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Formulation of architectural and aesthetical requirements for the BIPV building elements to be demonstrated within the PVSITES project

Project report

BEAR-iD

September 2016

Document summary

This document describes the architectural and aesthetical requirements of Building-Integrated Photovoltaic (BIPV) systems. For a good understanding, the report starts with a general introduction of architectural aspects that apply to roofs and facades of buildings. The second part focuses on the products that will be used within this project and finally it gives recommendations for building integration.

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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, large-scale deployment of 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

CONTENTS

TABLES

FIGURES

1. EXECUTIVE SUMMARY

1.1. Introduction

Subtask 2.1.3, "Architectural and aesthetical considerations" focuses on the description of a framework for the application of the building elements from an architectural point of view.

This subtask focuses also on the products, the dimensions in order to produce a wide range of building elements, the specific qualities like color, transparency, etc., together with the specific details for integration and mounting of the BIPV building elements. Other aspects like day-lighting, indoor shading patterns, indoor climate, user acceptance and acceptance from the inside out will be part of this study.

This subtask results in the current deliverable.

Reading guide:

One of the overall objectives of PVSITES is to demonstrate building-integrated solar technologies in the facade/roof.

Deliverable 2.4 is about the visual integration of PV in the overall architectural concept. The first part (section 2) of this document starts with a description of theory and used definitions.

In section 4 and 5 of this document a discussion on the building skin (the facades and the roof of a building) and its functionalities is followed by a description of typical BIPV building products (section 6). The positive and negative qualities of building integrated photovoltaics are discussed.

Followed in section 7 by a description on the requirements for integration in the building skin in general, the qualities of BIPV products to fit specific facades and roofs will be discussed in section 8. Both the reuse of existing structures as also the design of new buildings are taken into account.

Buildings are complex systems for which there are no universal design rules. In 'conclusions related to selected products' (section 9) we prefer to talk about design considerations instead of constraints. The conclusions are written as recommendations and focus on the selected building products to be elaborated in PVSITES project.

1.2. Reference material

Reijenga, T.H. & Kaan, H. (2010), 23. PV in Architecture. Luque, L. ed. Handbook of Photovoltaic Science and Engineering. New York, John Wiley & Sons.

1.3. Abbreviation list

BIPV: Building-integrated photovoltaics

PV: Photovoltaics

nZEB: Nearly zero energy buildings

BPIE: Buildings Performance Institute Europe

EED: Energy Efficiency Directive

EPBD: Energy Performance of Buildings Directive

2. THEORY

There are no universal rules to achieve aesthetical pleasing architecture. Buildings are complex structures and are designed for a specific location, climate and the demands of a client. Nevertheless there are design considerations which are generally accepted by architects. This study reflects on those ideas and how they can contribute to the integration of photo-voltaics into architecture.

2.1 Vitruvius

According to the Roman architect Vitruvius there are three qualities a building should have: firmitas, utilitas and venustas. Architecture is solid, useful and beautiful. Since the Roman era the architectural discourse evolved. Nevertheless the three aspects Vitruvius described are still main themes in discussions about architecture. A good design integrates functionality and techniques into one aesthetical pleasing entity.

2.2 Definition of BIPV

To focus the discussion on the integration of photovoltaic in architecture we should first look into the definition of integration in general and of BIPV in particular.

Definition in EN50583-1:2016: "Photovoltaics in buildings – Part 1: BIPV modules" (Approved by CENELEC on 2015-10-05):

Building-Integrated Photovoltaic modules - BIPV modules
"*photovoltaic modules are considered to be building-integrated, if the PV modules form a construction product providing a function as defined in the European Construction Product Regulation CPR 305/2011. Thus the BIPV module is a prerequisite for the integrity of the building's functionality. If the integrated PV module is dismounted (in the case of structurally bonded modules, dismounting includes the adjacent construction product), the PV module would have to be replaced by an appropriate construction product*."

Definition in EN-50583 2:2016 : "Photovoltaics in buildings – Part 2: BIPV systems" (Approved by CENELEC on 2015-10-12):

"*BIPV system, photovoltaic systems are considered to be building-integrated, if the PV modules they utilize fulfil the criteria for BIPV modules as defined in EN 50583-1 and thus form a construction product providing a function as defined in the European Construction Product Regulation CPR 305/2011*".

The EN 50583-2:2016 also gives a definition on BAPV:

"*Building Attached Photovoltaic system - BAPV system. Photovoltaic systems are considered to be building attached, if the PV modules they utilize do not fulfil the criteria for BIPV modules as defined in EN 50583-1.*"

EN 50583-2 assigns application-specific requirements to PV modules – divided into the main categories "containing-" and "not containing glass panes". It further differentiates general requirements that have to be fulfilled by all products (el. and building-related requirements) and such that only have to be fulfilled depending on the constructional set-up (e.g. fire resistance classification acc. to EN 13501-1).

Finally it should be noted that Figure 2.1 'Mounting categories A – E' (EN 50583-2:2016) focuses on glass panes. Nevertheless there are also modules on metal, steel, plastics and composite sheets. Also a range of PV incorporated in membranes can be used as BIPV systems.

The new standard furthermore defines several mounting/application categories and subdivides these into the essential requirements of the European Construction Product Directive.

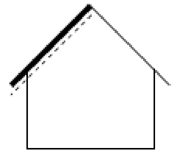
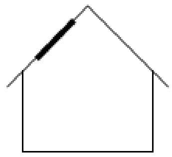
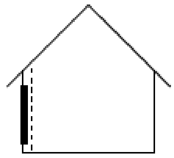
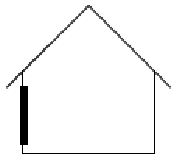
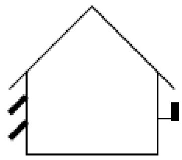
Category A:	**Sloped, roof-integrated, not accessible from within the building**	
	The PV modules are mounted in the building envelope at an angle between 0° and 75° (see Fig. 1) with a barrier underneath preventing large pieces of glass falling onto accessible areas below	
Category B:	**Sloped, roof-integrated, accessible from within the building**	
	The PV modules are mounted in the building envelope at an angle between 0° and 75° (see Fig. 1)	
Category C:	**Non-sloped (vertically) mounted not accessible from within the building**	
	The PV modules are mounted in the building envelope at an angle of between and including both 75° and 90° (see Fig. 1) with a barrier behind preventing large pieces of glass or persons falling to an adjacent lower area inside the building.	
Category D:	**Non-sloped (vertically) mounted accessible from within the building**	
	The PV modules are mounted in the building envelope at an angle of between and including both 75° and 90° (see Fig. 1)	
Category E:	**Externally integrated, accessible or not accessible from within the building**	
	The PV modules are mounted onto the building and form an additional functional layer (as defined in 3.1) exterior to its envelope (e.g. balconies, balustrades, shutters, awnings, louvres, brise soleil etc.).	

Figure 2.1 Mounting categories as defined in EN 50583-2 "Photovoltaics in Buildings"

Remarks on this definition

The definition of BIPV doesn't include aesthetical or architectural aspects. The IEA PVPS Task 7 "Building Integrated PhotoVoltaics", focused also on aesthetical aspects. Building Integration is a technical and an aesthetical issue. Technical: by integration, some other building materials or components are replaced, aesthetical: by integration, the solar system is part of the overall design and adds value to the design. So it was defined as: "Despite that for architects the aesthetics are as important as the physical integration, both definitions don't involve the aesthetical aspect. Many examples of physical integration show a lack of aesthetical qualities. Visual analysis of PV systems in buildings shows that the look of a poorly designed building does not improve, simply by adding a well designed PV system. On the other hand, a well-designed building, with a nicely integrated PV system, will be accepted by everybody". [15].

3. ARCHITECTURAL OBJECTIVES

The overall goal for architects is to combine aesthetical qualities with the functional (usability) and technical aspects into one design. From an architectural viewpoint the integration of PV has different sub-objectives.

Integration of PV to achieve:

1. A combination of technical functionalities;
2. The improvement of the usability (indoor qualities);
3. The envisioned proportions of the envelope (facades and roof) or of the shape of the building;
4. Visual integration in the 'concept of the design'.

Ad 1. Architects strive to integrate technique and usability into aesthetical pleasing constructions.

Ad 2. Since usability and aesthetics are inseparable in architecture, in this study we focus also on the indoor qualities. Day-lighting, indoor shading patterns, indoor climate, user acceptance and acceptance from the inside out will be discussed.

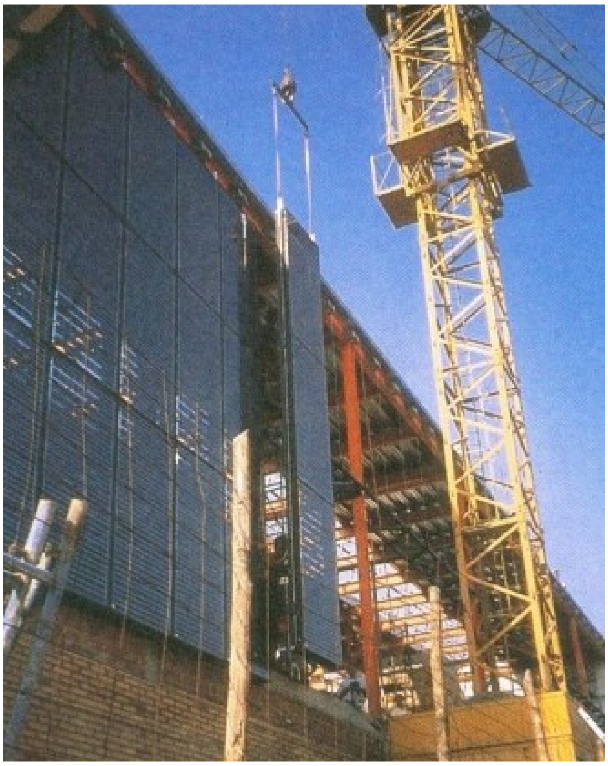


Figure 3.1 Pompeu Fabra library, Mataro (ES) Design: Brullet i Tenas

Figure 3.2 Providing daylight for the interior

An example of a facade producing electrical, thermal energy and providing indoor qualities as ventilation and daylight. The photovoltaic modules are cooled by air. In winter the surplus of thermal energy is used to preheat incoming ventilation air. By cooling the modules, the BIPV system is more efficient. Moreover the modules are translucent providing daylight for the interior.

Ad 3. The aesthetical qualities of a building are linked to the proportions of the facades or the proportions of the form of a building as a whole. Next diagram shows three different principles of integration of BIPV in architecture followed by three references illustrating these methods (a,b and c).

A BIPV system in the overall design can be:

a. recognisable in the lay-out of the facade (Figure 3.4);

b. part of the envelope as a whole (Figure 3.5);

i. defining the building shape to optimise energy performance (Figure 3.6).

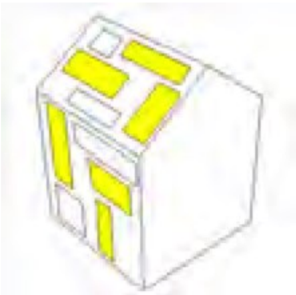
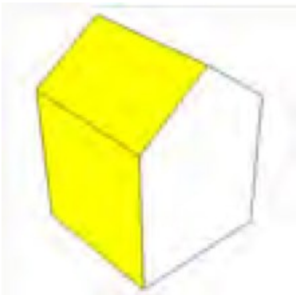
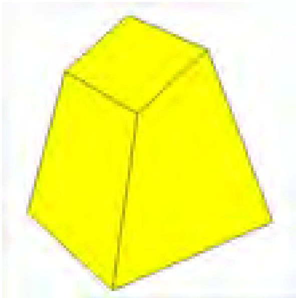
a.  b.  c. 

Figure 3.3 Three basic principles of integration of BIPV [8]

Figure 3.4 Steinhude Sea Recreation Facility (BRD). design: R.Stout.

Figure 3.5 Monte Rosa Zermatt. Design Bearth & Deplazes Architekten

Figure 3.6 Sunlighthouse, Pressbaum (AUS) Design: juri troy architects

Ad 4. The 'concept of a design' is linked to the design philosophy of the architect. These ideas are personal and linked to the cultural realm. For example, according to some architects a building should express that it generates its own energy while for others renewable energy systems should blend in with the architecture of the building. This obviously leads to different architectural expressions and thus asks for different qualities of BIPV building products.

The energy performance of the building is expressed in the architecture of the building. Sun shading devices are prominent features of the building showing how energy is generated (Figure 3.7)

Figure 3.7 SBL Offices Linz Austria. Sunshading: Colt

4. THE BUILDING SKIN

The building skin (facades and roof) is a 'system layer' of a building. Next to structure, services and space plan the ‘skin’ is one of the basic elements of each building.

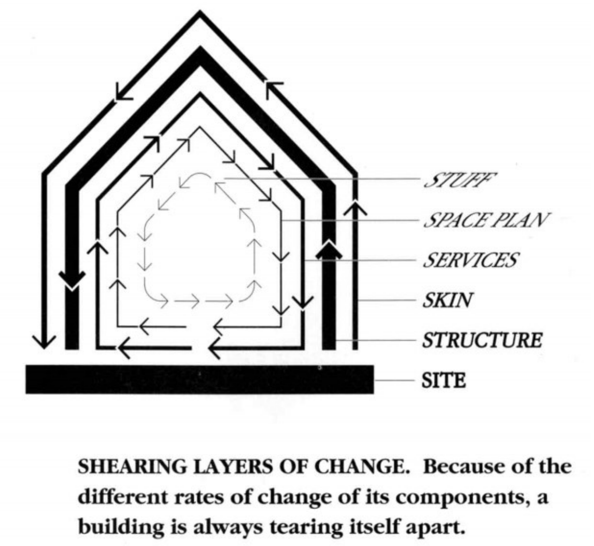


Figure 4.1 System layers, according to Stewart Brand

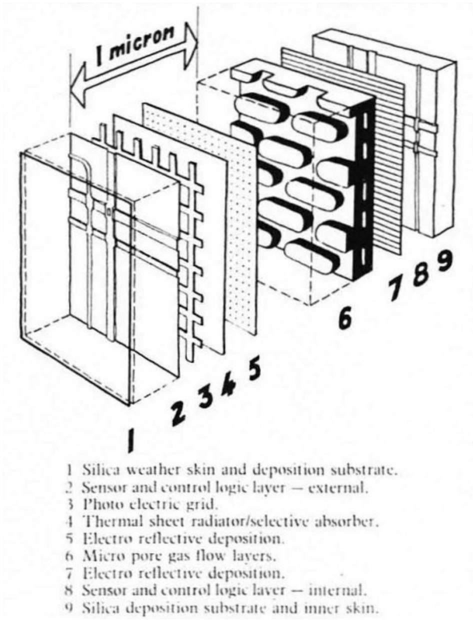


Figure 4.2 Davies M.(1981) a wall for all seasons

A wall for all seasons

In 1981 Mike Davies and Richard Rogers described the concept of a wall for all seasons. As an alternative to conventional facades, which are passive, the facade of the future will react actively to the conditions in- and outside of the building. In the 21st century the concept of an active facade is becoming generally accepted.

5. FUNCTIONALITY

Next to the primary technical functions such as weather impact protection and structural integrity there are additional functions facades fulfil. Energy economy a functionality that is becoming more and more important.

What the facade also should be able to provide is a good indoor climate for the users of the building. Day lighting, indoor air quality, enclosure are a few functionalities which the facade should be able to fulfil.

One special functionality to be mentioned is communication. Lately facade systems are developed to make buildings change in appearance overtime. This makes it for example possible to use facades for commercial messages.

5.1 Functionalities

- Weather impact protection (wind, rain, hail, snow): the most basic functionality.
- Structural integrity: facades can be structural and thus load bearing or facade elements can be non-structural and added elements to the main structure of the building. In any case should each facade element in itself have structural integrity. It should be able to withstand wind loads etc.
- Energy economy: facades can provide the use of solar energy in a passive way or have active energy systems integrated.
- Day lighting: the use of the building defines the amount of day light a facade element should provide.
- Glare avoidance: large contrasts in levels of daylight can be disturbing, especially for working environments.
- Shading: to avoid overheating or too much glare, facades should provide shade.
- Thermal insulation: the use of the building defines the level of insulation a facade should provide.
- Fire protection: the use of the building in relation to the lay-out of the facade define the amount of fire protection a facade element should provide.
- Noise protection: the use of the building and its location related to noise producing elements define the amount of noise protection a facade element should provide.
- Security, shelter or safety; facades in most cases do provide security, shelter and safety.
- Contact to the outside: in many building types facades should provide visual contact with the outside.
- Ventilation and indoor air quality: ventilation systems are in many building types integrated in the facade.
- Enclosure, visual protection: facades should not only provide visual contact with the outside but for especially residential building also provide enclosure and visual protection.
- Communication: communicational aspects of facades play a important role especially in public and commercial buildings.

5.2 Indoor related

In a design process all functions should be taken into account, but when considering the indoor qualities next functionalities play a prominent role:

- day lighting,
- avoiding glare
- shading;
- contact to the outside;
- enclosure;

- visual protection.

5.3 Communication

A functionality mentioned before are the communicational aspects of BIPV building products and facades.

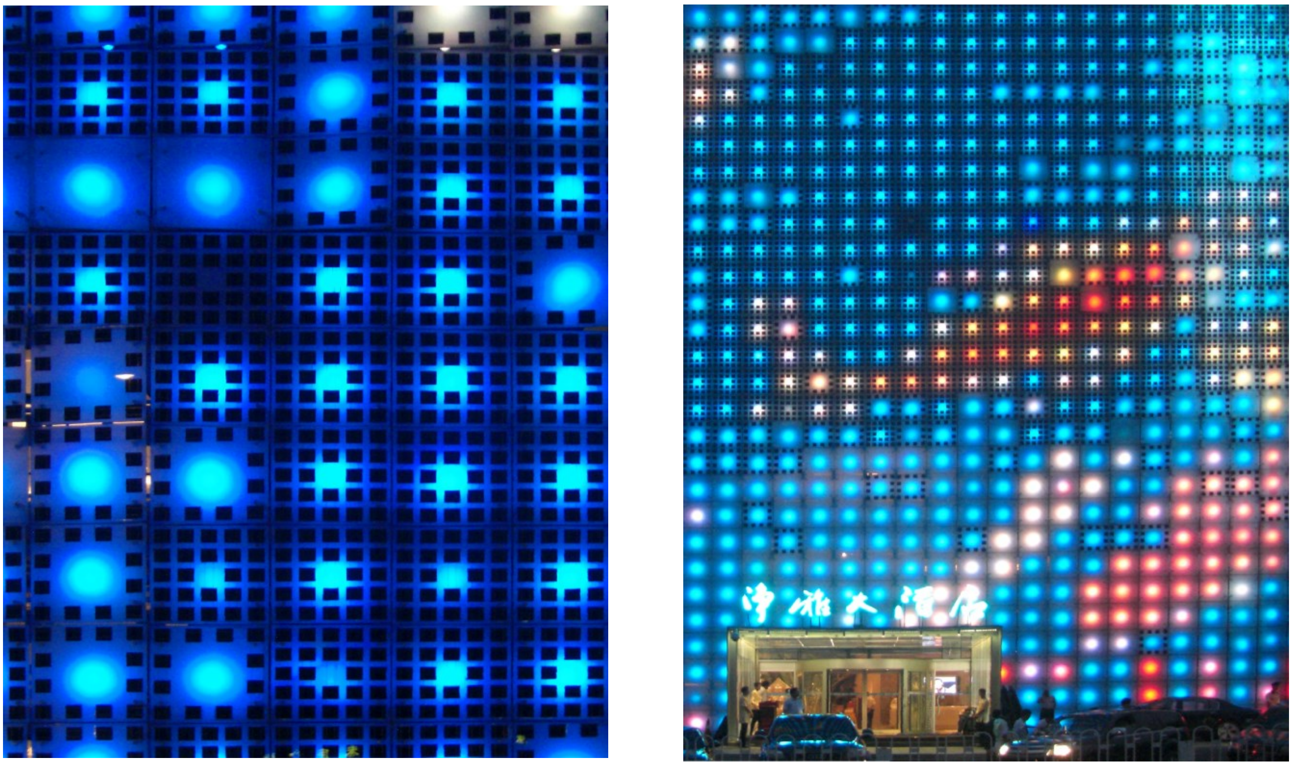


Figure 5.1 A communicating facade. Zero Energy Media Wall, Beijing. Design: Simone Giostra & Partners

6. BUILDING PRODUCTS

In the building skin there are certain elements suitable for BIPV products. In this document these elements are arranged according to the CI/SfB system. CI/SfB is a library system used by the building industry. According to this system elements are indicated by two numbers (for example (21)). The possible elements in which PV can be integrated are shown in table below.

CI/SfB	1 walls	7 roofs	8 others
2 Primary elements	21 prefab wall	27 prefab roof	
3 Secondary elements	31 windows / curtain wall	37 skylight	38 pergola
4 Finishes	41 cladding	47 cladding, tiles, covers	48 shading
8 Equipment			88 equipment

Table 6.1 Table of elements of a building PV can be integrated in

Very common in the building industry is the use of the CI/SfB notation for building products. SfB is an abbreviation for Samarbetskommitten för Byggnadsfrägor – a Swedish system of the late 1940s. The current CI/SfB edition was issued in 1976 and although the scheme is long overdue for revision (according to RIBA Information Services) the system is still widely used.

The CI/SfB has four main divisions:

- Table 0 Physical environment
- Table 1 Elements
- Tables 2 and 3 Constructions and Material
- Table 4 Activities and Requirements

6.1 About the design process

Architects work simultaneously on different scales. From the large urban scale to the smallest details are considered at the same time. Knowledge of building products is therefore essential. Not only how modules are detailed but also the availability in different shapes, colour and sizes are aspects which designers take into account while choosing a BIPV building product to integrate into the design.

On the smallest scale the qualities of the material itself are important. Colour, glossiness (reflection of light), texture and transparency are properties taken into consideration when making design decisions.

In a bigger scale the possibilities of facade systems and substructures are essential. Especially the mounting systems and the dimensions of fixtures and frames are relevant.

6.2 Modules

Modules are an arrangement of cells/PV-material and the wiring connecting those cells/PV-material.
For reasons of indoor qualities modules are made transparent. Not only day lighting but also shading and the contrast of the light (glare) should be taken into account. Especially in an office environment too much glare on the workstations can be disturbing.

In central areas of buildings contrasts in light intensity and colour differences can make the interior more playful (Figure 6.3).

Figure 6.1 Use of non-structural transparent panels in frames. Pompeu Fabra library, Mataro (ES)

Figure 6.2 Daylight entering via the openings between the cells

Figure 6.3 The colour and contrast in intensity of daylight can give central areas in buildings a playful appearance. ECN building 42, Petten (NL); design: BEAR-iD, Tjerk Reijenga

6.3 Material characteristics

The cells/PV-material have qualities like texture, glossiness, transparency and colour. These qualities play a role in the aesthetically integration of photovoltaics in the facade/roof of a building. Those qualities give nuances which are not only perceived on eye-level but can also define the integration of the building as a whole in its urban context or landscape.

a. Texture

Description

The grain and depth of the surface structure as perceived by the human eye.

Range: from sharp, medium to dull.

Design considerations

Perceived at short distance texture give richness to the surface.

Or when striving to blend photovoltaic in with the main building material the availability of different textures does make more combinations possible.

Aspect is related to: colour, glossiness

Reference

Material: polycrystalline silicon

Range: glossy

Figure 6.4 Prominent texture and green coloured cells define the architecture. Paul-Horn Arena, Tubingen, (BRD); design: Allman-Sattler-Wappner Architekten, 2004

b. Glossiness

Description

The reflection of light.

Range: from glossy, satin to matt.

Design considerations

Reflection can be disturbing or a quality to incorporate in the design.

Striving to blend photovoltaic in with the main building material the availability of different ranges of glossiness does make more combinations possible.

Aspect is related to: colour, texture

Figure 6.5 Roof reflects surroundings. private house, Laukaa (FIN); design: Soilikki Suntola, 1992

c. Transparency

Description

The translucency and/or transparency of the material can create possibilities for day lighting and the possibility to view through.

Range: 100%-80%....- 0%

Design considerations

Transparency can be achieved through the translucency of the modules or by the cells itself. Angular dependency transmission can help reduce glare and regulating privacy (visual protection).

Aspect is related to: building products

Figure 6.6 Prototypes of PV cells with angular dependency transmission 2011 (Signet Sola)

d. Colour

Description

Colour as perceived by the human eye.

Range: visible spectrum

Design considerations

Wide range of colours creates a larger pallet for the designer.

Aspect is related to: building products.

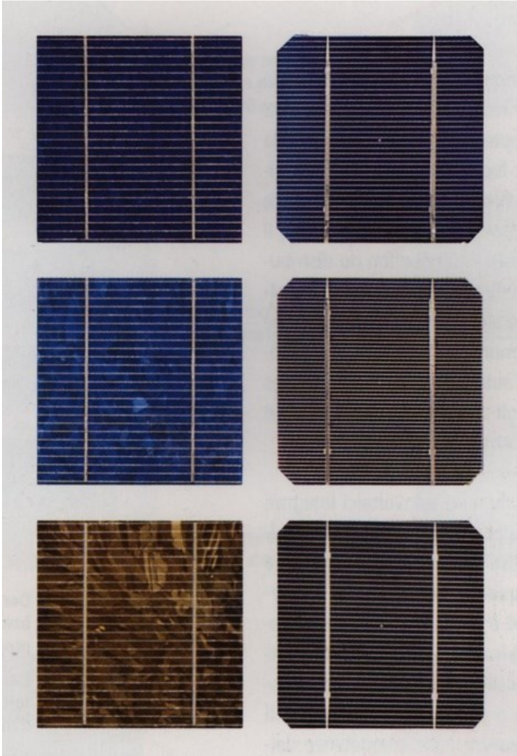


Figure 6.7 Different colours of crystalline cells

6.4 Sun shading and daylight systems

Besides flat facades alternatively there are layered facades (see chapter 6.2). These extra layers can have different functions such as shading and the integration of daylight systems. The latter is not only to regulate daylight but can also play a role in regulating the amount of glare.

Shading and daylight systems are for example:

- horizontal overhangs
- louvres (vertical and horizontal)
- movable louvres
- canopies
- screens
- vertical fins (lamellas)
- movable fins
- combination of horizontal and vertical systems

In one of the first books on bioclimatic design Victor Olgyay listed in 1962 the sorts of shading and daylight systems. This list of systems described in 'Design with climate, Bioclimatic approach to architectural regionalism' is still used to categorise the different systems available as up to today.

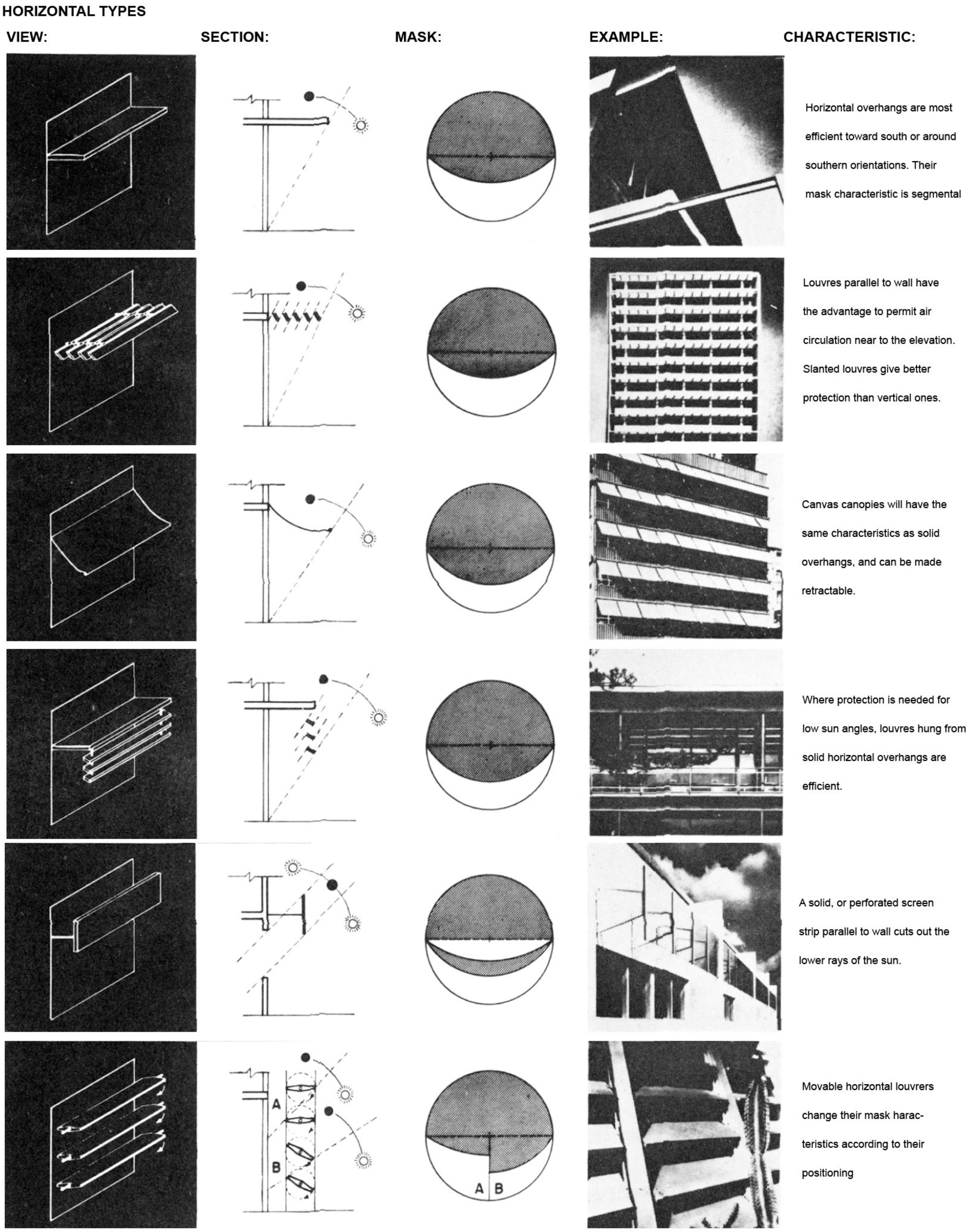


Figure 6.8 Fig. 20 Solar shading - Horizontal types

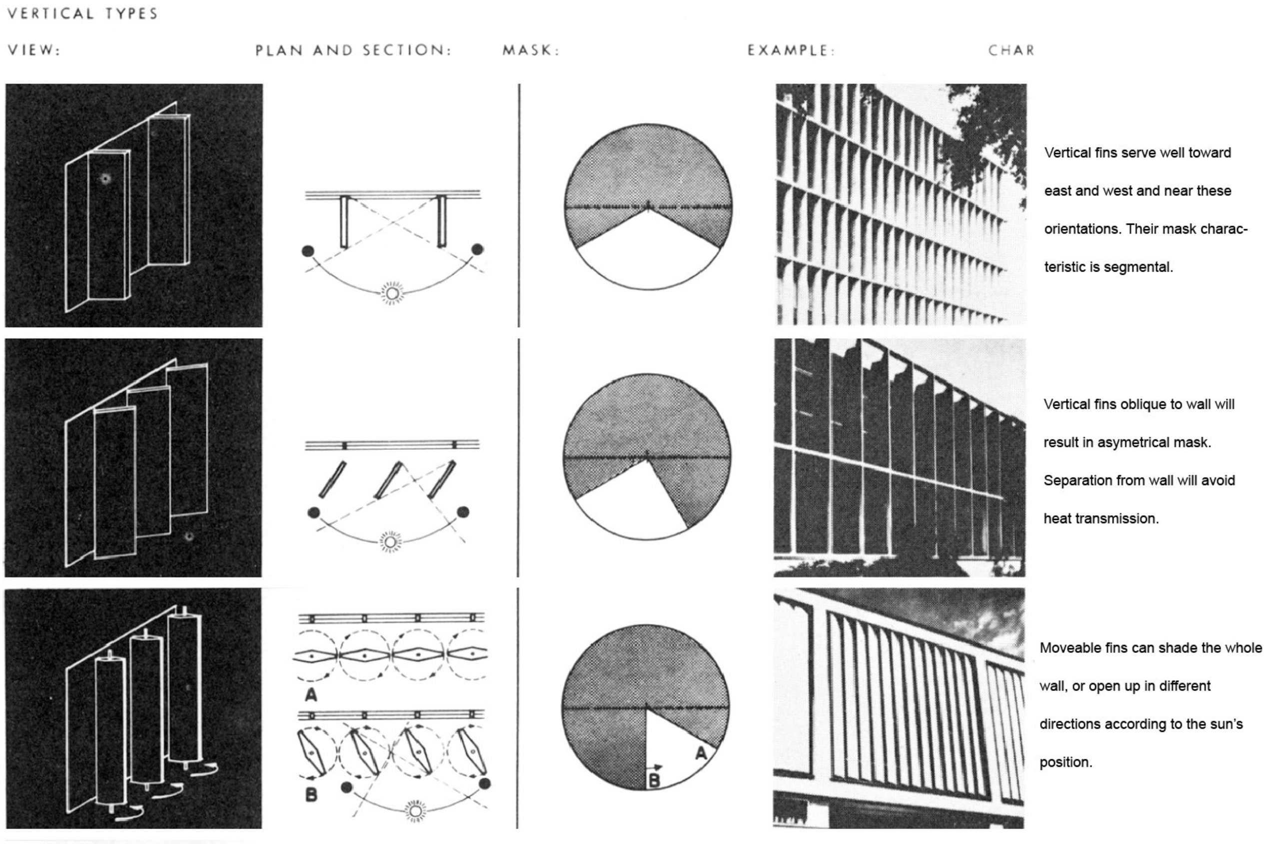


Figure 6.9 Solar shading - Vertical types

Shading systems for photovoltaics.
Not all sun shading systems are suitable for photovoltaics. The cells in the system shouldn't be shaded. The by Olgyav so called 'boxtypes' are therefore less likely to be transformed into an efficient photovoltaic system than the horizontal and vertical types. Movable (tracking) systems (both vertical and horizontal) do have the advantage that it maximises the exposure of the cells to the direction of the sun. Finally screens and canopies are made of textiles. Much research has to be done to find new photovoltaic materials which are both flexible, strong and durable.

Figure 6.10 Horizontale shading with solar modules. ECN building 31, Petten (NL). Design: BEAR-iD, Tjerk Reijenga

Figure 6.11 Vertical shading with Grätzel solar modules. SwissTech Convention Center, EPFL, Lausanne (CH). Photo: Hisashi Ishii

6.5 Facade and roof systems

BIPV products are part of roof and facade systems. In this section some of those systems are described. With at the left a conventional non-BIPV structure and at the right side a BIPV system.

Figure 6.12 Facade system: frame. Non-structural panels in frames

Figure 6.13 Product Schüco ProSol TF

Figure 6.14 Facade system: shingles. Non-structural panels on fixtures

Figure 6.15 Solaire France Sunstyle. Product: Saint Gobain

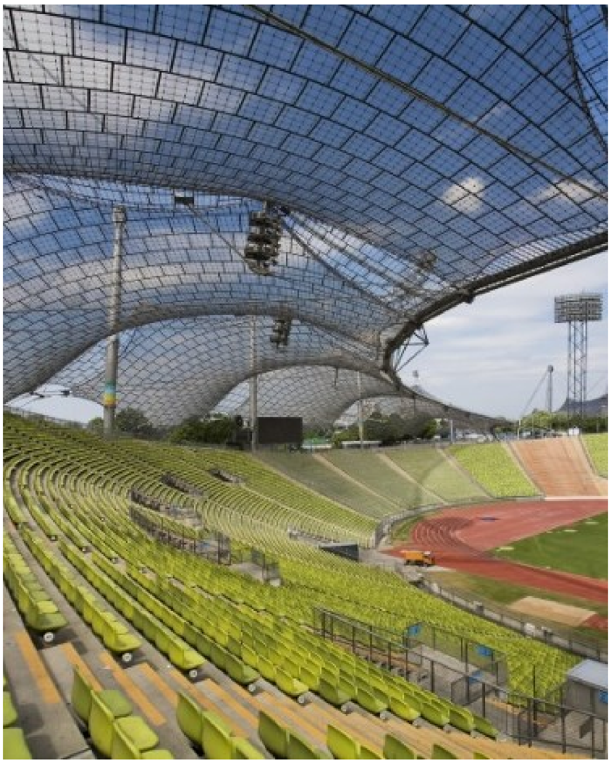


Figure 6.16 Roof system: Tensegrity. Olympiapark, München; design: Frei Otto

Figure 6.17 System: sheet with panels. Non-structural panels on sheet

Figure 6.18 PV and Art. Lux Nova, installation for a ventilation tower at Regent College Library in Vancouver. Design: Solar glass studio Sarah Hall

7. GENERAL AESTHETICAL REQUIREMENTS

The aesthetical qualities of a building are linked to the proportions of the facades or the proportions of the form of a building as a whole. As described in 2.2 ad 3 there are three different principles of the integration of PV in the building envelope of the building as a whole.

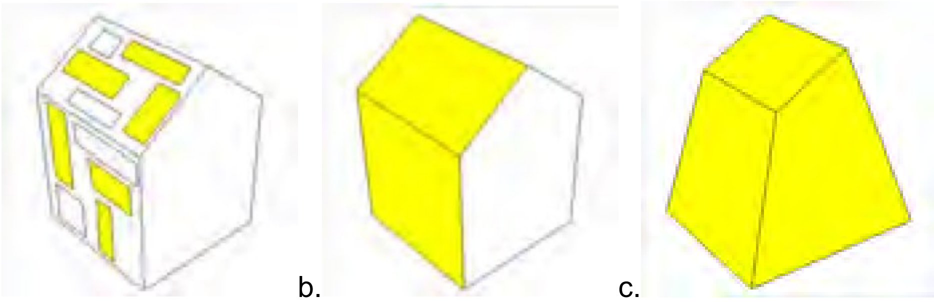


Figure 7.1 Three basic principle of integration of BIPV [8]

As mentioned in chapter 3, a BIPV system can be designed in different ways.

- it can be recognisable in the lay-out of the facade/roof (a);
- it can be part of the envelope as a whole (b);
- it can define the building shape to optimize energy performance (c).

Regarding the way the BIPV system is recognisable in the lay-out of the roof there are different possibilities. They are listed in the diagram below.

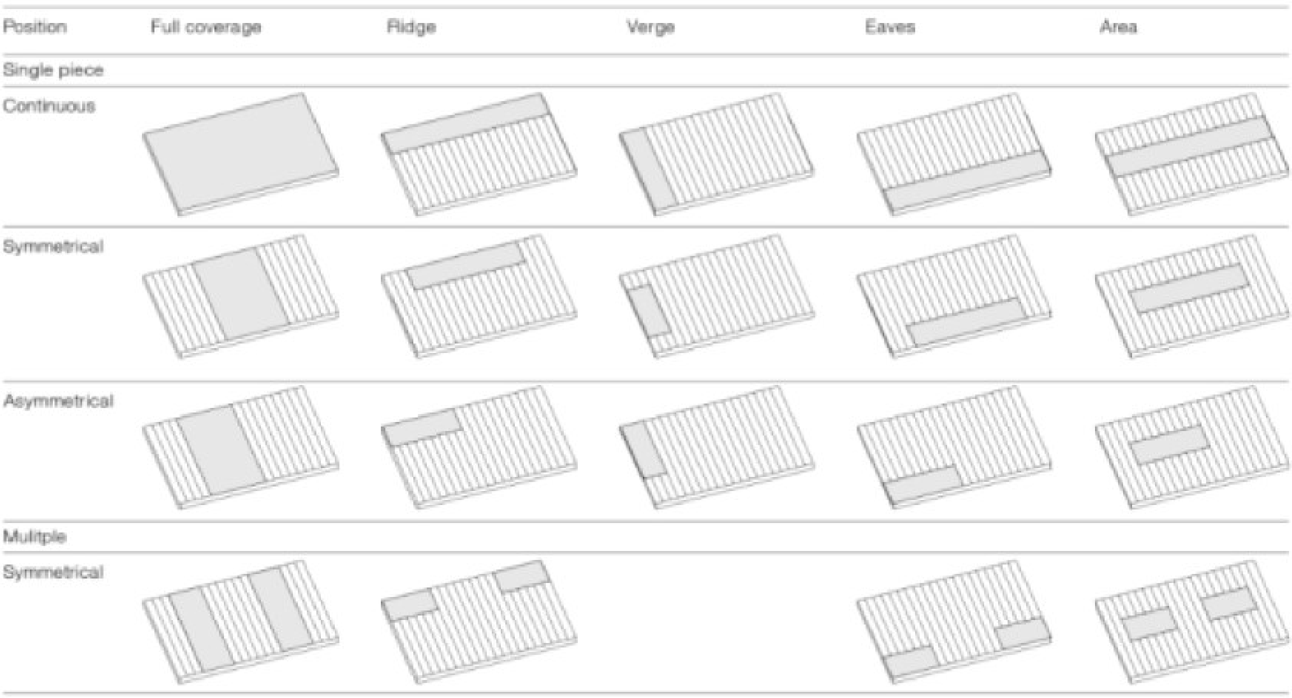
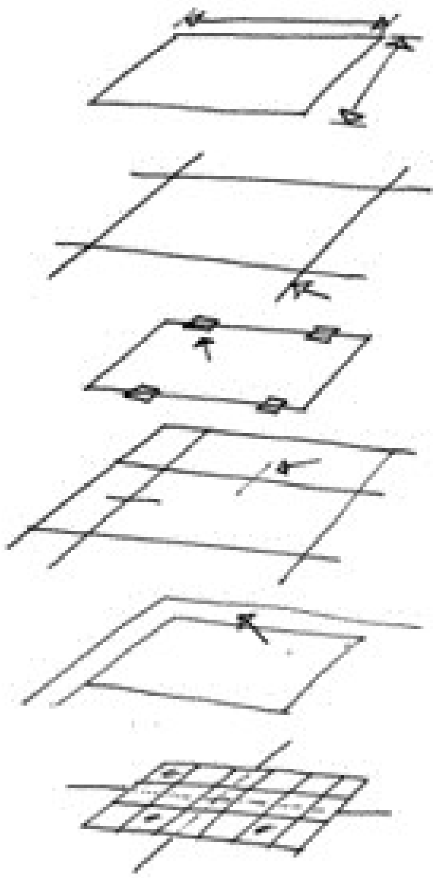


Figure 7.2 Different compositions of photovoltaic building product within a facade or roof surface

Figure 7.3 Typical BAPV solution of the type 'asymmetrical/area'

Many BAPV solutions are of the type 'asymmetrical/area' and are considered not aesthetical pleasing because the PV systems are interfering with the proportions of the roof/facade.

5.1
5.2
5.3
5.4
5.5
5.6



As can be seen in the picture (Figure 7.2) the harmony of the roof is disturbed by the solar modules.

In the next sections following aesthetical aspects will be discussed:

5.1- sizes and shapes;
5.2- jointing;
5.3- fixings;
5.4- combination with adjacent building products;
5.5- detailing of the edges/rims;
5.6- transparency.

Figure 7.4 Main aesthetical subjects

7.1 Sizes and shapes

The range of sizes of BIPV building products is generally limited. A larger range of sizes would create more possibilities to fit the panels in the layout of a building envelope. The same goes for shapes. Availability of different widths and heights of modules enlarge the flexibility in design.

7.2 Jointing

The arrangement of profiles between the cells (the jointing) is an important visual quality of the layout of facades. In 1st generation PV products the jointing was not very well designed. Not only were does products added to the building skin, the pattern of joints interfered with those of the pattern of the other cladding systems.

Jointing: the joint for the cover glass is usually made of black EPDM rubber and can be sometimes hidden by a metal plate which can also cover the module to module jointing.

The range of sizes and shapes can be based on standard sizes of much used building products or can be chosen on aesthetical considerations. A system of dimensions that fits to other architecture systems can help to make a more harmonious looking roof or facade. See the Morphotheek (Figure 7.6) or Le Corbusier (Figure 7.7)

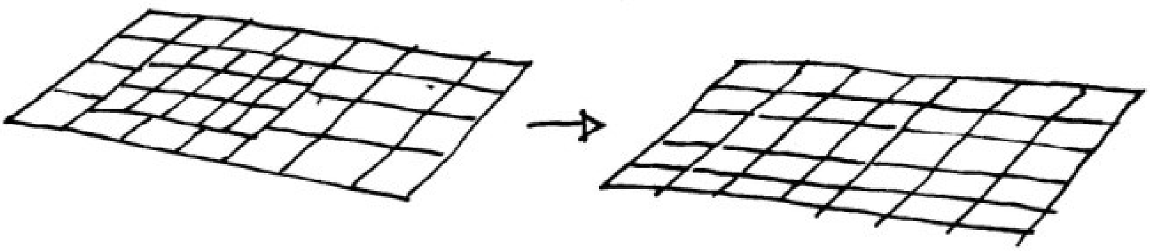


Figure 7.5 Limited availability in sizes can lead to a distinction between modules and adjacent roof/facades cladding

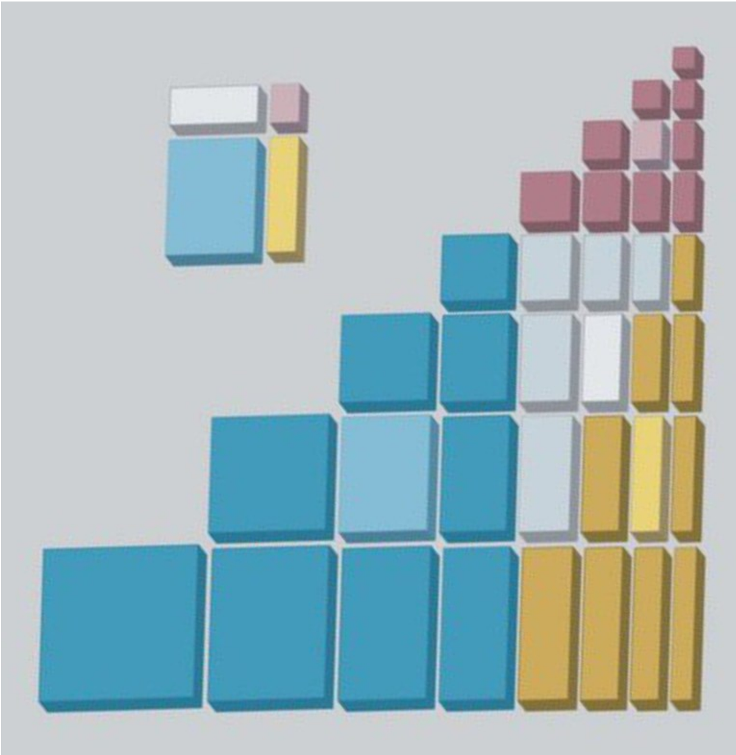


Figure 7.6 The Morphotheek by Dom van der Laan

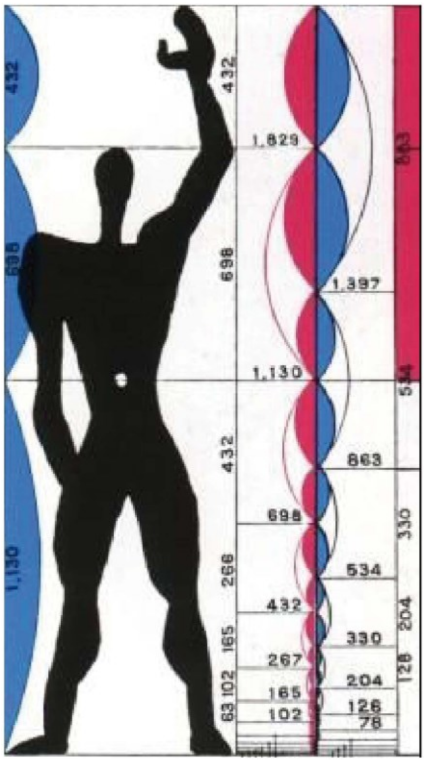


Figure 7.7 The Modulor by Le Corbusier

7.3 Fixings

The elements used to fix the modules to the substructure. Although it seems to be a detail, it is a very important detail for the total aesthetics of the system.

Figure 7.8 BP Solar system with visible mounting (diamonds). Langedijk-2 Mayersloot. □Design BEAR-iD, Tjerk Reijenga.

Figure 7.9 Almost invisible mounting with Alutec profiles. Langedijk-1 Mayersloot. □Design BEAR-iD, Tjerk Reijenga.

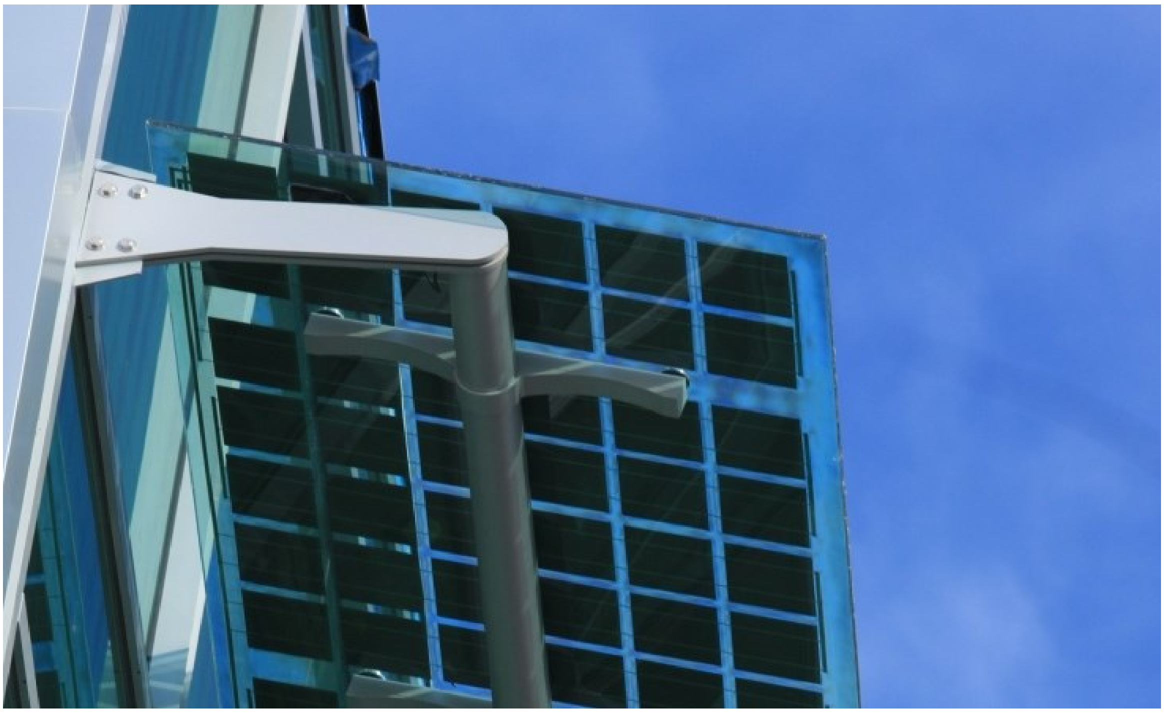


Figure 7.10 Fixings are more prominent than the actual lamella

7.4 Combination with adjacent building products

Not only in terms of the available sizes but also because of the limitations of the substructure does BIPV not yet combine well with other building products. First generation BIPV-systems were not designed to fit the adjacent cladding material of the facade or roof. Because of this the systems did not blend in.

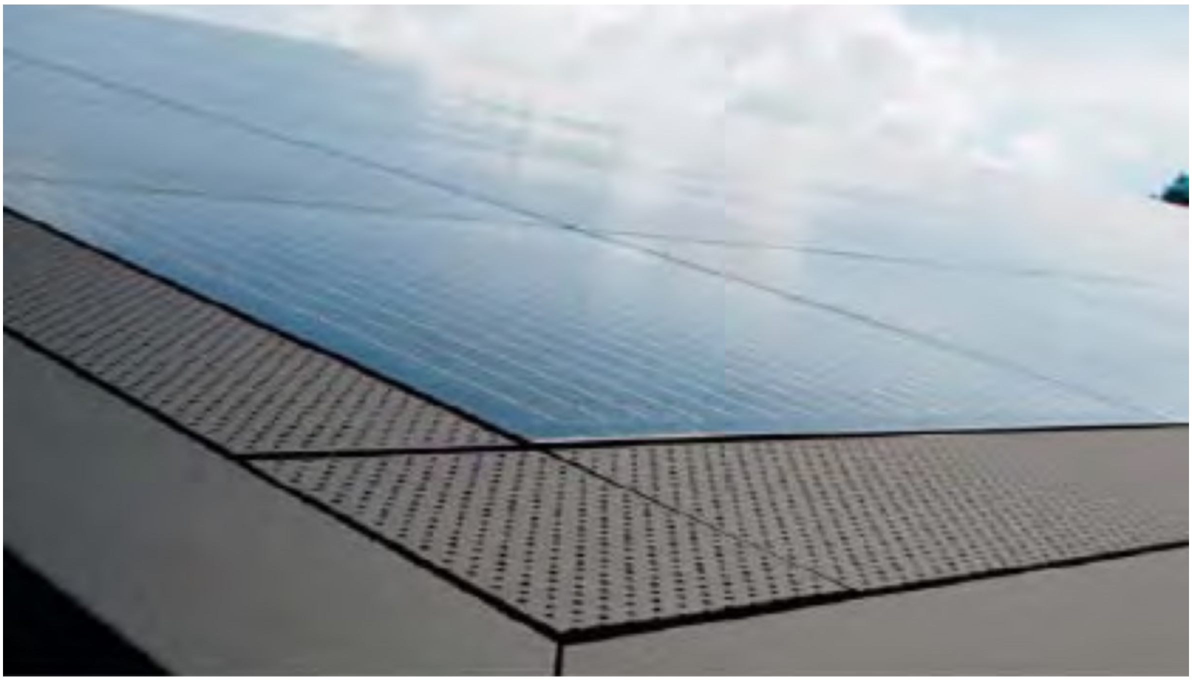


Figure 7.11 A good example of a building product incorporating adjacent non PV-products

7.5 Detailing of edges and rims

The perimeter of a facade/roof is an important detail. The possibilities building products have for proper detailing to the edges of facades and roofs are essential. Especially facade systems using frames have to be precisely detailed to avoid the prominent appearance of the frames dominating the overall appearance of the design.

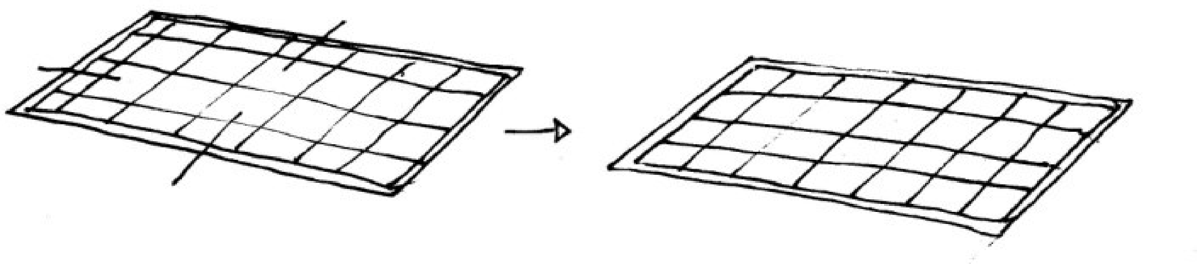


Figure 7.12 Substructure is more prominent than the actual lamella

7.6 Transparency

Transparency of the whole facade can be an enhanced by PV building products. Daylighting, glare, visual contact with the outside and enclosure to the outside are some of the functionalities achieved by transparent facades.

Transparency can be achieved by the space between the cells or by the cell material itself. The first option is a typical crystalline silicon product and it produces a typical light/dark pattern on walls and floors. Because the high contrast the product is less suitable for the working environment (desk work). The second option can be made with a thin layer of amorphous silicon. The daylight is more homogeneous and that makes the product more suitable in a working environment.

Figure 7.13 High contrast in shadows. ECN building 42, Petten (NL) Design: BEAR-iD, Tjerk Reijenga

Figure 7.14 Almost invisible solar modules. Schott Solar ASI Thru modules.

8. SPECIFIC REQUIREMENTS

There are many different ways to categorise facades. The most common one is at technical one. The single layered facade comes in different variants:

- a massive wall with insulation at the inside;
- a cavity wall with insulation at the inside and an outside a layer of for example brick;
- a massive wall with insulation at the outside protected by a plaster or rain-screen;
- a massive wall with insulation at the outside, a cavity and a massive outer facade.

A second method is to describe facades by its transparency. In this categorisation the range of facades goes from fully opaque on one side to fully glazed on the other side of the spectrum. In between are hybrid solutions that combine transparent and opaque materials.

Another criteria is to distinguish facades by the layers a facade is made of, to differentiate between single and multi layered facades. Most common for traditional facades is that they have one visible layer. More and more facades nowadays have a double layer. No only in new buildings but also in renewed buildings an extra layer can help to solve technical or physical problems of the building.

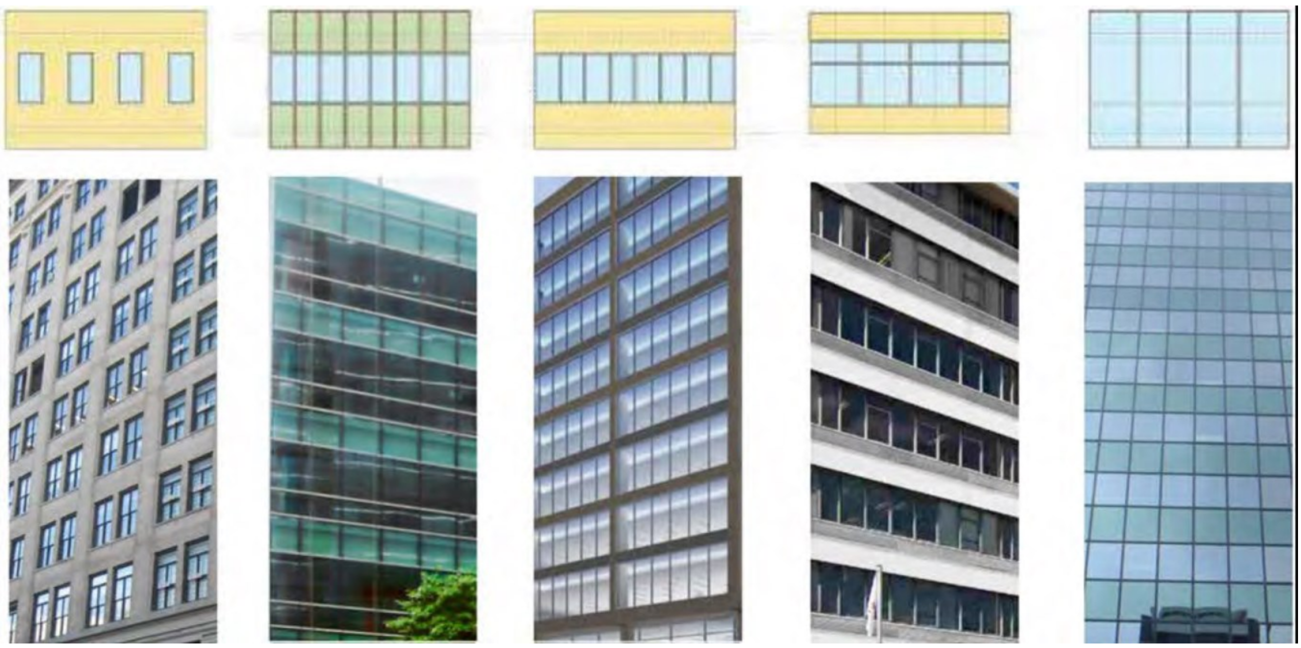


Figure 8.1 Punched holes facade, fully glazed facade, horizontal windows, recessed windows and curtain wall facade

8.1 Facades

In this report we categorise facades by visual aspects and therefore choose for a mix of the three methods mentioned above. With this categorisation we discuss three following sorts of facades:

- flat facades;
- layered facades;
- segmented facades.

A. FLAT FACADES

Flat facades can divided in opaque, transparent or hybrid facades. According to their appearance facades can by divided into the following typologies (see Figure 8.1).

- punched holes facade,
- fully glazed facade,
- horizontal windows,
- recessed windows
- curtain wall facade

B. LAYERED FACADES

The facade can be one integrated system in which also the shading is incorporated. Alternatively the facade can exist out of more layers. Multi layered facades consists of separable layers. An extra layer can, among other functionalities, facilitate shading devices and daylight systems.
Layered facades can be divided into:

a. Integrated systems

Mainly based on curtain wall facades including mechanical elements for heating and cooling. Many different technologies are currently in development like for example heat/cold storage through PCM (phase change materials).

b. Climate facades

Windows with an extra glass layer forming a cavity. The outside glazing is thermal glazing with on the inside single glazing. A shading system is mounted within the cavity. The facade has no openable windows. The mechanical ventilated cavity is part of the ventilation system. The air from the room is ventilated out of the building through the cavity. The calculated U-value of the window is higher because of the warm air in the cavity.

c. Second skin (double facade)

Difference with the climate facade is the natural ventilated cavity and the openable windows. In general the thermal glazing is on the inside and the single glazing is placed at the outside. Shading systems can be placed in the cavity even in a tall building.

d. Second layers

This can be seen as an open ventilated cavity. Inside is the thermal glazing and the second layer is a shading system. Shading systems can be for example fixed lamellas or moveable glass louvers.

e. Hybrid double facades

Extra layers to created depth to the facade. The double layered is also known as a double facade or second skin, and is used to create a buffer zone in front of the real facade to make it possible to open windows on a high floor level, to gain energy or to conserve energy.

Figure 8.2 Pompeu Fabre Library Mataro. Design: Brullet i Tenas

Example of application of a double facade. The photovoltaic modules are cooled by air. By cooling the modules, the BIPV system is more efficient. Moreover the modules are translucent providing daylight for the interior.

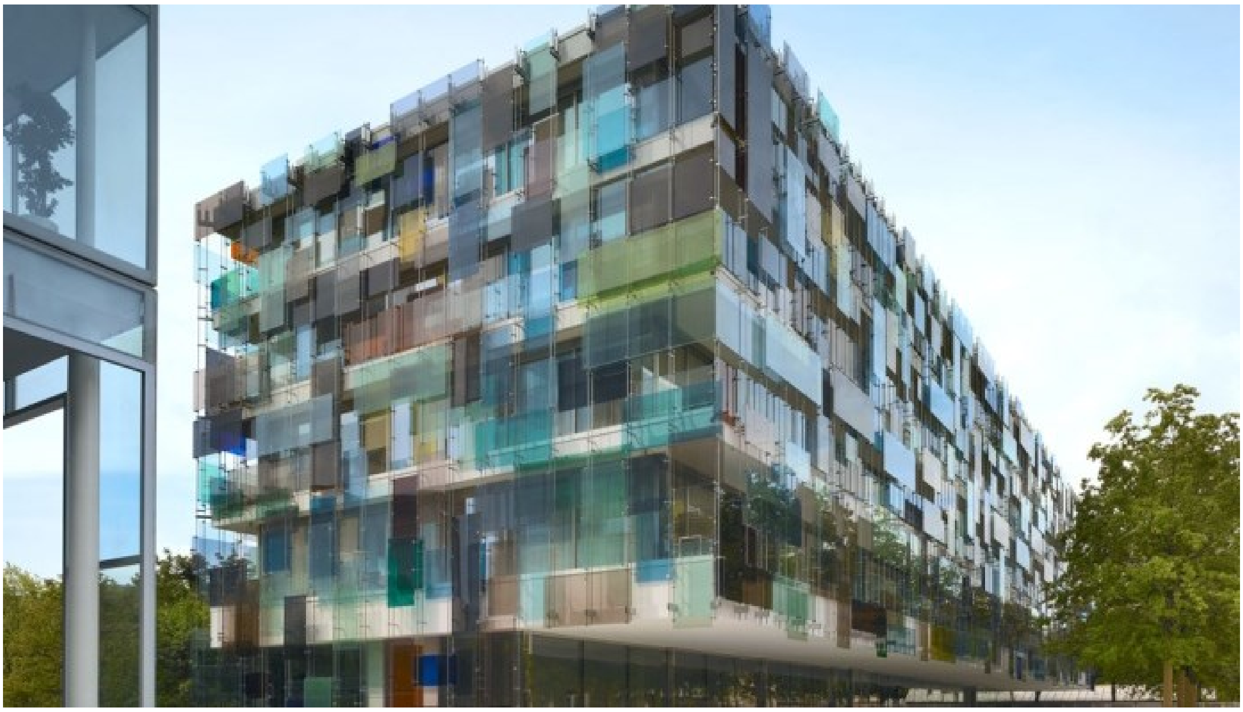


Figure 8.3 Hybrid double facade. Novartis Campus Forum 3, Basel. Design Diener&Diener.

The hybrid double facades. This extra layer provides coloured daylight in the circulation area in front of the closed teaching rooms.

f. Segmented facades

The third category is the segmented facade. The folding of the projecting facade, for instance, makes the optimum alignment of the integrated solar modules possible and increases the solar-active surface.

Figure 8.4 Energy performance optimisation. Marburg, (BRD) Design Opus Architekten

8.2 Roofs

Although the roof was of less importance in many cases, recently more attention goes into the design of the roof. Especially for projects in urban contexts the roof is more and more considered to be a fifth facade. In situations were looking down from higher buildings on the roof of lower buildings roofs are part of the urban landscape and thus more attention is paid to the design of roofs. In general we have:

- flat or slightly sloped roofs (until 15° angle)
- pitched roofs (15° - 75° angle)

Steeper then 75° is considered as a sloped facade.

A. FLAT / SLOPED ROOF

Exactly flat roofs do not exist. To let rainwater run off, roofs are slightly sloped. Thus we consider so called flat and sloped roofs in one section.

Figure 8.5 Large transparent roof. Akademie Mont-Cenis, Herne, (BRD) Design Jouda + Perraudin

Providing enough daylight for the interior was a leading design consideration for the layout of the roof. On top of the street between de office blocks the roof has less Photo-voltaic-modules. Thus providing more daylight where needed.

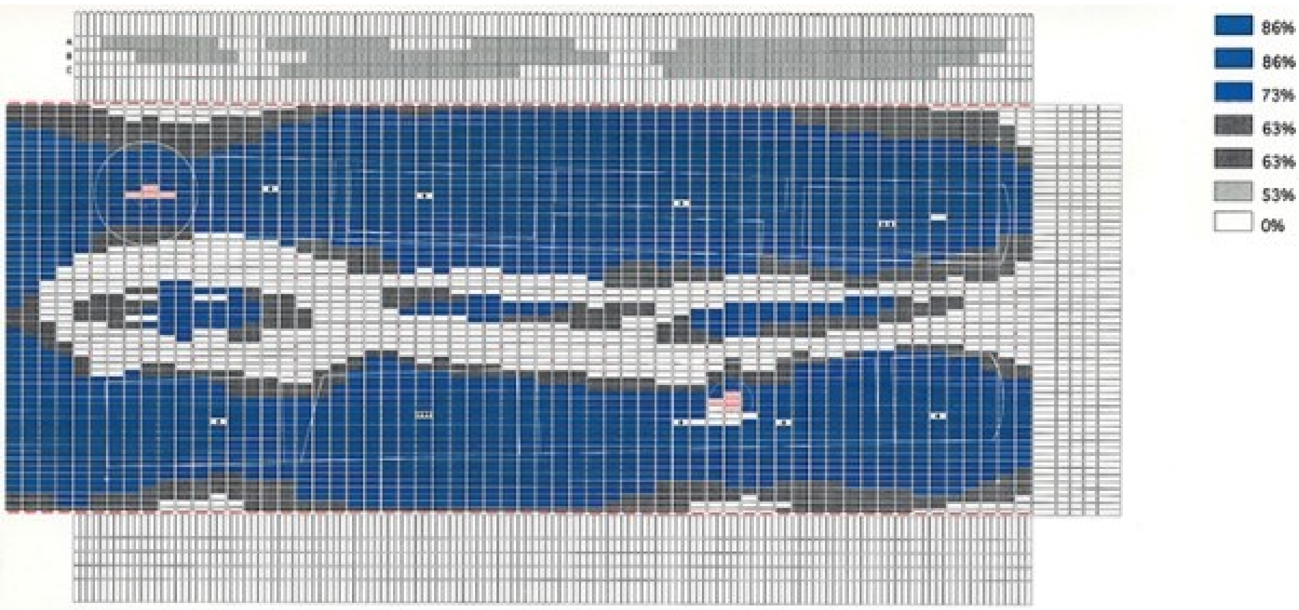


Figure 8.6 The design of the roof seen from above

B. PITCHED ROOF

Figure 8.7 Kraftwerk B, apartment building, Bennau (CH). Design: Grab architekten ag

A 220m^2 BIPV-system integrated in the south-west oriented roof, with an angle of 42°, provides enough energy for the apartments. Also the facade works as an energy generation area.

C. CURVED ROOF

Figure 8.8 Curved roof of the lobby of ECN building 42, Petten. Design: BEAR-iD, Tjerk Reijenga

9. RECOMMENDATIONS RELATED TO PVSITES PRODUCTS

In PVSITES project we have 8 BIPV products that will be demonstrated. Each product is given a code (X1 to X9).

Code	Product	Manufacturer	Demosite	Test benches
X1/X3	CIGS roofing shingle on metal substrate	Flisom	Demonstrated in single-detached dwelling – Belgium and Carport - Switzerland	
X2	CIGS large area flexible roofing membrane and bendable elements	Flisom	Demonstrated in industrial rooftop-Switzerland	
X4	CIGS large area elements on metal substrate	Flisom	Demonstrated in industrial buildings in Switzerland (façade) and Spain (roof)	
X5	C-Si glazed products with hidden bus bars	Onyx	Demonstrated in residential building-France	
X6	Glass-glass products with back contactc-Si cells	Onyx	Demonstrated in office building - Spain	
X7	Curved glass-glass, CIGS technology	Flisom, Onyx	-	CEA/NEST
X8	C-Si large area glass	Onyx	-	CEA
X9	C-Si semitransparent low concentration and solar control BIPV system	Onyx, Tecnaila, Film Optics	-	Acciona

Table 9.1 Table 2 Overview of PVSITES products

9.1 Product X1/X3: CIGS roofing shingle on metal substrate

Flisom is the producer of this product. There are different types for different applications. X1 is the Tile style application that will be demonstrated on a roof in Belgium. X3 is the standing seam style application that will be demonstrated on a carport roof in Switzerland.

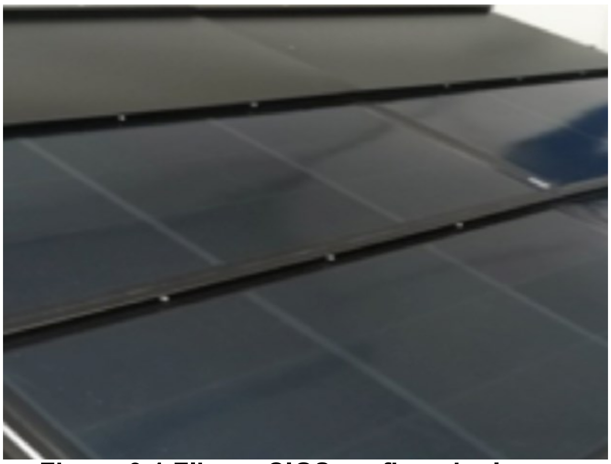


Figure 9.1 Flisom CIGS roofing single on metal substrate. Tile type

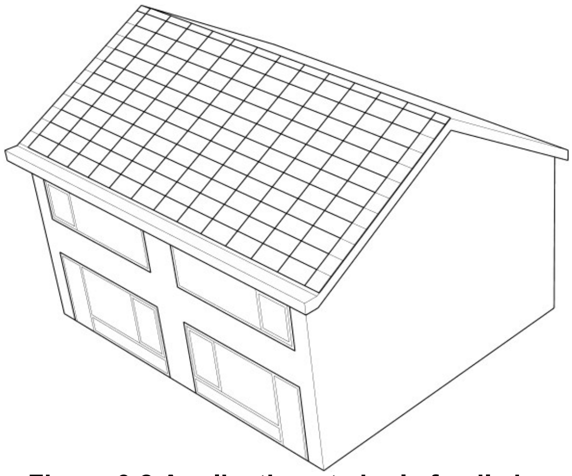


Figure 9.2 Application at single family house (schematic)

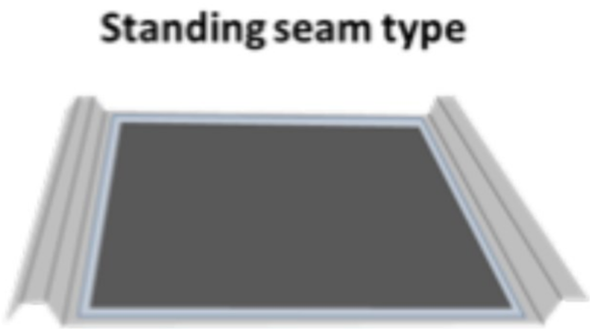


Figure 9.3 Flisom CIGS roofing single on metal substrate. Standing seam type

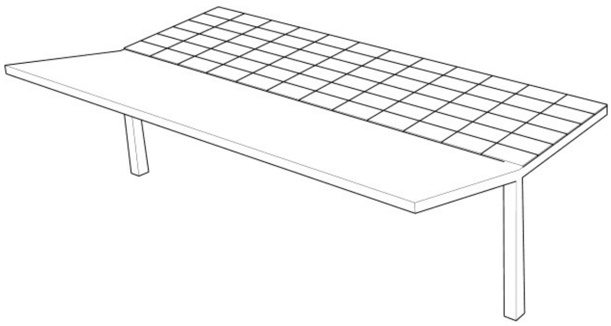


Figure 9.4 Application at carport (schematic)

Considerations

Systems with a variety of panel sizes and/or systems which fit panels with no PV makes it possible to create roof surfaces out of one material. The detailing of edges and rims are essential (see Figure 9.5 and Figure 9.6 as reference). Glossiness and colour of the material itself are important.

Figure 9.5 Multiple of panels define the size of the roof. The architect adjusted the rim and edges to create a clear surface. Mayersloot Langedijk. Design BEAR-iD, Tjerk Reijenga

Figure 9.6 The layout of the PV-modules on this roof is not designed. The edges and rim of the roof are clearly visual. The result is not very aesthetical. City of the Sun, Heerhugowaard

9.2 Product X2: CIGS large area flexible roofing membrane and bendable elements

Product X2 is produced by FLISOM. The products are CIGS large area flexible roofing membrane and bendable elements. It will be demonstrated on an industrial building (roof) in Switzerland.

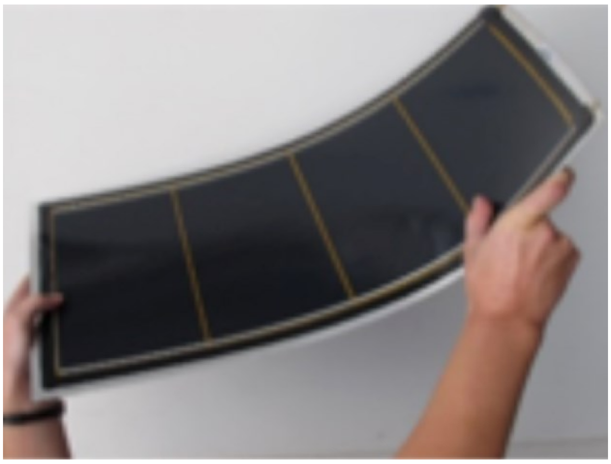


Figure 9.7 Flisom CIGS flexible roofing membrane

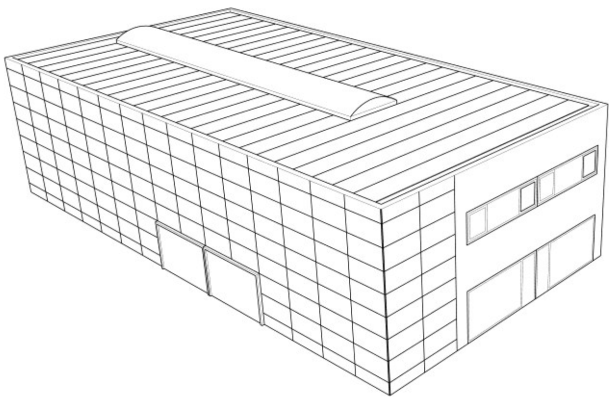


Figure 9.8 Application at industrial building (schematic)

Considerations

Membrane systems with a variety of widths limit the amount of joints. The detailing of edges and rims are essential. Also the edge of the roof has to be designed carefully.

Glossiness and colour of the material itself are important. As the application is on the roof, the material will become matt very fast.

9.3 Product X4: CIGS large area elements

Another product produced by FLISOM is the CIGS large area elements for industrial buildigs. The demonstration project will be an industrial building in Switzerland (facade) and an industrial building in Spain (roof).

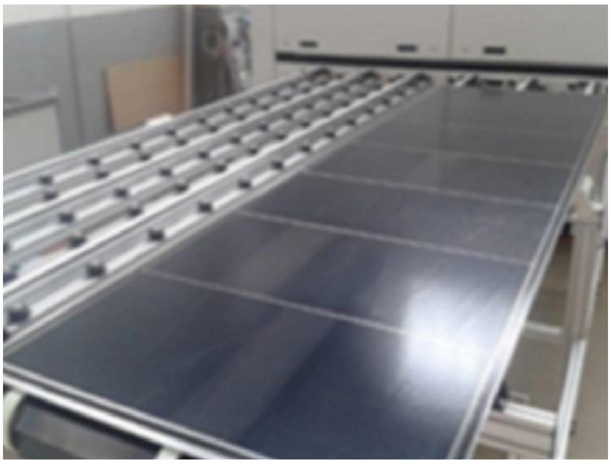


Figure 9.9 Flisom CIGS large area elements

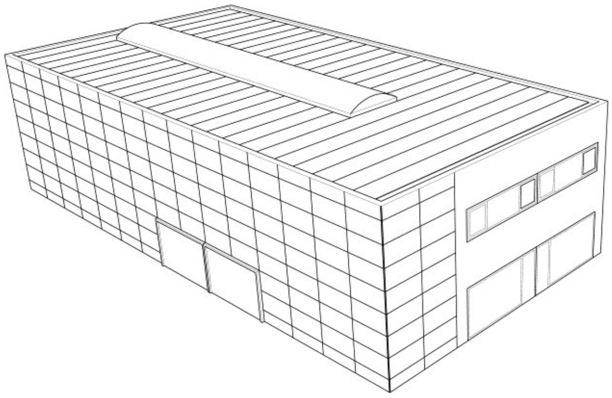


Figure 9.10 FIndustrial application (schematic)

Considerations

The plinth of the building cannot have any PV integrated because of shadow and dirt. The facade system should have elements without PV as well, that fit with the PV elements, to make a complete system for all facades including the lower part of the facade. In this way it is possible to create facade surface out of one material.

The detailing of edges and rims are essential. Glossiness and colour of the material itself are important.

Modest fixings are preferable to create abstract surfaces without any visual disturbances of technical elements.

9.4 Product X5: crystalline-silicon, glazed products with hidden bus bars

ONYX will produce the c-Si glazed products with hidden bus bars. The product will be demonstrated in a residential building in Villeneuve d'Ascq, France.

Figure 9.11 Example of facade with glazed products

Figure 9.12 Residential building (schematic)

Considerations

Systems with a variety of panel sizes and/or systems which fit panels with no PV makes it possible to create facade surfaces out of one material. The detailing of edges are essential. Glossiness and colour of the material itself are important.

The pattern of joints, the thickness of the joints and possible fixing and fastenings in the joints play a major role in the overall appearance of BIPV in the building envelope.

9.5 Product X6: crystalline-silicon glass-glass products with back contact cells

ONYX will produce the C-Si glass-glass products with back contact cells to demonstrate in an office building in San Sebastian, Spain.

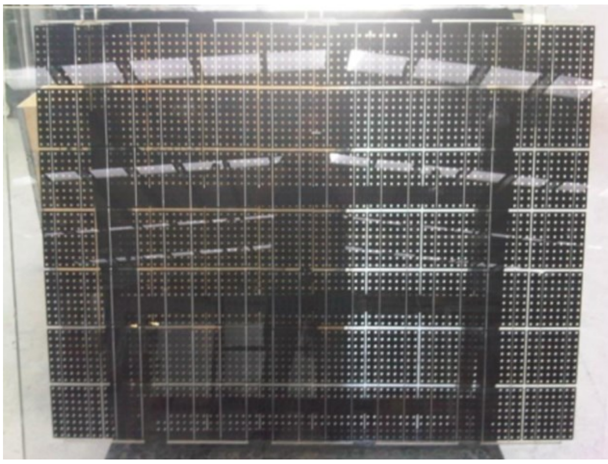


Figure 9.13 Example of c-Si glass-glass module with back contact cells

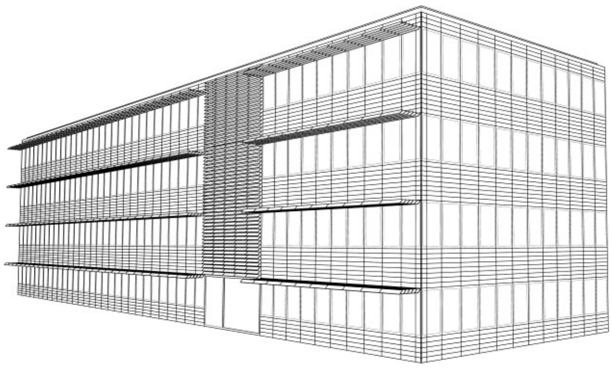


Figure 9.14 Office building (schematic)

Considerations

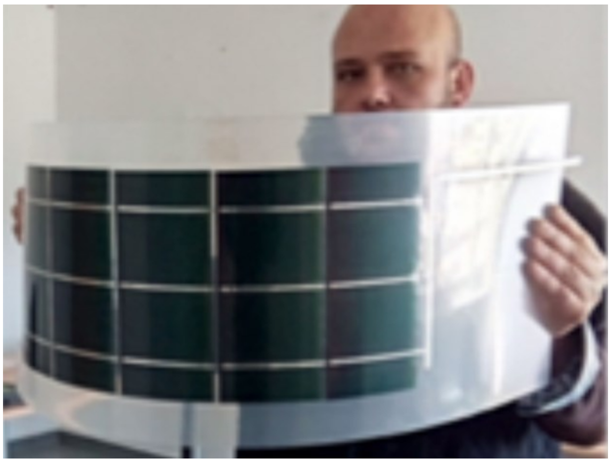
Systems with a variety of panel sizes and/or systems which fit panels with no PV makes it possible to create facade surfaces out of one material. The detailing of edges is essential.

Glossiness and colour of the material itself are important. Although for an office facade the glossiness is maybe less important.

Each type of cells/PV-material has its own qualities in terms of colour, texture, transparency and glossiness. When conceiving new buildings architects consider those qualities when selecting photovoltaic building products.

9.6 Product X7: curved glass-glass, CIGS technology

Flisom and ONYX will work together to produce prototypes of curved glass-glass CIGS modules. The modules will be tested at the test-benches of CEA, France and at the NEST experimental building in Zurich.



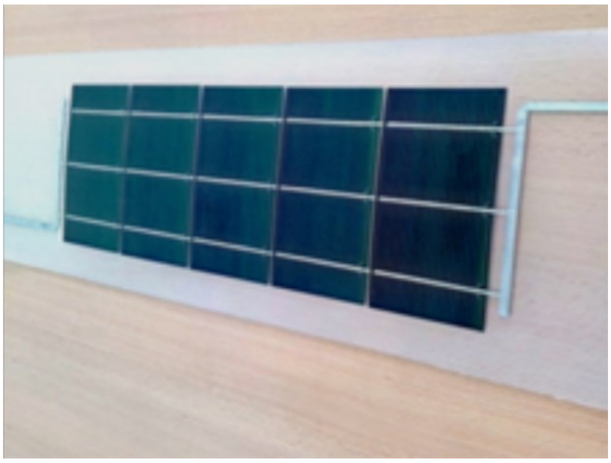


Figure 9.15 and Figure 9.16 Example of internal sheet of curved CIGS element

9.7 Product X8: crystalline-silicon large area glass

ONYX will work on the production of prototypes of large area glass C-Si modules. The modules will be tested at the test-benches of CEA, France.

Figure 9.17 c-Si large area glass module

9.8 Product X9: crystalline-silicon semi-transparent, low concentration roof/facade

This product is a co-operation between Tecnalia, ONYX, Film Optics and Acciona. The product combines energy production with solar control. There are many possible applications in buildings (offices) and also in the greenhouses. The modules will be tested at Acciona in Sevilla.

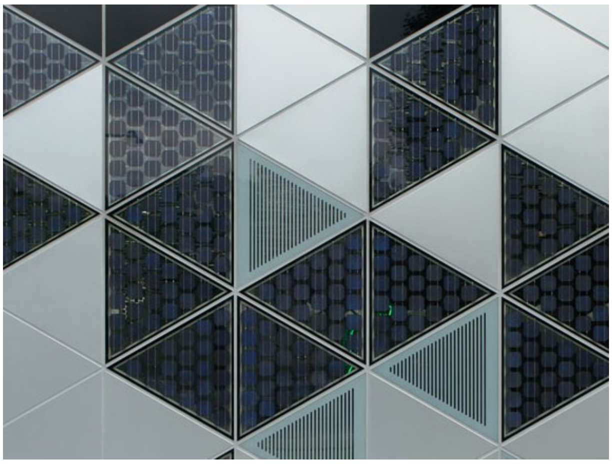


Figure 9.18 and Figure 9.19 Just an example of what light and BIPV can do in an interior

Figure 9.20 Test site with c-Si semi-transparent, low concentration roof in a greenhouse

10. CONCLUSIONS

Buildings are complex systems for which there are no universal design rules. In this conclusion we prefer to talk about design considerations instead of constraints.

The conclusions of this report D2.4 are actually more recommendations. Recommendation to make products that fit in an architecture context. Although the definition of BIPV (EN 50583) is purely a technical definition, the result and the attractiveness of BIPV is in the design and in the aesthetical added value of BIPV products.

So we can make the following recommendations:

- Don't use BIPV in a random way but design it careful and make it part of the overall building envelope.
- Design with added value, what means that a BIPV system does not only produce energy, but it can save energy through shading or daylighting besides the fact that it replace some building material.
- Building products should fit within a standard building sizing system to fit easily in a design.
- The arrangement of modules and profiles (jointing) is one of the most visible and aesthetical sensitive aspects of BIPV. This needs full attention.
- Fixings should be modest or even invisible. In general if the fixings are dominant it can ruin the total image of the BIPV.
- If it is needed to combine BIPV with adjacent products, the dimensions should fit together. In general it is better to have a BIPV product and a non-BIPV product that are from the same family of products. This also includes all profiles and supports for edges.
- Detailing of edges and rims is very essential for the total aesthetical image of the BIPV application. Flexibility is needed from both sides, the BIPV system and the under laying construction.
- Transparency of the BIPV system is probably one of the best selling architecture advantages of BIPV. Use it in an efficient way without causing other problems (overheating).

11. SOURCES

Definitions

Definition in EN 50583-1: "Photovoltaics in buildings – Part 1: BIPV modules" (Approved by CENELEC on 2015-10-05):

Building-Integrated Photovoltaic modules - BIPV modules
"photovoltaic modules are considered to be building-integrated, if the PV modules form a construction product providing a function as defined in the European Construction Product Regulation CPR 305/2011. Thus the BIPV module is a prerequisite for the integrity of the building's functionality. If the integrated PV module is dismounted (in the case of structurally bonded modules, dismounting includes the adjacent construction product), the PV module would have to be replaced by an appropriate construction product."

Definition in EN 50583-2: "Photovoltaics in buildings – Part 2: BIPV systems" (Approved by CENELEC on 2015-10-12):

"BIPV system, photovoltaic systems are considered to be building-integrated, if the PV modules they utilize fulfil the criteria for BIPV modules as defined in EN 50583-1 and thus form a construction product providing a function as defined in the European Construction Product Regulation CPR 305/2011".

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