Solar Façade

Energy generation with a 2.500 m2 BIPV facade

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Abstract

Today's growing BIPV market has marked a general need of BIPV façade solutions. There are yet not enough ready-made design tools on the BIPV market, that allows a hybrid between form finding, shape optimizations, simulations and fabrication optimization. To achieve a seamless process from design to detail planning, a set of computational tools was developed to find customized and optimized façade solutions. With this digital approach, the computational design workflow allows aesthetic design optimization, to create a shape that relates client's wishes within the design constraints of BIPV, optimizing energetic yields in a free form's façade arrangement. Parametric design, combined with optimizations search algorithms and energy simulation analysis, conform a design workflow toward informed façade design. Active façades using solar energy are as well optimized to find the best façade disposition within an aesthetics range and client's expectations. The design process use advance computational design tools and compared design options using solar values over rationalized ratios to enable stakeholders and designers to decide for the best optimized and informed design.

Keywords: Building Integrated Photovoltaics, (BIPV), Solar Façade Design, Form-Finding, Optimization, Search Algorithms, Radiation Analysis.

1.Introduction

BIPV façade solutions integrate aesthetic and chromatic design, with energetic yield and economic values to façade architecture projects, towards meeting the current era need to becoming a climate neutral continent by 2050 [1]. There are many evaluation tools for environmental conditions, analysis and yield simulations [2], yet free-form BIPV façade applications represent a challenge to bring PV into facades [3 4]. This requires specific attention to provide customized solution, that considers aesthetic design criteria, along with economic feasibility and also bring the facades PV energetic performance to its maximum. From design to planning phases, AVANCIS [5] has developed a digital workflow integrating design tools and software to plan and optimize the disposition of solar panels in active façades.

This paper summarizes part of the technical consultancy AVANCIS provided to Leipziger Stadtbau for a BIPV façade project for a parking house in Leipzig, designed by the architecture office Architektur Von Domaros. The preliminary architecture façade design from the Architects had to be rationalized and reshaped in a way that maintained the most of its design essence, keeping the aesthetics of a free curvature surface. This was possible using a combination of form-finding and shape optimization processes, with energetic yield analysis techniques that ensured highly efficient BIPV facades made of SKALA solar panels [6].

The BIPV façade project implements computational and automation tools in a highly efficient design and planning process [47]. These tools help designers think in an integrated framework with simulation, visualization and the spatialization of outcomes. This paper presents an overview into the design optimization process and shape rationalization to achieve an optimal custom shape, active façade composed of solar panels.

2. Methodology

In order to rationalize and optimize the facades shape, the boundary conditions that constraint the design are set as follow:

a. Form Rationalization to maintain Parking Haus design criteria.
The preliminary design is a freeform façade element composed of several bands in a freeform curve. Along with a separation between vertical bands to ensure proper air circulation inside the buildings.

b. Substructure frames optimization
The second stage of the form finding process led to the realization that this customized façade had to minimize the number of customized substructure elements, to ensure a feasible substructure planning. This too had to be rationalized and optimized to bring the special substructure elements to a minimum and standardize as much as possible.

c. Panel optimization
   To minimize costs and maximize energy outputs, it is a condition the use of maximum possible of Skala solar panels in standard sizes, and minimum possible passive elements.

d. Energy yield simulation.
   To ensure the high performance of the PV panels, certain criteria had to be met. To start the disposition of panels in south, east and west facades. And tilt of the panels could achieve a better performance in relation to the free form.

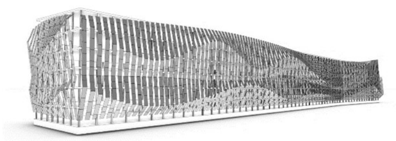
The Skala PV product used in the planning can be applied without need of special construction permits in surfaces up to 10 degrees facing downwards in a façade. This also allows the panels to be less exposed to shading and assures better yield outputs. The shape from finding had to incorporate this condition in it design constraints to meet the substructure requirement to minimize special custom substructure elements. It is constituted a series of structural frames in different angles that host the Skala panels. The substructure is adapted to every panel placement, allocating the substructure to the general structure.

2.1. Form Rationalization

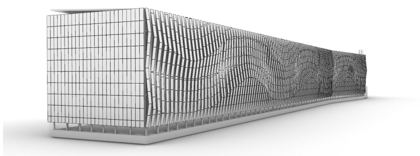
Rationalization and shape optimization use several algorithms that simplify while optimizes the design, with a combination of design constraint and design goals. Parametric design combined with genetic search optimization algorithms produce a generative optimized design and deliver informed solutions for designers to elaborate upon [7,8]. This methodology allows us to understand the qualitative and quantitative results of a design process in a holistic approach to integrate aesthetics with energetic and structural optimizations. This was possible using a combination of parametric form-finding and shape optimization processes using genetic search algorithms, with energetic yield analysis techniques using parametric software Rhino and Grasshopper plugins combined. Grasshopper is a visual coding environment that interacts with the Rhino modelling space. A genetic algorithm solver (GA) creates a population of solutions based on genomes – the variables subjected to change - that approximate to a fitness value– the desired parameters to maximize or minimize [9].

Three approaches to the design shape were carried out.

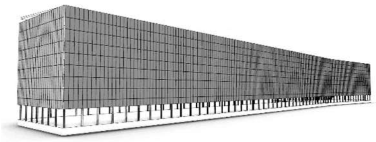
I. First a rationalization of the desired shape, a parametric model that approximates to the clients wishes and the architect's proposal.
II. Second, an optimized shape, using the form finding search algorithm to meet the highest energetic values without sacrificing PV panels to a shade and minimizing use of passive elements. This design accommodates the panels under 10 degrees of inclination and takes advantage of radiation a flat façade and the original freeform approximation.
III. Third a flat standard solution to serve as reference for the optimized and the complex solution.



I. original shape



II. Optimized shape



III. Flat façade

Figure 1. *Shape rationalization,*
I. Approximation to original shape.
II. Optimized shape. III. Flat façade solution

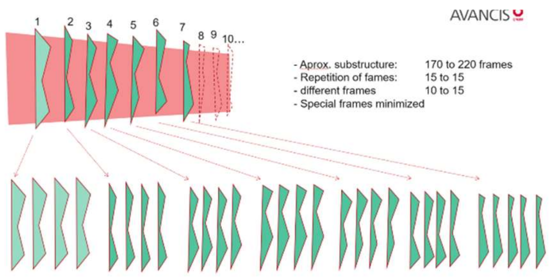


***Figure 2**. Substructure elements - trusses profile abstraction. Kinks produced by form finding process.*

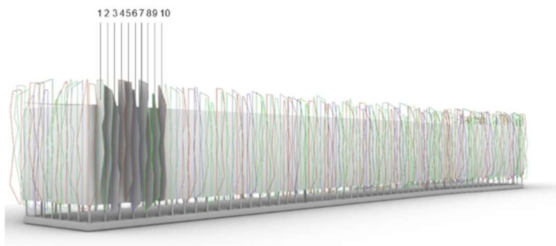


Figure 3. *Form Finding - Shape Optimization. Random disposition of profiles to obtain a free form facade.*

2.2. Substructure frames Optimization

Being the optimization tool a genetic search algorithm GA, the solver modifies the parametric model, created from the shape rationalization. After the fitness function evaluation, the solver modifies the disposition of the elements to find the best approximation to the given free form curve. Because it is an evolutionary solver it creates a population of solutions and finds the numerical best fit. It is known to designers this might not be the best aesthetical fit but approximates already very much an optimized solution [9].
The designed and implemented optimization search algorithm uses an abstraction of the profile for the trusses for the substructure elements. The search is set to find the optimal angles for the kinks in the substructure without overpassing 10-degree angle for the downward facing panels. And iterate through the possible combinations of a given number of trusses, ten (10) was the parameter of different truss to shape as substructure elements.

Combined with a search for optimal angles in the trusses profile kinks to fit the desired curve. The fitness for the optimization uses a combination of signalling visualization in red for the underperforming solutions and in blue when the fitness values where reached. Therefore, blue lines describe truss abstract profiles that are within fitness function results.

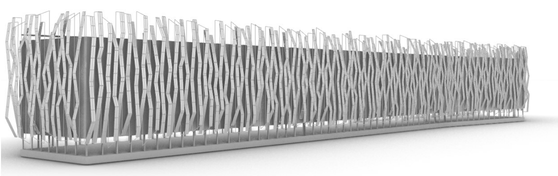


Figure 4. *Form Finding - Shape Optimization. Possible panel distribution in a random disposition of profiles for a free form façade.*

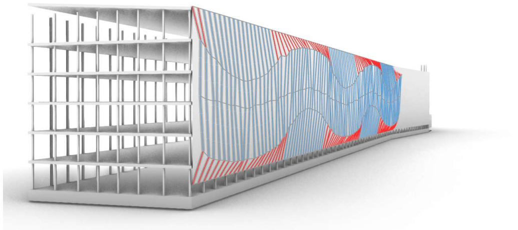


Figure 6. *Form Finding - Shape Optimization. Search algorithm near to final output to fit profiles to freeform curves from original shape*

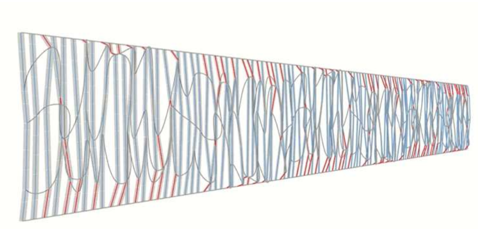


Figure 5. *Form Finding - Shape Optimization. Search algorithm intermediate output to fit profiles to freeform curves from original shape.*

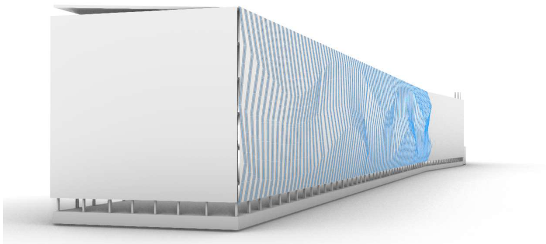


Figure 7. *Form Finding - Shape Optimization. Search algorithm final output to fit profiles to freeform curves from original shape*

The resulting curve described by the profile lines is outlined to compare with the original shape and asses aesthetically the shape. The optimized output describes yet a straight curve, and a need to include freedom to the curve is done by shifting the profiles in the vertical axis.

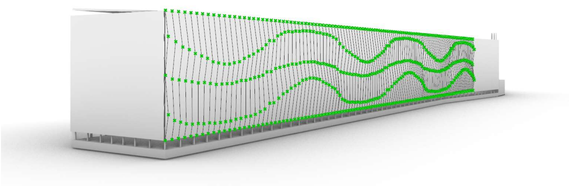


Figure 8. *Form Finding - Shape Optimizations. Curves described by optimized shape that approximates initial free form curves.*

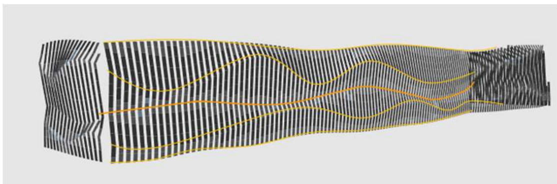


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Figure 9. *Original shape rationalization, with description of freeform curves.*

The solution was founded through adaptation to a top curve and the repetition and rotation of standardized substructure elements that describe the curves with the kinks. The final optimization rationalized the substructure elements in such a way that they describe a pattern, a combination of initial 1o frames that then rotate and mirror to achieve the final rationalized vertical frames. This way the number of repeated elements is maximized, and the number of special elements is minimized and the taken into consideration to achieve a special character to the curves according to design criteria and requirements. The special frames and the corners allow to evoque uniqueness to the emergence of the surface's special traits.

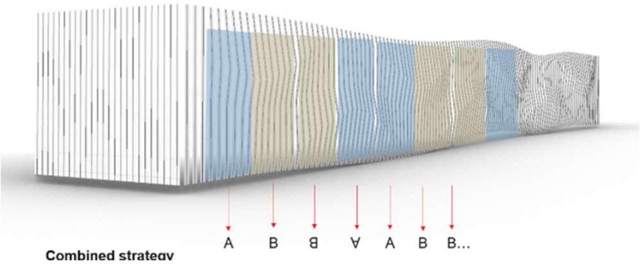

Figure 10 *Form Finding - Shape Optimization. Profile curve disposition creates a pattern and a curve, aligned with top curve to approximate initial free-form.*

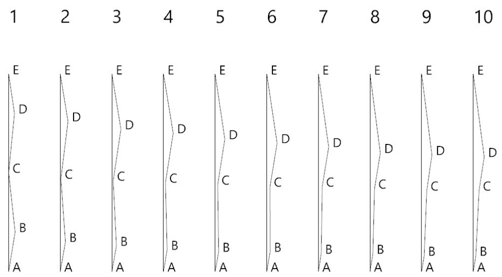

Figure 11. *Kinks produced by form finding process.*

To reduce the amount of customized substructure frames or trusses the design used a maximum of 10 elements and placed them sequentially in a pattern that describes a curve. Nevertheless, to achieve likeliness to the preliminary shape, this could not be done by hand without losing optimal design conditions.

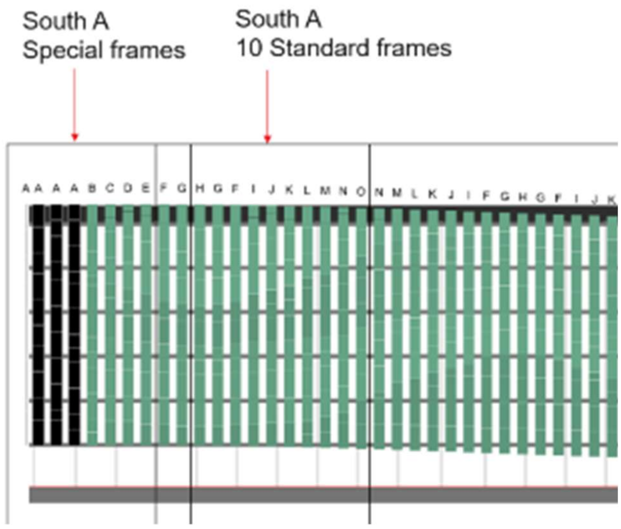

Figure 12. *Optimized façade section overview. Letters show substructure elements positions*

2.3. Panel Optimization

The amount of standard sizes was maximized, and minimum possible passive elements. At the same time, creating sets of special sizes and avoiding single modules. Additionally, the design uses the smallest dimensional Skala panel can be produced and operates freely with the dimensions to achieve a free form with restricted sizes, using scalable panels from standard sizes to customs and uses the minimal possible of dummies with sizes in ranges of the 30 cm panel size (Figure. 13).

The structural and shape optimizations produced 10 types of substructure frames and fewer special size (Table 1).

The elements are repeated and adjusted to the guide curve to provide the free form effect desired. (Figure. 10)

2.4. Energy simulation

Consequently, panels with lower inclination also receive more irradiance, a comparison between the original shape and the optimized shape proposal for Solar irradiation shows the improvement in the performance of the panels with the optimized freeform solution. (See Figures 15-17)

Main Building	
Standardized Truss Type	Amount
F	14
G	14
H	7
I	13
J	12
K	12
L	12
M	12
N	12
O	6
10	Total Standard Truss Types Main Building
Special Trusses South 2	
P	1
Q	1
R	1
S	1
Special Trusses South 1	
B	1
C	1
D	1
E	1
Total special Trusses Main Building	8

Table 1: *Truss substructure element types and amounts found in main building design.*

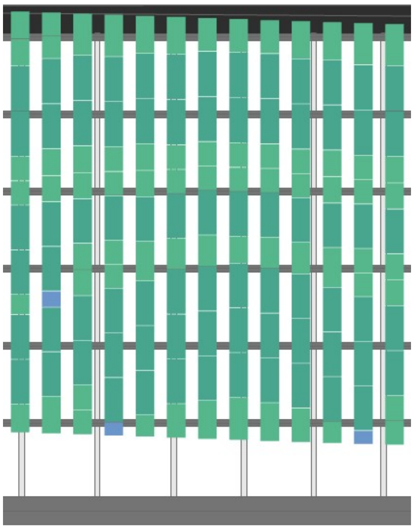

Figure 13. *panels distribution optimization. Blue colored panels represent minimized passive elements*

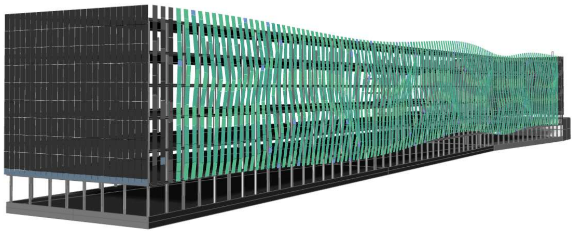

Figure 14. *Final Optimized shape*

Figure 15. *Solar radiation simulations on the rationalized façade solution I.*

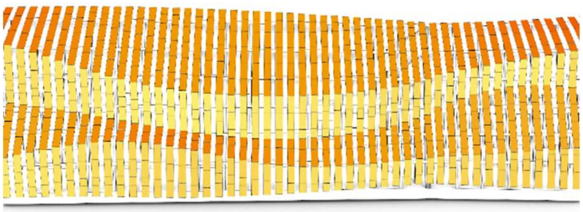

Figure 16. *Solar radiation simulations on the optimized shape façade solution II*

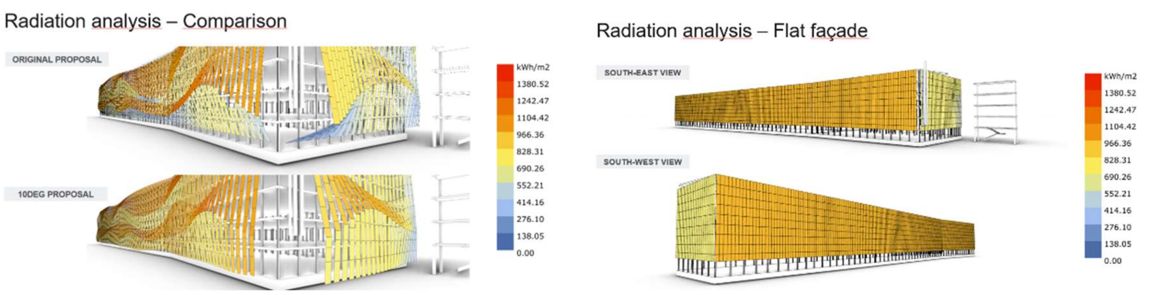

Figure 17. *Comparison of Solar radiation simulations of the different façade solutions*

3.Results

Energy calculations where performed to compare the 3 different scenarios. The analysis considers the original shape rationalization, the optimized shape and a standard solution flat surface with Skala color grey Anthracite G001. The original shape is the first approximation to the freeform shape that the rationalization produced, the optimized shape and a flat façade to serve as comparison point as a standard solution. Consequently, the performance ratio of the optimized solution exceeds 5.4% over the flat solution, and 8.7% over the original shape.

Option	Module number	Area	Annual irradiance	Module performance
	modules	m2	kWh/m2	%
Original	2,074	1,849.8	827	87.7
Optimized	2,099	1,876.5	909	96.4
Flat	2,439	2,486.8	857	91.0

Table 2. *Energy analysis output, comparison between three façade shape solutions*

4. Conclusions

This project combined state-of-the-art PV panels with advanced computational methods in the design and planning phases for the BIPV market. Computational tools were used to support an informed design that adapts to individual requirements of a climate-friendly façade solution with a desired free form shape. This project shows the use of computational tools to produce a design that adapts to free-form shape incorporating the boundary limitations of Skala solar modules and structural limitations. This digital workflow allows s and stakeholders to make informed decisions in relation to design costs and yield expectations, optimizing the use of solar energy in building envelopes.

5. References

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