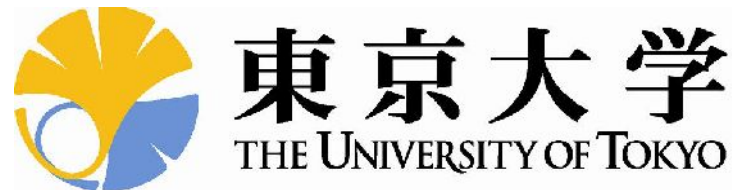


# ARCHITECTURAL INTEGRATION OF LIGHT-TRANSMISSIVE PHOTOVOLTAIC (LTPV)

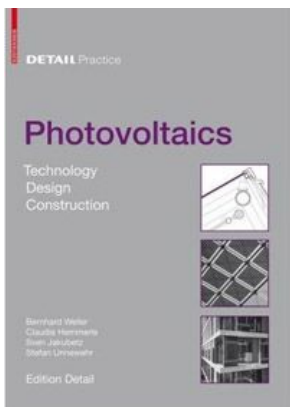
Robert BAUM

Department of Architecture, The University of Tokyo, Japan

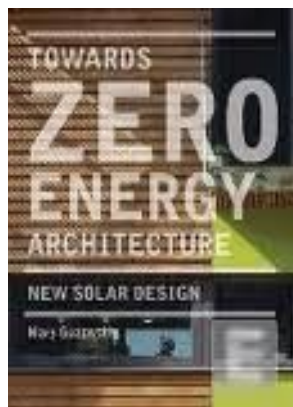


1. Introduction
2. Study approach and aim
3. Translucency and transparency
4. Analysis of built examples
5. Matrix for analysis
6. Case study
7. Conclusion

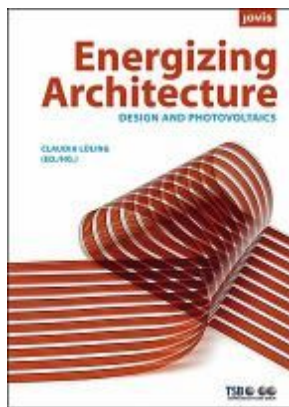
# 1. Introduction



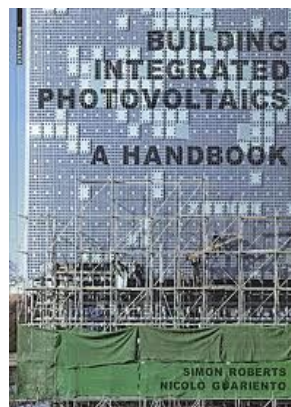
Weller, et al. 2010



Guzowski 2010



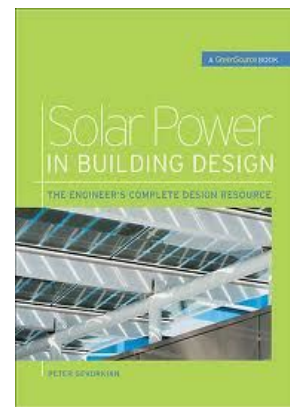
Lüling 2009



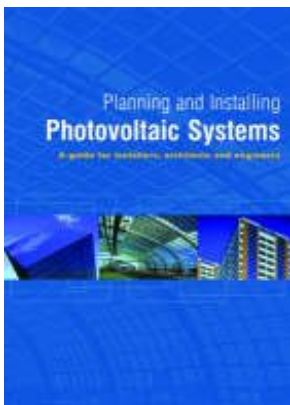
Roberts & Guariento 2009



Scognamiglio 2009



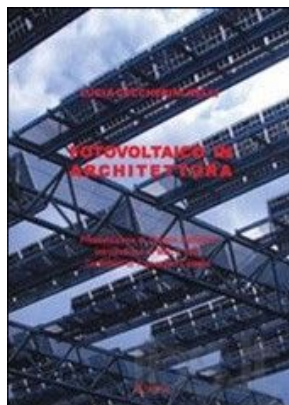
Gevorkian 2007



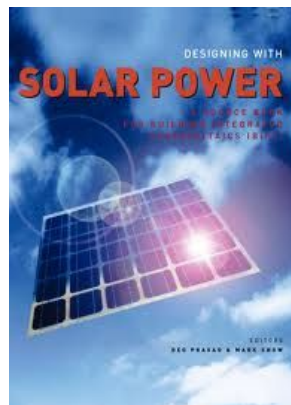
German Solar Energy Society (DGS), 2005



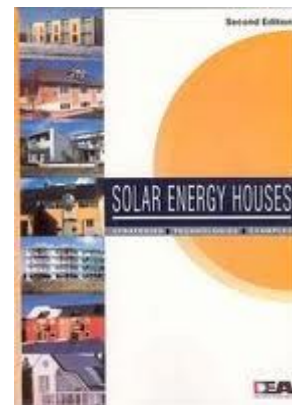
Nelli 2007



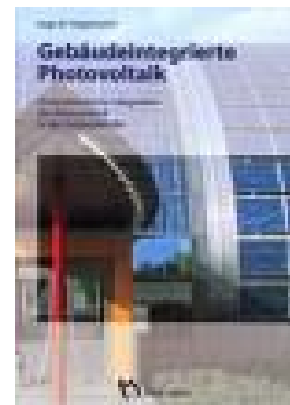
Nelli 2006



Prasad & Snow 2005



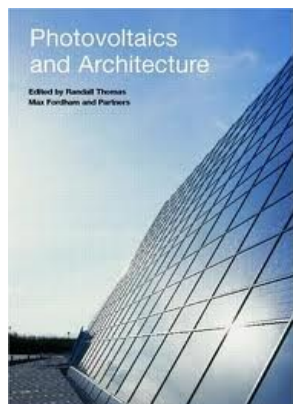
Hestnes 2003



Hagemann 2002



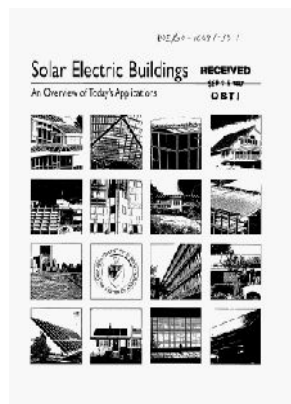
Rexroth 2001



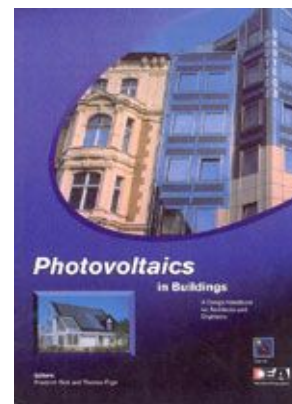
Thomas 2001



Eiffert & Kiss 2000



NREL 1997



Sick & Erge 1996



Humm & Toggweiler 1993

# Opaque PV ↔ Light-Transmissive PV



# 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 fulfilment of objective two, the third objective can be realised.

### 3. Translucency and transparency

# PV technologies

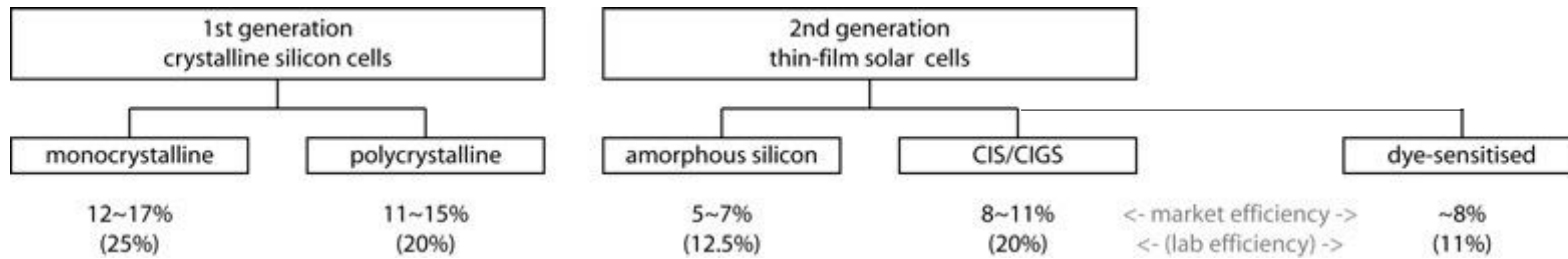


Fig.3 © Sunways Fig.5 © Sunways



Fig.6 © SCHOTT Solar

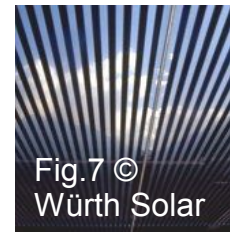


Fig.7 © Würth Solar

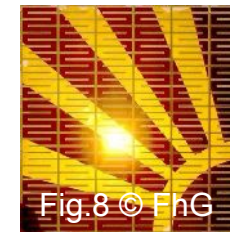


Fig.8 © FhG



Fig.9 © Bert Bostelmann



Fig.10 © RWE Schott Solar



Fig.11 © Richard Glover

# 'light-through' ↔ 'see-through'



Fig.12 © BSW-Solar/Langrock



Fig.13 © Kaneka Corporation



Fig.14 © BSW-Solar/Sunways

## 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 ...

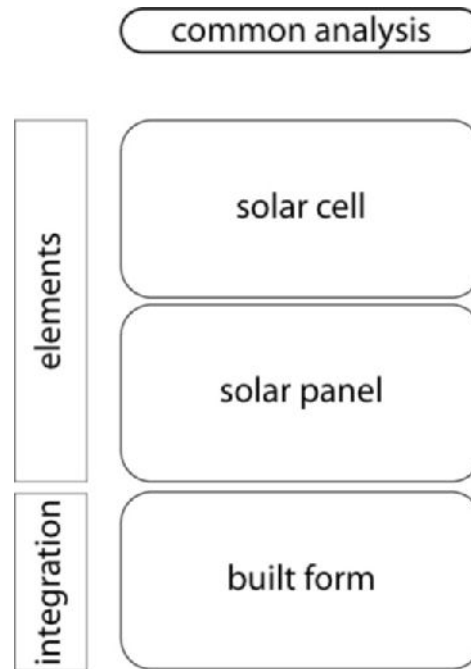


Fig.15 © Robert Baum

# ... + Newly considered ...

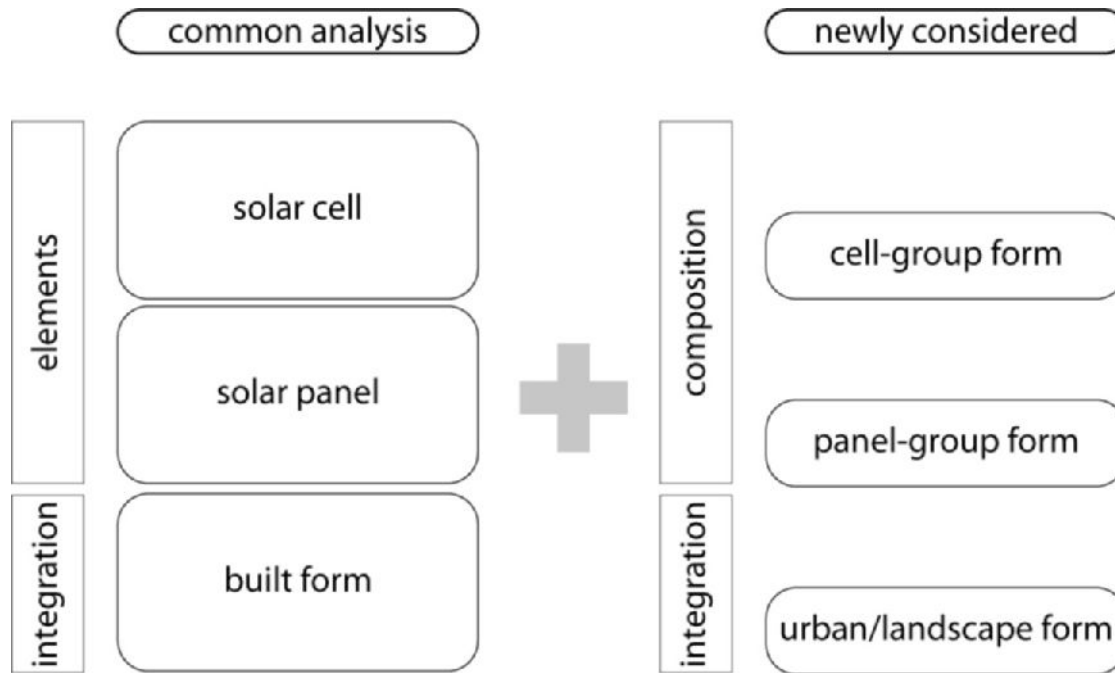


Fig.16 © Robert Baum

# ... = Six-Level-Matrix

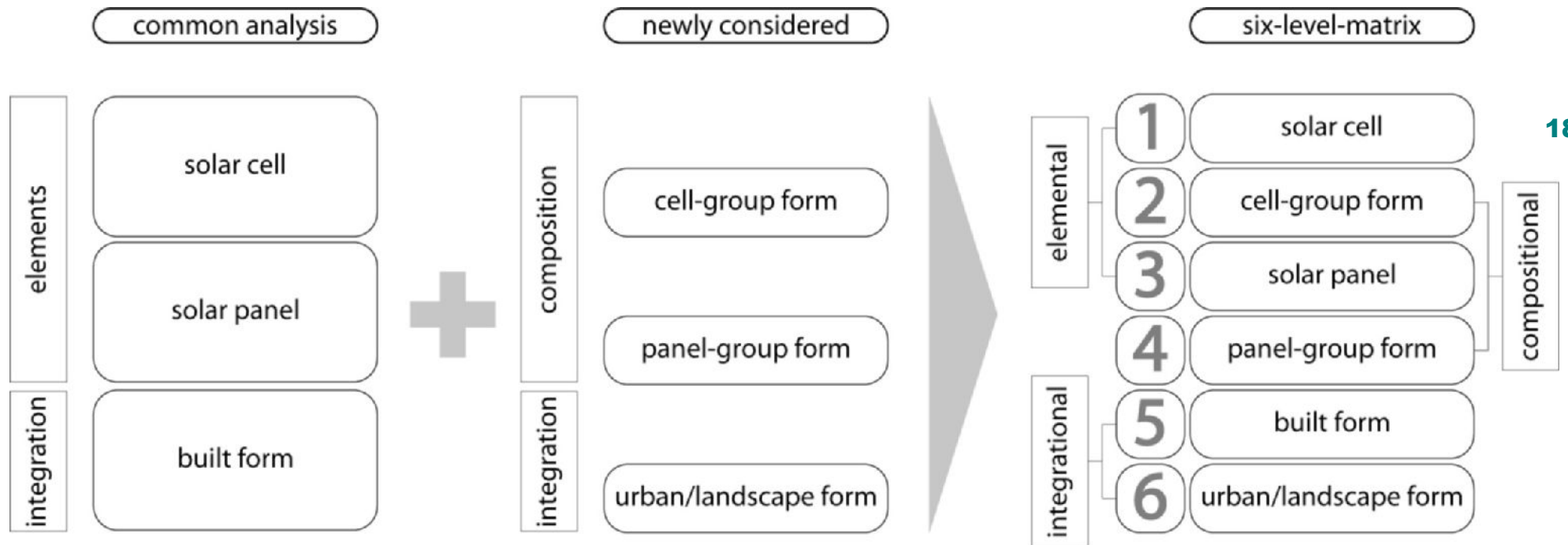


Fig.17 © Robert Baum

# Six-Level-Matrix

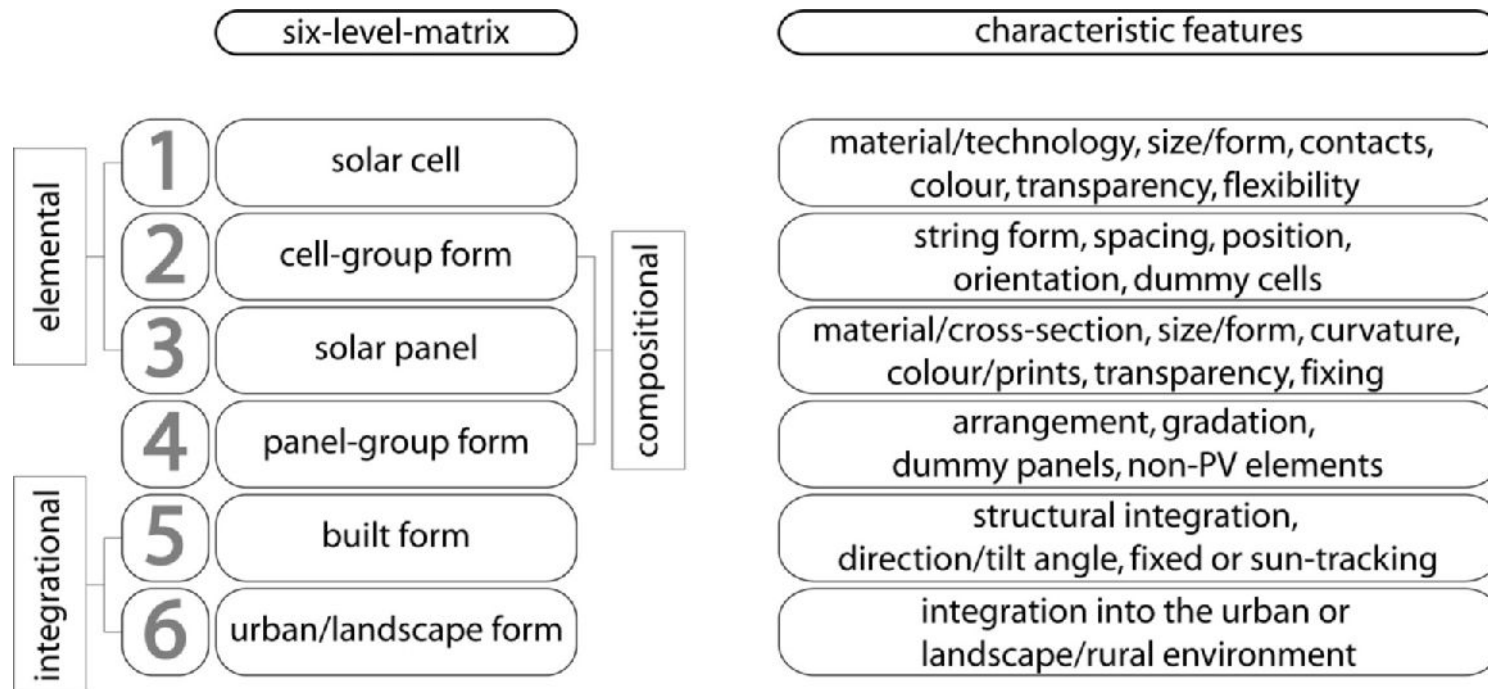


Fig.18 © Robert Baum

# Crystalline silicon cells

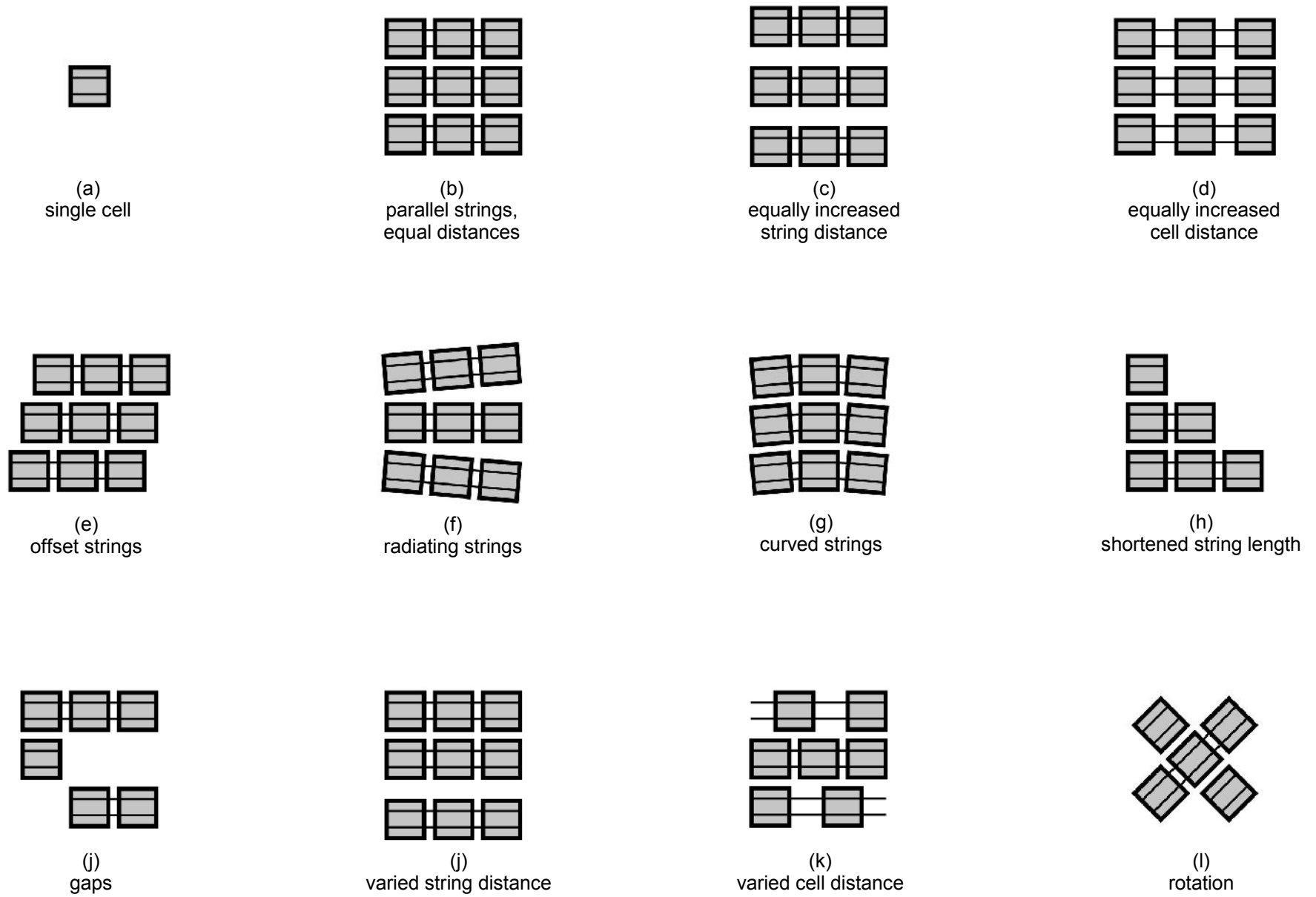


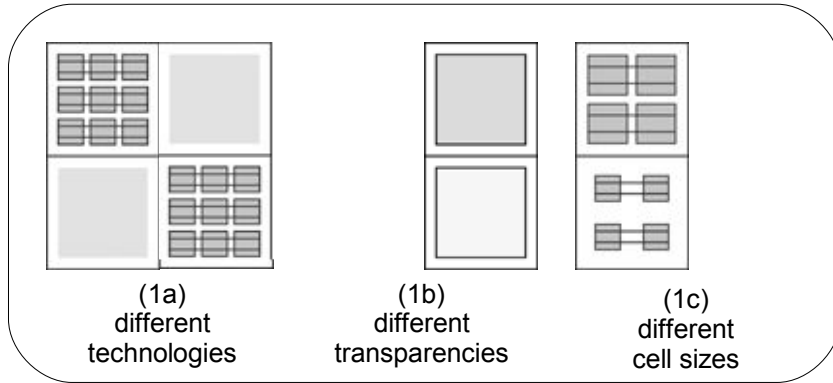
Fig.19 © Robert Baum

## Thin-film sheets

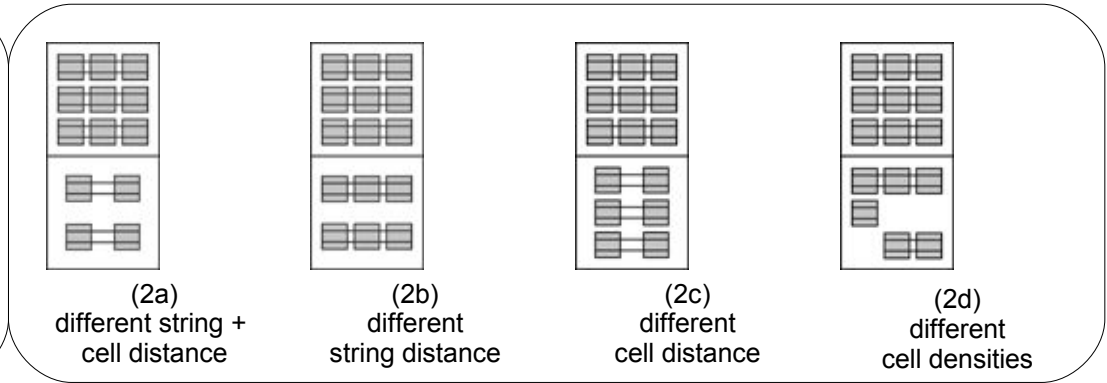


Fig.20 © Robert Baum

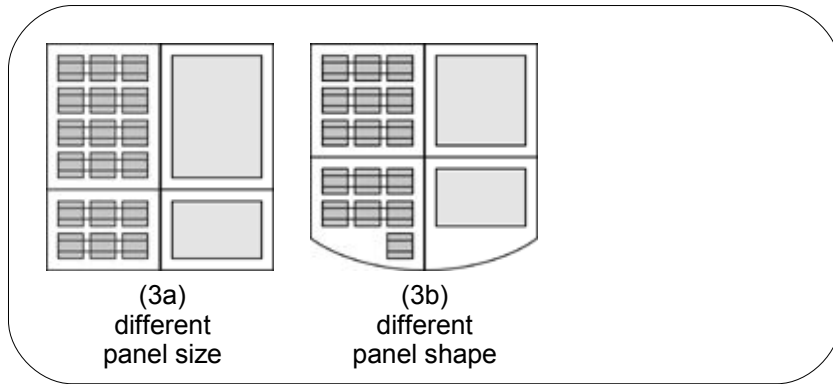
## Level 1 features



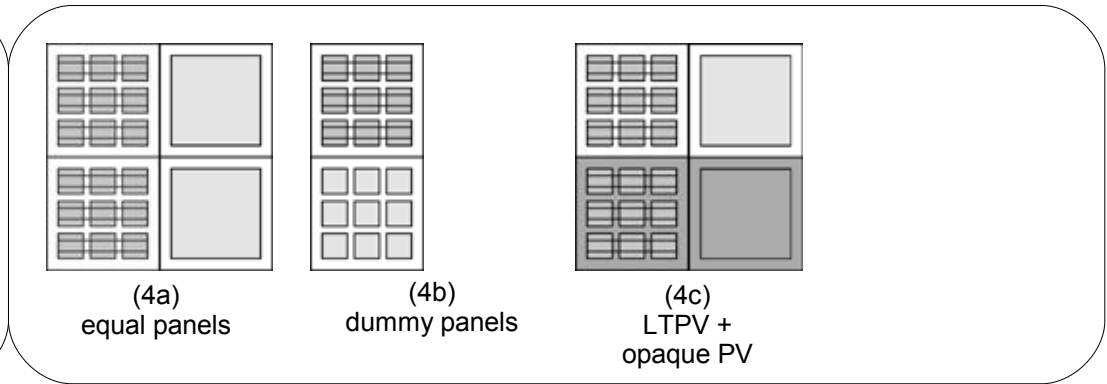
## Level 2 features



## Level 3 features



## Level 4 features



## Level 5 features

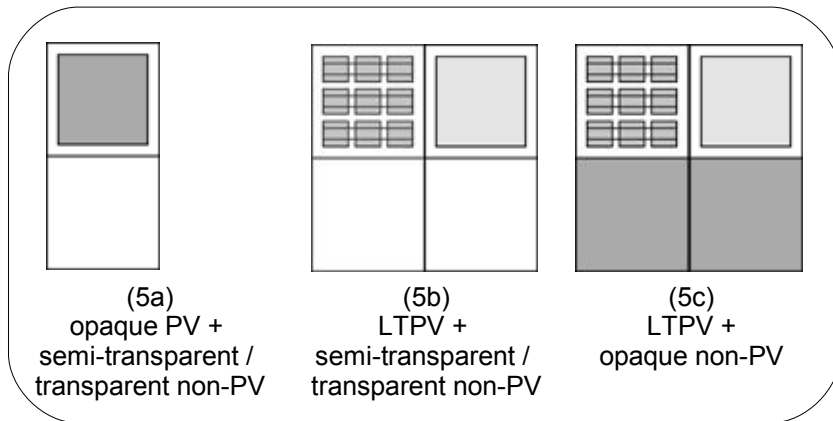


Fig.21 © Robert Baum

# Gymnasium Burgweinting

Regensburg, Germany, 2004  
architect: Regensburg Building Department, Tobias Ruf



Fig.22 © DBU

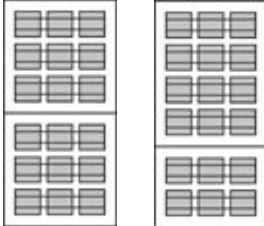
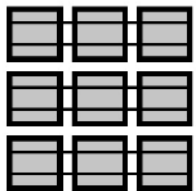


Fig.23 © Peter Ferstl



# Opera House

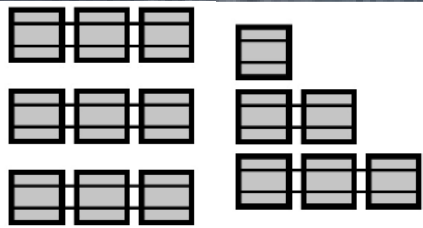
Oslo, Norway, 2007  
architect: Snøhetta



24

Fig.24 © Christopher Hagelund / The Telegraph

2



4

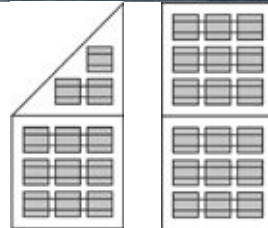


Fig.25 n.a.

# The Core at the Eden Project

Bodelua, Cornwall, UK, 2005  
architect: Nicholas Grimshaw & Partners



Fig.26 © copperconcept.org

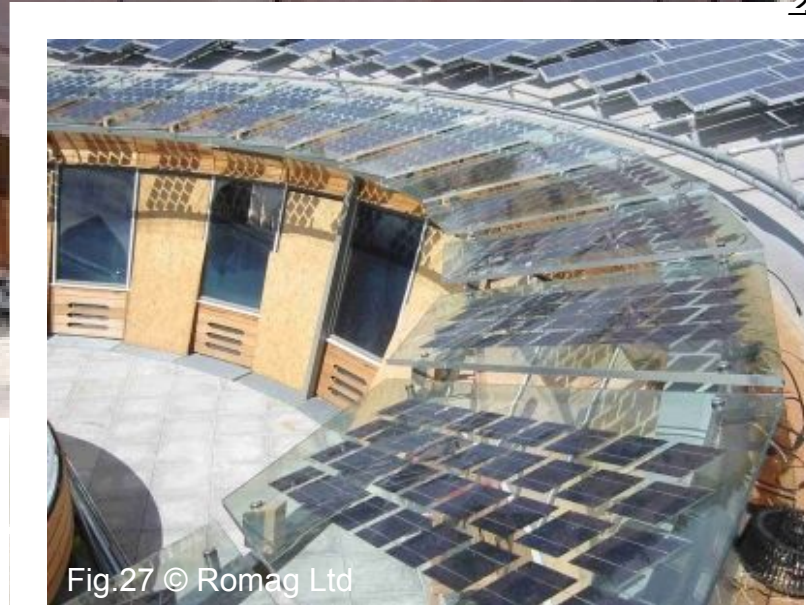
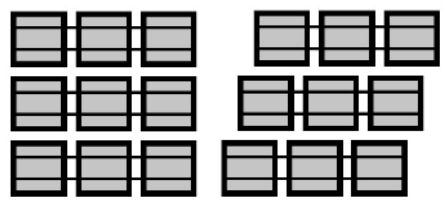


Fig.27 © Romag Ltd



# California Academy of Sciences building

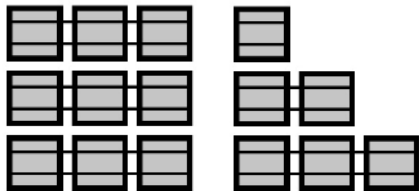
Golden Gate Park, San Francisco, USA, 2008

architect: Renzo Piano Building Workshop



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

2



4

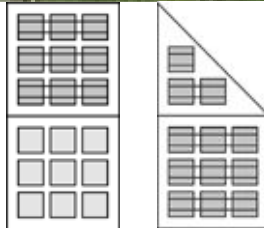


Fig.29 © glassmagazine.com

# Hotel Industrial (Hôtel Industriel)

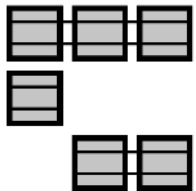
Paris, France, 2008

architects: Emmanuel Saadi, Jean-Louis Rey, François da Silva

COMPAGNIE PARISIENNE DE DISTRIBUTION D'ELECTRICITE

Fig.30 © ARCHIGUIDE

2



4

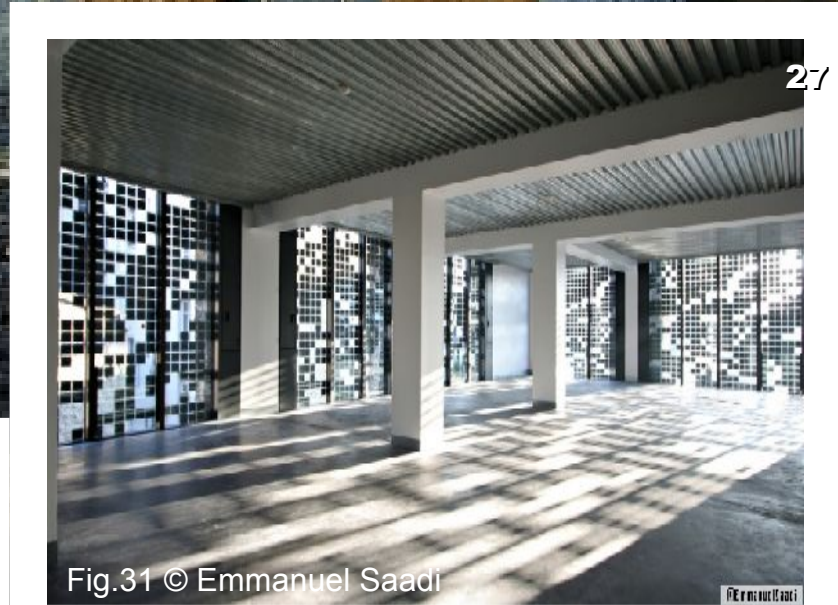
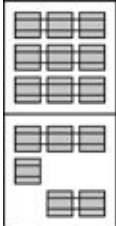


Fig.31 © Emmanuel Saadi

# Kindergarden

Dresden, Germany, 2003  
architects: Reiter & Rentzsch



Fig.32 © Lothar Sprenger / Reiter & Rentzsch

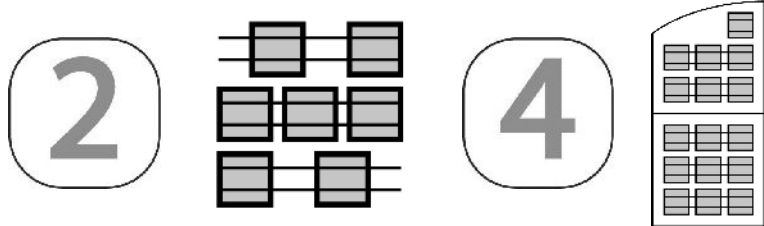


Fig.33 © Joe Morrissey / Atlantis Energy Systems

## 6. Case study

# Non-PV references

The Pyramids of Giza,  
Egypt, ~2560 BC~



Fig.34 © Ricardo Liberato

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



Fig.35 © Brian Tibbets

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



Fig.36 © Philipp Hienstorfer

# Non-PV references

The Pyramids of Giza, Egypt, ~2560 BC~



Fig.34 © Ricardo Liberato

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



Fig.35 © Brian Tibbets

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



Fig.36 © Philipp Hienstorfer

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



Fig.37 © Foster and Partners

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



Fig.38 © NLA

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

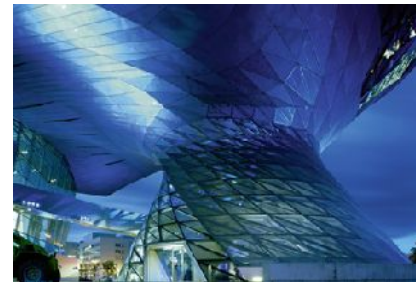


Fig.39 © Hélène Binet

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



Fig.40 © Hufton & Crow

\* 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)

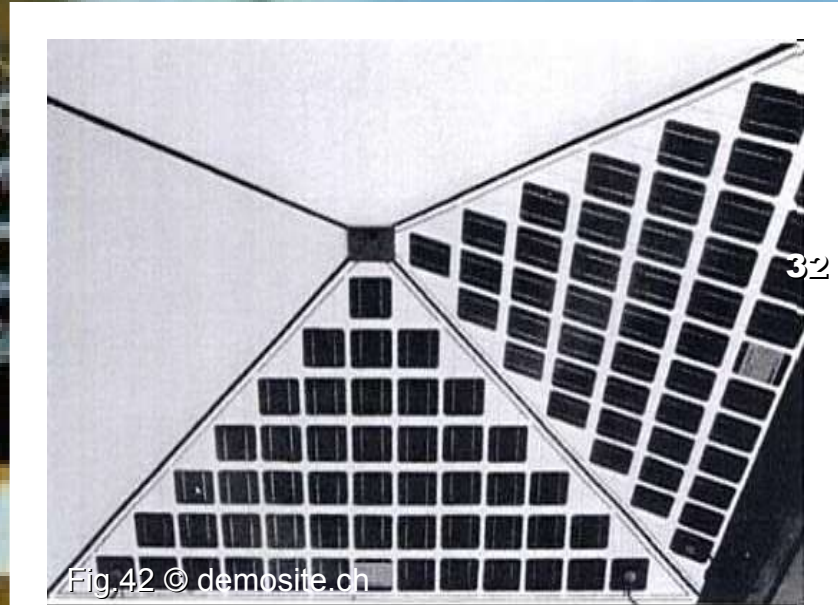
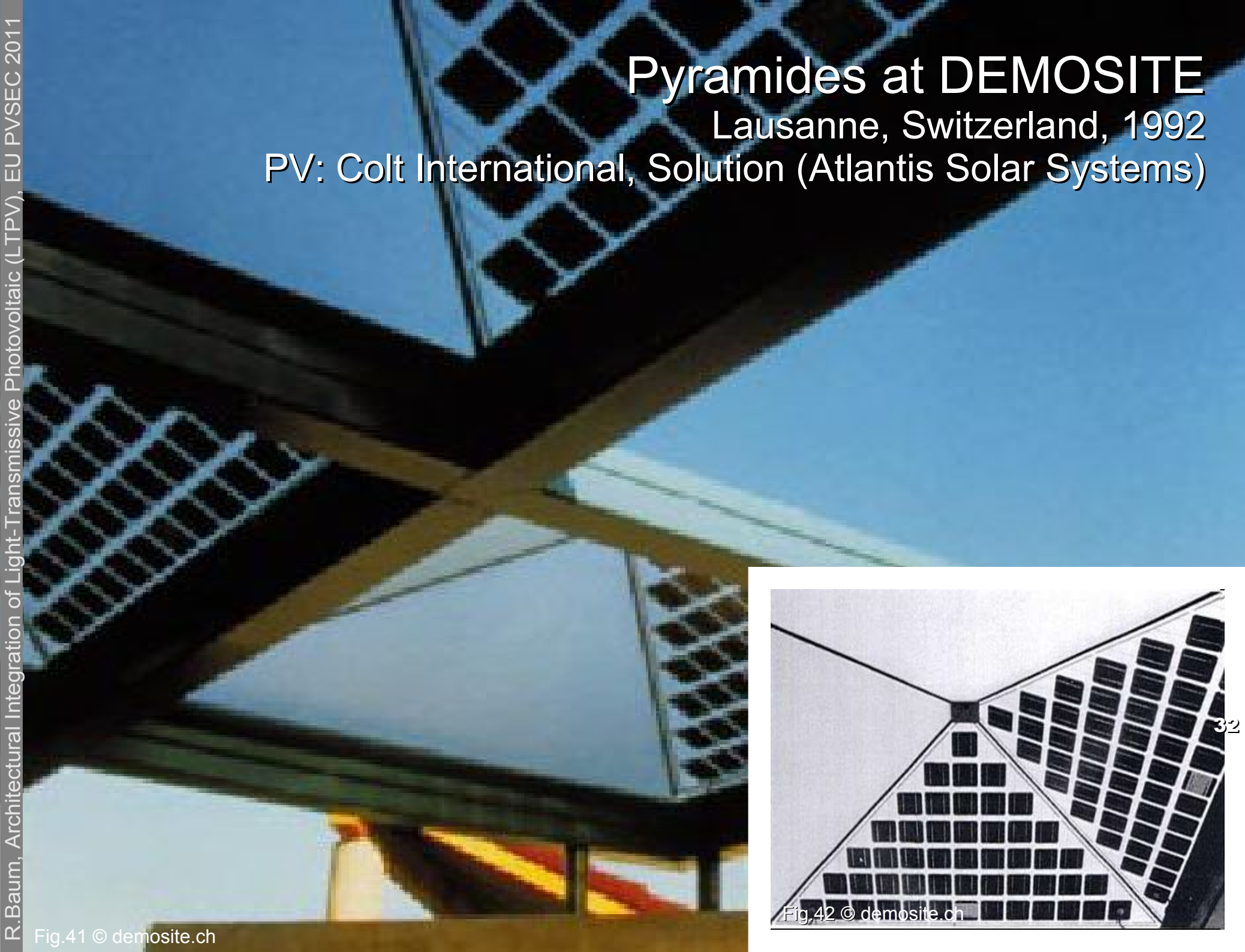


Fig.42 © demosite.ch

Fig.41 © demosite.ch

# Marrakech Ménara Airport

Marrakech, Morocco, 2008

architects: E2A Architecture

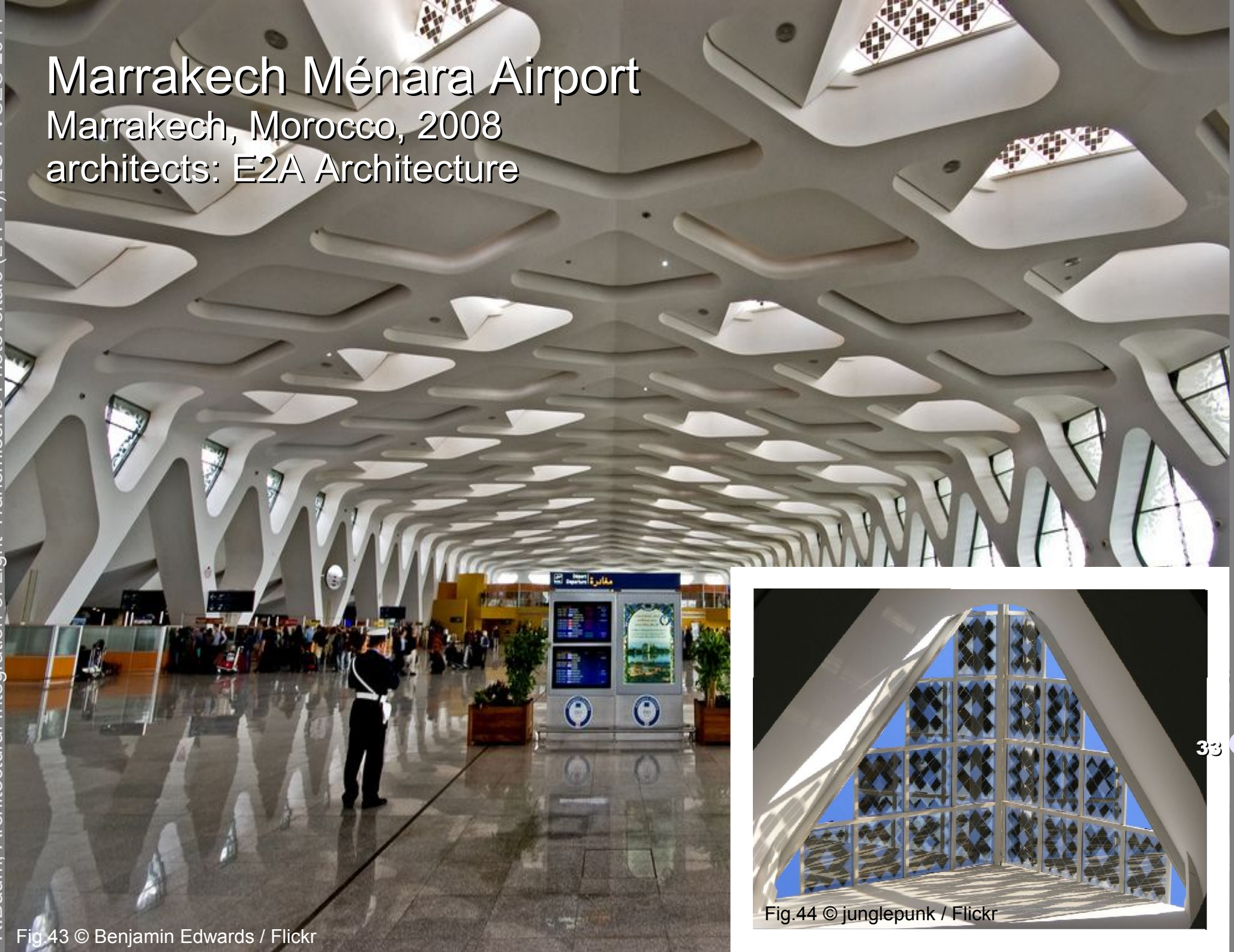


Fig.43 © Benjamin Edwards / Flickr



Fig.44 © junglepunk / Flickr

# Cité du Design

Saint-Étienne, Rhone-Alpes, France, 2010

architect: LIN Fin Geipel and Giulia Andri



Fig.45 © Jan Oliver Kunze / LIN



Fig.46 © EcoFriend

# House of Music Aalborg

Aalborg, Denmark, ~2012  
architect: Coop Himmelb(l)au

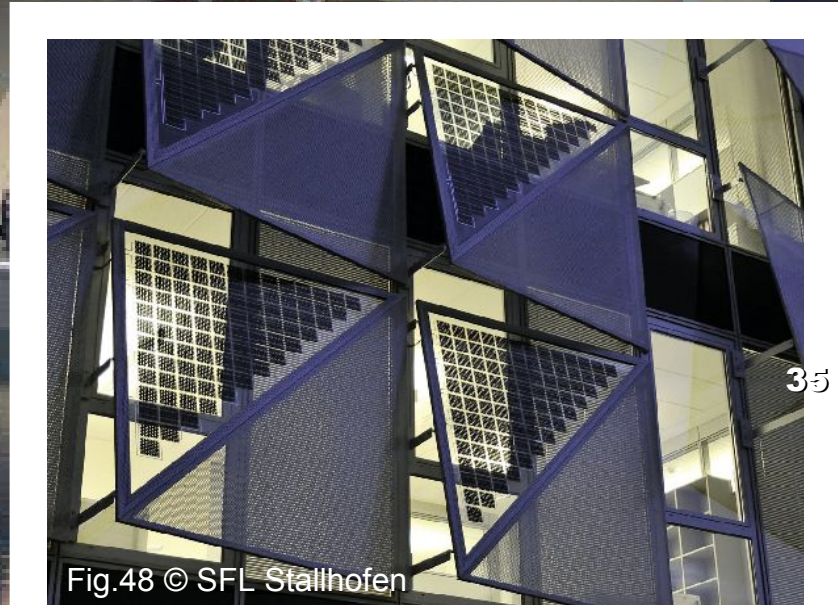


Fig.48 © SFL Stallhofen

Fig.47 © Coop Himmelb(l)au / Wallpaper

Pyramids at Demosite, Lausanne, Switzerland  
manufacturer: Colt / Solution, 1992

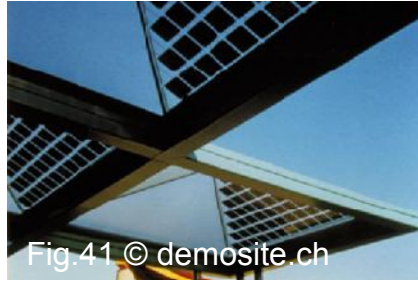


Fig.41 © demosite.ch

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



Fig.49 © John Bridges (redcrowstudio) / Flickr

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



Fig.50 © Jan Oliver Kunze / LIN

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

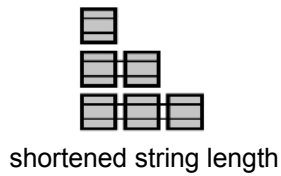


Fig.48 © S. Stallhofen

crystalline silicon cells

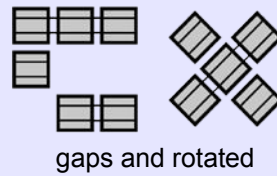
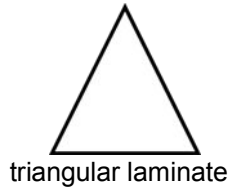
1

2



shortened string length

3



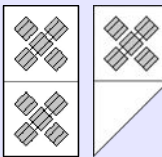
gaps and rotated



square laminate

4

triangular laminate

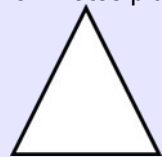


similar laminates plus glass

5

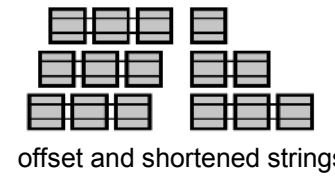


pyramidal canopy

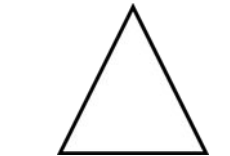


skylight

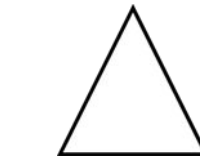
6



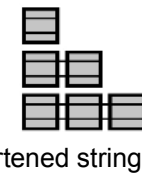
offset and shortened strings



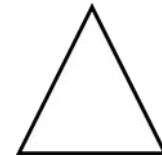
triangular laminate



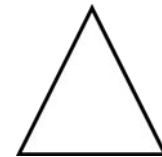
façade and flat roof



shortened string length



triangular laminate



sunshade (façade)

## 7. Conclusion

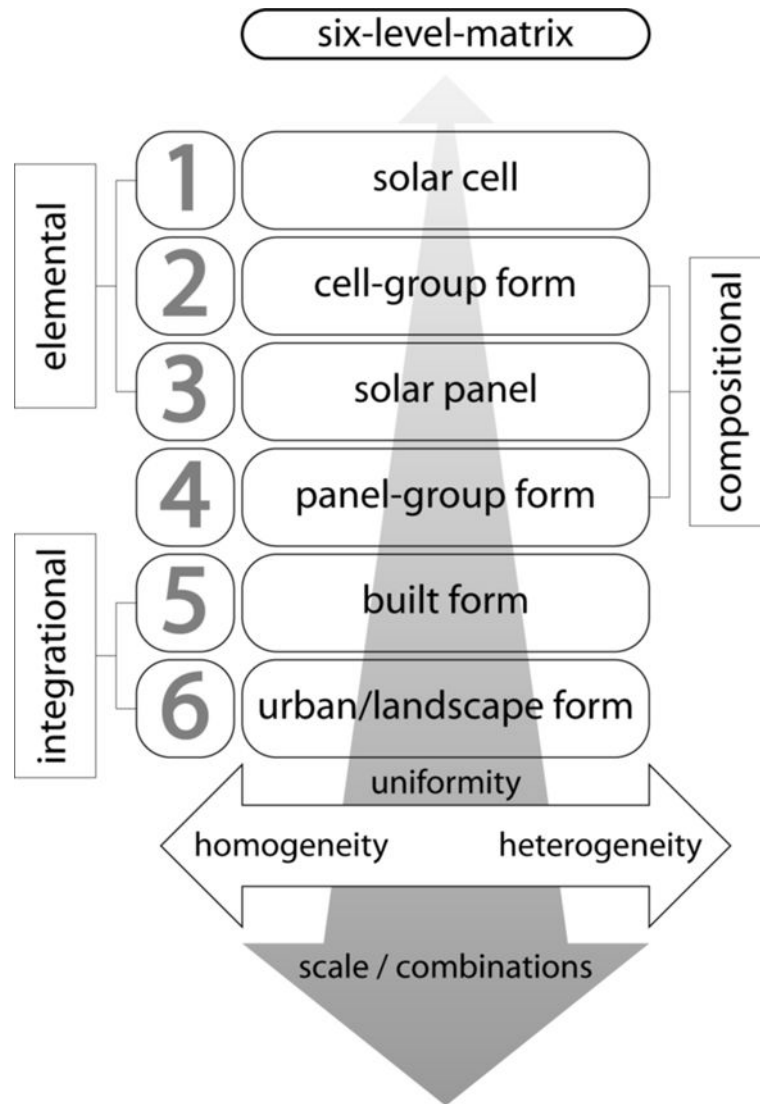


Fig.51 © Robert Baum

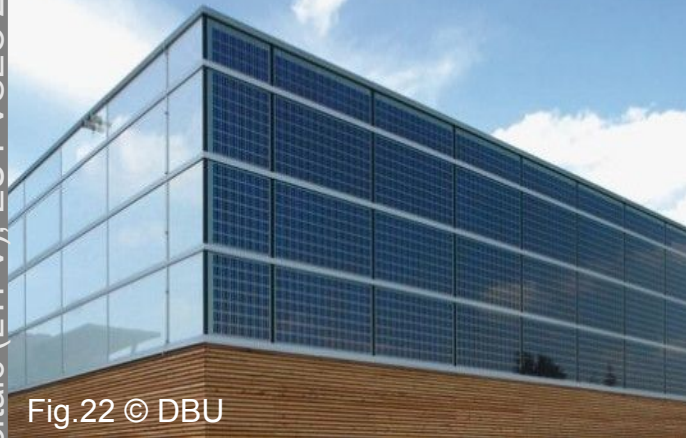


Fig.22 © DBU



Fig.24 © Christopher Hagelund



Fig.26 © copperconcept.org

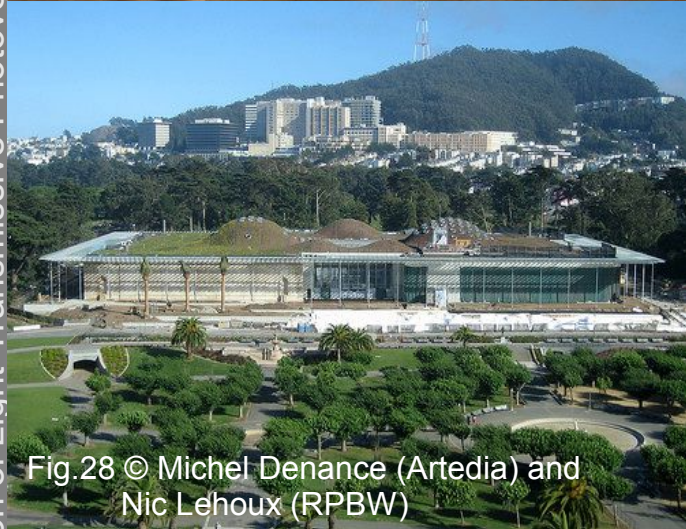


Fig.28 © Michel Denance (Arteria) and Nic Lehoux (RPBW)



Fig.30 © ARCHIGUIDE



Fig.32 © Lothar Sprenger / Reiter & Rentsch



Fig.41 © demosite.ch



Fig.43 © Benjamin Edwards / Flickr



Fig.45 © Jan Oliver Kunze / LIN



*Thank you for your attention*

Robert BAUM

- Fig.1 © Allmann Sattler Wappner Architekten, München - Source: [http://www.baunetzwissen.de/objektartikel/Solar\\_Paul-Horn-Arena-in-Tuebingen\\_72834.html?img=2&layout=galerie](http://www.baunetzwissen.de/objektartikel/Solar_Paul-Horn-Arena-in-Tuebingen_72834.html?img=2&layout=galerie) (18.01.2011)
- Fig.2 © Scheuten Solar - Source: <http://www.scheutensolar.de/references/jaume-universitat> (18.01.2011)
- Fig.3 © Sunways AG - Source: <http://www.sunways.eu/en/products/solar-cells/standard-cells/> (18.01.2011)
- Fig.4 © Sunways AG (2003). Sunways Solar Cell transparent monokristallin (100 x 100 mm) - Source: [http://www.solar-integration.de/uploads/tx\\_sprojekte/ohjrlplzdw/sw\\_transparent\\_cell.pdf](http://www.solar-integration.de/uploads/tx_sprojekte/ohjrlplzdw/sw_transparent_cell.pdf) (08.02.2011)
- Fig.5 © Sunways AG - Source: <http://www.sunways.eu/en/products/solar-cells/standard-cells/> (18.01.2011)
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