. On this basis, the identified criteria define a method for assessing the compatibility of heritage values with solar BIPV technology interventions applied to real case studies, whether in Switzerland, Italy or the rest of Europe. The assessment concerning both the case study analyzed and the BIPV technology used, serves also to check the energy benefits of the retrofitting interventions.



The main findings can be summarized as follows:

- The new BIPV technology, due to its technical and constructive characteristics, is perfectly suited to the needs of new buildings, as it is able to replace technological components of the building envelope. On the contrary, the use of the mentioned solar technology, integrated in historical buildings and contexts that have a strong identity, needs to be adapted to the needs of the built environment;
- From the synoptic comparison of Swiss and Italian legislation, in force of the non-binding documents and of the guidelines, the necessity to find a compromise between conservation and energy needs promoted by the respective territorial contexts arises. For this reason, key intervention criteria have been identified to update the existing guidelines with a common normative framework;
- The assessment method proposed and discussed underlines the importance of considering the impact that BIPV technology has on the historic building and its environment, considering three macro-categories of integration (i.e., geometric, aesthetic and functional characteristics) within which the criteria highlighted by the research have been arranged;
- Moreover, comparison with the standard EN 16883/2017 [41] confirms the need to consider the compatibility of the intervention from a point of view not only conservative or aesthetic, but also taking into account the energy aspects. The evaluation method applied to more than 35 case studies from Switzerland and Europe underlined the considerable energy contribution of BIPV systems when combined with other energy retrofit measures on the existing building envelope and facilities (e.g., internal and external insulation,
- The two examples of application of the method presented in this paper, shown in detail, represent two modes of intervention at opposite ends of the spectrum. The interventions on the rural building Galley at Fribourg attempt to mediate between conservation and energy requirements, while the Villa Carlotta building opts to optimize energy requirements as much as possible to the detriment of aesthetic and historical compatibility requirements;
- The assessment criteria applied to a broad spectrum of solar BIPV implemented in historic buildings (e.g., from listed to unlisted buildings, from rural to urban environments or conservation areas, from traditional to pre-industrial historical buildings) allow the review of different approaches, followed by interventions on a case-by-case basis, and to critically understand the motivations;
- The methodology and criteria for determining the compatibility of the interventions would be equally useful in other countries or climate zones, but would require a deeper understanding of the specific regulations and guiding criteria currently and in the future contemplated in these zones or countries. Through this analysis, it will be possible to determine the correspondence with the criteria considered in this study and whether it would be necessary to add new ones;
- The evaluation of case studies considered both the type of building (i.e., five typological schemes: 1. Courtyard buildings; 2. Blocks; 3. Towers; 4. Terraced buildings; 5. Line buildings) and different categories of possible BIPV intervention (i.e., five categories following the EN 50583:2016 standard for BIPV systems). In some cases, to assess the validity of the method, it was necessary to consider examples in other European countries because, examples of real implementation in historic buildings for all categories were not always found in Italy or Switzerland;
- Likewise, the energy assessment of the solar potential actually used by the BIPV system would prove its usefulness in those countries where a solar mapping system (solar cadastre) makes a complete and individualized building-by-building solar analysis possible, as is the case in Switzerland, Germany or Austria, for example [105,106]. Unfortunately, a more complex analysis will be required in other countries where the mentioned solar mapping tools are not well implemented. Besides, in order to

compare the results with the building's energy needs, in-depth data of the analyzed buildings have been required.

To conclude, the research presented is in line with the vision of the turnaround expressed by the President of the European Commission in the State of Union speech on 16 September, 2020 [113]. Collaboration between the experts involved in the integration of new technologies is essential for the success of the “reprogramming and rethinking action” promoted by the EU, which intends to relaunch the new European Bauhaus movement, based on sustainability, inclusiveness and aesthetics, bringing European citizens closer to renewable energy. In this process, it would be important to consider a harmonization in the sustainable development of adjoining regions and localities, especially in cross-border and neighboring territories, sometimes subject to different laws and ways of operating, as landscapes are historically related to urban territories and influences, characterized by local architecture. Thinking of renewable photovoltaic technology as a modern architectural language capable of satisfying aesthetic and energetic needs, and also integrated in the existing real state park (mostly historical buildings), is part of the European objectives and could help create a new value system in the built heritage.

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