OPV-Façades – Students design concepts of multi-functional solar façades

Roland Krippner[1] and Fabian Flade[2]

[1] Nuremburg Tech – Technische Hochschule Nürnberg Georg Simon Ohm, Faculty of Architecture, Nuremburg (Germany)

[2] Bavarian Association for the Promotion of Solar Energy – Solarenergieförderverein Bayern e. V., Munich (Germany)

Abstract

In the field of building integrated photovoltaics (BIPV), thin-film PV modules or films with organic solar cells (OPV) in particular also represent new solutions, especially when it comes to requirements for flexible module sizes and geometries. These potentials have not yet been exploited enough for further developments.

In the context of a course with master students of the Faculty of Architecture of the Nuremburg Tech in the summer semester 2018, a solar façade was planned for this innovative technology at the former ZAE office and research building in Erlangen as a beacon project and research object, which provides sun and glare protection for the interior and functions as a visible sign of advanced energy research. This eye-catcher is intended to demonstrate how a fully functional yet aesthetically pleasing construction can be realised.

In the end, the concepts developed did not always meet the requirement of planning a solar façade with simple means, but in the occupation with interesting references and their adaptation, the designs show consistently functional and aesthetically appealing solutions for a striking sign of advanced energy research.

Keywords: OPV, printed PV, BIPV, PV façades, solar architecture

1. Introduction

Decentralized energy supply is of crucial importance for sustainable architecture and urban planning. For a 100 percent renewable energy supply in Central Europe, solar activation of the building envelope plays a major role. Particularly in connection with the various approaches and activities such as the „Plus Energy House", „Energy Efficiency House Plus", „Active Solar House" and the implementation of the European Directive on the Energy Performance of Buildings (from 2019 / 2021), the issue of the integration of photovoltaic (PV) modules in building envelopes is of central importance in construction - especially for future-oriented façade designs.

2. Façades and solar technology

The use of solar technology in façades is often very limited, especially in dense urban structures. The solar yields are also reduced by up to 40 percent compared to optimally aligned south-facing roofs. Nevertheless, there are a number of reasons to consider the use of photovoltaics in façades as well. For example, if the roof surfaces of multi-storey buildings are unfavourably exposed, too small or unsuitable in terms of layout and surface area. Last but not least, solar technology also expands the design repertoire and can become a symbol for the use of renewable energies in façades.

Examples from the past decades impressively demonstrate that PV modules can be installed in almost any façade construction. [1] Multiple use is also considered a major advantage of photovoltaics; a particularly conclusive approach to overlapping functions is the use as sun protection. Both shading elements and PV systems work effectively when they are optimally aligned with the sun. The sun protection can be effectively increased with photovoltaics if these shutters are installed in front of the building and can be tracked.

doi:10.18086/eurosun.2020.01.10 Available at http://proceedings.ises.org

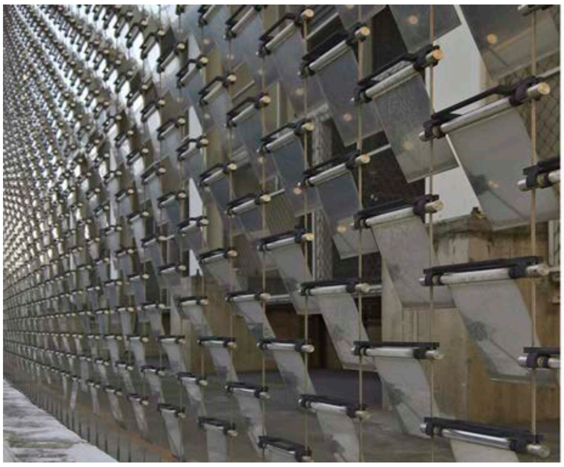
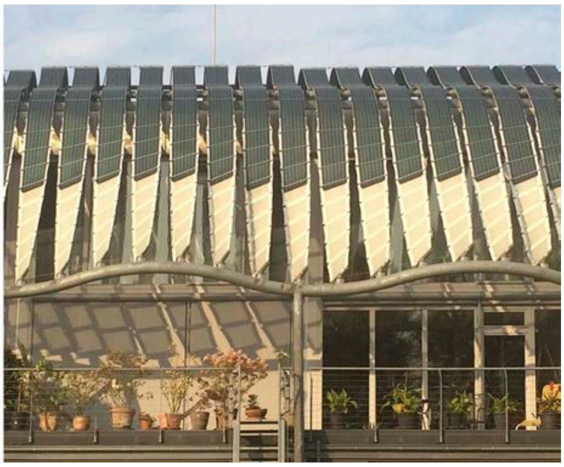



Fig. 1: Wind Arbor, Ned Kahn Studios (Photo: Christoph J. Brabec)
Fig. 2: Soft House, Kennedy & Violich Architecture (Photo: Roland Krippner)

3. Adaptive façades

Over the past decades, façades have developed from static systems to structures with a large number of different movable and controllable components. These should be able to react (automatically) to changing climatic factors under the site-specific conditions. The expansion from the pure, monofunctional protective functions of the façade to a variety of control functions plays an important role, especially in the area of energy management and thermal and visual comfort. [2] On the material side, lightweight construction materials, such as new textile composite construction methods, renewable raw materials and bio-based plastics as well as organic photovoltaics (OPV) enable promising developments.

One variant in this context are kinetic façades, where the use of moving elements also produces novel aesthetic effects. In recent years, Californian artist Ned Kahn has realized a number of projects in which he translates natural phenomena like the wind or sun rays into simple but fascinating constructions with constantly changing appearance, e. g. “Wind Arbor“, Hotel Marina Bay Sands (2011) in Singapore. (Fig. 1)

4. Flexible modules and OPV

Despite the numerous positive examples, architects continue to cite the lack of openness to adaptation with regard to formats, surface effects and colouring, especially of crystalline PV modules, as an obstacle to more intensive involvement with photovoltaics.

When it comes to requirements for flexible module sizes and geometries, thin-film PV modules or films with organic solar cells (OPV) in particular also represent new solutions, such as the SwissTech Convention Centre (2012) in Lausanne by Richter Dahl Rocha & Associés Architectes SA or the Smart Material House / Soft House (2013) by Kennedy & Violich Architecture from Boston, completed as part of the Hamburg IBA. (Fig. 2) Both façades show two different approaches to the use of (O)PV. On the one hand, it is used on or in rigid carrier materials, and on the other, flexible solutions are found in foil/rope net or membrane constructions.

At a company headquarters in Dresden (2014), blue semi-transparent foil strips are inserted into horizontally formatted laminated glass panes in two rows one above the other, while at the Duisport (2018) the solar foils are mounted vertically, three strips of equal width per panel, on the metal façade. Although this makes the warehouse „the world‘s largest façade installation with organic photovoltaics“ [3], in terms of design the approach falls far short of the solutions implemented by Friedrich Ernst von Garnier in the hot strip slitting line of ThyssenKrupp Stahl AG in Duisburg-Beeckerwerth (2002). HHS planners + architects from Kassel are gluing the OPV films directly to the thermal insulation composite system on the gable façade of apartment buildings dating from the 1950s in Frankfurt/Main. Conceptually, the vertically arranged sheets vary in terms of colour (green and red tones) and width as well as design as single or double elements, which at least creates a certain appealing variance with the barcode type arrangement. [4]

In the smart / BASF solar gate for the IAA 2011 in Frankfurt/Main the OPV foils were arranged under a massive polygonal steel girder by means of a tensioned cable construction, which nevertheless leads to a filigree solution. For the German pavilion at EXPO 2015 in Milan, Schmidhuber Brand Experience created a series of shade-giving solar trees with various hexagonal OPV „leaves“. Here as well as at the Peace and Security Building of the African Union (2016) in Addis Ababa, where square modules in a pixel-like arrangement under a glass dome replicate the African continent, new approaches in the area of sun protection devices and/or roofing for the light and flexible modules are becoming visible.

In connection with numerous ingenious and several artistic façade constructions, there is a pool of architectural reference projects here, which has so far been made far too little useable for further developments in the field of building-integrated photovoltaics (BIPV).

5. OPV façade for the ZAE building in Erlangen

Organic photovoltaic modules and printing processes for their manufacture in a roll-to-roll process are being developed by the former Bavarian Center for Applied Energy Research (ZAE Bayern). [5]

In the context of a course with master students of the Faculty of Architecture of the Nuremberg Tech in the summer semester 2018 [6], a solar façade was planned for this innovative technology at the front section of the ZAE in Erlangen (Fig. 3), which on the one hand provides sun and glare protection for the interior, and on the other hand functions as a visible sign of advanced energy research. This eyecatcher should demonstrate how a fully functional and yet aesthetically pleasing construction can be realized (with simple means).

The ZAE building is located at the western entrance to the southern campus of the Friedrich-Alexander-University of Erlangen-Nuremberg. The L-shaped structure is three-storeyed and oriented to the northeast/southwest. The building forms the access area. Due to clearance areas and the entrance to the underground car park, the two-storey front section tapers in the northwest and is indented in the southeast.

On the ground floor there is a meeting room and on the upper floor a lounge. To the east, both rooms have extensive glazing in posts and mullions construction (grey), which is inserted between the reinforced concrete structure (pillars and ceiling slabs). The adjoining solid exterior walls are designed with a thermal insulation composite system, which is also contrasted in colour (red) with the glazing area.

In these structural conditions resulted the constructional constraints for the load transfer, which can take place not only in the massive walls of the corridor/staircase (three-storey part of the front section) but also, and above all, in the floor slabs. With regard to the foundation, access to the underground car park had to be guaranteed.

Fig. 3: ZAE-Bayern / Office and research building (2011), architekturbüro fischer + partner (Photo: Tobias Stubhan)

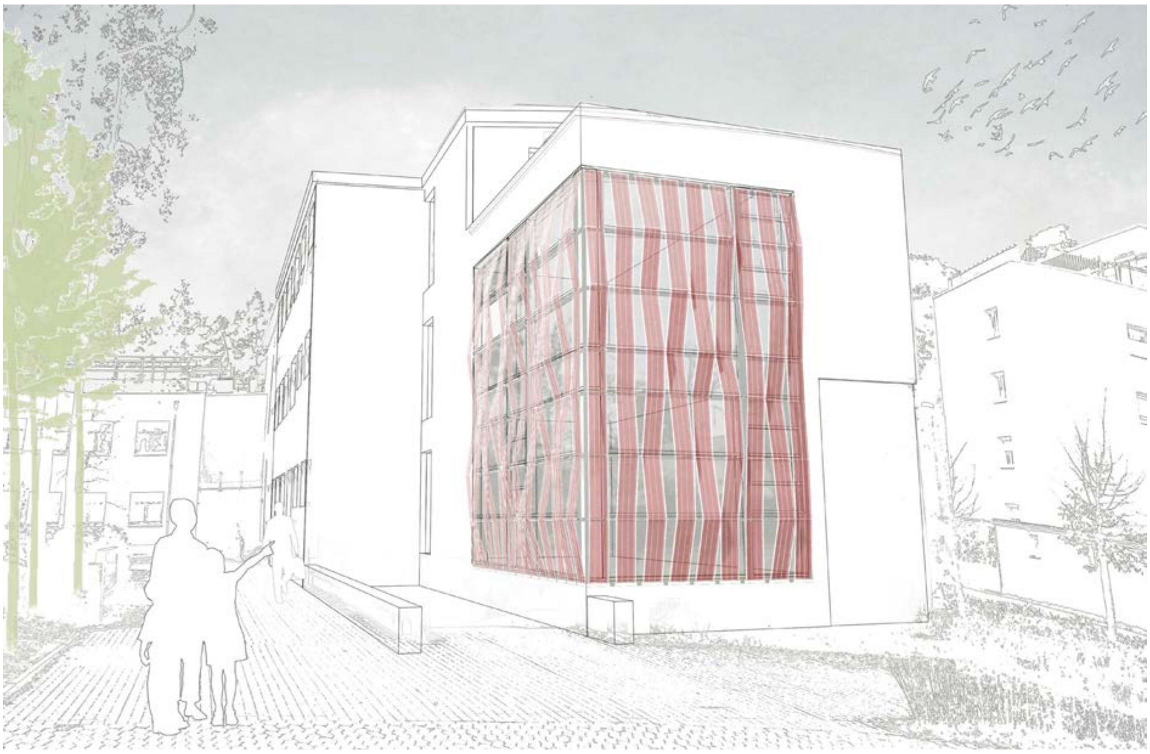


Fig. 4: Moritz Bachmann and Sven Vorliczky, rendering

6. The projects

A number of differences can be identified in the constructional design as well as in the façade structures. [7]

Essential parameters are:

- Structure
- Position to the building and façade area
- Supporting material
- Module design

With regard to the overall structural appearance, a simplified distinction can be made between band-like and planar/point-like solutions, which are designed to be flat or spatial. In terms of design, systems with flat or curved supports/primary and secondary beams or rope net and frame structures with secondary support structure can be found.

For the design, the position in relation to the building is an important requirement, especially since the exit to the underground car park makes the foundation of the structure difficult. Therefore, solutions can be found which are arranged parallel, directly on the existing façade, and designs in which the supporting structure is transmitted at a distance on the boundary wall of the underground car park exit. With regard to the covering of the façade area, concepts have been chosen that form the construction with two to three storeys in the southeast, while others also include the northeast façade in order to give the construction a certain visibility in the context of the access area to the university campus. Partial roofing in the area of the flat roof is also proposed.

In most projects, a plastic foil is used as a carrier material in which the OPV modules are encapsulated and thus additionally protected from the weather. Some solutions use rope nets or membranes in addition to rod-shaped steel profiles. In the module design, there are also strip and planar/point-like solutions that sound out the design potential of the OPV. In all projects, the aim was to make it as easy as possible to exchange the OPV modules with regard to the façade construction as a research object and test facility.

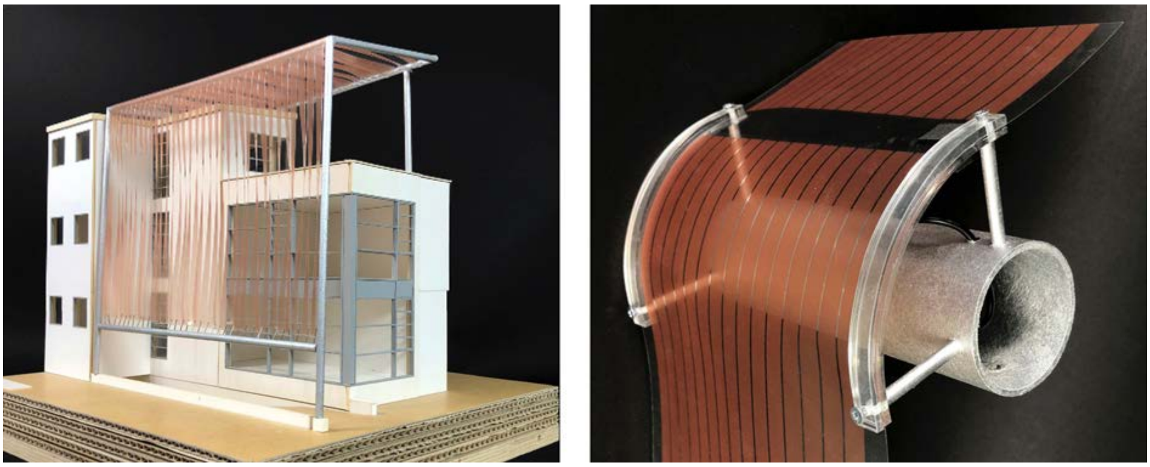


Fig. 5: Daniel Huuck and Alexis Lode, modell 1:50, model 1:2

6.1 Linear façade structures

Within the band-like concepts, Moritz Bachmann and Sven Vorliczky position the OPV façade in the area of the mullion and framed glazing façade. The solar foils are vertically mounted over the two storeys in the south- and the northeast. The substructure of square hollow profiles, which follows the structure of the existing façade, is fixed to the façade mullions at certain points. Based on the motif "rays of light from different points of the compass", different high and low points are distributed over the surface, which move the solar foils against each other in the area of the mullions. This results in different expansions for a view from the inside, which nevertheless provide sufficient sun protection. Integrated, opening frames allow access to the windows. (Fig. 4)

In contrast, Daniel Huuck and Alexis Lode move away their construction "Beyond" from the façade level. In doing so, they refer to the edges of the building and create the largest possible PV generator area. From the base point, the sheets are stretched over spacers (Fig. 5) in the plane of the parapet up to the edge beam of the roofing to also indicate the performance of the solar foils over the length. At end points, the sheets can be rotated 90° out of the plane. This allows partial tracking of the OPV modules and creates different viewing angles. To simplify the rotation, the paths are grouped in 5 areas. The partial roofing opens up additional possibilities of perception of the OPV in the overhead area.

Benedikt Buchmüller and Quirin Stammler extend the framework over two floors, but it is clearly extended beyond the alignment of the building. The length is determined on the one hand by the shading of the north-east façade, on the other hand the external effect is increased, as the OPV façade is thus also perceptible from the north. In addition, an "inviting gesture" to the main entrance is created and the access to the underground car park is separated from the pedestrian access. The tracks of the solar foils are fixed at the height of the floor ceiling and can be rotated by 45° in both directions by means of two movable holding points. (Fig. 6)

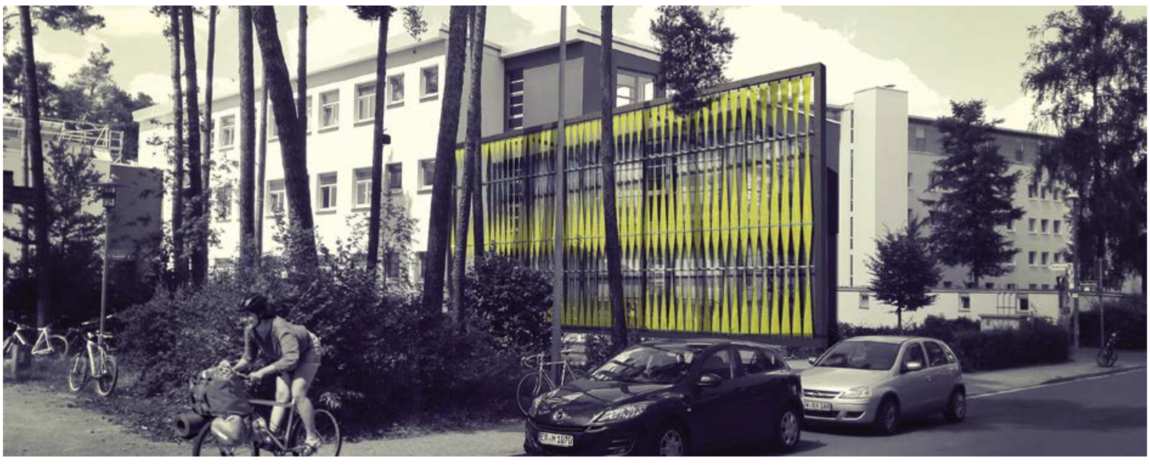


Fig. 6: Benedikt Buchmüller and Quirin Stammler, rendering

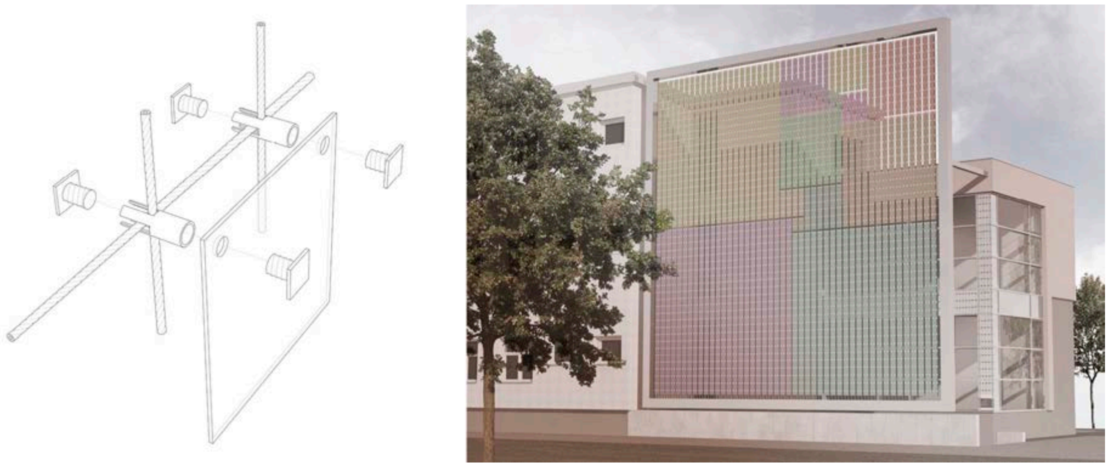


Fig. 7: Peter Simon and Benedikt Zarschizky, drawing and rendering

In the “Square“ concept by Peter Simon and Benedikt Zarschizky, the primary construction forms a square frame that ends at the height of the attic of the three-storey main building. An orthogonal cable net is stretched between the edge beams, to which the OPV modules are fixed in vertical stripes. Different square surfaces are generated with colour variations, which create a nuanced internal division. (Fig. 7)

Marjhonelly Concepcion and Nicole Polster chose a different approach, because they lay the solar films as horizontal strips around the three façades of the front section. Their “copper coil“ concept refers to the ZAE Bayern logo “as a significant symbol of energy research“. Horizontal sliding shutters, also fitted with OPVs, can be installed in front of the glazing on both floors to adjust the use of daylight and visibility as required. To stabilise the sheets, they are held in position field by field by springs on tensioning ropes. (Fig. 8)

6.2 Planar / point-like façade structures

The “squameus“ concept by Julia Credé and Astrid Pümmerlein was inspired by the roofing of a terrace at the AA School of Architecture in London. Two curved girders are placed at an angle in front of the south-west façade and run across the flat roof terrace. Folded plastic foils with integrated OPV modules are attached to the diamond-shaped stainless steel cable net stretched between them. The OPV modules are arranged closer and closer to the roof. (Fig. 9)

Fig. 8: Marjhonelly Concepcion and Nicole Polster, rendering

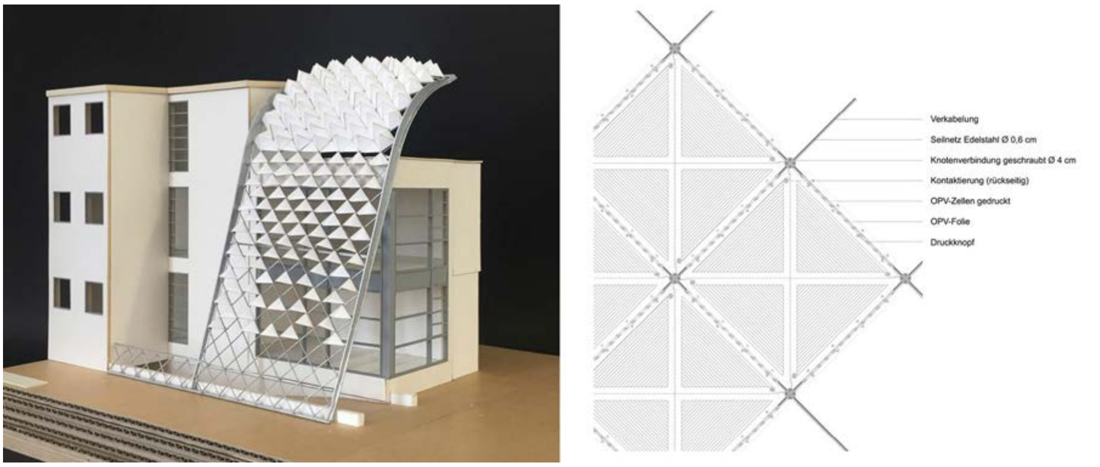


Fig. 9: Julia Credé and Astrid Pümmerlein, model 1:50, detail 1:5

The reference for Gözde Gürbüzler and Lisa Stapf is another realized project. The façades of the extension of the King Fahad National Library in Riyadh (2014) form a spatial zone of curtain-type, three-dimensionally shaped fibreglass membranes, equally elegant construction and efficient sun protection. For the ZAE building, this approach is varied in such a way that the membrane façade to the south-east is formed at a lesser depth, while to the north-east the aim is to create a three-dimensional spatial effect. The OPV modules are placed in horizontal strips on the sun sails, which are clearly spaced in the field of vision in terms of density. (Fig. 10)

The team of Antonia Bader, Stefanie Matthäi and Dominic Weinstein presents the post and beam construction with vertical steel tubes in a half façade grid, on which triangular frames are arranged offset to each other and rotated by 45° from the plane, which also creates a spatially attractive effect. (Fig. 11)

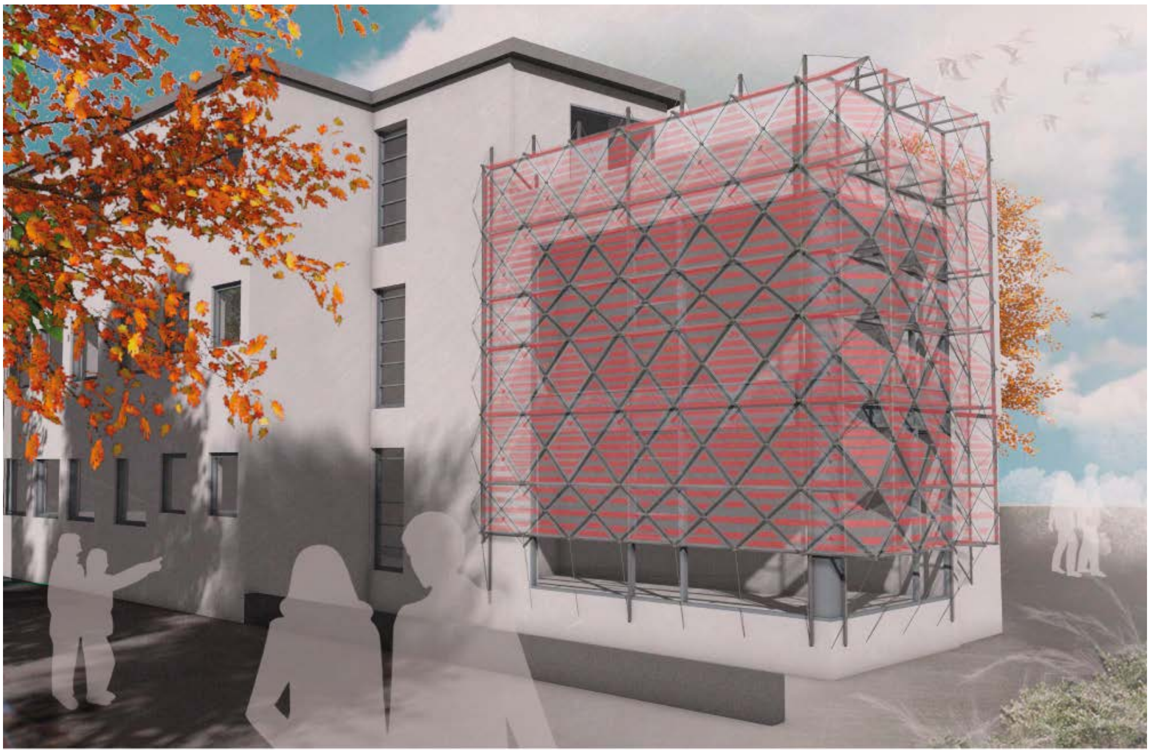


Fig. 10: Gözde Gürbüzler and Lisa Stapf, rendering

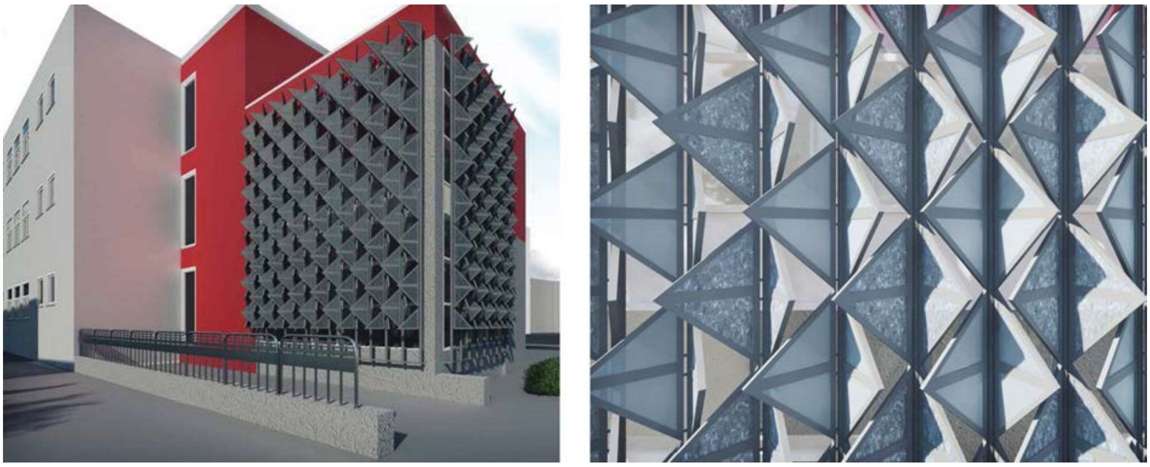


Fig. 11: Antonia Bader, Stefanie Matthäi and Dominic Weinstein, renderimgs

Robert Braun and Theresa Ketisch also position the OPV screen directly on the existing front section, but lay the frame construction with a square grid completely over the two façade areas. Three different sizes of the OPV modules (45 x 45 cm, 60 x 60 cm, 75 x 75 cm), which are suspended over the diagonal, are a response to the different requirements in the façade zones. (Fig. 12)

Tessa Distler and Merve Tufan in turn divide their construction, which is put in front to the south-east façade as a three-storey structure, into nine almost square sections. The horizontal cables of the hexagonal netting in front of it are also covered with hexagonal foils, each with three diamond-shaped OPV modules. (Fig. 13)

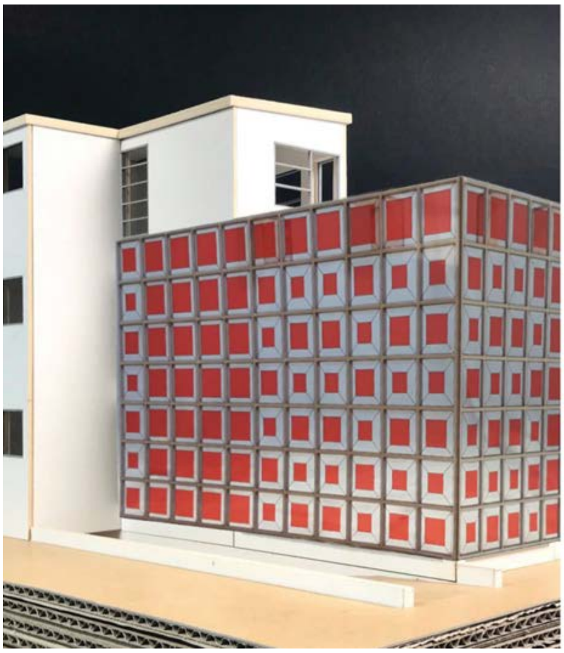


Fig. 12: Robert Braun and Therese Ketisch, model 1:50

Fig. 13: Tessa Distler and Merve Tufan, rendering

Fig. 14: Lisa Prokein and Lisa Schreiber, model 1:50

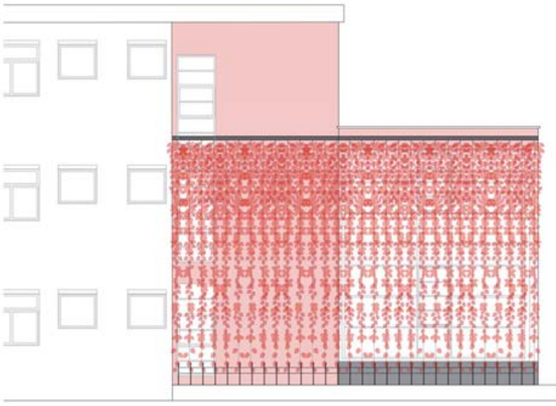


Figure 15: Giulia Rudloff and Katarina Sokac, drawing

Leaf-like structures show the projects of Lisa Prokein and Lisa Schreiber as well as Giulia Rudloff and Katarina Sokac. In the former, a fine net of vertical steel profiles is attached to the supporting structure, on which folded solar foils in six different sizes are alternately fixed, which additionally creates a shimmering appearance through variation in the arrangement. (Fig. 14)

In their "Plug-in Leaf" concept, Rudloff and Sokac stretch steel cables between the wall of the underground car park exit and a beam which rests on brackets at parapet height on the eastern corner of the front section. Three differently abstracted formats (based on leaves of oak, Norway maple (Fig. 15/16), hornbeam) are attached to these by means of thin, slightly bent metal tubing, which also includes the cable duct. In addition to the rotation of the surface between the base and the top of the construction, a very small but "natural" solution is created in the interplay of light and shadow, with advantages when replacing the modules.

Free forms, which are placed between the heterogeneous parts of the building, are chosen by two teams. Simone Baiz and Josefine Raab stretch a cable net construction over the south-east and north-east façades, in the meshes of which square modules of varying density are inserted. (Fig. 17)

In contrast, Kevin Beierlein and Fabian Holzer place a supporting structure with repeatedly spatially curved edge beams in front of the two façades of the head building. A plastic film is streched between them, curved in the same and opposite directions, as a carrier material for diamond-shaped OPV modules. (Fig. 18)

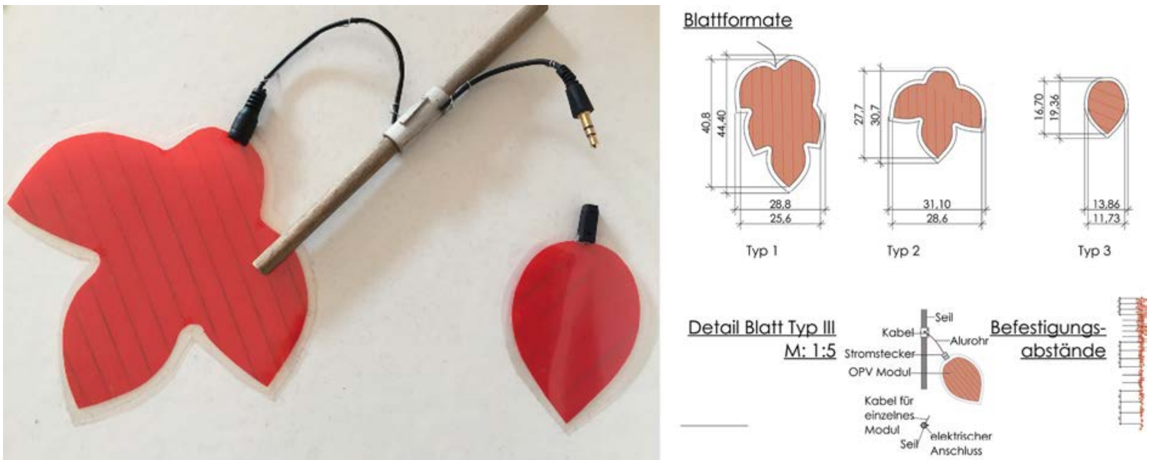
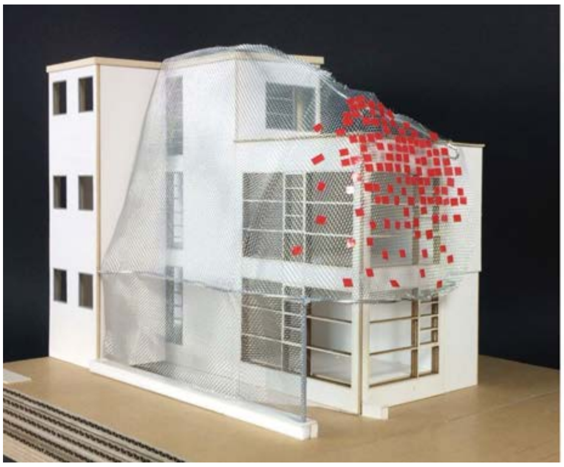


Fig. 16: Giulia Rudloff and Katarina Sokac, model 1:2, drawing (leaf sizes, detail leaf type III, fixing distances)



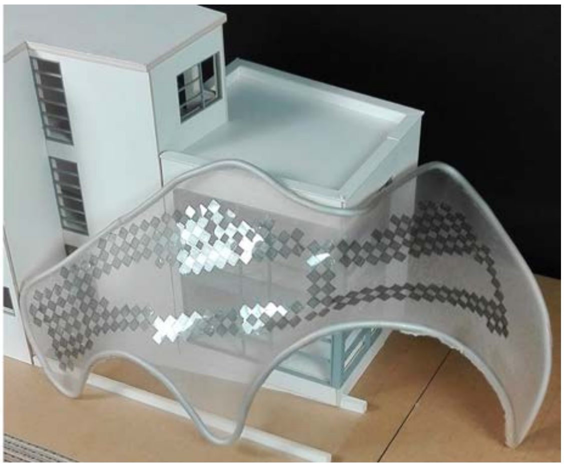


Fig. 17: Simone Baiz and Josefine Raab, model 1:50 Fig. 18: Kevin Beierlein and Fabian Holzer, model 1:50

7. (Interim) Conclusion

Considering the search for quality standards and competent decision-makers in the field of building-integrated photovoltaics (BIPV), architects – and planners – are primarily called upon to develop new solutions. This still means that the profession has to deal much more with the "progress in technology and science for an integral, future-oriented and resource-saving building" (Helmut C. Schulitz) [9].

With regard to Generation Y or Z, it is not only in the face of student strikes for the climate said, that "concern for the environment is politicized" and "sustainability is modern".[10] Therefore, students play an important role to interest architects in the multifunctional and design potential of photovoltaics. Even if topics such as BIPV continue to receive little attention in the curricula of architecture faculties, seminars such as "OPV Façade for the ZAE Building in Erlangen" show how curiosity and creativity can be successfully activated. [11]

In the end, the concepts developed did not always meet the requirement of planning a solar façade as a lighthouse project and research object with simple means, but in the occupation with interesting references and their adaptation, the designs, which also include in-depth structural engineering, show consistently functional and aesthetically appealing solutions for a striking sign of advanced energy research.

Students teams

Moritz Bachmann, Sven Vorliczky / Antonia Bader, Stefanie Matthäi, Dominic Weinstein / Simone Baiz, Josefine Raab / Kevin Beierlein, Fabian Holzer / Robert Braun, Theresa Ketisch / Benedikt Buchmüller, Quirin Stammler / Marjhonelly Concepcion, Nicole Polster / Julia Credé, Astrid Pümmerlein / Tessa Distler, Merve Tufan / Gözde Gürbüzler, Lisa Stapf / Daniel Huuck, Alexis Lode / Lisa Prokein, Lisa Schreiber / Giulia Rudloff, Katarina Sokac / Peter Simon, Benedikt Zarschizky

8. References

[1] See competition „Architectural Award Building-Integrated Solar Technology". https://www.sev-bayern.de <07.08.2020>, Krippner, R., 2017. Building Integrated Solar Technology. Detail green books. Munich. Solar Energy, in: Herzog, T., Krippner, R., Lang, W., 2017 (2nd edition). Façade Construction Manual. Munich, pp. 294-321 and Krippner, R., 2015. Energietechnik und Baukultur gehen Hand in Hand. In: B+B Bauen im Bestand, pp. 10–14

[2] See Manipulators, in: Herzog, T., Krippner, R., Lang, W., 2017 (2nd edition). Façade Construction Manual. Munich, pp. 266-293 and Krippner, R., 2005. (Gebäude-)Hüllen – zwischen bewußtem Nutzerverhalten und intelligenter Technik. In: Beton + Fertigteil Jahrbuch. Wiesbaden, pp. 50-54

[3] https://www.heliatek.com/blog/worlds-largest-facade-installed-with-organic-photovoltaics-in-the-port-of-duisburg/ <07.08.2020>

[4] https://www.hhs.ag/projects.html?projekt=aktiv-stadthaus-im-bestand-frankfurt&typologie= <07.08.2020>

[5] https://www.encn.de/en/research/renewable-energies/printed-photovoltaik <07.08.2020>

[6] MA-Modul Vertiefung 2 Technik „Material und Energie“: OPV-Fassade für ZAE-Gebäude in Erlangen. The seminar has been accompanied by Dr. Hans-Joachim Egelhaaf (Energie Campus Nürnberg / ZAE Bayern) and Dr.-Ing. Alexander Hentschel (Dr. Kreutz und Partner, Nuremberg).

[7] Meanwhile Helmholtz Institute Erlangen-Nürnberg for Renewable Energy (HI ERN). http://www.hi-ern.de/hi-ern/EN/home.html <07.08.2020>

[8] See exhibition: OPV-Fassade für das ZAE-Gebäude in Erlangen. Studentische Entwürfe [SS 2018, LV: MA-2200 Seminar „Material und Energie“]. Editors: Roland Krippner; Fabian Flade. Nuremburg Tech, Faculty of architecture, field of teaching Construction and Technology, Nuremberg, 2019.

[9| Schulitz, H. C., Form follows performance. 2010. In: Schulitz: Form follows performance / Leistungsform. Schulitz Architekten, Works 1995-2010. Basel [et al.], p. 9

[10] Stremmel, Jan: Alles Klima. In: Süddeutsche Zeitung, Nr. 40, 16./17.02.2019, p. 45

[11] The students have been awarded 2nd prize at the Innovationspreis Erneuerbare Energien 2018 of the Frank Seuling Stiftung (https://www.th-nuernberg.de/news/innovationspreis-erneuerbare-e/ <07.08.2020>