ARCHITECTURAL INTEGRATION OF LIGHT-TRANSMISSIVE PHOTOVOLTAIC (LTPV)

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1. Introduction

2. Study approach and aim

3. Translucency and transparency

4. Analysis of built examples

5. Matrix for analysis

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1. Introduction
Opaque PV ↔ Light-Transmissive PV

Fig.1 © Allmann Sattler Wappner Architekten, München

Fig.2 © Scheuten Solar
Light-Transmissive PV

Translucent or semi-transparent properties and qualities:

- ability to change the degree of light-transmittance,
- for illumination or shading,
- for allowing or preventing views,
- for letting in desired heat gains,
- for blocking undesired heat loads,
- fulfilling the basic function of PV as power generator,
- plus aesthetic qualities of rich shadow plays, colour and texture,

all in one building and architectural element.

Fig.2 © Scheuten Solar
2. Study approach and aim
Main objectives

This study is meant to fill the gap, the lack of research into LTPV as an architectural element.

This study is intended to

1) provide a comprehensive analysis of architectural-integration of light-transmissive PV systems,

2) establish key design parameters based on built examples,

3) illustrate development potential for PV manufacturing and architectural-integration.
Main objectives

Objective 1)

Provide a comprehensive analysis of architectural-integration of light-transmissive PV systems.

- To fulfil the first objective of the study, a corpus of ~500 realised LTPV projects from the last three decades has been compiled.
- This means about four times more built examples than the case studies published in the books about BIPV.
Main objectives

Objective 2)

Establish key design parameters based on built examples.

• To fulfil the second objective, 111 projects were selected for the detailed analysis.

• Criteria for this selection are:
  • early examples,
    • variety in geographic location,
    • variety in building typology,
    • variety in building integration as building element,
    • variety in PV technology,
    • variety in LTPV design parameters,
  • but also well published examples, to understand their stance in terms of architectural integration.
Main objectives

Objective 3)

Illustrate development potential for PV manufacturing and architectural-integration.

- Based on the analysis and fullfilment of objective two, the third objective can be realised.
3. Translucency and transparency
PV technologies

<table>
<thead>
<tr>
<th>1st generation crystalline silicon cells</th>
<th>2nd generation thin-film solar cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>monocrystalline</td>
<td>amorphous silicon</td>
</tr>
<tr>
<td>12~17% (25%)</td>
<td>5~7% (12.5%)</td>
</tr>
<tr>
<td>polycrystalline</td>
<td>CIS/CIGS</td>
</tr>
<tr>
<td>11~15% (20%)</td>
<td>8~11% (20%)</td>
</tr>
<tr>
<td></td>
<td>&lt; market efficiency -&gt;</td>
</tr>
<tr>
<td></td>
<td>&lt;- (lab efficiency) -&gt;</td>
</tr>
<tr>
<td></td>
<td>~8% (11%)</td>
</tr>
</tbody>
</table>

Fig.3 © Sunways  Fig.5 © Sunways  

Fig.4 © Sunways  Fig.6 © SCHOTT Solar  Fig.7 © Würth Solar  Fig.8 © FhG

Fig.9 © Bert Bostelmann  Fig.10 © RWE Schott Solar  Fig.11 © Richard Glover
'light-through' $\leftrightarrow$ 'see-through'
4. Analysis of built examples

4.1. Location, year of completion, rated power output

4.2. 'Light-through' vs. 'see-through'

4.3. Building typology

4.4. Building integration

→ more information can be found in the paper
5. Matrix for analysis
Common analysis ...

Fig. 15 © Robert Baum
... + Newly considered ...

![Diagram showing common and newly considered elements in architectural integration of Light-Transmissive Photovoltaic (LTPV), EU PVSEC 2011](Fig.16 © Robert Baum)
... = Six-Level-Matrix

Fig. 17 © Robert Baum
Six-Level-Matrix

![Diagram of Six-Level-Matrix]

**Fig. 18 © Robert Baum**
Crystalline silicon cells

(a) single cell
(b) parallel strings, equal distances
(c) equally increased string distance
(d) equally increased cell distance
(e) offset strings
(f) radiating strings
(g) curved strings
(h) shortened string length

(j) gaps
(i) varied string distance
(k) varied cell distance
(l) rotation

Fig. 19 © Robert Baum
Thin-film sheets

(m) single sheet

(n) adjacent sheets

Fig.20 © Robert Baum
Level 1 features

(1a) different technologies
(1b) different transparencies
(1c) different cell sizes

Level 2 features

(2a) different string + cell distance
(2b) different string distance
(2c) different cell distance
(2d) different cell densities

Level 3 features

(3a) different panel size
(3b) different panel shape

Level 4 features

(4a) equal panels
(4b) dummy panels
(4c) LTPV + opaque PV

Level 5 features

(5a) opaque PV + semi-transparent / transparent non-PV
(5b) LTPV + semi-transparent / transparent non-PV
(5c) LTPV + opaque non-PV

Fig. 21 © Robert Baum
Gymnasium Burgweinting
Regensburg, Germany, 2004
architect: Regensburg Building Department, Tobias Ruf

Fig. 22 © DBU

Fig. 23 © Peter Ferstl
Opera House
Oslo, Norway, 2007
architect: Snøhetta

Fig. 24 © Christopher Hagelund / The Telegraph

Fig. 25 n.a.
The Core at the Eden Project
Bodelua, Cornwall, UK, 2005
architect: Nicholas Grimshaw & Partners

Fig.26 © copperconcept.org
Fig.27 © Romag Ltd
California Academy of Sciences building
Golden Gate Park, San Francisco, USA, 2008
architect: Renzo Piano Building Workshop

Fig. 28 © Michel Denance (Artedia) and Nic Lehoux (RPBW)

Fig. 29 © glassmagazine.com
Hotel Industrial (Hôtel Industriel)
Paris, France, 2008
architects: Emmanuel Saadi, Jean-Louis Rey, François da Silva
Kindergarten
Dresden, Germany, 2003
architects: Reiter & Rentzsch
6. Case study
Non-PV references

The Pyramids of Giza, Egypt, ~2560 BC~

Eiffel Tower, Paris, France, architect: S. Sauvestre, G. Eiffel et Cie., 1889

Montreal Biosphère, Quebec, Canada, architect: Richard Buckminster Fuller, 1967

Fig.34 © Ricardo Liberato
Fig.35 © Brian Tibbets
Fig.36 © Philipp Hienstorfer
Non-PV references

The Pyramids of Giza, Egypt, ~2560 BC

Eiffel Tower, Paris, France, architect: S. Sauvestre, G. Eiffel et Cie., 1889

Montreal Biosphère, Quebec, Canada, architect: Richard Buckminster Fuller, 1967

Queen Elizabeth II Great Court, London, UK, architect: Foster and Partners, 2000

Federation Square, Melbourne, Australia, architect: Lab Architecture Studio, 2002

BMW Welt *, Munich, Germany, architect: Coop Himmelb(l)au, 2007

Guangzhou Opera House, Guangzhou, China, architect: Zaha Hadid architects, 2010

* Note: This project has building added opaque PV standard modules installed on the roof, but no light-transmissive PV, therefore it appears here as a non-PV reference.
Pyramides at DEMOSITE
Lausanne, Switzerland, 1992
PV: Colt International, Solution (Atlantis Solar Systems)
Marrakech Ménara Airport
Marrakech, Morocco, 2008
architects: E2A Architecture
Cité du Design
Saint-Étienne, Rhone-Alpes, France, 2010
architect: LIN Fin Geipel and Giulia Andi

Fig. 45 © Jan Oliver Kunze / LIN
Fig. 46 © EcoFriend
House of Music Aalborg
Aalborg, Denmark, ~2012
architect: Coop Himmelb(l)au
Pyramids at Demosite, Lausanne, Switzerland  
manufacturer: Colt / Solution, 1992

Ménara Airport, Marrakech, Morocco  
architects: E2A Architecture, 2008

Cité du design, Saint-Etienne, France  
architects: LIN - Finn Geipel+Giulia Andi, 2010

House of Music, Aalborg, Denmark  
architects: Coop Himmelb(l)au, ~2012

crystalline silicon cells

shortened string length

triangular laminate

triangular laminate

similar laminates plus glass

pyramidal canopy

square laminate

gaps and rotated

offset and shortened strings

skylight

façade and flat roof

sunshade (façade)
7. Conclusion
six-level-matrix

1. solar cell
2. cell-group form
3. solar panel
4. panel-group form
5. built form
6. urban/landscape form

uniformity
homogeneity heterogeneity
scale / combinations

Fig. 51 © Robert Baum
Thank you for your attention

Robert BAUM