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Building-Integrated Photovoltaics from Products to System Integration – A Critical Review

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Abstract. This review brings together research on the integration aspect of photovoltaic technologies in the building sector. Buildings are among the significant contributors of negative, yet not avoidable, environmental impact. Two primary drivers are pushing the building industry toward sustainability: a goal of lowering the emission levels emitted by the industry, and new norms and regulations on a zero-energy building. The zero-energy building concept is primarily based on the principle that the amount of renewable energy created on the site will be equal to the total amount of energy used by the building during its operational phase throughout its entire lifetime. As a result, the photovoltaic technology was introduced to the building sector, and from there started a rapid research and development of a merged field, building-integrated photovoltaics (BIPV). The market of BIPV is still young and is hence constantly changing. A few BIPV product manufacturers are steadily represented on the market, while new products and manufacturers are emerging and others disappearing now and then. A critical review presented herein provides technical information on existing BIPV products and systems, considering their multi-functionality as a climate screen, energy generator and aesthetic component. Therefore, this paper aims to help to understand BIPV products and systems as well as possibilities and challenges associated with their integration into the built environment of today, thus also giving guidelines for the development and design of BIPV components for the future.

1. Introduction

A building-integrated photovoltaic (BIPV) market is a young but fast-developing merged field of two industries – photovoltaic and building. According to the data from the United Nations Environment Programme (UNEP), up to 40% of global energy is consumed by buildings, and they emit approximately 1/3 of greenhouse gas (GHG) emissions [1]. Due to an expected population increase of 2.5×10^9 people by 2050 and the continuation of its growth in the future, the global energy system will experience additional pressure [2]. With growing energy needs, and as energy production nowadays is primarily based on fossil fuels [1] that release GHG emissions, the level of emissions will steadily continue to grow unless severe action is taken. The issue of GHG emissions, exceeding a sustainable level, is one of the most significant our society faces, and there is a need to find solutions to cope with it. Among other possible ways, GHG emissions mitigation could be achieved by applying energy efficiency approaches and using renewable energy sources [1]. In this regard, the concepts of zero-energy and zero-emission buildings (ZEB) have been established, also mentioned in sustainability in construction standards [3]. According to the European Parliament and the European Union Directive 2010/31/EU



(EPD 2010/13 EU) [4] on the energy performance of buildings, by the end of the year 2020, all new buildings should be “nearly zero-energy buildings.”. This directive is one of the key market drivers, along with the opinion that BIPV is most applicable to ZEB. Challenges of the BIPV market include among others the following: cost reduction, performance, service life, product availability and flexibility, better aesthetics, standardization across industry, construction details, and energy field regulations, mentioned in order of priority [5]. Additional drivers of BIPV technologies are the United Nations (UN) sustainability goals: 7 “Affordable and clean energy” and 11 “Sustainable cities and communities” [6].

Initially, photovoltaic (PV) systems were implemented into the built environment in remote areas to supply buildings with electricity off the grid (an example of such an installation is shown in figure 1, left). Then, grid-connected PV installations have gained popularity among various users (an example of this type of installation is shown in figure 1, middle). Further advancement in the PV field has led to the design and extensive production of various PV products for integration into a building envelope (an example of PV integrated into the roof is shown in figure 1, right).



Figure 1. Off-grid PV system installed on the façade of a mountain cabin, building applied PV (BAPV) system attached on the roof tiles, PV tiles system (BIPV) integrated into the roof. (Source: authors’ photos)

The main objective of the present study is to provide a critical overview of existing BIPV products, illuminating significant obstacles of the market, after its analysis, and to find solutions for further market development. Only in 2016 internationally agreed definitions for the BIPV industry were presented, which boosted the standardization base and better structured market.

To understand the intended meaning of the terms “BIPV module” and “BIPV system”, it is referred to the definitions proposed by members of IEA-PVPS Task 15, Subtask C report “International definitions of BIPV” [7]. Definitions are quoted here: “*A BIPV module* is a PV module and a construction product together, designed to be a component of the building. *A BIPV module* is the smallest (electrically and mechanically) non-divisible photovoltaic unit in *a BIPV system*, which retains building-related functionality. If *the BIPV module* is dismantled, it would have to be replaced by an appropriate construction product. *A BIPV system* is a photovoltaic system in which the PV modules satisfy the definition above for BIPV products. It includes the electrical components needed to connect the PV modules to external AC or DC circuits and the mechanical mounting systems needed to integrate the BIPV modules into the building.”. The term “BIPV product” is mainly equal to the term “BIPV module” but can also mean the full “BIPV system”.

2. Method

The information presented in this study was collected from various sources, mainly based on a review of relevant scientific publications and projects as well as communication with BIPV manufacturers, installers, users, and researchers. Years 2013-2020 were in the focus as the BIPV market and technologies are developing fast, and information is quickly getting outdated. The review presented here is not intended to be a complete list of all BIPV products represented on the market, but rather to provide a critical overview of the market giving examples of BIPV products.

3. BIPV standardization

Building integration of PV must always comply with two different standardization and regulation schemes. The first scheme refers to requirements of the building industry, often regulated in local building codes and international (ISO) standards; the second - to the electrical industry and international (IEC) standards as well as mandatory, local regulations [8]. All PV products must be approved by testing centres and laboratories according to current international standards. At the same time, as PV products designed specifically for building integration still represent a niche market, no harmonized standards for actual testing of these products exist [9]. The first BIPV standard EN 50583 [10,11] had been realized in 2016, which became a starting point for further work on BIPV standardization. The information provided by manufacturers is still insufficient for BIPV to fully enter the building sector, as they can only provide primary electrical performance data and standard module durability certification, while technical requirements for building integration are still missing [12]. Besides, the information provided in BIPV product data sheets has no defined form, making it harder to compare various products.

3.1. BIPV related standards

EN 50583 [10,11] standard, which was released in January 2016 classifies BIPV in specific categories and defines a series of requirements for the BIPV products to satisfy building specifications, although there has also been published earlier studies with BIPV categorizations. This standard applies to photovoltaic systems used as construction products integrated into the building envelope. EN 50583 consists of “Part 1: BIPV modules” and “Part 2: BIPV systems” due to the need to address the photovoltaic modules, and their mounting, and electrical systems. The focus of EN 50583 is on general, electrical, and building-related requirements, along with requirements for building products with and without glass panes, labelling, system documentation, commissioning tests and inspection requirements. EN 50583 includes an initial list of “basic requirements” for BIPV, however additional qualities such as durability and reliability, water- and airtightness, and seismic resistance should also be included when BIPV products are evaluated [8]. International standard for glass in buildings ISO 18178 [13] specifies requirements for appearance, durability, and safety as well as test methods and designation for laminated solar photovoltaic (PV) glass for use in buildings, which is defined as laminated glass that integrates the function of photovoltaic power generation. The International Code Council (ICC) has established criteria for BIPV as a roofing material that dictates its performance in terms of stability, wind resistance, durability, and fire safety. Building product test requirements are set in the acceptance criteria AC 365 [14]. The standard IEC 62980 PV modules for building curtain wall applications was cancelled and incorporated into the new IEC 63092 "Photovoltaics in buildings" (former IEC 63092 "Photovoltaics on the roof") restructured in 2017. For further detailed information on BIPV standardization, it is referred to the report IEA-PVPS T15-08: 2019 “Analysis of requirements, specifications and regulation of BIPV” [8] and standards themselves. All currently applicable BIPV standards are presented in table 1.

Table 1. BIPV related standards.

Number	Name
EN 50583-1 [10]	Photovoltaics in buildings. Part 1: BIPV modules.
EN 50583-2 [11]	Photovoltaics in buildings. Part 2: BIPV systems.
ISO 18178 [13]	Glass in buildings - Laminated solar PV glass for use in buildings.
AC 365 [14]	Acceptance criteria for building-integrated photovoltaic (BIPV) roof covering systems.
IEC 63092-1*	Photovoltaics in buildings - Part 1: Building integrated photovoltaics modules.
IEC 63092-2*	Photovoltaics in buildings - Part 2: Building integrated photovoltaics systems.

*on June 2020 seem still in progress

For further BIPV product development, there is a need for the definition of complementary tests for cases when existing test standards are suitable only for some of the BIPV system types. The results of the existing standards analysis are described in a Tecnalia report [9], and the review of standards for BIPV façade and roof integration is given by Rehde et al. [15].

3.2. PV related standards

As PV production is a global industry, test centres use common international standards to evaluate PV panels. While the focus of the existing standards is on PV panel quality, performance, and safety to some extent, product reliability must also be considered. Likewise, long-term system performance and the amount of energy produced over the system's service life should also be addressed [16]. The existing primary standards for PV modules are the International Electrotechnical Commission (IEC) standards, the European Standards (EN), and the Underwriters Laboratory (UL) standards. IEC, EN, and UL standard test requirements initially address qualification characteristics of PV modules [9]. National standards should also be considered when applying BIPV products in specific countries. From the viewpoint of PV, BIPV should comply with the standards for conventional PV modules such as IEC 61215 (design qualification, etc.) and IEC 61730 (construction requirements, etc.). The commercial success of conventional PV is based on the well-studied long-term reliability of the modules, which was mainly achieved due to PV product qualification and certification according to IEC 61215. Existing primary standards for PV are presented in table 2.

Table 2. Standards of PV industry.

Number	Name
PV design and performance	
IEC 61215-1 [17] (equal to EN 61215-1)	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements.
IEC 61215-1-1 [18] (equal to EN 61215-1-1)	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules.
IEC 61215-1-2 [19] (equal to EN 61215-1-2)	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules.
IEC 61215-1-3 [20] (equal to EN 61215-1-3)	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules.
IEC 61215-1-4 [21] (equal to EN 61215-1-4)	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,Ga)(S,Se) (CIGS) based photovoltaic (PV) modules.
PV safety	
IEC 61730-1 [22]	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction.
IEC 61730-2 [23]	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing.
UL 1703 [24]	UL standard for safety flat-plate photovoltaic modules and panels.

3.3. Building related standards

Many building industry standards can apply to BIPV products, but it is still debatable which of them must be obligatory and which should be voluntary. Standards concerning various aspects of safety and resistance to load impact must be of high priority and resistance to rain penetration could be classified as the second priority, as for most buildings a satisfactory rain tightness would be considered as obligatory. Two standards that are of particular use for BIPV are ISO 15392 and ISO 15686-1. ISO 15392 "Sustainability in building construction" could be a roadmap that will help to reach the objectives of sustainable development in buildings, like information on environmental impact, environmental product declaration, life cycle of the building or construction work, service life and performance requirements, life cycle cost, life cycle environmental assessment, and inclusion of use-phase concerns in project planning. ISO 15686-1 "Buildings and construction assets – service life planning" could be particularly useful when predicting service life, and estimation using reference service life and data from practical experience. The service life prediction could be especially challenging for innovative

components, like the BIPV products. The building industry standards that can be applied to BIPV are presented in table 3.

Table 3. Standards of building industry applicable to BIPV.

Number	Name
ISO 12543 [25]	Glass in building — Laminated glass and laminated safety glass.
IEC TR 63226 [26]	Solar photovoltaic energy systems - Managing fire risk related to photovoltaic (PV) systems on buildings.
ISO 15392 [27]	Sustainability in building construction – general principals.
ISO 15686-1 [28]	Buildings and construction assets – service life planning – part 1: general principals and framework.

Even though BIPV standardization has started to form a strong base for a better representation of BIPV products on the market, there is still a need for further development and work on more harmonized standardization. The necessity and suitability of international standardization for BIPV were defined in the IEA report “Analysis of requirements, specifications and regulation of BIPV” by Berger et al. [8]. In this report three categories of standardization to be addressed at the international level were proposed: “internationally mandatory“, “useful to design BIPV“ and “useful to characterize BIPV, but no need for pass/fail criteria“.

The building element’s functions applicable to BIPV are given in the European Construction Product Regulation (CPR 305/2011) [29] and are following: mechanical resistance and stability (rigidity or structural integrity); safety in case of fire; safety and accessibility in use; protection against noise; primary weather impact protection: rain, snow, wind, and hail; separation between indoor and outdoor environments; energy economy, such as shading, daylighting and thermal insulation; sustainable use of natural resources; security, shelter, or safety; hygiene, health, and the environment.

The same categories are listed in IEA report “Analysis of requirements, specifications and regulation of BIPV” IEA report “Analysis of requirements, specifications and regulation of BIPV” [8] as the ones that should be prioritized. Other categories recognized in the report, like technical requirements, will continue to be addressed best at the national or local level, as such requirements are not of immediate urgency or that some non-technical requirements are beyond the scope of the standardization efforts. Additionally, there should also be other functions to fulfil or to consider like aspects of user needs identified by Boddaert et al. [30] that complement the functions listed above. Needs concerning BIPV performance as a building component: water and air tightness, comfort during operation of a building. Needs concerning BIPV as an electrical generator: electricity for local use (self-consumption), energy self-sufficiency, applying simulation for reliable prediction of generated power. Needs concerning long-term BIPV operation: durability and reliability, ease of maintenance, protection against theft and vandalism. Needs concerning visual impact and interaction with the environment: aesthetically pleasing building appearance, flexibility in module dimensioning, visible expression of “green” values (corporate image), minimisation of disturbing reflection.

4. BIPV market analysis and discussion

To better understand the BIPV market, it is vital to start with its drivers and obstructions. As was mentioned in the introduction, there are two primary drivers of the building industry towards sustainability and hence drivers of a rapid BIPV market development. The first one – to meet the goal of lowering the emission levels emitted by the industry and second one is the new norms and regulations on zero-energy and zero-emission buildings. However, the BIPV market is still inconsistent and represents a niche market. Several barriers are causing this. Firstly, the use of BIPV is currently greatly complicated in the planning of the construction process. As such installations can be costly—it may be quite complicated to add BIPV systems later in the construction projects and therefore BIPV installations are rarely included at the beginning of the design process, budget calculation and life cycle cost (LCC). Secondly, the recently approved BIPV standard EN 50583 is not yet widely known in the building

industry. Only a few BIPV products certified as construction products and no easy installation methods (e.g. such as plug and play, plug and function) for BIPV exist [16,31]. What is more, BIPV products have not yet been integrated into widely available construction product catalogues (preferably online ones) and planning tools such as computer-aid design (CAD) and building information modeling (BIM) software. A valuable online catalogue [32] has been created by the Swiss BIPV Competence Centre at the University of Applied Science and Arts of Southern Switzerland (SUPSI). As the BIPV market is constantly changing product catalogues need consistent updating. The effort on planning, designing, and installation of BIPV is high. Additionally, specialists with knowledge of electrical design and wiring are needed [31]. For example, one may ask who has or should be given the responsibility for a multi-functional system like a BIPV roof system, e.g. the roofer or the electrician? This question would give several different answers depending who you ask. Only a small number of planners, building project managers, architects, and engineers are aware of the variety of BIPV technologies, their potential, and advantages when installed in the building envelope. Given these points, BIPV must be included in the early design phase of the construction process along with informing all the actors of the building construction industry about BIPV market products.

4.1. Critical aspects of BIPV market

A few critical aspects should be considered to support the BIPV market from the different actors involved in the decision process. These aspects are cost, reliability (including performance, output guarantee and product warranty), availability, aesthetics, maintenance, application of BIPV in the renovation of existing buildings and new constructions [5]. Some of the aspects are amplified below.

4.1.1. Cost of BIPV

The cost of PV technologies is gradually declining, while this fact has not directly resulted in lower BIPV product prices. BIPV could still be considered as a high cost investment. Therefore, BIPV product cost is the first and main obstacle for the BIPV market growth. It is promising that Renken [33] identified that the costs of BIPV modules per m^2 replacing facade elements are similar to common cladding materials. Similar cost of façade cladding and BIPV modules for façades can be explained by the fact that large BIPV modules reminiscent of standard PV modules hence can be produced by existing PV manufacturers without much changes in the production process. Frontini et al. [34] attained similar results for facades but found a difference in the cost of BIPV for roof integration of roughly 200 €/m² compared to conventional roofing materials. The Fraunhofer Institute for Solar Energy Systems ISE has developed a life-cycle cost model for BIPV systems. This model considers three main phases of the system lifetime and views the systems from the owner point of view: the investment/installation phase, the operation phase, and the demolition/disposal phase. Nowadays, BIPV prices are often calculated and published as €/Wp, or €/kWh; while in the future, €/m² will be more important to conform with construction industry practices [35], and should simultaneously increase the interest of architects and planners.

As mentioned earlier, to achieve a cost-effective production of PV modules, a highly automated technical process is required. PV manufacturers' primary market is the production of cost-competitive PV modules used for freestanding PV plants or rooftop PV applications (BAPV) [31]. In contrast, every construction product in the EU needs to satisfy the Construction Products Regulation (CPR), which leads to an extensive number of additional requirements for the PV modules, such as higher demands on fire safety or post-breakage behaviour. Furthermore, some basic properties of PV modules, especially the dimensions, need to be adapted to the different situations of the specific buildings. Due to their primary market, the automated processes required to produce PV modules do not allow the size of the PV modules to be changed arbitrarily. Consequently, only a few PV modules manufacturers can produce PV modules designed for building integration and in a range of customized dimensions. Furthermore, their automation process does not always allow PV modules to be manufactured with the appropriate mechanical specifications that construction products need to have.

4.1.2. Reliability of BIPV

The reliability of BIPV products is the second major aspect of slow BIPV market development [36]. For BIPV manufacturers, it is of major importance that standardized testing procedures are developed to evaluate the suitability of their products to defined applications. Additionally, at the moment there is not enough collaboration between the construction industry and the PV industry regarding the product optimization and application. Currently, it can often be seen that BIPV products are designed and developed from a PV point of view, instead of optimizing the products based on a construction point of view. The application should be simplified and better match the regular construction systems. A major advancement of the BIPV market could be achieved by the inclusion of architects in BIPV product development. Two more aspects that could be of interest for the BIPV products reliability, are (i) wind-driven rain intrusion and occurring water leakage problems, and (ii) various durability issues. Performance aspects could be expressed not only in amount of energy production, but also in need of easily understandable specific product performance information, technical drawings, installation details collected in a defined document form and available for a wide variety of specific BIPV products, which is collected into an extensive product database. Additionally, to ease BIPV installation, a verification of a long term guarantees of electricity output and a warranty of a proper BIPV product function of the as a building component are needed.

4.1.3. Availability

The availability of BIPV products is yet another aspect of the BIPV market. The products of compatible size and form must be consistently available on the market so that if there is a need to replace the system elements during the BIPV system service life, it will be possible to find replacement of the installed BIPV products. The market lacks large companies' representation and related marketing of BIPV products that could widely promote BIPV solutions, along with a database of BIPV products available on the market. All actors of the building sector should be informed about sources like BIPV database where they can find a suitable system for a building project. Further, all the data could be used in CAD and BIM software tools, which will guide architects to find the best suitable BIPV solution. An understandable ranking that could ease comparison of products could be useful to include in such libraries so that various market actors could easily understand a database without in-depth knowledge of PV and BIPV technologies. In Europe, each country still has its own legal procedures for building products. For BIPV, this is a serious constraint due to the limited demand for BIPV products within the as for today still limited market of each country.

4.1.4. Aesthetics

The aesthetics of BIPV may be relatively important as on the one hand more variations of coloured BIPV modules appear on the market that may make them more attractive to include in a building project, but on the other hand their cell efficiency is significantly reduced [37]. All so-called new technologies (dye-sensitized solar cell (DSSC), organic photovoltaics (OPV), and perovskite solar cell (PSC)) have the intrinsic potential for different colours. The materials of thin-film and crystalline technologies may be coloured to a limited extent, or the appearance changed using coloured front covers, either polymer sheets or glass [31]. Another alternative to BIPV appearance is semi-transparent modules. Semi-transparent thin-film based BIPV modules apply transparent conductive oxides instead of metals for the electrodes and are coloured in a neutral grey tone. Another possibility is to vary the distance between the PV-active areas and enhance the transparency of the BIPV module which hence simultaneously reduces the area-specific efficiency. Due to the limited space on roof and facade areas, the BIPV system efficiency should be as high as possible. Still, from an architectural point of view, it could be worth losing some degree of PV cell efficiency to gain a more aesthetically pleasing appearance. Aesthetics of a building may be also improved by reducing the complexity of mounting systems and increasing the flexibility in shapes and forms.

4.1.5. Maintenance

The maintenance of BIPV systems is not usually considered or suggested by the manufacturers, as typically, BIPV systems need little maintenance during its expected service life of 25–30 years. BIPV systems intrinsically have no moving parts. During certification, the BIPV products must withstand various mechanical loads and therefore mechanical stability is ensured before installation. Moreover, if BIPV systems installed correctly according to manuals they are expected to work without mechanical failures. The need to clean BIPV systems is highly dependent on their geographical location of installation and the meteorological conditions (rain, humidity, wind, dust, etc.), the tilt angle of the system, and the surface morphology. The only maintenance aspect that is vital to address is rubber sealant elements used for a better water tightness of BIPV systems. These elements could age tremendously in a much shorter period than 25–30 years and may need replacement by new sealant elements, thus research on the durability of such elements is needed

4.1.6. Application of BIPV in new constructions and renovation of existing ones

Application of BIPV in new constructions may seem easier as any of the BIPV systems represented on the market or specially designed BIPV products may be used. While in renovation of existing buildings it may be more difficult to find BIPV systems of suitable shape and colors. Regulations for compulsory use of BIPV products in new construction projects, and specific components development, which are adapted to application in renovation projects could be useful.

4.2. BIPV market overview

PV cell technologies that lead the existing BIPV market are the first generation PV cells (wafer-based), which are similar to the primary PV market of free-standing and rooftop PV applications. Among these technologies are mono-crystalline silicon cells (mono c-Si) and poly-crystalline silicon cells (poly c-Si). A smaller part of the market is shared by the second generation PV cells (also called thin-film solar cells), i.e. amorphous silicon (a-Si), cadmium telluride (CdTe) and copper indium gallium selenide (CIGS). The PV market share can be expressed by the percentage of global annual electricity production by each PV cell technology. The market share of the first-generation PV technologies is the biggest: poly c-Si – 60.8% and mono c-Si – 32.2%; followed by the second generation PV technologies thin-film solar cells – 4.5%, where the share is distributed between CdTe – 2.3%, CIGS – 1.9% and a-Si – 0.3% (data from a market analysis in 2017) [38]. The third generation PV cells are not included in the present study, as their market share is minimal.

All BIPV products can be categorized by the type of BIPV products [36], by the type of BIPV systems, and by the way of integration into the building envelope [39] and by the BIPV categories given in the standard EN 50583 [10,11]. These three categorizations are presented in table 4, table 5, figure 2, and summarized in table 6.

Table 4. Categorization by BIPV product type [36].

Product type	BIPV foil products	BIPV tile products	BIPV module products	Solar cell glazing products
Specification	Lightweight and flexible, often made from thin-film cells	Normally arranged in modules with the appearance and properties of standard roof tiles	Similar to conventional PV modules, but made with protective weather skin solutions	Utilized in windows, glazing, tiles, facades and roofs, and skylights

Table 5. Categorization by the way BIPV systems could be integrated [39].

System integration	Roofing	Façade
Type of integration	Solar tiles-shingles In-roof mounted systems Full roof BIPV solution PV membrane Metal panels	Cold façade Warm façade Accessories

The characteristics required of a specific BIPV module will depend on the function it assumes within the building envelope, replacing transparent or opaque building components for the walls or the roof, and the location of the building. Figure 2 BIPV presents categories that are defined in EN 50583 illustrating how both BIPV products and systems could be integrated into the building envelope.

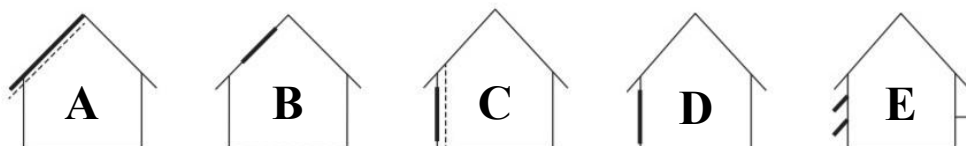


Figure 2. BIPV categories defined in EN 50583. (A) Sloped, roof-integrated, not accessible from within the building. (B) Sloped, roof-integrated, accessible from within the building. (C) Non-sloped (vertically) mounted, not accessible from within the building. (D) Non-sloped (vertically) mounted, accessible from within the building. (E) Externally integrated, accessible or not accessible from within the building [10,11].

Additionally, BIPV products may be subcategorized into two groups: designed and produced for integration, and customizable. In table 6, various selected commercial BIPV products, specially designed for integration, are presented. Such products have lower costs, are available for purchase right away and can be compared with each other. Customizable BIPV products must be designed for each project separately, which leads to higher cost and time constraints, however they still have an unbeatable advantage. If a project they are considered to be a part of is large enough, the cost may be less critical. Furthermore, the building may obtain a unique appearance and be better integrated into the surrounding built environment as aesthetics of this type of products is usually of a high importance. Companies as e.g. Onyx solar, Ertex, and Issol offer a wide range of customizable BIPV products. The substantial similarity of glass-glass PV modules to laminated glass panes simplifies their application as a construction product. Therefore, an extensive amount of glass-glass PV modules is presented on the market. Moreover, large parts of the existing standardization procedures for glass-based construction products can easily be adapted for glass-glass PV modules [31].

Table 6. BIPV categorization by type of product (module), system integration and BIPV category.







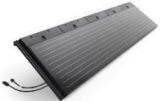

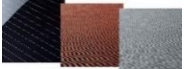





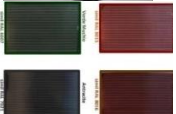


Producers	Illustration	BIPV product category (table 4)	BIPV system category (table 5)	BIPV integration category (figure 2)	Type of PV	Special features	Source
Flisom		BIPV foil	metal panels	A	CIGS	Glass-free, suitable for both roofs and facades	https://www.flisom.com/
Heda Solar		solar tile	solar tiles-shingles	A	mono c-Si	Made of composite materials, has a unique tile form that enables water drainage	http://www.orklaelektronikk.com/new/heda-solar/
Heda Solar		-	-	-	-	Dummy roof tile without PV	http://www.orklaelektronikk.com/new/heda-solar/
Sun-Net		solar tile	solar tiles-shingles	A	mono c-Si	Beton roof tiles designed with intention to integrate PV cells on them	https://sun-net.no/
Scarpnes		-	-	-	-	Dummy roof tile without PV	https://www.skarpnes.com/

Table 6. Continue

Producers	Illustration	BIPV product category (table 4)	BIPV system category (table 5)	BIPV integration category (figure 2)	Type of PV	Special features	Source
Solarteg		solar tile	solar tiles-shingles	A	poly c-Si	Might be out of the BIPV market, had 5 different colours	https://www.enf-solar.com/pv/panel-datasheet/crystalline/34338
Solinso		BIPV tile	solar tiles-shingles	A	mono c-Si	Solar tile that equals to width of four two compatible conventional roof tiles	https://www.solinso.nl/
Solinso		-	-	-	-	Dummy roof tile without PV	https://www.solinso.nl/
Sunstyle		solar shingle	solar tiles-shingles	A	mono c-Si	Compatible rubber sealant elements are provided with the Sunstyle solar shingles	https://www.sunstyle.com/en/Home.html
Nelskamp		BIPV tile	solar tiles-shingles	A	not specified	Available in four colours: brown, graphite, red and black	https://www.nelskamp.de/index.php/en/
Nelskamp		BIPV tile	solar tiles-shingles	A	mono c-Si	Compatible roof tiles are available from the same manufacturer	https://www.nelskamp.de/index.php/en/
Solitek		BIPV module	in-roof system	A	mono c-Si and poly c-Si	Frameless modules specially designed for integration	https://www.solitek.eu/en/products
Solibro		BIPV module	in-roof system, cold facade	A, C	CIGS	Only one module size and one colour are available	http://solibro-research.com/en/technology/
Sunage		BIPV module	in-roof system	A	mono c-Si	Capillary system for roof integration, enables water drainage	http://www.sunage.ch/prodotti/
Sunage		BIPV module	in-roof system, warm facade	A, C	mono c-Si	Can be customized in size and shape of the module	http://www.sunage.ch/prodotti/
Ennogie		BIPV module	in-roof system, warm facade	A, C	CdTe	Modules provided already with installation system attached to modules and compatible rubber sealant elements	https://ennogie.com/documentation_uk-2/
Solitek		Solar cell glazing	solar glazing/sky light	E	Bi-facial		https://www.solitek.eu/en/products

5. Conclusions

The building-integrated photovoltaic (BIPV) market is expected to expand drastically in the coming years. The first BIPV standard EN 50583-1 and 2 “Photovoltaics in buildings. Part 1: BIPV modules” and “Photovoltaics in buildings. Part 2: BIPV systems” is a major step toward a standardized BIPV market with better structure, as this standard defines five different integration categories of BIPV, depending on the intended way of application. This categorization complements already existing BIPV categorization by product type and system type. However, EN 50583 is not yet widely known in the building industry. Unfortunately, the number of BIPV market actors that are simultaneously aware of the needs and standard procedures of the building industry is limited. Therefore, with the development of BIPV standards and the availability of corresponding BIPV products, the next step is to create widely available sources of the BIPV products’ representations for the building sector such as a database of BIPV modules and systems. Such database may be integrated into computer-aid design (CAD) and building information modelling (BIM) software that will ease the inclusion of BIPV in the early design phase of the construction process. Building elements that are not part of the available databases have a limited chance to be considered in sophisticated construction projects. As soon as BIPV modules are available as database objects, including all the information needed in the construction process, BIPV systems will be able to take the step from a niche market to a standardized commodity product. Despite the fact that a variety of BIPV products and their compilation in systems that exist today on the market give many choices and possibilities to designers and construction project actors, there are still several obstacles on the way for this young but fast-growing field. The first obstacle is a specific BIPV standardization. Even though EN 50583 has created a solid base for BIPV standardization, there is still a need for more harmonized standards which include testing concerning BIPV systems as climate screen and durability along with other additional examination to existing testing from PV field. When applying BIPV products in specific countries national standards should also be considered. The last aspect here is standards related to the building industry, as there is still a question which of these standards must be obligatory and which should be voluntary. Standards concerning various aspects of safety and resistance to load impact must be of high priority. Also, the service life prediction could be especially challenging for innovative components, like the BIPV products.

Testing of BIPV systems is yet another aspect of the BIPV market. Right now, BIPV systems are tested according to the main standards for PV modules, assessing modules quality, safety, and durability to some extent. Additional testing that will evaluate BIPV systems as building components should be developed and implemented. Various aspects may be tested, like durability and reliability, examination of a performance as a climate screen, including ability to withstand rain with measuring a degree of water tightness of BIPV systems.

Further BIPV market development is dependent on finding solutions to cope with the barriers such as cost, reliability (including performance, output guarantee and product warranty), availability, aesthetics, maintenance, application of BIPV in renovation of existing buildings and new constructions. BIPV products' cost could be improved by producing a vast number of specially designed BIPV products in a highly automated production line that allows differences in size, shape, colour, and power output. Availability may be improved by development of standardized BIPV products for selected building categories, which should be carried out in collaboration with specialists representing all the involved fields such as engineers and architects, as well as manufacturers, project developers and building owners. Another approach to improve the BIPV market is to identify building classes with standard constructions and dimensions by detailed analysis of the building stock. The resulting comprehensive data base will allow the definition of standardized modules that can be prefabricated, and which may be designed to be equipped with plug-and-play technologies. Provision of the same BIPV products and systems during their service life must be ensured. Cases when components of the BIPV systems need to be replaced (during 25-30 years' service life of products), but with the actual manufacturers disappearing from the market, should be minimized. Aesthetical aspect may be improved by BIPV products of various colours and shapes. Most of the latest technologies allow inherently different colours and semitransparency, which give them a great design potential. The use of the immense design potential

may open and boost new market segments for BIPV products focusing on the design. The main concern for the maintenance aspect is the use of sealant elements made of rubber materials, which may need replacement during the BIPV system lifetime of 25-30 years.

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