

ARCHITECTURAL INTEGRATION OF LIGHT-TRANSMISSIVE PHOTOVOLTAIC SYSTEMS

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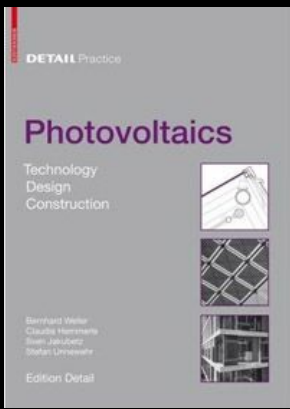


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1. Introduction
2. Translucency and transparency
3. Analysis of crystalline silicon PV
4. Analysis of thin-film PV
5. Analysis of PV independent variations
6. Discussion and outlook

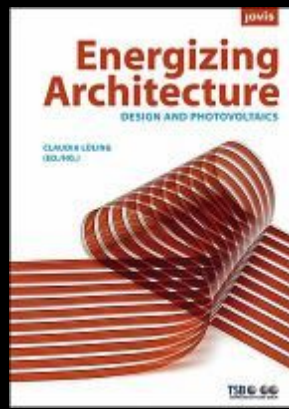
1. Introduction



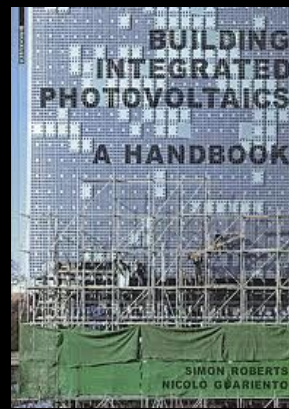
Weller, et al. 2010



Guzowski 2010



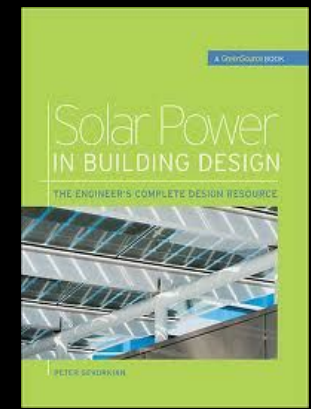
Lüling 2009



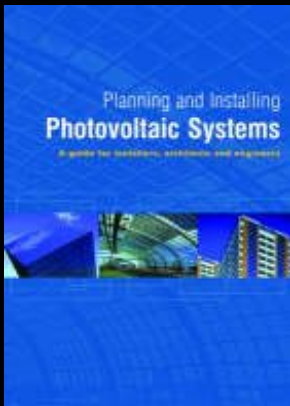
Roberts & Guariento 2009



Scognamiglio 2009



Gevorkian 2007



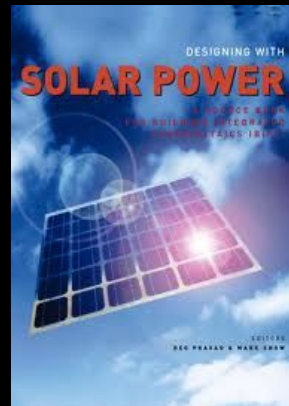
German Solar Energy Society (DGS), 2005



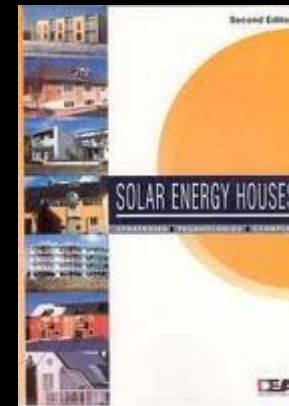
Nelli 2007



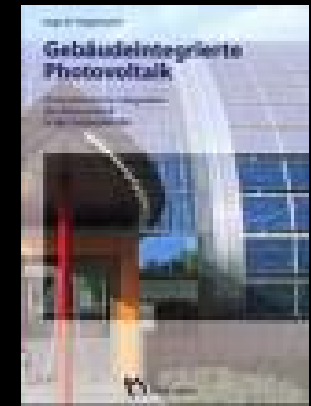
Nelli 2006



Prasad & Snow 2005



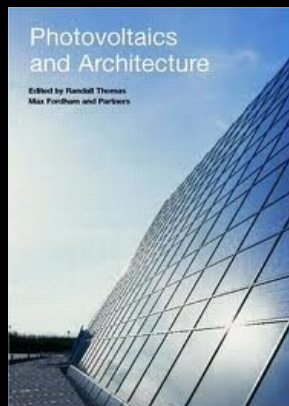
Hestnes 2003



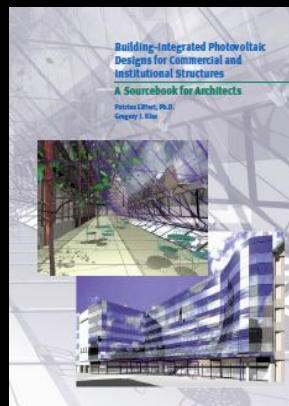
Hagemann 2002



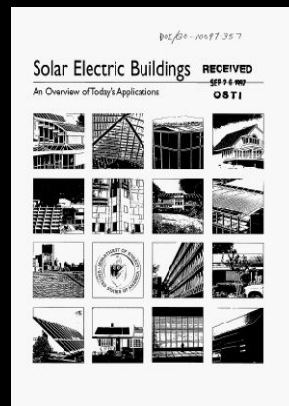
Rexroth 2001



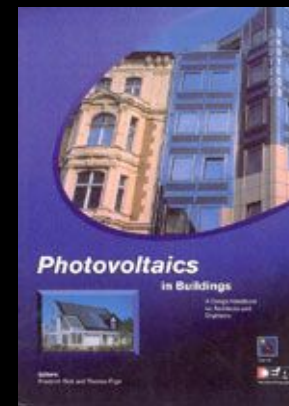
Thomas 2001



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. Translucency and transparency

PV technologies

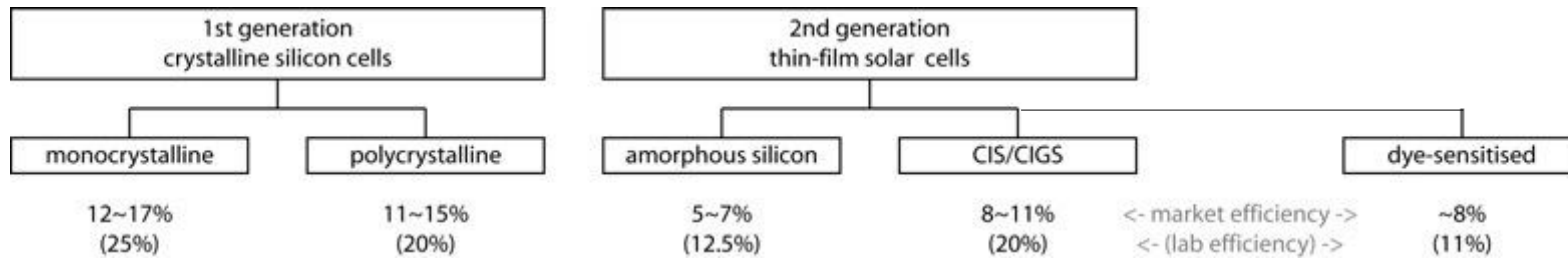


Fig.3 © Sunways Fig.5 © Sunways

Fig.4 © Sunways



Fig.6 © SCHOTT Solar

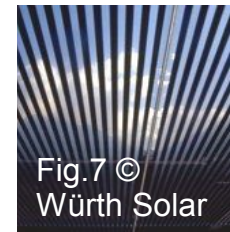


Fig.7 © Würth Solar

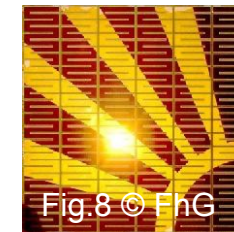


Fig.8 © FhG

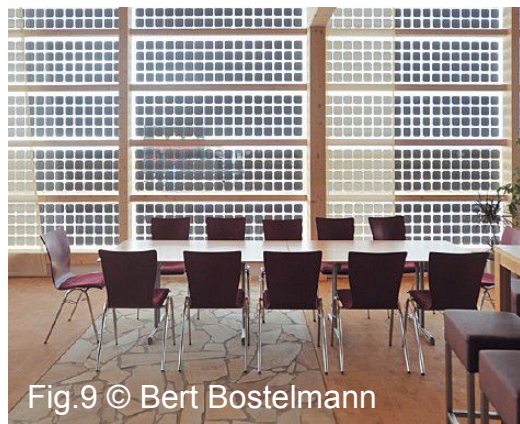


Fig.9 © Bert Bostelmann



Fig.10 © RWE Schott Solar



Fig.11 © Richard Glover

'light-through'



'see-through'



Attribute 1: Comparison of technologies

A

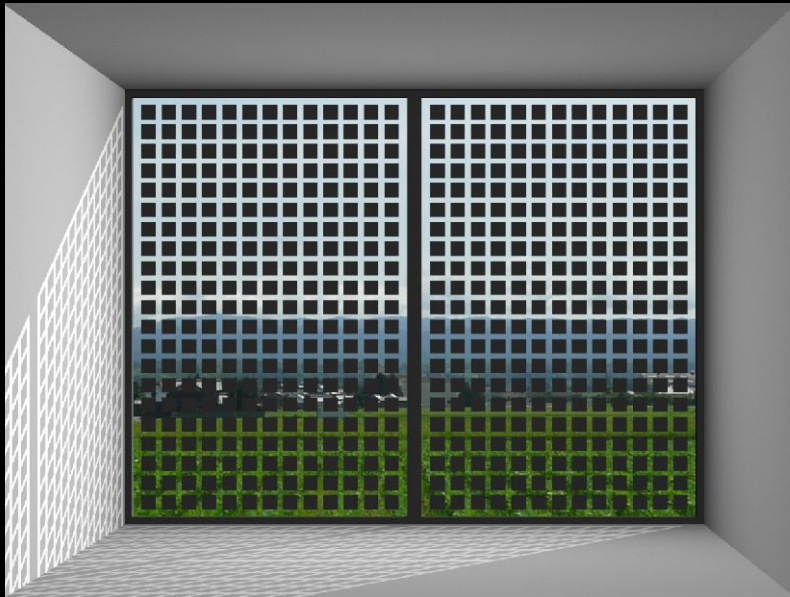


A no PV
100% transparency

B crystalline silicon
~50% transparency

C thin-film
~50% transparency

B



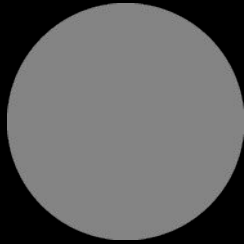
C



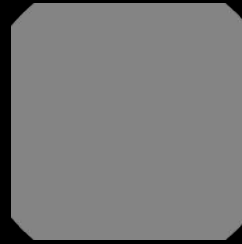
3. Analysis of crystalline silicon PV

Attribute 2: Shapes of crystalline silicon cells

round



pseudo-square

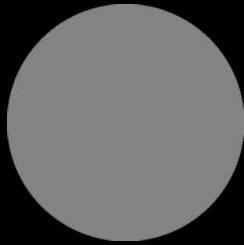


square



Attribute 2: Shapes of crystalline silicon cells

round



pseudo-square

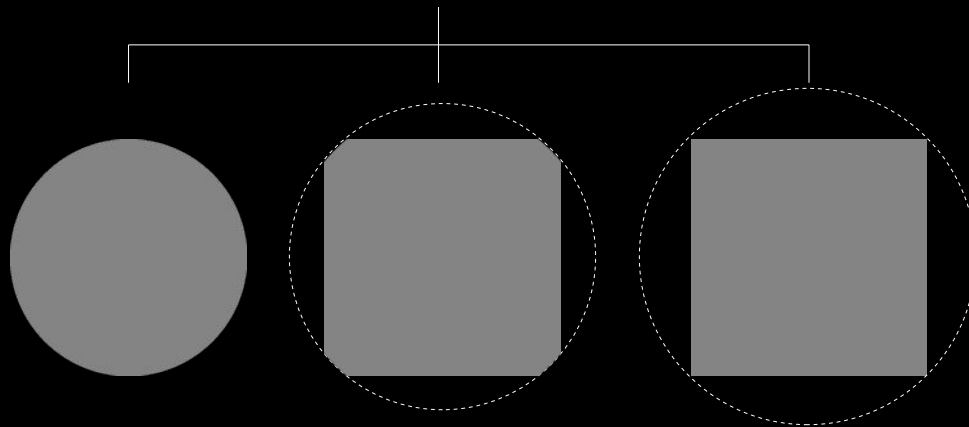


square



12 ●

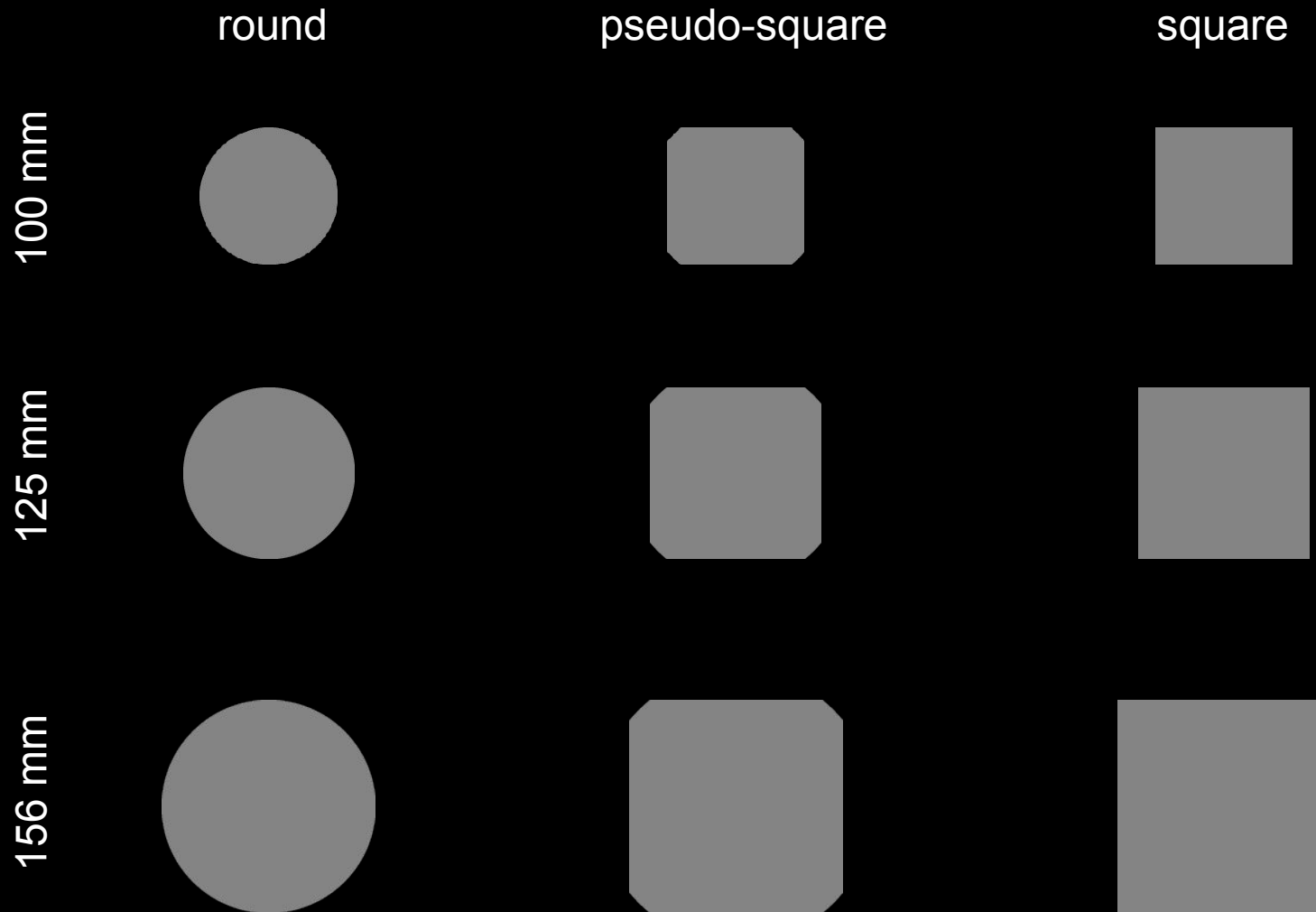
monocrystalline silicon cells



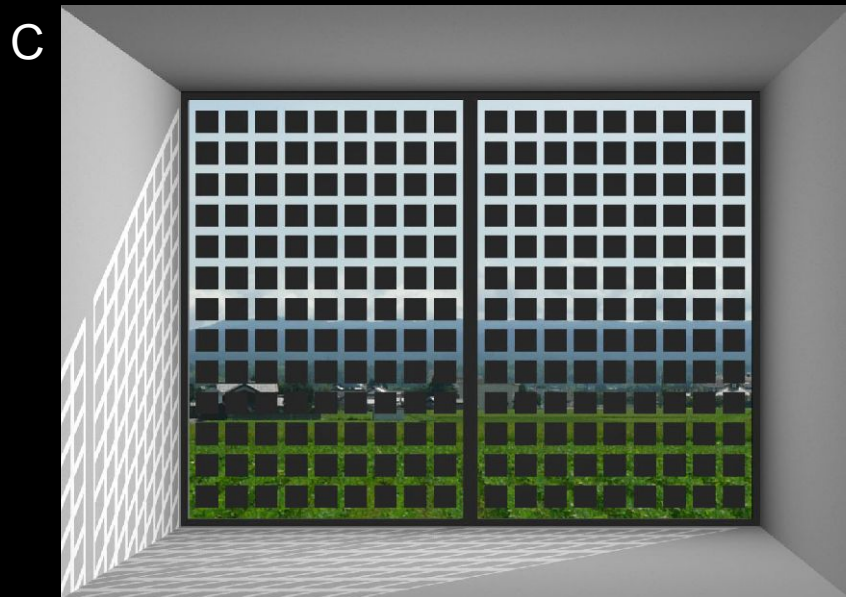
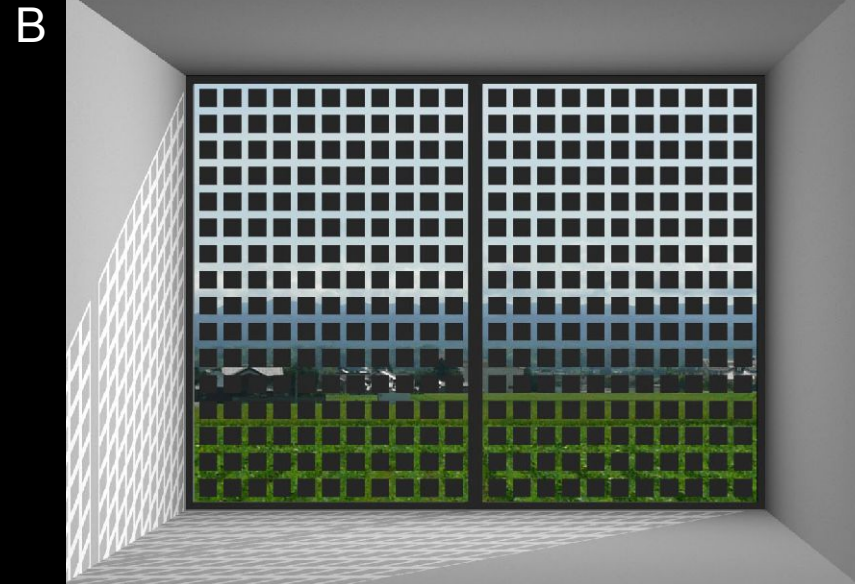
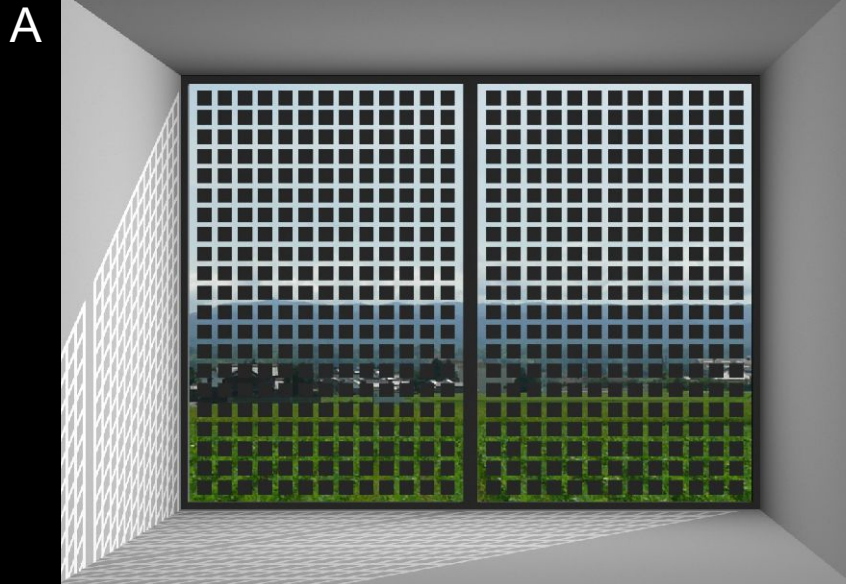
polycrystalline silicon cells



Attribute 3: Sizes of crystalline silicon cells



Attribute 4: Square crystalline silicon cells



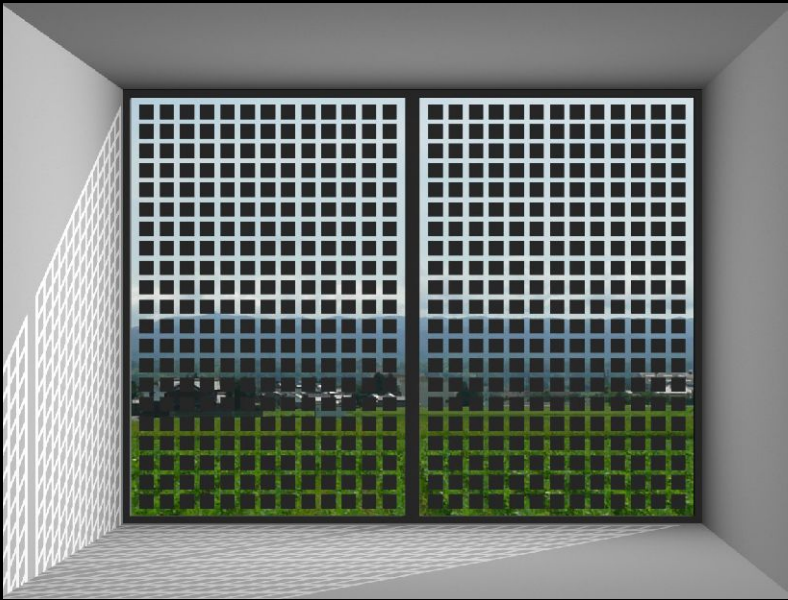
A 546 square cells
100x100 mm²
hor 40 mm / ver 35 mm spacing

B 352 square cells
125x125 mm²
hor 45 mm / ver 55 mm spacing

C 234 square cells
156x156 mm²
hor 50 mm / ver 60 mm spacing

Attribute 4: Square and round crystalline silicon cells

A



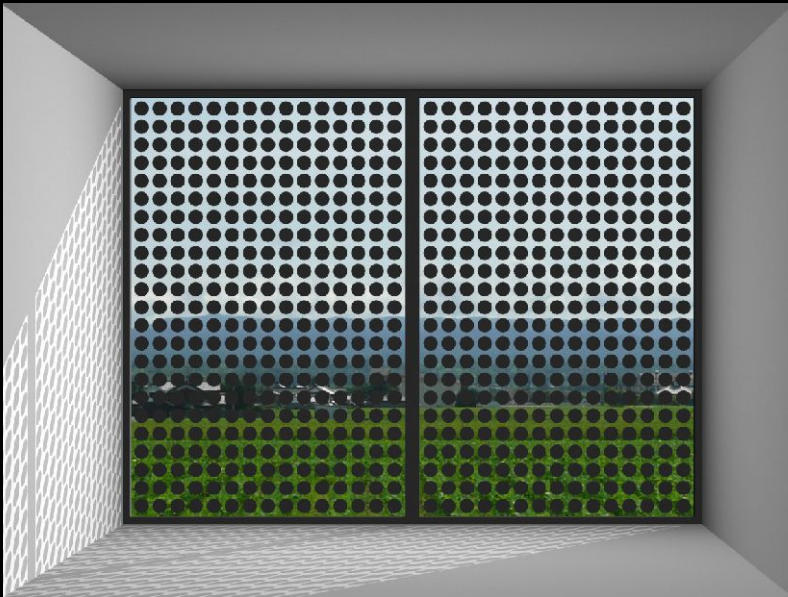
A 546 square cells
100x100 mm²
hor 40 mm / ver 35 mm spacing

D 690 round cells
Ø100 mm
hor 25 mm / ver 25 mm spacing

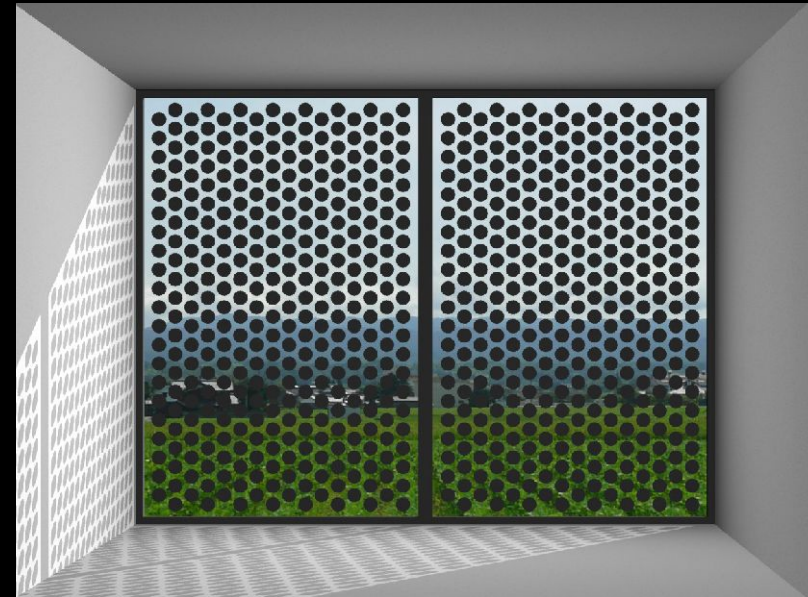
E 688 round cells
Ø100 mm
oblique 30 mm spacing

15 ●

D



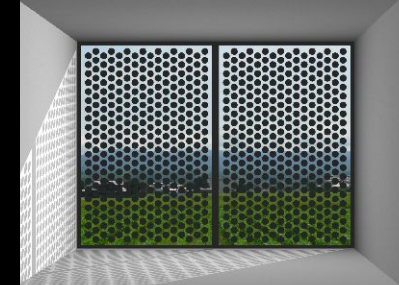
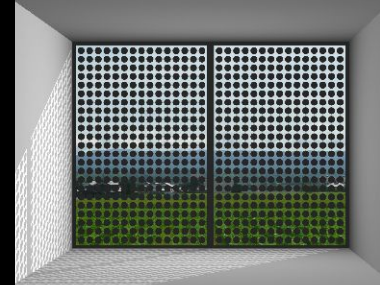
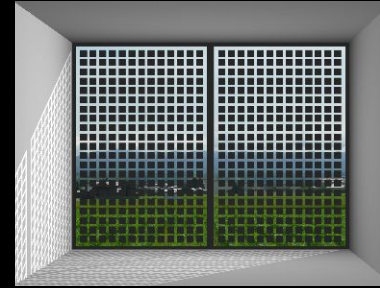
E





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

Fig.15 © DBU



Tsukuba OSL
Tsukuba, Japan, 2001
architect: Nihon Sekkei

Fig.16 © Kenji Otani



Brundtland Centre
Toftlund, Denmark, 1995
architect: KHR AS arkitekter

Fig.17 n.a.

Attribute 5: Variation of wider cell spacing in one direction



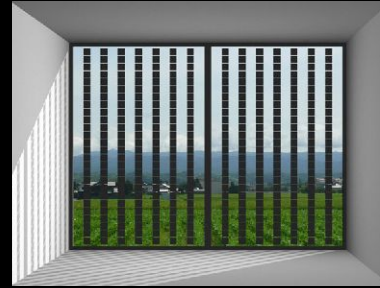
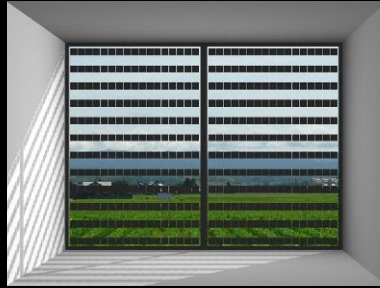


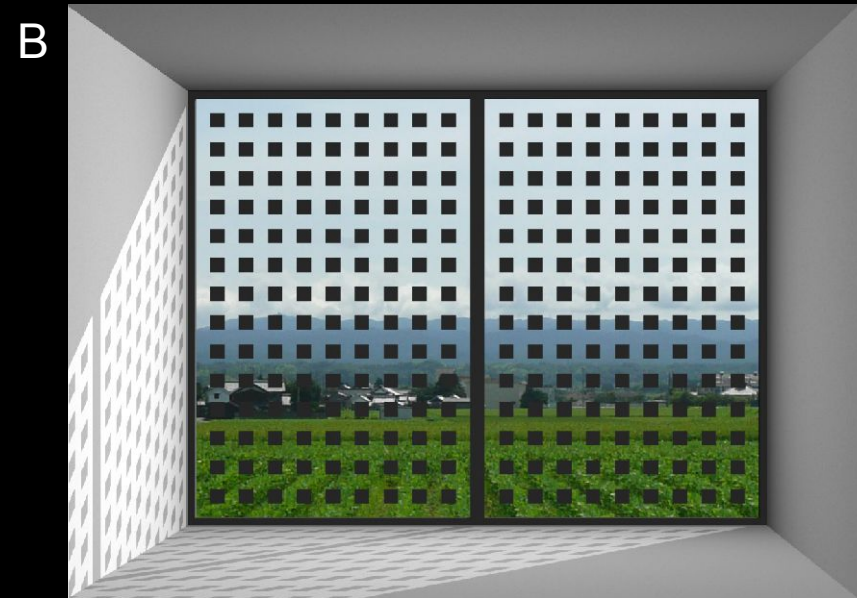
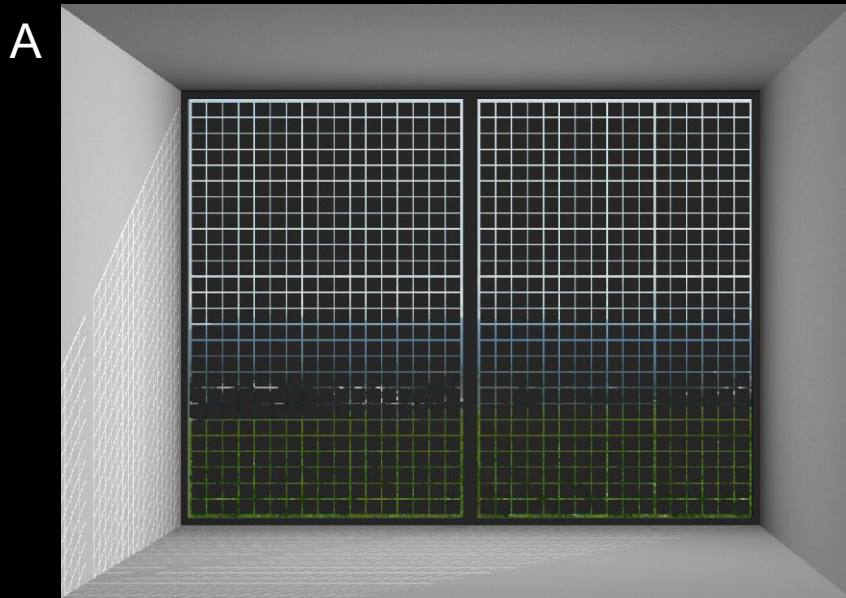
Fig.18 © Christopher Hagelund / The Telegraph

Opera House
Oslo, Norway, 2007
architect: Snøhetta

Fig.19 © Robert Baum

Daito Bunka University, Itabashi, Bldg.3
Itabashi-ku, Tokyo, Japan, 2003
architect: Ben Nakamura and
Yamamoto Hori Architects

Attribute 6: Variation of equal cell spacing in two directions



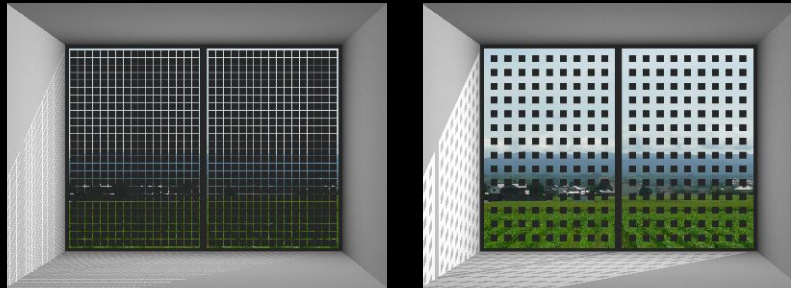
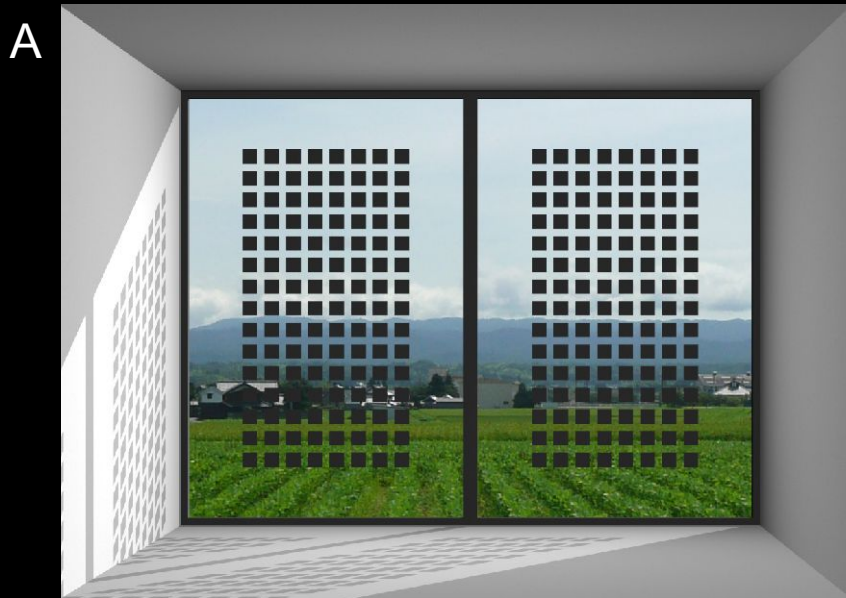


Fig.20 © Sapa Building System

OLV Hospital
Aalst, Belgium, 2009
architect: VK STUDIO

Attribute 7: Centre / frame variation



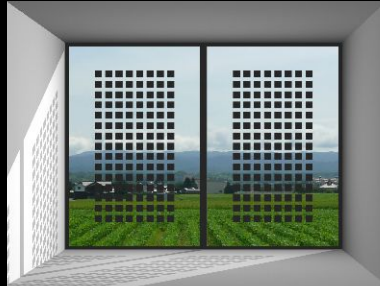


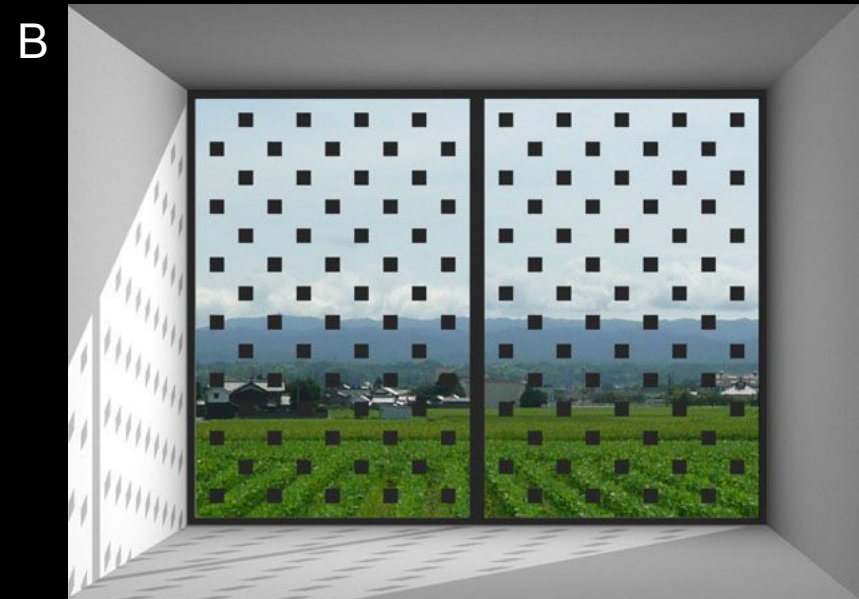
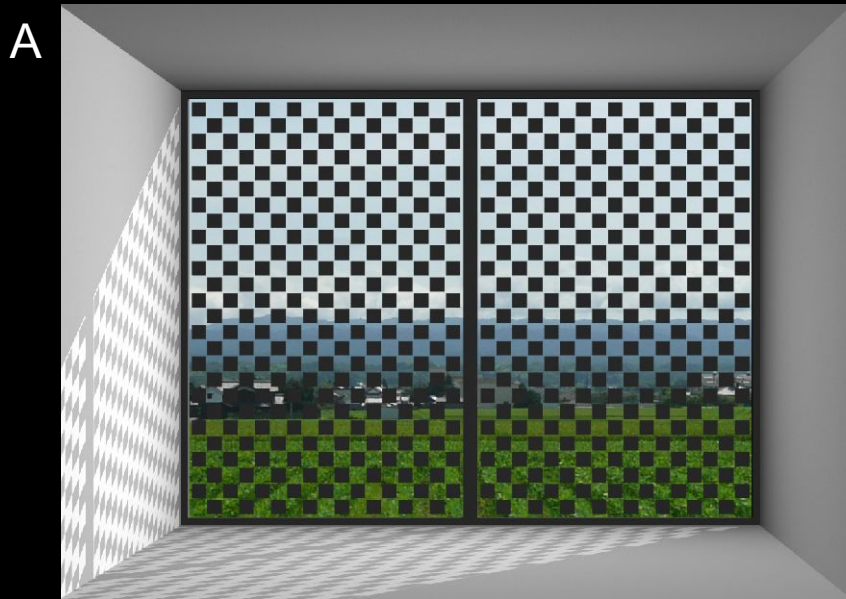
Fig.21 © Tegnstuen Entasis

Recreation centre Vestervang
Copenhagen, Denmark, 2002
architect: Tegnstuen Entasis

Fig.22 © Simone Giostra & Partners/ Arup

GreenPix – Zero Energy Media Wall
Beijing, China, 2008
architect: Simone Giostra & Partners

Attribute 8: Chequerboard



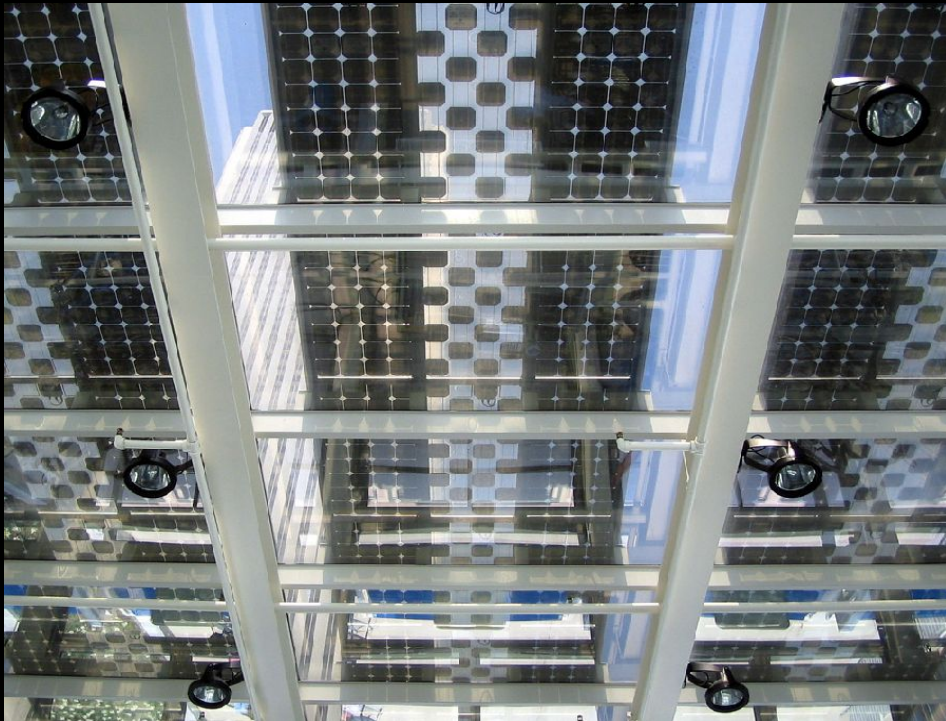
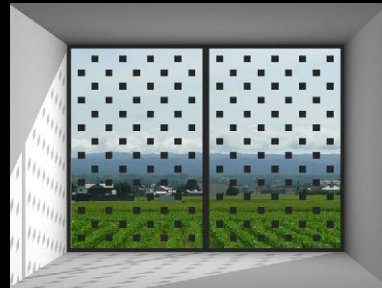
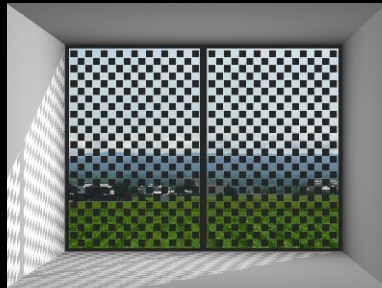


Fig.23 © Nathan Kirkman & Robert Murphy

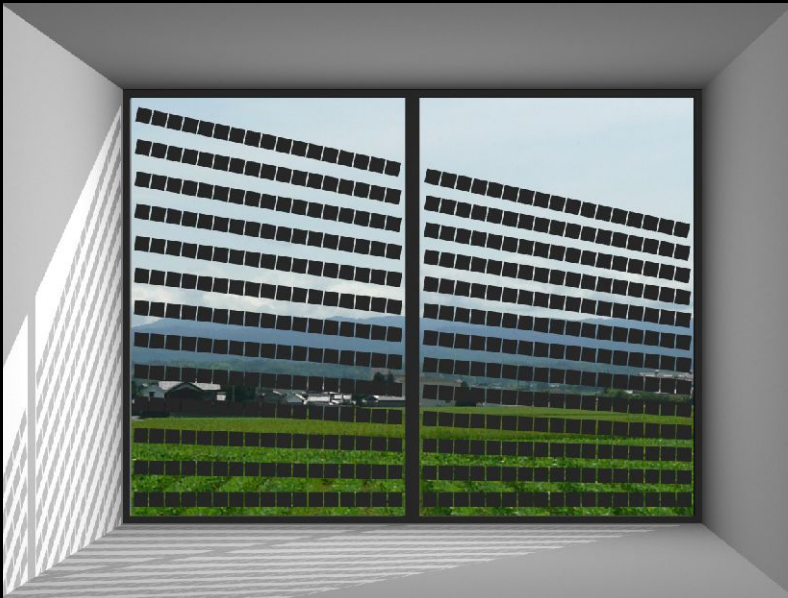
Fig.24 © Legat Architects

McDonald's Cycle Center
Chicago IL, USA, 2004
architect: Muller & Muller

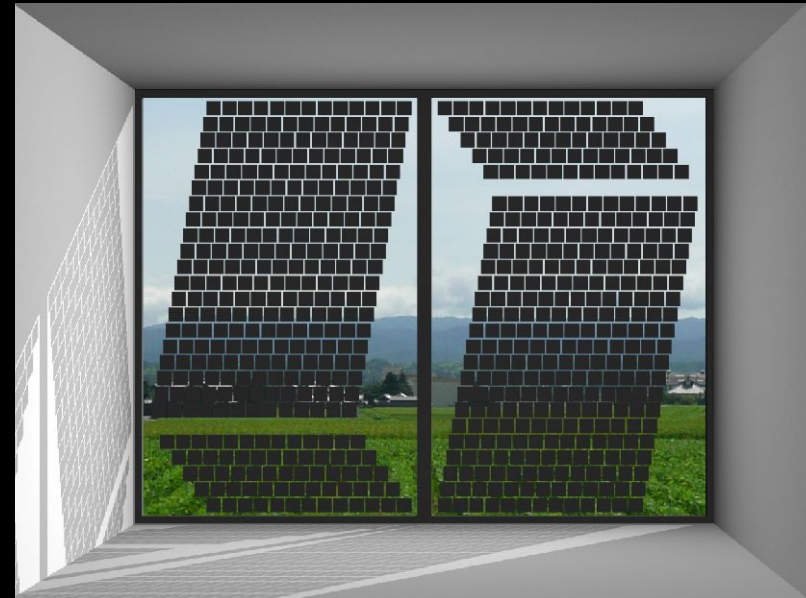
Kankakee Community College
Kankakee IL, USA, 2007
architect: Legat Architects

Attribute 9: String variation non-rectangular panels

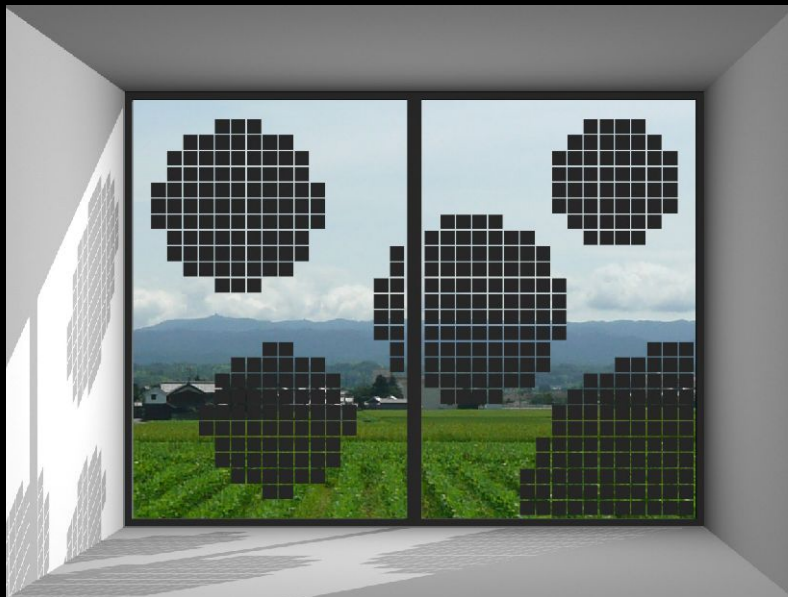
A



B



C



A radiating strings

B offset strings

C differing string lengths



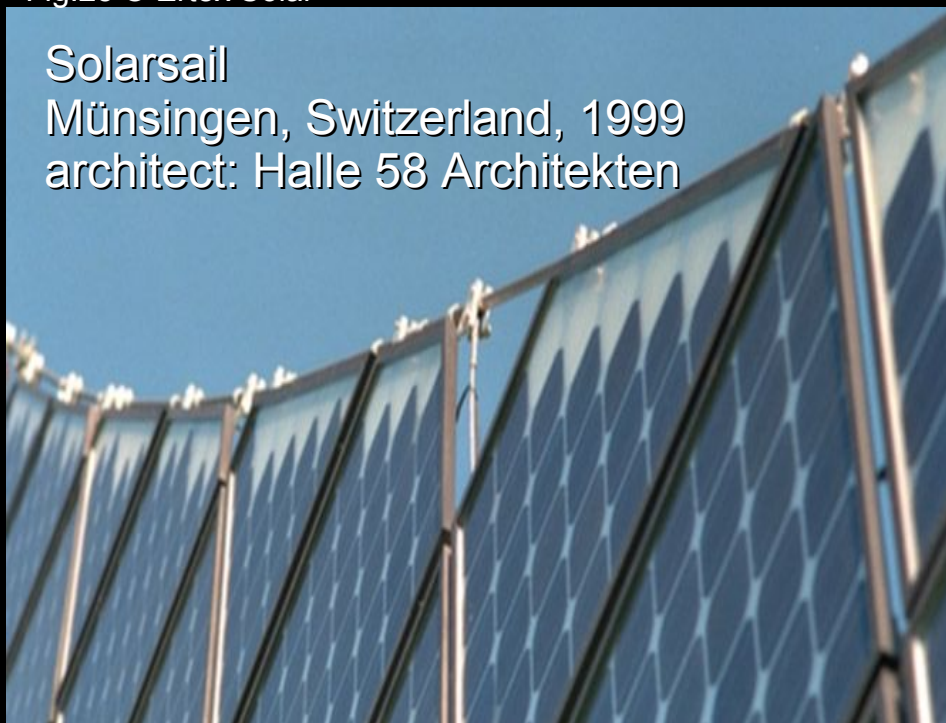
"La Vaguada" shopping mall
 Madrid, Spain, 1983/2003 bldg, 2007 PV
 architect: José Á. Rodrigo, César
 Manrique (1983), Chapman Taylor
 Espana (2003)

Fig.25 © Ertex Solar



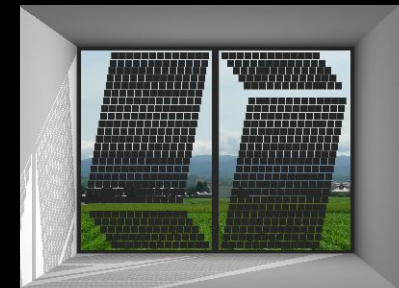
The Core at the Eden Project
 Bodelua, Cornwall, UK, 2005
 architect: Nicholas Grimshaw & Partners

Fig.26 © Romag Ltd



Solarsail
 Münsingen, Switzerland, 1999
 architect: Halle 58 Architekten

Fig.27 © Halle 58 Architekten



Attribute 10: Non-uniform gaps



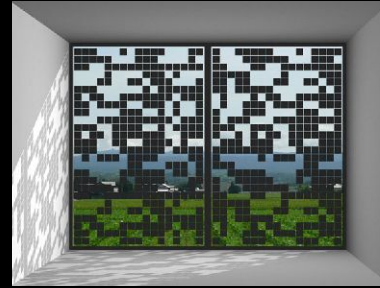
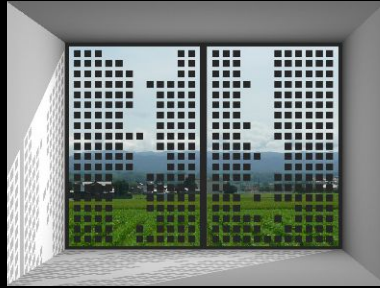


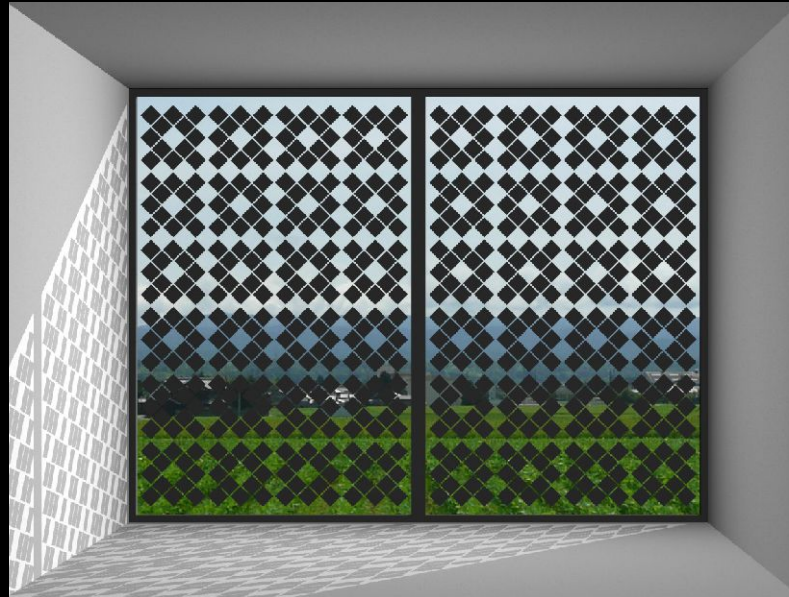
Fig.28 © Walter Francl

Fig.29 © ARCHIGUIDE

True North / Lux Nova
 Vancouver, BC, Canada, 2008
 artist: Sarah Hall
 architects: Clive Grout, Walter Francl

Hotel Industrial (Hôtel Industriel)
 Paris, France, 2008
 architects: Emmanuel Saadi, Jean-Louis
 Rey, François da Silva

Attribute 11: Rotation of whole pattern



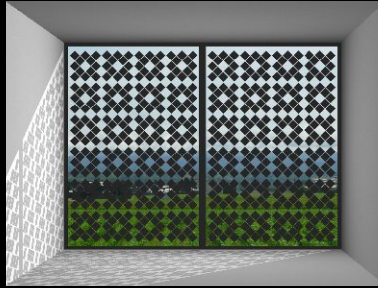
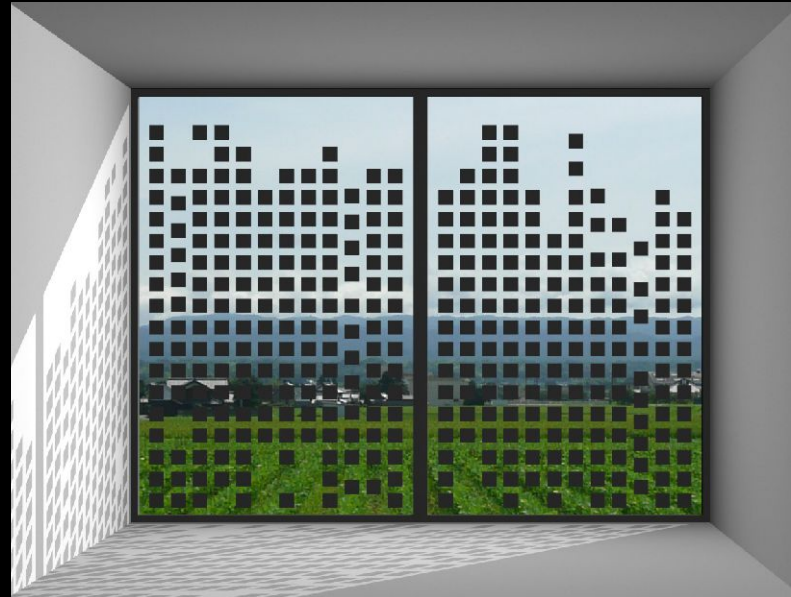


Fig.30 © Benjamin Edwards / Flickr

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

Attribute 12: Varied cell distance within strings



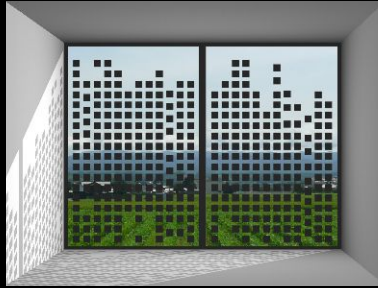


Fig.31 © Joe Morrissey / Atlantis Energy Systems

Kindergarden
Dresden, Germany, 2003
architects: Reiter & Rentzsch

4. Analysis of thin-film PV

Attribute 13: Differently sized thin-film sheets

A



B



C



A one sheet per laminate

B four sheets per laminate

C nine sheets per laminate

Kanazawa Bus Terminal
Kanazawa, Ishikawa, Japan, 2005
architect: TODEC Inc., Taiyo Kogyo Corp.



Fig.32 © Taiyo Kogyo corporation

Kulturhaus Milbertshofen
Munich, Germany, 2005
architect: RPM-Architekten



Fig.33 © Bettina Großhardt

Würth Holding Headquarters
Chur, Switzerland, 2002
architect: D. Jüngling + A. Hagmann



Fig.34 © Würth Solar

Houses of the Future
Sydney, Australia, 2004
architect: Innovarchi



Fig.11 © Richard Glover

5. Analysis of PV independent variations



Kulturhaus Milbertshofen
Munich, Germany, 2005
architect: RPM-Architekten

Fig.35 © Torsten Masseck



Fujipream Kohto Factory
Hyogo Prefecture, Japan, 2003
pv manufacturer: Fujipream

Fig.36 © Fujipream



Sun Monument "Greeting to the Sun"
Zadar, Croatia, 2008
architect: Nikola Bašić

Fig.37 Joadl / Wikimedia



Fujipream Kohto Factory
Hyogo Prefecture, Japan, 2003
pv manufacturer: Fujipream

Fig.38 VidurSolar

6. Discussion and outlook

Design parameters for crystalline silicon and thin-film PV laminates

Crystalline silicon		
No.	Design parameter	Comment
1	PV technology	c-si, mc-si
2	Cell shape	Attr.2
3	Cell size	Attr.3, 4
4	Cell colour	limited range
5a	Cell spacing between strings	Attr.5, 6, 8
5b	Cell spacing within a string	Attr. 6, 8, 12
6	String length	Attr.9:C, 10-12
7	String position	Attr.4, 7, 9
8	String orientation	Attr.9:A, 11
9	non-PV elements	dummy cells, screen prints, coloured interlayers, art
10	laminates	glass or film, bent glass

Thin-film		
No.	Design parameter	Comment
1	PV technology	a-si, CIS/CIGS, DSC
2	Sheet shape	usually rectangular
3	Sheet size	manufacturer dependent
4	Sheet colour	limited range
5	'see-through' pattern	manufacturer dependent
6	'see-through' transparency	manufacturer dependent
7	Sheet position	variable
8	Sheet orientation	variable
9	non-PV elements	dummy cells, screen prints, coloured interlayers, art
10	laminates	glass or film, bent glass

*“This is not a dream, because
technology plus poetry equals architecture [...].
All architects [...] have to do is make it happen.”*

(Wigginton, 1996, p.238)

Thank you for your attention

Robert BAUM

Figure List

- 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 (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_siprojekte/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)
- Fig.6 © SCHOTT Solar AG (2010). ASI Glass, Integrated Architecture Powered by the Sun - Source: http://www.schottsolar.com/no_cache/global/sales-services/downloads/brochure-downloads/?cid=1034&did=12&sechash=655a5839 (11.08.2010)
- Fig.7 © Würth Solar - Source: http://www.baunetzwissen.de/objektartikel/Solar_Verwaltungsgebäude-der-Wuerth-Holding-in-Chur_CH_72798.html (18.01.2011)
- Fig.8 © FhG - Source: http://www.colorsol.de/fhg/Images/Solarzelle_tcm391-70361.png (14.02.2010)
- Fig.9 © Bert Bostelmann, Frankfurt - Source: http://www.baunetzwissen.de/objektartikel/Solar-Buerogebäude-in-Woerrstadt_665903.html (18.01.2011)
- Fig.10 © RWE Schott Solar - Source: http://www2.epia.org/images/photos/phoID_532.jpg (18.01.2011)
- Fig.11 © Richard Glover - Source: <http://www.innovarchi.com/innovarchi.html> (05.09.2011)
- Fig.12 © BSW-Solar/Langrock - Source: <http://www.solarwirtschaft.de/medienvetreter/fotoarchiv.html> (18.01.2011)
- Fig.13 © Kaneka Corporation - Source: http://www.pv.kaneka.co.jp/products_s/index.html (18.01.2011)
- Fig.14 © BSW-Solar/Sunways - Source: <http://www.solarwirtschaft.de/medienvetreter/fotoarchiv.html> (18.01.2011)
- Fig.15 © Deutsche Bundesstiftung Umwelt (DBU), Osnabrück - Source: http://www.baunetzwissen.de/objektartikel/Solar_Turnhalle-Burgweinting-in-Regensburg_72832.html (05.09.2011)
- Fig.16 © Kenji Otani - Source: <http://www.energyelec.aist.go.jp/~k.otani/en/doc/oslbipv-e.htm> (09.06.2011)
- Fig.17 n.a. - Source: <http://svasist.blogspot.com/2009/03/denmark-brundtland-centre.html> (23.09.2011)
- Fig.18 © Christopher Hagelund / The Telegraph - Source: <http://www.telegraph.co.uk/news/picturegalleries/uknews/3684926/The-shortlist-for-the-Brit-Insurance-Designs-of-the-Year-2009-competition.html?image=19> (05.09.2011)
- Fig.19 © Robert Baum
- Fig.20 © Sapa Building System - Source: <http://www.sapagroup.com/en/Company-sites/Sapa-Building-system-Group/Projects/Healthcare/OLV-hospital-Aalst/> (16.06.2011)
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