Brick modules for improved aesthetics in PV
Introducing the Dutch Solar Design project

John van Roosmalen[1], Lenneke Slooff, Lars Okel, Menno van den Donker, Tessa de Vries (ECN), Tom Minderhoud, Ningzhu Wang, Ger Gijzen (UNStudio), Thijs Sepers (TS Visuals), Marieke Rietbergen, Lianne Polinder (Design Innovation Group), Renee Heller (Amsterdam University of Applied Sciences), Alwin Versluis, Frank Frumau (Aldowa)

[1] ECN Solar Energy, ECN

Petten, The Netherlands, vanroosmalen@ecn.nl

Abstract

Solar energy will become increasingly important in the energy mix in the coming decades and will become much more visible in urban areas. Standard, rectangular size solar panels do not allow full roof or façade coverage. Together with their blueish appearance, they are visible, but not in an attractive way. Dutch Solar Design (DSD-PV) façade elements stimulate the acceptance of PV in the public space. PV as a product matures and from a 'one size fits all' approach becomes more varied, differentiating and attainable for large groups of users. In this work the basis is formed by the back contact foil technology, offering size and shape flexibility without the need to change the complete module manufacturing line. Findings are that by adding designed graphics to the inside of DSD-PV elements with a coverage of up to 30% their appearance can be altered completely, without a large sacrifice in efficiency. The efficiency reduction can be kept to 20%. Brick modules, referring to bricks as an import aspect of the Dutch urban landscape, as well as artistic modules and full size façade elements (900 x 1200 mm^2) have been realized, a small part of the potential portfolio.

Keywords: Photovoltaics, aesthetics, print, design, façades, BIPV.

1. Improving the aesthetics of PV

When in fifty years from now we look back and conclude that it has been the age of renewables and that all our power is now provided with renewable energy, one can wonder what our cities will look like when we go out in the streets. Will every available surface be used for solar energy, and if so, what will it look like? To enable a transition into a renewable energy society with cities that look prosperous, diverse, colourful, and are a healthy environment to live, work and play in, the development of solar panels into attractive, aesthetically pleasing building products is a major task ahead. It is important that the perception of PV remains positive, even when large surface areas are used for power generation, storage, conversion and transport.

Our aim is to development Dutch Solar Design-PV (DSD-PV) façade elements that produce solar power cost effectively and adapt themselves flexibly to user demands, design and application area. DSD-PV façade elements stimulate the acceptance of PV in the public space. PV as a product matures and from a 'one size fits all' approach becomes more varied, differentiating and attainable for large groups of users. The goal of the Dutch Solar Design project is to develop cost effective, integrated (solar) energy generating façade elements based on the back-contact metal wrap through (MWT) concept, full colour printing technology, artistic design and aluminium building element technology, driven by user desired design variations (colour, shape, texture, size). A design print is applied on the inside of the DSD-PV elements, where it is well protected against environmental influences. A particular design print that we have elaborated on is the 'brick' design. In the Dutch urban landscape and architecture bricks largely determine the appearance. Our approach to transforming PV modules into building material is to finish the rear of the modules with aluminium parts, allowing regular mounting structures to be used.

2. The back-contact module concept as technology platform for DSD-PV

2.1 Back-contact module concept

ECN's back-contact module concept enables the manufacturing of high-power modules using any type of back-contact cell, including MWT and IBC. With its proven performance and reliability, this technology offers the major benefits of higher production yield and a 5% higher power output over conventional technology. The metallization wrap through (MWT) technology by ECN and partners is one of the most promising new technologies for achieving low-cost and high-efficiency solar cell modules [1-3]. The back-contact module technology allows a single-step encapsulation and interconnection process of the back-contact cells. The main distinctive feature of this technology is the use of a patterned conductive back-sheet foil and a conductive adhesive to electrically connect the cells [4]. MWT modules are gaining increased interest from industry, mainly because their efficiency can be up to 10% higher and due to their interesting aesthetic features [5, 6]. Intrinsically shadow tolerant versions of this technology are also under development [7].

2.2 An ideal platform for aesthetics

Standard modules have shiny tabs that form the interconnection between the cells. These tabs show pronounced lines in the modules and are often considered to be aesthetically less appealing. For this reason their appearance is sometimes obscured or hidden, but even then the regular rectangular pattern remains.

The Dutch Solar Design concept is a module adaptation that makes use of back-contact foil technology design. In this technology the module consists of a backsheet with Cu foil on top. The solar cells make contact with the patterned Cu foil via electrically conductive adhesive dots. Outside the dots, the cells are isolated from the foil by EVA. Transparent EVA is used as the encapsulant between the cells and the front side glass. For Dutch Solar Design-PV, the module also contains graphics on the inside of the modules. The appearance can be easily varied by changing the graphics. With this concept the modules can be built on a standard back-contact foil manufacturing line.

2.3 Freedom of design

This paper focusses on obtaining aesthetically pleasing modules by integrating graphics in the module. The back-contact module concept has another interesting feature that can be beautifully combined with graphics, adding more possibilities. These possibilities are related to the conductive copper foil that is used to connect the solar cells in series. This foil is patterned, e.g. by laser, and the pattern can be easily adjusted when the cells are given alternative positions, e.g. the cells can be rotated (Figure 1) or shifted. In this way, the contrast between the cells and the (white) background can be used as a design feature. Cells can be placed a little further apart to increase these possibilities. This concept also allows cells to be placed very close to each other, so groups of cells can form new shapes, e.g. bricks. Shifting and rotation can be combined to create more interesting patterns. Colour can be added to the space in between the cells (Figure 2) and graphics can also be applied across the entire module surface, as will be elaborated further below.

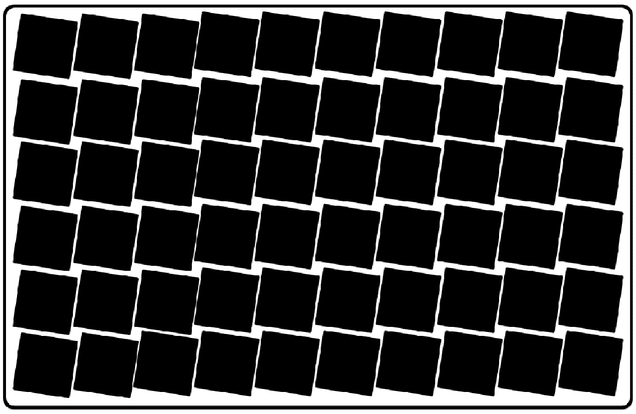


Figure 1. Interesting and appealing black and white designs can be created by playing with the white space between the cells. Here an example is given with rotation.

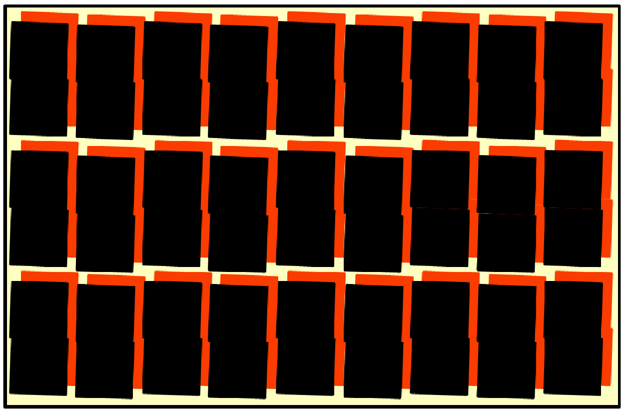


Figure 2. An example of a combination of rotation, shifting and bricking of the cells, with colours added to the white space in between the cells.

2.4 From PV modules to energy generating building elements

2.4.1 Flexibility in size, adaptation to building standards

Another aspect that makes the back-contact module concept especially interesting for BIPV applications is the ease of adaptation to building standards, the flexibility in dimensions and even shape. As already shown, the copper foil can be easily adjusted to match any cell position. In addition to that, the other manufacturing process steps are easily adaptable as well, including cell placement e.g. by a pick-and-place robot. For the modules described in this paper we have chosen to adapt to multiples of 30 cm, which is typical in many building standards, getting to modules of 900 x 1200 mm^2. They can be used both in landscape as well as in portrait configuration. These dimensions fit to the use of 5 rows of 7 cells, with one string of 17 and one string of 18 cells, equipped with bypass diodes in the junction box. With regular H-pattern cells this would be far less easy. By choosing half or quarter cells, the module could even be filled better. In this way, modules of all sorts of dimensions can be manufactured, in multitudes of 30 cm or in any other desired sizes.

2.4.2 Building elements, front and rear finish

The modules described in this paper are not just regular PV modules equipped with an aluminium frame. In fact, an important aspect of BIPV is that the solar panels become building elements, i.e. plate material that can be used in construction like any other building material. To this end, the rear side of modules is finished with aluminium parts. These allow for various assembly methods, e.g. cold welding, enabling the use of regular mounting structures for façade and other building elements. The front side finish of the module strongly influences the appearance. Textured glass was tested to get a uniform appearance and strongly reduced reflections from all view angles. Polymer front sheets were also studied both for improved appearance and as a lightweight alternative. Regular glass was used as well, providing a high quality, glossy appearance.

3. DSD-PV module assembly

Up to now, three types of modules were used for the project,

- 2 x 2 cells laminates, the ECN standard research vehicle, 365 x 365 mm^2 and 365 x 440 mm^2;
- Brick with ¼ cells, 372 x 472 mm^2;
- 900 x 1200 mm^2 building elements.

For the 2x2 cells modules, the ECN pilot research line is used. In this line, the copper foil is patterned using milling to define the conductive pathways of the different polarities (Figure 3). Then the conducting adhesive dots are printed on the copper foil. Next the EVA is punched at the positions of the conductive adhesive dots. The punched EVA is then placed on the copper foil, followed by cell placement. Another EVA sheet is placed on top of the cells and finally the top glass is placed, followed by lamination (Figure 6). For the brick with ¼ cells and the 900 x 1200 mm^2 building elements modules the same layer build up is used, but due to distinctive size of cells or overall size, some steps were done by hand (e.g. Figure 5), conductive adhesive dots were printed on the cells (Figure 4) or materials were purchased commercially. All modules contain a design print in the interior of the module, protected by the front cover. The 900x1200 mm^2 building elements modules were supplied with an aluminum backing to facilitate mounting to faced structures.

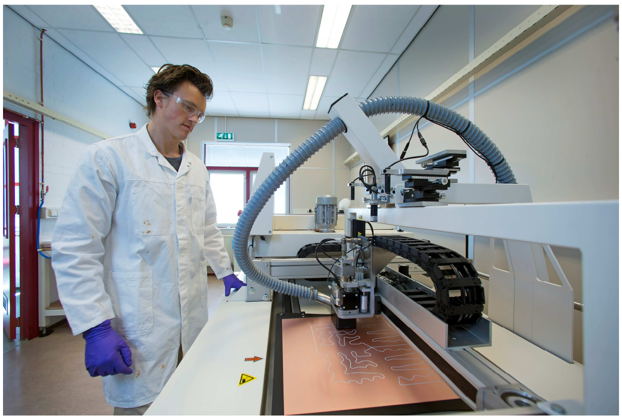


Figure 3. Copper patterning in the 2x2 cells laminates pilot line.

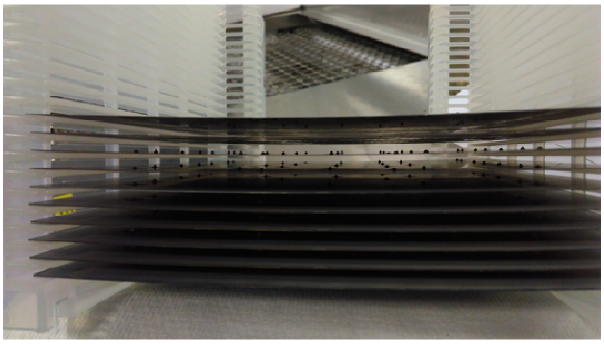


Figure 4. Conductive adhesive printed onto the cells for the 900 x 1200 mm^2 modules.

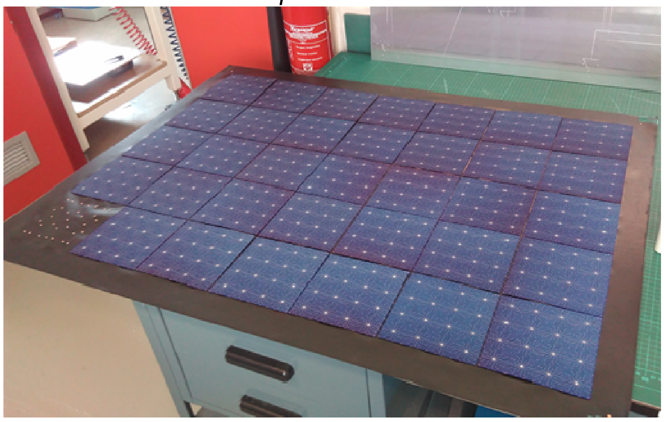


Figure 5. Cell placement on conductive backsheet foil for 900 x 1200 mm^2 module.

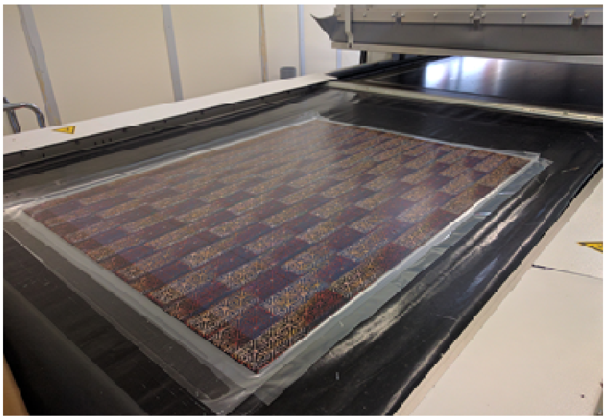


Figure 6. 900 x 1200 mm^2 module with design print prior to lamination.

The brick modules with ¼ cells contain twenty ¼ cells that were laser cut from full cells. They were placed in 4 rows with alternating groups of 2 and 3 cells to mimic a brick pattern. Between the cells in a group a minimum distance was applied, whereas between the groups of cells the spacing was enlarged. A design print was applied to the modules, partly covering the active part of the cells. Coverage percentages of 0, 13, 20 and 45% were applied. The designs that were applied are shown in Figure 7 (top). Pictures of the finished modules with 0% and 45% coverage are shown in Figure 7 (bottom). Glass types that were used were standard 4 mm glass, 2 mm thick glass with Anti Reflection Coated (ARC) and 4 mm textured glass for reduced reflectivity.

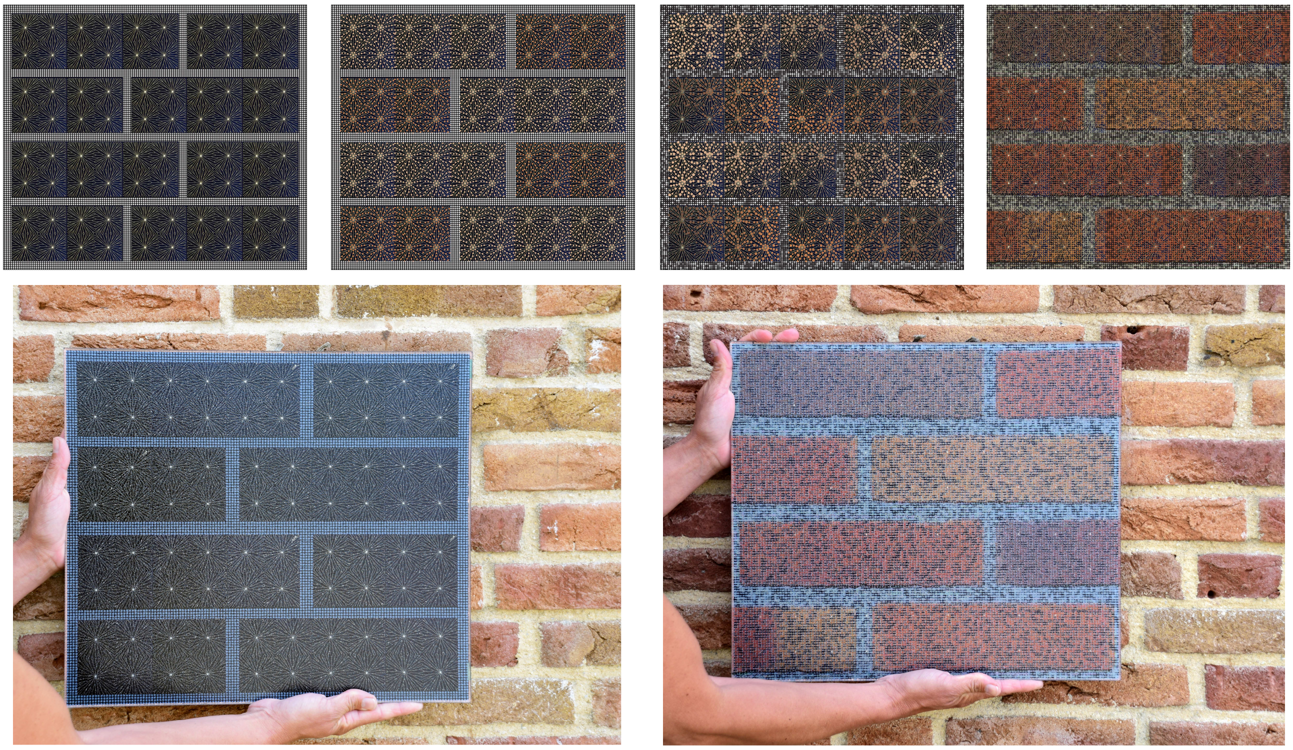


Figure 7. Brick modules with ¼ cells. Top, as designed with 0, 13, 20 and 45% coverage. Bottom, realized modules with 0% (left) and 45% (right) coverage, both with textured glass

4. Brick modules and their performance

The effect of the design print on the performance of the solar panels was tested mainly with the brick modules with ¼ cells. The effect of the coverage for the various glass types is shown in Figure 8 (left). The numbers were normalized to the output of a module with the same glass, but without the graphics layer. The lines are a guide to the eye. Also shown is the one–to one relationship, representing the case if the loss in performance were equal to the percentage of coverage by the design print. As can be seen, all modules show a lower loss compared to the coverage of the graphics. This indicates that either the print is semi-transparent, or that the light is scattered from the print and gets trapped in the module after which it can still reach the solar cell. For low graphics coverage, there is not much difference between the glass types, but in case of higher coverage the textured glass seems to perform slightly better. Although the ARC glass should have a lower reflection and thus a higher light transmission it does not perform as well as the standard glass. An explanation might be that the glass itself is less transparent. This was not tested.

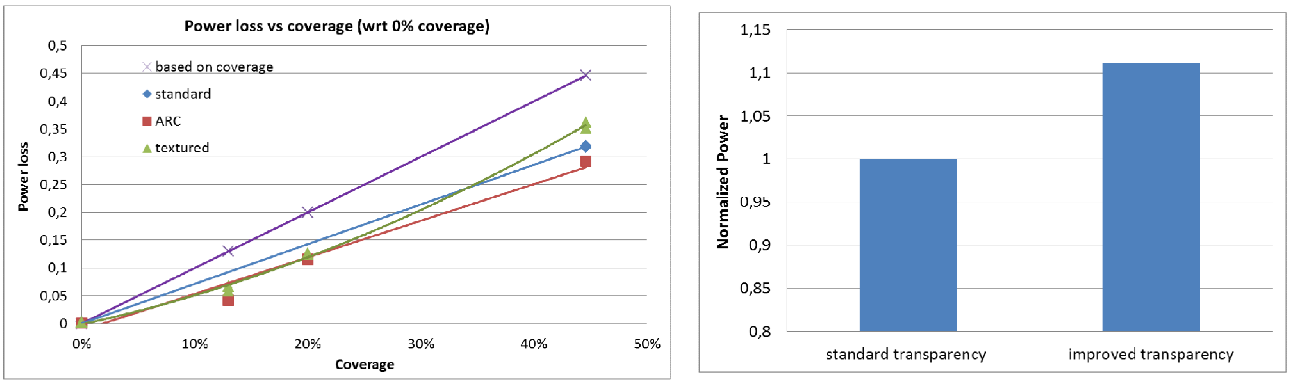


Figure 8: Left: The power loss of the modules versus the coverage of the graphical layer for 3 different glass types: standard 4 mm glass, 2 mm thick Anti Reflection Coated (ARC) glass and 4 mm textured glass. Right: Performance increase by improving the transparency of the print, for 45% coverage.

Next, the transmission of the design print itself was varied to see if the results could be further improved. The print was made more transparent, without sacrificing the visual appearance. For these experiments the ECN standard research vehicle 2x2 cells laminates were used and the print as shown in Figure 7, top right, 45% coverage, was applied to them. Figure 8 (right) shows the normalized output power of the cell with the highest output, where the normalization was done with respect to the cell of the less transparent print. The cell behind the lower absorbing design print shows a 10% higher power output compared to the more absorbing design print. This is also observed for the other cells in the laminate. This means that for 45% coverage the loss in power is reduced from 32% to 25%.

5. Other designs

The brick module is just an example of the designs that can be realized. By applying full colour printing, any image can be realized. It is not only the intention to create individual modules with design print, but also to create images with multiple modules, using buildings as canvas. A division into two kinds of designs can be made. On the one hand, designs like the brick modules can be applied, i.e. designs that mimic standard building materials or natural surroundings. These can play a role in a large part of the applications, since buildings without PV regularly have a similar appearance. On the other hand, more artistic designs can be applied, enabling new looks and buildings with new and surprising surface finishes and designs.

An example of a more artistic design is shown in Figure 9. Two different prints are applied to standard 2x2 cells modules of 365 x 365 mm^2. The design is based on printed dots of various sizes and on the underlying metallization pattern of the MWT cells that were used for these modules. The density and colour of the dots varies from the lower right corner to the top left corner of the modules. The left picture has a dot coverage of 18%, whereas the right one has a coverage of 27%.

Figure 9. Pictures of fabricated 2x2 cells DSD-PV modules. The left module has a dot coverage of 18%, the right one 27%.

Another category in the more artistic modules are modules based on images, i.e. images translated into dot patterns and applied as a design print in the module. Figure 10 shows an example of a picture of the Erasmus bridge in Rotterdam translated into a dot pattern and applied to a 900 x 1200 mm^2 size module is. The dot coverage is 30%, corresponding to ~20% power loss due to the print.

Figure 10. 900 x 1200 mm^2 module, based on an image of the Erasmus bridge in Rotterdam, an example of a 'light weight' building element with an aluminium rear and a polymer front sheet. Design print coverage is 30%, ~20% power loss.

6. Application and outlook

The brick modules shown in Figure 7 (top right, bottom right) have appealing aesthetics with a coverage of 45%. Meanwhile, we have established that visually appealing modules can also be achieved with a coverage of around 30%. This should result in a remaining power conversion efficiency of ~80% compared to a module without print (see Figure 8). In Figure 11, an example is given of a 900 x 1200 mm^2 full size façade element with 30% dot coverage, with a different type of brick design.

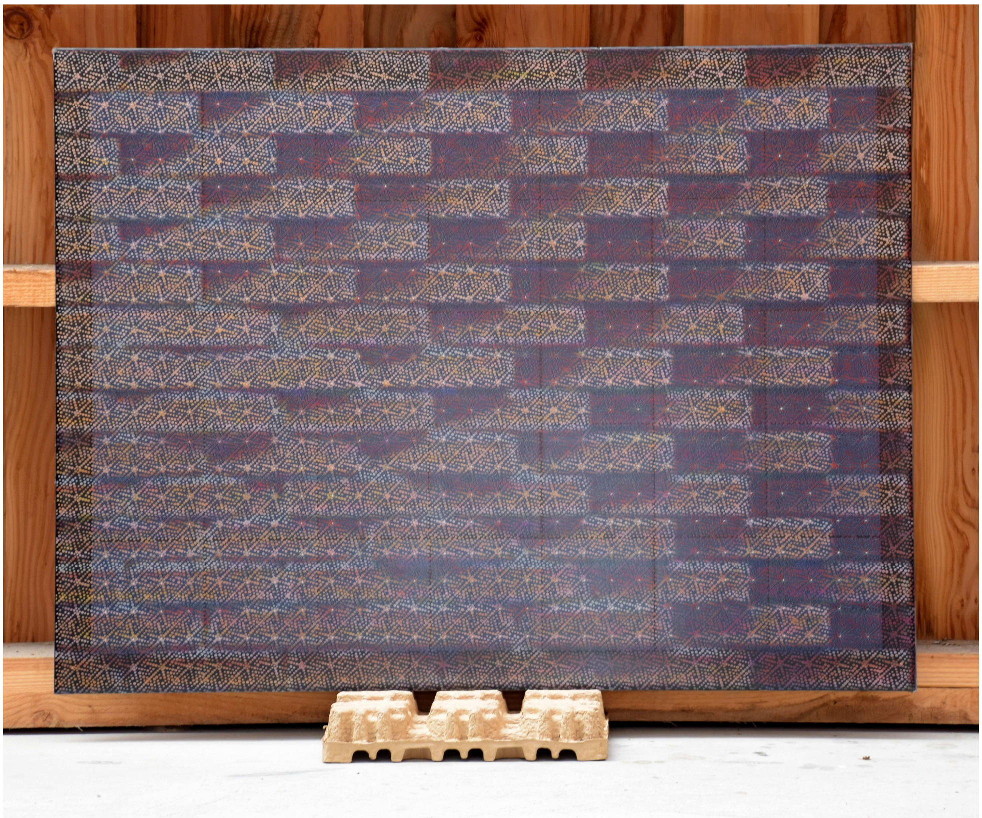
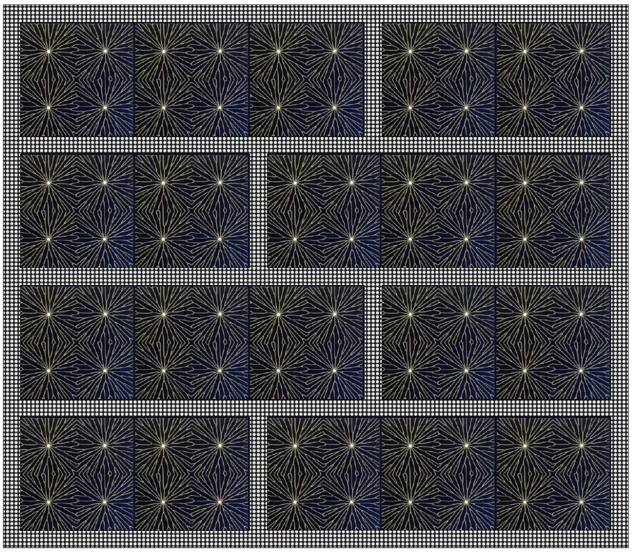
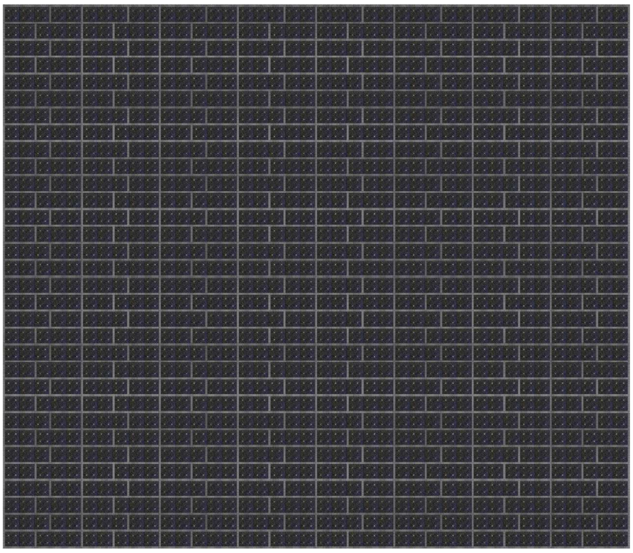


Figure 11. 900 x 1200 façade element. A visual appearance is realized that makes you forget that it is a solar panel. Design print coverage is 30%, ~20% power loss.

To envision how these brick designs can be applied to (brick) buildings some simulation studies were performed. Figure 12 shows what the brick modules with ¼ cells with 0 and 20% coverage would look like in a wall. In Figure 13 it is shown how building elements of houses could be realized with DSD-PV brick modules, with 30-40% coverage.





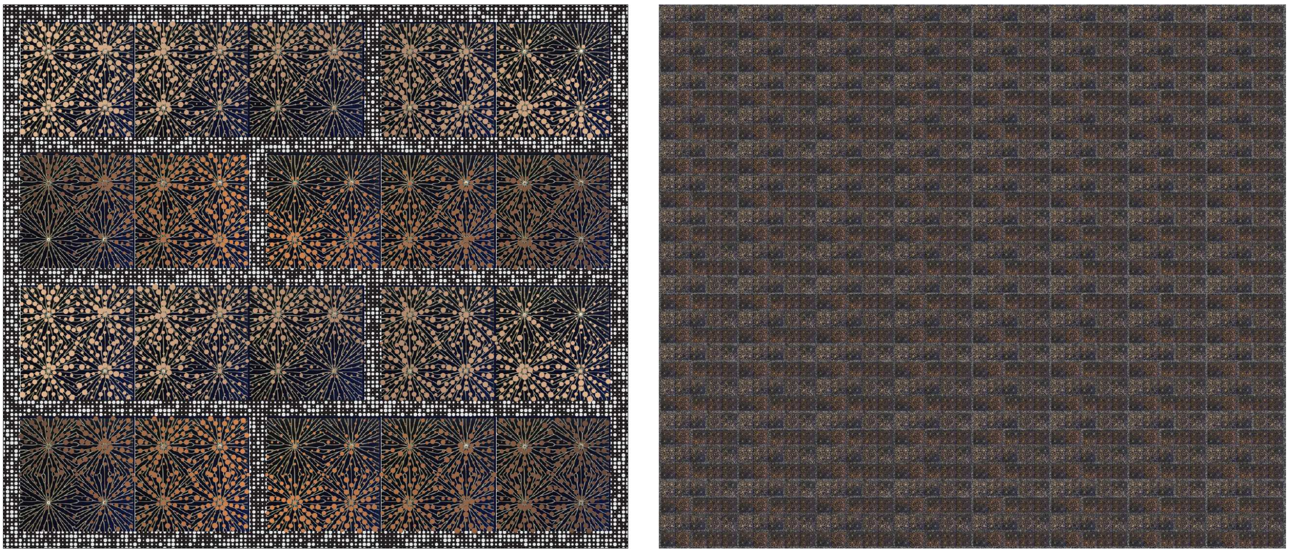


Figure 12. Design study with brick module with ¼ cells with 0% (top) and 20% (bottom) coverage. On the left side the modules are shown, on the right side what a wall would look like.

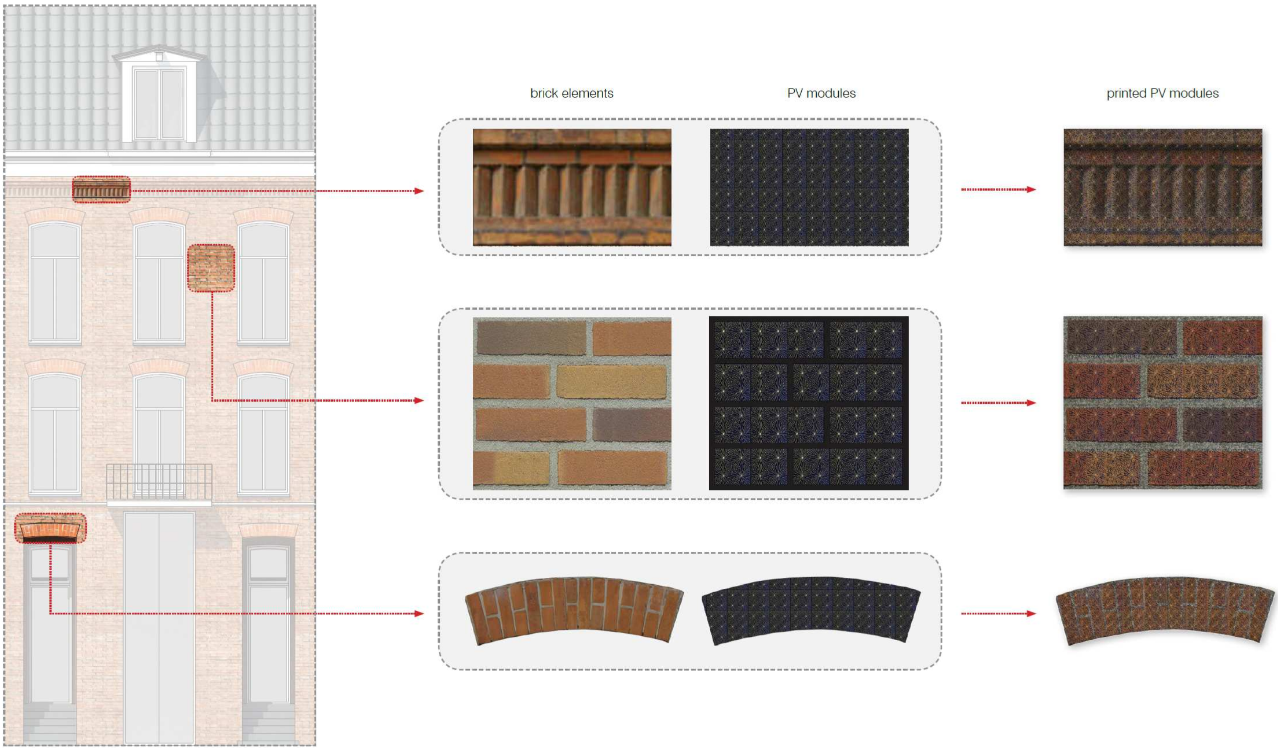


Figure 13. Design study of an example Dutch house how design prints can be applied to various parts of the building façade. Print coverage 30-40%.

Further optimizations of improving aesthetics and performance are under way. The materials used in the modules are chosen for optimal durability. Indoor and outdoor tests (Figure 14) are being started to obtain more knowledge of expected lifetime. DSD-PV is presently developed as façade elements. Standard modules, roof-top modules, infrastructure and landscape integrated modules can of course also be enriched with an aesthetical appearance by adding a design print.

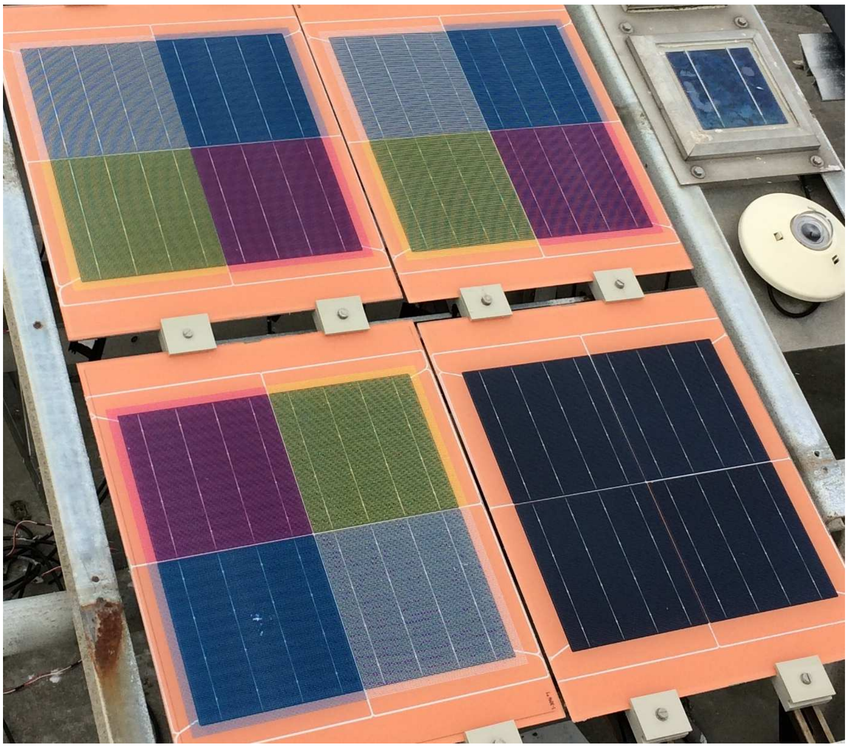


Figure 14. Part of the outdoor test setup with basic colours (magenta, yellow, cyan, white) and reference in 2x2 cells laminates.

7. References

[1] I.J. Bennett, C. Tjengdrawira, A.A. Mewe, M.W.P.W. Lamers, P.C. De Jong, A.W. Weeber, World record module efficiency for large and thin mc-Si MWT cells, *Proceedings of the 24th European Photovoltaic Solar Energy Conference and Exhibition*, Hamburg, Germany, 2009.

[2] M. Spath, P.C. De Jong, I.J., Bennett, T.P. Visser, J., Bakker, A novel Module assembly line using back contact solar cells, *Proceedings of the 33rd IEEE Photovoltaic Specialist Conference*, San Diego, USA, 2008.

[3] C. Tjengdrawira, M.W.P.W. Lamers, I.J., Bennett, P.C. de Jong, World first 17% efficient multi-crystalline silicon module, *Proceedings of the 35th IEEE Photovoltaic Specialist Conference*, Honolulu, USA, 2010.

[4] V. Rosca, I.J. Bennett, W. Eerenstein, Systematic reliability studies of back-contact photovoltaic modules, *Proceedings of the SPIE*, San Diego, California, USA, 2012.

[5] C. Meyer, et al., Efficiency Delta between MWT and H-Pattern Cells: Calibration Issues and Hybrid Reference Cell as Solution, *Proceedings of the 26th European Photovoltaic Solar Energy Conference and Exhibition*, Hamburg, Germany, 2011.

[6] L.M. Augustin, et al., Mass Production and Field Performance of Durable Metal-Wrap-Through Integrated Back Contact Foil Based “Sunweb” Modules, *Proceedings of the 26th European Photovoltaic Solar Energy Conference and Exhibition*, Hamburg, Germany, 2011.

[7] L.H, Slooff et al, this conference.