

# Alternative solar cell patterns for light-transmissive photovoltaic panels

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## Abstract

This paper focuses on emerging and alternative heterogeneous patterns for light-transmissive photovoltaic (LTPV) panels. It presents some architectural, parametric design proposals. **Study Background** With the kind of PV panels called 'light-through', translucency is achieved by spacing opaque solar cells, so that light can penetrate through the resulting gaps. **Aim** To improve the versatility of light-transmissive PV panels used for architectural integration into building skins (BIPV). **Methodology** First, the spacing of the solar cells in cell-strings can have more than one distance. Second, interconnection between neighbouring cell-strings doesn't require the cells to lie exactly side by side, an offset between cell-strings is possible. **Innovation** In combining the two parameters, tilted and wave-like solar cell patterns become possible. This enhances the options for individual designs, smoother pattern transition, and architectural integration of PV panels greatly. **Parametric Patterns** Clear parameters allow for parametric design to run through a whole series of design options and to quickly understand the impacts of changing the wall screening panels on levels of transparency, light transmission, number of photovoltaic solar cells and energy generation. **Conclusion** With the parametric approach 'W(e)AVE' a wide range of solar cell pattern variations akin to contemporary architectural design become possible.

*Keywords:* BIPV Innovation, Light Transmissive PV (LTPV), Architectural Integration, Patterned Gradation of Transparency, Parametric Design

## 1. Introduction

Solar modules can be categorised into different groups, depending on the chosen criteria. From the point of solar photovoltaic technology, two major groups, crystalline silicon and thin-film are common. From the point of architectural BIPV, however, it seems to be reasonable to distinguish between opaque modules and semi-transparent or translucent modules. Opaque modules are often used as cladding material, whereas semi-transparent / translucent modules are used as light-transmitting or shading element. Even though both module types generate electricity, their inherent and sought after qualities can be very different. Whereas opaque modules are first and foremost electricity generators densely populated with solar cells to maximise power output, this can be quite the opposite with semi-transparent / translucent modules. Densities are intentionally reduced or holes are laser-cut, so that light can pass through the resulting gaps or holes, taking into account the reduced power output, in exchange for the ability to change the degree of light-transmittance, for illumination or partial shading, for allowing or preventing views, for letting in desired or blocking undesired heat loads, plus the aesthetic qualities of rich shadow plays, colour and texture, all in one building and architectural element.

## 2. Study approach and aim

This study focuses on the possibilities of spacing opaque cells for light-transmissive photovoltaic (LTPV) panels, an approach often called 'light-through' and commonly used for crystalline silicon cells. Based on built examples, key design parameters were established. A list of the built projects and the results of the analysis are described in more detail in a separate paper (Baum, 2011). Semi-transparent thin-film-sheets with laser-cut microscopic holes or widened scribing lines, often called 'see-through', are not discussed in this paper. The aim of the study is to improve the versatility of LTPV panels used for architectural integration into building skins.

### 3. Solar cell patterns of crystalline silicon cells

#### 3.1. rectangular PV panels – homogeneous cell patterns

A high packing density of solar cells to maximise performance has been the starting point for the design of opaque modules that make up the lion's share of production. Whereas in the early days of PV, solar cells were round and a hexagonal grid was the most space efficient arranging method, nowadays it is a square / rectangular grid with mainly square and pseudo-square or sometimes rectangular cells. What has been the starting point for opaque standard modules is having a strong impact on the development of LTPV as well. The usual design alternatives offered by many PV manufacturers are mostly restricted to an equal spacing of the cells / strings throughout the grid pattern. Starting from a dense spacing as in Fig.1a, the string distance (Fig.1b) or the cell distance (Fig.1c) or both (Fig.1d) can be increased. A wide cell / string spacing increases light-transmission ratio, whereas a dense spacing increases shading. These options for rectangular modules are the most widely offered, as well as most widely integrated in building skins.



Fig. 1: Varied cell and string spacing, schematic

#### 3.2. non-rectangular PV panels – homogeneous cell patterns

However, sometimes non-rectangular modules are used, that require alternative arranging methods. Based on the built projects, the following string patterns (Fig.2) can be found. Offset patterns (Fig.2a) follow parallelogram shaped panels, radiating patterns (Fig.2b) follow trapezium shaped panels, curved patterns (Fig.2c) follow curved panels, and patterns with shortened string lengths (Fig.2d) can be used for any shape.



Fig. 2: String patterns for non-rectangular laminates, schematic

#### 3.3. emerging heterogeneous cell patterns

Most of the analysed built examples use panels with a homogeneous arrangement of cells and strings, and only few projects exist that employ panels with varied cell or string distances, i.e. neighbouring cells or strings with changing intervals. Just to name two projects, the Solar Office Doxford International in Sunderland, UK, built 1998 and designed by Studio E Architects, employs bespoke panels with increasing string distances (Fig.3a), whereas the Christian Kindergarten Ulmenstrasse, in Dresden, Germany, built 2003 and designed by Reiter & Rentzsch architects, uses panels with equal string distance but partially random cell distances (Fig.3b).

Most of the analysed patterns express a strong linearity. This is a feature of the electrical interconnection of cells in strings, the most dominant and pattern-defining factor. It is interesting to note, that even with LTPV where the most space-efficient arrangement of solar cells isn't the main objective, the dominance of linear, panel edge-aligned patterns is hardly ever questioned. Only recently, at some airport projects in Morocco, e.g. the Marrakech Ménara Airport, built 2008 and designed by a team led by E2A Architecture, the strings were rotated by 45° (Fig.3c). The resulting patterns are reminiscent of traditional mashrabiya (Baum and Liotta, 2011), underlining the search for and necessity to develop alternative approaches to match PV with the local context and the requirements of the architecture.

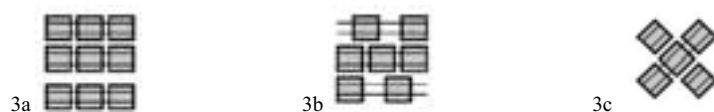


Fig. 3: Heterogeneous cell patterns, schematic

### 3.4. the quest for designed, parametric patterns

Even though few built examples exist, an interest in heterogeneous patterns can be taken for granted. Pellegrino et al. (2002) suggested PV panels with increasing string distance using the red scale of the Modulor. Scognamiglio et al. (2006) suggested patterns with random solar cell positions taking inspiration from Piet Mondrian's painting *Broadway Boogie-Woogie*. The random omission of solar cells in a grid-like arrangement leads to patterns, reminiscent to early, low-resolution, pixellated computer graphics (Baum and Liotta, 2011).

More generally speaking, in the advent of designed, parametric pattern generation, Patrick Schumacher, partner at Zaha Hadid Architects, values patterns as “a potent device for architectural articulation” (Schumacher, 2009), and Alejandro Zaera-Polo as “critical expressive devices”. Furthermore, Zaera-Polo identifies an opposition to the Cartesian grid-division in contemporary building envelopes. However, if an orthogonal grid is used as the organising structure for the construction, “it is usually disguised by introducing an overlapped pattern or a 3-D manipulation of the surface” (Zaera-Polo, 2009). Scognamiglio et al. (2006) describe this tendency as “substituting orthogonal matrixes with innovative geometries developed by means of complex generative processes, based on casualness”. This raises the question, whether standardised orthogonal PV patterns that reinforce the orthogonal grid are able to satisfy such needs.

## 4. 'W(e)AVE' – tilted and wave-like cell patterns

How can a general approach of “disguised by introducing an overlapped pattern” be achieved?

Here I'd like to draw an analogy to the craft of weaving, where a pattern is created by interlacing two distinct yarns. The intersection of warp and weft form a criss-cross pattern.

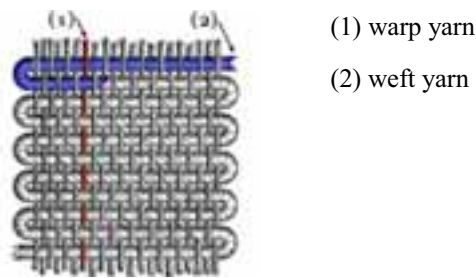


Fig. 4: Weaving, source: <http://de.wikipedia.org/wiki/Weben>

Textile weaving forms, strictly speaking, an orthogonal grid, for the purpose of stability of the fabric. However, in the case of PV stability is given by encapsulation. The analogy of weaving, that I call 'W(e)AVE', can be applied to PV as basically a two-directional pattern generating approach. The process of overlapping liberates the generation of patterns from the linearity of the cell-strings by superimposing the electrical interconnection in cell-strings with a deliberate crossing pattern (Fig.5).

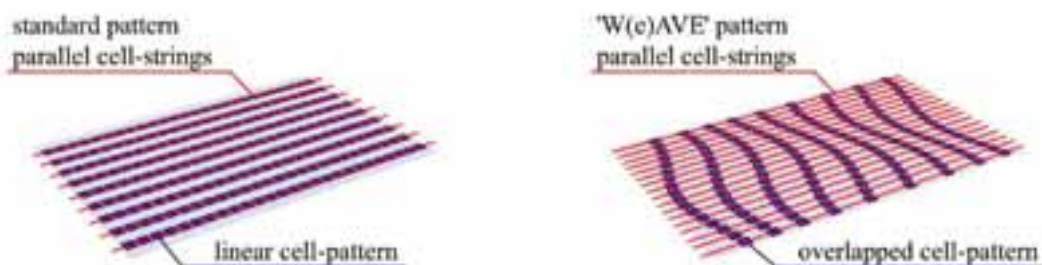


Fig. 5: Comparison of standard pattern and 'W(e)AVE' pattern

To make this approach operational, 'W(e)AVE' is based on two parameters:

- First, the spacing of the solar cells in cell-strings can have more than one distance. However, linearity is kept in cell-strings.
- Second, interconnection between neighbouring cell-strings doesn't require the cells to lie exactly side by side, an offset between cells is possible. However, parallel position of cell-strings is kept.

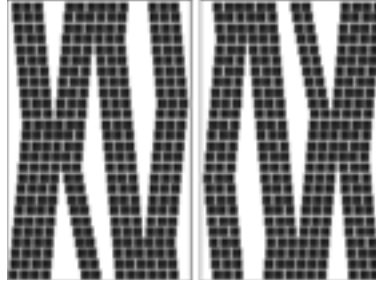


Fig. 6: 'W(e)AVE' case study I: tilted pattern, rendering of a two-panel BIPV

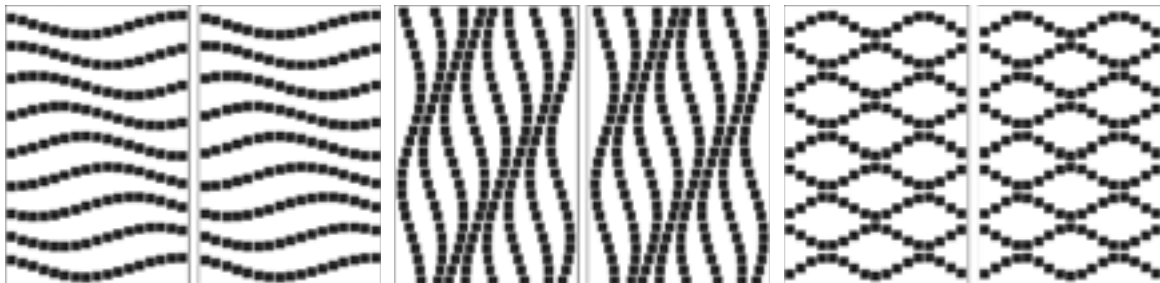


Fig. 7: 'W(e)AVE' case study II: sinusoidal patterns

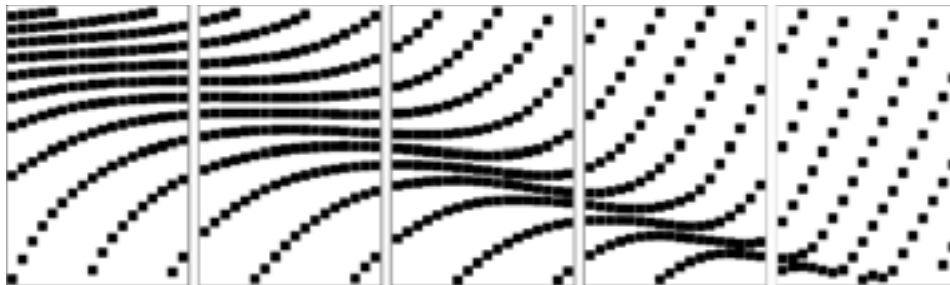


Fig. 8: 'W(e)AVE' case study III: free-form pattern, rendering of a five-panel BIPV

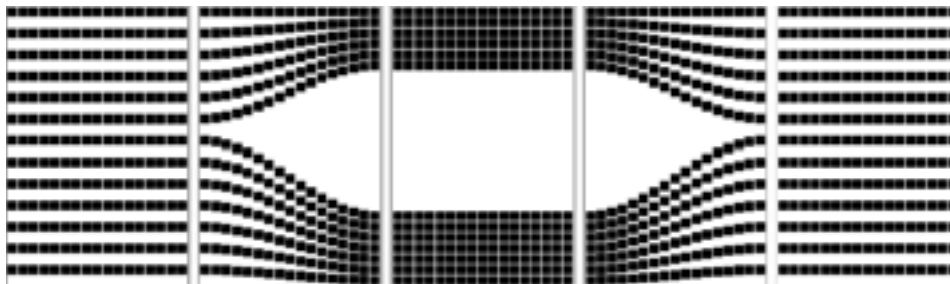


Fig. 9: 'W(e)AVE' case study IV: 'W(e)AVE' pattern as transition between different linear standard patterns

In combining the two parameters, a tilted and wave-like arrangement of solar cells becomes possible. Furthermore, in keeping linearity and parallel position of cell-strings, an easy integration into manufacturing processes can be achieved. Clear parameters also allow for parametric design, to run through a whole series of design options and to quickly understand the impacts of changing the pattern on levels of transparency, light transmission, number of photovoltaic solar cells and energy generation.

To proof the versatility of 'W(e)AVE', a number of alternative patterns were generated and visualised using the parametric design software Rhino / Grasshopper. As can be seen from the case studies in Fig.6 to 8, 'W(e)AVE' enhances the options for individual designs and architectural integration of PV under the premise of “disguising” greatly. It also allows for smooth pattern transition between standard patterns (Fig.9)

## 5. Conclusion

With the parametric approach 'W(e)AVE' a wide range of solar cell pattern variations akin to contemporary architectural design become possible, of which some are illustrated with renderings. Furthermore, a flexible change in the level of transparency enables the architect to set the visible connection between the interior space and outside of a building into a complex relation.

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