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Overview and analysis of current BIPV products: new criteria for supporting the technological transfer in the building sector

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ABSTRACT

The growing demand for nearly-Zero Energy Buildings is rapidly contributing to change the building skin from being a passive barrier towards a sensitive and active interface. Building Integrated Photovoltaics (BIPV) is a unique solution for delivering clean, safe, affordable and decentralized electricity to people transforming the building surfaces in active solar collectors. Despite photovoltaic (PV) technology and their basic usage are today known to everybody, the particular requirements for building integration have brought to the surface some issues over the years so that BIPV is still a niche market. Starting from this observation, the paper presents the results of an investigation on the current market of BIPV products for roofs and façade. The analysis aimed to identify the relevant possibilities the products today offer and the level of information that the producers make available within the technical description of BIPV systems. After disclosing the actual lack of information in comparison to conventional building products, the authors propose to implement a new "building-based" approach that could support the BIPV market by including a more comprehensive description of the product's quality (today mainly comprising electrical and basic physical features). Such a "building-technology" perspective, also considering the recent normative framework in BIPV field, is expected to encourage the technological transfer of PV in the building sector by facilitating the daily work of architects, installers and the whole value chain.

KEYWORDS

BIPV, BIPV market, BIPV products, technological transfer, nZEB

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1. INTRODUCTION AND MOTIVATION

The growing demand for nearly-Zero Energy Buildings (nZEB), as introduced by the European Performance Building Directive (Directive 2010/31/EU, 2010), the Directive on energy efficiency (Directive 2012/27/EU, 2012) along with the contemporary paradigm of sustainability, is rapidly contributing to change the building skin from being a passive barrier towards an increasingly sensitive and active interface. Building is a key-sector for current policies on energy efficiency since it is responsible for approximately the 40% of the final energy consumption in Europe (Web link 1). Energy saving and the production of renewable energies are today essential strategies for reducing the primary energy needs of constructions (Boie, 2014). Photovoltaics (PV) is considered an essential technology for the future energy production and Building Integrated Photovoltaics (BIPV) is a unique solution for delivering clean, safe, affordable and decentralized electricity to people transforming the building surfaces in active solar collectors (Moosavian, 2013). "The enormous potential of PV and its benefits for society are more obvious than ever. PV is becoming a mainstream player within the power system increasingly delivering clean, safe, affordable and decentralized electricity to people" (Web link 2). In 2011 the Swiss Federal Council developed a long-term energy policy ("Energy Strategy 2050") based on profound changes in energy perspectives (Web link3, Web link 4). In the recent years the PV field has encountered many changes in terms of technological evolution, production, installed capacity as well as application methods (Loferski, 1993, Green, 2005, Hosenuzzaman, 2015) so that nowadays the basic usage of PV technology is known to everybody.

Some years ago, PV technologies were still considered a breakthrough innovation that could be applied in strict cases and with high cost. They started being used for space applications and thanks to the progress in new materials, manufacturing methods and better understanding of their behaviour and performance, PV started becoming more and more popular and accepted as an alternative energy production system for terrestrial applications (Strobl, 2009).

BIPV has enabled the implementation of PV, not only as a technical device but also as a building material, part of the building envelope and its expressiveness in contemporary architecture. The BIPV market had to wait long time to gain credibility in comparison to the conventional PV market. Despite manufacturers today can provide the building sector with a variety of interesting products and customization levels, ready to be used by architects and planners, the adoption and application of BIPV by the building sector is relatively slow. It is expected that the European BIPV market will experience a rapid growth in the years to come, thanks to some drivers such as the European directive promoting the nearly-Zero Energy Buildings (Web link 5, Frontini, 2014). But, apart the positive role of these leading drivers, other aspects, still obstructing the BIPV growth, will have to be recognized and overcome in the near future.

The first aspect in our perspective is still *cultural*. In the case of BIPV, differently from a conventional PV installation (Building Added Photovoltaic, BAPV), a diverse concept of "integrability" is required from the Early Design Phase (EDP), according to a synergic approach that bridges building and energy knowledge. The difficulty to undertake a really integrative approach from the first stages of design, merging energy, PV and building requirements, remains one of the strongest barriers to BIPV market proliferation (Web link 6, Web link 7, Web link 8). Also the difficulties to consider and compare BIPV with other building cladding materials rather than with conventional PV, is often the main cause leading to the issue of unaffordable cost of BIPV. Moreover the success of creating new BIPV markets depends on the capability to overcome other *practical barriers* as identified also by the IEA SHC Task 41 (Web link 9): a good market availability ensuring a good customizability and convincing aesthetics, governmental and local incentives (Hosenuzzaman, 2015, Azadian, 2013, Sarasa-Maestro, 2013) for ensuring cost-effectiveness, the development of specific standards and reference codes for supporting the building practice, and, more in general, a concerted effort by players in the supply chain to work together towards an integrated design. In this direction, the pioneering references (as in example Fig.1) developed by architects and façade makers play an important role as a market driver showing the quality, the beauty and the possibilities in architecture. Moreover the absence of clear *standards and reference normative* for BIPV system's qualification is another issue: only a very few industries make available today, along with the electro-technical certification, the building certifications complying with Construct Products Regulation 305/2011 (Web link 10): this means that the so acclaimed multifunctionality of BIPV is not always translated in clear building requirements so that the CE-marking of a BIPV system, as a building product, is often unavailable.

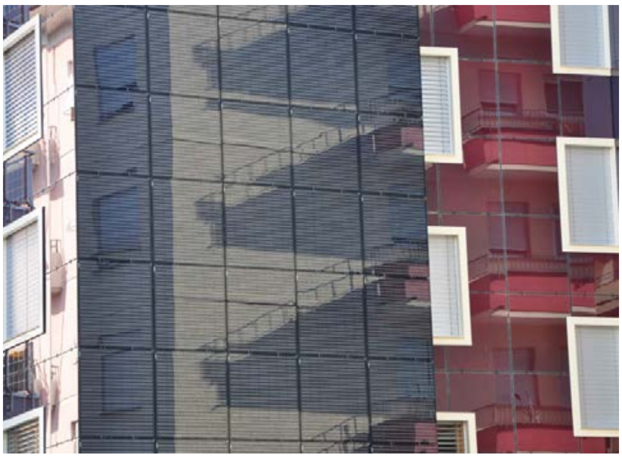

Figure 1.

BIPV opaque façade. Crystalline and thin-film technologies have been used as cladding material. Re-cladding in the refurbishment of Palazzo Positivo, Chiasso, Switzerland.

If, on the one hand, industry demonstrated that BIPV technology is feasible, reliable and in some cases even affordable, on the other hand the *information* about these systems is still not enough and BIPV has not yet fully entered the building sector (and its stakeholders such as architects, building engineers, building industry, contractors, etc.) in terms of language, lexicon, requirements and approach. An example, as following reported, is the fact that until now the documentation available for BiPV products is often strictly limited to elementary datasheets directly imported by conventional PV panels and collecting only basic (mainly electrical) performance and features (e.g. dimensions, weight) (Frontini, 2014, Petter Jellea, 2012, Bizzarri, 2011, Cerón, 2013, Verbene, 2014). As a consequence building requirements and proper analysis of construction interfaces with the building skin, compatibility with building layers and materials, technical details for integration in building technical elements, maintenance instructions, etc. are often missing. Therefore only fragmented and partial information are available during the design process thus today the problem is not the use of PV itself but the use

of PV as active building material (Frontini, 2013). Lessons learned from the history of "technology in architecture" teach us that the transfer of new technologies in building field has always had a recurring and complex process. The "new" is initially used within the traditional process, anchored to past archetypes and to the techniques of tradition, without originally introducing a *link between technological innovation and innovation in building and architecture*. The old legacies are only progressively and slowly overcome, moving from permanence (use of "new" according to traditional/old processes) towards innovation of architecture when the new technology became an evolving factor of the whole building concept (Bonomo, 2015).
In this framework, we expect that a deeper information concerning BIPV in terms of building qualities and requirements will become a crucial driver in order to overcome the last barriers and to push BIPV as a valid alternative to conventional building solutions both from a constructional and architectural perspective.

2. METHODOLOGY

In the conceptual framework described above, the documentation and the analysis of the state-of-art and already occurring evolution, both in terms of available technologies and reference examples provides the status of the "technological transfer" and a record of how far technology has come. The paper, starting from the categorization of PV systems to be used in buildings, will investigate the contents and the nature of products' information today available by producers. As a result, after identifying the scarcity of available information, a new approach for a more accurate description of BIPV elements will be proposed.
Following the premises and the motivation already explained, the methodological layout consists in:

1. Definition of a reference categorization for BIPV products according to a "building-technology" approach;
2. Analysis of the main technological alternatives existing on the market and identification of information provided by manufacturers for describing technical features of BIPV products;
3. Identification of missing information/data in comparison to the building sector and proposal of possible improvements with the goal to support a more effective technological transfer of PV products in the building sector (as results).

2.1 REFERENCE CATEGORIZATION OF BIPV SYSTEMS

The categorization has the goal of organizing the product analysis according to a reference grouping clearly linked to the building skin. Many attempts on categorizing BIPV products have been documented along the way. The IEA (Web link 11), BBC Research (Web link 12), NREL (Web link 13), WIP Munich through the Sunrise project (Web link 14), SEAC (Web link 15), SUPSI (Web link 16) have all expressed a definition of BIPV. Moreover, plenty of other definitions of "Building Integration", more or less coherent, have been related to national and local regulations for incentives (e.g. Feed-in-Tariffs and other supporting measures). In the framework of this paper a new classification was performed, by means of the reference regulatory of the performance-based building design (UNI 8290, 1981) in the direction of a common language between PV and building sector. Thus, the analysis was based on a scheme considering (see Fig. 4 as example):

- Technological units (e.g. façade);
- Class of technical elements (e.g. Stick-system, Unitized curtain wall, Structural Sealant Glazing SSG, point-fixed façade, etc.);
- Technical solutions (e.g. technical alternatives such as watertight/open joint, etc.).

2.2 PRODUCT'S DATA ANALYSIS

The product's analysis and data acquisition was mainly performed through the re-elaboration of technical and scientific input derived from the wide databases available on the website www.bipv.ch (Web link 17), prepared by SUPSI in collaboration with EnergieSchweiz (ES) and the Swiss Federal Office of Energy (SFOE). The list of BIPV products is the core of the website (Fig. 2) together with the examples of buildings.
Further information and data have been collected through a research on manufacturer's websites and technical datasheets, the attendance to national and international exhibitions and symposiums as well as the direct contact/collaboration with manufacturers, architects and other stakeholders interested in solar energy. This allowed obtaining realistic information as well as a more comprehensive perspective.

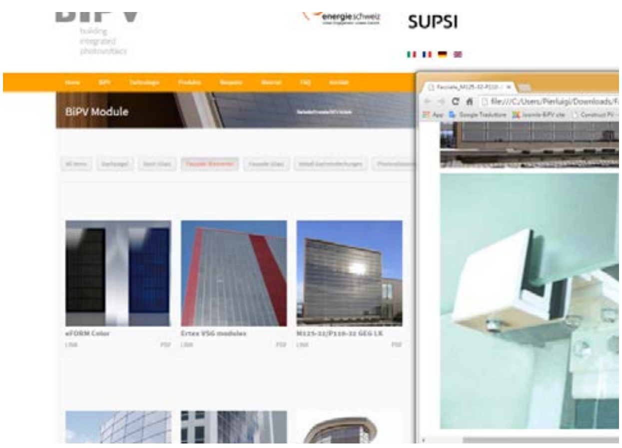

Figure 2.

The web database published on the website www.bipv.ch. It collects more than 100 products representing the main building skin elements, and for each product a technical datasheet is available (source: SUPSI).

General Aspects	Technological Aspects
Product name	Technology
Producer	Power [W]
Country	Specific power [W/m^2]
Category	Front glass
Sub-category	Composition of PV module
	Custom-made possibilities
Structural Aspects	**Warranties & Certifications**
Module dimensions	
[mm x mm x mm]	Product warranty [yrs]
Module area [m^2]	Power warranty [yrs]
Cell number	Certifications
Cell dimensions [mm x mm]	
Cell area [m2]	
Weigh [kg]	
Minimum inclination [°]	
Frame	

Table 1.

Data collection for the product analysis. Main data available from the manufactures.

The investigation carried out involved not only electrical characteristics but also all the other features available from datasheets such as the composition of the PV module (cells, layers, frames, etc.) and the mounting/integration system, the data on dimensions, weight, material layering, the certifications and its warranties as declared by the manufacturer. In Tab. 1, a list of all the main information gathered is presented. The table is divided into four main categories: general, technological, structural and warranties & certifications. Even though more than 100 products are published on www.bipv.ch, 47 systems were chosen for a more detailed analysis -including both roof and façade applications- since they were considered representative of the current market for the purposes of this investigation.
The analysis was performed through the collection of relevant data in synthetic tables for each product (that, for brevity, have not been included in the paper but can be requested to the authors), including both Building Applied PV (BAPV) and BIPV systems, giving a detailed overview of all the main features described in products' datasheets and reported in Tab. 1.
Also an effort aimed to understand how BIPV products were correlated with the building skin in terms of construction technology, was carried out for the main technological solutions (Fig. 3).

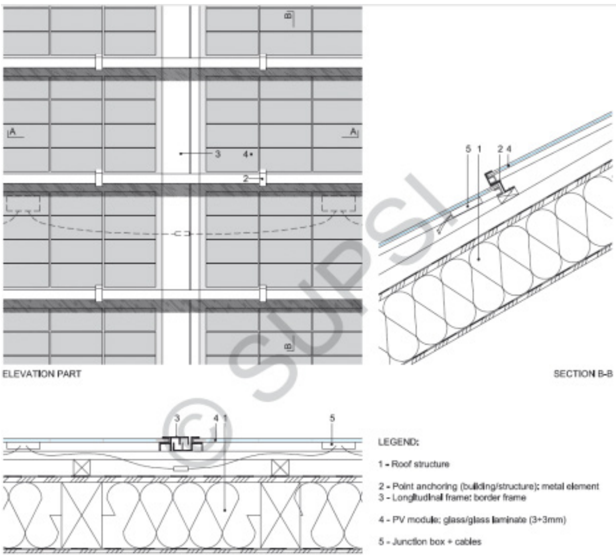

Figure 3.

Analysis of interfaces between the BIPV cladding and the building skin (source: SUPSI).

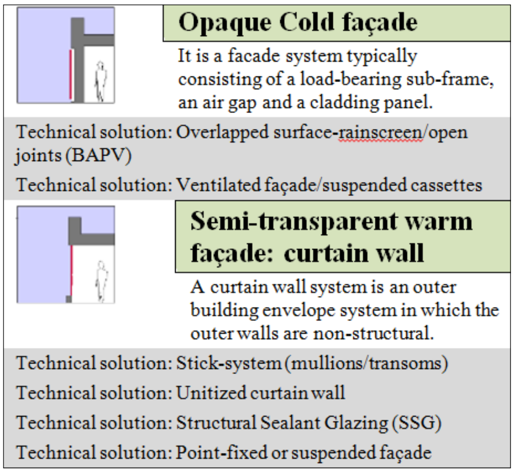

Figure 4.

Example of BIPV systems as elements of the building technological system

2.3 PROPOSITION OF A NEW INFORMATIVE APPROACH FOR BIPV

The last part of this paper presents the authors' proposition for a new set of information useful to better support an effective technological transfer of BIPV in the building sector. By analysing the websites of building manufacturers that produce façade/roof systems (claddings, windows, curtain-walls,…) the investigation focused on the type and contents of the technical documentation available on the current market. This allowed to define the level of information actually supporting the design phase in the building sector and to compare it with the current BIPV industry, finding also suggestions and references.

3. ANALYSIS OF MARKET INFORMATION FOR BUILDING ADDED PV (BAPV) PRODUCTS

In this category enter all products that are used as an added/overlapped element to the building envelope, usually through the installation of a special mounting system. These products do not always replace a building layer as a whole. For this paper the two main categories representing the technological units will be analysed: roof and façade products.

3.1 ROOF BAPV PRODUCTS

In this sub-category, thirteen products have been evaluated. The fastening system plays the primary role in these products (since the system usually consists in a mounting/anchoring kit for fixing solar panels) and both compatible and specifically produced PV modules can be used. In the case of fastening systems that incorporate specific modules, the description of the module's electrical characteristics is available. For the majority of the products, the manufacturer gives a description of the fastening system along with a separate installation manual reporting the whole kit of components (profiles, framing, hooks, clamps, etc.), the installation phases and the mounting procedures. When investigating the dimensions of the product, it is usually not clarified whether they are referring to the installed system or only the modules. As far as the weight of the fastening system is concerned, the situation gets more complicated since producers consider different references in datasheets. Some producers state that the weight is referring to the module alone,other consider only the weight of the mounting system, other provide the weight including the whole system. Almost half of the systems investigated require framed modules because the products are basically consisting of rails and clamps that incorporate the module along with its frame. A few declare no frame and some give no information on the subject. The availability of custom-made BAPV products (fastening systems) for roofs is rather limited in comparison to that of BiPV products since these systems are conceived as standardized kit universally produced. Referring to the fastening system itself and not to the PV modules used along with it, the typical customization possibilities are the dimensions of the system, the system version, the edge cover colour and the profile type and colour. Even though these applications are quite conventional and almost exclusively for roofs, the possible interferences of frames, hooks, ballasting and fixings with the building layering (water tightness, mechanical stability, safety, etc.) or the potential low effectiveness of this systems in special contexts (e.g. very snowy or windy areas with high loads) are some examples regarding to which the importance of a proper information assisting the design process appears crucial. The warranties provided by the producers were found to be significantly unclear to what they were referring to. The same problem occurs also for the certifications of the products. Most products have only electro-technical certifications for the PV modules and not for building requirements.

3.2 FACADE BAPV PRODUCTS

Eight products have been analyzed in this sub-category. Half of them are stated to be compatible with any PV module available in the market. The description of the system by the producer generally includes details on materials, profiles, components and catalogues of elements available. Also the installation manual is provided for the majority of the products but with the limitation above mentioned in terms of interaction with the building envelope. In addition, producers stating the compatibility of their fastening system with specific PV modules provide information concerning the panel. Limited information was found concerning both the module and system dimensions. Scarcity of information was identified concerning need of frame for the modules to be used in the fastening system. Few manufacturers provide custom-made possibilities. One in terms of color for the aluminum profiles and retainers, one provides customized modules (dimensions, color). In one case the possibility of different materials used and the color variety for a complementary part of the system (a reflector) was declared. Again, a lack of warranties for product is identified and when declared, they are referring mainly to the PV panel and not to the fastening system. Very few are the products for which building certifications (such as the DIN 18516, DIN 18008-3) are declared.

4. ANALYSIS OF MARKET INFORMATION FOR BUILDING INTEGRATED (BIPV) PRODUCTS

This category contains all products that may be used in the building envelope by replacing the traditional construction material. Again, also in this case, only two main categories will be analyzed: roof and façade.

4.1 ROOF BIPV PRODUCTS

In this section seventeen products have been analyzed. Despite the attractiveness of thin film technology products (appearance discretion, surroundings harmonization, etc.) all the identified products are crystalline. In the past a big selection of thin film modules for building integration purposes was offered by producers but in the last few years very well-known manufacturers have ceased production. On the other hand, innovative systems have emerged trying to join aesthetic, multi-functionality and cost effectiveness so that they are expected to drive the BIPV industry in the following years. In this case, BiPV modules have evolved from low power to more powerful modules reaching

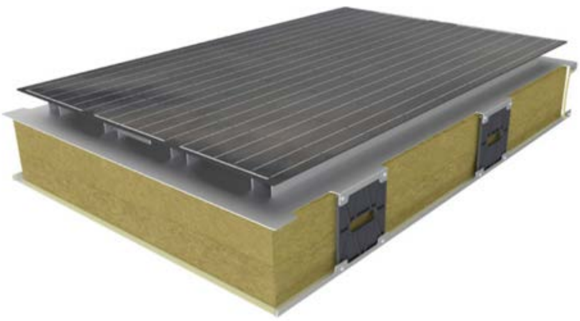

Figure 5.

Example of a BIPV roof system consisting in a unitized and pre-assembled elements easy to install on roof structure, ensuring water resistance, thermal insulation and production of electric energy thanks to the integrated PV (Source: Designergy SA)

delivering levels equal to standard PV. The products investigated in this sub-category replace the external cladding part of the roof (e.g. roof tiles, in-roof systems, etc.).
Only a few of them are complete systems substituting the entire roof such as skylights or prefabricated unitized roof panels (such as the one in Fig. 5). For such products a more complete description in terms of building integration is usually provided, sometimes along with an installation manual.
In other cases, producers mostly focus on the composition of the PV module rather than that of the system. The weight of the modules depends strongly on their dimensions as well as their composition. In case of customized modules (e.g. glass-glass large modules that weight up to 100kg) testing and certifications for building application are very important. Basic custom-made possibilities are numerous and most of the manufacturers offer tailored modules in terms of dimensions, cell type, backsheets, frame and materials. Moreover in case of glazed modules produced by some industries coming from the construction world, the possibility to customize the cell type/arrangement as well as the module shape and layering (front/back glasses, encapsulants, etc.) is available. As far as warranties are concerned, it is more usual to find the power warranty than the whole product warranty in the datasheet. Last but not least, certifications were found to be adequate for the electrical properties rather than construction standards.

4.2 FACADE BIPV PRODUCTS

In this sub-category nine representative products have been analysed. In general, almost all products evaluated are being offered without a frame (provided separately) for façade. The mounting system to be used is not clearly mentioned in most cases and as a result, the separation with the building envelope is still evident since the technological solution is missing (mounting structures, joints, constructional systems, etc.). Only a few producers are referring directly or indirectly to the anchoring system. It is clear that this lack of information together with the absence of clear performance certification for building requirements is still a barrier in some application fields. Concerning weight, there have been found cases for BIPV façade weighting up to 110kg due to the large size and the particular layering. As custom-made services, most of the manufacturers offer the possibility to produce modules of various power output (this is mainly the case of semi-transparent element like in Fig. 6), form, glass serigraphy/printing and colours as well as to change the cell arrangement and the glass surface (clear glass, prism, enamelled) with different properties (i.e. glare reduction) and finishing. Other products available on the market allow a completely hidden perception of rear cells thanks to special coloured filters applied just behind the front glass, with consequent decrease of energy production in favour of better aesthetics. For only a few products the warranties offered in terms of product as well as power were mentioned. As in most of the BIPV products, manufacturers provide the certification of modules for the electrical part but few specify those for building application. An exception is represented by some manufacturers of glazed modules, coming from the construction sector, concerning the security of the glass that is certified according to the building standards (EN12543-4, UNI EN 12600, UNI EN 356, etc.). This lack of information for most products is today considered a challenge for the industry and the research field.

Figure 6.

BIPV facade of the CSEM Research Center in Switzerland, City of Neuchâtel, Viteos and CSEM (photo: SUPSI)

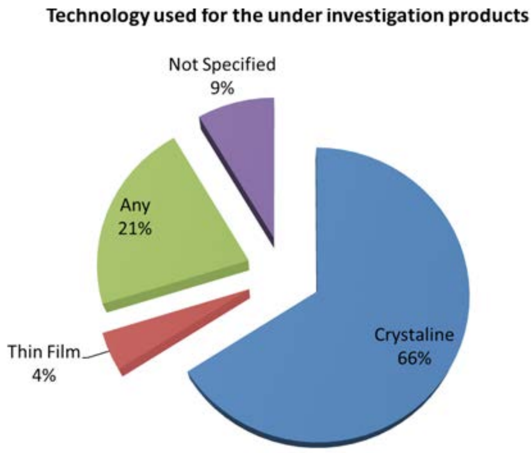

Figure 7.

Technology used for the products under investigation, as declared by the producers.

Table 2.

Value ranges of products under investigation as declared by the producers.

	BAPV Roof BAPV façade	BIPV roof	BIPV façade
Power range [W]	80-260 80-135	120-355	100-350
Weight [kg]	6.5-21.5 12.5-25.0	10.0-30.0	15.0-50.0
Width range [mm]	805-1574 600-1205	701*-2028 (2440**)	580-2400 (2440**)
Length range [mm]	792-1705 600-1520	870*-2500 (5100**)	590-3800 (5100**)
Specific power [W/m2]	120-187 111-125	86-153	80-165

** for tiles* *** custom-made (max.)*

5. DISCUSSION ON RESULTS

As seen in Fig. 7, the majority of products (66%) embed crystalline cells while only 4% are of thin film technologies. The one fifth (1/5) of them was declared to use any type of technology and a 9% of the producers did not state the cell's technology used for their products.

Tab. 2 depicts the values ranges of the most important characteristics of the products under investigation as these are included in datasheets. More in particular, the average value of power for BAPV products was found to be 170W (±90W) for roof applications and approximately 108W (±27.5W) for façade applications. On the contrary the average value of power for the roof integrated BIPV products was established at approximately 238W (±117.5W) and for the façade integrated BIPV products at 225W (±125W). It can be observed that, apart from the higher power, the BIPV products have a wider range of power values. Simply said, more and higher possibilities can be found as far as the integrated products are concerned.

When it comes to the weight, a general observation is that the BAPV products weigh less than the BIPV products. However, as observed in the previous paragraphs, there is not a reference standard for calculating the data. The BAPV-Roof products exhibited a weight range between 6.5 and 21.5kg, (average: 14kg), whereas the BAPV-Façade products exhibited a weight range between 12.5 and 25.1kg, (average: 18.8kg). In the case BIPV-Roof products the average value was found to be 20kg (±10kg) and when integrated on the façade the average value is 32.5kg (±17.5kg). These results, although not considering specially customized products, display that the weight usually ranges between 15 and 25 kg/m^2.

When looking into the dimensions, producers offer a vast range of lengths and widths. The biggest average dimensions correspond to the

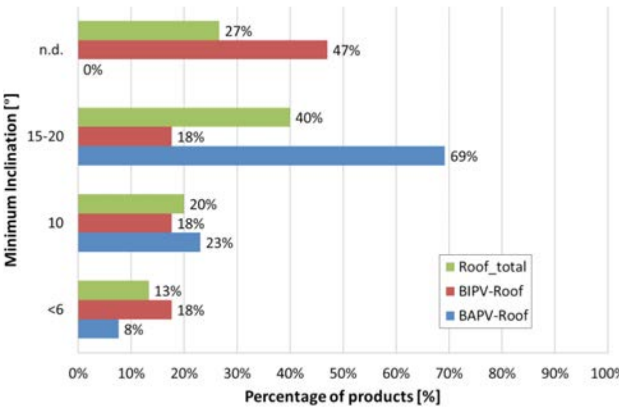

Figure 8.

Minimum inclination BAPV and BIPV products (for roof application/integration) as declared by the producers.

BIPV products for facade with an average area of 3.3m^2 (2195mmx1490mm), followed by the BIPV products for roof with average dimensions of 1685mmx1365mm and average area of 2.3m^2. BAPV products for roof have an average area value of 1.5m2 (1250mmx1190mm). The smallest average dimensions are those of the BAPV for façade products, with average dimensions of 1060x900mm and an average area of 0.95m^2.

As seen in Fig. 8, the minimum inclination of integration/application can be grouped in four main categories; lower than 6°, at 10°, between 15° and 20° and not defined (n.d.).When looking into the case of BIPV-Roof products, it can be seen that almost half of them (47%) did not include a minimum inclination possible for integration. Approximately 70% of them lay between 15° and 20°, the 23% can be applied on a roof at 10° and a small percentage for less than 6° with an appropriate substructure. A special case is the declaration of possible application and/or integration for inclinations less than 6°. In such situations, a careful investigation of the substructure needed is essential and producers should give all the necessary details.

In synthesis we can summarize the current situation stating that information available on the building features/requirements for BAPV and BIPV products is rather limited and based on a prescriptive approach, as the following:

- Construction system: the instructions often do not concern specific building details and requirements to comply with, so that physical and constructive interactions and interferences with the building skin layers are not clarified.
- Physical/mechanical aspects: a clear reference to structural requirements for mechanical stability/safety (e.g. static loads, snow, wind, etc.) is not reported in most cases so that it is not clear which are the normative references (Eurocodes,

building codes, standards for metallic structures, etc.) and actions to consider for the analysis.

- Prescriptions (e.g. minimum inclination): it is not clear in most cases which is the driving requirement for this declared parameters (stability, water tightness, wind resistance, etc.) so that the tendency is to apply a prescriptive approach to comply with rather than a clear performance-based target.

As a consequence, due to the absence of a clear set of requirements, the actual information is heterogeneous and often missing basic aspects for building. In the following chapters, the authors are proposing possible insights and suggestions for improving the actual information level in the BIPV product sector.

6. TOWARDS A NEW INFORMATION FOR BIPV ACCORDING TO A BUILDING-BASED APPROACH

As resulted from the analysis, all data provided by manufacturers in BIPV products' datasheets are related to the electrical properties (power, temperature coefficients, current, voltage, etc.) and to basic dimensional or physical data of the PV module or sub-structure (dimensions, weight, size). Information on the building features/requirements (e.g. the compliance with building standards, the description of material performance for each layering, etc.) is rather limited and often not included in the technical documentation. Thus, the majority of the current datasheets contain most of the information listed in Tab. 1. Just taking a look to the current market of building products, it is common to observe that the building industry provides, along with general brochures similar to BIPV datasheets, a more detailed documentation including, in example, technical catalogues (safety, maintenance, use, installation, applications, handling and installation, workability, fixing, joints and connections, transportation and storage, method of delivery), testing reports and certificates, (reference standards and contract specifications, declarations of performance), system's components libraries (CAAD and BIM objects, user-friendly tools help configuring the system), etc.. The product's benefits and features are usually highlighted through reference projects including details of real case-studies so that also recommendations on energy and environmental design, life-cycle costing and smart design are offered to users.

It's quite evident the lack of useful data in comparison with a conventional product for the building skin. Consequently architects, building engineers and contractors do not have at their disposal an effective informative support since the Early Design Stage with the result to not consider BIPV as a design option.

However, as the "Photovoltaic Architecture" is emerging rapidly, more information on BIPV components is needed in order to enable architects and planners to perform a proper design and an effective (technological and processual) integration of PV technology since the Early Design Phase. In this perspective the authors propose some key-questions to be addressed by the manufacturer or system provider in order to overcome this barrier and provide further technical information. Three topics have been identifies:

- The building skin technology
- The building function and performance
- The product customization

6.1 WHAT IS THE CONSTRUCTIONAL INTEGRATION OF THE BIPV SYSTEM IN THE BUILDING SKIN?

Since BiPV is part of the building skin (e.g. as roof, façade, shading element), its constructional role as well as its physical, geometrical and functional correlation with other layers of the envelope should be clear.
How? Technical details (at least drawings in scale 1:10 as proposed in Fig. 9) showing materials, correlations and interferences of BIPV component/system with all the other building components/layers would help to understand the technical solution. A catalogue of all the installation possibilities would be helpful (e.g. considering the different building skin structures and technologies).

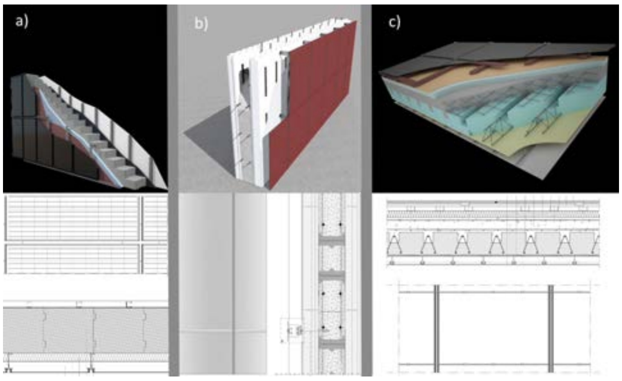

Figure 9.

Screenshots of some BIPV solutions analysed on different building skin technologies. Solar cold façade on a concrete brick wall, on the left (a); solar cold façade on a load-bearing reinforced concrete wall, in the middle (b); solar system on a massive roof, on the right (c) (source: SUPSI-University of L'Aquila)

6.2 WHICH BASIC BUILDING FUNCTIONS AND PERFORMANCE DOES THE SYSTEM HAVE?

This question is aimed to clarify the role of PV "as building element" in terms of building requirements. From a functional side a BIPV product is able to fully replace a building component so that a coordinated performance approach among PV and building skin is necessary. It is important in this perspective to understand the role of BIPV in satisfying the basic requirements for construction works set out in Annex I of CPR, so

Levels of aesthetical customizability for BIPV

Cell level	Module level
Material/Technology	Module layering (e.g. materials for front cover, encapsulant, back cover)
Texture, variation of grain, crystallography	Size, form and morphology
	Color/Printing/Treatment of materials
Shape and size	Density of cell's assembly, cell's pattern
Electrical contacts	Semi-transparency
Color	Light reflection, glare
Transparency	Flexibility
Building level	Frame
Mimicry or invisible	Building parts: Fixings/Joints
Low-recognizable	
Evident/distinguishable	Electrical parts: Junction box, Cable systems, micro-inverters, power optimizers, etc.
Variable PV language (e.g. patterned surfaces)	
Interactive envelopes (e.g. media)	Other multifunctional components

Table 3.

Levels of aesthetical customizability for BIPV products that can be made available by producers.

that a proper assessment should be an important part of the product's information provided by manufacturers with the goal to clarify the strengths and weaknesses of the BIPV system for its building use.

6.3 WHICH MANUFACTURING PARAMETERS CAN AN ARCHITECT USE FOR CUSTOMIZING THE ARCHITECTURAL LANGUAGE?

This is another very important aspect since BiPV concept involves, along with these constructional aspects, the architectural quality of integration. As international examples have already shown (Van Berkel, 2014 within the European project ConstructPV www.constructpv.eu), an interesting aesthetical customization is possible (Tab. 3, Fig. 10), ranging from cell to module design.
Since a wide range of opportunities are generally available, it should be clear, in the product's description, what are the main features that can be customized, which are the ranges of parameters

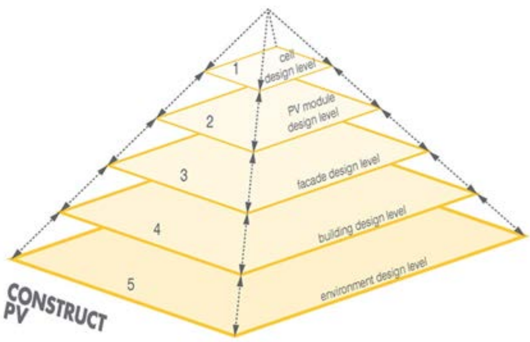

Figure 10.

Design Innovation from PV-Module to Building Envelope: Architectural Layering and Non Apparent Repetition, UNStudio, Netherlands (source: Van Berkel, et.al. 29th EUPVSEC 2014).

available for the product's design and which are the implication in terms of technology, energy performance and costs.

6.4 NEW APPROACH AND NEW INFORMATION

As emerged, detailed information by producers aiming to clarify the product's quality in terms of architectural customizability, building function and performance is necessary in the current market to better clarify the potentials and the limits of BIPV. A basic list of possible communication tools, covering the informative gap from the design phase to the installation and operation, could include:

- technical catalogues, technical bulletins, white papers, safety datasheets reporting building properties (mechanical features, hygrothermal, acoustical, fire class, etc.);
- testing reports and certificates (e.g. for structural analysis, energy saving, acoustics, sustainability, LEED certification, EPD, etc.), Declarations of Performance and CE marking, NBS clauses, catalogues of reference standards and contract specifications, system's components libraries, CAAD details and BIM objects;
- training material for installation phases, safety, instructions for use, maintenance advices, documentation for applications, handling and installation, workability, fixing, joints and connection, transportation and storage, method of delivery, etc.;
- special user-friendly calculation tools, virtual showrooms, and apps for configuring the system, check the main building requirements, choose the adequate product for the construction and work out the quantities within an interoperable building process;
- special and detailed documentation focusing


Datasheet for building envelope solutions with integrated Photovoltaics.

Tab n. 1 Pag. 4/4 — Opaque vertical facade (CO.O) energy high-efficiency (H) built with steel "dry" system (S) and PV integrated thin film modules (TF)

CV.O.-H.S.TF

TECHNICAL SHEET	BIPV	Without PV
Physical aspects of PV component		
Thickness (cm)	48.10	48.00
Weight (kg/m2)	160	158
Transparency (%)	-	-
Size (widthxlenghtxtickness) (cm)	120 X 60	120 X 60
Thermal and hygrometric aspects		
U value (W/m²K)	0.110	0.110
Thermal wave attenuation (-)	0.003	0.003
Thermal wave phase shift (hours)	20:33	20:33
Absence of interstitial condensation	•	•
Airtightness	•	•
Control of linear/point thermal bridges	•	•
Energetical data		
A: equivalent thermal demand index on envelope surface (kWh/m²y)	8.25 kWh/m²y	-
B: Electrical energy PV production (kWh/m²y)	98 kWh/m²y	-
C: Self-sufficiency index (B/A)	32.66	-
Environmental features		
D:Grey embodied energy (MJ/m²)	5710.04	4339.79
E: PV pay-back time (B/D)	16.185 years	-
Economic data		
F: Cost (€/m²)	1356.10	943.60
G: Electric fee (€/kWh)	0.23	-
H: Feed-in tariff—equivalent (€/kWh)	0.24	-
I: Saved money by PV in 30 years (€/m²)	195.58	-

Photovoltaic features	
PV material	CIGS
Frame	frameless
Cell type	Stoventec Artline Invisible Panel
Module type	Würth Solar Modul
Front glass	Tempered Trasparent Glass
Back-material	Plaster base slab made from recycled glass, with reinforcing mesh
Power (kWp/m²)	0.11 kWp/m²
Power NOCT (kWp/m²)	nr
Power low radiation (kWp/m²)	nr
Temperature coefficient on max Power (%/°C)	- 0.36 %°C

Reference:
StoVerotec Photovoltaic
http://www.sto-industrie.de/

Figure 11.

Technical features that could be included in a new format of datasheet for BIPV products in a building-based approach.

on thematic topics such as thermal efficiency, fire safety, durability, environmental impact, acoustics and health providing.
In this direction, that is expected to involve all the value chain in a significant effort and with a certain time duration, a gradual enhancement of information could be a right approach. The revision of the datasheets from the actual format into more useful and complete technical documents could be a first action taken, in the perspective to prepare, step by step, a richer offer in terms of practical tools.

SUPSI already started some investigations by analyzing some archetypal solutions for different constructional systems (roofs and façade, high and low energy efficiency targets, "dry" system or massive ones, etc.), with the scope to assess the role of PV within the whole envelope solution (Bonomo P. et al., 2014) .
By considering the whole building skin as a unitary technological element, the final results have been collected in data-sheets (a screenshot is reported in Fig. 11) reporting, along with the conventional electrical data of PV, also information concerning the energy performance of the building skin (U value, parameters of thermal inertia, etc.), the building requirements, the environmental (embodied energy) and economic information (costs and benefits). This approach, focused on a multi-criteria analysis, demonstrated the need for project developers (architects, installers, etc.) to consider the several interacting aspects of BIPV and the potentials to compare it, through common parameters, with conventional building products. Results also confirm that a multi-criteria perspective is necessary for evaluating the added values and benefits of BIPV as an integrated part of the building skin.
The role of producers, as one of the key-players, is recognized important in covering the gap between PV and building sector. It is expected that, by introducing all the experience and complexity of the "building world", it will be possible to cover a first step and to motivate the "building direction" of PV. In this framework a change of perspective is encouraged and, as summarized in Tab. 4, starting from datasheets and technical information this new approach should be tangibly taken into account.

General aspects	PV Technological Aspects	Aesthetical Aspects
Product information and details	PV technology information	Customizability at cell scale (color, size, etc.)
Clear identification of the PV role in the building envelope. (Class of technical element, Technical solution, etc.)	Electrical data (power, temperature coefficients, etc.)	Customizability at module scale (layering, size, shape, color, etc.)
Identification of building construction typologies (e.g. lightweight, massive, etc.)	Electrical aspects: solutions to integrate cabling systems, Junction box, micro-inverters, batteries, etc.	Customizability at building scale (mounting system possibilities, assemblage options, etc.).
Clear drawing: e.g. exploded axonometric view, details, etc.	Indications on basic electrical installing procedures	Correlation of customizability with energetic, technological and economic aspects
Cost (investment cost, LCC)	Operation and maintenance strategies	Catalogue of possible configurations
Digital component available (e.g. CAD, BIM objects)		Reference examples for each products

Physical and Performance Aspects	Construction Aspects	Standards Warranties
Dimensional and physical aspects (size, weight, etc.)	Details for each layer of the BIPV panel (materials, performance, etc.)	Electrical standards (Low Voltage Directive)
Thermal and hygrometric aspects (U value, transparency, g value, thermal inertia data, airtightness, thermal bridge data, moisture control data)	Building requirements to be satisfied for the specific building skin application	Building standards to be respected for each class of requirements (safety, weather protection, energy efficiency, environmental impact, etc.) (CPR 305/2011)
Energetic data (e.g. PV energy potential in reference location)	Graphical analysis of technical details for the integrated solution with analysis of all the main nodes and joints, and the identification of interferences, best practice solutions	BIPV special standards
Environmental features of products (e.g. embodied energy, recyclability, etc.)	Indications on building installation stages/procedures (e.g. installation guide)	Product and power warranty
	Indication of maintenance strategies during the life-cycle (e.g. use and maintenance booklet)	Certifications, declaration of performances, labels

Table 4.

Overview of possible information that could be considered in datasheets and technical documents for BIPV products with the purpose to enhance the PV transfer in the building sector.

CONCLUSIONS

Despite the fact that BIPV is already an acknowledged and affirmed sector where a lot of topics have been investigated or are under examination, it is still a niche market and reserved mainly for a restricted group of expert, with still a low awareness within the majority of the building and construction stakeholders. Goal of this paper, starting from the examination of the products' market, is to propose a building-based approach to disclose innovative perspectives for BIPV systems, with a specific focus on information regarding manufacturers and system providers. Based on a large database of BIPV products, collected by the authors through many years of activities and listed on the web-site www.bipv.ch, it has been proven that the current state of information and documentation is not yet adequate. In the PV sector information is mainly provided by datasheets that, when referring to BiPV products, are not sufficient for informing the stakeholders on the building performance, potentials and limits of the product if compared with conventional or alternative building materials or systems.
Therefore the main aspects that should be available for planners, architects and/or owners of a BiPV project, have been identified, also presenting some possible suggestions for overcoming the actual lack of information.
In 2016 the new international standard for BIPV initiated by CENELEC TC82 (FprEN50583: Photovoltaics in building) will come in force, officially introducing the procedures for BIPV products to have a CE-marking according to the Construct Product Regulation. In this direction some of the most important industries manufacturing BIPV glasses, thanks to the combination of extensive glass know-how with PV technology, already develop and test their products according to CE-marking for laminated safety glasses beyond the normal electro-technical function of PV modules.
Therefore the need to comply with building requirements will become compulsory very soon for BIPV so that a proper building-based approach will gain importance more and more.
In this framework the paper aims to contribute towards an interdisciplinary effort to connect PV and building sector, so far restricted in decoupled process chains that have resulted from years of specialization and diversification in the respective fields.
Thanks to this integrated approach -bridging architecture, building technology and energy knowledge- the research is expected to provide the fundamentals for a new methodological path common to the architecture/building engineering field and the PV sector. Practical results are expected to create a positive impact in the real value-chain as well as realistic opportunities for starting up new and concrete ways of collaboration between research and industry.

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