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Prototype of BIPV simulation tool - Second version

Project report

CADCAMation, BEAR-iD, Tecnalia, Nobatek

December 2016

Summary

This deliverable summarizes the PVSITES software tool prototype state to date (M12) and its exploitable results. It characterizes the distinctive functionalities, connections, maturity levels and steps needed to maximize exploitation, market uptake and commercialization. It is part of WP7 (BIPV software tool) and specifically of T7.1 “Development of BIPV software tool”.

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The present report was mainly prepared by PVSITES project partner CADCAMation, with additional contributions from BEAR-iD, TECNALIA and NOBATEK. The report was originally submitted to the European Commission as Project Deliverable D7.2 in December 2016.

Disclaimer

About the PVSITES project

PVSITES is an international collaboration co-funded by the European Union under the Horizon 2020 Research and Innovation program. It originated from the realisation that although building-integrated photovoltaics (BIPV) should have a major role to play in the ongoing transition towards nearly zero energy buildings (nZEBs) in Europe, the technology in new constructions has not yet happened. The cause of this limited deployment can be summarised as a mismatch between the BIPV products on offer and prevailing market demands and regulations.

The main objective of the PVSITES project is therefore to drive BIPV technology to a large market deployment by demonstrating an ambitious portfolio of building integrated solar technologies and systems, giving a forceful, reliable answer to the market requirements identified by the industrial members of the consortium in their day-to-day activity.

Coordinated by project partner Tecnalia, the PVSITES consortium started work in January 2016 and will be active for 3.5 years, until June 2019. This document is part of a series of public reports summarising the consortium's activities and findings, available for download on the project's website at www.pvsites.eu.

The PVSITES consortium:

Tecnalia Research & Innovation	CTCV	FormatD2
Onyx Solar	Flisom	Vilogia
BEAR-iD	Cricursa	R2M Solution Research to Market
Nobatek	CEA	CADCAMation
Film Optics	Acciona Infraestructuras	WIP - Renewable Energies

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1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

This deliverable summarizes the PVSITES software tool prototype state at date (M12) and its exploitable results. It characterizes the distinctive functionalities, connections, maturity levels and steps needed to maximize exploitation, market uptake and commercialization. It is part of WP7 (BIPV software tool) and specifically of T7.1 “Development of BIPV software tool”. T7.1 activities will continue all along the project duration with the development of an enhanced version of the software, prototype of web services platform and a pre-commercial version of the BIPV tool. They will be documented in 4 different deliverables (D7.1-4). They run in parallel (from M06) to the research and development efforts to create BIPV virtual objects (3D, parametric and BIM ready), testing activities (real projects, real objects) and real data comparison to ensure readiness for market entry, and at the same time advising on the development routes to increase the strengths while limiting the weaknesses of the technical and economic models linked to digital simulation and prediction.

The deliverable content is all about users’ needs (called User Story), software specifications, users interfaces and development process (AGILE and SCRUM methodologies).

The description of the software itself is made through screenshots of the user interface and mind mapping graphs.

1.2 Relation with other activities in the project

Table 1.1depicts the main links of this deliverable to other activities (work packages, tasks, deliverables, etc.) within PVSITES 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
D7.3	D7.2 provides a standalone simulation tool for BIPV services developed with a SaaS strategy (SOA). The PVSITES simulator is able to dialog with the PVSITES online platform to perform 3D display for the scene, main outcomes from simulation, in line with the users needs (watch, check, share).

1.3 Reference material

Not applicable.

1.4 Abbreviation list

AEC: Architecture, Engineering and Construction

BIM: Building Information Modeling

BIPV: Building Integrated Photovoltaic

BoS: Balance-of-System

DoA: Description of Action

ER: Exploitation Results

nZEB: Nearly Zero Energy Buildings

PV: PhotoVoltaic

SaaS: Software as a Service

SOA: Service Oriented Architecture

SPEC: technical specification

UI: User Interface

US: User Story

2 INTRODUCTION & METHODOLOGY

Developing a BIPV software "from scratch" is a complex task, but possible today with the appropriate resources and a reasonable time frame. CADCAMation, as WP7 leader, will apply its strong experience in BIM software development and the digital experience acquired during the development of BIPV-Insight project (funded by InnoEnergy), in which the basic calculation algorithms and simulation platform were developed and implemented.

The aim is now to create a specific PVSITES plugin focused on BIM methodologies and BIPV objects. This plugin will specify and enhance the generic functionalities of the platform and generate dedicated results and reports, through web interfaces.

The specific objectives for the BIPV software are the following:

• To complete and test first version of code: prototype, "alpha version" (M6, D7.1)

• To develop an advanced version of the program, incorporating all inputs from software testing activities, "beta version" (M12, D7.2)

- To implement a first version of web services model (M12, D7.3)
- To generate a pre-commercial version of web services platform (M18, D7.4)
- Delivering e-catalogs containing PVSITES products in BIM format (M18, D7.5)
- To assess the software performance, generate associated documentation and international versions, "public release" (D7.6, M42)
- Training courses on the tool towards relevant stakeholders (M36 to 42, as part of WP9, D9.19)

2.1 Specifications

We use a slight and fast methodology to specify and develop the software at the same time: AGILE/SCRUM process:

1. First the Users Stories (US) are created: the experts express their wishes and the way they expect each functionality, each result and report;

2. The US are written and transmitted to the development manager, and they are reviewed, discussed and validated;

3. The development team starts to code at the same time as every US manager translates his US into SPECIFICATIONS (Procedures>Documents>Recordings);

4. As the software is pushed forward through chronological iterations and versions, debugs and corrections are made, the partners may even submit new User Stories. The development process is live and is not finished until the end of the project.

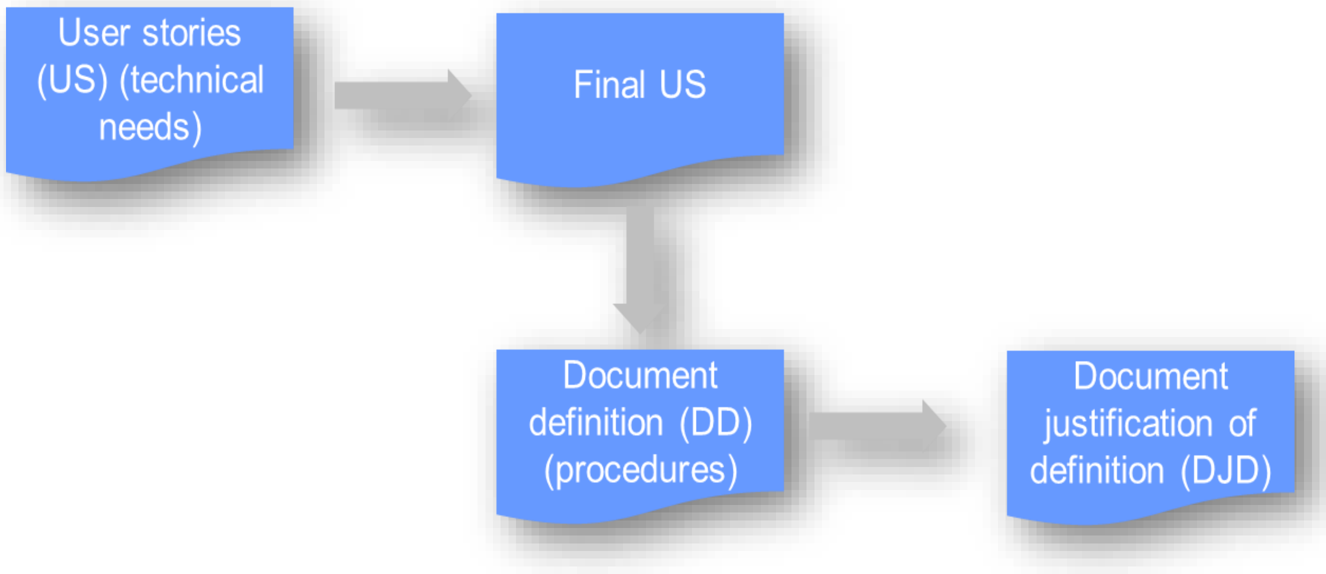

Figure 2.1: User Story process

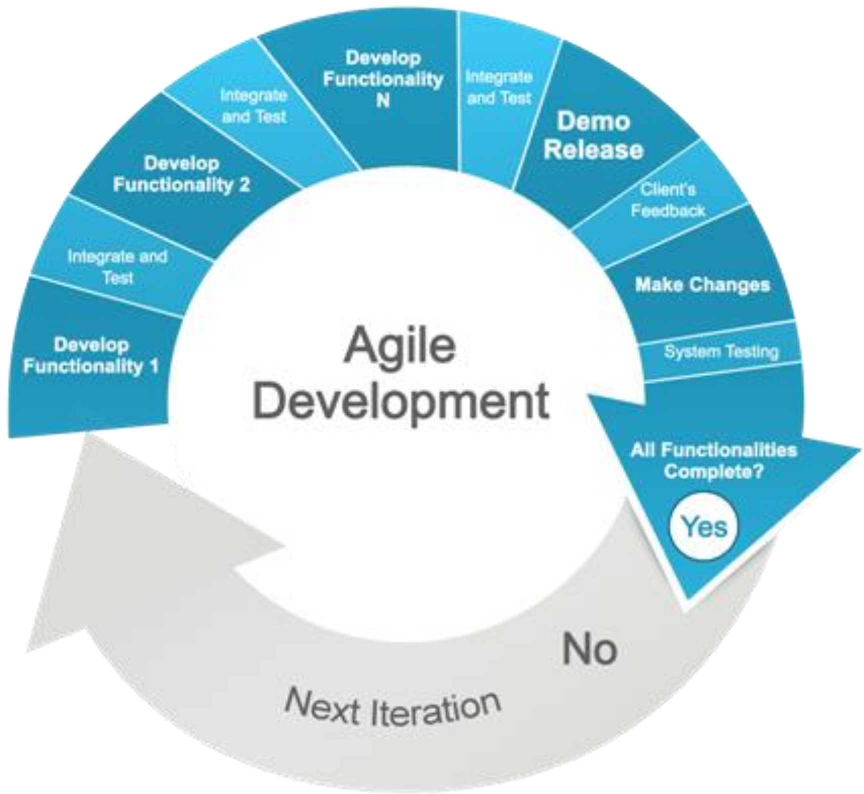

Figure 2.2: AGILE development

2.2 Software coding

The baseline for the coding work comes from the requirements definition, software design and the development of the models to be implemented in the software (US to documents). CADCAMation, will translate the information into the C++ language, JavaScript, webGL for dynamic 3D interfaces, and optimize the performance regarding the SaaS requirements.

Debugging and alpha testing (CADCAMation, BEAR, TECNALIA, NOBATEK)

As a key stage of software development, a rigorous testing process is carried out for EACH VERSION, in order to check the compliance with the established requirements and the rest of features that are essential for the quality of the final product. Bugs within the code are traced and corrected. Performance against requirements, as well as installation procedures, databases, and even support documentation, webinars, will be tested.

Internal Beta testing (BEAR, TECNALIA, NOBATEK and any WP partner)

Partners with an “end-user” profile within the consortium are in charge of performing the general beta testing. Every partner provides feedback (report on beta testing) not only on results, but also on easiness-of-use and suggestions from improvement.

Since the release of the BETA version, Beta testing is widely opened to every PVSITES internal user, in order to gather the most feedback possible and to start to work on realistic uses cases.

3 SPECIFICATIONS FOR THE BIPV TOOL (BETA VERSION, ENHANCED PROTOTYPE)

The following US are a summary of the preliminary list of User Stories and specifications and issues proposed in T7.1, which are currently being developed and are the vision of the partners. Each US is assigned to a manager who is responsible for providing information and updates on the writing, defining the steps needed to reach full commitment with the development team and testing it eventually with selected experts. This AGILE process is managed and supported by CADCAMation.

Table 3.1: List of PVSITES Users Stories to specify the BIPV tool

#	TASK	User Story	US Manager
1.	T7.1.	1.1 PHOTOVOLTAIC INSTALLATION LAYOUT	TECNALIA
2.	T7.1.	1.2 INVERTER DATABASE & SELECTION	TECNALIA
3.	T7.1.	1.3 PV SYSTEM WIRING	TECNALIA
4.	T7.1.	1.4 PV SIMULATION: LOSSES	TECNALIA
5.	T7.1.	1.5 FINANCIAL ANALYSIS	TECNALIA
6.	T7.1.	1.6 PROJECT REPORT GENERATION	NOBATEK
7.	T7.1.	1.7 APPLICATION FEEDBACK TO DIRECT THE DESIGN	NOBATEK
8.	T7.1.	1.8 ENERGY STORAGE	TECNALIA
9.	T7.1.	1.9 STANDARDIZED OPTICAL SIMULATION OF GLAZING SYSTEMS	TECNALIA
10.	T7.1.	1.10 ANGULAR OPTICAL SIMULATION OF GLAZING SYSTEMS	TECNALIA
11.	T7.1.	1.11 STANDARDIZED THERMAL SIMULATION OF GLAZING SYSTEMS	TECNALIA
12.	T7.1.	1.12 HEAT TRANSFER DEVELOPMENT	TECNALIA
13.	T7.1.	1.13.1 Aesthetical issues	BEAR
14.	T7.1.	1.13.2 BIPV issues	BEAR
15.	T7.1.	1.13.3 Design process motivation	BEAR
16.	T7.1.	1.13.4 Design process responsibility	BEAR
17.	T7.1.	1.14 User Interface	CADCAMATION
18.	T7.1.	1.15 BIM for the Architect	BEAR
19.	T7.1.	1.16 BIM for the Engineer	NOBATEK

3.1 Photovoltaic installation layout

The BETA version includes now a logical process, typical of sustainable design approaches:

STEP #1: 3D MODEL IMPORTATION and CONTEXTUAL SETTINGS

- 3D models importation is now multisource: genuine SketchUp (TRIMBLE) files, IFC (official openBIM format), gbXML (green building XML format) and IDF (EnergyPlus compatible format). This aims at providing the PVSITES tool with a large range of inputs, not only geometrical, on the way to a BIM ready approach, and even thermal simulations (EnergyPlus simulation);

- 3D scene: the originality of the software is to process in fulltime 3D, for most of the UIs. This is done in order to keep the user in his/her professional environment, because of the prominence of the 3D in the CAD today;

- Geo-referencing of the project's location: on a simple embedded Google Map (API Google), the user is able to select or enter his/her location then the related weather file (weather site) is automatically uploaded to his/her the database (if not existing) or selected from the database. Weather files are TM2 files or EPW files and cover most of the countries over the planet;

- "Heliodon" or "sun course" tool displays the position of the sun at the selected time of the day. Realistic shadowing is calculated and displayed into the UI.

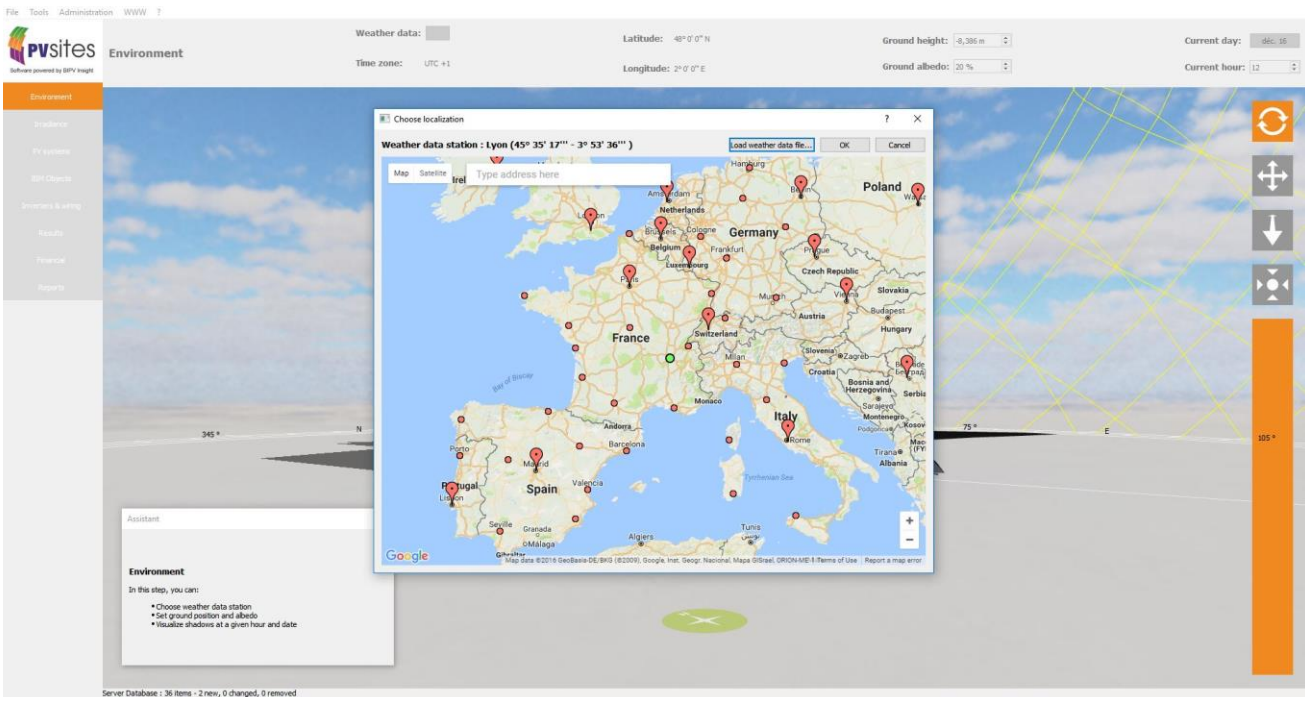

Figure 3.1: First UI - contextual settings – 3D scene

STEP #2: IRRADIANCE CALCULATION and DISPLAY

- Solar Energy potential is crucial in the process. The software runs IRRADIANCE calculation and displays qualitative + quantitative results on the 3D scene (color shades + total irradiance value on the mouse pointer). Irradiance means: total, direct, reflected and diffuse solar irradiance.

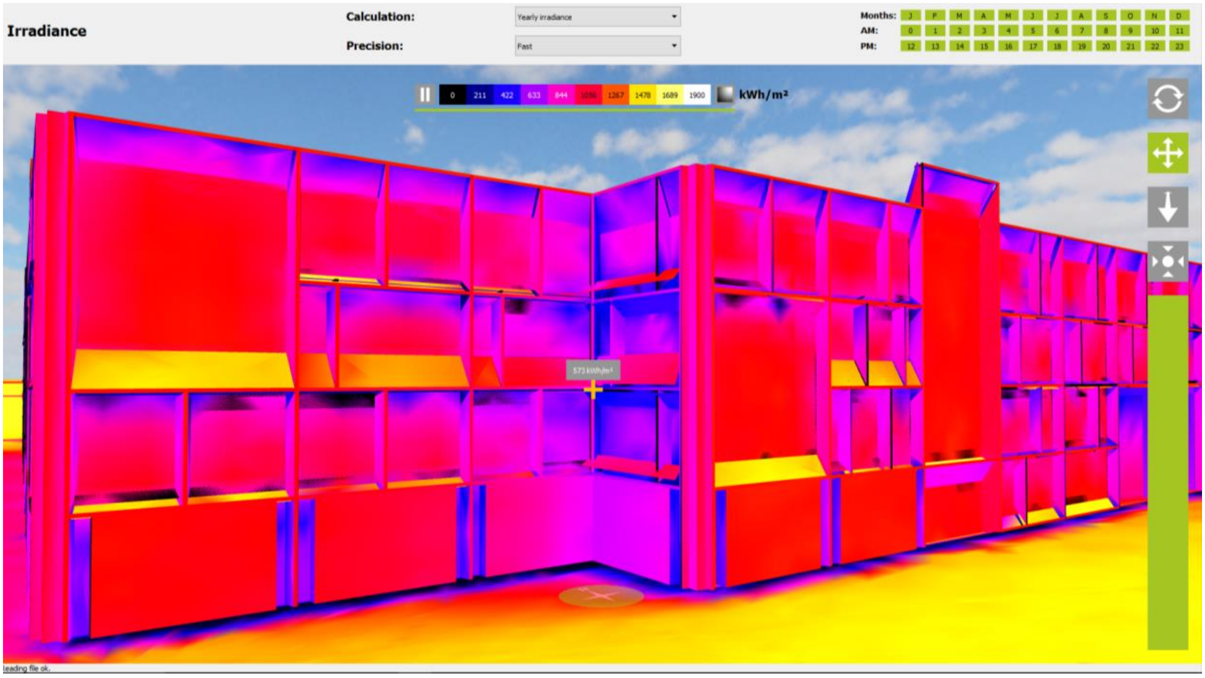

Figure 3.2: Irradiance simulation and display – 3D scene

STEP#3: PV LAYOUT and INTEGRATION into the MODEL

In order to obtain a dynamic and interactive configuration for PV systems, different possibilities for the definition of the best cells and modules arrangement are made possible, given that BAPV, opaque BIPV or transparent BIPV are to be selected:

- For a given BIPV module and surface, the optimisation of the maximum number of cells that can fit that surface has been implemented. The pattern editor checks geometrical boundaries for the selected pattern of cells and surface, and the user obtains the best arrangement in order to maximize PV generation. For BAPV systems, rooftops and brise-soleil, the modules layout (vertical ▯, or horizontal ▭ positioning) is included in the design exercise; the user can cover the surface and even tilt the modules and optimise the array in rows and columns in order to minimize shadowing losses;

- In some cases, e.g. residential market, the client wants to cover only a certain amount of power by means of PV. In this case, the total power of the installation would be an input given by the user (thus, also the number of PV modules of the installation), and for a chosen surface the best arrangement of cells and modules should be calculated to maximize PV generation: this is expected for the next iteration of the tool;

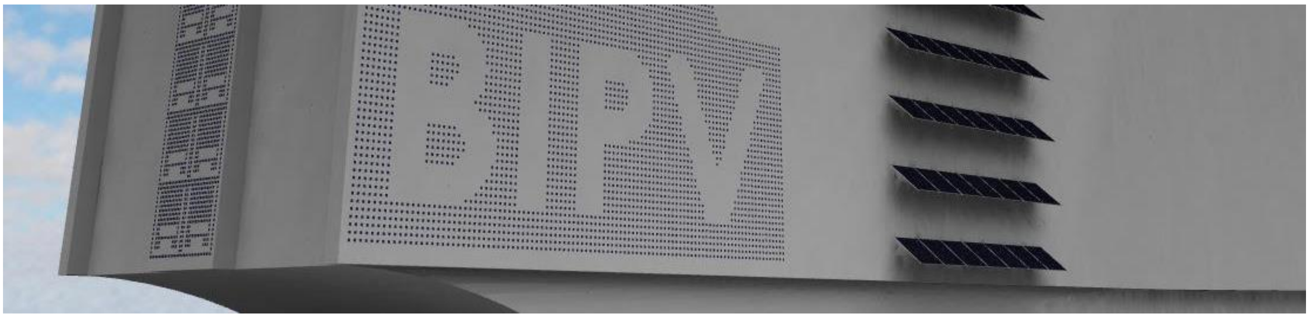

Figure 3.3: Various configurations of cells and modules integration on the same project

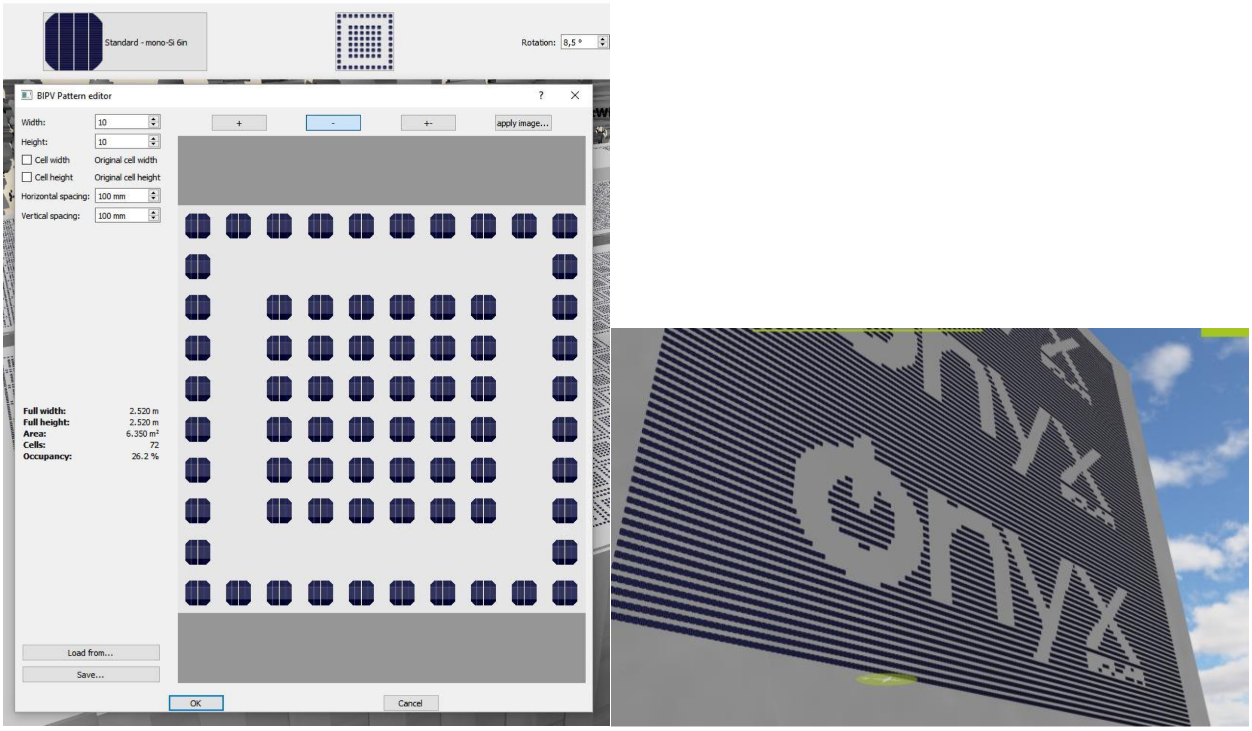

Figure 3.4: Pattern editor for BIPV – Cell design to module design and surface covering

- In its BETA version, the software embeds the PHOTON® database of modules (N=50,000);

3.2 Inverter database & selection

An inverter database must exist as a part of the innovative dynamic library model for the PVSITES tool.

In its BETA version, the software embeds the PHOTON® database of inverters (N=7,500).

Once the PV systems have been set in the desired locations of the 3D model, the inverter selection is the next step of the process. In the inverter selection window, the user is directly provided with some suggestions of possible configurations for the installation, clicking “automatic inverters”. Generating own configurations is also possible.

EXAMPLE:

Current PV installation parameters

Module array: 14 x Sunways 200 Wp

Total output: 3.5 KWp

Configuration Selection

☑ Manufacturer: ☐ Inverter model: (inverters included in the selection)

Manufacturer		Inverter model
• **SMA Solar Technology**	➔	SMA Solar Technology WWW
Power One		SMA Solar Technology XXX
Kaco		SMA Solar Technology YYY
Advanced Energy		SMA Solar Technology ZZZ
Fronius		…

☑ Filter by Sizing Factor

115%

(only configurations above this threshold are shown)

Inverter Selection:

(options below should be directly suggested by the program according to the model under study and the inverter manufacturer selection)

No. Inverters	**Inverter model**	**No. modules per inverter**	**Configuration**	**Sizing Factor**
1	SMA WWW	14	1 string of 14 modules	120
1	SMA XXX	14	1 string of 14 modules	115
1	SMA YYY	14	2 strings of 7 modules	117
2	SMA ZZZ	7	1 string of 7 modules	119

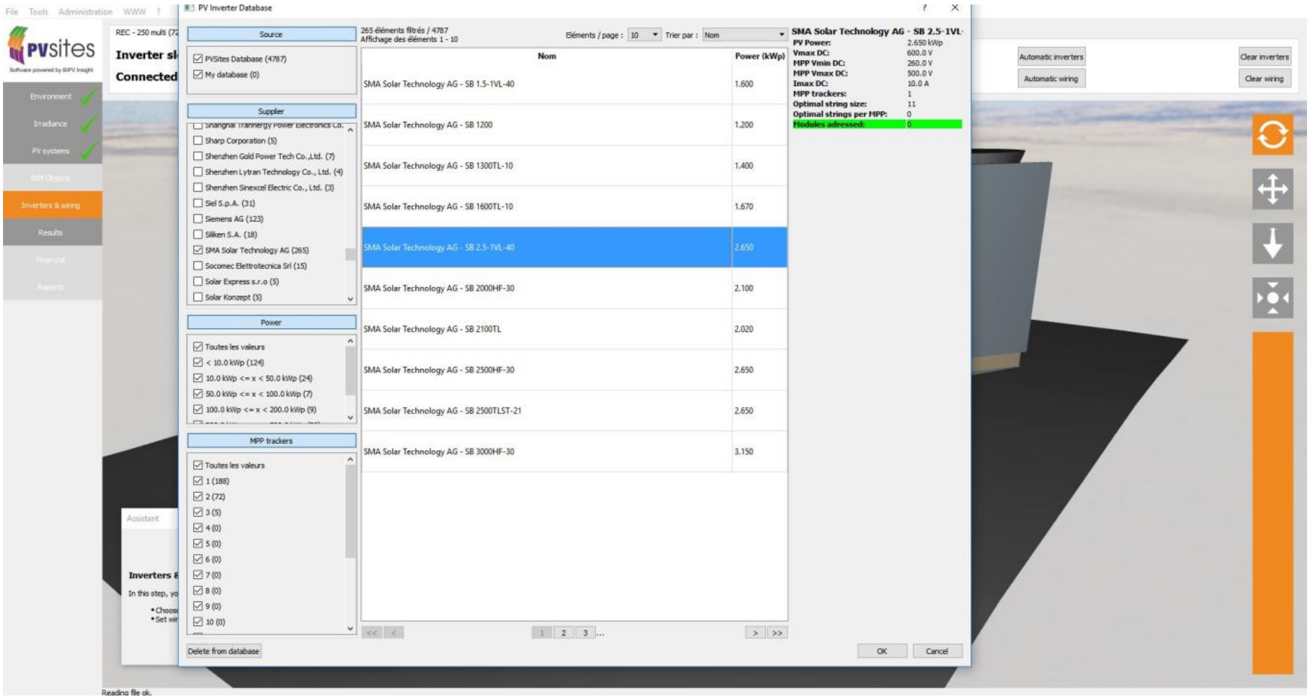

Figure 3.5: Inverter configurator

3.3 PV system wiring

The wiring of the PV system is a really important issue in the design and installation stages, as the energy yield and system costs depend on it.

But establishing a good wiring strategy does not only depend in the number and position of the interconnected modules, but also of the selected electrical architecture (central, string, power optimizer or micro inverters).

Without analyzing aspects related to the selection of the best system architecture, the PV modules wiring could be a tedious and boring experience for the system designer. In order to facilitate the wiring task the application gives the user the opportunity to work in an automatic mode, proposing* the designer different wiring scenarios.

In this BETA version the default mode has been implemented for automatic wiring: minimization of the wiring losses, best balance for the number of MPPTs.

Other automatic wiring scenarios should be created according to different criteria: more US to be written, depending on the PVSITES products parameters.

**This issue is part of the US 7- Application feedback to direct the design.*

Figure 3.6: Wiring configurator

3.4 PV simulation: losses

The PV simulation takes into account the different phenomena affecting the energy yield of the photovoltaic system.

A detailed analysis on output losses related to different aspects of PV installations is important to know where the losses come from and how they can be overcome.

- Shadowing: quantifying the annual loss of each module in the installation due to shadowing effects in a direct and visual way (like PV Sol software does). Allowing the movement of the installation to compare different shadowing effects would be useful; in the BETA version of the software, a detailed analysis for losses is displayed on the 3D, for each BAPV module. Shadow losses represent the difference between theoretical irradiance in the case of the entire environment was omitted (including the modules themselves when they produce shadows) and actual irradiance. This difference is usually positive (when some elements of the environments produce shadows over the modules), but can become negative when the environment brings more energy by reflections that it removes;
- Mismatching effects: calculated and displays in the results section of the software, for inverters selection; Mismatching losses are due possible difference of irradiance when several modules on the same wire receive different amounts of energy ;
- Cable losses: losses due to the wiring of the PV installation. Different cross sections should be eligible and cable losses calculated directly;
- Inverter losses:
- Soiling:
- Losses due to the effect of temperature on efficiency: Thermal losses are the difference between calculation of modules at an ideal temperature and actual calculation.

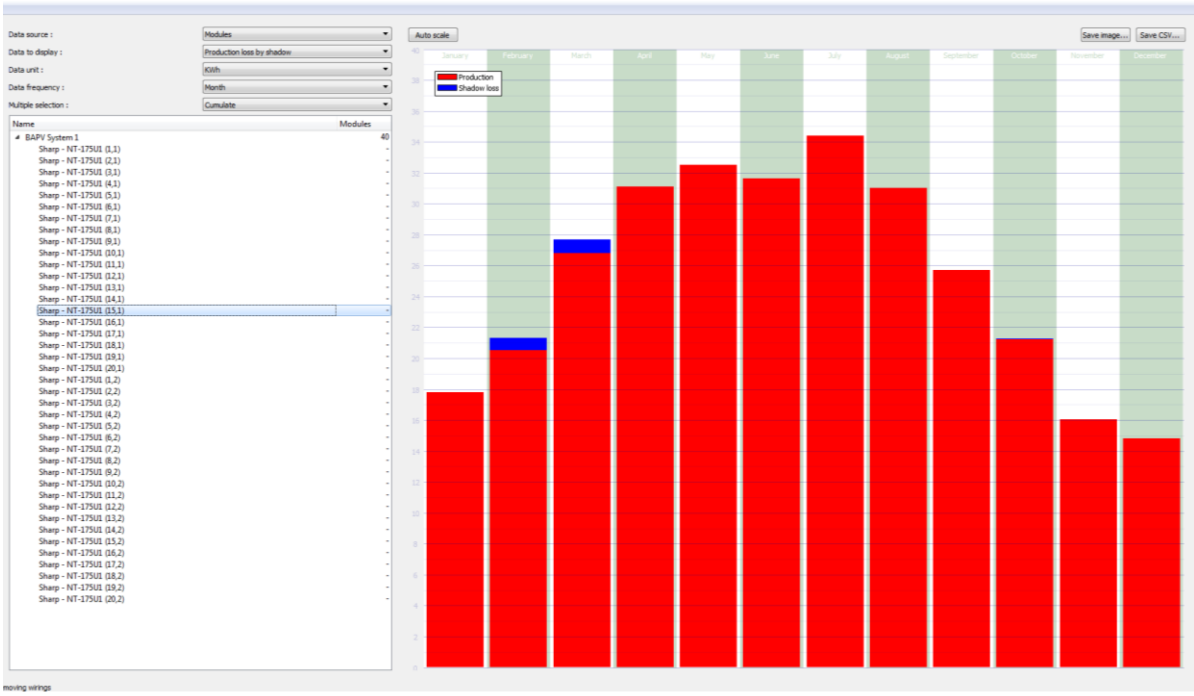

Figure 3.7: PV losses display in graph mode

3.5 Financial analysis

Financial analysis is essential to know the turnover expected from the BIPV/BAPV system under study. This analysis is strongly dependent on the legislation of the country in which the installation is performed: feed-in-tariffs, retail prices, taxes… The program is be able to consider different scenarios fort PV electricity commercialization: net-metering, other self-consumption strategies. In its BETA version, the software computes a simplified financial mode, providing simple parameters to the user. After the beta testing phase, we should be able to implement enhanced modeling and setting of the financial analysis, with consumption loads importation for example.

The general features that the Financial Analysis are:

1. **The Financial Analysis Mode, that first requests the following inputs:**
   - Feed-in-tariff features
     - Feed-in-tariff (€/kWh)
     - Period of validity of FiT (years)
     - Expected yearly variation (%) (if any)
   - Income from export to utility grid (€/kWh) (British/Italian case, not implemented yet, and to be assessed for other scenarios)
   - Power Purchase agreement (€/kWh)
   - Retail price (€/kWh)
   - Inflation (%)

2. **General parameters**
   - Assessment period (years)
   - System degradation due to aging (% output reduction)
   - Maintenance costs

3. **Income and expenditure**
   - Tax deductible cost of system setup parts and labour (€)
   - Non-tax deductible outgoing cost of system setup parts and labour (€)
   - Incoming subsidies (€)
   - OPEX (€/year)
   - Annual consumption costs (€/year)
   - Outgoing other annual costs (€/year)
   - Incoming other annual income/savings (€/year)
4. **Financing: include the cost of a loan (not implemented yet)**
5. **Tax**
6. **Financial Analysis Results: graphs, tables, report**

   Payback period, yield, LCOE (with formula), profits at the end of the assessment period. In this part, the results of the analysis are be presented, including tables and graphs in order to ease the understanding.

3.6 Project report generation (to be specified for future versions)

A predefined report should be generated (if requested by the user) comprising the different parts of the design procedure: shadowing analysis, inverter selection, wiring, PV simulation results, Financial Analysis…

Screen shots taken through the different design steps would be useful for the report generation. PVSol uses a 'camera button' to take 'screen shots' and save images of the different design phases. These images are then included directly in the automatic report.

E.g. during the shadowing analysis of an installation, screen shot the result of that installation in different positions, to ease the comparison of different models and ease the justification of the adopted solution.

The report generation should allow choosing the parts to be included, in order to adapt it to the needs of the customer, which will be different depending on its role (building owner, architect, BIPV manufacturer, etc.)

The BIPV tool should allow exporting the report through .docx, .rtf, .csv or .pdf formats.

3.7 Application feedback to direct the design

A good system design is important in conventional PV systems in order to enhance the yield, but even more for BIPV ones due to the **common mismatching in operation conditions**.

Usually, BIPV system design starts with the location of the PV modules in the building's envelope best site and analyzing the energy potential, continue with BoS issues (module connection and inverter selection) and finish with an abstract of the annual energy balance (generation and losses).

But during the design process the different selections are based only in the knowledge and expertise of the designer. A poor application feedback is given in order to direct the choice of the designer. Some commercial programs give the user only the opportunity to move the PV generator on the roof or façade, or to select different inverter configuration according to the number of strings.

These recommendations or options should be given during all possible design process steps and argued quantitatively. In its BETA version, the PVSITES software is already a decision support tool, by enabling the user to:

1. Define the nature of the installation and the design optimization criteria (grid injection, self-consumption, net balance, etc.);
2. Optimise the PV generator building location (irradiation step + objects handling into the 3D scene, connected to the original design, with a lot of versatility, through “What If Analysis”);
3. Configure the BAPV/BIPV module/technology (as a result of diffuse irradiation, temperature dependence, etc.);
4. Be efficient and progress in **PV system architecture** + wiring (number of strings, central inverter, multistring inverter, micro inverters, power optimizers, batteries, etc., to be implemented step by step);

   …

N. Design BIPV system annual energy balance (generation and losses). And beyond, EnergyPlus connection is expected through IDF file enrichment and outputs integration into the PVSITES software to provide key figures about improvement of the energy efficiency of the building (heat gains during cold periods, cooling reduction for hot periods). Even daylighting efficiency for the spaces behind the BIPV surfaces is expected through a specific embedded module.

For each selection step a ranking of the most suitable items would be displayed, providing clear arguments (energy performance, etc.) for the decision-making. A performance comparison of different system designs would be also interesting.

All those expected evolutions must be translated into US for the next versions. The following schematic views are abstracts related to expectations towards design process

(Source: NOBATEK®).

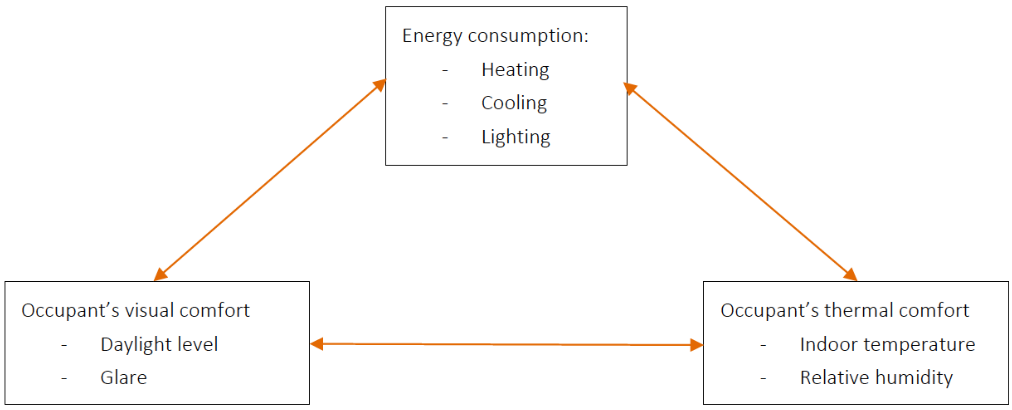

Figure 3.8: feedback to direct the design – Engineering workflow

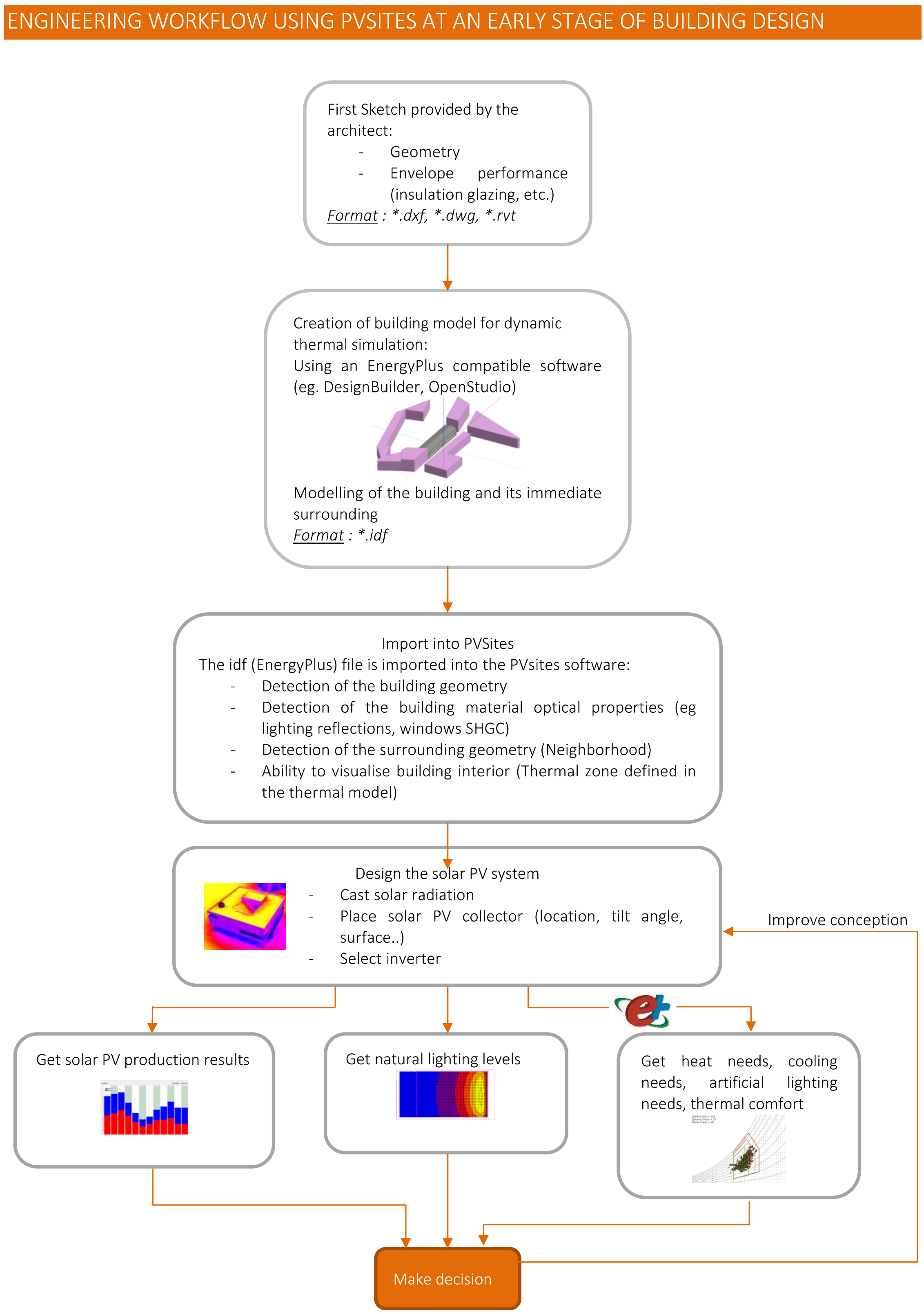

Figure 3.9: feedback to direct the design – Engineering workflow

3.8 Energy storage (to be specified for future versions)

BIPV and energy management systems are closely related to each other. Self-consumption requires a storage system in which the energy that isn't instantaneously self-consumed shall be stored, in order to use it when required.

The BIPV tool should include this functionality. The software should allow the definition and use of storage systems (batteries) and their implementation within the PV installation.

The storage system definition could be arranged just after the PV system definition and should comprise the following aspects:

- Number of batteries
- Voltage (V)
- Capacity (Ah): number of hours for which a battery can provide a current equal to the discharge rate at the nominal voltage of the battery

Calculations required:

1/ **PV energy stored**: annual PV energy stored. Absolute amount of energy stored in the batteries fed by means of the BIPV system

2/ In case of **self-consumption**, the stored energy of the BIPV system should be computed related to the consumption profile of the building, household, etc. The analysis should take into account the optimal moment to self-consume the stored energy, depending on the electricity price. That is to say, if electricity price is higher at night than in the afternoon, it will be better to store PV energy in the afternoon and consume energy from the grid in the afternoon, in order to self-consume the stored energy at night. These sort of optimization analysis should be implemented when a BIPV simulation + self-consumption is performed.

Observations: The PV storage system configuration is properly addressed in the current US, although it must be also considered in a global analysis. This overall analysis should take into account not only the parameterization of the elements in the system (PV modules, inverters, batteries, and other BoS components), but also different scenarios (self-consumption, net-metering, etc.), energy management strategies, etc. The aim of the global analysis would be to address in as much as versatile way all the future possible PV system operation scenarios.

3.9 Standardized optical simulation of glazing systems

An important number of BIPV installations include glazing systems with integrated PV cells: skylights, ventilated façades, curtain walling, etc. A good optical description of the transparent zones of the glazing system is necessary for the accuracy of the calculation of the thermal behaviour of the building. In addition to this, architects/designers need to know the standardized optical properties of the designed glazing systems to ensure that they comply with the corresponding building codes.

Manufacturers usually provide transmittance and reflectance values of single glass panes. An algorithm is needed to combine the optical properties of each glass pane into laminated glass and double gazing systems.

EN-410 standard provides a calculation method for this purpose, for normal incidence conditions.

Necessary (internal) inputs are:

- Spectral transmittance (280-2500 nm range) of individual glass panes of the same composition as those defined by user (thickness can be converted by calculation).

- Spectral reflectance (280-2500 nm range) of individual glass panes of the same composition as those defined by user. If the glass is coated, reflectance of both surfaces.
- Original thickness of glasses.

Inputs from user:

- External glass:
  - If simple glass: reference and thickness.
  - If laminated glass: reference and thickness of external glass; Type of interlayer (EVA, PVB, etc.), reference if available, number of layers, layer thickness; reference and thickness of internal glass.
- Air chamber thickness
- Internal glass (same considerations as external glass)

External (to user) outputs:

- Integrated solar and visible transmittance of glazing system.
- Integrated solar and visible reflectance (both sides) of glazing system.
- Absorptance of external and internal glazing.

An internal database of EVA and PVB optical properties has been created and can be extended by the user, with his/her own parameters. Experimental inputs necessary to calculate these properties may be obtained from manufacturers (Dupont®, Kuraray®, Solutia®, etc.) or from internal measurements (Tecnalia).

Triple glazing is also included.

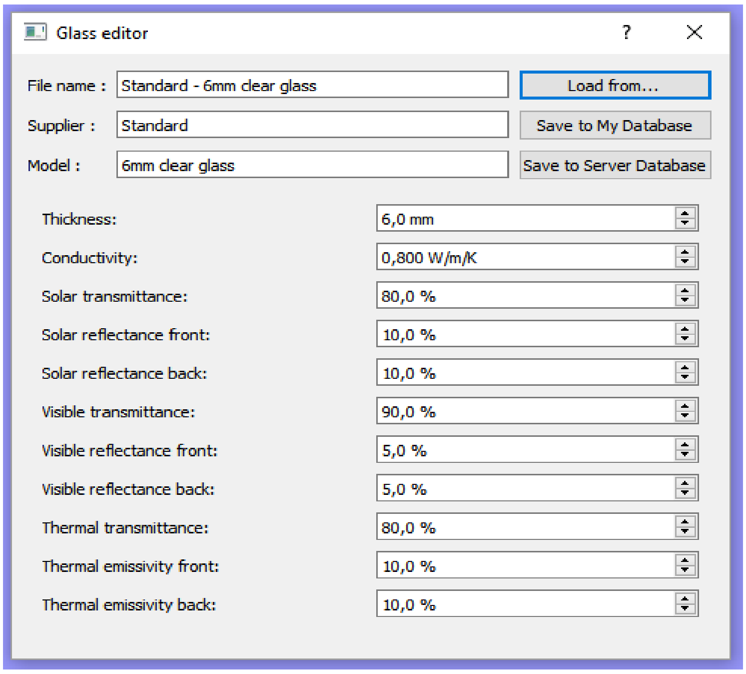

Figure 3.10: Glass editor

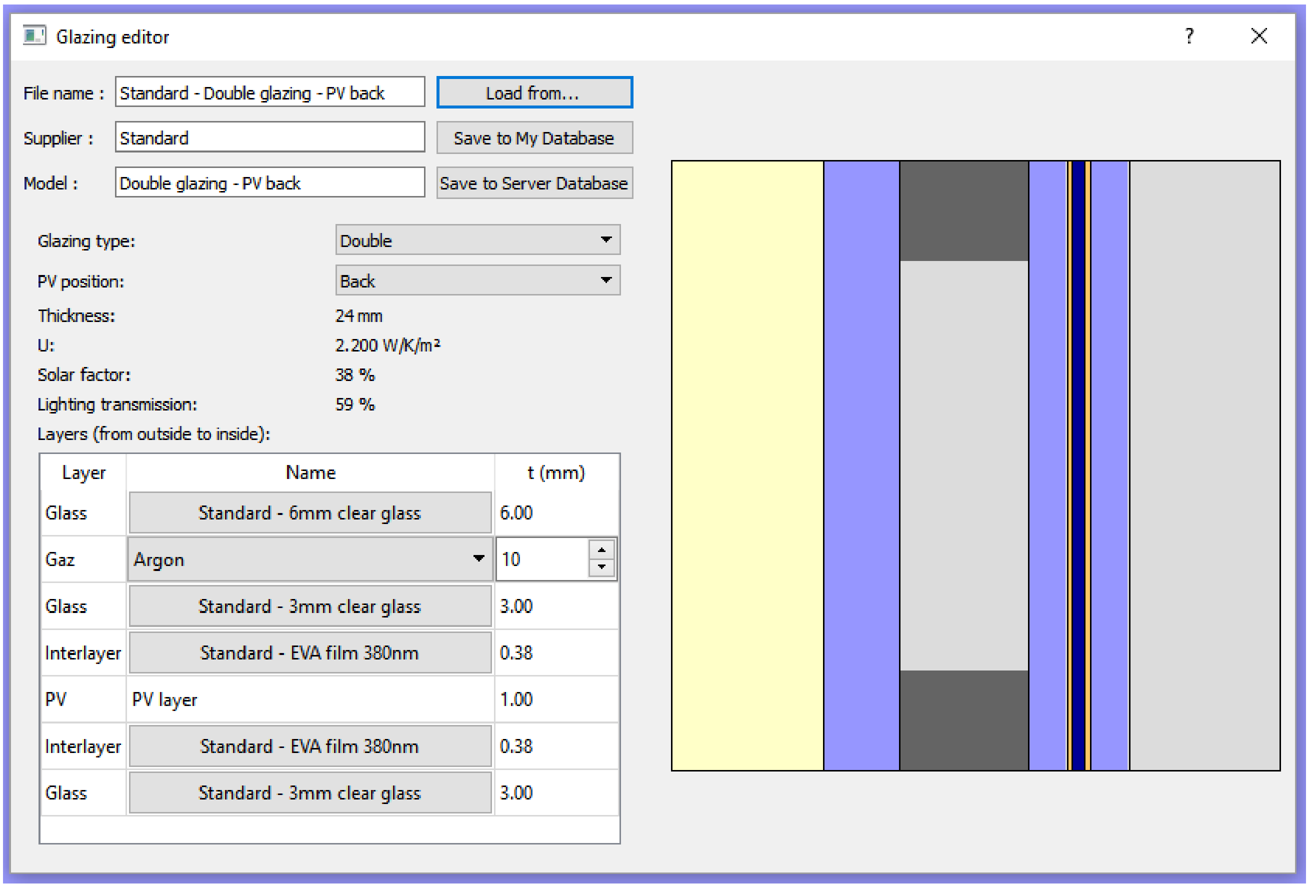

Figure 3.11: Glazing editor

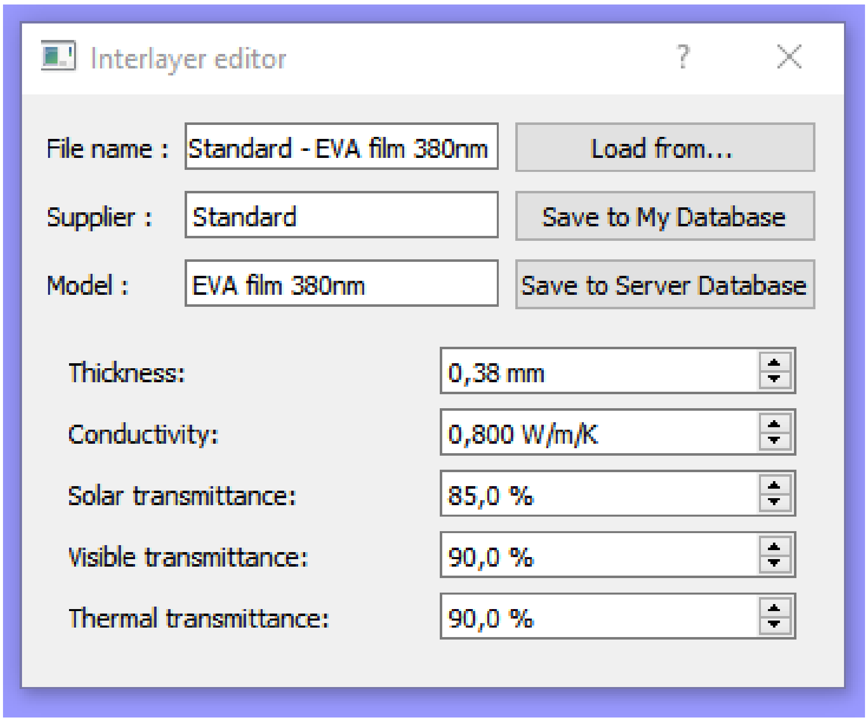

Figure 3.12: Interlayer editor

3.10 Angular optical simulation of glazing systems (to be specified)

The integrated properties discussed in US « Standardized optical simulation of glazing systems » are given for a near normal angle of incidence, but in practice they vary with the angle of incidence. Since the solar irradiation strikes a roof or a façade at a wide range of incidence angles, it is important to account for this dependency. For many locations the main part of the irradiation impinges at an incidence angle (by definition measured against the normal) of about 40-60° on a vertical surface. The transmittance data at normal incidence is important for glazing comparison and compliance with standards, but has less relevance when it comes to performing accurate building energy simulations.

Obtaining the optical properties at other angles than normal incidence is far from being a trivial issue. Angular resolved optical measurements are complex and time consuming so that characterization at normal incidence only is preferred. Theoretically, angular resolved properties are well defined by the Fresnel equations. This is a rigorous way to get the data as long as the thickness and optical constants of all the system layers are known. When it comes to uncoated glazing this theoretical approach is analytically feasible since the optical constants can be obtained from transmittance and reflectance by using inverse methods. The problem becomes more complex when coated glazing are included. Composition of (often multiple) coatings is not generally known and may even be a corporate secret. As a consequence it has been proposed in the literature to use different kinds of approximations (empirical, semi-empirical or numerical) in order to simulate the angle dependence of simple coated glasses or the whole glazing unit.

Proposal:

1) To derive and implement the analytical expressions for uncoated simple or double-glazing systems.

2) To analyze the convenience of empirical, semi-empirical or numerical methods for coated glass in terms of induced loss of accuracy (e.g. when considering a yearly building energy simulation) and implement the chosen solution.

This work will be conducted in association with the Fresnel Lenses product modeling (Skylight) developed by TECNALIA in WP3/T3.1.

3.11 Standardized thermal simulation of glazing systems

An important number of BIPV installations include glazing systems with integrated PV cells: skylights, ventilated façades, curtain walling, etc. Building codes usually refer to standardized thermal transmittance values in order to take into account these elements into the building thermal description.

EN 673 standard is the one referred by most European standards, many building codes, and therefore by the European glazing industry for this purpose. It provides a calculation method for centre-of-glass U value of glazing systems.

Thermal conductivity of laminated glass to be calculated internally from user inputs for glazing and interlayer.

Inputs from user:

- External glass:
    - If simple glass: glass reference and thickness (emissivity to be taken from internal glass database).
    - If laminated glass: glass reference and thickness (emissivity from internal glass database); Type of interlayer (EVA, PVB), number of layers, layer thickness and thermal conductivity (if not available, take values from internal data base);
- Air chamber thickness and gas composition
- Internal glass (same considerations as external glass)

External (to user) outputs:

- Thermal transmittance (U value, W/m^2K)

3.12 Heat transfer simulation (to be implemented)

During the design process, modelling the building thermal behaviour is essential in order to estimate the overall heating/cooling needs, or the occupants' comfort level. Numerous parameters can impact the thermal performance of a building such as envelope material properties, occupant's behaviour, internal heat gain associated with electric equipment, amount of transmitted solar radiation, etc.

Depending on the technologies, BIPV system can also have a strong impact on the building thermal behaviour. For example, integration of opaque PVs in walls or roof may alter their thermal resistance. The use of transparent BIPV as windows or skylight strongly modifies the amount of transmitted solar radiation, and will probably also affect the artificial lighting energy requirement.

Hence, there is a need to have relevant indicators taking into account and depicting these effects in order to guide and support the design phase. However, thermal simulation is a heavy process involving a large number of inputs and complex physic equations. Thus two kinds of indicators will be defined and used: simplified indicators given by BIPV simulation tool and more complex ones computed with the EnergyPlus software.

3.12.1 Simplified thermal indicators within BIPV simulation tool

Transparent BIPV technologies have a strong impact on building solar heat gains. To assist the designer in perceiving this impact, two indicators will be displayed.

The first indicator is the amount of solar gain reduction (in percentage) between a "standard" windows (user defined) and transparent BIPV solution. It can be interpreted as a shading solar factor.

A more advanced indicator is the amount of radiation that the building will receive for different periods of time. Figure 3.13 provides an example of graphical representation of the annual solar gain. In this figure for each month, the quantity of solar radiation getting inside the building is given for a typical day. Maximum and minimum levels should also be displayed using a colour map. This graphical representation helps the user to design a BIPV system that would enable heat gains during the cold season while reducing them during the summer months.

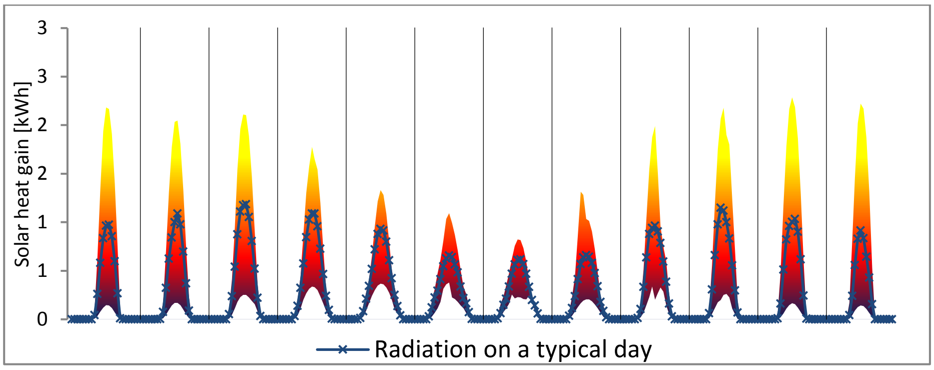

Figure 3.13: Yearly solar heat gain division

3.12.2 Comprehensive Building Thermal simulation using EnergyPlus

While simplified indicators are useful for a quick design, more complex indicators such as heat needs, cooling needs or occupant thermal comfort, may be required as well. As the PVSITES simulation tool doesn't embed any building thermal model, an interaction with the EnergyPlus software is created. The workflow, the inputs and outputs of the whole interaction are detailed in the Figure 3.14 below.

As depicted, the EnergyPlus simulation requires an EnergyPlus model file (*.idf) that can be generated from a thermal modelling tool (OpenStudio, DesignBuilder, etc.). The PVSITES simulation tool uploads the thermal model and displays it in the 3D environment. The user defines his/her BIPV installation according to the standard procedure. The software automatically modifies the EnergyPlus file to take the PV products into account. Then it executes the EnergyPlus engine, and gets the results back once the simulation is complete. At the end of the process, the results are displayed in the user interface in a graphical user-friendly form:

- Heat needs/cooling needs evolutions
- Artificial lighting needs
- Heat gains proportion
- Occupant discomfort for each thermal zone

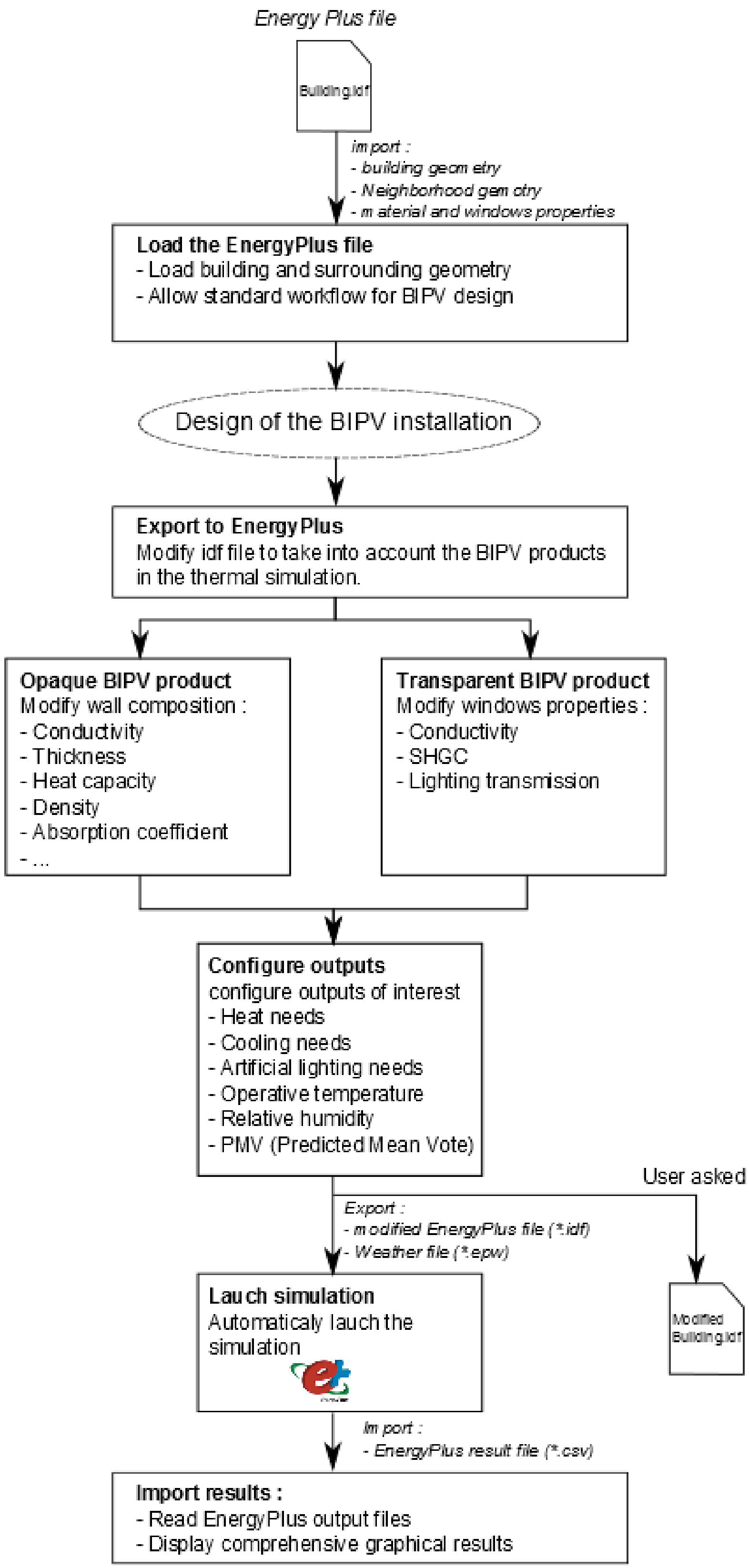

Figure 3.14: EnergyPlus workflow

3.13 Users stories on design (architect overview)

3.13.1 Aesthetical issues

In order to decide whether BIPV systems are well integrated, we need to distinguish between the following:
• Technical quality of the integration of the BIPV system, that is, the technical aspects of PV, cables and inverters.
• Building quality of the BIPV system. Here we look for the quality of the integration of the system as a building element (part of the roof or the façade that is replaced by modules). The module and its integration must meet typical building standards, such as an impermeable layer or a structure strong enough to withstand wind or snow loads.
• Aesthetical quality of the BIPV system. This is the least scientific and most subjective part of judging BIPV systems. But the reality is that architecturally elegant, well-integrated systems will increase market acceptance.

Both the technical and building qualities of the PV system have been considered as preconditions. All installations in a building must function correctly.

Aesthetical quality is not a precondition. The discussion of architectural values is very broad. The average architect is not yet convinced of the “beauty” of a PV system on the building he/she designs.

The criteria formulated by the IEA PVPS Task 7 workgroup for evaluating the aesthetical quality of building-integrated PV systems are:
- natural integration,
- designs that are architecturally pleasing,
- good composition of colors and materials,
- dimensions that fit the gridula, harmony, composition,
- PV systems that match the context of the building,
- well-engineered design,
- use of innovative design.

These architectural criteria need to be explained particularly to non-architects and manufacturers developing photovoltaic systems for integration into roofs and façades, who often believe that their systems fit perfectly.

- *Natural integration*: This means that the PV system seems to form a logical part of the building. The system adds the finishing touch to the building. The PV system does not have to be that obvious. In renovation situations, the result should look as though the PV system was there before the renovation.

- *Architecturally pleasing*: The design has to be architecturally pleasing. The building should look attractive and the PV system should noticeably improve the design. This is a very subjective issue, but there is no doubt that people find some buildings more pleasing than others.

- *Good composition of colors and materials*: The color and texture of the PV system should be consistent with the other materials.

- *Fit the gridula, harmony, and composition*: The dimensions of the PV system should match the dimensions of the building. This will determine the dimensions of the modules and the building grid lines used (grid = modular system of lines and dimensions used to structure the building, and should not be mixed up with the electrical grid).

- *Matching the context of the building*: The entire appearance of the building should be consistent with the PV system used. In a historic building, a tile-type system will look better than large modules. A high-tech PV system, however, would fit better in a high-tech building.

- *Well engineered;* This does not concern the waterproofing or reliability of the construction. However, it does concern the elegance of the details. Did the designers pay attention to detail? Has the amount of material been minimized? These considerations will determine the influence of the working details.
- *Innovative design:* PV systems have been used in many ways but there are still countless new ways to be developed. This is all the more reason to consider this criterion as well.

3.13.2 BIPV issues

How to integrate PV systems in buildings? What does BIPV mean?

The following focuses on the way in which BIPV systems can be integrated into the architectural concept of the building.

The integration of PV systems in architecture can be divided into five categories:
1. Applied invisibly
2. Added to the design
3. Adding to the architectural image
4. Determining architectural image
5. Leading to new architectural concepts.

These categories have been classified according to the increasing extent of architectural integration. However, a project does not necessarily have to be of a lesser quality just because PV modules have been applied invisibly. A visible PV system is not always appropriate, especially in renovation projects with historic architectural styles. The challenge for architects, however, is to integrate PV modules into buildings properly. PV modules are new building materials that offer new designing options. Applying PV modules in architecture should therefore lead to new designs. In some of the selected projects, the design was based on this principle.

1. *Applied invisibly*: The PV system has been incorporated invisibly (and is therefore not architecturally 'disturbing'). The PV system harmonizes with the total project. An example is the use of standing seam (Unisolar) modules, to try to integrate PV modules into the design less visible. This solution can be chosen because of the concerned historic architecture. A modern high-tech PV module look would not be appropriate for a historic style.
2. *Added to the design*: The PV system is added to the design. Building integration is not really used here, but this does not necessarily mean that architectural integration is also lacking. The "added" PV system is not always visible either.
3. *The PV system adds to the architectural image*: The PV system has been integrated beautifully into the total design of the building, without changing the project's image. In other words, the contextual integration is very good.
4. *The PV system determines the architectural image*: The PV system has been integrated into the design in a remarkable and beautiful way and plays an important role in the total image of the building.
5. PV system leads to new architectural concepts: Using PV modules, possibly in combination with other types of solar energy, leads to new designs and new architecture. The integration of PV modules was considered on a conceptual level, which gives the project extra value.

3.13.3 Motivation - Decision making in the design process

The decision to apply a PV system in a building can have different backgrounds (motivations). Depending on the motivation the process and the decisions will be made differently.

Some examples:

a. The client wants to promote his company as a green company and ask for a green building (LEED or BREEAM certified).

b. The client wants to invest in PV because of the good pay-back (often based on incentives).

c. The client wants to be zero-energy

d. The utility wants to invest in PV systems.

a. The client wants to promote renewables as part of a green design. The total amount of installed PV is not so important. More important is that it counts in the assessment and that it adds to the building image. The system should be visible and good looking. Regular places with a high visibility are facades and glass roofs with semi-transparent modules. Investment is an important point but is part of a bigger scheme.

b. The client wants to invest because of the good pay-back. This depends strongly on the financials. The aesthetics are less important but still important because of the ROI of the whole building.

c. The client wants a zero-energy building. The energy balance is the most important input for the PV system. Based on the energy calculation of the building, the amount and the resource of renewable energy will be determined. In general PV will be an important part of the renewables.

d. The utility will invest. In general this is a political decision. A certain % of the energy production should be green. Mostly a mix of water, wind and sun. The utility will look for location to place PV systems. Not only on meadows (difficult) but also on large roofs.

Because each type of client has its own motivation, the questions raised will be different. Scheme “a” and “c” will have a strong requirement for an aesthetic solution while in scheme “d” this is no important question.

3.13.4 Responsibility issues

The application of PV systems in the building design or BIPV is still a process that is not fully integrated.

First question is: “who will do the integration and who takes the full responsibility for the final product (or building)?”.

A few procedural steps may be necessary to ensure that the PV system is successfully integrated into the design. A common rule is to integrate the PV system into the building process without disturbing that process.

Step 1: The first step is consultation with the authorities about local regulations, building permits and the electrical connection to the grid.

Step 2: The second step is to consult the utility company about the grid connection, electrical diagrams and the metering system.

Step 3: The third step is the internal meeting with all building partners. A kick-off meeting very early in the process may be useful to discuss the entire integrated PV system with the architect, the structural engineer and the electrical (PV) engineer on the paper issues and with the building contractor, the roofing company, the electrician and the PV supplier on the responsibility issues.

There are many unique issues to resolve in installing BIPV. The main points in this meeting concern the responsibilities of each party in the building process. Who is responsible for the waterproofing of the roof—the roofing company or the PV installer? Who is responsible for electrical safety—the electrician or the PV installer? Who is responsible for safety on the site—the general contractor or the PV installer? All these aspects must be clearly defined and noted in advance.

Many PV suppliers offer turnkey contracts. This is easy for clients because they receive a complete working system for their money. However, the client is then responsible for the coordination between PV supplier and building contractor. Placing all responsibility with the building contractor means an extra surcharge of perhaps 10% on the cost of the PV system. A good solution is to make the building contractor (general contractor) responsible for the PV system and negotiate a special fee for coordination and use of equipment (scaffolds and crane) from the building contractor.

3.14 User Interface

Modern, avant-garde software has to be designed “graphical” today.

Because the user will work in a 3D environment, connected to his/her CAD solution (also 3D today), because he/she will have to be able to gap the bridge between professional design tools and office suite (text processing, calculation sheets, presentation software).

The PVSITES UIs have to be identifiable but must respect a certain degree of communality with reference software and public UIs:

- CAD solutions and 3D navigation;
- Icons, buttons, typical of office suites;
- Icons, buttons, generic and imposed by the three majors in operation systems: MICROSOFT®, APPLE® and GOOGLE®.

Until this BETA version, we have focused on technical and practical efficiency, not on high design.

This User Story has been created to allow CADCAMation to gather and analyze a large range of various comments and suggestions from different users.

This is to prepare the future commercial version.

3.15 BIM for the architect

Introduction of the BIM Design Process

Design is typically an iterative process where ideas are successively refined in a series of phases or stages, each focusing on specific aspects of the design. While the process followed by every project team will have its own unique features, the stages typically include:

- Conceptual or schematic design
- Preliminary design
- Design development
- Construction documents and details

Each of these design phases has a specific focus and questions that are typically answered before moving to later stages.

Architectural software tools currently available for BIM are: Graphisoft Archicad® (PC and Mac), Nemetschek Vectorworks® (PC and Mac), Nemetschek Allplan® (PC only), Bentley Microstation® (PC only) and Autodesk Revit® (PC only). Rhinoceros with Rhino® (PC and Mac), Virtual Build Technologies with RhinoBIM® (PC only) and ASUNI with VisualARQ® for Rhino® (PC and Mac) can also used as part of the BIM design process with the plug-ins. Autodesk Revit® has a light version under the name Revit LT® (Vasari project) on the market to use in the conceptual design process. It looks similar to Sketchup® and is introduced to make a better connection with REVIT®.

Impact of BIM on the Design Process

The use of BIM tools creates the opportunity to radically change and improve the design process in several ways. Traditional 2D CAD-based design approaches focused on increasing the productivity of the construction document phase. A BIM-based design workflow changes the process in a more fundamental way by enabling the sharing and enhancement of design information through all project phases.

Building modeling enables design teams to systematically assess and evaluate the performance of their designs at even the earliest stages of a project. The use of a BIM-based workflow also provides a vehicle for sharing proposed designs that enables members of the design team to more easily collaborate using a live version of the building model. All members of the design team can access the latest model changes and assess the impact of their design recommendations in the context of the overall design.

Our vision for PVSITES software

The purpose of the PVSITES software is to be BIM ready for every user. That means:

- Able to read any 3D geometry coming from any CAD solution,
- Able to plug into REVIT as this CAD solution is on the way to be the worldwide leader for the AEC industry;
- Able to exchange BIPV outputs (assessment issues) at the earliest stage of the architectural phase;
- Able to aggregate more and more BIPV outputs as far as the user needs to go and export them to his/her BIM tools;
- Able to integrate BIM outcomes from other solutions.

BETA version of PVSITES software

In its BETA version, the PVSITES software embeds:

- SketchUp native format (.skp) reader for 3D modeling;
- IFC openBIM format (.ifc) for 3D modeling interoperability (thus sourcing every BIM CAD solutions);
- gbXML greenBuilding format (.gbxml) for 3D modeling interoperability with engineering solutions.

3.16 BIM for the engineer

Because of the new way of processing AEC, the engineer has to interact a lot and much earlier with the architect to provide a large set of data to the project stakeholders.

The choices made in "BIM for the architect" are compatible with the needs of the engineers, as they have to share data (inputs/outputs) between the central BIM model (CAD model) and their specific solutions such as:

- Dynamic Simulation software: our assessment is that we have to be connected to EnergyPlus® through IDF exchange format;
- Thermal/Energy modelers using gbXML greenBuilding format (.gbxml) for 3D modeling interoperability;
- Structural calculation software: these software are currently parts of the design suites of the major editors. Therefore, BIM issue is to provide mechanical data (framing, mounting, fixing) to the CAD virtual space through BIM objects generation;

In its BETA version, the PVSITES software launches the BIM process for the engineers, which will have to be connected to the BIM objects strategy developed in task T7.2.

4 RESULTS – OVERVIEW OF THE PROTOTYPE

In the following table, for each US introduced above, more details are presented to establish the statement of the development of the current version of the software and guarantee a better visibility to the PVSITES consortium. Specifically, for each US we describe the innovative features under development, or already completed.

4.1 US and development statement (beta version)

Table 4.1: Expanded view of the US registration list as " ER table" for the software use before next task

	TASK	User Story	US Manager	Completed features (BETA version)	Under development or expected (next version)
1.	T7.1.	1.1 PHOTOVOLTAIC INSTALLATION LAYOUT	TECNALIA	Design cell, module, BAPV, opaque BIPV, transparent BIPV Pattern editor (iconic BIPV) Photon® database	Self configuration to a designated Surface PV glass (no cell) Power target to system configurator
2.	T7.1.	1.2 INVERTER DATABASE & SELECTION	TECNALIA	Inverter configurator New inverter generation Photon® database	Micro inverters Other BoS features
3.	T7.1.	1.3 PV SYSTEM WIRING	TECNALIA	Manual wiring Automatic wiring	Wiring configurator Strings simulator
4.	T7.1.	1.4 PV SIMULATION: LOSSES	TECNALIA	Shadowing Losses due to temperature Mismatching Cable losses	Losses due to inverters Glazing defaults

	TASK	User Story	US Manager	Completed features (BETA version)	Under development or expected (next version)
5.	T7.1.	1.5 FINANCIAL ANALYSIS	TECNALIA	Simplified overall financial analysis	Analysis configurator
6.	T7.1.	1.6 PROJECT REPORT GENERATION	NOBATEK	Generic user story	Ongoing specifications depending on products outcome
7.	T7.1.	1.7 APPLICATION FEEDBACK TO DIRECT THE DESIGN	NOBATEK	Sun course (shadowing, weather data) Real time indicators: irradiance, shadowing, temperature losses, peak power, energy production Shadowing values displayed on BAPV modules	More users stories expected depending on products issues Mismatching Thermal impacts Optical impacts
8.	T7.1.	1.8 ENERGY STORAGE	TECNALIA	Generic user story	More users stories and specifications expected
9.	T7.1.	1.9 STANDARDIZED OPTICAL SIMULATION OF GLAZING SYSTEMS	TECNALIA	Glass configurator Glazing configurator Interlayers editor	Optical tools Optical indicators Daylighting module
10.	T7.1.	1.10 ANGULAR OPTICAL SIMULATION OF GLAZING SYSTEMS	TECNALIA	Generic user story	More users stories and specifications expected depending on products modeling
11.	T7.1.	1.11 STANDARDIZED THERMAL SIMULATION OF GLAZING SYSTEMS	TECNALIA	Generic user story	Thermal tools Thermal indicators More users stories and specifications expected depending on products modeling

	TASK	User Story	US Manager	Completed features (BETA version)	Under development or expected (next version)
12.	T7.1.	1.12 HEAT TRANSFER DEVELOPMENT	NOBATEK	Generic user story	Heat transfer under implementation Connection to EnergyPlus under specification Thermal impact indicators
13.	T7.1.	1.13.1 Aesthetical issues	BEAR-ID	Generic user story + alpha test feedback	BETA Test report > more US
14.	T7.1.	1.13.2 BIPV issues	BEAR-ID	Generic user story + alpha test feedback	BETA Test report > more US
15.	T7.1.	1.13.3 Design process motivation	BEAR-ID	Generic user story + alpha test feedback	BETA Test report > more US
16.	T7.1.	1.13.4 Design process responsibility	BEAR-ID	Generic user story + alpha test feedback	BETA Test report > more US
17.	T7.1.	1.15 User Interfaces	CADCAMATION	3D scene navigation toolkit Pictures exporter	Navigation toolkit to be improved Snapshot HD picture exporter Icons and buttons to be improved
18.	T7.1.	1.16 BIM for the Architect	BEAR-ID	BIM process for architect BIM tools: state of the art	BETA Test report > more US
19.	T7.1.	1.17 BIM for the Engineer	NOBATEK	IDF import, gbXML import, Properties of objects	IDF export gbXML export Indicators translation: local solar gain, thermal transmittance, light factor, solar factor BETA Test report > more US

4.2 Software interface overview (BETA version)

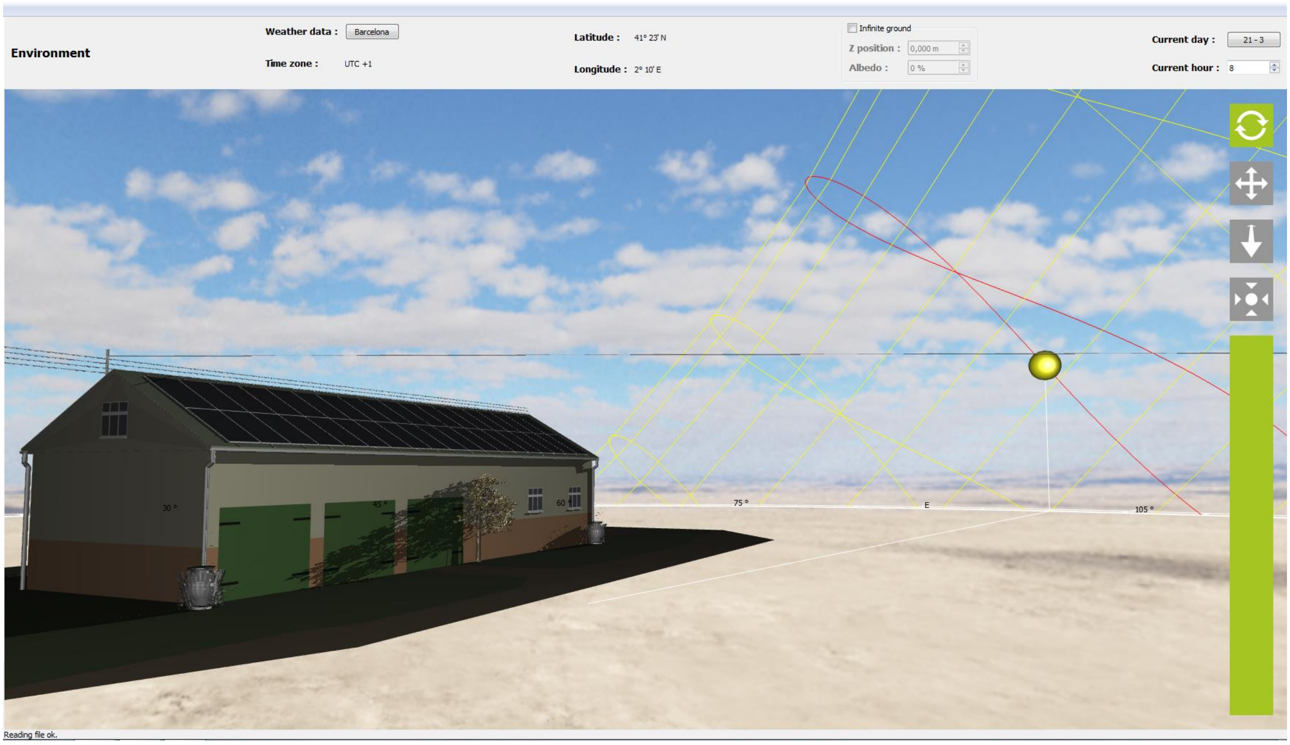

Figure 4.1: Heliodon, localization, sun course, visible shadowing

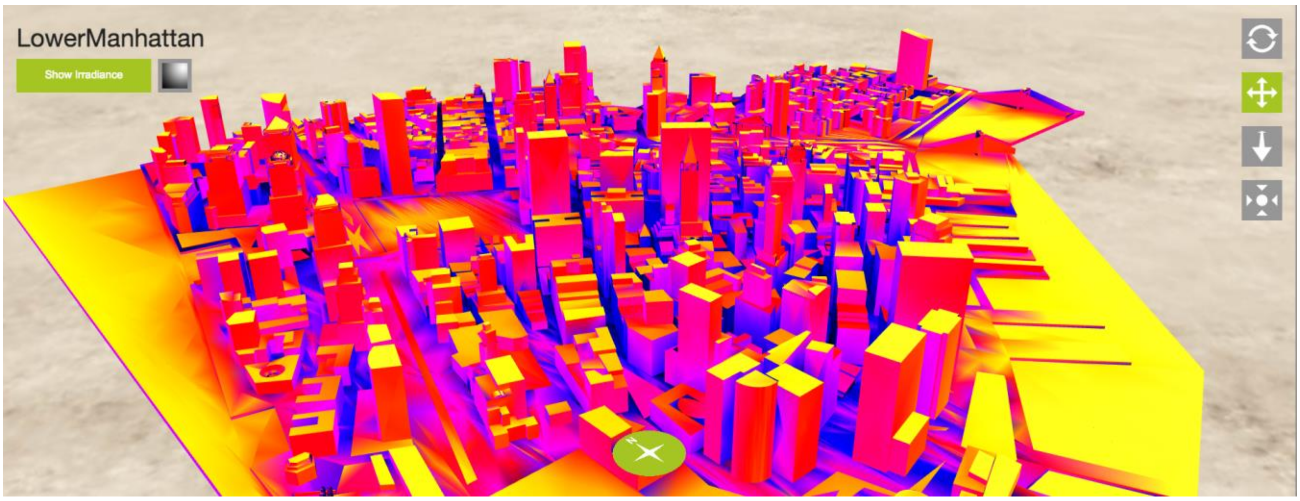

Figure 4.2: Irradiance displayed as a web service

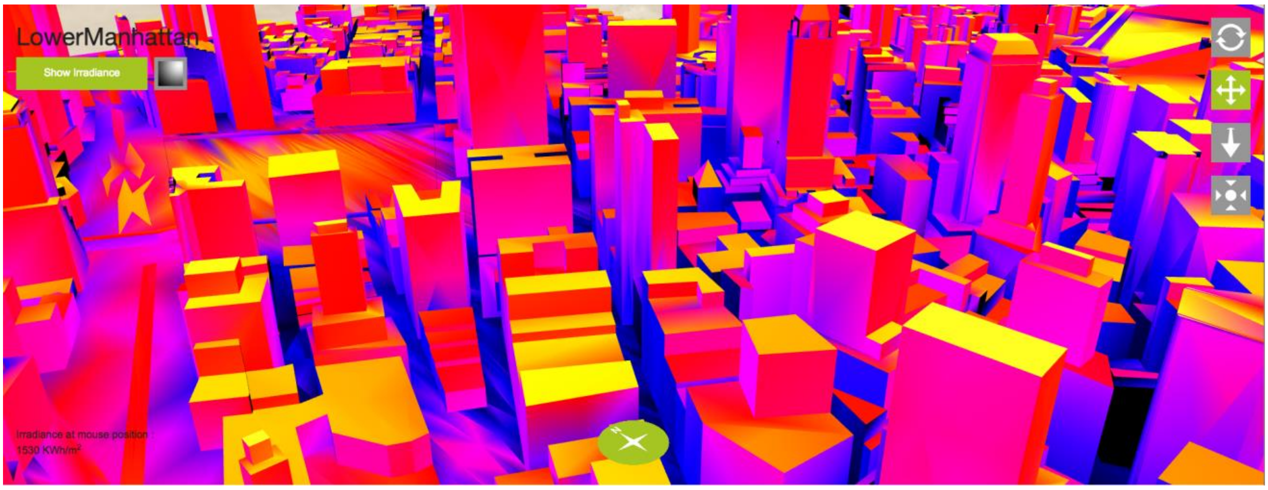

Figure 4.3: Irradiance: city scale

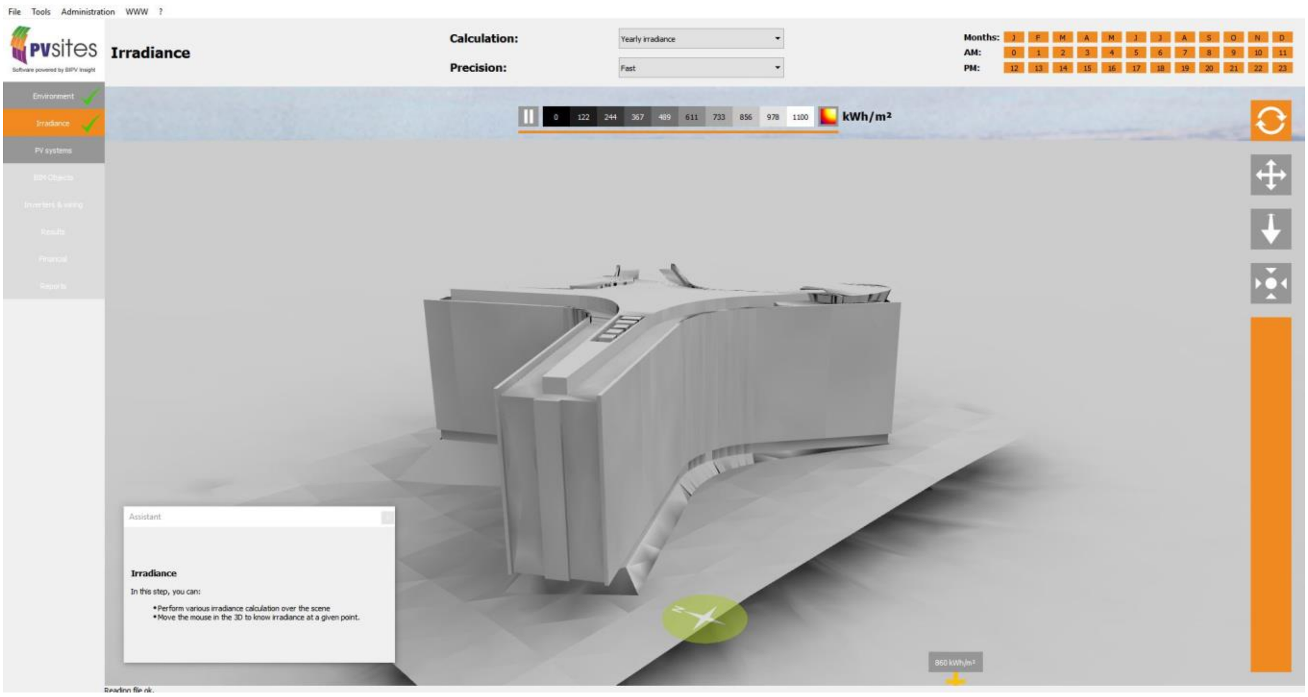

Figure 4.4: Irradiance: shades of grey / color

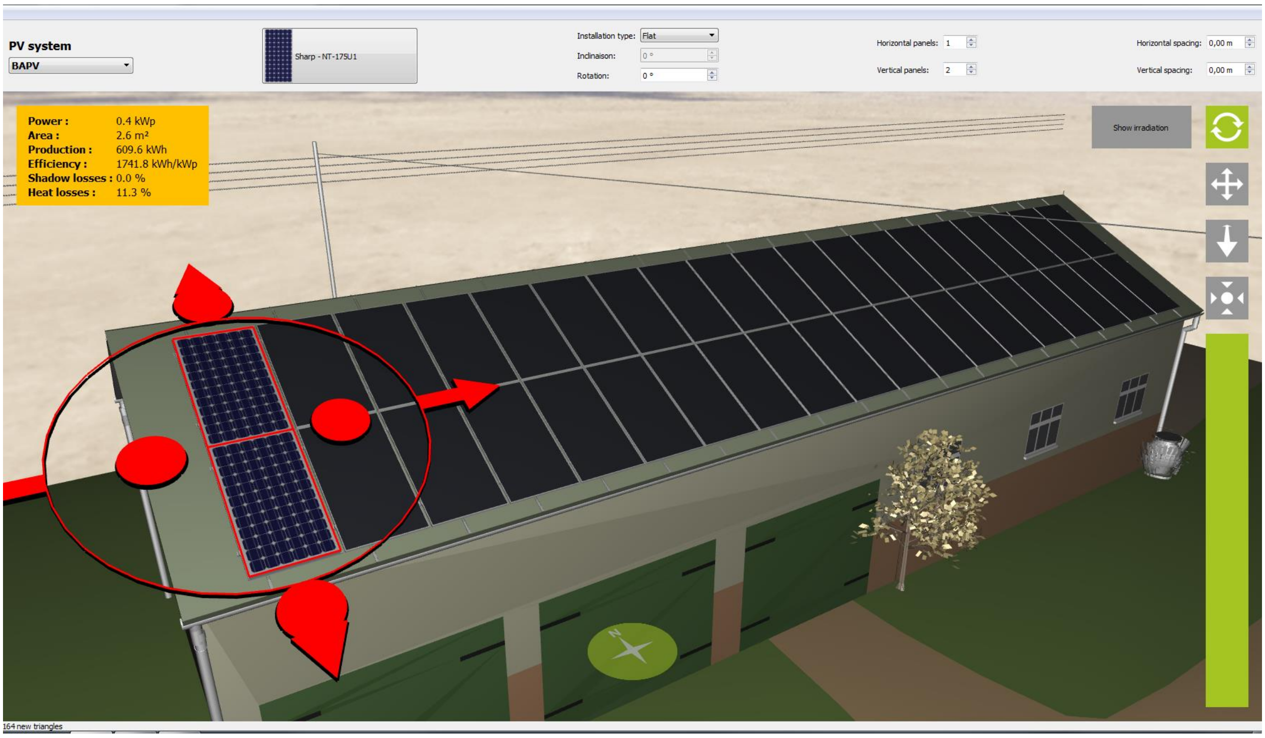

Figure 4.5: PV installation layout, module editor (BAPV)

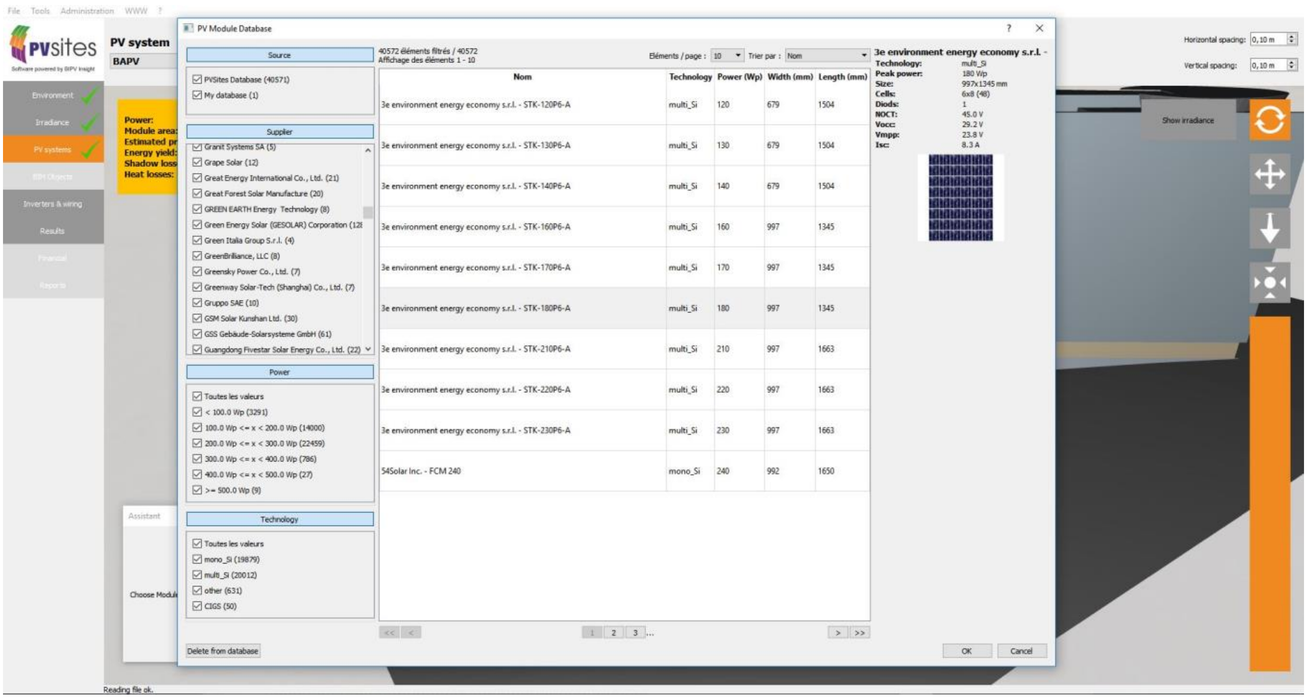

Figure 4.6: PV installation layout, modules database (BAPV)

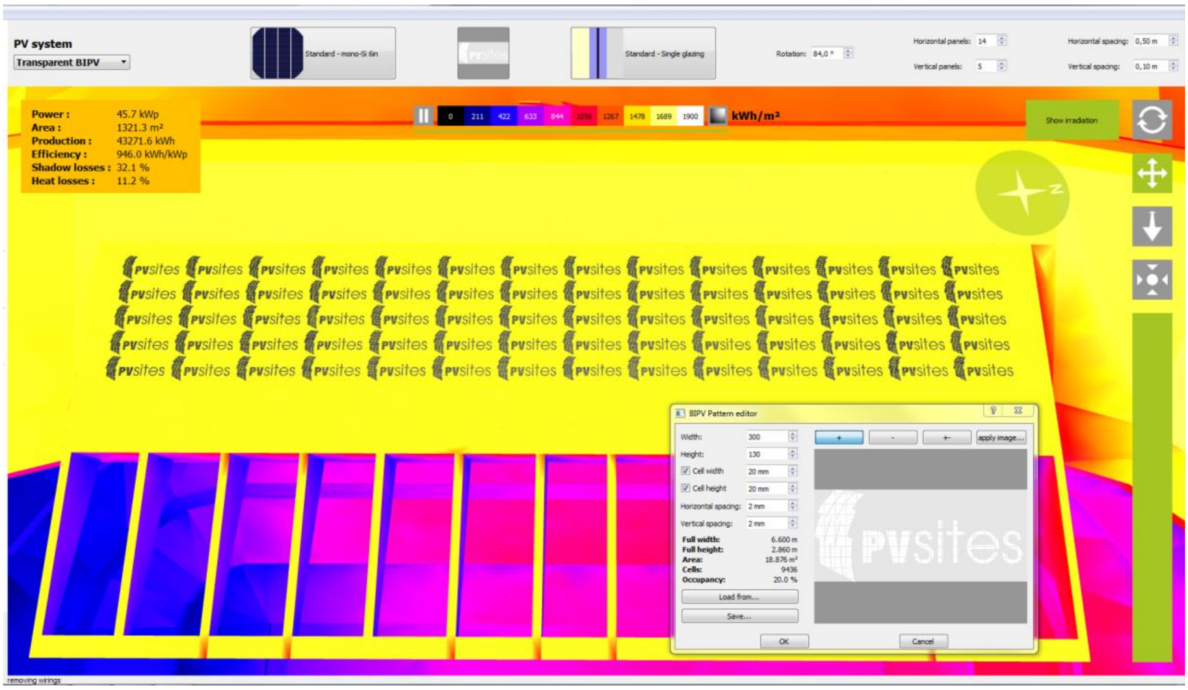

Figure 4.7: PV installation layout, pattern editor (BIPV)

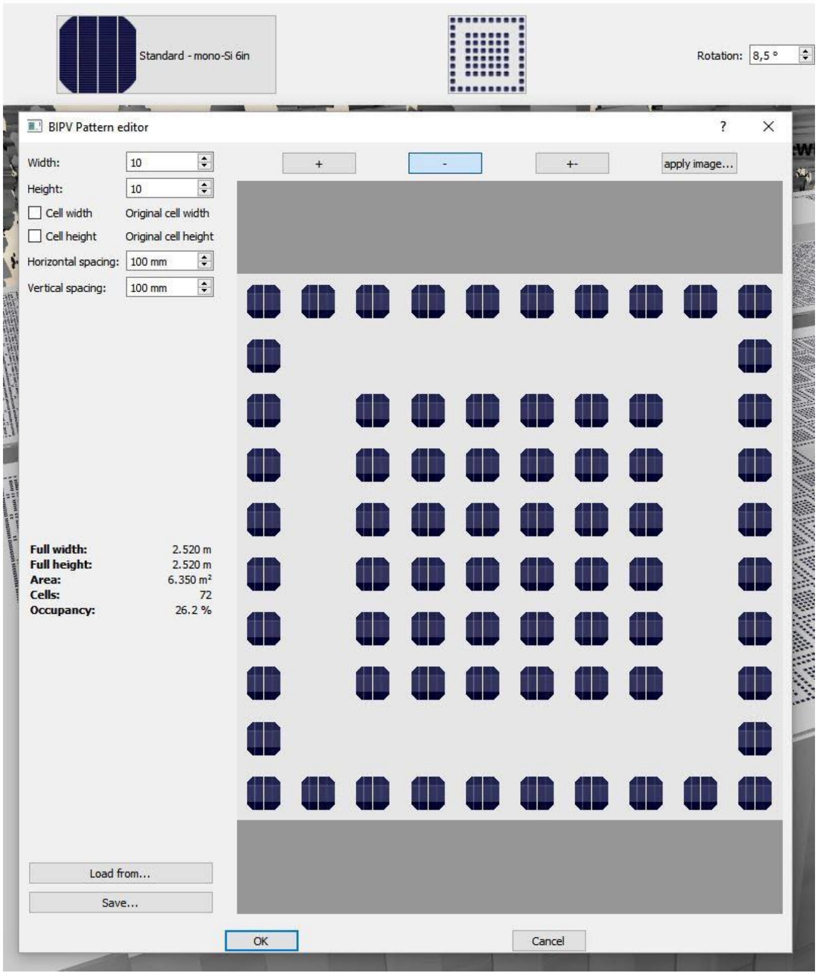

Figure 4.8: Pattern editor

Figure 4.9: PV installation layout, transparent BIPV

Figure 4.10: PV installation layout, transparent BIPV

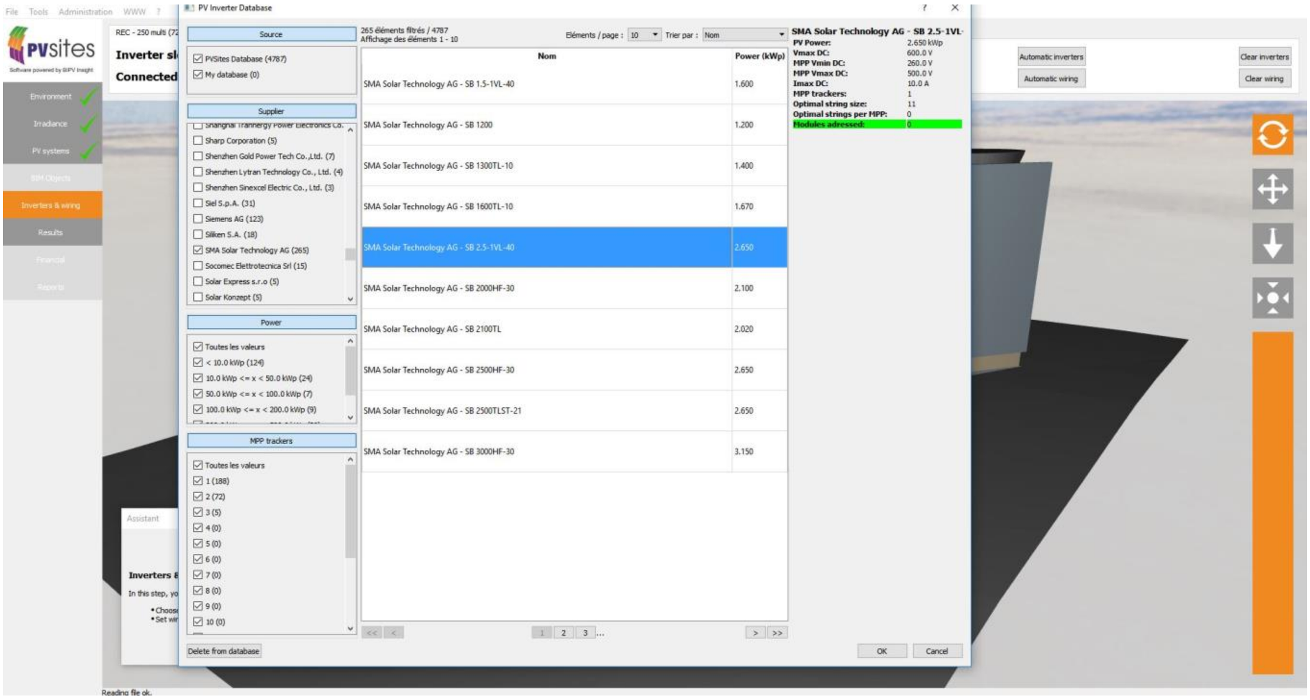

Figure 4.11: Modules database

Figure 4.12: Wiring

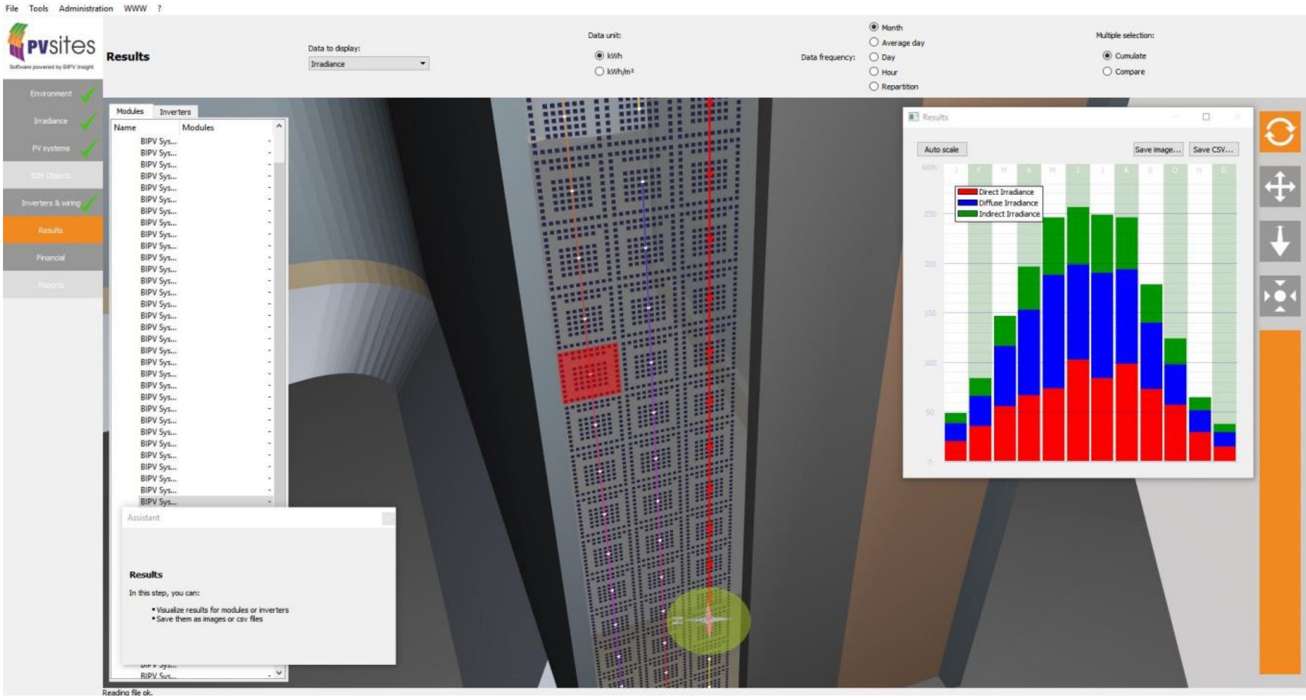

Figure 4.13: Results configurator

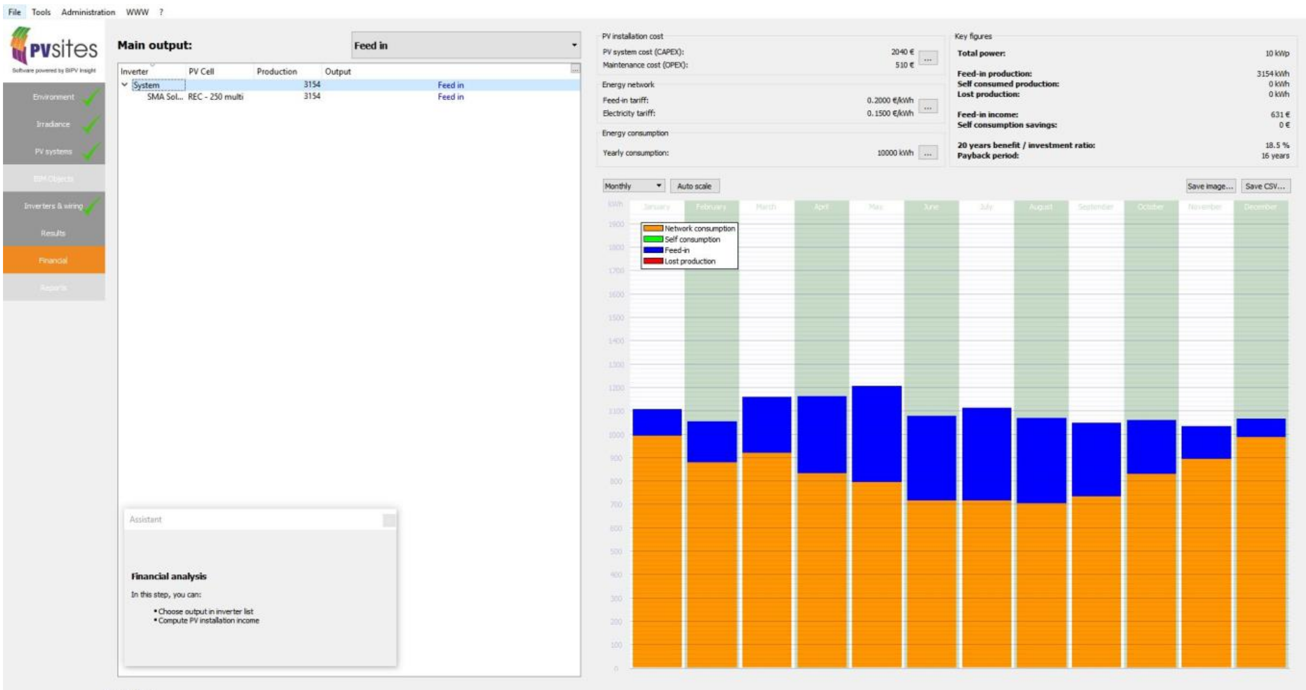

Figure 4.14: Financial evaluation

5 CONCLUSIONS

This deliverable reports the development framework of the BIPV tool (software tool and links to the web platform), illustrates its graphical interfaces and makes a statement for the enhanced beta version.

Every User Story is identified, managed by a leader, and the technical specifications are under implementation. We expect more US as the software is entering its beta test phase and the rest of the consortium will be able to challenge it, as soon as the specific PVSITES products will be able to be integrated as BIM objects.

The main objective now is to continue on improving the quality of the graphical UI, specifying and developing the PVSITES web services from the SaaS platform as soon as we will be able to deal with BIM compatibility and eCatalogs experimentation for the manufacturers.

6 REFERENCES

IEA PVPS Task 7: Photovoltaic power systems in the built environment.