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Towards the Energy Transition of the Building Stock with BIPV: Innovations, Gaps and Potential Steps for a Widespread Use of Multifunctional PV Components in the Building Envelope

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Abstract: The scenario that emerges from scientific research on the use of BIPV systems in architecture shows that photovoltaic technologies and systems have reached a significant development in production and installation, becoming a strategic approach in the field of energy efficiency and enabling a progressive decarbonisation of the building stock. Still, knowledge and methods of architectural integration are not fully developed, especially in Italy. The present paper reports the results of a research activity that, systematising the main criteria and indicators for assessing the integrability of BIPVs in architecture, has led to the development of BIPV Product and Case Study Catalogues that define an up-to-date state of the art on aspects of design and technological innovation using BIPV systems and components. Catalogues have been created with the objective of contributing to the growth of knowledge on the most up-to-date methods of design by implementing a 'technology transfer' from good practice, in which photovoltaic systems are an integral part of the design concept and construction techniques of the architecture. The analysis related to the production of BIPV systems and components and their application in architectural projects allows one to highlight the main critical factors in the diffusion throughout the country and to identify the main research demand arising from the specific national situation.

Keywords: BIPV; energy transition; architectural integrability

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1. Introduction

The IPCC assessment report of 2021 shows that, compared to pre-industrial levels, we are now facing an increase of about 1.1 °C in the planet's temperature and that exceeding the 1.5 °C threshold could cause an uncontrollable feedback loop, exposing ecosystems to cascading climate change [1]. The belief that adaptation and mitigation actions in the short term will influence the risks of climate change throughout the 21st century raises important decisions for governments and communities [2]. By far the most prevalent objective across the technical policy spectrum leads to the transition to a carbon-neutral society: an important possibility is offered by renewable energies that are rapidly entering the market as a primary source and, in particular, by the photovoltaic sector, which may experience a second generation compared to the early 2000s. Over the last ten years, research on photovoltaic systems has focused, among other things, on performance enhancement, integration of renewables energies, solar cells [3]. Recent studies show that in most markets, renewable sources of energy such as wind and solar PV now represent the cheapest available source of new electricity generation, and clean energy technology is becoming a major new area for investment and employment and a dynamic arena for international collaboration and competition [4]. Among the renewable energy sources with the greatest potential for growth is electrical energy produced by photovoltaic systems, which has grown from 2.6 GW in 2004 to 227 GW in 2015, with a very strong reduction in prices and with the plus of providing energy that can be used immediately without transmission costs, enabling de facto grid parity [5].

A significant achievement is the reduction in the average generation cost of photovoltaic solar power, which has fallen by 80% since 2009 thanks to advances in material science and technology. In the coming years, it will be possible to rely on a cost that is gradually lower and, above all, not exposed to the volatility that characterises the costs of hydrocarbon and gas energy sources. Estimating that photovoltaics now account for more than 60% of the world's renewable electricity generation, one can see how progressive its expansion will inevitably have to be, especially if one compares the approximately 160 GW of renewable generation capacity in 2017 with the estimated 300 GW per year in 2040, when the share of renewables in the world energy mix will be more than 60% [6].

The growth in energy demand in the future will be linked to the increase in population, which is expected to reach 9 billion on a global scale by 2050, with around 2/3 of the population living in megacities and densely populated cities. Buildings will become central in terms of both the production of materials and components, and life cycle management in air conditioning, artificial lighting and the use of household appliances. This is expected to lead to a 1/3 increase in primary energy demand and 50% increase in electricity consumption by 2040.

Estimates of electricity needs for air conditioning in buildings will cover at least 65% by 2050 and this will be coupled with increased efficiency and improved thermo-hygrometric performance. The increased drive for electrification to achieve the appropriate levels of carbon neutrality by 2030 will inevitably push for a strong increase in electrification supported by renewable energy from photovoltaics. This scenario needs to be supported by the digitisation of the sector with smart grids increasingly enabling the penetration of renewables and PV, in particular, through smart meters and distributed generation aggregation platforms with active demand for storage facilities [6].

Buildings will increasingly represent—in Rifkin's words—the 'semi-permeable membrane' for storing energy, cells of a large technological organism linking many communities collectively engaged in complex economic, social and political relationships [7]. Hub-buildings, conceived as micro-energy plants, will have to be incorporated into an electricity grid equipped with storage technology to provide continuity to the flow of intermittent electricity by balancing peak loads: this can only be done with digital connectivity, as 'thus the distributed smart electricity infrastructure will enable previously passive electricity consumers to become active managers of their own green electricity' [7].

Building Integrated Photovoltaics (BIPV) fully responds to innovative ways of interpreting energy, sustainability, distributed and renewable production, as well as focusing on reducing energy needs and sharing energy and energy-related data [8]. From being an experimental field and linked to a technical and cultural niche issue, building-integrated photovoltaic systems could be one of the most dynamic and innovative building sectors within the more general framework of replacing fossil fuels with renewables.

The scenario that emerges from scientific research on the use of BIPV systems in architecture shows that photovoltaic technologies and systems have reached a significant level of development in production and installation, but that the knowledge and methods of architectural integration are still not well developed, particularly in Italy. The concept of Building Integrated Photovoltaic (BIPV) encompasses all photovoltaic technologies designed to be applied to buildings as integrated technical systems within the building envelope. The diffusion of such systems becomes strategic not only in the field of energy efficiency of buildings but represents an opportunity for new scenarios related to the progressive reduction of CO_2 emissions. The need to mitigate the causes of climate change impacts, now recognised by the international scientific community as a non-reversible threat, calls for the development of correlation scenarios between the widespread integration of PV in existing buildings, the experimentation of nZEB—nearly Zero Energy Buildings—and the implementation of the programmes foreseen by the climate-energy plans, including the 2030 Agenda.

Given this background, the research demand for BIPV in the framework of the project at the building scale moves from the implications induced by the evolution of technical policy and operating conditions in view of the new ecological and environmental challenges. These implications require an architectural design, in its conception and technological design components, capable of appropriately managing the levels of technical information, technical-operational feasibility and execution aimed at maximising photovoltaic production through the optimisation of PV surfaces and system performance.

Assuming that the use of innovative BIPV products and systems has implications not only for the construction process but also for the project design, its spatial qualification and its morphological and linguistic-expressive outcomes, the paper presents the results of the first phase of a research activity in which the main outcomes have been BIPV product Catalogues and case studies, developed with the aim of contributing to the growth of knowledge on the most up-to-date project methods by implementing a 'technology transfer' from good practice, where PV systems are an integral part of the design concept and construction techniques of architecture.

The catalogues consist of product and project sheets in digital format. At the end of the research activity, a digital database will be available for free consultation within the publication of the research reports. The sheets have been structured with blocks of information on the main technological and energy aspects in order to facilitate a comparative reading of the key information and guide professionals to the choice of BIPV systems in new or retrofit projects. In particular, the catalogues analyse aspects of architectural integrability and evaluate them through specific criteria and indicators with the aim of highlighting the coherence and morphological and technological suitability of multifunctional photovoltaic systems for building project qualities. The elaboration of the catalogues and the comparative reading of the results also provided an up-to-date picture of the national production situation, and of the use of BIPV in design practice in Italy and Europe, stimulating a consideration of the main critical factors in its diffusion on a large scale.

2. Research Methodology for the Development of BIPV Product and Project Catalogues

The research methodology included a strong correlation between knowledge about the production of BIPV systems, case studies of design experiences in Europe, design support tools with technical information, critical success factors, as well as compliance with defined targets in relation to architectural integration, considering several factors, from energy efficiency to safety and other classes of requirements.

The research activity was carried out in two phases (Figure 1), as follows:

- A first analytical-knowledge phase concerned the definition of an updated state of the art on the aspects of design and technological innovation implemented using BIPV systems and components. In this phase, the main European research experiences at the building scale have been examined, analysing with a critical approach the main outcomes referable to project and product databases.
- in the second synthetic-comparative phase of the research, based on a comparison with the scientific literature on the subject, the main criteria and indicators recurrently used to evaluate the integrability of BIPVs in architecture were systematised.

These steps led to the development of two research products:

- BIPV Product Catalogue. The catalogue gathers the industrial offer of BIPV systems and components on the Italian market, representative of specific types of products with information on their performance and architectural integration characteristics, using a system of indicators to highlight the application advantages and performance gains offered.
- BIPV Case Study catalogue. The catalogue of national and international 'exemplary' design references contains successful examples in terms of the integration of BIPV into the building design concept and the results achieved in terms of architectural integrability, transferability of good practices and contributions to the reduction of energy requirements and environmental impacts; The catalogue is divided into fact

sheets on BIPV integration 'success stories' (150 fact sheets, of which 60 refer to national examples and 90 to European examples) and analytical fact sheets on 'good practices' (30 fact sheets, of which 15 refer to national examples and 15 to European examples).

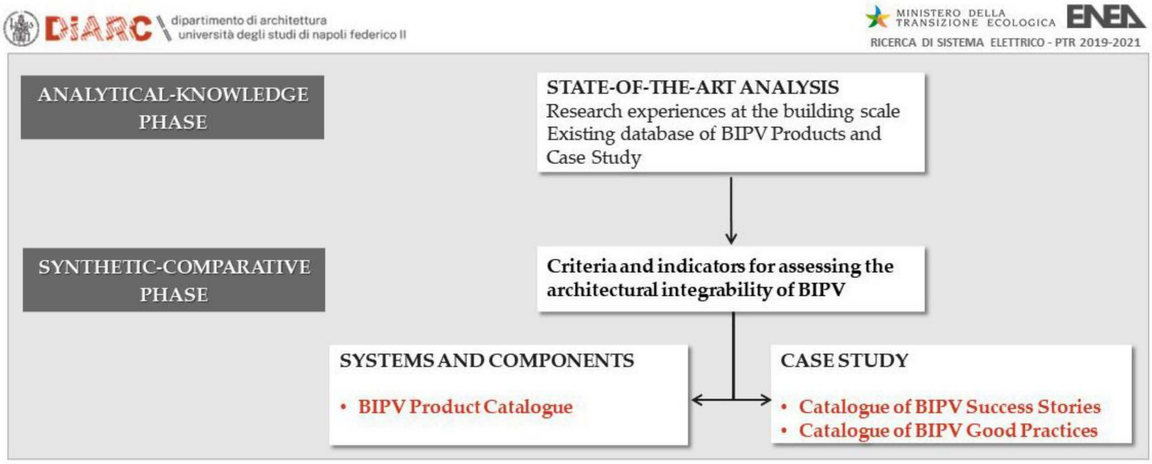


Figure 1. Flow-chart with research steps and related outputs.

3. State of the Art: Analysis of BIPV Product and Project Catalogues

Among the actions aimed at the dissemination of good practices for the integration of PV in architecture and implemented by well-known European research institutions and organisations, it is important to refer to current BIPV catalogues and databases relevant for this research.

Repertoire of international case studies referred to new construction or retrofit—usually, diffused in the form of user-friendly interactive database—are frequently developed with the aim of demonstrating how technologies can be integrated into the building concept, contributing to quality architecture, as in the case of the IEA-SHC Task 41 [9]. In addition to the interactive platforms, catalogues of case studies and innovative BIPV products are commonly collected also in published reports as criteria and guidelines [10].

In some cases, as for IEA PVPS Task 15—Sub task A [11], collection of international projects is analysed in depth, highlighting the potential, challenges and constraints—also of an economic nature—encountered in all phases of the decision-making, design and implementation process, on the topic of building integration (energetic, technical-constructive and architectural) with the aim of guiding professionals throughout the process of developing effective and successful BIPV projects.

Some platforms focus on products and projects relating not only to the international field but also to specific territories, as in the case of Switzerland [12,13] providing information on the integration of BIPV systems in buildings and, in some cases [13] with construction details based on detailed graphs provided by the designers and specific focus on technological and energy characteristics of the interventions, together with an accurate description of the BIPV module in use, including pictures and graphics.

Online platforms usually provide large amount of multimedia content, whose strength lies in the wide range of active solar products and projects, presented in a descriptive way, unfortunately not always available in English as well [14].

In relation to the Italian context, the Institute for Renewable Energies of EURAC Research has developed an interactive platform BIPV—Building Integrated Photovoltaic [15] containing case studies (private and public buildings) illustrated starting from the description of the levels of technological, aesthetic and energy integration achieved, the decision-making process and the lessons learned. The documentation is supported by descriptions, technical information, images and detailed graphs. In addition to the projects, it is also possible to access a catalogue of BIPV products, subdivided into modules, installation systems, and energy integration systems, and described according to energy and technical–constructive (photovoltaic technology, power, weight) and aesthetic–formal (materials, shape, size, transparency, colour) characteristics.

A summary overview of the databases and catalogues consulted for this research, indicating in which languages they are presented and highlighting the respective fields of investigation (projects, products and construction details) with the number of projects, products and BIPV details catalogued by them is shown in Table 1.

Table 1. Main platforms and databases consulted for this research, with identification of the respective field of investigation (accessed on 30 May 2021).

	Databases and Catalogues Consulted	Short Description	Language	Case Study	Products	Details
1	IEA SHC Task 41	User-friendly interactive database—Solar Energy and Architecture: Collection of Case Studies—with the aim of demonstrating how technologies can be integrated into the building concept, contributing to quality architecture Catalogue of case studies and innovative BIPV products, classified by building elements	ENG	50 + 20	20	
2	IEA PVPS Task 15	Successful Building Integration of Photovoltaics. A Collection of International Projects. A selection of international case studies which have been analysed in depth, highlighting the potential, challenges and constraints encountered in all phases of the decision-making, design and implementation process, on the topic of building integration (energetic, technical–constructive and architectural)	ENG	25		
3	SUPSI	On the BIPV platform, it is possible to find essential information on the integration of photovoltaic technology in buildings, as well as extensive databases on the main BIPV products on the European market and project examples from Switzerland and abroad	IT/ENG	126	136	
4	SOLARCHITECTURE	Multidisciplinary and inclusive Swiss platform on solar energy Solarchitecture—Sun as building material. Recent European and Swiss projects, construction details and latest-generation BIPV products are presented in depth using cross-references, so that it is possible to move from the case study to the BIPV product and from the latter to the corresponding construction details	IT/ENG	20	10	7
5	SOLAR AGE	Interactive platform with a large amount of multimedia content, whose strength lies in the wide range of active solar products and projects, presented in a descriptive way	DE/ENG	205	555	
6	EURAC Research	Interactive platform BIPV—Building Integrated Photovoltaic—containing case studies illustrated starting from the description of the levels of technological, aesthetic and energy integration achieved, the decision-making process and the lessons learned	IT/ENG	60	30	

4. Criteria and Indicators for Assessing the Architectural Integrability of BIPV Systems

The use of innovative technologies and products in architectural design requires specific in-depth studies connected with the relationship between production technologies, construction techniques and design outcomes, highlighting the central role of information and knowledge for the quality of interventions. The use of innovative BIPV products and systems has implications not only for the construction process but also for the conception of the project, its spatial qualification and its morphological and linguistic-expressive results. Technology, in this case represented by the combination of PV technology and building systems with photovoltaic components, is an enabling factor for architectural design in order to achieve the desired results. The conception of the building as an integrated system preludes the overcoming of a building defined by functionally distinct parts, providing multiple, multifunctional and integrated responses.

The integration of photovoltaics in buildings is a complex problem, and its success is linked to the competence of the designer and the choice of appropriate photovoltaic systems and components with respect to the project requirements, and therefore evaluated not only according to efficiency criteria, but above all, according to criteria linked to its morphological integrability [16], so that BIPVs begin to be part of the architectural design process as components and systems for design and construction and not as an add-on technical device [17].

UNI 8290-2:1983 defines integration as "aptitude for functional and dimensional connection" [18]. The definition is partial, since it does not consider architectural integration in its morphological meaning extended to the architectural character of the intervention. A coherent architectural integration aims at redefining the morphological and expressive rules that govern the structure and composition of the architectural language of the building, combining the capacity of the PV to produce electricity with the quality of the space that contains it [19]. The quality of the architectural integration must be evaluated from a functional, constructive and morphological point of view, in its geometrical characteristics and in its material and chromatic qualities.

In this sense, one of the primary aspects to be analysed and therefore evaluated is the 'perceptive' one, not as a purely visual phenomenon but as the result of a cultural processing of the sensory data according to the aesthetic–formal parameters of the culture of the time. Integrating photovoltaics into architecture means balancing the requirements of the technical aspects of photovoltaic technology with the formal and aesthetic value of the building as a whole, a value that has to be respectfully preserved or even enhanced by the introduction of new "signs" [20].

All system characteristics that influence the building's appearance have an impact on the quality of integration and therefore, should be congruent with the overall design. The assessment of the multiple qualities of the integration of BIPV technologies is, however, not easy to implement, as there are no univocally shared tools to support the (propositional) work of designers, and (evaluative) work of Public Authorities, such as Superintendencies and Public Administrations, especially in the case of listed buildings, with an architectural value or located in historical contexts or with a high landscape value [21–23]. Among other things, these criteria, in relation to the concept of qualitative perception, are linked to interpretative and subjective considerations, and therefore always refer to the specific nature of the building or to a broader idea of architecture, typical of a given socio-cultural context and a given era.

It is preferable to adopt the concept of coherence of the photovoltaic solutions used within the architectural concept [24], rather than focusing on the assessment of the objective quality of the installation itself, considering the relational compatibility of the BIPV system with the compositional principles of the envelope and with its technological and type-morphological characteristics. To adapt to different buildings and contexts, photovoltaic systems should provide maximum flexibility in relation to a number of architectural integration parameters. The greater flexibility and customisation offered by a product or solution should correspond to a higher level of design coherence and potential architectural integration [25].

In order to assess the potential integration of photovoltaic components in buildings and the effectiveness of the proposed solutions, it is necessary to define the general criteria to be fulfilled to ensure that the system is harmoniously integrated in its context. Starting from the most interesting results of the research on the architectural integration of BIPV systems and components, a set of interrelated criteria and qualitative indicators has been critically defined to describe the aspects of architectural integration of the different BIPV systems and to express their suitability in relation to the building.

In particular, the architectural integrability criteria are aimed at assessing the coherence of the BIPV system used with the architectural building on the design scale, while the indicators are useful operational tools for assessing the suitability of a product in comparison with other similar products, to ensure choices consistent with the objectives of the project, in compliance with the four integration criteria identified.

The use of these criteria and indicators allows one to investigate the relationships between performances considered significant for the integrability of PV at the design level and the production and technological characteristics peculiar to each technology or system that contribute to the achievement of this objective, thus defining the possibilities of application in architecture in relation to the potential or technical limits of each one.

The assessment of compliance is related to the presence of certain characteristics in the BIPV product or solution, without providing for the attribution of scores or weights; the preference of a BIPV product depends on the compliance with the indicators considered as priorities for the evaluation and offering an adequate level of customisation with respect to the project objectives.

The set of criteria and indicators (Tables 2–5) is presented here according to recurring information:

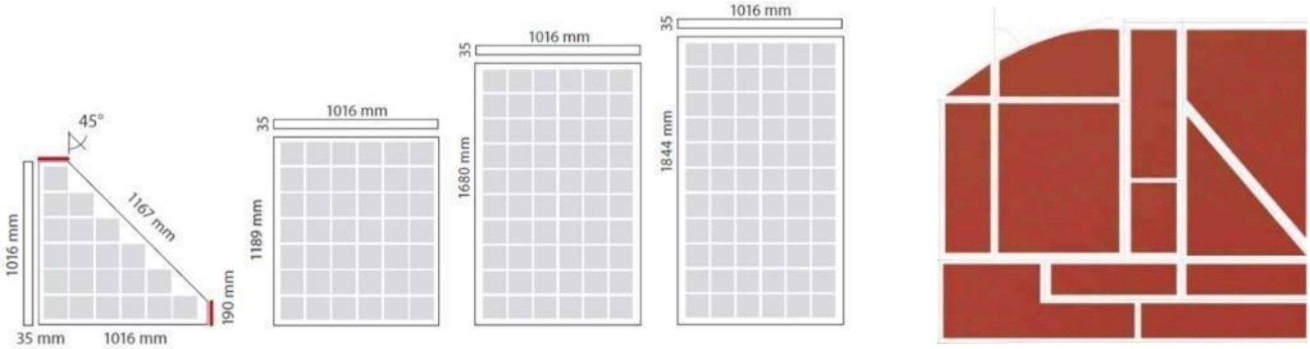
- name of the criteria/indicator;
- description of the criteria/indicator;
- check on the fulfilment of the criteria/indicator: description of the criteria/indicator according to qualitative attributes, which allow to assess how the goal of architectural integrability can be achieved by a BIPV solution, within a project-specific application (criteria), or by a BIPV product (indicators); the occurrence of what is described determines the check on the fulfilment of the indicator.

Table 2. Criteria 1: Geometric coherence.

Criteria 1	**Geometric Coherence**
Compliance check (yes/no)	The size, shape and position of the modules are consistent with the overall architectural design and character of the building, as well as with the geometric-dimensional characteristics of the technical elements belonging to the technological subsystem into which they are integrated.
Indicator 1.1	**Geometric Customisation**
Compliance check (yes/no)	Tailor-made modules can be obtained, capable of adapting perfectly to the surfaces on which they are installed, through a varied offer in terms of shapes, geometries and dimensions.
Indicator 1.2	**Availability of Dummies**
Compliance check (yes/no)	Possibility of obtaining made-to-measure passive elements (dummies), with geometric, formal and chromatic characteristics (structure, model, finishing material, colour) identical to those of the active module, in order to guarantee a coherent perception.

4.1. Indicator 1.1. Geometric Customisation

BIPV modules, according to the photovoltaic technology used, are available in a wide variety of shapes and sizes. Standard products generally have a production range consisting of pre-set or limited customisable formats (Figure 2a), while custom modules offer the possibility of obtaining modules made-to-measure in terms of shape, size and thickness, adapting to multiple design requirements (Figure 2b).



(**a**) (**b**)

Figure 2. (**a**) Standard modules with different geometries and dimensions (Source: TRIENERGIA); (**b**) Custom modules with tailor-made geometries and dimensions [Source: ISSOL].

For products with crystalline silicon photovoltaic technologies, the dimensions of the module are defined by the cell multiple standards, which can, in turn, be characterised by customisable shapes and dimensions. Thin-film modules, which are not subject to pre-established dimensions, have greater geometric-dimensional flexibility, as they can potentially be produced in any format (if it is compatible with the production lines).

4.2. Indicator 1.2. Availability of Dummies

Dummies are non-active elements that have the same technological (performance) and morphological (colour, structure, model, finishing material) characteristics as the active module, which are particularly useful for solving geometrical problems or to be foreseen in some parts of the envelope that are not suitable for energy production (e.g., parts of the envelope that are shaded or not adequately exposed to the sun) [26].

Table 3. Criteria 2: Morphological coherence.

Criteria 2	**Morphological Coherence**	
Compliance check (yes/no)	The visible finish, surface texture and any pattern generated by the solar cells of the module are consistent and harmonious with the finishing materials and textures of the technological sub-system in which they are integrated.	
Indicator 2.1	**a. Pattern Customisation** (visible photovoltaic cells)	**b. Non-Visibility of the PV System** (invisible photovoltaic technologies)
Compliance check (yes/no)	Possibility of controlling, designing and customising the patterns generated by the composition of the solar cells as an integral part and focus of the building envelope concept, enhancing coherence and harmony with the sub-system in which they are integrated.	Possibility of concealing photovoltaic technology by using technical and design measures to hide crystalline silicon cells (coloured/selective films, screen printing, coloured glass, etc.) or thin film photovoltaic technologies.
Indicator 2.2	**Finishing Customisation**	
Compliance check (yes/no)	Customisable textures, surface finishes and degrees of opacity.	
Indicator 2.3	**Frameless Installation Option**	
Compliance check (yes/no)	Possibility of avoiding the frame in the design and installation of the BIPV system (e.g., glass-glass modules or flexible rolls).	

The morphological characteristics of the system strongly depend on the specific solar technology adopted [10]. In order to make photovoltaic modules visually acceptable and attractive, production is based on two design hypotheses: maintaining the visibility/recognition of photovoltaic cells and using them as a design element, working on the pattern (a) or making the PV cell "invisible", hiding it through the adoption of design devices and technologies capable of concealing it (b) [27].

4.3. Indicator 2.1a. Pattern Customisation

The rigid image associated with blue photovoltaics, in which repeated elements (modules/cells) are organised in orthogonal patterns, has been recognised as a possible barrier to its acceptance, especially in valuable or protected contexts. The search for new approaches has led to the proposal of alternative geometries, for example, replacing the typical orthogonal grid with horizontal/vertical striped patterns, or random/pixelated patterns, developed through generative processes based on randomness [28].

Each pattern can be associated with a certain density (or semi-transparency), corresponding to the quantity of solar cells detectable per unitary portion of surface (n° cells/m^2), and therefore, to the nominal power of the system (Wp/m^2). As the semi-transparency increases, the flexibility of the geometric articulation increases, with improved aesthetic–formal outcomes; at the same time, a proportional loss of system power will be detected [29].

The visible cells, intentionally used as design elements, in the semi-transparent glass-glass modules are responsible for controlling the solar factor and light flow, as well as controlling privacy, by varying their density and distribution.

4.4. Indicator 2.1b. Non-Visibility of the PV System

The non-visibility of the photovoltaic system may depend on two factors:

- the photovoltaic technology used (e.g., thin film);
- the hiding of the solar cells through the customisation of the surface finish (indicator 2.2) or colour (indicator 3.1).

Thin-film modules are characterised by the non-recognisability of the photovoltaic technology and by customisable degrees of semi-transparency. Used for glazed enclosures, they have the advantage of illuminating interior spaces, customising the degree of shading and protection from UV and infrared radiation, but without presenting any perceptive difference compared to ordinary glass. The semi-transparency is obtained thanks to the partial removal of the active layer, by laser treatment for amorphous silicon modules (a-Si) and water jet polishing combined with dry sandblasting for copper indium gallium selenide (CIGS) modules; different degrees of transparency can also be obtained with cadmium telluride technology (CdTe) [30]. Higher transparency corresponds to a lower specific power (Wp/m^2). In the case of modules with organic photovoltaic (OPV) or dye-sensitised solar cells (DSSC), semi-transparency and colour variability depend on the absorption spectrum of the specific materials used as active layer [31].

4.5. Indicator 2.2. Finishing Customisation

In order to achieve a better morphological integration in existing buildings and to have a greater choice of architectural features (in the case of new buildings but also for retrofit interventions), it is possible to customise the surface finishing of photovoltaic modules. The most common techniques are listed below, classified according to the position of the finishing layer [30]:

- products with customised interlayers. Graphically customised films can be laminated directly into the module (also acting as an encapsulant or backsheet). Traditional printing techniques from the graphic industry or semi-transparent inks, which allow light to pass through, can be used.
- satin-finish products and printing on glass. The outer surface of glass is satin-finished, appearing matt or satin-finished; sometimes this technique is combined with screen-printing on the inside of images, designs and textures that simulate the appearance of traditional building materials [31].

- digital printing on glass. The process of printing special inks onto glass surfaces to produce a customised image or texture (including HD).
- products with textured, ribbed or textured front glass. Attention must always be paid to the possible energy implications of such surface treatments: altering the front glass leads to changes in the optical behaviour of the glass pane, which may reflect or absorb a portion of the solar spectrum, reducing energy production [31].

4.6. Indicator 2.3. Frameless Installation Option

The frame, generally made of natural anodised or painted aluminium, is intended to improve the mechanical strength, protection and attachment of the module; most glass-glass BIPV modules are mounted without a frame and provided with a polymer seal at the edges to prevent the penetration of moisture from outside; some modules are protected with an aluminium frame connected by a silicone adhesive [26].

Table 4. Criteria 3: Chromatic consistency.

Criteria 3	**Chromatic Consistency**
Compliance check (yes/no)	The colours of the module components are consistent and balanced with the colours of the technological sub-system in which they are integrated.
Indicator 3.1	**Chromatic Customisation**
Compliance check (yes/no)	Possibility of choosing between several available colours or requesting customised colours; this indicator is applicable to each of the photovoltaic module components (cells, front cover, back cover, encapsulants, interlayer, etc.).

4.7. Indicator 3.1. Chromatic Customisation

In order to achieve better colour integration in existing buildings and to have more design alternatives in the case of new constructions, it is possible to colour the photovoltaic modules. Given the reduction of incident light on photovoltaic cells due to colouring, the challenge is to optimise the technological, morphological and energy performance without excessive loss of efficiency.

The most common techniques for obtaining coloured BIPV products are listed below, classified according to the module layer on which the colouring is applied (Figures 3 and 4) [30]:

- products with coloured anti-reflective coatings on the solar cells (solar cell, c-Si);
- products with coloured active layers (solar cell, thin film);
- products with coloured interlayers and selective solar films (interlayer);
- products with coloured polymeric films (encapsulant, backsheet);
- products with printed or tinted front glass (front glass).

Table 5. Criteria 4: Installation coherence.

Criteria 4	**Installation Coherence**
Compliance check (yes/no)	Junction and fastening systems are carefully considered during the design and installation of the system, and are consistent with the substructures, supports and the dimensional, constructional and morphological characteristics of the sub-system they are part of.
Indicator 4.1	**Installation Flexibility**
Compliance check (yes/no)	Possibility of using the modules in different positions (inclined, horizontal, vertical) and/or parts of the building (façade, roof, shading element, etc.), adopting fixing systems compatible with the type of application; possibility of using laying, assembly and installation methods that simplify the number and degree of complexity; possibility of using modules that adapt to any type of surface.

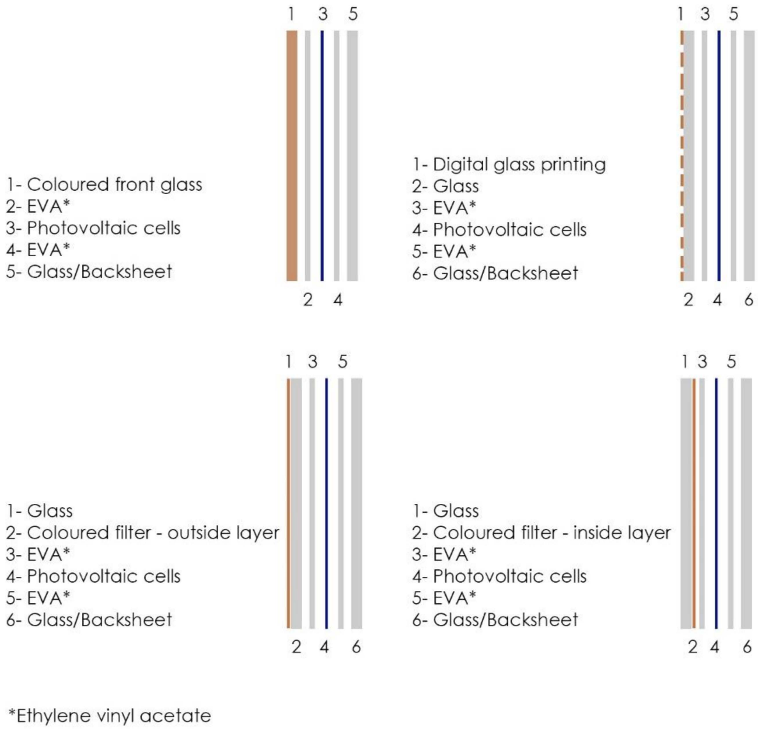


Figure 3. Possible layering of coloured BIPV modules, showing a range of technological possibilities related to the integration of colour, highlighted in red.

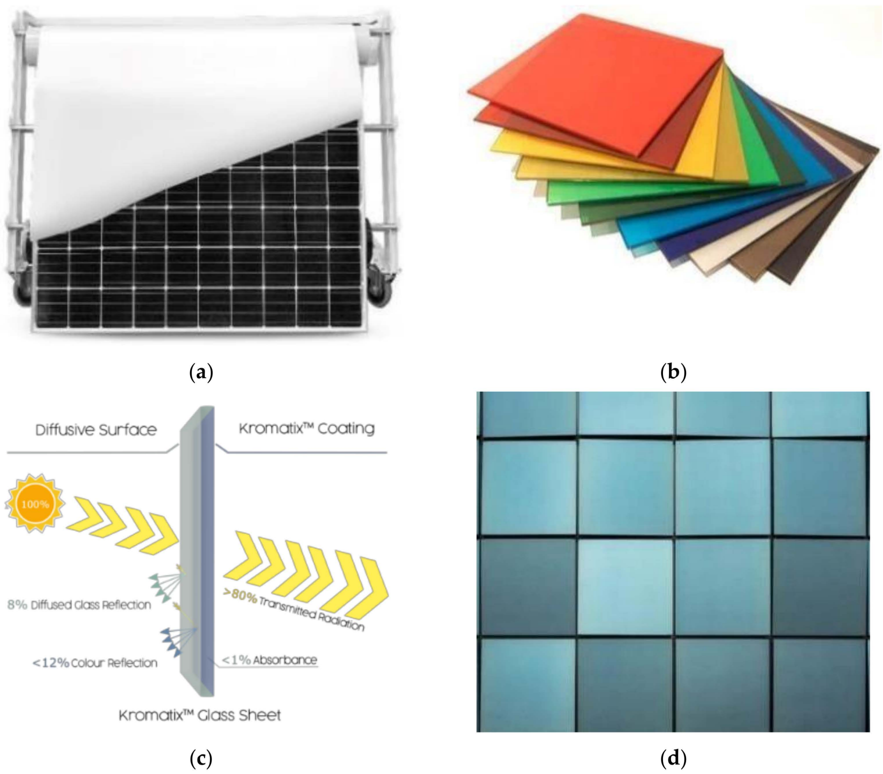


Figure 4. (**a**) Selective solar film lamination on photovoltaic cells (Source: SOLAXESS); (**b**) Range of colours available for translucent amorphous silicon modules with coloured PVB (Source: ONYX SOLAR); (**c**) Functional diagram of the glass fitted with the Kromatix interference filter (Source: SWISSINSO); (**d**) Modules with Kromatix glass appear in a different shade as the viewing angle changes (Source: SWISSINSO).

4.8. Indicator 4.1. Installation Flexibility

In general, the methods of installation of BIPV systems and components do not present any constructional difficulties compared to the technical solutions adopted for the installation of building materials and components of similar use, guaranteeing compliance with the requirements of mechanical stability, flexibility, safety, reliability, impermeability, etc., during the construction phase.

Particular attention should be paid to the technological integration of the cabling and electronic components (such as junction boxes), and to any implications relating to critical constructional, aesthetic or fire safety issues. For all categories of installation, there are different solutions for the management of electrical components, which can be adapted on a case-by-case basis [27]. The possible interference of frames, hooks, ballasts and fastenings of BIPV systems with different building subsystems or the potential lack of effectiveness of these systems in particular contexts (e.g., very snowy or windy areas with high loads) are only a few examples where the importance of correct information to support the design process is crucial [17].

5. Catalogues of BIPV Products and Case Studies

The construction of the catalogues included a dual survey of the use of BIPVs in Italy and Europe in the field of new buildings and technological retrofit, identifying the main morphological and technological characteristics of the installations.

A catalogue focuses on the BIPV products on the Italian market, representative of the main categories of applications in architectural design, with information on their performance and architectural integration characteristics, highlighting the application advantages and performance gains offered by adopting architectural integration indicators. It was considered significant to investigate a sample of 30 systems and components. The survey sample provides a quite varied overview of the possible technological options currently present on the BIPV market in Italy, provided by Italian and foreign manufacturers, including all the different types of integration in the building envelope. The product selection criteria are based on the availability in our country in terms of production and/or marketing, the availability of technical-commercial information regarding the performance offered, including installation manuals and construction details, the use of market-ready technologies and the presentation, on the company website or technical-commercial department, of realised examples and/or application cases with clear references to the design outcomes of the integrations.

The input data necessary for the compilation of the product sheets are taken from the technical documentation and from the information material provided by the companies, suitably standardised to allow a comparison between the data and the performance offered by products of a similar type; the technical–scientific literature on the subject of production for the building industry, as well as the data collected during seminars and technical–professional meetings promoted by some of the best-known production companies in our country, provide an adequate theoretical and cognitive apparatus to integrate the data of a technical-scientific nature (BIPV product catalogue). The number of products has been selected in order to provide a sufficiently large survey sample to include the most recurrent product types of BIPV systems intended for integration in the building envelope.

The second Catalogue concerns the analysis of national and international design references that are ‘exemplary’ from the point of view of the integration of BIPV in the design concept of the building, expressed in terms of compliance with the criteria of architectural integrability. The latter, as does the BIPV product catalogue, is intended to provide a synthetic framework of organised information useful for understanding the main type-morphological and technological characteristics of the applications of BIPV systems within building systems, both for new buildings and for technological retrofit applications.

The objective of this inventory is to highlight the main aspects of integrability using indicators for both products and projects and to detect the correlation between the architectural quality of the buildings in which photovoltaics have been integrated, the morpho-typological characteristics of the buildings and contexts of intervention and the BIPV solutions used, in order to establish their potential reproducibility in future projects.

The case studies were analysed and reported in two different categories: "success stories" and 'good practices'. The success stories are described in the form of summary sheets, from which it is possible to find quick information about the solutions adopted and the products used. They are presented in the form of significant images and detailed graphs, accompanied by a summary table with some salient data on the project and the BIPV system used (Catalogue of BIPV 'Success Stories').

Within the framework of the success stories, a number of projects have been selected, defined as good practices and described in the form of analytical sheets, for the compilation of which in-depth information on project objectives, results achieved, critical points encountered and BIPV solutions adopted has been acquired, where possible through direct contacts with design studios, manufacturing companies and professionals in the sector; these, suitably systematised and generalised, could potentially be adaptable and replicable in situations and contexts similar to that in which the result was positively achieved (catalogue of BIPV 'Good Practices').

A technological-functional classification parameter has been adopted, identifying the BIPV systems starting from the technological sub-system in which the integration of a functional layer intended for the production of electrical energy is detected. For each of the functional macro-categories (Technological Units: Roof, Façade, Integrated External Devices), constitutive parts of the technological system are identified (Classes of Technical Elements), which will univocally identify the system components involved in photovoltaic integration (Table 6).

Table 6. Technological units with respective classes of technical elements [26,32].

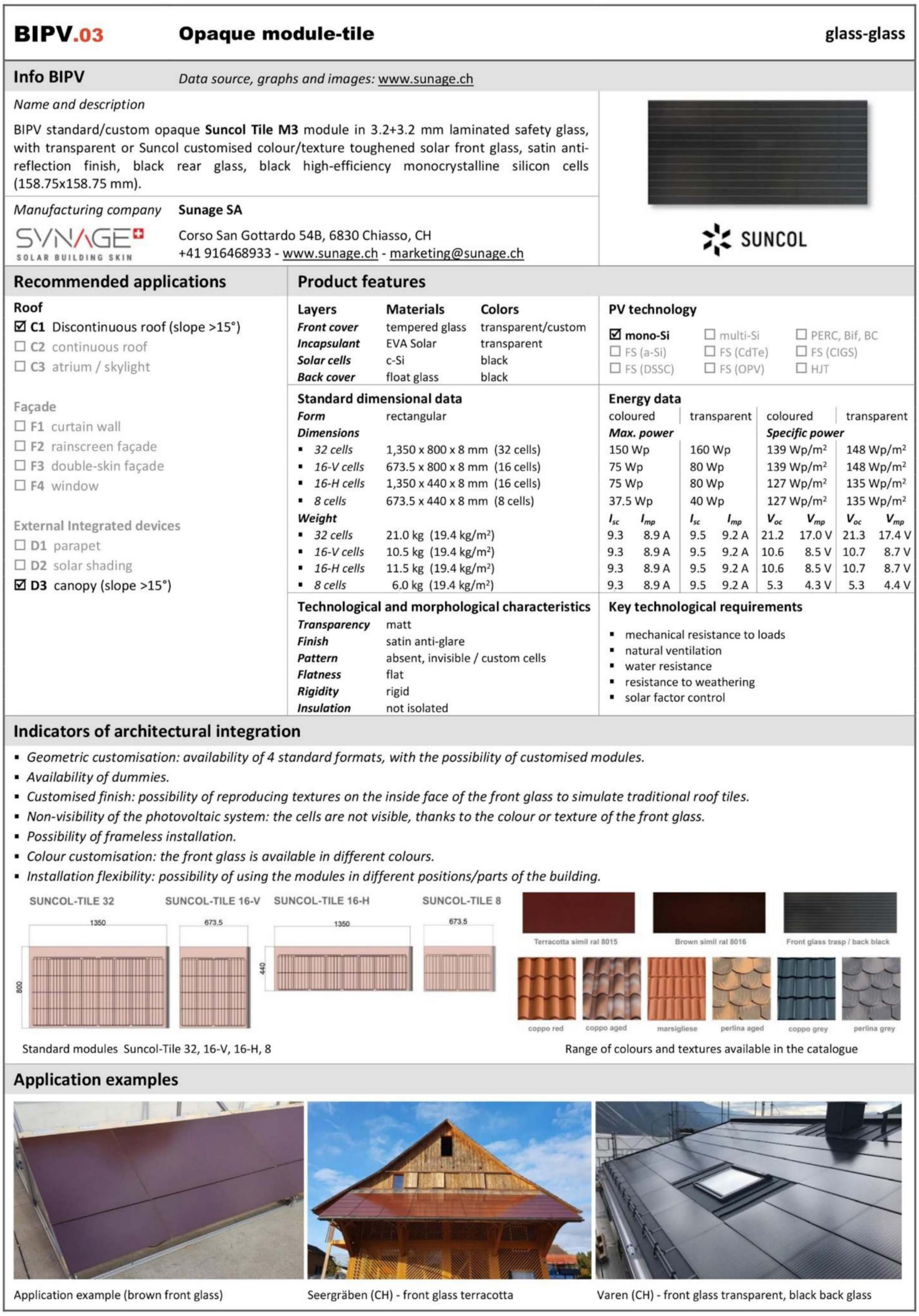
Technological Units	Classes of Technical Elements	Categorization of BIPV Applications
Roof	C1 discontinuous roof C2 continuous roof C3 atrium/skylight	cold roof, shingled roof, pitched roof, sloped roof flat roof, planar roof, low-sloped roof glazed roof, (semi)transparent roof
Façade	F1 curtain wall F2 rainscreen façade F3 double skin façade F4 window	warm façade cold façade, ventilated façade second skin fenestration
External Integrated devices	D1 parapet D2 solar shading D3 canopy	balustrade, railing louvres, breise-soleil, shading devices, shutters, blinds shelter, pergola

Starting from the assumption that the BIPV component or system replaces a technical element or a group of technical elements, it is necessary to determine the performance it must ensure, and consequently the connotative technological requirements associated to it [18,33]. Integration does not necessarily imply that the module replaces all the functional layers, so its complexity (translated into the set of connotative requirements) is proportional to the technological complexity of the replaced layer [16]. In order to streamline the structure of the sheets, it has been decided to report only the specific requirements of the analysed solution, implicitly considering all the essential requirements for the correct functioning of the technological sub-system as a whole to be satisfied.

The Product Sheets (Figure 5) are divided into uniform information sections:

- BIPV Info: information section aimed at describing the general aspects that define and characterize the product under analysis, briefly outlining the main features of the BIPV module;
- Recommended applications;

- Product characteristics: section, structured in five subsections, which describes in depth the main technological, morphological and energy characteristics of the BIPV product through a series of useful parameters to facilitate a comparative reading between different options;
- Architectural integrability indicators: section that offers indications about the potential architectural integrability of the analysed product, by means of compliance with the set of indicators identified;
- Application examples.



BIPV.03 **Opaque module-tile** **glass-glass**

Info BIPV *Data source, graphs and images: www.sunage.ch*

Name and description

BIPV standard/custom opaque **Suncol Tile M3** module in 3.2+3.2 mm laminated safety glass, with transparent or Suncol customised colour/texture toughened solar front glass, satin anti-reflection finish, black rear glass, black high-efficiency monocrystalline silicon cells (158.75x158.75 mm).

Manufacturing company **Sunage SA**

SUNAGE SOLAR BUILDING SKIN

Corso San Gottardo 54B, 6830 Chiasso, CH

+41 916468933 - www.sunage.ch - marketing@sunage.ch

SUNCOL

Recommended applications

Roof

☑ **C1** Discontinuous roof (slope >15°)

☐ C2 continuous roof

☐ C3 atrium / skylight

Façade

☐ F1 curtain wall

☐ F2 rainscreen façade

☐ F3 double-skin façade

☐ F4 window

External Integrated devices

☐ D1 parapet

☐ D2 solar shading

☑ **D3** canopy (slope >15°)

Product features

Layers	Materials	Colors
Front cover	tempered glass	transparent/custom
Incapsulant	EVA Solar	transparent
Solar cells	c-Si	black
Back cover	float glass	black

PV technology

☑ **mono-Si** ☐ multi-Si ☐ PERC, Bif, BC

☐ FS (a-Si) ☐ FS (CdTe) ☐ FS (CIGS)

☐ FS (DSSC) ☐ FS (OPV) ☐ HJT

Standard dimensional data

Form rectangular

Dimensions

- *32 cells* 1,350 x 800 x 8 mm (32 cells)
- *16-V cells* 673.5 x 800 x 8 mm (16 cells)
- *16-H cells* 1,350 x 440 x 8 mm (16 cells)
- *8 cells* 673.5 x 440 x 8 mm (8 cells)

Weight

- *32 cells* 21.0 kg (19.4 kg/m²)
- *16-V cells* 10.5 kg (19.4 kg/m²)
- *16-H cells* 11.5 kg (19.4 kg/m²)
- *8 cells* 6.0 kg (19.4 kg/m²)

Energy data

coloured		transparent		coloured		transparent	
Max. power				*Specific power*			
150 Wp		160 Wp		139 Wp/m²		148 Wp/m²	
75 Wp		80 Wp		139 Wp/m²		148 Wp/m²	
75 Wp		80 Wp		127 Wp/m²		135 Wp/m²	
37.5 Wp		40 Wp		127 Wp/m²		135 Wp/m²	
I_{sc}	I_{mp}	I_{sc}	I_{mp}	V_{oc}	V_{mp}	V_{oc}	V_{mp}
9.3	8.9 A	9.5	9.2 A	21.2	17.0 V	21.3	17.4 V
9.3	8.9 A	9.5	9.2 A	10.6	8.5 V	10.7	8.7 V
9.3	8.9 A	9.5	9.2 A	10.6	8.5 V	10.7	8.7 V
9.3	8.9 A	9.5	9.2 A	5.3	4.3 V	5.3	4.4 V

Technological and morphological characteristics

Transparency matt

Finish satin anti-glare

Pattern absent, invisible / custom cells

Flatness flat

Rigidity rigid

Insulation not isolated

Key technological requirements

- mechanical resistance to loads
- natural ventilation
- water resistance
- resistance to weathering
- solar factor control

Indicators of architectural integration

- *Geometric customisation: availability of 4 standard formats, with the possibility of customised modules.*
- *Availability of dummies.*
- *Customised finish: possibility of reproducing textures on the inside face of the front glass to simulate traditional roof tiles.*
- *Non-visibility of the photovoltaic system: the cells are not visible, thanks to the colour or texture of the front glass.*
- *Possibility of frameless installation.*
- *Colour customisation: the front glass is available in different colours.*
- *Installation flexibility: possibility of using the modules in different positions/parts of the building.*

Standard modules Suncol-Tile 32, 16-V, 16-H, 8

Range of colours and textures available in the catalogue

Application examples

Application example (brown front glass)

Seergräben (CH) - front glass terracotta

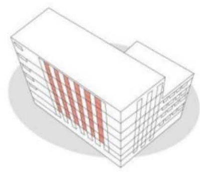
Varen (CH) - front glass transparent, black back glass

Figure 5. Example of a product sheet from the catalogue of BIPV product.

The contents of the 'good practice' sheets (Figure 6) are divided into the following sections:

- Project data;
- BIPV data;
- Environmental and type-morphological aspects related to the building and the context;
- Description of the BIPV System;
- Achieved targets and success factors;
- Detailed images and graphs.

CS.IT.08	**Residential building in Via Brisa, Milan**	**Retrofit**
Project data	*Source: GDieni Architetti*	
Localisation	Via Brisa 7, 20123 Milan *Coordinates*: 45°27′54.20″N, 9°10′49.20″E / *Altitude:* 120 m a.s.l.	
Type of use	■ Residential - MFH	
Designers	GDieni Architetti - www.dieniarchitetti.com	
Year	2010	
Intervention scale	☑ building ☐ urban complex ☐ open space	
Type of intervention	☐ ex novo ☑ retrofit: ☐ addition ☑ recladding ☐ replacement	



BIPV data	**F2.** **rainscreen façade - opaque modules**	
Application category	Integrated into the facade, not accessible from the inside	☐ A ☐ B ☑ C ☐ D ☐ E
Name and description of modules	Custom opaque IS-170 modules with microstructured toughened front glass, black mono-Si cells on white backsheet, mounted with retractable system	
Module manufacturer	ISOFOTÓN	Isofotón Italia Srl - Milan, IT *(discontinued activity)* Isofotón S.A., Malaga, ES *(discontinued activity)*
Façade system manufacturer	DALLERA Tecnologie S.r.l.	Dallera Tecnologie Srl - Agrate B.za (MB), IT +39 039 6056490 - info@dalleratecnologie.it www.dalleratecnologie.it

Environmental and type-morphological aspects related to the building and the context	
Annual global radiation in the horizontal plane	1.404 kWh/m²
Orientation	N-S
Type of urban fabric	historical urban context
Building morphology	flat cover, compact shape

Figure 6. *Cont.*

CS.IT.08 **Residential building in Via Brisa, Milan** **Retrofit**

BIPV System Description

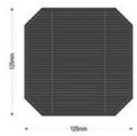
Technological unit: Façade	Technological and morphological characteristics of the BIPV module				
☐ F1 curtain wall	*Production*	☐ standard	☑ custom	*Form*	rectangular, single format
☑ F2 rainscreen façade	*Transparency*	☐ semi-trasp.	☐ translucent ☑ matt	*Dimensions*	1,224x1,047x30 mm
☐ F3 double-skin façade	*Flatness*	☑ flat	☐ curved	*Colours*	cells: standard black
☐ F4 window	*Rigidity*	☑ rigid	☐ flexible		backsheet: white
	Insulation	☐ isolated	☑ not isolated	*Finish*	standard
	Frame	☑ present	☐ absent	*Pattern*	regular grid, closely spaced cells
	Dummies	☐ present	☑ absent		

Key technological requirements for the BIPV system

☐ mechanical resistance to loads	☐ fall protection	☐ thermo-acoustic insulation
☑ natural ventilation	☐ watertightness	☑ resistance to weathering
☐ lighting control	☑ sun factor control	☐ passive heating through solar gains

Energy data

PV technology	☑ *crystalline*	☑ mono-Si	☐ multi-Si	☐ PERC, bifacial, back-contact	☐ HJT
	☐ *thin film*	☐ a-Si	☐ CdTe	☐ CIS/CIGS ☐ DSSC	☐ OPV
Azimuth (orientation)	–5° (S)				
Tilt (inclination)	90° (verticale)				
Photovoltaic system size	n.105 modules (72 cells)	156 m²			
Nominal system power	17.85 kWp				
Annual energy production	n.d.				
Covering energy requirements	n.d.				



Cell in mono-Si 125x125 mm

Targets achieved - success factors

Criteria for architectural integration

- *Geometric consistency:* the use of custom modular modules with black cells allows perfect chromatic and geometric integration in the south façade, in continuity with the porcelain tile cladding.
- *Consistency of installation:* the dark grey sheet metal stringcourse fascia provides a suitable compensating seat to connect the various construction elements and conceal the wiring.

Aspects of efficiency and reduction of energy consumption

- External insulation using a double layer of 50+50 mm polyurethane insulation panels, with a 40 mm ventilation gap opened at the base and at the top by means of special microperforated grids.

Impact and communicability of results

- A virtuous example of sustainable redevelopment in an area located near archaeological excavations and therefore subject to archaeological constraints, which has succeeded in obtaining a favourable opinion from the Superintendence for the harmonisation of the photovoltaic system with the building concept.

Images and graphics

View of the south (on completion) and east (under construction) facades

Figure 6. *Cont.*

Figure 6. Example of an analytical 'good practice' sheet referring to the Italian context.

6. Results

The catalogues allowed some synthetic considerations on the data collected, with reference to the types and characteristics of the products and projects analysed. The resulting considerations allow us to reflect on the criticality and potential for the application of BIPV in the national regulatory and production context, with some possible objectives for innovation in the BIPV industry. Tables and graphs are provided showing synoptic evaluations of the most significant aspects of the products analysed.

6.1. Considerations on Product Catalogues

Figure 7 shows the list of BIPV products analysed, correlated to their respective application categories. Most of the products analysed show great versatility of application, with greater functional flexibility attributable to semi-transparent or translucent glass-glass BIPV modules (e.g., BIPV 17b–20b). On the other hand, greater functional predetermination can be attractive, since in this case, the product can be equivalent to a conventional building system in commercial and technical-performance terms by potential buyers (e.g., BIPV floors or solar shading).

In relation to production characteristics, Figure 8 shows that 27 out of 30 of the BIPV products filed can be customised in shape, colour, finish and/or format. Most manufacturers have a standard production range, with the possibility of making custom products upon customer request, based on the capacity offered by the company's production lines.

The same figure shows that the commercial offer in Italy is still dominated by crystalline silicon (24 products out of 30), due to the major advantages in terms of conversion efficiency, reliability and price. Some manufacturers offer the possibility of integrating different photovoltaic technologies into the BIPV module, depending on specific project requirements, but these are mostly foreign manufacturers with effective sales channels in Italy (e.g., BIPV 05, 10, 24).

As far as the composition of photovoltaic modules is concerned, excluding flexible modules (3 out of 30), made of encapsulating polymeric materials of different nature, the most widespread rigid BIPV modules and the most advantageous characteristics in terms of potential customisation and versatility are the so-called glass–glass laminates (19 out of 30).

Concerning the indicators of architectural integrability, Figure 9 shows that 26 out of 30 of the BIPV products filed can be customised in terms of geometry (shape and size), a prerequisite for the adoption of integrated photovoltaic solutions. Other recurring indicators in most of the products are installation flexibility (25 out of 30), the possibility of frameless installation (23 out of 30), for the benefit of a homogeneous perception of surfaces, and the possibility of producing dummies modules (19 out of 30), passive construction elements that are morphologically and technologically identical to active modules. The morphological customisation, as already mentioned in paragraph 3.3, is based on two design hypotheses: maintaining the visibility/recognition of the photovoltaic cells and using them as a design element, working on the pattern (2.1a) or making the PV cell 'invisible', camouflaging it through the adoption of design devices and technologies capable of hiding it (2.1b). The sample of BIPV products analysed shows that most manufacturers aim at achieving the goal of mimicking photovoltaic technologies (17 products out of 30), working on the customisation of colours (24 out of 30) and surface finishes (9 out of 30).

BIPV Products			Application categories classified by Classes of Technical Elements										
			n°	C1	C2	C3	F1	F2	F3	F4	D1	D2	D3
01	Coloured opaque tile module	ENERGYGLASS	2	☑									☑
02	Coloured opaque cladding module	ENERGYGLASS	2					☑			☑		
03	Coloured opaque tile module	SYNAGE SOLAR BUILDING SKIN	2	☑									☑
04	Coloured opaque cladding module	SYNAGE SOLAR BUILDING SKIN	2					☑			☑		
05	Coloured opaque cladding module	Kromatix by swissinso	3	☑				☑			☑		
06	Terracotta matt tile module	ISSOL	2	☑									☑
07	Matt black tile module	3S Solar Plus	3	☑				☑					☑
08	Coloured opaque cladding module	TRIENERGIA	3	☑				☑					☑
09	Coloured opaque cladding module	Sunerg	3	☑				☑					☑
10	Matt white cladding module	SOLAXESS	2	☑				☑					
11	Flexible opaque tile module	TEGOLA CANADESE innovation in building	2	☑	☑								
12	Flexible opaque module	GENERAL MEMBRANE	1		☑								
13	Flexible module	SOLBIAN	1		☑								
14a	Floating floor translucent	onyx	1		☑								
14b	Floating floor semi-transparent	onyx	1		☑								
15	Matt floating floor	Invent	1		☑								
16	Semi-transparent glass module	VGS	2								☑		☑
17a	Semi-transparent glass module	ENERGYGLASS	2									☑	☑
17b	Semi-transp. structural glass module	ENERGYGLASS	6		☑	☑	☑		☑	☑			☑
18	Semi-transp. structural glass module	UNION GLASS	7			☑	☑		☑	☑	☑	☑	☑
19	Semi-transparent glass module	PILKINGTON	4			☑	☑		☑	☑			
20a	Translucent glass module (double-glazed)	onyx	7			☑	☑	☑	☑	☑		☑	☑
20b	Translucent glass module (triple glazing)	onyx	5			☑	☑	☑	☑				☑
21a	Semi-transparent glazed parapet	ENERGYGLASS	1								☑		
21b	Semi-transparent glazed parapet	ENERGYGLASS	1								☑		
22	Translucent glazed parapet	onyx	1								☑		
23a	Sliding opaque slat solar shading	abba	1									☑	
23b	Fixed opaque slat solar shading	abba	1									☑	
24	Slat solar shading	METRA	1									☑	
25	Semi-transparent solar shading canopy	ENERGYGLASS	1										☑
Number of BIPV products that can be used per application category (CET)				9	7	5	5	9	5	4	8	6	13
				C1	C2	C3	F1	F2	F3	F4	D1	D2	D3
				Roof			Façade				External devices		

Figure 7. Correlation between catalogued products and application categories. Legend: C1: discontinuous roof, C2: continuous roof, C3: atrium/skylight; F1: curtain wall, F2: rainscreen façade, F3: double skin façade, F4: window; D1: parapet, D2: solar shading, D3: canopy.

	BIPV Product	Production characteristics							
		Manufacturer	Production		PV Technology		Composition		
		IT/EU	ST	CU	c-Si	FS	GG	IGU	GB/FB
01	Coloured opaque tile module	ENERGYGLASS (IT)	ST	CU	c-Si		GG		
02	Coloured opaque cladding module	ENERGYGLASS (IT)	ST	CU	c-Si		GG		
03	Coloured opaque tile module	SUNAGE - SUNCOL (CH)	ST	CU	c-Si		GG		
04	Coloured opaque cladding module	SUNAGE - SUNCOL (CH)	ST	CU	c-Si		GG		
05	Coloured opaque cladding module	KROMATIX (CH)		CU	c-Si	FS	GG		
06	Terracotta matt tile module	ISSOL (BE)	ST	CU	c-Si		GG		GB
07	Matt black tile module	3S SOLAR PLUS (CH)	ST	CU	c-Si				GB
08	Coloured opaque cladding module	TRIENERGIA (IT)	ST	CU	c-Si				GB
09	Coloured opaque cladding module	SUNERG (IT)	ST	CU	c-Si				GB
10	Matt white cladding module	SOLAXESS (CH)		CU	c-Si	FS			GB
11	Flexible opaque tile module	TEGOSOLAR (IT)	ST			FS			FB
12	Flexible opaque module	GENERAL SOLAR (IT)	ST			FS			FB
13	Flexible module	SOLBIAN (IT)	ST	CU	c-Si				FB
14a	Floating floor translucent	ONYX SOLAR (ES)	ST	CU		FS	GG		
14b	Floating floor semi-transparent	ONYX SOLAR (ES)	ST	CU	c-Si		GG		
15	Matt floating floor	INVENT FLOOR (IT)	ST	CU	c-Si				GB
16	Semi-transparent glass module	VGS (IT)	ST		c-Si				GB
17a	Semi-transparent glass module	ENERGYGLASS (IT)	ST	CU	c-Si		GG		
17b	Semi-transp. structural glass module	ENERGYGLASS (IT)	ST	CU	c-Si		GG	IGU	
18	Semi-transp. structural glass module	UNION GLASS (IT)		CU	c-Si		GG	IGU	
19	Semi-transparent glass module	PILKINGTON (IT)	ST	CU	c-Si		GG	IGU	
20a	Translucent glass module (double-glazed)	ONYX SOLAR (ES)	ST	CU		FS	GG	IGU	
20b	Translucent glass module (triple glazing)	ONYX SOLAR (ES)	ST	CU		FS	GG	IGU	
21a	Semi-transparent glazed parapet	ENERGYGLASS (IT)	ST	CU	c-Si		GG		
21b	Semi-transparent glazed parapet	ENERGYGLASS (IT)	ST	CU	c-Si		GG		
22	Translucent glazed parapet	ONYX SOLAR (ES)		CU		FS	GG		
23a	Sliding opaque slat solar shading	ABBA (IT)		CU	c-Si				GB
23b	Fixed opaque slat solar shading	ABBA (IT)		CU	c-Si				GB
24	Slat solar shading	METRA (IT)		CU	c-Si	FS	GG		GB
25	Semi-transparent solar shading canopy	ENERGYGLASS (IT)	ST	CU	c-Si		GG		

Figure 8. Production characteristics. Legend: Manufacturer—IT: Italian; EU: European; Production—ST: standard; CU: custom; PV Technology—c-Si: crystalline silicon, FS: thin film; Composition—GG: glass–glass, GB: glass–backsheet, IGU: insulated glass unit, FB: front sheet–backsheet.

In Italy, more than abroad, the possibility of keeping photovoltaic cells visible is still considered a formally feasible hypothesis (6 products out of 30), working on the density (and sometimes on the colour) of photovoltaic cells, so that they become an integral part of the envelope design and aiming at maximising energy performance.

	BIPV Products	Indicators of architectural integration								
		Tot.	1.1	1.2	2.1a	2.1b	2.2	2.3	3.1	4.1
01	Coloured opaque tile module	6	☑	☑		☑		☑	☑	☑
02	Coloured opaque cladding module	6	☑	☑		☑		☑	☑	☑
03	Coloured opaque tile module	7	☑	☑		☑	☑	☑	☑	☑
04	Coloured opaque cladding module	7	☑	☑		☑	☑	☑	☑	☑
05	Coloured opaque cladding module	6	☑	☑		☑		☑	☑	☑
06	Terracotta matt tile module	4	☑	☑		☑		☑		
07	Matt black tile module	5	☑	☑		☑		☑		☑
08	Coloured opaque cladding module	5	☑	☑		☑			☑	☑
09	Coloured opaque cladding module	5	☑	☑		☑			☑	☑
10	Matt white cladding module	6	☑	☑		☑		☑	☑	☑
11	Flexible opaque tile module	3				☑		☑		☑
12	Flexible opaque module	3				☑		☑		☑
13	Flexible module	6	☑			☑	☑	☑	☑	☑
14a	Floating floor translucent	3	☑			☑			☑	
14b	Floating floor semi-transparent	2	☑						☑	
15	Matt floating floor	5	☑			☑	☑	☑	☑	
16	Semi-transparent glass module	3			☑			☑		☑
17a	Semi-transparent glass module	6	☑	☑	☑			☑	☑	☑
17b	Semi-transp. structural glass module	7	☑	☑	☑		☑	☑	☑	☑
18	Semi-transp. structural glass module	7	☑	☑	☑		☑	☑	☑	☑
19	Semi-transparent glass module	4	☑			☑		☑		☑
20a	Translucent glass module (double-glazed)	7	☑	☑	☑		☑	☑	☑	☑
20b	Translucent glass module (triple glazing)	7	☑	☑	☑		☑	☑	☑	☑
21a	Semi-transparent glazed parapet	5	☑	☑				☑	☑	☑
21b	Semi-transparent glazed parapet	4	☑	☑				☑	☑	
22	Translucent glazed parapet	7	☑	☑		☑	☑	☑	☑	☑
23a	Sliding opaque slat solar shading	3	☑						☑	☑
23b	Fixed opaque slat solar shading	3	☑						☑	☑
24	Slat solar shading	3	☑						☑	☑
25	Semi-transparent solar shading canopy	5	☑	☑				☑	☑	☑
Recurrence of architectural integration indicators in product sheets			26	19	6	17	9	23	24	25
			87%	63%	20%	57%	30%	77%	80%	83%

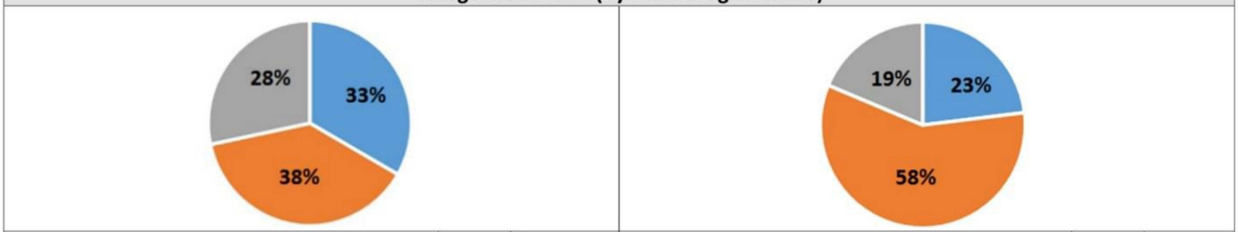
Figure 9. Indicators of architectural integration. Legend: 1.1 Geometric customisation, 1.2 Availability of dummies, 2.1a Pattern customisation, 2.1b Non-visibility of the PV system, 2.2 Finishing customisation, 2.3 Frameless installation option, 3.1 Chromatic customisation, 4.1 Installation flexibility.

6.2. Considerations on Case Study Catalogues

Figures and graphs from 9 to 11 show the most significant aspects of the projects analysed, both in absolute and relative terms: the intended use is specified, explaining the type of intervention (new/retrofit) and the class of Technical Elements involved in photovoltaic integration. Two parameters considered significant for a comparative analysis of the different BIPV systems used in architectural design are also reported: transparency and photovoltaic technology, trying to understand which are the most widespread systems with the greatest potential for growth in the Italian market.

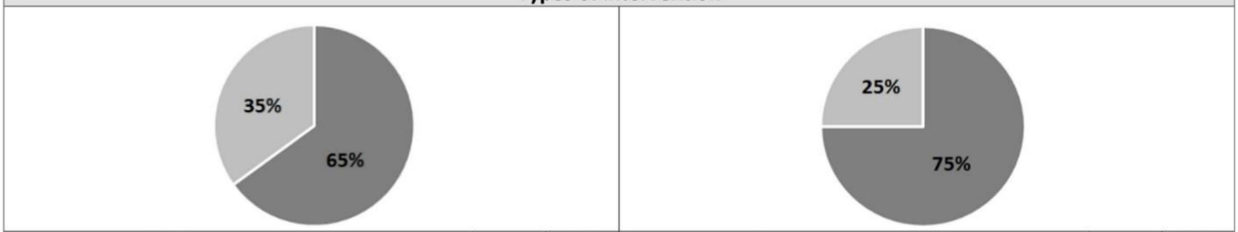
Figure 10 provides pie charts to show in more detail, in percentage terms, the characteristics of the investigated case studies in relation to each of the above categories, comparing Italian and European case studies. There is a general equality in the number of Italian case studies for each technological unit, while the European case studies show a clear prevalence of BIPV integration in the façade (58% of cases), regardless of the intended use of the buildings. In both cases, the integration of BIPV systems and components in new projects is clearly prevalent compared to technological retrofits, with an accentuation of this percentage for the European cases (75% of cases).

Categories of BIPV (by Technological Units)



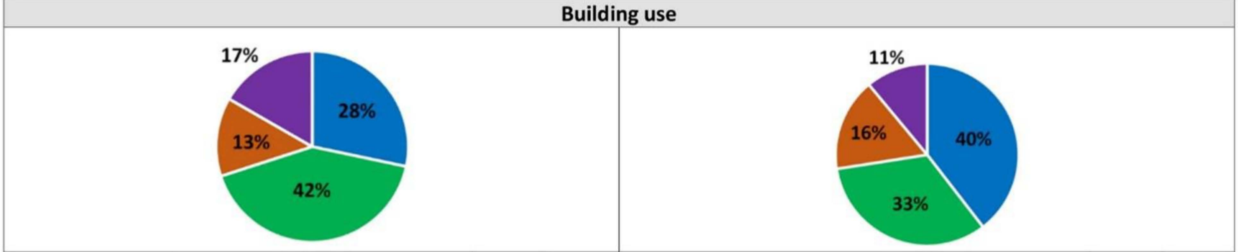
Italian case studies	n.	%	European case studies	n.	%
Roof	20	33.3%	Roof	21	23%
Façade	23	38.3%	Façade	53	58%
External integrated devices	17	28.3%	External integrated devices	17	19%

Types of intervention



Italian case studies	n.	%	European case studies	n.	%
Ex novo	39	65%	Ex novo	68	75%
Retrofit	21	35%	Retrofit	23	25%

Building use



Italian case studies	n.	%	European case studies	n.	%
Residential	17	28%	Residential	36	40%
Administrative	25	42%	Administrative	30	33%
Cultural	8	13%	Cultural	15	16%
Commercial/Productive	10	17%	Commercial/Productive	10	11%

Figure 10. Comparison charts between Italian and European case studies.

Finally, with regard to the intended use of buildings in which BIPV systems are integrated, in Italy, there is a prevalence of interventions on office and administrative buildings (42% of cases), in particular, for ex novo; one of the reasons lies in the lower number of barriers to BIPV implementation, also due to the fact that the owners are often large multinationals with capital to invest in renewable energy. Except in rare cases, there is an insufficient number of exemplary projects in the residential sector, most of which are concentrated on detached and/or single-family buildings. On the contrary, European examples show that BIPV integration is technically possible, cost-effective and efficient also (and especially) in the residential sector (40% of cases).

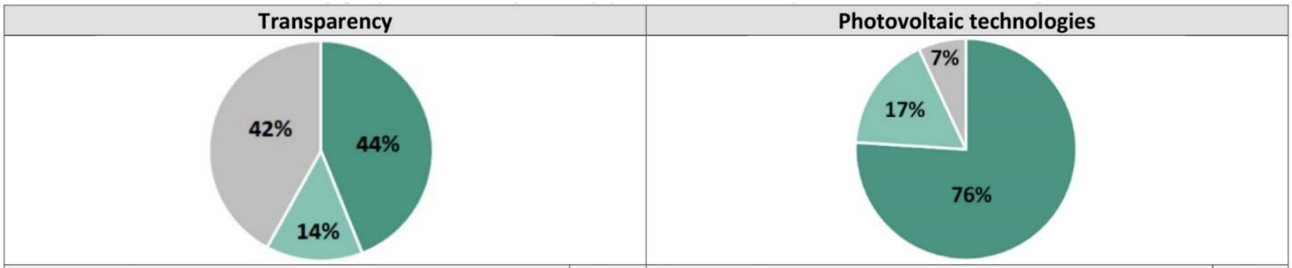
Figure 11 presents a synoptic overview of the correlations between uses, types of interventions and applications categorised by Classes of Technical Elements, distinguishing between Italian and European case studies; the number of applications investigated for each of the above categories in absolute terms is thus shown in the individual cells. For some case studies, more than one BIPV system is used in different parts of the building envelope, so the total number of applications reported is higher than the number of case studies analysed.

BIPV integrations		Uses							
Classes of Technical Elements (CET)	Types of intervention	■ Residential		■ Administrative		■ Cultural		■ Comm./Prod.	
		IT	EU	IT	EU	IT	EU	IT	EU
C1 discontinuous roof	Ex novo	2	6				1	1	
	Retrofit		3	1	1		1		
C2 continuous roof	Ex novo		2		1	2	1		1
	Retrofit	2				2			1
C3 atrium / skylight	Ex novo	1	1	3	3		3	3	1
	Retrofit				2	1		2	2
ROOF	50 BIPV	5	12	4	7	5	6	6	5
		■ 17 (34%)		■ 11 (22%)		■ 11 (22%)		■ 11 (22%)	
F1 curtain wall	Ex novo			7	3	1	2	1	2
	Retrofit			1	1		1		
F2 rainscreen façade	Ex novo	1	13	4	7		2	1	1
	Retrofit	1	7	2	3				
F3 double skin façade	Ex novo	1	2	7	5		4		2
	Retrofit				2				
F4 window	Ex novo			1	1				
	Retrofit								
FAÇADE	86 BIPV	3	22	22	22	1	9	2	5
		■ 25 (29%)		■ 44 (51%)		■ 10 (12%)		■ 7 (8%)	
D1 parapet	Ex novo	1	9	1	1				
	Retrofit	2	4		1				
D2 solar shading	Ex novo	1	3	1	5	2	1		
	Retrofit	1	2		1	1			
D3 canopy	Ex novo			1	1		1	2	1
	Retrofit	4		1				1	
EXTERNAL INTEGRATED DEVICES	49 BIPV	9	18	4	9	3	2	3	1
		■ 27 (55%)		■ 13 (27%)		■ 5 (10%)		■ 4 (8%)	

Figure 11. Summary overview of Case Studies.

Reading the graph in relative terms, prioritising the classes of technical elements, it is possible to note that the integration of BIPVs in the roof is a choice adopted independently of the intended use of the building, with a slightly higher total number of BIPV integrations (Italian and European case studies) in the residential sector (34% of BIPVs); for integration in the façade, a clear prevalence of the office sector over the other categories is observed (51%); integrated external devices represent a dominant category for the residential sector (55%), both for new and retrofit projects.

Figure 12 presents the percentages of use of opaque, translucent and semi-transparent modules over the total number of case studies, as well as the recurrence of different photovoltaic technologies.



Italian and European case studies	%	Italian and European case studies	%
Opaque	44%	Crystalline (c-Si)	76%
Translucent	14%	Thin film (a-Si)	17%
Semi-transparent	42%	Other	7%

Figure 12. Summary graphs on transparency parameters and photovoltaic technologies used.

As far as the transparency parameter is concerned, it is possible to notice that on the total of the analysed project examples, opaque and semi-transparent BIPV modules present almost the same frequency of use (42–44%), while only in a small percentage of case studies, an integration of translucent BIPV modules is observed (14%). It is necessary to correlate this evidence with the graph of photovoltaic technologies, which shows a clear prevalence of use of modules (opaque or semi-transparent) with crystalline silicon cells (monocrystalline, polycrystalline, PERC, back contact, etc.) over other photovoltaic technologies (76% of case studies). In second place, with a clear gap (17%), amorphous silicon thin-film modules (mostly translucent) are used, while the other technologies (thin film in CIGS, CdTe, DSSC or heterojunctions) represent only a very small percentage of the total number of cases investigated (7%).

7. Conclusions

The analysis and cataloguing related to the production of BIPV systems and components and their application in architectural projects shows that, despite excellent premises and a favourable general framework, there are still several criticalities and barriers related to the widespread penetration of BIPV in the construction market, both at national and international level. A number of stakeholders demands that are not adequately addressed in the BIPV value chain, consisting mainly of economic, technological, legal, reliability and regulatory issues, are the main cause of the deviation between growth forecasts and what is measured by industry analysts.

In the last decade, the problems related to the field of solar design are mainly related to the large information gap between the results of scientific research and the knowledge applied in practice. In the past, there has been a general failure to promote the BIPV product, which is a prerequisite for the widespread use of new technologies [34]. This has been reflected in the building professionals in a lack of technical knowledge, a general lack of interest in BIPV technologies and, among the most relevant critical aspects, the perception that the integration of photovoltaic components is not economically justifiable [35]. Several barriers were perceived to the widespread use of BIPV, including aesthetic (aesthetic-formal inadequacy of proposed solutions), regulatory, technical (lack of experienced installers and criticality in meeting durability, reliability and maintainability requirements of modules), market (incomplete or inadequate product information), economic (lack of government subsidies) [36].

Some of these critical issues are now considered to have been overcome. In particular, the analysis of the case studies shows a renewed interest in these technologies, due to a greater awareness of the benefits deriving from the use of BIPV solutions in the current context of energy transition and a much broader and more articulated market offer compared to the one on the market ten years ago.

There are many enabling factors of a technological, productive and design nature for the successful application of BIPV systems and the ordering of technical information in relation to architectural integration, taking into account a series of external conditions linked to the market, production chains, technical-performance compatibility and regulatory factors.

The developed Catalogues intend to overcome the gaps still present in the transfer of information (paragraph 7.1), on the morphological and linguistic-expressive outcomes of BIPV interventions (paragraph 7.2), reflecting on the role of technical information as a critical guide in the choice between different technical options (paragraph 7.3).

Other broader and recurring criticalities in the application and dissemination of BIPV systems (paragraph 7.4–7.10) are presented here with specific observations deriving from the study of the state of the art and the drafting of product and project Catalogues; these gaps, if adequately addressed, could lead to a broad penetration of BIPV in the European and, in particular, the Italian market.

7.1. Critical Aspects of Information Transfer

Research shows that the two most important aspects related to the lack of diffusion of BIPV systems among designers are the lack of clear information and specific knowledge about BIPV technologies and the insufficient expressive quality of some solutions. While on the one hand, the industry has proven that BIPV technology is feasible, reliable and in some cases, even cost-effective, on the other hand, there is still insufficient information about these systems, which translates into concrete difficulties for architects in selecting components that are suitable for the current regulations.

The documentation available for BIPV products is often strictly limited to elementary data sheets imported directly from conventional photovoltaic panels, which only collect basic (mainly electrical) performance and characteristics [17]. Similarly, some considerations can be made regarding the reciprocal relationship between effective BIPV production and the targets achieved in many of the case studies analysed. To varying degrees, promising results in terms of the development and use of BIPV products, the dissemination of good practices and the definition of new architectural integration methodologies were achieved in the heterogeneous and diverse projects analysed. The analysis has therefore led to the identification of some key factors, which are considered to contribute to the strategic positioning of companies producing BIPV modules and systems in the Italian market.

7.2. Diffuse Innovation and Morphological Quality of Integration

The morphological quality of architectural integration represents one of the major challenges for the widespread use of BIPV products, which have not yet fully entered the building sector in terms of vocabulary, requirements and approach. For most designers, one of the barriers to the deployment of BIPVs is the conventional appearance of crystalline silicon photovoltaic panels, which are typical of a style expression dating back to the early 1990s and therefore considered unattractive by most today [36]. To overcome this gap, the photovoltaic industry, already ten years ago, proposed aesthetically appealing alternatives, such as coloured cells or semi-transparent perforated cells; the latter, due to high production costs, limited demand and considerable loss of efficiency, are no longer available on the market today.

After the years characterised by the exhibition of the expressive potential of technology, there has been a slow but steady reversal of the trend, with a fall in the ‘representation’ of innovation in favour of the explication of constructive coherence, better performance and innovations suited to the transformations taking place in the environmental and urban context. The desire to make PV technology visible at all costs has also generated architecture with many grey areas, poor functioning, low durability and, in some cases, only apparent innovation, as if this were emblematically recorded by the presence of certain high-tech elements or cutting-edge technological systems.

A BIPV solution, in order to be considered competitive and preferable to the use of conventional photovoltaic panels, should nowadays show an aspect totally divergent from the latter, but with a comparable energy performance and with technological performances similar to those possessed by passive components for the envelope, in terms of mechanical, optical, thermal properties, etc. From the point of view of the evolution of the use of photovoltaics in buildings, if the pioneering cases of photovoltaics in buildings were strictly influenced by the aesthetics of photovoltaics aimed at achieving maximum efficiency, recent technological developments allow greater design freedom, proposing BIPV components for cladding facades and roofs that are very similar to conventional building elements.

The role of industrial product design favours the competitive positioning of morphologically or aesthetically characterised BIPV products and constitutes a differentiating factor between various products, which are alternative to each other due to small details linked to textures, surface treatments, formats, colours, material consistency, combinatory and integration possibilities, and connections. It is interesting to note that the trend towards the mimicry of architectural materials is one of the main focuses of product innovation, through, for example, glass treatments (printing, sandblasting, etc.), coloured filters and layers interposed in the stratification of the module. In particular, the market diffusion of BIPV modules from 'invisible' photovoltaic technologies contributes to increase the social acceptance of photovoltaics in sensitive areas, where they have often been considered unsightly by designers and end users [31].

Today, it is common to clad the entire building envelope with solar solutions regardless of orientation, preferring a homogeneous architectural language to maximise energy production (total cladding) [37]. However, it is important to note that the quality of design and integration plays an equally important role as the choice of modules and can be achieved either by using standard or customised products; and it is equally true that the results that can be obtained with custom modules are not necessarily better than those obtained using standard modules. Where possible, and/or where the budget does not allow access to niche products, it is preferable to use standard or limited customised products, using available production ranges. Regardless of the level of customisation offered, it is important that the choice falls on modules that present the best balance between morphological integration and energy performance, in virtue of the criterion of optimised exploitation of the envelope surfaces destined for photovoltaic integration, paying particular attention to the use of appropriate installation and fixing systems to meet all the technological requirements of the building [38].

7.3. The Role of Technical Information

Today, technical information in the field of BIPV still has much room for improvement and capillarisation structured and developed for the overall performance of products and systems that can guide the operator in the sector in the evaluation and choice of the most appropriate system among the various technologies on the market or in development. Specialised information represents the way in which technical knowledge systems guide the choice of technical options to support the design process. The quality of interventions should be pursued by guiding the choice between several technical options, reducing the technical risks on site, as well as the impact of any changes required during the construction process. It is necessary to support the reasons for a technical choice by means of tools that allow its evaluation with respect to different technological options, to be supported by the development of technical information able to highlight the advantages of technical, applicative, design and economic nature. The structuring of technical information and catalogues of technical solutions requires the acquisition and systematisation of information relating to the problems of the construction process (implications of a morphological, technological, construction site type and between the various phases of the process), of the technical/construction and construction site ones in relation to the design problems and of the technical risk conditions and relative implications on the design phase of projects [17].

7.4. Critical Economic Issues

BIPV systems are still considered a niche solution in the solar industry by architects and contractors, perceived as too expensive or experimental compared to traditional systems (BAPV), even though the drastic reduction of production costs in recent years has made them enormously more competitive. Cost issues tend to be cited as an obstacle, with doubts expressed about product longevity and maintenance issues. BIPVs should not only be evaluated on the basis of investment costs: after an initial outlay of design and financing costs, the multi-functionality of BIPV modules has a favourable effect on the overall project costs and on the amortisation of the photovoltaic system itself; the low operating costs of energy efficient buildings with a significant share of electricity generated by photovoltaics have a long-term value; and the overall cost of installation can be compensated using the same labour as for standard building materials. Although a higher initial cost is permissible, the net investment for selecting BIPV over other building materials should never exceed 20–30% of the initial budget. In other words, the cost of BIPV should be close to that of building components meeting similar passive requirements. Furthermore, the payback time of the investment should be perceived as competitive (about 5–7 years), offering a real economic return.

Finally, as most European countries have cancelled or reduced support programmes and incentives for photovoltaic systems, such as feed-in tariffs, it is necessary to maximise the self-consumption of the energy produced, also taking into account the hourly profile of the energy needs of the building, in order to maximise the economic benefits of the system [37]. Some manufacturers believe that taxing CO_2 emissions would help the market adoption of many integrated solar envelope technologies [39].

7.5. Critical Regulatory Issues

The lack of adequate test methods and references, as well as regulatory gaps, hinder the dissemination of innovative integrated products. This scenario is further complicated by the varied landscape of codes and standards that differ from country to country [32]. The efforts of the scientific community and the action of growing industries can lead to an acceleration of standardisation processes and the development of specific technical standards (as was the case for the reference standard IEC 63092-1:2020 [40]), which integrate with local ones, in force in the different countries of the European Union.

7.6. Integrated Processes

The difficulty to undertake an integrated approach from the earliest design phases is still one of the major barriers to the deployment of BIPV components and systems. The problem of lack of BIPV experience of architects and installers and the lack of coordination between key partners in the decision-making process (owners, suppliers, installers, etc.) could be solved through BIPV consulting services and digitisation processes of the whole value chain. Active involvement and cooperation from the earliest stages of building design between all stakeholders, including the BIPV manager, could simplify the entire process. Furthermore, up-to-date manuals, tutorials and directories of technical solutions and construction details for the design, construction and management of installations could simplify design and construction activities [27,37].

All the case studies analysed present success factors linked to the willingness to integrate BIPV systems as a prerequisite for the project on the part of those involved in the decision-making process. Collaboration between the research sector, designers and the world of production makes it possible to develop technological innovation projects that find real applications in the world of construction, developing well-integrated solutions from an architectural and economic point of view with tangible results in terms of quality.

7.7. Service Supply and Producer Responsibility

One of the key factors in bridging the gap between photovoltaics and the construction sector is the role of manufacturers: the know-how and complexity characteristic of the construction world could come to the aid of the BIPV sector, laying the foundations for a new common methodological path, creating opportunities for collaboration between research and industry. A renewed and more in-depth technical information on BIPV in terms of quality and construction requirements could become a crucial driver to overcome the last barriers and aim at BIPV as a valid alternative to conventional building solutions, both from a construction and architectural point of view [17].

However, the policy of product innovation alone is not enough: the complexity inherent in interventions that contemplate the integration of BIPV systems requires assistance from manufacturers that goes beyond mere technical support during installation operations; the product needs to be enriched with performance but also with services, prior to and subsequent to the implementation or integration phase, establishing relationships of trust and integration upstream and downstream with various subjects such as suppliers, employees, companies, designers, installers. The product–service approach prefigures a new system of relations between producers and other players in the building process, by selling not only products but also services and results. For this reason, the choice of products and building systems characterised by a higher level of integration of services associated with the product is rewarding; in general, products for which there is a shift of attention from the product seen as a physical good to a series of intangible aspects, including the creation of relationships of trust and integration upstream and downstream with different actors, such as designers, suppliers, companies, installers, in order to obtain a higher perceived added value. In particular, the formation of a qualified network of BIPV installers would be crucial [36].

7.8. Dematerialisation, Functional Integrability and Production Flexibility

The value and role of increased knowledge embedded in the technological processes of BIPV systems is implemented through production chains and product ranges based on the principles of dematerialisation, flexibility, and high added value embedded in the product. The current trend is for the number of parts that make up a product to be reduced, with an increase in the number of functions performed by each part. The driving force behind this change is the environmental cost of assembly operations, and the consequent convenience of producing parts integrating several functional sub-components in a single operation [41]. The integration of multiple functions at the scale of the building component, conceived as a function of a differentiated performance package, in response to different, multiple needs, must therefore be promoted.

BIPV systems can be considered integrated systems because they are based on distinctly multi-material or multi-product logics and, frequently, on principles of layering and specialised integration of numerous elements. Although the systems are 'closed' in the offer provided by the companies, they can be correlated with other technical elements, thus modernising the consolidated principles of open catalogue prefabrication, thanks to the characteristics of integrability and versatility, diversification, customisation, quality policies and activation of marketing and corporate image strategies.

Semi-finished products that can be assembled into 'packages' or systems are flexible and versatile products, with flexibility being maximised in terms of the many combinatory possibilities offered by integrated systems that are the 'formula' by which they are marketed. The prerogatives of dematerialisation introduce quality and added value, acting on a reduced use of materials and the increasing use of embedded knowledge in the form of high performance and properties alongside significant product-integrated services.

Processes and products designed as BIPV offer, with an overall lower amount of material resources used, superior performance compared to products conventionally used for the same purposes. The success factors of these technologies can be found in the production, design and realisation phases. At all stages, the innovative product corresponds to the needs of the end user, bringing real benefits to users and marking the technical superiority of the new products over those already on the market.

Faced with the complexity of interventions, due to the onset of unpredictable conditions linked to the control of the relationship between energy outcomes and performance responses, the world of production must propose flexible packages and customised solutions linked to the technological and morphological specificities of the built environment, able to adapt to different types of buildings and contexts [42]. BIPV products capable of responding specifically to the needs of users are favoured, so that the possible variations in constituent elements, appearance and performance represent a designable method and therefore integrated into the product offer.

Considering that it is often not possible to intervene on buildings with standard products and modules, given the many specific requirements that vary from case to case, there is a need to select products characterised by less formal pre-setting and the possibility of being 'made to measure', by means of a custom-fit concept (variations on standard products within reasonable ranges and not very costly in terms of production and marketing), rather than on demand (considerable variations on standard products, which flow into ad hoc redesigns, which are difficult to reproduce subsequently in production lines). Industrialised production lines that are varied in their offerings (in shape, size, colour, surface finish, etc.) represent an important competitive advantage for BIPV industries, increasing the pool of demand, reducing production times and costs, and providing data from laboratory tests on the energy performance of the modules [31].

7.9. Effectiveness of Marketing, Distribution and Logistics Channels

The time saved in production can be lost if distribution, transport or any services linked to supplies become the weak link in the chain. The decision to use systems and components made in Italy is undoubtedly one of the key points of the BIPV deployment strategy. When this is not possible, i.e., in the case of products that are scarcely available on the territory because of their high level of innovation, it is necessary to resort to specialised foreign suppliers; this aspect can affect the increase in the overall costs of the intervention, making delivery times uncertain and leading to the choice of standard or conventional products. It is therefore advisable to focus on the reliability of the sales network, assessing the degree of availability of the product on the market and the guarantees on production and delivery times and methods. In this case, the brand often plays an important role, as it enables reliable choices to be made and makes it clear what the product represents to the market.

7.10. Intelligent Interaction with the Grid

Energy integration refers to the ability of a BIPV system to interact with the building's or neighbourhood's energy system to maximise the on-site use of the electricity produced. It is therefore about energy management, an issue that is set to become increasingly important in a new way of looking at the building, no longer as a simple independent unit that draws energy from the grid, but as a component that consumes, produces, stores and supplies energy within a wider energy system. The need for more predictable, manageable, grid-compatible and profitable BIPV solar generation in terms of building energy savings could be a solution.

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Conflicts of Interest: The authors declare no conflict of interest.

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