Sun Shades

About Designing Adaptable Solar Facades

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External shading structures are a well-established typology for reducing solar heat loads. A major disadvantage is their inflexible nature, blocking views from inside and desired solar radiation for seasons with less sunshine hours. An adaptive approach on the other end can accommodate dynamic environmental exchange and user control. Furthermore, kinetic movement has great potential to create expressive spatial structures. However, such typologies are inherently complex. This paper presents the design process for two novel adaptive façade typologies, conducted on an experimental level in an educational context. Moreover, we will discuss the conception of a suitable methodological framework, which we applied to engage the complexity of this design task. Thereby we will highlight the importance of employing various methods, combining analogue and computational models not in a linear sequence, but rather in an overlapping, iterative way to create an innovation friendly design setting. The Sun Shades project offers insight into the relationships between design potentials inherent in adaptable structures and the advantages and limitation of computational methods employed to tackle them.

Keywords: computational design methodology, performance-based design, associative geometry modelling, solar simulation, physical form-finding, design theory

INTRODUCTION

Sun Shades is a project-grounded research studio (Findeli et al., 2008) exploring design possibilities for two novel adaptive solar façades typology on a prototypical, experimental level. It combines passive shading with energy harvesting through a kinetic concept; strong emphasis is placed on exploiting the expressive and spatial potential of such structures. Key design drivers include lightweight construction, spatially extending structures, low maintenance soft actuation, the capacity to adapt to environmental change through movement and a certain geometrical ‘fuzziness’, which allows the structure to adjust to different urban situations. (see Figure 1) The chosen technological basis are organic photovoltaic cells (OPV).

Computational design practice offers many advantages to tackle the complexity of such a task.
However, they can also present a serious limitation concerning design innovation and creativity, because creative approaches require complex, ill-defined problems offering enough freedom to develop novel solutions (Sakatani 2005). Consequently, we employed a design methodology which included various analogue and computational models to create an open, innovation friendly design setting.

This paper offers both, insight into the conception of two functional adaptive, lightweight solar façades, on a prototypical scale, named Miuso and Sola Swarm, realized by a multi-disciplinary team of future architects, designers and engineers as well as a discussion about designing an adequate design methodology. We (a) identify key issues and design drivers relevant for the development of responsive kinetic solar façades. Furthermore, (b) we discuss potential advantages and limitations of digital design methods. Based on this discussion, we (c) present an open methodological framework, capable of representing interdependencies of analogue and computational tools, which informed design decisions across different design stages and scales. Finally, we demonstrate (d) how this framework was implemented in the actual design process and summarize our conclusions.

**KEY ISSUES OF CONTEMPORARY FAÇADES**

The project starts with the simple assumption, that a large number of heritage buildings can be retrofitted with external solar shading structures, like Volker Staab’s C10 High-Rise Building, to reduce power consumption. In contrast to hermetically sealed, single-layer envelopes, external sun shading systems allow for environmental exchange and spatial expression. Such *second-degree auxiliary structures* (Hensel 2013), behave more like a membrane and less as barrier.

The major drawback of external sun protection,
such as Le Corbusier’s seminal *Brise Soleil*, is their immovable nature potentially blocking views to the outside or desired solar radiation at winter times. The latter can be especially problematic for locations in central Europe, where only 35% of all daylight hours show actual sunshine (Achstetter 1995). Adaptable structures are a potential solution.

FROM DESIGN POTENTIALS TO DESIGN DRIVERS

Based on this analysis, we identified the expressive and spatial potentials of kinetic structures in combination with solar shading and photovoltaic energy performance as key aspects for our *Sun Shades* façade typology. Four initial design drivers were selected to define the scope of our design framework: *spatial movement, adaptability, lightweight and organic photovoltaics.*

Existing examples of kinetic facades include the *Al-Bahr* Tower in Dubai or Jean Novell’s *Institute du Monde Arabe* in Paris. However, they are either limited to passive solar shading, require massive substructure, or are comprised of highly mechanistic and complex components. Neither of those projects combines adaptive solar shading with photovoltaic energy production. A recent research project, *SoRo-Track* (Svetozarevic 2016) highlights the importance of designing appropriate actuation and movement control systems.

The driver *spatial movement* addresses a twofold aspect of kinetic structures: the aesthetics of the actual movements and the potential to exploit the three-dimensionality inherent in this movement. Both aspects require a rethinking of immobile façade solutions. Patrick Schumacher argues for a “differentiation of façades with respect to environmental parameters” (Schumacher 2009). However, our approach should not result in a parametric patterns without the possibility for actual dynamic responsive behavior. (e.g. as in Zaha Hadid’s *Madrid Civil Courts Proposal*)

Adaptability describes the capacity to respond to changing environmental parameters through movement. A good example is the bi-metal installation *Bloom* by Doris Sung, as it varies the permeability of its skin according to surface temperature. However, Adaptability refers in this paper also to the topology of a structure, which allows for the adjustment in relation to different architectural geometries. (e.g. sun screen for double curved facades). (see Figure 2)

The design driver *lightweight* refers to structures, which are physically and aesthetically light and which control their movement easily and logically with as little components as possible.

The implementation of organic photovoltaics forms the technological basis. We have chosen cells, sponsored by Opvius GmbH®, with an electric efficiency converting approx. 5% of total sun power to energy. Although, overall efficiency is lower compared to high performance silicon based photovoltaic cells with approx. 20%. However, OPV cells do not suffer from substantial efficiency loss in case of partial coverage or imperfect solar angles. The cells are light, flexible, and partially transparent. The amount of grey energy required for their production is regained within days. Summing up, their properties are ideal to speculate on novel architectural applications and spatial potentials.
DIGITAL DESIGN METHODS - THEORETICAL BASIS FOR DECISION-MAKING

Rittel and Webber observation that for wicked problems, “the choice of explanation determines the nature of the problem’s resolution” (Rittel at al. 1973), was the starting point of our considerations about method design. We conclude, that how and by what means a design subject is approached already implies its potential solution - assuming, that a set of methods, at least implicitly, represents the explanation of a problem. For the Sun Shades project, we implemented several distinct methods to create a framework that is innovation friendly, generating solutions to address differing requirements in various fields. Methods design is a challenging task prone for misconceptions. Nevertheless, it offers abundant possibilities for new opportunities.

The multidisciplinary nature of our project, with its manifold areas of exploration, representation and realization, resulted in a high “effective complexity”. Gell-Mann and Loyd defined complexity “as the length of a highly compressed description of [an entities] regularities” (Gell-Mann et al. 2004). In the case of the Sun Shades project, a substantial amount of these regularities consists of relationships between geometrical elements and physical properties, within a kinetic, spatially expanding structure. From this perspective, digital design tools and strategies, potentially combined into a single process chain (see Figure 3), seem at first to be a self-evident choice, offering obvious advantages for exploring and maneuvering this complexity.

Potential advantages

Geometrical, mechanical and kinetic qualities situate perfectly well within the realm of direct digital representation, because of their mathematical nature. Methods of “associative geometry modelling” (Burry 2003), geometry modelling in combination with physical analysis, allow to use resulting simulation data immediate for geometry formulation, or for iterative strategies like topological optimization. This facilitates a seamless extension of the digital, associative design model, which can include production data and assembly information. Furthermore, it can prevent, for example, fabrication and communication mistakes. If the final design consists of a high number of individualized members, or if its geometry adapts in detail to physical parameters, associative design modelling even becomes imperative. By altering design parameters, many variant solutions can be generated and easily evaluated. Next, the entire data model can be used as sole, central structure, as interface, which provides, for example all necessary data for model-making, prototyping, and for producing representations. In case of design thinking, the need to transform design intentions into formalized descriptions of relationship helps to reveal and structure a projects complexity. The digital design process can be understood “primarily as a disclosure of constantly reappearing patterns of thinking that govern the design process” (Kotnik 2011). Thus, a digital design process clarifies these thinking patterns and helps to develop the underlying methods concisely. However, this clarification process requires the interchange of project information, to use digital models as a medium for knowledge interchange.

The algorithmic representation of some design maps like the Analysis-Synthesis-Evaluation Model (Gero 1999) is similar to the representation used to depict algorithmic structures (i.e. flow diagrams of parametric models) - design as logical process, nicely organized in clear causal structures.

However, from a more practical, designerly point of view a design process can also be represented as “negotiation between problem and solution through the three activities of analysis, synthesis and evaluation” (Lawson 2006). This negotiation involves human communication and therefore inevitably a certain degree of vagueness. Negotiation refers, according to Lawson, to problem definitions, constraints and solutions, which are comparable to moving targets, adding a touch of unpredictability. Consequently, it seems natural to understand design as a fuzzy, potentially even messy activity, a far cry from well-organized structures. (see Figure 4).
For such a concept, effective complexity unfolds by imagining increasingly precise future designs in their different, dynamic forms of manifestation. This is not only true for clear, pre-rationalized cause-result-structure (read planning), but also for a post-rationalization approach, where the arguments may follow the solution. Moreover, the arguments may not necessarily align with any formal connection in this growing design mycelium of different positions, definitions and solutions, generated through a broad variety of tools and techniques.

Resuming Rittel’s argument, that our “`world view´ is the strongest determining factor in explaining [...] and therefore resolving a wicked problem” (Rittel et al. 1973), signifies that this is also true for the meta-task of designing a framework of design methods. A diversity of opinions, tools and methods favors different perspectives on a given design subject, and therefore expands the potential solution space.

**Potential limitations**

However, a mindset appropriate for developing algorithmic design models is not necessarily suitable for an open, innovation friendly design setting. Thus, the just described advantages of a digital design perspective can also present potential limitations. These limitations may narrow the designers view on the problem at hand and constrain design possibilities to the solution space of his or her digital box.

It is rather doubtful, whether decision patterns, expressed in a digital design model, originate from considerations relating to desired design qualities or whether they are superimposed by instrumental needs related to the implementation of digital strategies. Therefore, the argument is relevant, that digital design has a tendency to favor cognitive patterns related to organization and hierarchy (read quantity) rather than patterns related to topology (read quality) (Kotnik 2011). Furthermore, representing design ideas within associative models implies an `Ockham's Razor`, which permits only information to pass, that can be explicitly expressed through formal language, favoring convergence over divergence and syntactic strength (read rules) over semantic (read meaning). Finally, activities associated with creativity have their own, non-linear temporal rhythms and rational...
ization strategies. These are different from the ones in digital modelling, characterized by the slow accumulation of a multitude of building blocks in a strictly causal, linear way.

**APPLIED DESIGN METHODOLOGY**

Seeking for heterogeneous and experimental solutions, our foundation was not based on a single consistent digital design model. Instead, we used explicit geometry modelling, physical simulation, radiation analysis and some ‘on-the-fly’ made grasshopper snippets as separate elements. A broad range of analogue modelling techniques accompanied the computational ones: two- and three-dimensional sketching, physical form-finding, and experimentation of material properties, kinetic models, mock-ups and prototypes, among others.

This diversity of modelling strategies facilitated explorations into different fields, mutually informing each other, without the need to connect them formally. Different patches of an associative computational model formed integrated but not limiting elements of this weave (read tools and methods).

Clear formulation design tasks encouraged the use and interplay of those methodical patches along almost all stages of the design process, allowing for recapitulation of design choices from different perspectives. The result was a dynamic, accumulating network of models, representing a multitude of aspects of design knowledge and decisions.

**PRACTICAL IMPLEMENTATIONS**

This paragraph exemplifies the practical implementation of our methodological setting, with the aid of our design drivers, reflecting on the design process from conception to completion of two fully functional demonstrators.

The design driver *spatial movement* implies a strong interest in the expressive potentials of kinetic structures. (see Figure 5)

In reference to Manuel de Landa’s interest in materials that “compute” form, we started with material properties and physical forces that “compute” movement (Landa 2010). This shows that analogue
form-finding procedures facilitate not only structural formation and expedite design decisions regarding shape but also regarding movement. The results confirm that analogue form-finding facilitates structural formation and expedites design decisions regarding shape and movement.

From this pool of ideas, some kinetic strategies advanced further. Refinement included cross pollination with information from solar, structural or fluid physics simulations, as well as with constraints inherent to different forms of movement actuation (i.e. pneumatic vs. mechanic). Other tools, besides physical models, were used to investigate movement scenarios. For example generated the use of Blender, a fluid physics simulation insight into the differing behavior of pneumatically inflated geometries.

An alternative approach analyzed the interdependencies between geometry and movement of traditional origami pattern through simple paper models. The results were diagrammed graphically, transferred into a three-dimensional digital model from which the unrolled geometry served as production data for a cnc-cutting center.

The qualities of a movement cannot be characterized solely through static forms of representation. Therefore, investigations refining speed, sound and movement choreography included prototypes, physically inflated by lungpower, bicycle pumps or a compressor, as well as the programming of physical computing components to test muscle wire actuation (e.g. shape memory alloys) or the behavior of pneumatic valves. This all shows that advancements evolved not in a linear fashion, but rather in a fractal way, leaping for example from physical model to computational simulation and physical computing.

The design driver adaptability is one of the key aspects of the Sun Shades project, referring to both kinetic and topological adjustment. Kinetic adaptability reflects the complex relationship of environmental exchange over time. Topological adaptability addresses the adjustment to different architectural geometries. The latter was mostly tested through a series of visualizations for different scenarios.

Kinetic adaptability designates, in our project, a specific focus on combining photovoltaic energy production and shading, which requires the functional adjustment of movements in time and space. The team used solar simulations (in this case off-the-shelf available Ladybug plug-in for Rhino Grasshopper) as a “[...] tool [...] to develop intuitions and analysis of performance” (Marsh et al. 2011). In our case, it supported a better understanding of the complex relationship between sun vectors and geometrical organization over time. (see Figure 6)

Digital solar analysis tools were applied in two ways, in a concise associative geometry model and
at the end of various short digital process chains. The latter proved especially useful to inform design decisions by testing widely different geometric typologies (i.e. rotating logic vs. folding logic), and to test variations of macro-geometry orientation together with different opening states of photovoltaic cell assemblies. The former was used in a more general, educational sense, to provide an example how solar simulation data can directly inform geometry (e.g. size and inclination of elements) to understand and modify shading effects for summer or winter scenarios. Moreover, estimating overall photovoltaic energy performance, based on total sky radiation, proofed crucial for the communication with the engineering part of the team to determine the basis for self-sufficient actuation options. This knowledge sharing resulted for example in a kinetic scenario, which induced reactive movement. Light sensors triggered pneumatic actuators, controlled by physical computing components. (see Figure 7)

Lastly, a lightweight approach, matching the ephemeral aesthetics of OPV solar cells, requires material optimization and the actuation of movement with as little components as possible.

The Miuso team tested a topological optimization approach, which resulted in the increased structural stability of solar panels. The form of the panels evolved through a series of structural simula-
tions, conducted with Karamba plug-in for Rhino Grasshopper, to inform the topology of the supporting structure. These structures where then crosschecked through physical prototypes, realized by vacuum forming polyethylene-foil over a three-dimensional, cnc-milled mold.

The Solar Swarm team on the other end based their approach on the material properties of the available OPV-cells. They used the orientation of tree leaves and their growth patterns as functional metaphor to generate an assembly logic, based on soft, flexible and dynamic properties. In contrast to the Mioso team, this solution was mainly developed by a systematic series of physical models and prototypes, until the successfully implementation in form of a 1:1 prototype. However, a more rigorous computational analysis would have been necessary to develop this notion further. (see Figure 8)

CONCLUSION AND FUTURE RESEARCH

To summarize, we can recommend our strategy of loosely connected ‘method-patches’ as an innovation friendly way to combine digital and analogue models. It uses the advantage offered by digital design methods without implementing its biases. Although the specificity of our task does not allow for an overall generalization of this framework, it illustrates however, that a creative design practice can profit from combining computational methods with other raw materials for the advancement of ideas.

The methodical framework resulted in various novel design approaches. Within seven weeks, we had nine different, concepts for new types of solar facades, showing innovative, and at the same time
realistic designs. From there, it took another seven weeks two develop two concepts further, **Miuso** and **Solar Swarm**, which are represented in this paper.

Quite often educational projects with such a broad, ambitious agenda show tendencies to diffuse their efforts and end up following design tasks of minor importance. This was not the case in the Sun Shades project, portraying a good balance between divergence and convergence. We assume, that our framework not only ‘softly’ urged students to use multiple methods in an interrelated way, but also to evaluate and discuss their progress with each other. Consequently, knowledge in one area of expertise (e.g. analogue models) informed other areas (e.g. physical simulation or other computational techniques) in this network. Particularly the digital physical simulation reconnected our design investigations always with the properties of the real world; thus this tools formed a perfect connection to our early, vivid experiments.

REFERENCES


