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Information modelling/management for BIPV cost-reduction. Digital adoption plan and guideline for a data-driven BIPV process and optimization strategies

BIPVBOOST

"Bringing down costs of BIPV multifunctional solutions and processes along the value chain, enabling widespread nZEBs implementation"

Start date: 10/2018. Duration: 4 Years

Summary

This document addresses the topic of the information modeling and management to support BIPV cost-reduction, in accordance with the activities of WP6 "Digital and data-driven process for BIPV cost reduction along the value chain, from design to installation".

Therefore, the contents of this report provide the basics for the development of an optimal BIPV process that tries to include and manage efficiently all the BIPV stages and actors, also in relation to the traditional building process, by adopting a BIM-based approach and envisioning the implementation of novel BIM tools with new functionalities.

Specifically, Chapter 2 illustrates the current BIPV process and its fragmentation, as well as the possible perspective to overcome the current bottlenecks. Hence, in Chapter 3 a BIM-based approach for BIPV cost-reduction is described by means of an information management strategy to deal with cost reduction goals in the BIPV process and an information modeling strategy to effectively use BIM BIPV objects. Finally, Chapter 4 includes the Digital Adoption Plan that translates the information management strategy in new features and tools of the BIMSolar® software through the implementation strategy, and the information modeling strategy into guidelines for the implementation of BIM BIPV objects into the forthcoming BIMSolar® Platform.

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1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

The present deliverable constitutes the framework for the WP6 "Digital and data-driven process for BIPV cost reduction along the value chain, from design to installation".

The purpose of this document is to provide the results of the Task 6.1 which are the basics for the development of a digital BIM-based approach for improving the BIPV process with the final aim to contribute to the cost reduction of BIPV. Task 6.1, in fact, is aimed at defining the current limits ad bottlenecks in order to set up information management strategies to effectively implement a digital BIPV process as well as a collaborative/interoperable BIM-based approach to reduce costs along the value chain.

Therefore, starting from an overview of the current BIPV process and the related potential improvements collected from the state of the art and user-stories of BIPV stakeholders, the main contributions of this deliverable are represented by the information management strategy proposed for the digitalization of the BIPV process, and by its technical translation thought the Digital Adoption Plan for the implementation that will be carried out in Task 6.2 "BIM-based platform for a data-driven cost reduction along the BIPV process".

1.2 Relation with other activities in the project

Table 1.1 depicts the main links of this deliverable to other activities (work packages, tasks, deliverables, etc.) within BIPVBOOST project. The table should be considered along with the current document for further understanding of the deliverable contents and purpose.

Table 1.1 Relation between current deliverable and other activities in the project

Project activity	Relation with current deliverable
D1.2	D6.1 provides inputs for the current BIPV process stages to be used as references for assessing the cost-reduction goals.
Task 6.2	D6.1 provides the theoretical framework and the basics for the technical implementation of the BIM-based platform for a data-driven cost reduction.
WP7	D6.1 identifies the main informative relations among the BIM model of the BIPV project developed thanks to BIM-based platform and the digital model that is required for developing a digital twin for O&M within WP8.

1.3 Reference material

Documentation from Construct-PV European Project (FP7/2007-2013) under grant agreement No 295981. Deliverables and manuscripts regarding the WP5 "Integrated approach: from building components to buildings" [www.constructpv.eu/]

Documentation from PVSITES European Project (H2020) under grant agreement No 691768. Deliverables and manuscripts regarding the WP7 "BIPV software tool" [www.pvsites.eu/]

1.4 Abbreviation list

AEC	Architecture, Engineering and Construction
BEP	Building Execution Plan
BIM	Building Information Modelling
BIPV	Building Integrated Photo Voltaic
CAD	Computer-Aided Design
CAPEX	CAPital Expenditure
DAP	Digital Adoption Plan
IM	Information Management
LCOE	Levelized Cost Of Electricity
LOD	Level of Development
LOG	Level of Geometry
LOI	Level of Information
OPEX	OPerating Expenses
O&M	Operation and Maintenance
ZEB	Zero Energy Building

2 BIPV PROCESS: WORKFLOW, BOTTLENECKS AND PERSPECTIVES OF OPTIMIZATION

HIGHLIGHTS

- *Current BIPV process is fragmented also due to its intrinsic multidisciplinary approach. This can implicate bottlenecks especially in timing management and information workflows, which can make the BIPV process not efficient, thus increasing BIPV costs*
- *To overcome BIPV value-chain fragmentation towards cost reduction, the enhancement of the interoperability among the BIPV work stages is required starting from the early-design stage thanks to the adoption of the BIM approach*

BIPV stakeholders currently dealing with PV design, manufacturing and installation, invest significant amount of resources and time (with an impact on the final cost) to translate potential clients' requests and wishes into a BIPV project proposal with a technical layout, economic offer and feasibility analysis for energy production and installation (efficiency-performance, cost, building skin integration, compliance with regulations, etc.). Typically, the process is highly fragmented so that the information flow is not linear, resulting in significant flaws in the transmission of information. Therefore, there is a large room for process optimization in order to cover the inefficiencies between pre-design, design, manufacturing and installation stages. **An integrated and collaborative digital process** where information is defined, stored and shared between stakeholders through a digital model and an integrated platform, would reduce efforts, time, repetitive work, risk of mistakes, information losses, etc., transforming an almost "manual" and fragmented work into an **interoperable workflow** along the value chain. Overcoming these challenges to support cost reduction of BIPV can be achieved by the implementation of **BIM (Building information modelling/management)** from the construction sector into the BIPV value-chain, in order to introduce a digital and integrated process, supported by methodologies and platforms, ensuring clear structures, efficient processes, less time, lower costs and higher quality across the entire lifecycle.

Once a BIPV system is installed, it is essential to ensure its optimal operation during its whole service life. Therefore, the role of the digital model for the energy management is also another important link to achieve an optimal energy use, O&M, towards a digital twin able support a data driven failure detection and diagnosis. The **fragmentation of the value chain**, especially in BIPV, where building and electrotechnical sectors need to work in a coordinated way, is a real threat for the competitiveness of the sector. In fact, a considerable share of cost matrix for BIPV systems is not only related to the product (module, BOS, etc.), manufacturing and operation but also to inefficiencies along some project stages that affect the final cost. So far, BIPV is still not supported by a completely digitized process which ensures clear structures, efficient processes, lower costs, less time and higher quality across the entire lifecycle. In the **construction sector**, BIM working methods are already at a mature level in the practice, and digitalization is seen as being a key contributor in driving the estate to be more energy and cost efficient from both a CAPEX (capital cost) and OPEX (operating cost) perspective. Improving the operational efficiency of buildings by using real-time data could lower total energy consumption between 2017 and 2040 by as much as 10%. The widespread deployment of active controls, assuming limited rebound effects, would save up to 65 PWh cumulatively to 2040, or twice the energy consumed by the entire buildings sector in 2017 (1).

Also the **energy sector** has begun a fundamental transformation from the old analogue system to a fully digital network. Although the energy sector has been an early adopter of digital technologies, solar PV has a huge amount to gain from this, with new ways of selling, controlling and gaining revenue from smart PV emerging from a digitalized electricity ecosystem. Digitalization holds the potential to build new architectures of interconnected energy systems, including breaking down traditional boundaries between demand and supply and between energy and building systems. Namely, the improvement of processes for a Solar Industry 4.0 and the challenge to connect digital technology from small-scale PV to fully aggregated Virtual Power Plants and to a whole digital process is one of the key-topics today. The members of SolarPower Europe Digitalization & Solar Task Force (2) at the SolarPower Summit 2017 declared that they:

- Believe that the digitalization of the electricity ecosystem can improve the customer experience of using solar and increase engagement, make the process of going solar more convenient and make the billing process more transparent.
- Highlight how Solar Industry 4.0, and in particular digitalization and decentralized decision-making, can improve processes, increase efficiency and bring costs down in solar, which will in turn help tackle energy poverty.
- Highlight how smart buildings can bring a holistic approach to electricity, heating & cooling and mobility, creating demand flexibility and increasing solar self-consumption rates.
- Underline the importance of digitalization as a means to better integrating solar PV into the existing grid, helping to modernize the grid, and as a tool for solar to provide and be remunerated for new services to the system.

Among the SolarPower Europe's "Seven commitments on digitalization" (3) are listed:

- Reducing costs: We will use digitalization to make solar more cost-effective both in terms of up-front costs and levelized cost of electricity (LCOE) and increase system availability and reliability, thus enhancing the competitiveness of solar.
- Interoperability: We will encourage the interoperability of software with compatible hardware, to enable the transfer and sharing of data that is both secure and efficient

Use digitalization to develop flexibility markets with more automated tools and standardized products is one of the focus to ensure that EU-level work on standards and interoperability, within the Digital Single Market includes solar PV systems, smart buildings and smart grids. Encourage the Commission to come forward with its "baseline" standardized data format as soon as possible, which individual device or service manufacturers will then add additional features to, is one of the focus at European level (4). The baseline for the project developments is BIMSolar software, developed by project partner EnerBIM within PVSITES project, which provides a web-services based platform for the simulation of BIPV systems PV and energy performance, as a support for the pre-design and design phases of a BIPV installation. Existing analysis rates the BIM positive impact on a closer cost control by project teams and reducing final construction cost toward the middle range of 5-10% (5). A first step for improving the BIPV process in order to support interoperability, integrated approach and cost-reduction is represented by the identification of the current main barriers that affect the process, and, thus, the definition of the needs for enhancing such a process. For this reason, this chapter includes the main steps of the research methodology:

- A **state of the art** about the current BIPV process, that has been developed both thanks to the literature review and the collection of user-stories from real BIPV players (Section 2.1);
- A definition for a **reference BIPV process** (Section 2.2) that serves as a framework for the identification of the stakeholders' needs and the consequent improvement strategies;

- The main requirements and relevant information needs in the different work stages which still represent **bottlenecks** and lack of interoperability;
- The **perspectives for process improvement**, through interoperability and implementation of a BIM-based approach towards cost-reduction (Section 2.3)

We relied on a strong cooperation with project partners who gained several years of experience in the real construction process and provided the main information to ground the analysis. In detail the research steps were articulated in:

- **literature review** of scientific articles and reports about BIPV installations and processes,
- **collection of feedback** from real BIPV players and their experiences about the BIPV process,
- **elaboration of feedback and information gathering** through an analysis matrix including the process work stages and the real stakeholders.

Thanks to this framework, the next chapters will define the main work stages of the BIPV process, the information categories, the key-stages and the main information modeling/management (IM) strategies to effectively implement a digital process as well as a collaborative/interoperable BIM-based approach to reduce costs along the value chain.

2.1 State of the art of the BIPV process

As a general approach, the BIM (Building Information Modeling) methodology widely used in construction industry can be transferred to PV and BIPV processes. However, a first step is represented by the definition of a reference process map aimed to highlight the main work stages in the value-chain on which the current main barriers and needs to improve interoperability are detected, towards the definition of a full digital process for the solar sector. In (6) and (1),a literature review for conventional installation (utility scale, large solar rooftops) was carried out in order to identify the main stages of the current PV processes, ranging from manufacturing to dismantling of the PV plant and components recycling. In the following, we will focus on BIPV literature review and BIPV user stories in 2.1.1 and 2.1.2 respectively, as well as in adopting a definition for a reference process value-chain in 2.2. This is a first step in order to understand how the process is structured, with the goal to detect limits and bottlenecks and then cover a further step for BIPV in next research.

2.1.1 Literature Review

In order to collect information about the BIPV process, some scientific manuscripts and other reports have been retrieved. Even if there is a huge amount of literature about BIPV, there are few documents reporting the BIPV process and related stages.

2.1.1.1 Manual for BIPV Projects (2011)

This manual has been developed “to provide an overview of the design potential of BIPV modules and the factors that influence planning considerations, and can be used as a guideline for relevant projects” (7).

Even though in this manual there is not a specific section concerning the BIPV process, Figure 2.1 reports the main stages for designing efficiently a BIPV system, as well as the parties involved. In detail, the first stage is strictly related to the preliminary building design phase where it is strategic to consider also BIPV. In the second stage, the BIPV manufacturer provide information about products and possible design options, whereas the electrical engineer provide support for the electrical installation. The third stage concerns the detailed definition of the specifications of BIPV system which are needed for the fourth stage, where the specifications are used to develop the specific BIPV products. Once the BIPV products are realized, the BIPV system is installed (stage 5).

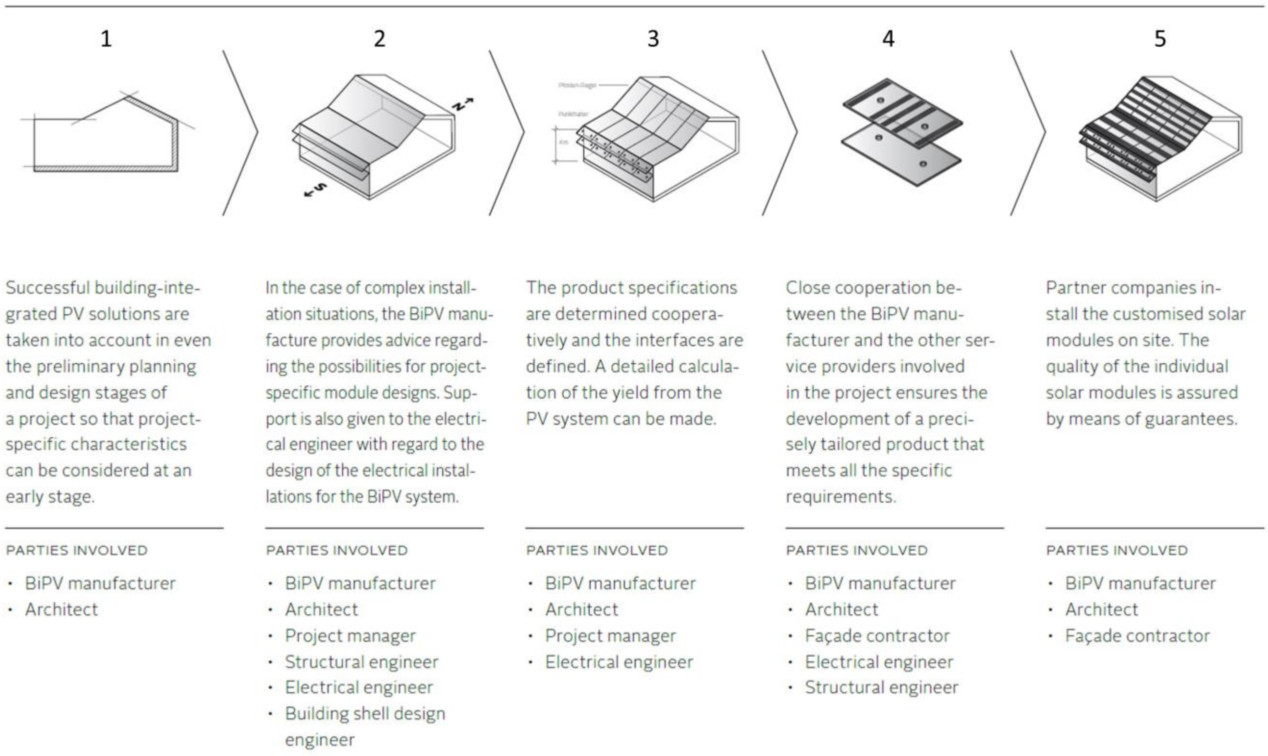


Figure 2.1. Manual for BIPV Projects. Source: (7).

2.1.1.2 BIPV value chain (2018)

In order to identify barriers and facilitators for BIPV adoption in (8), a BIPV value chain has been proposed, as shown in Figure 2.2, including also relevant stakeholders.

In this case, the BIPV process is considered in a holistic perspective starting from the upstream process (***manufacturing stage***) to the downstream process: the second stage of the BIPV process concerns the ***financing*** of the project, the third stage consists in the ***project planning and administration***. Hence, the ***installation*** and the ***grid integration*** are included as following stages, as well as the ***O&M stage***.

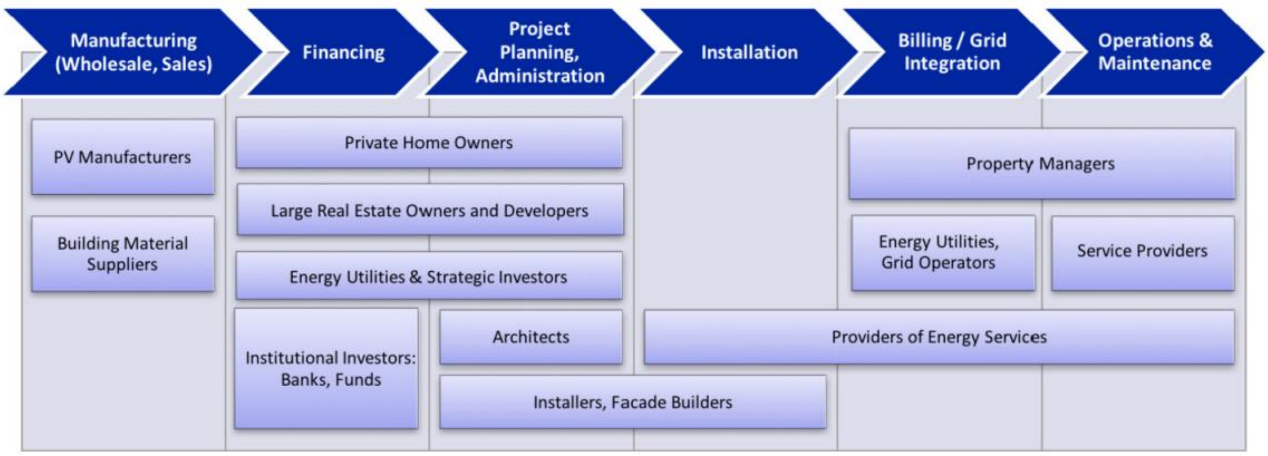


Figure 2.2. BIPV value chain. Source: (8).

2.1.1.3 BIPV in Construction (2018)

The BRE National Solar Centre provides a document that "looks at the division of roles and responsibilities for BIPV project delivery" in order to identify synergic approaches to incorporate efficiently BIPV into building envelopes (9).

In particular, the BIPV process is analyzed by considering the British building process described by the RIBA (10). Each BIPV stage – here called "task" – is associated to the building' process stage in order to give insights to all the stakeholders involved in the realization of a BIPV envelope. What is interesting to note is the comparison among the typical scheduling of BIPV task (blue section in Figure 2.3) and the ideal scheduling (green section in Figure 2.3).

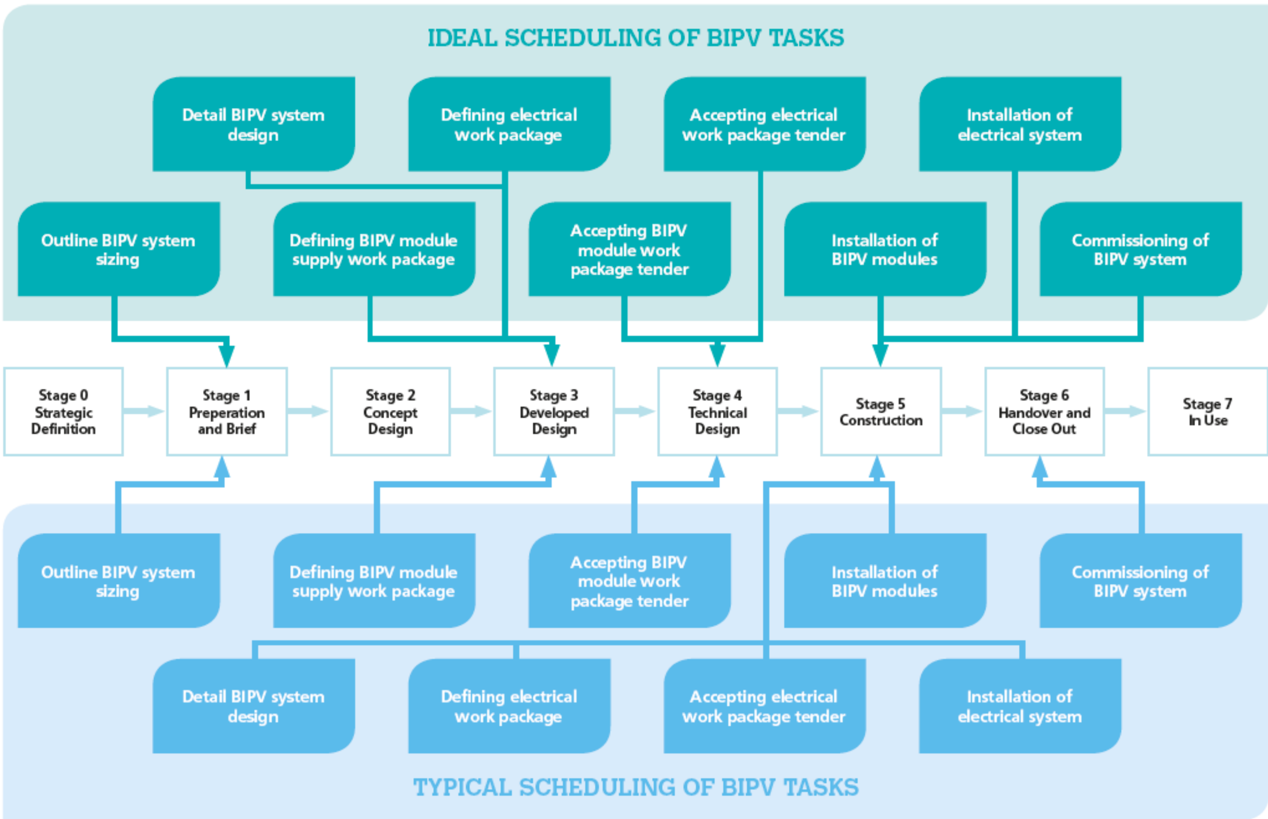


Figure 2.3. BIPV in Construction. Source: (9).

2.1.2 Feedback from real BIPV experiences and stakeholders

In order to deepen the analysis about the current BIPV process, beyond the literature review, specific experiences from real BIPV stakeholders have been collected. Indeed, thanks to the collection of information from real BIPV players, a better understanding of the BIPV process and the workflows is possible.

a) Manufacturers

BIPV Manufacturers usually provide also technical advices on the BIPV project, starting from the design stage till the construction stage. For instance, Onyx provides a general plan of work as a guide for developing BIPV projects (11), that can be modified depending on the peculiarities of each project. This work-plan consists of four main stages (Figure 2.4), which are:

1. ***Project design***, when clients' requirements are translated into solution adapted to their needs and technical information,
2. ***Project pre-construction***, when the detail design is achieved and fabrication starts,
3. ***Project construction***, when the procurement is set and the realization starts, and
4. ***Project hand-over***, that includes all the necessary tasks to deliver the project to the client.

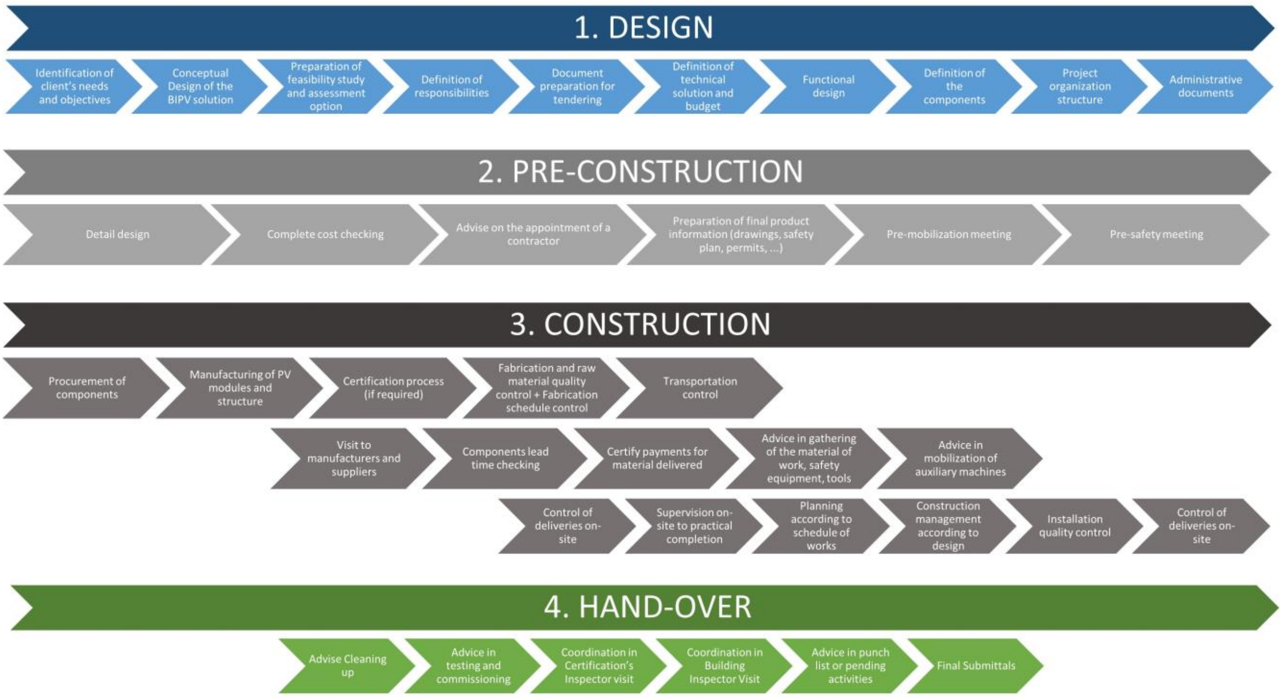


Figure 2.4. Onyx Plan of Work. Source: (11)

b) BIPV Engineers

Thanks to the collection of feedback from BIPV engineers who operate in the BIPV field and internally to the Consortium, it has been possible to draft the BIPV process, and the relation with the traditional building process as reported by RIBA.

The BIPV process is subdivided into in the upstream and the downstream processes and, in detail, it consists of 6 main stages, as shown in **Error! Reference source not found.**. The stages are the followings:

1. ***Conceptual design***, when the architect develops the conceptual model of the BIPV project,
2. ***Developed design***, when the conceptual design is transferred to the BIPV manufacturer, the building envelope engineer, the electrical engineer and the structural engineer. Indeed, they develop the preliminary BIPV project that also contains the economic offer,
3. ***Technical design***, that can be developed after the architect's acceptance by the BIPV manufacturer, the building envelope engineer, the electrical engineer and the structural engineer, which are also responsible of carrying out the detailed design,
4. ***Construction stage***, that can be started by the façade or roof contractor after the approval of main contractor and ends with the realization of the "as-built" BIPV project,
5. ***Hand-over and close out***, when the grid connection and the commissioning are carried out, and
6. ***O&M***, that is the stage where the BIPV system operates.

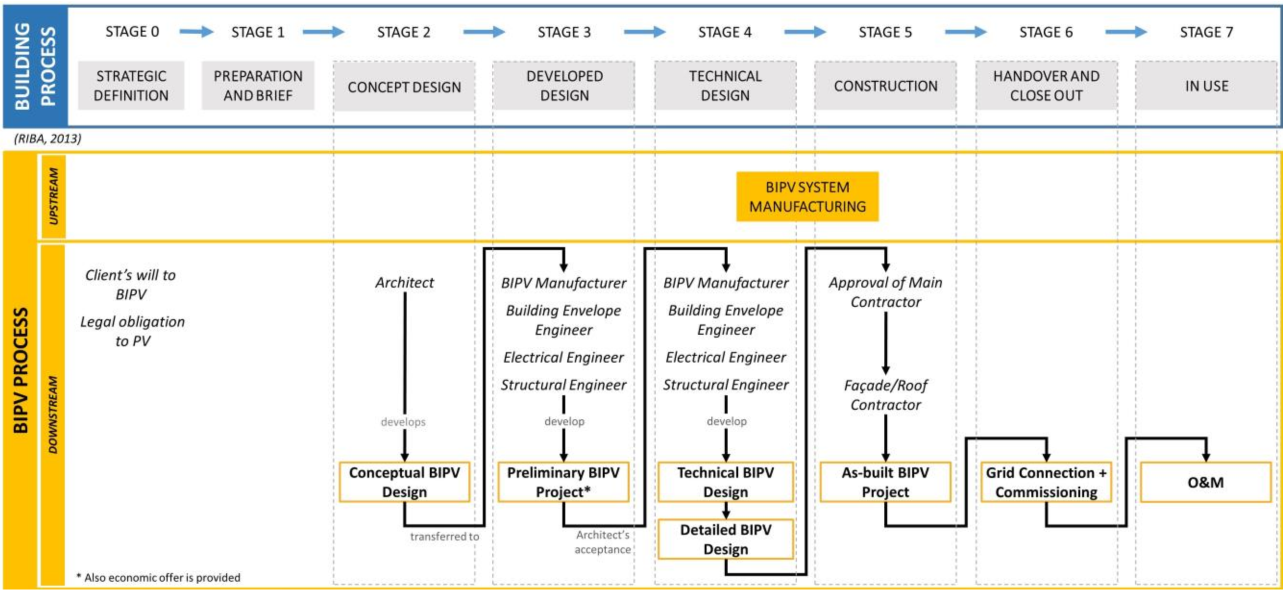


Figure 2.5. BIPV process retrieved from BIPV engineers experience

c) Architects and Building Skin Contractors

In order to collect as much information as possible about the BIPV process, an internal workshop with Viriden and Partners AG and Ernst Schweizer AG together with SUPSI and EnerBIM has been organized in Zürich. In particular, this workshop has allowed to analyse the specific phases related to BIPV project development as well as their relations with the building process and the main BIPV stakeholders involved in this process.

The BIPV process arising from this workshop is related to the Swiss context (due to the experience of the workshop's participants) and for this reason the Swiss standard SIA 112 (12) has been used as a reference for the analysis of the BIPV process.

Specifically, there are four main stages for the design of BIPV projects (Figure 2.6), which are the followings:

1. ***Project definition and feasibility study***: at this stage (correspondent to the SIA 112 phase 2.1), the Solar Architect drafts the building volume and can ask the BIPV Consultant to estimate the solar potential (meaning the average potential solar irradiation of surfaces),
2. ***Preliminary project***: in parallel to the architectural studies about the building's volume, the positioning and size of openings and balconies (during phase 3.1 of SIA 112), there is the selection of the type of technological substructure, the selection of the type and appearance of BIPV module, as well as the preliminary estimation of the BIPV potential (meaning the potential electrical production), which are carried out by the Solar Architect together with the BIPV Consultant and the BIPV Manufacturer,
3. ***Construction project***: once the building envelope is defined (during phase 3.2 of SIA 112), the BIPV modules and the grid layout can be determined together with the definition of the specific mounting structure. At this stage, the BIPV potential can be better defined,
4. ***Final construction project***: when the building envelope project is defined (during phase 5.1 of SIA 112), the detailed projects of the mounting system and the BIPV system are delivered by the BIPV Manufacturer, the Structural Engineer and the Electrical Engineer. At this stage, the detailed estimation of the BIPV yield can be performed.

SIA 112 BUILDING PROCESS	Phases	1. STRATEGIC PLANNING	2. PRELIMINARY STUDIES		3. PROJECT PLANNING			4. TENDER	5. CONSTRUCTION	
	Sub-phases		2.1. PROJECT DEFINITION + FEASIBILITY STUDY	2.2. SELECTION PROCEDURE	3.1. PRELIMINARY PROJECT	3.2. CONSTRUCTION PROJECT	3.3. PERMITS OBTAINING PROCEDURE		5.1. CONSTRUCTION PROJECT	5.2. REALIZATION
BIPV PROCESS	Main Stakeholders		Solar Architect		Solar Architect BIPV Consultant BIPV Manufacturer	Solar Architect BIPV Consultant BIPV Manufacturer Structural Engineer Electrical Engineer			BIPV Manufacturer Structural Engineer Electrical Engineer	
	Phase description		• Definition of building volume • Solar potential estimation (irradiation)		• Study of building volume, positioning and size of openings, positioning and size of balconies • Selection of type of technological substructure • Selection of type of BIPV material / appearance • BIPV potential estimation	• Definition of building volume, positioning and size of openings, positioning and size of balconies • Definition of the BIPV modules • Definition of the technological substructure • BIPV potential estimation			• Detailed building envelope project for construction • Detailed project of substructures • Detailed project of BIPV (modules, electrical layout) • Detailed estimation of BIPV yield	

Figure 2.6. BIPV process arising from internal workshop with Viriden and Partners AG and Ernst Schweizer AG

2.2 Definition of the current reference process for BIPV

Grounding on the state of the art of the BIPV process presented in Section 2.1, the current reference BIPV process is described in this section. Even though different BIPV processes can be set, depending on the architectural approaches and national regulations, the main common elements have been analysed and included within main key-stages, which are also in relation with the traditional building process. The major goal was trying to have a representative description of its stages, in order to identify the key- activities of the many parties involved in the design, construction and management of a project. In fact, designing BIPV means also designing active building envelopes that require to be coherent with the whole building process.

Therefore, Table 2 presents the key stages of the current reference BIPV process and their relations with the analysed building processes:

- the British building process from RIBA (10),
- the Swiss building process from SIA 112 (12),

which are the two building processes mentioned in the literature review (Section 2.1.1) and from the real BIPV stakeholders (Section 2.1.2). Even though specific standards about the building process can be identified in other countries, the main stages reported in Table 2 represent the generic key stages that can be used also in other national contexts.

Specifically, the main stages of the current BIPV process (Figure 2.7) are briefly described together with the role of the main stakeholders involved (Figure 2.8):

1. ***Strategic Planning***

   In this stage, the definition of the energy goals is carried out by the **architects** (eventually, the architectural team with specific consultants). These energy goals can arise from different "sources", such as energy requirements/standards or voluntary building energy performances required by the **client**. This stage is developed during the strategic planning phase of the traditional building process where the client's needs and objectives are set, not only for energy aspects but also for functionalities, architectural and economic aspects.

2. ***Conceptual BIPV Project***

   During this stage, the BIPV envelope is shaped by the **architect** as a generic study model, meaning that the most suitable surfaces for hosting BIPV are identified together with the main technologies that can be adopted. Thanks to this conceptual design, a preliminary estimation of energy contribution of BIPV can be carried out together with a preliminary evaluation of budget, which are the basis for the **client**'s strategical decisions.

3. ***Developed BIPV Project***

   The developed BIPV stage allows the architect to finalize the BIPV envelope design thanks to the support of the **BIPV consultant** and, in some cases, the consultancy of the BIPV manufacturer and the structural engineers. Indeed, in this stage, the BIPV design that suits energy, aesthetical and economic goals is carried out.

4. ***Technical BIPV Project***

   During this stage, the **BIPV Consultant**, the **BIPV Manufacturer**, the **Structural Engineer** and the **Electrical Engineer** work together to deliver technical detailed BIPV documentation, plans, notices to open tender to manufacturers and installers, whereas the **client** takes the final decision about BIPV project acceptance.

5. ***BIPV Permits Procedures***

   This stage is characterized by the activity of obtaining BIPV permits, in accordance with local administrative procedures.

6. ***BIPV Tendering Procedure***

   The tendering procedure consists of a phase where the contractors for realizing the BIPV envelope are selected. Depending on the country and on the local regulation, as well as on the size of the building project, there can be different procedures. Generally speaking, for small building projects, the contractors are also the designers of the BIPV system, mounting structures and electrical layout.

7. ***Construction BIPV Project***

   During this stage, the technical design is translated by the **BIPV Consultant** into technical drawings and details for the realization of the BIPV envelope.

8. ***BIPV Installation on-site***

   The BIPV installation means the realization of the BIPV envelope by the selected contractors, starting from the substructures until the electrical connection to the grid or internal network.

9. ***Hand-over***

   In this stage, the BIPV envelope is delivered to the client.

10. ***O&M***

    This stage is usually partially considered in the BIPV value chain, but it represents the in-use stage where electrical parameters are monitored and maintenance operations are carried out, generally by the electrical contractor.

Moreover, Figure 2.9 details the input of each stage, the description of the elaboration performed in that stage and the tools used to achieve the outputs.

BUILDING PROCESS	Generic Phases	STRATEGIC PLANNING	PRELIMINARY STUDIES			PROJECT PLANNING			TENDER	CONSTRUCTION			OPERATION	
	RIBA Phases	0. STRATEGIC DEFINITION	1. PREPARATION & BRIEF	2. CONCEPTUAL DESIGN		3. DEVELOPED DESIGN	4. TECHNICAL DESIGN			5. CONSTRUCTION		6. HANDOVER & CLOSE-OUT	7. IN USE	
	SIA 112 Phases and Sub-phases	1. STRATEGIC PLANNING		2. PRELIMINARY STUDIES		3. PROJECT PLANNING			4. TENDER	5. CONSTRUCTION			6. OPERATION	
				2.1. PROJECT DEFINITION	2.2. SELECTION PROCEDURE	3.1. PRELIMINARY PROJECT	3.2. CONSTRUCTION PROJECT	3.3 PERMITS-OBTAINING PROCEDURE		5.1. CONSTRUCTION PROJECT	5.2. REALIZATION		6.1. OPERATION	6.2 MAINTENANCE
BIPV PROCESS	Stage	**STRATEGIC BIPV PLANNING** “when client’s objectives are set”	**CONCEPTUAL BIPV PROJECT** "when theories meet reality into drawings and study models"			**DEVELOPED BIPV PROJECT** "when the design starts to become real"	**TECHNICAL BIPV PROJECT** "from drawings to rigorous technical drawings"	**BIPV PERMITS PROCEDURE**	**BIPV TENDERING PROCEDURE**	**CONSTRUCTION BIPV PROJECT** “from technical drawings to instructions”	**BIPV INSTALLATION ON-SITE** “when project is realized”	**HANDOVER** “when project is delivered”	**O&M FOR BIPV** “when the project works”	
	Defini-tion	Generic definition of the energy goal (e.g. BIPV to fulfil electrical demand ... TBD)	Building envelope is shaped and preliminary estimation of energy contribution of BIPV to self-sufficiency, preliminary evaluation of budget... are provided			Building design has been finalized and BIPV modules that suits energy, aesthetical and economic goals are selected	Technical detailed BIPV documentation, plans, notices to open tender to manufacturers + installers	BIPV Project Acceptance	Selection of contractors for BIPV realization	Technical design is translated into details for BIPV modules realization and BIPV envelope installation	BIPV envelope is realized and connected		Electrical parameters are monitored and maintenance operations are carried out	

Figure 2.7. Relation among the building process and the BIPV process

BIPV STAKEHOLDERS	STRATEGIC BIPV PLANNING	CONCEPTUAL BIPV PROJECT	DEVELOPED BIPV PROJECT	TECHNICAL BIPV PROJECT	CONSTRUCTION BIPV PROJECT	BIPV INSTALLATION ON-SITE	O&M FOR BIPV
Client	• Definition of desires in terms of energy performances and costs	• The client may challenge the architects. • The client takes strategic decisions considering the architectural works/preliminary studies/competition's goals		• Evaluation and acceptance of the technical solution			• For small residential BIPV system, the client/building' owner is responsible for the O&M
Architect	• Translation of client's desires into objectives	• Development of a conceptual BIPV project to the client in order to demonstrate preliminary energy gains and cost aspects	• Delivery of the conceptual project to BIPV consultant (after client approval) and evaluation of design alternatives together with BIPV consultant	• Evaluation and acceptance of the technical solution			
BIPV consultant	• Early Consulting position to support architect's decision	• Early Consulting position to support decision or, in big projects, development of the conceptual BIPV project together with the architect	• Translation of the conceptual design into developed design alternatives describing the grid layout, the modules to be used, the energy yield and the total cost • Iterative process with architect to define the final design	• Starting from the developed design, development of the engineering/technical model of BIPV system with detailed estimation of energy yield, self-sufficiency and economic aspects are determined.	• Development of technical drawing for the realization of the BIPV system • Deliver of technical drawings and details of the project to BIPV manufacturers and to façade/roof contractors		
Structural engineer			• Early consulting to provide feasibility assessment studies and preliminary costs about mounting structures	• Receives the 3D model of BIPV envelope and designs the mounting system accordingly			
BIPV module manufa-cturer		• May provide early Consulting position to support decision	• May provide early consulting to support the development of custom BIPV modules	• Consulting to provide data of custom BIPV modules • Consulting to provide data about BIPV modules	• Manufacturing of BIPV modules		
Electrical engineer				• Consulting to realize the electrical configuration (when required)			• Consulting to realize the O&M system (when required)
Façade / roof contractor					• Manufacturing of substructures and mounting systems	• Installation of BIPV system	
Electrical contractor						• Installation of electrical systems and connections	

Figure 2.8. BIPV stakeholders' roles in current BIPV process

BIPV PROCESS	Stage	STRATEGIC BIPV PLANNING	CONCEPTUAL BIPV PROJECT	DEVELOPED BIPV PROJECT	TECHNICAL BIPV PROJECT	CONSTRUCTION BIPV PROJECT	BIPV INSTALLATION ON-SITE	O&M FOR BIPV
	Input	• Electrical/Energy targets from regulations (if present) • Client's desire about energy labels (if present) • Client's budget • Client's desire about profit targets (as a productive asset)	• Energy targets (from strategic planning) • Architect's vision / intuition about solar architectural surfaces	• 2D drawings with sketches about surfaces covered by BIPV (from conceptual design) • Separated documentation about energy and cost estimations (from conceptual design)	• 3D model of BIPV system (with modules type and grid layout) (from developed design) • Documentation about cost and energy assessment (from developed design)	• Documents and drawings developed by the BIPV consultant, structural engineer and electrical engineer	• Technical drawings for the realization of BIPV systems • Guidelines for installation of BIPV modules • Guidelines for installation of substructures • Guidelines for installation of electrical components	• Technical drawings about the BIPV system (from BIPV consultant) • Electrical component and BIPV modules datasheets
	Description	The architect catches the client's desires and, thanks to them, the architect defines energy targets	The architect identifies surfaces available for BIPV and provides a preliminary rough energy estimation and cost assessment. In project competitions, there can be a BIPV consultant that provides such data	Starting from the sketches and the documentation about energy and costs, the BIPV consultant develops design variants that are discussed with the architect till the selection of one variant	• The 3D model of BIPV system with modules and grid-layout is delivered to the structural engineer that designs mounting systems and substructures. • The 3D model is also used by the BIPV consultant or the electrical engineer for the design of the electrical configurations	• The architect and the client approves the project • The BIPV consultant delivers technical drawings and details for BIPV manufacturers, as well as technical drawings and details for substructure manufacturers	• Façade/roof contractors install the BIPV modules and substructures • Electrical contractor installs the electrical components	• Once the BIPV system is connected, main electrical parameters are evaluated. • Depending on failures or programmed operations, maintenance is carried out (e.g. cleaning, periodic checks of electrical connection integrity, and confirmation of functionality of safety and isolation devices...)
	Common Tools		Traditional CAD/BIM architectural tools	CAD/BIM tools for the BIPV modules' design	• Specific tools for electrical design of PV (e.g. PVSyst, ...) • Specific tools for substructures designs	CAD/BIM tools		Traditional meters or web-interfaces for real-time monitoring (when most advanced inverters are used)
	Output	• Energy targets	• 2D drawings with 3D sketches about surfaces covered by BIPV • Separated report with energy and cost estimations	• 3D model of BIPV system (with modules type and grid layout) • Documentation about cost and energy assessment	• 3D model of BIPV system • 3D model of substructures • 3D model of electrical components • Documentation about CAPEX, energy yield, contribution of BIPV to the energy self-sufficiency (sometimes)	• Technical drawing for manufacturing of BIPV modules • Technical drawing for manufacturing of substructures • Technical drawing for the realization of the BIPV system		• Report about energy performances

Figure 2.9. Current reference BIPV process

2.3 From bottlenecks to perspectives for process improvements towards cost-reduction

By means of the reference BIPV process described in paragraph 2.2 and the analysis of the information collected from Consortium Partners, it has been possible to detect not only the strengths and the weaknesses of the current process but also the needs expressed by BIPV stakeholders for enhancing the BIPV process towards cost-reduction.

In detail, the strengths and the weaknesses are summarized in Figure 2.10, whereas specific needs of BIPV stakeholders are reported in Figure 2.11 by considering the different work stages and stakeholders.

The collection of these information has allowed to draft the potential improvements for the BIPV process towards cost-reduction. In particular, what clearly arises is the fragmentation of the BIPV value-chain and specifically:

1. the lack of an information workflow capable to describe which data (architectural, electrical, structural, etc.) are required to one stage to another,
2. the not-efficient communication among stakeholders of the different disciplines (architect, BIPV consultant, BIPV manufacturer, structural engineer and electrical engineer) involved in the BIPV process,
3. the lack of a framework to handle data from different disciplines in a single environment capable to represent BIPV components as both building elements and electrical devices.

As emerged from the real stakeholders the main **weaknesses** of the current process can be related to the following categories:

- *time*: there are some time-spending activities for the evaluation of the different BIPV solutions since the conceptual BIPV design stage till the construction BIPV project stage. The amount of hours for this evaluation can be significantly reduced depending on the specialist's knowledge, however there is often a recursive process to provide different scenarios for the different BIPV solutions,
- *information*: especially in the preliminary stages, the information about BIPV costs and energy production are not realistic and can be retrieved from standard PV, thus involving huge errors.
  In addition to this, there is still the need to combine different data and files containing different information categories, ranging from the architectural model of the building to the electrical data of BIPV components.

In this framework, stakeholders call for specific **needs** in order to overcome the current barriers. Some of the most relevant and recurrent are represented from:

- user-friendly tools for *fast evaluation of the solar potential of the building in the conceptual BIPV design stage*,
- *interoperability of the building's architectural model and related BIPV data* from the conceptual BIPV design stage till the construction BIPV project stage,
- *design of custom BIPV modules* (colored glass, transparency, surface texture) in accordance to feasibility rules provided by manufacturers and evaluation of the new product in terms of aesthetics and electrical production,
- *optimization of the substructure / mounting system* in accordance to the modules' layout,

but a complete description of the needs for specific BIPV stakeholders are described in Figure 2.11.

BIPV PROCESS		STRATEGIC BIPV PLANNING	CONCEPTUAL BIPV PROJECT	DEVELOPED BIPV PROJECT	TECHNICAL BIPV PROJECT	CONSTRUCTION BIPV PROJECT	BIPV INSTALLATION ON-SITE	O&M FOR BIPV
	Weaknesses	• Lack of informative materials about BIPV buildings for architects	• Assumptions about BIPV might derive from literature data about generic PV and there can be under-estimations of costs or over-estimation of energy yield • Additional costs for other software to perform solar simulations or additional cost of BIPV consultant • Time-spending activity for the evaluation of different solutions • Energy Performance Targets are not clearly defined	• Time-spending activity for the realization of the 3D building model starting from the 2D drawings and sketches of the conceptual stage • Time-spending activity for the design and simulation of different solutions • Cost evaluation is managed as separated topic • Iterative process among BIPV consultant and the architect to evaluate and select the solution	• OPEX, LCOE are usually not assessed • Interoperability of formats among BIPV consultant, structural engineer and electrical engineers	• Time-spending activity to combine different data and files • Time-spending activity to deliver technical drawings for manufacturing of BIPV modules and substructures		• The design of the O&M system (when required) shall be developed from zero
	Strengths		• Experience of the architect in screening the most reliable solutions	• Experience of the BIPV consultant in screening the most reliable solutions	• OPEX and LCOE from similar projects are available			

Figure 2.10. Strengths and weaknesses of the main key-stages of the BIPV process

NEEDS OF BIPV STAKEHOLDERS	STRATEGIC BIPV PLANNING	CONCEPTUAL BIPV PROJECT	DEVELOPED BIPV PROJECT	TECHNICAL BIPV PROJECT	CONSTRUCTION BIPV PROJECT	BIPV INSTALLATION ON-SITE	O&M FOR BIPV
Architect	• Translation of client's desires into objectives	• Rapid changes of 3D building model and fast evaluation of solar potential as add-in of common architectural tools • Fast evaluation of the energy self-sufficiency due to BIPV • Definition of the project location and easy inclusion of surrounding buildings	• Evaluation of colored glass or printed glass, to choose transparency, to upload textures				
BIPV consultant	• Material to support architect's decision	• Possibility to quickly handle feasibility studies and give good options in contextual and collaborative mode	• Obtaining a 3D model of the building with preliminary sketches of BIPV surfaces from conceptual design • Custom design of BIPV modules: inclusion of standard design rules concerning minimum spacing, power degradation of coloring etc. to reduce the risk of not realistic BIPV modules designs and to improve the efficiency of the manufacturing • Evaluation of colored or surface textures for BIPV modules • Possibility to identify low performing modules in order to replace modules with dummies • Possibility to select preferred modules (supplier evaluation) • Obtaining module's parameters (e.g. energy and costs)	• Starting from the developed design, development of the engineering/technical model of BIPV system with detailed estimation of energy yield, self-sufficiency and economic aspects are determined.	• Development of technical drawing for the realization of the BIPV system • Deliver of technical drawings and details of the project to BIPV manufacturers and to façade/roof contractors		
Structural engineer			• Optimization of module grid/layout of modules and dummies • Rear frame associated to the PV-laminate dimensions	• Obtaining a 3D model of BIPV modules (size&position) • Possibility to select and design preferred substructures			
BIPV manufa-cturer	• Showcase of the potentialities of BIPV products and realized solar buildings to be selected later		• Providing evaluation of the custom BIPV modules in terms of construction feasibility, energy and costs		• Need to receive drawings and quantities for BIPV module production		
Electrical engineer				• Obtaining a 3D model of BIPV envelope with modules position			• Obtaining the as-built BIPV system (when O&M is required)
Façade / roof contractor					• Need to receive drawings and quantities for substructures and mounting systems production	• Obtaining technical drawings and instructions for BIPV system installation	
Electrical contractor						• Obtaining technical drawings and instructions for electrical component installation	

Figure 2.11. BIPV stakeholders' needs for improving BIPV stages

In order to try to overcome this fragmentation and meet the BIPV stakeholders' needs, the adoption of the BIM methodology seems to play a key-role. Indeed, in the AEC sector, BIM provides the opportunity to integrate the activities of different stakeholders on building projects with the final aim to increase efficiency of the process by enhancing communication and reducing errors, saving time and controlling costs. Literature about BIM benefits for the AEC sector can be found in (13).

One of the core concepts of BIM is the contextual and collaborative environment that allows to efficiently manage information coming from different fields thanks to data interoperability.

In fact, implementing a BIM-based approach to BIPV process can offer the following **benefits**:

- the opportunity to manage the information workflows (e.g. the one related to costs, the one related to electrical data, the one related to BIPV products, etc.) in a structured process, thus avoiding complex and laborious solutions created *ad-hoc* for managing all these workflows,
- the chance to reduce technical errors and conflicts within a project thanks to the multidisciplinary environment, thus improving the efficiency of the BIPV process,
- the possibility to enable different stakeholders to work together with a common and understandable "language" that allows to exchange data without losing information, thus reducing the need to run again the same stage.
- the opportunity to consider multifunctionality of BIPV products by designing an envelope component that is both a building element and an electrical device,
- the chance to customize BIPV products in order to suit the building envelope, instead of using standard products applied to the building envelope or designed in specific PV software tools.

Moreover, it is important to highlight that few BIM-based approaches have been developed so far for BIPV (e.g. in the European Projects CONSTRUCT-PV and PV-SITES) but efforts are still required to have an efficient BIM-based BIPV process. Another important element that can support the improvement of the BIM-based process towards cost-reduction is represented by the possibility to design BIM BIPV objects to be implemented into BIPV envelope projects.

Therefore, considering the potentialities of the BIM approach, Section 3 will describe how the BIPV process can be translated in accordance to a BIM perspective by providing a framework for the information management along the BIPV process and for the information modeling of BIPV objects with the final aim to include cost assessment and manage them.

3 A BIM-BASED APPROACH FOR THE BIPV PROCESS: INFORMATION MANAGEMENT SUPPORTING COST OPTIMIZAZION

HIGHLIGHTS

- *A BIM-based approach is envisioned to merge the different disciplines and stakeholders of the BIPV field in order to increase the efficiency of the BIPV process and manage costs along the value-chain*
- *An information management strategy for a BIM-based process is presented. This strategy includes the most relevant information categories that need to be managed at each BIPV stage, as well as KPIs. The latter, indeed, can be used as indicators for addressing decision-makers in developing the "optimal" BIPV solution in terms of energy and costs.*
- *Through an information modelling strategy, the geometrical and not geometrical information to be embedded in BIM BIPV modules are described.*

From the results of Chapter 2 "Current BIPV processes and perspectives for addressing cost-reduction", it arises that a strategical solution to reduce costs in the BIPV process is represented by the adoption of a BIM approach. Indeed, such an approach allows to integrate different disciplines and the different activities of stakeholders involved in the same building project to overcome inefficiencies and reduce unexpected extra-costs due the typical complexity and fragmentation of the building process.

Considering the intrinsic multidisciplinary domain of BIPV, that is both an electrical and building element characterized by several different requirements coming from different disciplines, a BIM-based BIPV process is proposed to cope with all BIPV related aspects and involve BIPV stakeholders in a collaborative and interoperable environment to avoid inefficiencies, bottlenecks and pitfalls, thus reducing BIPV costs.

In accordance with this perspective, this chapter introduces two main topics:

- ***an information management strategy*** that consists in a framework for managing all the information categories which need to be digitalized and embedded in each stage of a BIM-based BIPV process, as well as ***KPIs to manage BIPV project results and performances***, and
- ***an information modeling strategy*** that describes the approach for including all the required geometrical and informative data of BIPV objects to be used in a BIM-based BIPV process

with the final aim of overcoming current bottlenecks and control costs along the BIPV value chain.

3.1 Towards BIM implementation in BIPV sector: previous experiences, missing gaps and next steps

BIPV field is, by definition, an integration of PV and building sectors. On one hand, there is the PV process and, on the other hand, there is the Architecture, Engineering and Construction (AEC) process. In AEC process, digitalization is having a major impact at European and international level. However, few technical information and reference examples still make hard the real implementation in the everyday practice. Mostly in multidisciplinary sectors, like in the field of solar building skins, a clear definition of information categories, criteria and approaches for modelling geometry and information (e.g. LOD), is not yet adopted and standardized in the main work stages of the process. Thus the responsibility matrix, the roles, the digital adoption strategies for the main stakeholders, specifications on information modelling/management, process workflows, interoperability aspects and BIM levels to adopt are not clear, with the result that it is still difficult to implement such a technology within a digitized process. The approach proposed in this work moves from the idea to cover the gap in the digitalization of building envelope systems and, in detail, the building integrated photovoltaic systems, by providing a step ahead for operators in the realization of energy-efficient buildings through a collaborative, efficient and integrated process by supporting the definition of some basic information (6). Some previous studies and ongoing researches already approached the topic of process digitalization towards BIM implementation in BIPV sector. A study was done within the framework of IEA SHC Task 41 – Solar Energy and Architecture (13). In order to analyse the obstacles faced by architects when using the tools for solar design in the conceptual phase, preliminary design phase, detailed design phase and the construction drawing phase of a solar project. However, this study was done through architects' perspective in conceptual phase to construction drawing phase of a solar project. Therefore, it does not consider the needs of other stakeholders and other work phases of the process.

As summarized in the internal report "BIPV Planning: Design and Performance Modelling Tools and Methods" developed in the framework of IEA – PVPS Task 15 (14), several past studies have been conducted to compare the key features of the major tools. Unlike the studies mentioned above provided a comprehensive state of art and details of the tools under availability, factors such as process bottlenecks, interoperability lacks among work-stages, key-aspects of process fragmentation and needs for improvement have not yet been discussed in an applied perspective to support the real market implementation.

A first step in this direction has been done in the framework of IEA – PVPS Task 15, that provided a review report of the available BIPV design and management software with also the objective to provide a first insight into possible limitations and bottlenecks of particular functions, procedures and tools, to target needs and facilitate decision-making of end-users and to propose potential improvements for an integrated solution for PV design and management.

In the European Project Construct PV (www.contructpv.eu), another milestone was developed. Once identified the absence of supporting tools capable to overcome the gap between PV and building sector as a barrier, the project offered a versatile software environment for design and evaluate BIPV customizable components where energy, architectural and construction aspects were jointly taken into account. The software tool and the workflow had the goal to facilitate the stakeholders during the "creation process" of BIPV customized components, since the Early Design Stage, in connection with a BIM-based design approach. The potential link to the manufacturing stage was also offered. The web-tool allowed a real time visualization and customized editing of the BIPV object created by the user considering the different module's materials, glass types and finishing, cell's arrangement, transparency, etc. by also preliminarily assessing the relative influence on the final power of the front layer main features. The transition to a BIM-based process became strategic in order to support the penetration of BIPV within the real Architectural, Engineering and Construction (AEC) process so that the Interoperability was ensured through a plug-in allowing efficient exchange of the defined components as native BIM objects in BIM environment (15).

Another important step for approach the BIPV design in a BIM perspective has been carried out within the European Project PVSITES (www.pvsites.eu/). The aim of PVSITES was to enhance BIMsolar performance through its BIM readiness with market leader BIM solutions (such as Autodesk Revit®) while developing a virtual portfolio of BIM PVSITES products (BIPV BIM objects). The main achievements within this project are the implementation of BIM technology enabling bi-directional set-up of:

- Original BIM model (mainly architectural at pre-design stage) translation and set-up into the BIMsolar software (creation of BIPV layouts from BIPV materials and modules, performance analysis towards feasibility study);
- BIPV BIM objects creation and translation back from BIMsolar to Autodesk REVIT (using the concept of REVIT families of parametric BIM objects).

PVSITES portfolio enables every designer willing to join the BIM and BIPV processes to pre-study integration into the building skin with PVSITES products (such as FLISOM CIGS modules and ONYX Solar crystalline and aSi cell modules). This first step in full BIM adoption focuses only on pre-design stage without cost-reduction model.

The objectives achieved within these projects are relevant but there are still some missing gaps (e.g. focus only a specific stage, need for interoperability among the BIPV value chain, need to design BIPV objects by including also evaluation of energy yield and costs) that required to be filled for supporting the adoption of a BIM approach in the whole BIPV value chain. Indeed, a holistic BIM-BIPV vision should be implemented starting from the conceptual stage (that is recognized as a fundamental stage to implement correctly BIPV in buildings) to the detailed design stage (where energy and costs analyses are needed to grab all the aspects related to BIPV) till the construction and O&M stages, where main un-expected extra-costs can arise.

Currently, there are some commercial BIM software where solar energy analyses for PV have been implemented to favour the design of sustainable buildings. Among the most common ones for architectural purposes, there are Autodesk Revit® where the plug-in "Revit Insight" can be added to analyse the contribution of PV surfaces, which are selected by the user and some standard PV parameters are used for calculating the PV energy yield and related revenues (16), and Nemetschek ALLPLAN® that is provided with the tool PVSOL Expert that allows to electrically design the PV system within the BIM environment (17). Even though these tools provide the chance to include PV analysis in the BIM environment, they do not allow to choose BIPV modules and design custom BIPV envelope elements, which instead are often required when designing BIPV buildings.

Therefore, to effectively support the design of BIPV buildings within the BIM environment, a new comprehensive approach is required to merge efficiently the different disciplines involved in the BIPV domain grounding on the already achieved steps through novel information management strategies for managing BIPV process's efficiency and cost-reduction and new information modelling strategies for developing and using efficiently BIPV products and related data.

3.2 Information management strategy for a BIM-based BIPV process and related KPIs

The aim of this Section is to introduce an information management strategy, depending on users' and stakeholders' specific needs, that can be defined as a theoretical framework for a BIM-based implementation within the BIPV process. Indeed, such a framework can provide a useful basis for the development of reliable and effective design and construction processes supported by a digitized and BIM-based approach.

The main core of this framework, however, is represented by a collaborative and interoperable BIM environment where the BIPV model can evolve both graphically (if needed) and in terms of associated information in accordance with the BIPV process stages.

Therefore, each work stage is described in terms of information categories needed as inputs, the related elaborations and the information categories produced as outputs, which are needed in the following stages. Furthermore, the main KPIs to assess the BIPV project results and cost reduction goals are reported for each stage.

3.2.1 Strategic Planning Stage

The strategic planning stage is crucial for BIPV. Indeed, during this stage, the client presents the project's needs and objectives (business case, sustainability, life cycle, aspirations, etc.) to the architect, who is responsible for the development of initial statement of requirements, feasibility studies and assessment options which can be translated in first project's parameters also by showing potential problems and pitfalls, as wells as alternative options and solutions. It is a discovery phase were mostly BIPV-oriented architects propose BIPV envelopes as a design key-feature to achieve energy goals requirements (when set by regulations) and add "green" value to the building. Purpose of BIM including benefits and implications are advised to the client, including the level and extension, the involved Integrated Team scope, definition of long-term responsibilities.

Therefore, the information categories needed at this stage are:

- ***The energy targets for BIPV*** set by local standards or regulations,
- The voluntary ***building energy labels*** required by the client,
- ***The budget constraints*** set by the client,
- ***The information about similar BIPV real examples with data*** about energy and costs to be presented to the client as demonstrations of possible solutions to be adopted.

At this stage, the definition of KPIs is not possible since BIPV goals are still under discussion, but ***KPIs from similar BIPV buildings can be collected into a digital database*** and used to address achievable BIPV goals and requirements.

3.2.2 Conceptual BIPV Design Stage

The conceptual stage is aimed at obtaining a preliminary BIPV project with the design of BIPV surfaces and preliminary assessment of energy yield and costs. Basic data defining the agreement on Project Quality, protocols, outline of proposals for architectural, structural and environmental strategies and services systems, preliminary cost and energy plans are defined.

Initial model sharing with Design Team for strategic analysis and options appraisal on energy/environmental performance and area analysis, with the identification of the key model elements allow creating concept level parametric objects for the major elements.

To achieve these results, the required information categories from the previous stage are represented by:

- BIPV targets or requirements, set by the client or by regulations,
- budget constraints.

Moreover, additional information is required for developing the BIPV model in the BIM environment, such as:

- ***building location with nearby buildings and obstacles***, to retrieve the correct environmental conditions needed for solar analysis,
- **BIM building model representing the gross volume and shape**, to have a geometrical basis for preforming irradiation simulations,
- ***BIM objects representing the presence of BIPV surfaces***, not detailed graphically but with associated preliminary data for preliminary analyses about energy and costs.

Indeed, all these information categories allow not only to design the preliminary BIPV model that can be shared in a collaborative BIM environment but also to evaluate associated data related to potential energy production, expected investment costs or the potential contribution for the building energy self-sufficiency.

The KPIs of the conceptual BIPV design stage can be the followings:

- ***preliminary BIPV potential*** (kWh/y) that should be in accordance with the BIPV targets, and
- ***preliminary cost impact of BIPV on the whole building cost*** (e.g. € of BIPV/m^3 of the building or € of BIPV/m^2 of the building) that should be in accordance with budget constraints,

which can be used by the architect or the BIPV consultant to evaluate different BIPV design alternatives, as well as to show BIPV results to the client.

3.2.3 Developed BIPV Design Stage

Once the conceptual BIPV design is accepted by the client, the architect, together with the BIPV consultant, can start the developed design stage. The aim of this stage is to detail the information of the preliminary BIPV project by adding specifications about BIPV modules constituting the envelope, such as module type, dimensions, power, detailed costs, positioning and the associated mounting system. Use of project BIM data is needed to include structural and environmental strategies and services systems, cost and energy plans. Data sharing and integration for design coordination and detailed analysis including data links between models, Integration/development of design components, BIM data for environmental performance analysis, export data for Planning Application, possible 4D and/or 5D assessments can be defined in this and/or the next stage.

To achieve this goal, it is necessary to rely on the following data coming from the previous stage:

- ***the interoperable BIM model of the BIPV surfaces*** with the information categories about BIPV potential and preliminary cost impact together with the constraints and the requirements set by the client,

as well as additional information categories such as:

- ***BIPV module datasheet*** including data about electrical, mechanical and geometrical properties,
- ***cost of BIPV modules***, dummies and average cost of associated mounting systems, and
- ***electrical demand profile***

which are needed to carry out more detailed analyses about BIPV potential and investment cost assessment.

Indeed, the final result of this stage is represented by at least the BIM model of the BIPV envelope with:

- the ***BIPV module grid layout***,
- the ***BIPV modules specifications***, including all the information of the datasheet, as well as quantities and related costs,
- the ***estimation of the hourly BIPV production*** and the contribution for building self-consumption, and
- the ***estimation of the building (extra-) costs due to BIPV***.

The KPIs of this stage needed to assess the BIPV project results and control costs are:

- the ***BIPV yield*** (kWh/y),
- the cost of BIPV and in particular the ***extra-cost for BIPV*** (€/m^2) in respect to conventional non photovoltaic element,
- the ***expected electricity self-consumption***.

3.2.4 Technical BIPV Design Stage

Starting from the developed BIPV design, the BIPV consultant can move to the technical design starting from the interoperable BIM model of the BIPV project with all the information categories defined in the previous stage.

The technical design stage has the goal to completely define the BIPV envelope in detail to also meet all the technical requirements set in local standards and regulations. Therefore, two main aspects are investigated and defined in this stage: the technical specifications about the electrical layout and the mounting structures.

As a consequence, the information category about the ***specific BOS (Balance of System)*** has to be included in order to describe in detail the string layout and properties definition, inverters properties and positioning, as well as storage systems properties when required, with associated quantities and costs. In addition to this, the structural engineer can design the most suitable mounting structure in accordance with the set of solutions identified in the previous stages and in accordance to budget constraints in order to include in the BIM project of the BIPV envelope also the information category related to ***the mounting structures***, including the properties of the structural elements, their sizing and positioning, as well as associated quantities and costs.

By combining all these information categories within the BIM environment, it is possible to detail the following KPIs:

- the ***detailed estimation of the BIPV yield on an hourly basis*** (kWh),
- the ***final extra-cost of BIPV*** (€/m^2), and
- the ***detailed estimation of the electricity self-consumption.***

3.2.5 Link with other work stages

Once the technical BIPV project has been accepted, one of the benefits of the collaborative BIM environment is the whole BIPV model with all the required information for the next stages of the process. However, the BIM model of the BIPV technical project cannot be used directly for other work stages of the BIPV value chain as it is.

Indeed, each stage is characterized by the need of different information categories and data with different level of details. These information categories, however, can be extrapolated from the BIM model and transferred to specific BIM/CAD software or tools developed for the specific purposes of the next stages which are:

a) the installation stage,
b) the manufacturing stage, and
c) the O&M stage.

a) Installation Stage

The installation stage is a critical work stage especially in BIPV realization due to the presence of different stakeholders in the same construction site. Indeed, at the same time, there are the mounting structure' installers and the PV/BIPV modules' installers, as well as electricians in some cases. This requires a great effort of coordination and this can be achieved when all information and materials are provided correctly.

Depending on the façade/roof contractors and their protocols and workflows, as well as on the specific construction site of the BIPV project, there can be different parameters, data and drawings that are required to manage and carry out this stage.

We detected and validated through experience that a strong commitment to pre-design stages from reference installers is a crucial issue to design and build a performing BIPV installation. In particular, installation barriers have to be declared very early in the process to prevent “no-go” decisions due to lack of information. Example: pre-design studies ask for big and heavy glass modules on existing façade and even if lamination is possible, framing, mounting and maintaining such a configuration is seen as impossible.

Therefore, thanks to a survey spread among the Consortium Partners involved in this stage, the main information categories have been identified. The main information categories needed for the installation stage usually are:

- ***geometrical characteristics and weight of module*** and dummies,
- ***geometrical characteristics and weights of the elements of the mounting structures***,
- ***technical details of the construction wall and/or roof*** where the BIPV system is installed,
- ***electrical details of the connections among modules and strings***,
- ***position of the inverters and related cabling entry point into the building façade/roof***.

Moreover, not only informative data are required but also ***drawings and plans with mounting instructions*** are particularly significant to realize the BIPV system on-site, such as:

- drawings/plans with the ***layout pattern of modules, dummies and fitting pieces***, with their own identifiers,
- drawings/plans with ***layout of the mounting structures*** (e.g. back rails, mullions, transoms, etc.) with their own identifiers,
- drawings/plans with the ***electrical layout of strings*** with their identifier.

Moreover, depending on the complexity of the single BIPV project, different detailed drawings and documents can be developed.

b) Manufacturing stage

The manufacturing stage for BIPV typically requires a high degree of flexibility and customization to realize BIPV modules and components capable to suit correctly the building envelope on every technical issues (electrical, mechanical, thermal, optical, aesthetical). Indeed, depending on the complexity of the building and the layout pattern of modules, different sizes of BIPV modules need to be produced with different characteristics and features. This involves the need for production lines capable to “read” the parameters specified in the BIPV design stage to manufacture the desired BIPV product or, vice versa, the inclusion of the customizable parameters in the BIPV design tool to make aware architects of the feasible solutions.

We detected and validated through experience that a strong commitment to pre-design stages from reference manufacturers is a crucial issue to design and build a performing BIPV installation. In particular, manufacturing barriers have to be declared very early in the process to prevent as previously mentioned “no-go” decisions due to missing information. Example: pre-design studies ask for big and heavy glass modules on existing façade and even if lamination is possible, framing, mounting and maintaining such a configuration is seen as impossible.

Generally, the main information categories that are required for the BIPV modules’ manufacturing lines consist of:

- ***geometrical characteristics of the module***, as well as of their single ***sub-components*** (e.g. cells, encapsulant, junction-box, etc.) and their precise ***positioning***,
- ***electrical characteristics of the module*** (e.g. maximum current intensity, maximum voltage, etc.),
- ***material characteristics of each single sub-component*** of the module,
- ***technological configuration of the mounting structure*** (e.g. type of profiles and clamps)
- ***total amount of modules and dummies***, as well as the ***total power*** to be achieved.

c) O&M

The O&M stage for BIPV so far has been represented by typical maintenance operations that generally occur when the electrical performances behave under the expected values or accidental failures occur. Especially thanks to most recent inverters, there is the opportunity to have a real-time monitoring of the BIPV system but also specific O&M systems can be developed to monitor the performances and planning smart maintenance of the system thus reducing extra-costs.

The concept of Digital Twin, originally developed within high tech industries (aeronautics, nuclear) towards wider and generalized “Industry 4.0” concepts (placing Internet of Things – IoT in central position), should be asked in our vision to anticipate failures and mitigate operational risk. Because of the existence of a BIM 3D model embedding BIPV layouts + Balance of Systems data, inclusion of operational data gathered from monitoring devices and mixed together with BIM data within a specific lighter 3D model should be a strong innovation.

The main information categories that are needed for these purposes are:

- ***technical details of the components*** of the BIPV system (e.g. modules number, string identifiers, inverters, micro-inverters, inverter type, storage type, etc.)
- ***real-time electrical parameters*** of BIPV modules (e.g. current, voltage, power, etc.) and other physical characteristic (such as mechanical integrity)
- ***expected BIPV production and yield***.

3.3 Information modelling strategy for BIM BIPV objects

Today CAD blocks, so far used to create repeated contents, such as drawing symbols or standard components, are going to be replaced by BIM objects. BIM objects still carry the representation of products in 2D and 3D like a CAD block would, but they also carry so much more in terms of information. The digital product in BIM environment is usually as close as possible to the physical AEC real product both for 3D representation and with the correct information and properties (materials, costs, maintenance, etc.). Accordingly, the model element can be developed in reference to a Level of Development (LOD) that can vary during the different design and project phases. BIPV-BIM objects families that can be used by architects, contractors and other players, are key-aspects of BIPV digitalization, making possible to consider and share the BIPV design with all the stakeholders since the first phase of the project along the process work stages. Thanks to a BIM-based process, the BIM BIPV objects can be integrated in the whole AEC process. BIPV component can be conceived collaboratively and verified virtually, before it will be built for real, with substantial integration features, reducing the problems in construction and operation. The development of a BIM object, in order to reproduce the real features of the constructive component both in terms of geometry and information according to the LOD concerned, usually requires detailed and precise parametric information. Typically, the “digital families” represent common building components made available by industries in catalogues and that can be uploaded in the project model (e.g. furnishing objects, constructive parts, etc.). The main challenge for developing a BIM object in case of a customizable BIPV component is that all the main object’s features are not fixed or pre-defined but rather they can be established case by case during the design phase. This is related to the fact that BIPV modules as envelope components need to be tailored to meet also aesthetical and constructive requirements, beyond energy aspects and, hence, a contextual parameterization of BIM BIPV modules is required. For instance, parameters that can be tailored can vary from module’s shape to type and arrangement of cell, up to the panel layering and materials generating in each case a completely different layout of the component with different properties and performance. In this perspective the conventional strategy to develop a library of BIM objects through a catalogue can be not effective, and the development of a certain adaptability of the component is needed. A digital family is a group of elements with a common set of properties, called parameters, and a related graphical representation. In software environment like Revit® loadable families are used to create building components that would usually be purchased, delivered, and installed in and around a building, such as windows, doors, casework, fixtures, furniture, and planting.

Thus, in order to develop a BIM-based BIPV process, beyond the IM strategy needed to address the information categories for each BIPV stage, it is necessary also to define a strategy for the **information modelling of BIPV objects** included in the BIM project. The information modelling of BIM objects is strictly related to the Level of Development (LOD) concept. This concept has been introduced by the American Institute of Architect and the refined by BIMforum along years. From BIMforum 2019 (18), the Level of Development indicates "*the degree to which the element's geometry and attached information has been thought*". The Level of Development indeed is related to the concept of reliability or "*the degree to which project team members may rely on the information when using the model*" (19). BIMforum definitions for the reference Level of Developments are reported in the Table 3.1.

Unfortunately, the definition of LOD as Level of Development is sometime confused with the LOD intended as Level of Detail. The Level of Detail, indeed, refers to the amount of graphical and non-graphical information included in the object, and the Level of Detail can be considered as the input to obtain the reliable output (Level of Development).

Table 3.1. Level of Development Specification from (18)

LOD	Specifications
100	The Model Element may be graphically represented in the Model with a ***symbol or other generic representation*** but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements
200	The Model Element is graphically represented within the Model as ***a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation***. Non-graphic information may also be attached to the Model Element
300	The Model Element is graphically represented within the Model as a **specific system**, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element
350	The Model Element is graphically represented within the Model as a ***specific system,*** *object, or assembly in terms of quantity, size, shape, location, orientation****, and interfaces with other building systems***. Non-graphic information may also be attached to the Model Element
400	The Model Element is graphically represented within the Model as a ***specific system,*** *object or assembly in terms of size, shape, location, quantity, and orientation* ***with detailing, fabrication, assembly, and installation information***. Non-graphic information may also be attached to the Model Element
500	The Model Element is a ***field verified representation in terms of size, shape, location, quantity, and orientation***. Non-graphic information may also be attached to the Model Elements

In particular, **BIMForum has developed a guideline to define the LOD of each building element, as well as a document where baseline attributes are specified and other attributes can be filled-in to achieve the desired LOD** that "*enables practitioners in the AEC Industry to specify and articulate with a high degree of clarity the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process*". Even though the Level of Development are not defined by process stages, the specific BIM Execution Plan of each project includes a matrix with rows representing building elements and columns representing project stages, where each cell can be filled-in with the Level of Development required. **Regarding the BIPV objects, there is not any specification in the BIMForum document**, and when looking for photovoltaic only, the **LOD specifications are provided considering photovoltaics as a generic "energy generator"**. Specifically, Figure 3.1 shows the narrative descriptions and illustrations of the element "energy generator" at each LOD (LOD Specification for Building Information Models 2019 – Part I), whereas specific attributes are included in the "Associated Attribute Information" document that is provided by BIMForum. Such a document consists of a main matrix whereas each row indicates the building element and columns are included to indicate the LOD at each project's milestone or stage and the author of the BIM building element. Moreover, each row/building element has a link to a specific attribute table (Figure 3.2), where baseline attributes are listed, and where additional attributes can be implemented by the author of the BIM building element.

D5010.10 21-04 50 10 10 Packaged Generator Assemblies

Includes: Generator, frequency changers, and rotary converters and uninterruptible power units.

Associated Masterformat Sections: 26 32 00 / 26 32 13 / 26 32 16 / 26 32 19 / 26 32 23 / 26 32 26 / 26 32 29 / 26 32 33

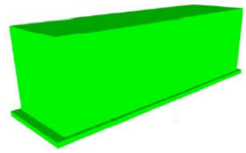
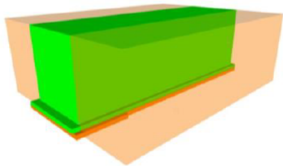
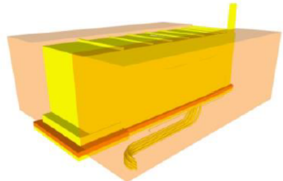
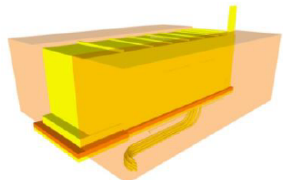
100	See D50	
200	See D5010	 *180 D5010.10-LOD-200 Packaged Generator Assemblies*
300	Modeled as design-specified size, shape, spacing, and location of equipment and associated components; approximate allowances for spacing and clearances required for all specified supports and seismic control; access/code clearance requirements modeled.	 *181 D5010.10-LOD-300 Packaged Generator Assemblies*
350	Modeled as actual size, shape, spacing, and location of equipment and associated components; actual size, shape, spacing, and location for supports and seismic control; actual size, shape, and location/connections of equipment and support structure/pads. actual access/code clearance requirements modeled.	 *182 D5010.10-LOD-350 Packaged Generator Assemblies*
400	Supplementary components added to the model required for fabrication and field installation.	 *183 D5010.10-LOD-400 Packaged Generator Assemblies*

Figure 3.1. Element Geometry description for the specific element "Generator"

BIMForum LOD Specification 2019 Part II					
D50 - Electrical					
Baseline / Additional — This work is licensed under the Creative Commons Attribution-NonCommercial 4.0 International License	**Part 1 - Attribute Description**				
Attribute	**Data Type**	**Units - Imp.**	**Units - Metric**	**Option Examples**	**Commentary**
Global Attributes					
Component ID	Text				Part or Equipment Tag
Condition Status	Text			New, Existing, Demolish, Temporary, User Defined	Status of the element, predominately used in renovation or retrofitting projects
Room Number	Text				Room number where component **to be**/is installed
Room Name	Text				Room name where component **to be**/is installed
Story Number	Text				Floor or level room is located
Manufacturer Name	Text				The organization that manufactured and/or assembled the item.
Product Name	Text				The manufacturers model name of the product model (or product line)
Model Designation	Text				The manufacturers model number or designator of the product model (or product line)
Target LOD	Text			100, 200, 300, 350, 400	
Current LOD	Text			100, 200, 300, 350, 400	

Figure 3.2. Attribute Table for the specific element "Generator"

Another approach to this topic has been developed by the UK that in 2013 launched a ***new LOD definition in the BIM standard PAS 1192-2*** (20). In this standard, LOD stands for Level of Definition and it encompasses both the Level of Detail (LOD) as a measure of the geometric representation and the Level of Information (LOI) as a measure of the data content. The level of definition ranges from 0 to 7 and are correlated to the construction stages which are:

- 0- Strategic definition
- 1- Preparation
- 2- Concept stage
- 3- Developed design
- 4- Technical design
- 5- Construction
- 6- Hand-over and close-out
- 7- In-Use

What is interesting to note is that, grounding on these fundamentals, the Technology Strategy Board has developed a tool to define the LOD and LOI of building objects: the NBS BIM Toolkit. Even though BIPV elements are not present, PV objects are described through Level of Detail (LOD) as shown in Figure 3.3, and Level of Information - LOI as shown in Figure 3.4.

Uniclass2015 - Pr_60_70_65_63 Photovoltaic modules

Level of detail | Level of information

Manufacturer Product Data template
Complete this electronic spreadsheet to ensure that your Photovoltaic modules product information meets the requirements of Level 2 BIM. This is important as it will enable your customers to select, specify and use your products within the BIM environment. Once you have completed this template you can host it on your own website or distribute it to your customers. Please note that we do not host completed product data templates within the BIM Toolkit.

3

Requirement

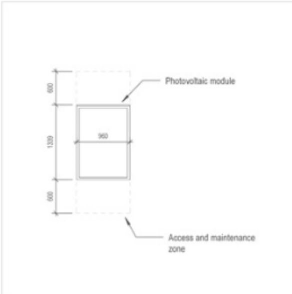
Visual information to provide developed principles of the design to a greater level of detail. Developed coordination between all professions. Visual development showing coordination for general size and primary relationships between different elements of the construction.

Can form a brief for a specialist sub-contractor or fabricator to progress with their technical design, fabrication and installation. This would be expected to include critical dimensional coordination, performance requirements and qualities of finish.

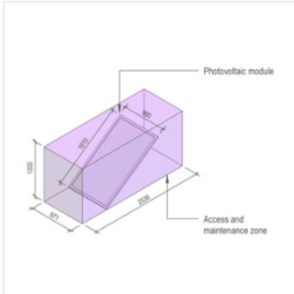
Purpose of information

To provide a visual representation of proposals, confirming brief for technical Design stage supporting full spatial coordination.

Plan



Model



The above illustrations are for *Photovoltaic modules* from the NBS section *Small wind turbines and photovoltaics*. This is indicative of the LOD requirements for *Photovoltaic modules*.

4

Requirement

Visual information to provide fixed principles of the design supporting procurement. Developed coordination between all professions. Visual representations showing coordination for general size and relationships between different elements of the construction.

Graphical representation of system, dimensionally accurate indicating primary performance characteristics.

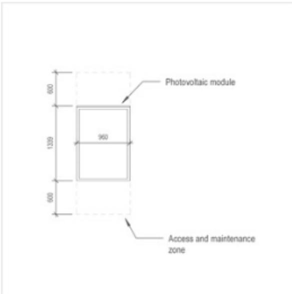
Graphical information represented may alter dependant on visual information to be produced, eg: Scope of work drawings, setting out, floor loading etc

Typical / Installation details separately produced linked to model element and adjacent constructions.

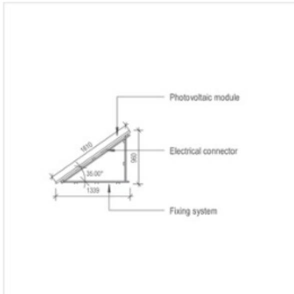
Purpose of information

To provide a visual representation of proposals at a Technical Design stage supporting full spatial coordination.

Plan



Elevation



Model

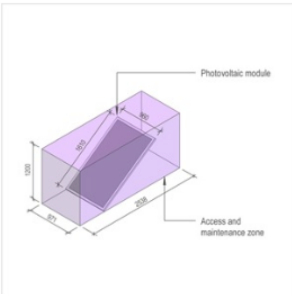


Figure 3.3. NBS Level of Detail for Photovoltaic Modules.
From: https://toolkit.thenbs.com/definitions/pr_60_70_65_63/?downloadpdt=true

Uniclass2015 - Pr_60_70_65_63 Photovoltaic modules

Level of detail | Level of information

Manufacturer Product Data template
Complete this electronic spreadsheet to ensure that your Photovoltaic modules product information meets the requirements of Level 2 BIM. This is important as it will enable your customers to select, specify and use your products within the BIM environment. Once you have completed this template you can host it on your own website or distribute it to your customers. Please note that we do not host completed product data templates within the BIM Toolkit.

2

Provide an outline description of the deliverable.

Name	Definition
Description	A description of the type of object to detail any design intent.

3

Provide an outline description of the deliverable.

Name	Definition
Description	A description of the type of object to detail any design intent.

4

Provide enough information to allow the selection of the manufacturer product to meet requirements. This information may also be used to replace the installed product during the operation stage of the building's lifecycle. Information covering the execution of the deliverable should also be provided in the associated specification.

Name	Definition
Manufacturer	The Manufacturer of the Photovoltaic modules.
Standards	An example value being To BS EN IEC 61730-1 and BS EN IEC 61730-2.
Third party certification	The Third party certification of the Photovoltaic modules.
Application class	An example value being To BS EN 61140, Class II.
Cell type	An example value being Monocrystalline to BS EN 61215-1.
Format	An example value being Screwed frame modules.
Framework - Material	An example value being Anodized aluminium.
Framework - Colour	The Framework - Colour of the Photovoltaic modules.
Module interconnections - Standard	An example value being To BS EN 62852.
Module interconnections - Module connectors	An example value being Polarized and suitably rated for the applicable d.c. voltage and current.
Module interconnections - Ingress protection (minimum)	An example value being To BS EN 60529, IP55.
Nominal output of module - Peak power	The Nominal output of module - Peak power of the Photovoltaic modules.
Nominal output of module - Power output tolerance	An example value being 0/3%.
By-pass diodes	An example value being Two, integral to panel.
Output warranty	An example value being Minimum of 90% power output after ten years.

Figure 3.4. NBS Level of Information for Photovoltaic Modules.
From: https://toolkit.thenbs.com/definitions/pr_60_70_65_63/?downloadpdt=true

It is fundamental to highlight that the PAS 1192-2 and related PAS standards have been used as the basis for the ***international standard ISO 19650 and one of the main novelties is represented by the level of information need*** (ISO 19650-1 clause 11.2) (21).

Even though a specific definition on how to define the level of information need is still under development, the ***level of information need can be understood as "a framework for describing how much information to deliver"***. It intrinsically refers to the concepts of LOI/LOD (level of information/detail) and it should be specified in the BIM Execution Plan (22).

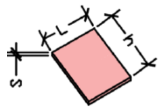
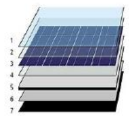
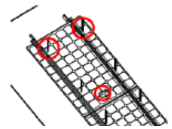
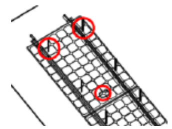
Therefore, since it is critical to have a clear definition of the level of information need that helps in dealing with information (both geometrical and non-geometrical) that should be included in the model, this work assumes the following information modeling strategy for BIM BIPV objects in accordance with the perspective adopted in the new ISO 19650 standards: ***the definition of the information needed for each building object or system at the different project stages is demanded to the BIM Execution Plan (BEP) where the specific attributes for generic BIPV objects in terms of geometry (LOG) and informative data (LOI) are described for each intended use and purpose***.

What is necessary to highlight is that the proposed modeling strategy tries also to overcome the gap represented by the lack of BIPV objects in common BIM object libraries. Indeed, BIM BIPV objects are not only electrical devices but also a building components that require to fulfill construction requirements and provide specific performances in accordance to their use and application in the building envelope. As a consequence, not only electrical attributes need to be considered in the definition of informative data (LOI) but also building-related parameters.

Preliminary activities for the LOG and LOI definition for BIPV objects are reported in (6) and (22) but, still, a standardization for these definitions is far due to the fact that each single BEP can define LODs in different ways. Therefore, the main goal for supporting the development of BIM BIPV objects is represented by the definition of the main parameter categories (e.g. electrical, thermal, mechanical, etc.) and the related baseline BIPV attributes on which a common agreement can be achieved. Instead, further attributes can be added to meet the specific BEP requirements.

Baseline attributes for BIM objects representing a generic BIPV module are provided in the Table 3.2. LOG and LOI definitions for generic BIPV modules in order to address BIPV stakeholders in selecting the most relevant attributes when defining the level of information needs.

Table 3.2. LOG and LOI definitions for generic BIPV modules

	100	200	300	400	500
LOG					
Graphic representation					
	Generic surface	Schematic representation	Layout representation of the BIPV module	Module and generic fixing systems	Module, with fixing and electrical connections
LOI					
Generic Information	- Type of building application[1]	- Type of building application[1]	- Specific building application[2] - Manufacturer - Model	- Specific building application[2] - Manufacturer - Model - ID module - ID string - Associated fixing system type	- Specific building application[2] - Manufacturer - Model - ID module - ID string - Installer - Associated fixing system manufacturer - Associated fixing system model
Geometric specification	- Total Area	- Length - Width - Total thickness (optional)	- Length - Width - Total thickness - Front glass thickness - Rear-layer thickness - Junction box length (optional) - Junction box width (optional) - Junction box thickness (optional)	- Length - Width - Total thickness - Front glass thickness - Rear-layer thickness - Junction box length - Junction box width - Junction box thickness	- Length - Width - Total thickness - Front glass thickness - Rear-layer thickness - Junction box length - Junction box width - Junction box thickness - Fixings sizes

[1] Type of building application: opaque façade or roof, semitransparent façade or roof
[2] Specific building application: cladding of rainscreen façade, cladding of prefabricated façade, glazing of façade, sunscreen, roof-tile, glazing of roof

LOI	100	200	300	400	500
Mechanical Specification			- Weight	- Weight - Wind load resistance - Impact resistance - Hail resistance	- Weight - Wind load resistance - Impact resistance - Hail resistance
Electrical Specification	- Average power per square meter	- Average power per square meter - PV technology	- Cell type - Cell power - Number of cells - Maximum Power (Pmax) - Maximum Power Voltage (Vmp) - Maximum Power Current (Imp) - Open-circuit Voltage (Voc) - Short-circuit Current (Isc)	- Cell type - Cell power - Number of cells - Maximum Power (Pmax) - Maximum Power Voltage (Vmp) - Maximum Power Current (Imp) - Open-circuit Voltage (Voc) - Short-circuit Current (Isc) - Temperature coefficients of Pmax - Temperature coefficients of Voc - Temperature coefficients of Isc - Connectors type - Bypass diodes - Micro-optimizer type (if present)	- Cell type - Cell power - Number of cells - Maximum Power (Pmax) - Maximum Power Voltage (Vmp) - Maximum Power Current (Imp) - Open-circuit Voltage (Voc) - Short-circuit Current (Isc) - Temperature coefficients of Pmax - Temperature coefficients of Voc - Temperature coefficients of Isc - Connectors type - Bypass diodes - Micro-optimizer type (if present)
Materials Specifications		- Main material (e.g. glass-glass, glass-backsheet) (optional)	- Front glass type and colour - Rear-layer type - Encapsulant type - Cells type and colour	- Front glass type and colour - Rear-layer type - Encapsulant type - Cells type and colour	- Front glass type and colour - Rear-layer type - Encapsulant type - Cells type and colour

	100	200	300	400	500
LOI					
Thermal Specifications		- Typical U-value (optional)	- U-value	- U-value	- U-value
Optical Specifications (for semi-transparent)		- Typical solar factor (optional) - Typical visible transmittance	- Solar factor - Visible transmittance - Solar transmittance	- Solar factor - Visible transmittance - Solar transmittance	- Solar factor - Visible transmittance - Solar transmittance
Fire Protection				- Fire reaction class	- Fire reaction class
Economic Specifications	- Average cost per square meter	- Average cost per square meter	- Cost per module	- Cost per module	- Final cost per module - Replacement cost - O&M cost
Certifications			IEC 61215 IEC 61730 Building-related standards	IEC 61215 IEC 61730 Building-related standards	IEC 61215 IEC 61730 Building-related standards

4 DIGITAL ADOPTION PLAN FOR IMPLEMENTING ADVANCED FEATURES FOR BIMSolar®

HIGHLIGHTS

- *The information management strategy and the information modelling strategy are here addressed for implementing advanced features of the current BIMSolar® tool.*
- *Advanced features of the BIMSolar® tool are envisioned for improving the BIPV process from the strategic planning to the developed design. These advanced features are implemented in accordance with BIM BIPV stages and related information categories and KPIs to manage energy and economic aspects.*
- *Finally, guidelines for implementing BIM BIPV modules in the BIMSolar® tool are also provided in order to make BIPV modules available for the BIM design of BIPV envelopes.*

Thanks to the precise definition of the reference BIPV process and strategies to manage BIPV information categories, in order to overcome bottlenecks and optimize the current workflows through tangible instruments and tools, the next step is the development of advanced features to extend the effectiveness of the existing BIM-based software (BIMSolar®) along the whole value chain. Indeed, an integrated and data-driven process in the value chain, from early-design to installation and O&M, requires novel BIM-based tools and features for improving an optimal collaboration between the stakeholders. In the previous Chapters, digitalization goals and information management structures were reported: they set out the required information strategies aligned to crucial project points and process stages.

In this chapter, the goal is to translate strategies into a **Digital Adoption Plan (DAP)** that is actionable to create a successful implementation of an effective BIPV process aimed at cost reduction along the complete value chain. The goal is the definition of implementation lines for the next developments in Task 6.2 to 6.3, including the guidelines for the development of BIMSolar® BIPV objects that will be exported as BIM objects.

Namely, in order to implement the proposed BIM-based BIPV process, the ***DAP is here defined as the reference document for the "translation" of***:

- the ***novelties proposed in the information management strategy into advanced features of the BIMSolar® tool*** in order to improve the BIPV process and achieve at cost-reduction, and
- the ***proposed information modelling strategy into real BIMSolar® BIPV objects*** that can be used in the new BIMSolar® tool in order to represent digital twins of real products.

In detail, this work is based on previous developments of the BIMSolar® tool (23) that is a BIM-based software for the design and simulation of BIPV envelopes. In fact, the current BIMSolar® tool will be improved by adding advanced functionalities to enhance collaboration among BIPV stakeholders and to pursue BIPV cost-reduction.

Therefore, the Digital Adoption Plan consists of two main sections regarding the “Implementation Strategy for the enhanced version of BIMSolar®” (Section 4.1) and the “Guidelines for implementing BIMSolar® BIPV objects” (Section 4.2).

Moreover, Section 4.3 pinpoints the expected benefits of adopting a BIM-based perspective through the BIMSolar® tool and its advanced features, as well as their impacts on the BIPV cost-reduction.

4.1 Implementation Strategy for the enhanced version of BIMSolar®

The core part of the DAP is represented by the implementation strategy that defines the **objectives** of the advanced features of the BIMSolar® that are going to be implemented and the related specific functionalities, users, workflows, whereas advantages and benefits are going to be described in Section 4.3.

To provide a clear description of the implementation strategy, it is necessary to consider the framework for the information management strategy that has been presented in Section 3.1, as well as the available tools that have been developed so far and their limitations when the whole BIPV process needs to be improved to achieve cost-reduction.

As already introduced, the implementation of the digitized approach will be carried out grounding on the existing BIMSolar® tool which so far represents one of the most advanced software for BIPV design and simulation, also ensuring an advanced level of interoperability with common architectural BIM software. However, what is envisioned is a software that enables to deal with BIPV since the preliminary process stages and to manage BIPV aspects till the developed BIPV design stage thanks to an effective information exchange, with also the opportunity to provide/export all the useful information that are required along the value chain and among the key-players of the process till the operational and maintenance stage.

Therefore, the enhanced version of the ***BIMSolar® tool has been envisioned as a tool*** *that* can support BIPV stakeholders since the preliminary stages of the design till to the definition of the developed project ***with the following main objectives***:

- include BIPV **cost evaluation** also through novel optimization engines to favor the direct BIPV cost-reduction since the **early design stages**, and
- reduce indirect costs (related to the design and planning process) by **improving the process’s efficiency** and the interoperability between the design stages and with the rest of the process.

Interoperability is the ability to communicate between people and between software. As our built environment becomes more digitized and relies on BIM technology, it becomes increasingly dependent on interoperability. Nowadays, players spend more time communicating their design intents with other project participants than on their actual design work. The type and the content of the required data often differ greatly depending on who wants to use it, e.g. depending on the different disciplines. For instance, architects have different BIM requirements than engineers: modelling and the model’s internal logic may differ significantly: architectural BIM is NOT the same as the BIM of other disciplines. Typically, engineers (e.g. involved in structural, mechanical and energy design applications) prefer programs supporting the standards of their own country, and these are usually specific local applications. Recognizing the complexity of building projects, and once clarified that each discipline is responsible for its work, the key-topic is to provide architects and engineers with appropriate platforms for information exchange to design and assess buildings more quickly, reduce the cost and increase the accuracy of analysis, and achieve the performance required by project needs and standards.

Each **discipline** is responsible for its work. For example, the BIPV consultant is responsible for the parts of the building skin she/he design and calculates according to harmonized and local design standards. Each discipline should be able to edit and modify its model while using the others’ models only as a reference alongside their own (e.g. the BIPV consultant will use the architectural project provided from the architect).

The models coming from the various disciplines are quite different in their details so that they need different tools and specific analysis software in a dedicated environment. For example, the **architects** define the contour of a facade, using a curtain wall element with some glass/structure properties, while the BIPV engineer, doing design calculations with detailed BIPV modules panels, defines the final module's design and information. However, the models of the two disciplines differ in the element type, level of detail of components, the relative positions of some elements, etc. Moreover, the goals are also quite different: the architect will "sketch" BIPV macro-types[1] on the conceptual building design and will perform only fast evaluation of in terms of energy and cost assessment. The **BIPV consultant** launches optimization tool for evaluating which BIPV modules fit the energy and economic constraints evaluates in case of customized BIPV modules, which are the design features in accordance with the manufacturer possibilities. Then, energy and economic evaluations are run to obtain all the data for effective manufacturer's consultancy and the technical information of the BIPV envelope according to project needs and standards in force.

A smooth all-round workflow is needed in this framework so that **not only a new version of the BIMSolar® tool with advanced features has been though for the developed design stage but also a BIMSolar® add-in for Autodesk® Revit® (also available in a standalone software) for the conceptual design stage.** Indeed, considering the specific needs of the different stakeholders, a single software does not represent a feasible solution. Instead, the creation of a collaborative environment thanks to these two interoperable BIMSolar® tools allows to embrace the complexity of the BIPV process and the presence of different stakeholders which, in this way, can efficiently share and integrate BIPV data though BIM.

The principle is that a conceptual BIM model of the building developed in an architectural software can be used for the conceptual BIPV design thanks to the BIMSolar® Revit® add-in (or its standalone version). In this way, every BIM architect can be supported in the BIPV decision-making process since the early stages. Once defined the conceptual BIPV design, the BIM model can be imported into BIMsolar® that allows a wide range of analytical activities for BIPV design and energy simulation, to generate information that can be then shared with other process stages and other expert software (e.g. for the structural analysis of the mounting structures for BIPV modules, for the planning of the construction site, etc.). The tools that are going to be implemented, the related functionalities and the main final users are reported in Table 4.1. Furthermore, each specific stage is detailed and deepened in following sub-sections with specific Tables.

In particular, what is worth to highlight is the role of the KPIs for each stage. Indeed, KPIs serve as indicators for the decision-making process within each BIPV project design stage to address the architect or the BIPV consultant in selecting the most optimal BIPV solution to achieve energy and economic targets.

[1] BIPV macro-types are defined as homogeneous BIPV product categories which are identified in accordance to 1. building application (opaque façade, semi-transparent façade, opaque roof, semi-transparent roof, etc.), 2. PV technology (crystalline or thin-film)

Table 4.1. Implementation strategy for the enhanced version of BIMSolar®

STAGE	STRATEGIC PLANNING	CONCEPTUAL BIPV DESIGN	DEVELOPED BIPV DESIGN	TECHNICAL BIPV DESIGN	CONSTRUCTION BIPV PROJECT	BIPV INSTALLATION	O&M
TOOLS	**3D BIPV virtual showroom and BIPV web community**	**BIMSolar® Revit® add-in or BIMSolar® standalone software**	**BIMSolar® (with enhanced features)**	CAD/BIM tools + tools for specific electrical or structural analyses	CAD/BIM tools	CAD/BIM tools	Specific tools Digital Twin
FUNCTIONALITIES	• To provide **digital showcases of existing BIPV projects** with related data and KPIs	• To **"sketch" directly BIPV macro-types** (opaque façade or roof, semitransparent façade or roof) on the conceptual building design or to run an **optimization tool for obtaining the best BIPV design** in terms of energy and/or extra-costs 3D graphic representation of the possible BIPV design alternatives • **Fast evaluation of BIPV alternatives in terms of energy yield, self-sufficiency and preliminary extra-cost of BIPV** • To **export** the chosen BIPV macro-types and related parameters **to BIMSolar®**	• To **import interoperable BIM model with BIPV macro-types** and related economic and energy parameters, which serve as constraints • To launch **optimization tool for** evaluating which **BIPV modules** fit the energy and economic constraints • In case of customized BIPV modules, to launch **optimization tool to design the BIPV module in accordance with the custom parameters** which are provided by the manufacturer. Then, energy and economic evaluations are run. • To obtain a **digital model of the customized BIPV module**, that includes all the data for effective manufacturer's consultancy • To obtain **the BIM model of the BIPV envelope with information about energy and costs** (including average costs of associated mounting structures and BOS) • To **export** relevant information **for manufacturing** • To **export** relevant information **for the technical project** • To **export** relevant information **for the installation** • To **export** relevant information **for O&M**	• To design electrical layout in detail in accordance to • To detail the technical design of mounting structures	• To develop drawings and plans, as well as details and guidelines for the installation phase	• To develop time schedule plans and to check and validate real product installation	• To monitor and assess BIPV system behavior and performances

STAGE	STRATEGIC PLANNING	CONCEPTUAL BIPV DESIGN	DEVELOPED BIPV DESIGN	TECHNICAL BIPV DESIGN	CONSTRUCTION BIPV PROJECT	BIPV INSTALLATION	O&M
TOOLS	**3D BIPV virtual showroom and BIPV web community**	**BIMSolar® Revit® add-in or BIMSolar® standalone software**	**BIMSolar® (with enhanced features)**	CAD/BIM tools + tools for specific electrical or structural analyses	CAD/BIM tools	CAD/BIM tools	Specific tools Digital Twin
FINAL USER	• Architect • BIPV consultant	• Architect • BIPV consultant	• BIPV consultant	• BIPV consultant • Electrical engineer	• BIPV consultant • Electrical engineer • Structural engineer	• BIPV consultant • Roof and/or façade contractors	• BIPV consultant • O&M company

4.1.1 Strategic Planning Stage

As already introduced in paragraph 3.2.1, the strategic planning is a crucial stage for go/no-go decisions towards BIPV. Even though this stage seems not related to the BIM approach and cost reduction, there are some important links. Indeed, thanks to already existing BIM models of BIPV buildings, the architect and/or the BIPV consultant can not only showcase solar architecture buildings, but also provide some basic information embedded in such models such as the energy production or the extra-costs in projects similar to the one desired by the client. For this reason, a 3D BIPV virtual showroom and a BIPV web community with most relevant energy and economic aspects can be realized grounding on the previous experience of the BIMSolar® Community [25].

Indeed, at this stage the common inputs are represented by client's requests or completion's requests together with the budget's targets, and the architect or the BIPV consultant are responsible to translate them into project objectives that can be:

- Green Building Labels (LEED, BREEAM, …),
- Profit targets (as a productive asset),
- Electrical/Energy targets of the building (e.g. Minergie).

Specifically, thanks to the development of a 3D BIPV virtual showroom including significant KPIs (energy yield and extra-costs of BIPV per m^2 of floor surface) and a related BIPV web community, these project objectives can be defined more easily and realistically.

Table 4.2. Strategic Planning stage for the enhanced version of BIMSolar®

Tool	3D BIPV virtual showroom and BIPV web community
Input	• Client's requests or competition's requests (e.g. vision on a green label or solar for its building) • Budget targets
Elaboration (sub-process)	Architect and/or BIPV consultant communicates and disseminates solar architecture examples and proven BIPV performance thanks to digital database, in order to support the client to clearly define the objectives and to carry out project objectives and parameters.
Output	• Green Building Label • Profit targets (as a productive asset) • Electrical/Energy targets of the building (e.g. Minergie)
Stakeholders	• Architect and/or BIPV consultant (especially, for large projects)
KPIs	KPIs about energy and extra-costs from BIPV real use cases (featured projects)

4.1.2 Conceptual BIPV Design Stage

The conceptual BIPV design stage is also a fundamental step that addresses the implementation of BIPV in building surfaces that are sketched by architects during the simultaneous conceptual design stage of the building. Questions that concern this stage are:

- is it possible to have a fast evaluation of the solar potential of the building surfaces? This is due to the fact that building design changes several times, due to other design aspects such as regulations, statics, etc.
- is it possible to obtain a preliminary estimation of the extra-cost of BIPV for the whole building in comparison to building design without BIPV? Indeed, during this stage the cost of the building is not detailed per element, but it is the whole cost per cubic or square meter.

Considering that designing BIPV means also designing the building envelope, it is fundamental that architects can deal with BIPV at this stage and that they can be enabled to perform preliminary energy and cost evaluations within their common architectural tools. For this reason, among possible implementation solution, the implementation of a BIMSolar® add-in for Revit has been envisioned. The choice to integrate some BIMSolar® functionalities into the commercial solution Autodesk® Revit® is related to the fact that it is the most used BIM AEC software, covering all the BIM value chain, and in this way BIPV opportunities can be managed by most of the architects using BIM. However, in order to reach also architects who don't use this specific software, a BIMSolar® standalone software version is also carried out to enable all the architects' community to design BIPV in the conceptual stage from non BIM 3D models of open BIM architectural models, and evaluate since the early design both energy and economic aspects.

Indeed, thanks to the BIMSolar® Revit® add-in or BIMSolar® standalone software, the **conceptual BIM model of the building** (that generally consists of gross surfaces and volumes) can be used as a **basis for the BIPV feasibility study by means of BIPV macro-types**. In particular, **BIPV macro-types have been defined as categories representing the main BIPV products depending on their building application, average power and average cost per square meter**. The reason for using BIPV macro-types instead of real BIPV products at this stage is due to the fact that the conceptual stage is characterized by a huge uncertainty about the building design details and, hence, there is no need to increase the level of detail of BIPV spending a great amount of resources and time.

In order to support the optimization of the workflow during this stage, an **optimization tool** is envisioned as a tool that **explores the optimal BIPV macro-types in terms of geometry and energy to be installed** in the building in order **to achieve the energy optimum** (that is represented by the electrical self-consumption of the building) **or both the energy and cost optimum** (that is represented by the electrical self-consumption of the building and the minimum investment cost for BIPV). **The result is a set of BIPV solutions** in accordance to the optimization goal reporting the BIPV design **with representation of macro-types and** related:

- **preliminary estimation of production** (kWh/y),
- **cost per square meter of floor**, and
- **building self-sufficiency due to BIPV**.

These results can support the architect or the BIPV consultant in selecting the most appropriate BIPV design **reducing time spent in evaluating manually each single solution**.

In particular, this optimization tool has to be intended as a **decision-support tool that addresses BIPV in the conceptual stage**, but the design can be modified by the architect or the consultant and their custom BIPV designs can be used to launch single simulations of costs and energy.

Specifically, the **final KPIs** for this stage are:

- **Preliminary overall production** (kWh/y)
- **Preliminary cost of BIPV macro-type per square meter of floor surface**,
- **Preliminary building self-sufficiency thanks to BIPV**.

It is important to highlight that the strategies for the development of the optimization tool are investigated in the deliverable "D6.6: Parametrization, optimization and automation during design stage in order to optimize the BIPV cost-to-power ratio".

Specific inputs needed for this stage, elaborations and related outputs, as well as involved stakeholders and KPIs are detailed in Table 4.3.

Table 4.3. Conceptual BIPV Stage for the enhanced version of BIMSolar®

Tool	**BIMSolar® Revit® add-in or BIMSolar standalone software**
Input	From previous stage: • Electrical/Energy targets • Green Building Label • Profit targets (as a productive asset) Other inputs: • BIPV macro-types with associated data about average cost and power • Client's wish for BIPV macro-types • Building location (coordinates, orientation + typical meteorological year weather file) • Nearby buildings • 3D model of conceptual volume/shape of the building
Elaboration (sub-process)	The architect or the BIPV consultant needs to provide a **feasibility study with BIPV macro-types** responding to client's target. Thanks to the **optimization tool** integrated in the BIMsolar® add-in for Revit and in the BIMSolar® standalone software, the architect or the BIPV consultant can explore the optimal BIPV macro-types in terms of geometry and energy by choosing type of optimization: • **only energy optimization**, • **both energy and costs optimization**, or by exploring manually the BIPV solutions
Output	3D integrated and collaborative BIM model of the building with surfaces representing BIPV macro-types with rough estimation of production, cost per square meter of floor and building self-sufficiency due to BIPV
Stakeholders	Architect and/or BIPV consultant (especially, for large projects)
KPIs	• Preliminary overall production (kWh/y) • Preliminary cost of BIPV macro-type per m^2 of the building floor • Preliminary building self-sufficiency thanks to BIPV

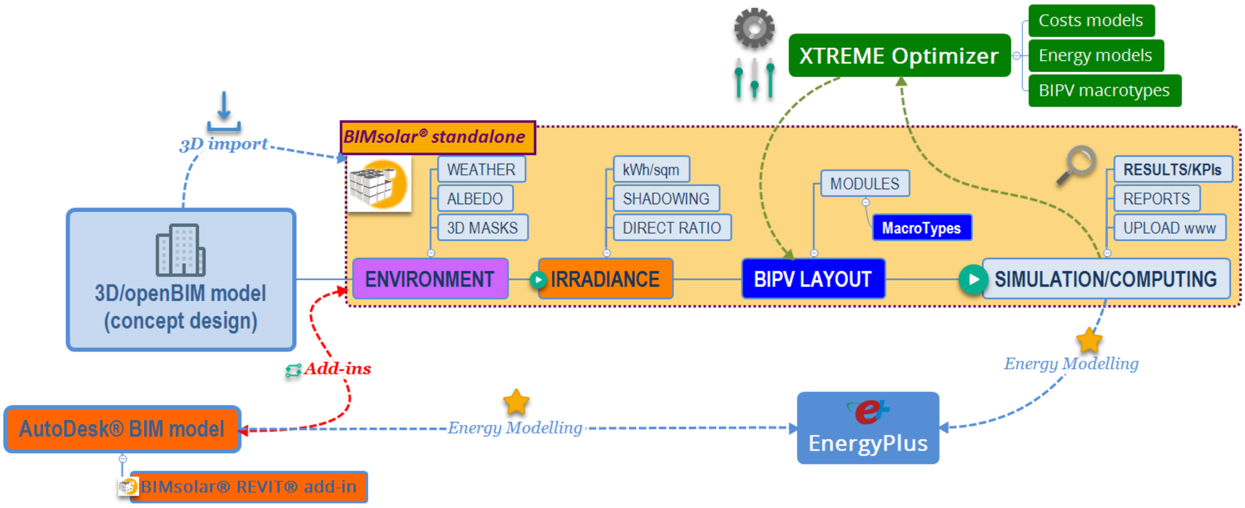


Figure 4.4. Conceptual BIPV Stage for the enhanced version of BIMSolar®

4.1.3 Developed BIPV Design Stage

Once the conceptual BIPV design is defined, the **3D model of the building with BIPV macro-types and related information** about rough estimation of production, cost per square meter of floor surface and building self-sufficiency due to BIPV represents the main input of this stage.

Such a model **can be imported into the enhanced version of the BIMSolar®** tool that is a stand-alone software **envisioned for expert users such as BIPV consultants with advanced features for BIM and Energy Modelling**.

At this stage the main task that the BIPV consultant has to tackle are:

- the realization of different BIPV envelope design solutions to be evaluated together with/by the architect,
- the assessment of the energy aspects for each solution,
- the evaluation of costs for each solution

by considering the "constraints" set in the previous stage, which are:

- the energy production,
- the cost per square meter of floor surface, and
- the self-consumption.

In particular, the design of the BIPV envelope is here aimed to the **design of the layout pattern of BIPV modules that should meet also the architect's requirements**.

To achieve this goal, two design options are envisioned and described below:

1. **Design of BIPV layout pattern using conventional BIPV modules**

   When "commercial and conventional" BIPV modules can be used to develop the BIPV envelope, an optimization tool is developed to automatically select the most convenient BIPV modules among a digital BIPV module database. In this way, the generic BIPV macro-type can be replaced by real BIPV products capable to fulfil the macro-type's requirements in terms of energy production, investment cost and building self-consumption due to BIPV.

   As the conceptual optimization tool, this optimization must be considered as a decision-support tool that can be useful for the BIPV consultant to evaluate at the same time different solutions in terms of energy and cost. Moreover, it can save costs not only because of the automatic selection of the most convenient solution but also thanks to the time-saving in the design process.

2. **Design of BIPV layout pattern using custom BIPV modules**

   Often the design of BIPV envelopes usually requires customizing BIPV modules not only in terms of shape and sizes to suit the façade or roof design, but also in terms of aesthetical appearance. Thus, there can be the need to change the colour or the type of the front glass to camouflage PV cells, or even to have a particular cell arrangement to create special patterns with PV material.

   However, customization options can be limited due to the presence of manufacturing boundaries. To avoid the design of BIPV modules which cannot be produced, an optimization tool has been envisioned as an additional tool for the "Module Configurator" tool that already exists in the current version of the BIMSolar® software. Specifically, the optimization tool acquires the desired parameters set by the user in the Module Configurator (e.g. type of PV cells, type and colour of the front glass, PV cell distance in the two directions, etc.), it provides the optimal BIPV module by: (i) taking into account manufacturing boundaries and costs, and (ii) fulfilling also the manufacturing boundaries (e.g. minimum PV cell distance from edges, minimum internal PV cell distance, minimum glass thickness, maximum number of PV cells per string, bypass diodes, available front glass types and colors, etc.).

This optimization permits to save time because only feasible BIPV modules can be designed by the user and, moreover, all data and drawings of the custom BIPV module can be extracted and sent to the manufacturer to have a confirmation of feasibility, investment cost and power.

Thanks to the application of these optimization tools, it is possible to **obtain the most convenient design alternatives for the BIPV envelope in terms of**:

1. **energy yield**;
2. **building self-consumption thanks to BIPV**;
3. **CAPEX**.

A further functionality that could be included is represented by the possibility to represent the BIPV solution on the 3D model in accordance with the above-mentioned aspects (this option will be deeply investigated with the D6.7 "Parametrization, optimization and automation during design stage in order to optimize the BIPV cost-to-power ratio").

In particular, at this stage, it is important to include into BIPV modules parameters also information about average cost of the suitable mounting structure (depending on the BIPV macro-type) and the average cost of BOS. In this way, it is possible to obtain a preliminary assessment of investment costs that need to be verified during the next stage of the technical design.

The **relevant KPIs** for this stage are represented by:

1. **Estimation of energy yield** (on hourly basis),
2. **Estimated extra-cost** and, eventually, the Return of Investment related to the extra-cost,
3. **Estimation of self-consumption** (due to BIPV - on hourly basis),
4. **Preliminary estimation of LCOE.**

It is worth to note that the description of optimization tools will be included in the deliverables D6.6 and D6.7 "Parametrization, optimization and automation during design stage in order to optimize the BIPV cost-to-power ratio".

Table 4.5. Developed BIPV Stage for the enhanced version of BIMSolar®

Tool	**BIMSolar® with enhanced features**
Input	From previous stage: • 3D BIM model of the building with surfaces representing BIPV macro-types with rough estimation of production, cost per square meter of floor and building self-sufficiency due to BIPV • Building location (weather file) • Nearby buildings Other inputs: • BIPV module database with associated electrical and economic data, as well as average cost of mounting structure • Electrical demand profile (from other tools)
Elaboration (sub-process)	The 3D model of the building with related data about BIPV macro-types is imported into the BIMSolar® tool by the BIPV consultant as a "constraint" for the definition of design alternatives. In the BIMSolar® tool, the BIPV consultant has two options for designing the BIPV envelope: • **OPTION 1 "STANDARD BIPV MODULES"** BIPV consultant selects possible BIPV modules that are analysed by the optimization tool to obtain for each selected module the following results: 1. energy yield; 2. building self-consumption thanks to BIPV; 3. CAPEX. • **OPTION 2 "CUSTOMIZED BIPV MODULES"** BIPV consultant designs the BIPV modules to achieve the desired building envelope layout from the "module configurator" by selecting the module's design parameters, which can be optimized to obtain a realizable BIPV module. In this case, the customized BIPV module should be sent digitally to the manufacturer to have the cost offer and the electrical characteristics. Then, these values are used as inputs to calculate: 1. energy yield; 2. building self-consumption thanks to BIPV; 3. CAPEX.
Output	3D real-time display of design alternatives of the BIPV envelope in terms of: 1. energy yield; 2. building self-consumption thanks to BIPV; 3. CAPEX.
Stakeholder	BIPV consultant
KPIs	• Estimation of energy yield on hourly basis • Estimated extra-cost • Estimation of self-consumption due to BIPV, on hourly basis • Preliminary estimation of LCOE

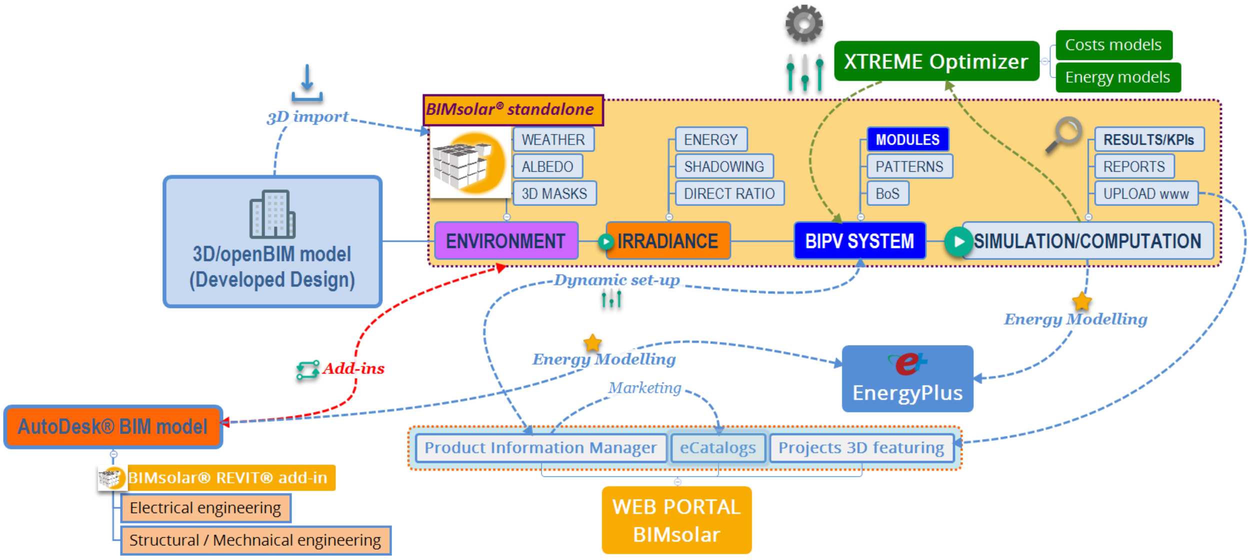


Figure 4.6. Developed BIPV Stage for the enhanced version of BIMSolar®

4.2 Guidelines for implementing BIMSolar® BIPV objects

As introduced in Section 3.2, the specification of the information needed for each building object or system should be included through the definition of the Level of Geometrical Detail (LOG) and the Level of information (LOI) in the BIM Execution Plan (BEP).

Considering that the Implementation Strategy for the enhanced version of the BIMSolar® tool requires the use of BIM BIPV objects during the various stages of the digital process, the specifications of LOG and LOI for BIPV modules is provided. It should be noticed that **these definitions are specific for the new version of the BIMSolar® tool** and they are not mandatory for the BIM Execution Plan of the projects. For this reason, **when BIPV modules are exported, the LOG and LOI contents should be checked and validated by the BIPV stakeholder** in accordance to the specific BEP of the BIPV project.

Hence, Section 4.2.1 includes the description of LOG and LOI required for BIPV modules that will be included in the BIMSolar® tool at specific stages, whereas Section 4.2.2 provides real examples of LOG and LOI for the real BIPV product "ePIZ" that will be developed in the framework of the BIPVBOOST project and implemented in the new version of BIMSolar®.

4.2.1 LOG and LOI for BIMSolar® BIPV modules

The description of the geometrical and informative contents for BIPV modules that will be implemented in the BIMSolar® is provided in accordance to the building application type, which are:

a) BIPV module used as cladding of rear-ventilated façade or roof tile
b) BIPV multifunctional component for BIPV façade or roof
c) BIPV module used as glazing of windows or skylight
d) BIPV module used as other building component, such as shading element (d.1) and parapet (d.2).

Indeed, when BIPV modules are used as building materials, they have to fulfil specific requirements that refers not only to IEC standards but also to building standards depending on their specific use. Thus, depending also on the BIPV process stage in the BIMSolar® tool (Table 4.7), LOG and LOI definitions are provided in the following sub-sections.

Table 4.7. Relation among the process stages implemented in the BIMSolar® tool and the LOG/LOI of BIPV modules

BIMSolar® stage	Conceptual stage aimed at designing BIPV macro-types	Developed stage at designing the BIPV envelope with real and optimized BIPV elements
LOG / LOI	200	300

a) BIPV module used as cladding of rear-ventilated façade or roof

Table 4.8. LOG definition for BIPV cladding of rear-ventilated façade or roof

LOG	BIMSolar stage	Graphic aspects
LOG 200	**Conceptual**	Dimensions Shape Color/texture (optional)
LOG 300	**Developed**	Dimensions Layers representation (glass panes, rear layer, PV cells...) Shape Surface appearance (referenced colour or PV cells type) Junction box dimensions and positioning

Table 4.9. LOI definition for BIPV cladding of rear-ventilated façade or roof

LOI	BIMSolar stage	Informative Parameters	
LOI 200	**Conceptual**	Generic	Type of building application
		Geometric	Length Width
		Electrical	Technology (cSi or thin film) Average power per square meter
		Thermal	Typical U-value
		Economic	Average cost per square meter
LOI 300	**Developed**	Generic	Specific building application Manufacturer Model
		Geometric	Length Width Total thickness Front glass thickness Rear-layer thickness Encapsulant thickness Junction box length Junction box width Junction box thickness
		Material	Front glass type (including colour + reference) Rear-layer type Encapsulant type
		Thermal	U-value
		Electrical	Number of cells Cell type / reference Cell peak power Module peak power Module Vmpp Module Impp Module Voc Module Isc

			Module power coefficient Strings/diodes
		Mechanical	Weight
		Economic	Cost per module Average cost of fixing system
		Certifications	IEC 61215 IEC 61730 Building-related standards

b) BIPV multifunctional components for façade or roof

Table 4.10. LOG definition for BIPV multifunctional components for façade or roof

LOG	BIMSolar® stage	Graphic aspects
LOG 200	**Conceptual**	Dimensions Shape Colour / texture (optional)
LOG 300	**Developed**	Dimensions Layers representation (glass panes, rear layer, PV cells...) Shape Surface appearance (referenced colour or PV cells) Junction box dimensions and positioning

Table 4.11. LOI definition for BIPV multifunctional components for façade or roof

LOI	BIMSolar stage	Informative Parameters	
LOI 200	**Conceptual**	Generic	Type of building application
		Geometric	Length Width
		Electrical	Technology (Si or thin film) Average power per square meter
		Thermal	Typical U-value
		Optical	Typical solar factor Typical visible transmittance
		Economic	Average cost per square meter
LOI 300	**Developed**	Generic	Specific building application Manufacturer Model
		Geometric	Length Width Total thickness Front glass thickness Rear-layer thickness Encapsulant thickness Additional layer thickness Additional adhesive thickness (optional) Junction box length Junction box width Junction box thickness
		Material	Front glass type + reference (including colour) Rear-layer type Encapsulant type Additional layer type Additional adhesive type or mechanical fixing type (optional)
		Thermal	U-value

		Optical	Solar factor Solar transmittance Visible transmittance
		Electrical	Number of cells Cell type Cell peak power Module peak power Module Vmpp Module Impp Module Voc Module Isc Module power coefficient Strings/diodes
		Mechanical	Weight
		Economic	Cost per module Average cost of fixing system
		Certifications	IEC 61215 IEC 61730 Building-related standards

c) BIPV module used as glazing of façade or roof

Table 4.12. LOG definition for BIPV used as glazing of façade or roof

LOG	BIMSolar® stage	Graphic aspects
LOG 200	**Conceptual**	Dimensions Shape
LOG 300	**Developed**	Dimensions Shape Layers representation (glass panes, rear glass, PV cells...) Surface appearance Simplified frame representation Junction box dimensions and positioning

Table 4.13. LOI definition for BIPV used as glazing of façade or roof

LOI	BIMSolar® stage	Informative Parameters	
LOI 200	**Conceptual**	Generic	Type of building application
		Geometric	Length Width
		Electrical	Technology (Si or thin film) Average power per square meter
		Economic	Average cost per square meter
LOI 300	**Developed**	Generic	Specific building application Type of glazing (double glazing, triple glazing, PV front, PV back, …) Manufacturer Model
		Geometric	Length Width Total thickness Front glass thickness Encapsulant thickness Rear glass thickness Additional glass layer thickness (optional) Air cavity thickness (optional) Junction box length Junction box width Junction box thickness
		Material	Front glass type Encapsulant type Rear glass type Gas type in the air cavity (optional) Additional glass type (optional) Interlayer type (optional)
		Thermal	U-value
		Optical	Solar factor

			Solar transmittance Visible transmittance
		Electrical	Number of cells Cell type Cell peak power Module peak power Module Vmpp Module Impp Module Voc Module Isc Module power coefficient Strings/diodes
		Mechanical	Weight
		Economic	Cost per module Average cost of fixing system
		Certifications	IEC 61215 IEC 61730 Building-related standards

d1) BIPV module used as shading element

Table 4.14. LOG definition for BIPV used as shading element

LOG	BIMSolar® stage	Graphic aspects
LOG 200	**Conceptual**	Dimensions Shape Colour/texture (optional)
LOG 300	**Developed**	Dimensions Shape Layers representation (glass panes, rear glass, PV cells...) Surface appearance Simplified frame representation Junction box dimensions and positioning

Table 4.15. LOI definition for BIPV used as shading element

LOI	BIMSolar® stage	Informative Parameters	
LOI 200	**Conceptual**	Generic	Type of building application Fixed or adjustable (optional)
		Geometric	Length Width Minimum distance among elements
		Electrical	Technology (Si or thin film) Average power per square meter
		Economic	Average cost per square meter
LOI 300	**Developed**	Generic	Specific building application Type of glazing (double glazing, triple glazing, PV front, PV back, …) Manufacturer Model
		Geometric	Length Width Total thickness Front glass thickness Encapsulant thickness Rear glass thickness Minimum distance among elements Maximum distance among elements Maximum inclination/rotation (optional) Junction box length Junction box width Junction box thickness
		Material	Front glass type Encapsulant type Rear-layer type
		Thermal	U-value

		Optical	Solar factor Solar transmittance Visible transmittance
		Electrical	Number of cells Cell type Cell peak power Module peak power Module Vmpp Module Impp Module Voc Module Isc Module power coefficient Strings/diodes
		Mechanical	Weight
		Economic	Cost per module Average cost of fixing system
		Certifications	IEC 61215 IEC 61730 Building-related standards

d2) BIPV module used as parapet

Table 4.16. LOG definition for BIPV used as parapet

LOG	BIMSolar® stage	Graphic aspects
LOG 200	**Conceptual**	Dimensions Shape Colour / texture (optional)
LOG 300	**Developed**	Dimensions Shape Layers representation (glass panes, rear glass, PV cells...) Surface appearance Simplified frame representation Junction box dimensions and positioning

Table 4.17. LOI definition for BIPV used as parapet

LOI	BIMSolar® stage	Informative Parameters	
LOI 200	**Conceptual**	Generic	Type of building application
		Geometric	Length Height
		Electrical	Technology (Si or thin film) Average power per square meter
		Economic	Average cost per square meter
LOI 300	**Developed**	Generic	Specific building application Type of glazing (double glazing, triple glazing, PV front, PV back, …) Manufacturer Model
		Geometric	Length Height Total thickness Front glass thickness Encapsulant thickness Rear glass thickness Additional glass layer thickness (optional) Junction box length Junction box width Junction box thickness
		Material	Front glass type Encapsulant type Rear glass type Additional glass type (optional) Interlayer type (optional)
		Optical	Solar factor Solar transmittance Visible transmittance

		Electrical	Number of cells Cell type Cell peak power Module peak power Module Vmpp Module Impp Module Voc Module Isc Module power coefficient Strings/diodes
		Mechanical	Weight
		Economic	Cost per module Average cost of fixing system
		Certifications	IEC 61215 IEC 61730 Building-related standards

4.2.2 BIMSolar® BIPV modules: a real use case with LOG and LOI

The geometrical and informative contents described in Section 4.2.1 are the generic features and parameters that should be assigned to a BIPV module for its implementation and use in the BIMSolar® tool.

To better understand the geometrical and informative contents that can be associated to a BIPV module, a real BIPV product is provided.

The ePIZ is a multifunctional BIPV product that is going to be developed within the BIPVBOOST project. in detail, this product will be a multifunctional BIPV opaque cladding solution for façades integrating thermal insulation.

The geometrical and informative contents that are going to be implemented for this product are described in Table 4.18, Table 4.19 and **Error! Reference source not found.** for the different level of detail and BIMSolar® stages.

Table 4.18. LOG200 and LOI200 definitions for e-PIZ BIPV product

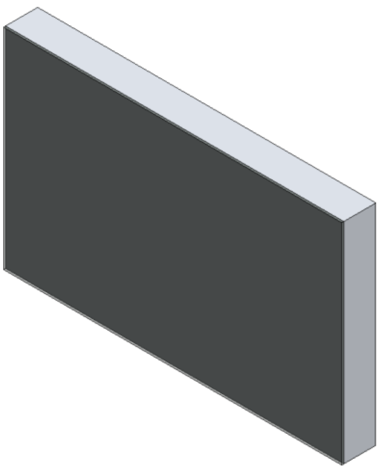
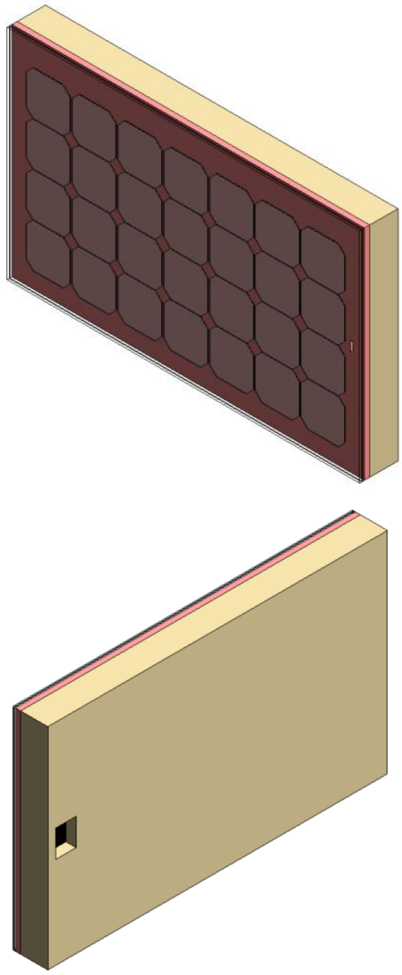
<table>
<tr><th colspan="2">Conceptual stage</th></tr>
<tr><th>LOG200</th><th>LOI200</th></tr>
<tr><td></td><td>
<table>
<tr><th>Parameter</th><th>Value</th><th>Formula</th><th>Lock</th></tr>
<tr><td colspan="4">Construction</td></tr>
<tr><td colspan="4">Text</td></tr>
<tr><td>PV Technology</td><td>Crystalline silicon</td><td>=</td><td></td></tr>
<tr><td>Type of Building Application</td><td>Prefabricated Facade</td><td>=</td><td></td></tr>
<tr><td colspan="4">Materials and Finishes</td></tr>
<tr><td colspan="4">Dimensions</td></tr>
<tr><td>Length</td><td>1.0000 m</td><td>=</td><td>☑</td></tr>
<tr><td>Height</td><td>0.6200 m</td><td>=</td><td>☑</td></tr>
<tr><td colspan="4">Analytical Properties</td></tr>
<tr><td colspan="4">Data</td></tr>
<tr><td>Avg cost per sqm</td><td>0.000000</td><td>=</td><td></td></tr>
</table>
</td></tr>
<tr><td colspan="2">At this stage, in the BIMSolar® Revit® add-in (or the standalone version), this basic BIM BIPV element can be used to represent the BIPV macro-type and provide the basic information that are needed to obtain a preliminary BIPV project with the design of BIPV surfaces and preliminary assessment of energy yield and costs.</td></tr>
</table>

Table 4.19. LOG300 and LOI300 definitions for e-PIZ BIPV product

LOG300



LOI300

Parameter	Value	Formula	Lock
Construction			
Text			
Specific Building Application	Prefabricated Facade	=	
Materials and Finishes			
Encapsulant type	<By Category>	=	
Rear glass type	Verre, vitrage transparent	=	
Front glass type	Verre, vitrage transparent	=	
Finish		=	
Electrical			
Cell peak power (Wp)	0.000000	=	
Cell type	Mono-crystalline	=	
Module Impp (A)	0.000000	=	
Module Vmpp (V)	0.000000	=	
Module Isc (A)	0.000000	=	
Module Voc (V)	0.000000	=	
Module peak power (Wp)	0.000000	=	
Module power coef (%/°C)	0.000000	=	
Number of cells	28	=	☐
Dimensions			
Width (Y)	0.6200 m	=	☑
Length (X)	1.0000 m	=	☑
Total thickness	0.1030 m	=	☑
Front glass thickness	0.0032 m	=	☑
Encapsulant thickness	0.0010 m	=	☑
Rear glass thickness	0.0032 m	=	☑
Mortar support thickness	0.0150 m	=	☑
Insulation thickness	0.0800 m	=	☑
J-box length (X)	0.0600 m	=	☑
J-box width (Y)	0.0800 m	=	☐
J-box thickness	0.0150 m	=	☐
Mechanical			
Weight (kg)	0.000000	=	
Analytical Properties			
Identity Data			
Avg cost of fixing system	0.000000	=	
Building certifications	ETA-06/0135	=	
IEC 61215	Yes	=	
IEC 61730	Yes	=	
Type Image		=	
Keynote		=	
Model	e-PIZ	=	
Manufacturer	PIZ	=	
Type Comments		=	
URL	http://www.piz.it/it/	=	
Description		=	
Assembly Code		=	
Cost	300.00	=	

This BIPV BIM element with LOI300 and LOG300 can be uploaded in the BIMSolar® database in order to provide all the necessary data required for carrying out the developed design of the BIPV envelope. In particular, advanced features of BIMSolar® allows to consider the BIPV parameters included in these object for the optimizazion of energy and cost aspects.

4.3 Expected impacts of the advanced features of BIMSolar® tool on BIPV cost reduction

The novelties introduced by the adoption of a BIM-based approach for BIPV can be summarized as following:

- an information management strategy to enhance the BIPV process and deal with the plethora of BIPV related data in order to reduce extra-costs due to inefficiencies,
- an information modeling strategy to describe correctly and effectively the geometrical and informative contents of BIM BIPV object,

and, consequently, thanks to the digital adoption plan aimed at the implementation of the above mentioned strategies,

- new interoperable BIMSolar® tools capable to make interoperable the stages of the BIPV value chain, at least from the conceptual BIPV stage to the developed BIPV stage, overcoming the typical fragmentation and the use of different non-BIM software and tools,
- BIPV BIM objects that can be used in the new version of the BIMSolar® tool and shared among stakeholders. For this purpose, we have developed the “PIM concept”. PIM (as “Product Information Manager”) will be a web-service connecting manufacturers’ databases and BIM workspace through BIMsolar®. PIM will deliver crucial product information in contextual mode (from element level to building level design) to set up BIPV BIM objects. PIM will be a dynamic web library aimed at enabling users to build and perform BIPV cost effective solutions.

Thanks to these novelties, some improvements due to the digitalization of the BIPV process can be identified as shown in Table 4.20, as well as the gains for the stakeholders involved (Table 4.21).

In addition to this, also impacts on cost-reduction can be figured out (Table 4.22), as direct impacts (when there is a cost-saving due to the selection of the most convenient BIPV elements or systems) or indirect impacts (when the process is enhanced reducing inefficiencies and/or it is improved by reducing risk of errors, thus reducing potential extra-costs).

The use of BIM clearly improves the process quality and an enhanced collaboration makes construction projects more predictable, replicable and cost-controlled. BIM has been reported to provide at least 5% saving of project costs (5).

Up to an additional 5% is estimated from BIPV-related BIPVBOOST developments. The evaluation of these improvements and cost-reduction impacts will be demonstrated during the next steps of the project by comparing a traditional process with the new proposed approach, by also implementing it on real demo cases from WP8, and they will be finally included in the updated versions of the Deliverable D1.2 “Cost-reduction roadmap for the European BIPV sector”.

Table 4.20. Expected improvements potentially arising from the implementation of advanced features for BIMSolar®

	STRATEGIC BIPV PROJECT	CONCEPTUAL BIPV PROJECT	DEVELOPED BIPV PROJECT	TECHNICAL BIPV PROJECT	CONSTRUCTION BIPV PROJECT	INSTALLATION ON-SITE	O&M FOR BIPV
TOOLS	3D-BIPV web viewer, BIPV virtual showroom, BIPV web community	BIMSolar® Revit® add-in or BIMSolar® free standalone software (both with optimization tool)	BIMsolar® (with advanced features)	CAD/BIM tools + tools for specific electrical or structural analyses	CAD/BIM software	CAD/BIM software	Specific tools Digital Twin
IMPROVEMENTS	• Electrical/Energy targets from regulations (if present) • Client's desire about energy labels (if present) • Client's budget • Client's desire about profit targets (as a productive asset)	• Energy targets (from strategic planning) • BIPV macro-types representing BIPV surfaces graphically and including non-graphic information about costs and power	• Interoperable 3D model from BIMsolar® add-in for REVIT® that can be imported into BIMsolar® tool for BIPV design. • Optimization for "standard BIPV modules" allows saving time for obtaining sets of solutions instead of one single what if analysis and evaluation of each option at a time. PIM • Optimization for "customized BIPV modules" allows to design the BIPV module that best fit the building envelope, optimization of the module configuration depending on "construction constrains" internally embedded in the module configurator, digital transfer of the BIPV module to the manufacturer to have back information about the feasibility of the module, as well as energy and economic parameters • No other tools provide energy and cost assessment at the same time and possibility to design custom BIPV modules that are evaluated by manufacturers in a digital format • No other tools provide cost assessment (extra-cost and CAPEX) and preliminary evaluation of LCOE	• Possibility to obtain from BIMSolar® graphical and non-graphical data about BIPV modules, preliminary electrical layout and preliminary mounting structure layout, thus reducing errors due to the lack of interoperability	• The use of interoperable files allows to identify defects before the installation stage • technical drawings for customized BIPV modules already prepared from the developed design stage	Interactive installation guides, check lists and manuals (related with nomenclatures from BIM design and 3D viewers on mobile devices)	• No need to model the BIPV system but existing 3D model from "as built" BIM project with validated and operative information can be used as a basis for the Digital Twin

Table 4.21. Expected gains for stakeholders potentially arising from the advanced features of BIMSolar®

	STRATEGIC BIPV PROJECT	CONCEPTUAL BIPV PROJECT	DEVELOPED BIPV PROJECT	TECHNICAL BIPV PROJECT	CONSTRUCTION BIPV PROJECT	INSTALLATION ON-SITE	O&M FOR BIPV
TOOLS	3D-BIPV web viewer, BIPV virtual showroom, BIPV web community	BIMSolar® Revit® add-in or BIMSolar® standalone software (both with optimization tool)	BIMsolar® (with advanced features)	CAD/BIM tools + tools for specific electrical or structural analyses	CAD/BIM software	CAD/BIM software	Specific tools Digital Twin
GAINS FOR STAKEHOLDERS	• The client may get better consideration on BIPV innovations and claim for preliminary studies	• User-friendly tool for architects: add-in for Revit or standalone software • Architects can think about solar building design since the preliminary stage and propose solar architecture to client easily with 3D representations • BIPV Consultants get sets of BIPV macro-types proposals + linked KPIs from OPTIMIZATION services. Save time and offers flexibility, reactivity	• BIPV consultant can directly use 3D models from Revit® or from BIMsolar® standalone software with BIPV surfaces representing macro-types • BIPV consultant can screen standard BIPV modules from the database depending on local suppliers - PIM • BIPV consultant can evaluate several scenarios at a time, providing architects with most convenient design variants - PIM • BIPV consultant can design custom BIPV modules by choosing the desired modules' parameters - PIM • Custom BIPV modules can be exported and sent in a digital format to the manufacturer to have feedback on feasibility, energy output and cost offer • Not only energy is evaluated but also whole life costing is an output of the tool • BIPV objects can be exported and used as inputs for other stages (e.g. installation, manufacturing and O&M)	• Mounting systems and substructures developed the structural engineer can be developed grounding on a 3D model of BIPV envelope	Potential gains • Accuracy of the envelope project (products, materials, …) • Technical risk mitigated (integration into the building skin set-up with better preparation) and shared in collaboration between manufacturers (materials/products) and integrators (systems/solutions) • Bill of materials • Nomenclatures	Potential gains • Accuracy of the envelope project (products, materials, …) • Technical risk mitigated (integration into the building skin set-up with better preparation) • Bill of materials • Nomenclatures	Potential gains • Modern Dashboard (3D, interactive) • Real data related to virtual twins (mixed reality to provide feedback and comparison between prediction and operation within the same interface)

Table 4.22. Direct and indirect impacts on cost-reduction potentially arising from advanced features of BIMSolar®

	STRATEGIC BIPV PROJECT	CONCEPTUAL BIPV PROJECT	DEVELOPED BIPV PROJECT	TECHNICAL BIPV PROJECT	CONSTRUCTION BIPV PROJECT	INSTALLATION ON-SITE	O&M FOR BIPV
TOOLS	3D-BIPV web viewer, BIPV virtual showroom, BIPV web community	BIMSolar® Revit® add-in or BIMSolar® standalone software (both with optimization tool)	BIMsolar® (with advanced features)	CAD/BIM tools + tools for specific electrical or structural analyses	CAD/BIM software	CAD/BIM software	Specific tools Digital Twin
INDIRECT IMPACT ON COST-REDUCTION	• Time to decision • Added value for the programme could be considered as cost reduction	• Free tool for preliminary investigation of BIPV opportunities, • Time-savings: thanks to the optimization tool to select most convenient and appropriate BIPV macro-types • Risk mitigation due to the selection of most appropriate BIPV solutions	• Interoperability among the conceptual stage and the developed design stage reduce time for modeling the 3D building from 2D architectural drawings, • Time-savings: thanks to the optimization tool to evaluate several scenarios at a time • Time savings: reduction of time for manufacturer's reply thanks to digital objects that can be exported and evaluated directly by the manufacturer • Risk mitigation due to the design of feasible solutions using real BIPV products or feasible custom BIPV products	• Interoperability of the developed design project can save time for the importation in specific tools • Risk mitigation due to the precise description of the BIPV envelope both graphically and non-graphically • Time savings: the precise description of substructures and mounting system data can save time for quantity take-off and economic evaluations	• Technical risk mitigation thanks to the more precise description of BIPV envelope set-up that is shared between manufacturers, consultants and contractors	• Technical risk mitigation thanks to the more precise description of BIPV envelope set-up that is shared between manufacturers, consultants and contractors • Time for realizing the BIPV envelope is reduced thanks to better scheduling	• Technical risk mitigation thanks to the more precise description of BIPV envelope set-up that has been installed
DIRECT IMPACT ON COST-REDUCTION		• Identification of most convenient BIPV macro-types to achieve self-sufficiency	• Fast and easy identification of the solution that has the lowest overall cost in the whole life cycle	• The selection of most convenient electrical and structural material and configuration (that is made easier thanks to the availability of BIPV envelope specifications)		• No need for on-site modifications thanks to better preparation	• Selection of most convenient O&M material and set-up in accordance with BIPV set-up

5 CONCLUSIONS

Integrating photovoltaics in building skin involves a strong integration of energy, electrical, architectural and construction requirements during the whole process, requiring a multidisciplinary and integrated approach by architects, engineers and manufacturers since the initial design stages. Today, Europe solar landscape is characterized by fragmentation of the value chain, especially in BIPV, where building and electro-technical sectors need to work in a coordinated way. This fragmentation is a real threat to the competitiveness of the sector. Building Information Management (BIM) is the answer to today's construction process challenges. So far, BIPV is still not supported by a completely digitized process which ensures clear structures, efficient processes, lower costs, less time and higher quality across the entire lifecycle. BIPVBOOST ambition is to contribute towards cost reduction by further developing a digital approach to the work process, namely providing solutions which can be implemented as supporting tools for the real stakeholders.

The proposed BIMSolar® Revit® add-in and the BIMSolar® with advanced features will be developed to create a collaborative value chain, from pre-design to the developed design, based on advanced 3D BIM techniques and optimization algorithms. Further development of web catalogues, BIM objects for project outputs will guide the process from its early stages towards cost control. Supporting tools to optimize the conceptual BIPV design, simulation algorithms for special BIPV modules, translation of technical and detailed design into specific bill of materials, information and manufacturing orders by linking design and construction stages, generation of instructions for installers and quality control checks will be developed.

The framework described and defined in this report, represents a first step of this path aimed at providing a common methodological framework and guideline for architects, BIPV and building skin manufacturers, specialists and installers through the definition of an integrated and collaborative digital process along the value chain for taking BIPV solutions to the BIM environment. Cost-reductions are foreseen along the design and execution process of BIPV project. This action is expected to support the decision making and to ease the assessment of BIPV technologies under the EPBD framework, designing and accurately calculating the impact of a specific BIPV solution on the energy performance of a given building, in terms of energy consumption and on-site electricity generation capacity to cover building's energy needs, since the early design stage.

Finally, the dissemination and exploitation strategy will allow to raise awareness and knowledge among the public as well as professionals of the construction sector on the need to progress towards more efficient buildings.

Once actioned, the report is supposed to help all partners within the project to stay on course on implementing a digitized approach even if there are setbacks or minor details that need changing, so that the overall plan of execution for digitizing the BIPV process is clear and can be carried out

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