International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:10, No:2, 2016

# Climate Adaptive Building Shells for Plus-Energy-Buildings, Designed on Bionic Principles

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***Abstract*****—**Six peculiar architecture designs from the Frankfurt University will be discussed within this paper and their future potential of the adaptable and solar thin-film sheets implemented facades will be shown acting and reacting on climate/solar changes of their specific sites. The different aspects, as well as limitations with regard to technical and functional restrictions, will be named.

The design process for a "multi-purpose building", a "high-rise building refurbishment" and a "biker's lodge" on the river Rheine valley, has been critically outlined and developed step by step from an international studentship towards an overall energy strategy, that firstly had to push the design to a plus-energy building and secondly had to incorporate bionic aspects into the building skins design.

Both main parameters needed to be reviewed and refined during the whole design process. Various basic bionic approaches have been given [e.g. solar ivy ™, flectofin ™ or hygroskin ™, which were to experiment with, regarding the use of bendable photovoltaic thin film elements being parts of a hybrid, kinetic façade system.

***Keywords*****—**Energy-strategy, photovoltaic in building skins, bionic and bioclimatic design, plus-energy-buildings, solar gain, the harvesting façade, sustainable building concept, high-efficiency building skin, climate adaptive Building Shells (CABS).

## I. Introduction

WITH the participation at the courses, students in the master- and bachelor- degree program were asked, to deal with a specific design-project [14]. The design-requirements had been very challenging, for there were different functional needs that were to incorporate in a convincing energy-strategy that should use photovoltaic [pv] thin-film cells in a very unconventional way into the building skin. The design-studies show their bionic approach [3] and their longing to balance the users' needs and communication with the facades and the technical requirements of hinge-less, adaptable shading devices.

## II. Contents

### A. An Introductory Outline Towards a Global Impact

The essential question for the future is how architects can add to overcome the problem of an increasing waste of energy in a fast rising world population. One challenging and promising aspect that has already been started in the academic field and vividly discussed within a minority of architects, would be the goal to develop, in a time range of approximately 50 years, buildings that never again use up and waste energy and other resources but instead become themselves a mean of generating the necessary output for themselves and for other intentions as well, the so called "plus-energy building" or "active house".

Fig. 1 Bionic Façade- Design, South + West Side of Biker Lodge Bingen [5]

The strategy would be to concentrate on the development of the inherent principles regarding the most proposing element of the buildings for reaching this goal – the "building envelope".

Future facades will have to massively collect energy in a very economical way, while at the same time fulfilling all amenities for the users. All aspects like transparency, translucency, opacity, building physics to comfort the wishes of the human users, technical restrictions to meet fire-safety, and so on, need to be researched and their reciprocity [see Figs. 1 and 2]. Especially when it comes to the original matters of architecture, like described by Vitruvius, and as one of them is beauty, the differentiation of the mere technical elements of the bionic facades need to be discussed and researched with regard to proportions, harmony in appearance and excellency. This will explicitly be true for the parts of the building and even for the smaller details they are made of. And so the whole building concept and its appearance will be in close design- relationship to its smallest parts and their interaction with the surrounding. Even more, we must explore building techniques and materials to operate in a modus of adjusted flexibility. This kind of adaptability to what is happening climate wise in the surrounding will be the most difficult and challenging part for architects and engineers in the future, because we need a visionary understanding of how to create these effects with lowest power input and minimum maintenance while at the same time solving all the problems of bending, rotating and other kinetic issues. So, this is the point where biology starts to intrude into architecture, because evolution has, although during long times, developed and optimized, yet on different scales, wonderful and harmonious plants, plant-parts or animals

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and animal-parts, that have been made to work in an absolutely efficient way with regard to very specific functions and the natural law of minimizing energy-losses wherever possible.

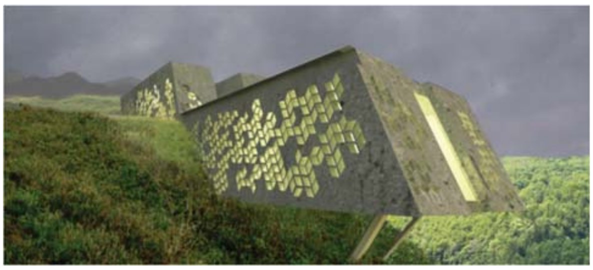


Fig. 2 Bionic Façade, South + East elevation, Korpa-Design Biker Lodge [5]

The broad field within the discipline of bionics has already discovered some very inspiring answers that were adapted to the field of engineering and building-works [4].

*B. Developing the Initial Research Target for the Design*

The first step into this architectural research study on building facades was done by explicitly collecting weather and climate data as well as doing research on natural sources of the given site [see Fig. 3].

Fig. 3 Site exploration and search for natural resources, Bingen [5]

Having closely looked at and discussed natural parameters worth to exploit at the given site and using the building itself as an energy supplying factor, an energy-strategy for every single design was individually developed to give ground for the main bionic principle [e.g. hygroskin ™ [12]] that had to be aimed for. This principle and its constructive elements had to allow the possibility for further attachment or improvement as a natural energy collecting device. Most of the design-researches were heading for the exploitation and use of solar power within these elements of the building shell. E.g. designing the case study towards a plus-energy building or heading within the design frame for a non-heated and non-cooled building.

*C. Existing Parameters and Focus on Points of Interest*

In order verify an acceptable approach, every student was asked to undergo a specific research procedure to meet the limitations of his specific design, e.g. power outcome with regard to element sizes, rotation angles towards the sun (during winter and summer time), of the facades less oriented towards the sun. The integration of the roof surfaces in all case studies was principally neglected in order to maintain the focus on those parts of the façade that are always much harder to implement with regard to user interference and transparency| opacity issues. This means, basically what will work on the building façade, will also work on the opaque roofs as well. By focusing on the facades of all 4 cardinal directions, the students had to undergo a process of refinement including the question for the main parameters that the chosen façade has to work for and what the initial output and target will be?

*D. Implementation of Solar-PV Thin-Film Elements on the Bionic Mechanism*

Although taken in consideration one primary bionic principle, it became very obvious right from the beginning that simplification was needed; the bio-mechanism system was completely converted to a shadowing device in front of the building façade.

Having a closer look on the "high-rise studies" we can realize, that two different approaches were taken by the students.

1.) "solar ivy" – a bionic principle that was directly derived from the ivy-plant and their imitation of the photosynthesis effect by implementation of pv-thin-film cells onto the artificial leaves surfaces. A pre-commercial development for the building sector was initiated by SMIT-New York [see Figs. 4 and 6].

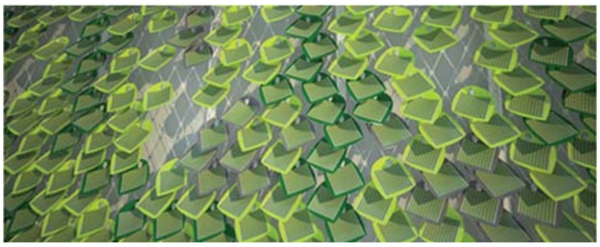


Fig. 4 Solar Ivy –artificial leaves with pv-attachment [2]

Whereas the "Müller"-design [9] had completely taken into consideration and as a design-driving force the "solar-ivy", we can clearly see the manifestation within the façade design of a rather unusual and unique way to treat opaque, transparent and translucent parts. Moreover, it is also realizable that this bionic principle **does not** [see Fig. 6] offer the options of flexibility towards a changing climate and weather situation and so has to be accepted as a rather static device [14]. Still unsolved in case of fire is the problem of electrical tension and voltage during fire-fighting efforts.

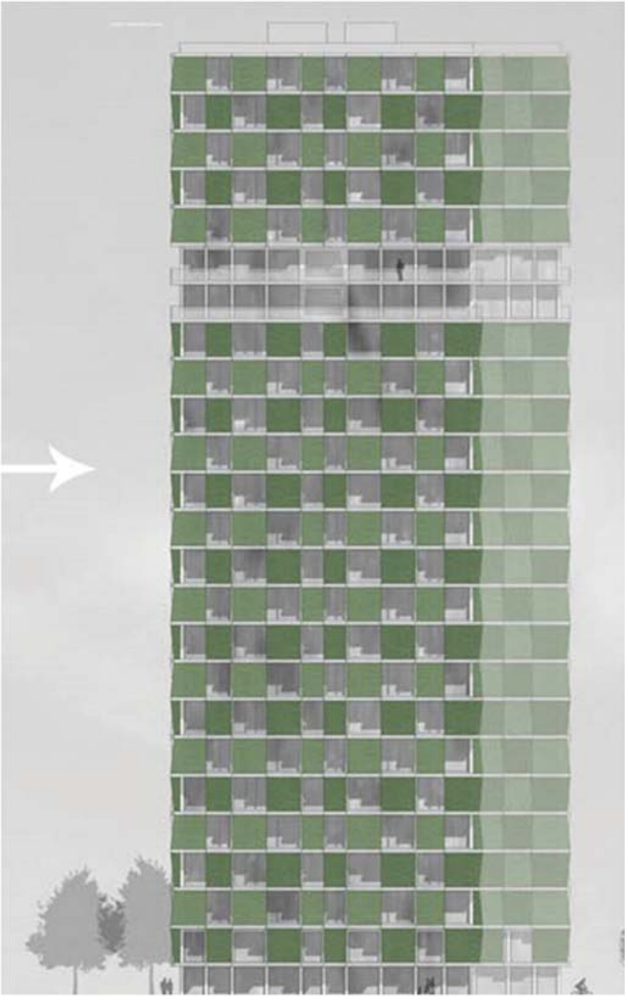


Fig. 5 High-Rise Revisited: Façade -“Müller”-Design using solar ivy [9]

Fig. 7 Proposal for new cladding with solar ivy, south and west elevation [9]

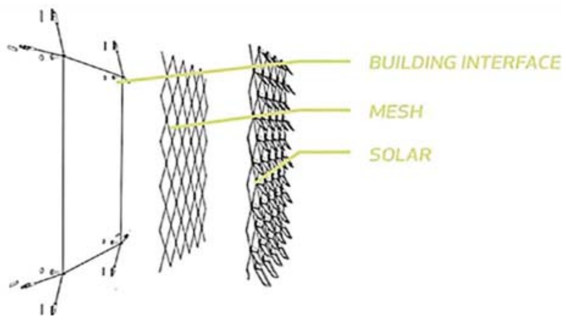



Fig. 6 Technical detail for the use of solar ivy [2]

Fig. 8 New entrance situation and transfer zone [9]

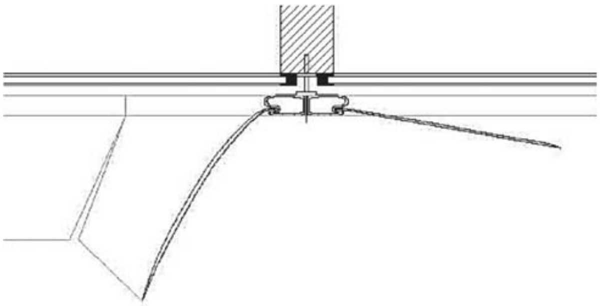


Fig. 9 Detail of flectofin-principle attached to façade-sub construction [11]

2.) "*flectofin*™" – a bionic principle that has been adapted and transformed from the Bird-of-Paradise-Flower [1] "strelizia reginae". A pre-commercial development for the building sector was initiated and a prototype being built by ITKE-University Stuttgart | Albert-Ludwigs- University of Freiburg | ITV-Denkendorf | Clauss-Markisen [see Figs. 10-13].

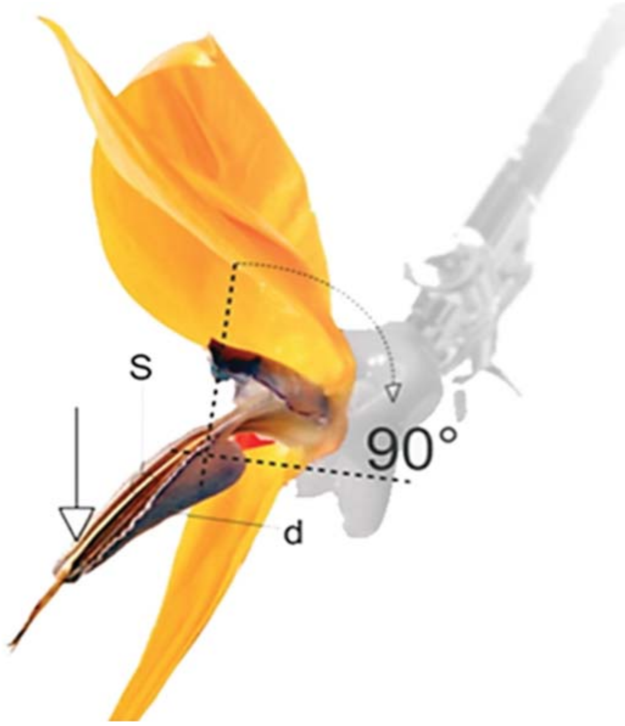



Fig. 10 Bird-of-Paradise-Flower "strelizia reginae" [1]

This research study has won the International Bionic Award 2012 and the Techtextil Innovation Prize 2011 and will be the bionic principle which this scientific research will focus on, mainly. Strategies to apply bendable thin-film pv-modules onto these textile "wings" or "flaps", opaque or translucent and with different shapes and sizes, need to be researched in detail.

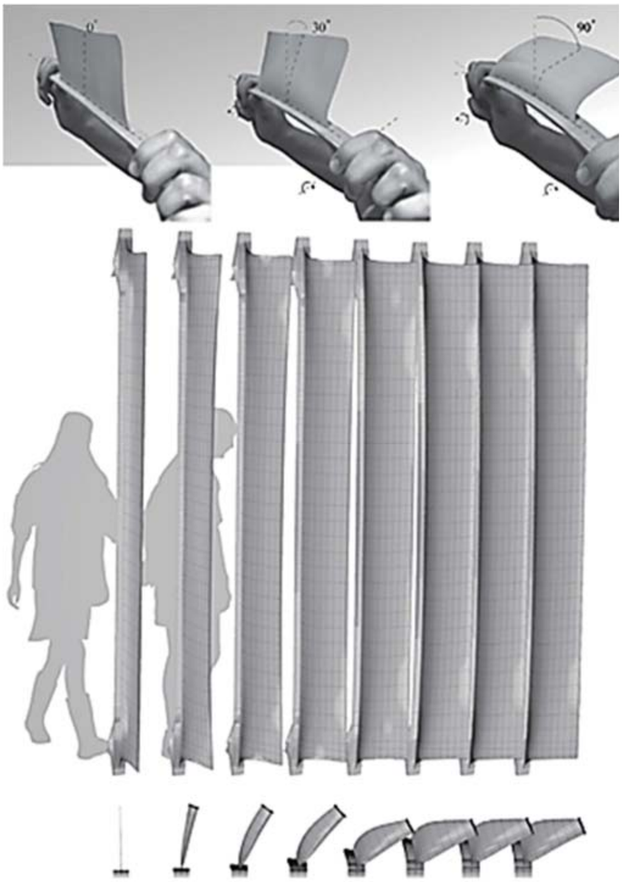



Fig. 11 Theoretical model of flectofin-lamellas [1]

Fig. 12 Prototype under real working conditions [1]

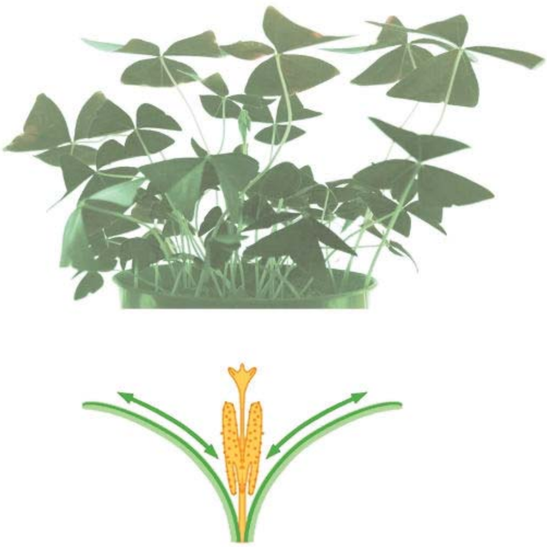
Very important will be the aspect that the materials work together in their behavior to bend likewise, comparable to a bi-metal material. As the sun-light hits the pv-modules and the "hinge-less flaps" [made of a mixture of carbon textiles and layers of synthetic resins], the increasing temperature on the surface starts to curl the "flaps" and makes the photovoltaic-modules expose themselves more and more directly and unobstructed to the sun.

Fig. 13 Mock-up showing 4 different stages of openings [1]

All other students “Neverbickaite” [11] – “Dittmar” [10] - and “Immenkamp” established their designs on the “flectofin-principle” as described beforehand under number 2.) and added an energy collecting pv-system onto the sun-facing surface of each flapping mechanism-element [see Figs. 14, 15, 19].

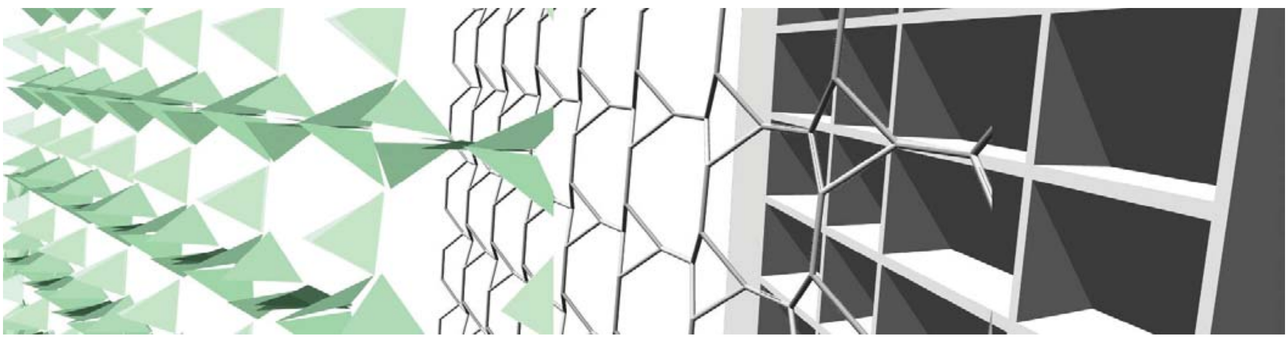
The power collection would also work on dusky days, because the output and efficiency of the thin-film-pv-modules is working on a wide range of climatic conditions. An electrical induced manual override gives the opportunity to accomplish human user behavior. A “nithinol-wire gaze interwoven into the flaps” [see Fig. 19], works as a kind of resistor and because of its electrical conductibility, which starts to build up an internal constraint when targeted by sun rays, the flaps steadily change their state of condition from “completely open” to finally “completely closed”. And having reached this last position, the full shading for the space behind is completed – overheating is absolutely minimized and the parallel work of collecting solar energy is at its peak.

Astonishingly two of the three designs – namely the “Neverbickaite” – and “Dittmar”- design, have come to end up with a hexagonal [see Fig. 20] and an octagonal [see Fig. 18] structure as the primary [storey-high] module to arrange the flapping-mechanism of the flectofin-flaps.



(a) Clover open up for photosynthesis process

(b) Clover closed down for energy storage



(c)

Fig. 14 Clover-plant open at daytime (a) and closed at night-time (b) [10]

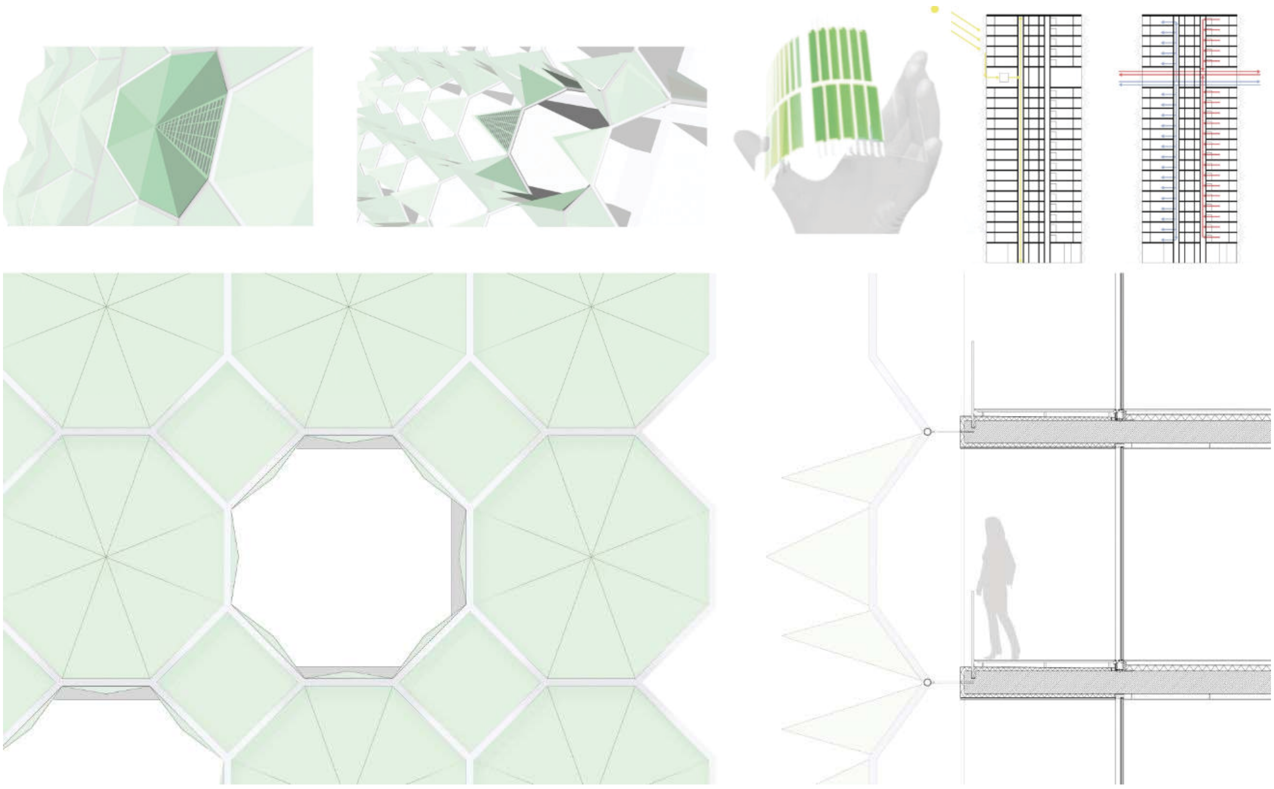


Fig. 15 Octagonal module, each using 8 flectofin-shading-elements [10]

The “Immenkamp”-study was embarking on a rather unusual almond-like primary module. The working mechanism of the flectofin-principle would have needed much more detailed refinement which at that stage could not be carried out because of the time schedule.

Having a closer look on the “biker-lodge studies” we can realize, that all students were focusing on the “flectofin” bionic mechanism and surprisingly we learn that all of them had started an individual approach and improvement, which finally resulted in differentiated and convincing design-statements [7]. The shading devices have become an integral part of the design process for the appearance of the building as a whole.

So we find, the “Aubertin”-design [6] was coming up with a star-like module derived from the opening and closing mechanism of pine-cones [see Figs. 22-24]. By choosing different element sizes, a playful and variable appearance gives a unique expression to the building.

The “Frischholz”- design [8] on the other hand uses upright standing elements in a very slender triangular shaped version, each overlapping the other by a certain amount of the element-area. As we can see on the interior perspectives, there is a great potential for interplay of “intimacy and transparency” and a high design-potential for the appearance of the whole building itself [see Figs. 25, 26, 28, 30].

Especially the “adaptable appearance” or the “changing face of the building due to climatic conditions” is a topic for further research studies. This means that, according to the sun-path, different successive parts of the same façade are activated and adapt themselves to the specific solar condition at that very hour of the day.

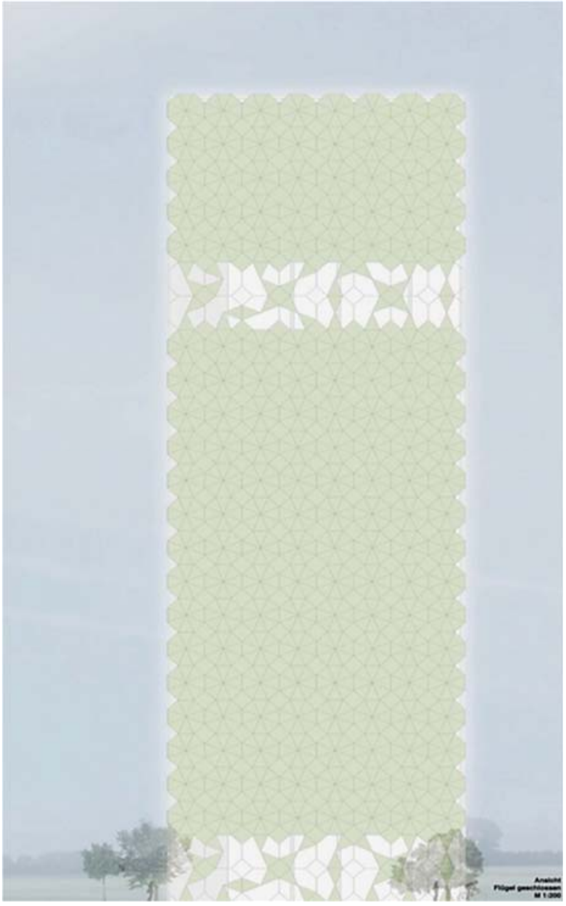


Fig. 16 Façade of “Dittmar”-Design under full solar radiation – elements showing closed state [10]

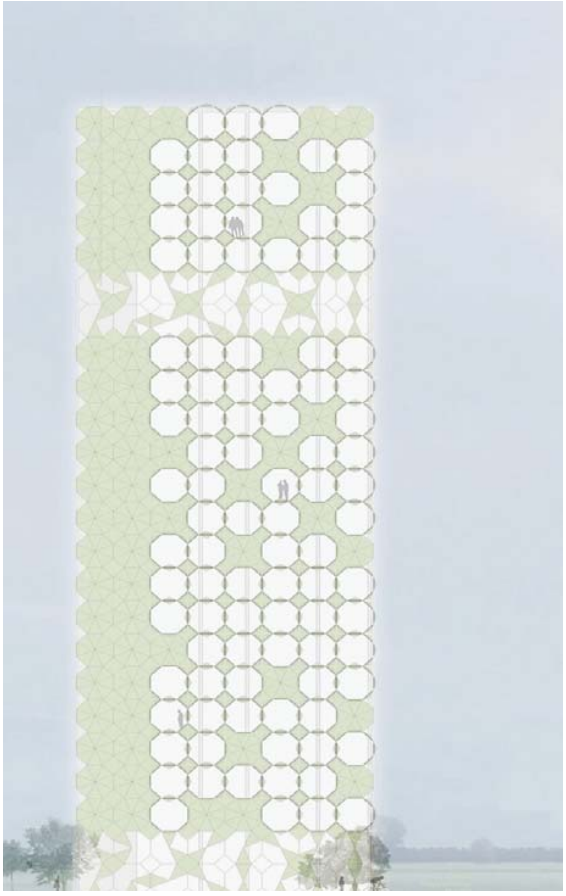


Fig. 18 Façade partially opened (individual override) + partially closed [10]

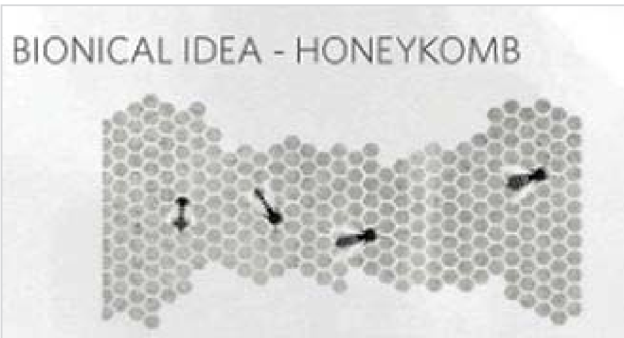



Fig. 17 Honeycomb-idea for module-structure [11]

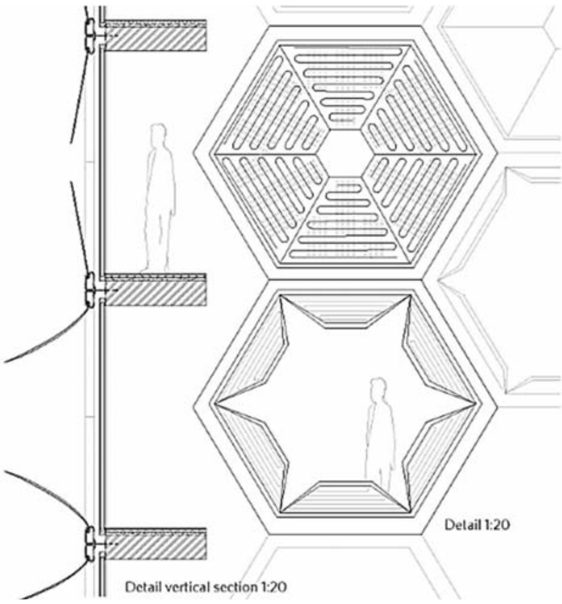



Fig. 19 Honeycomb – structure for shading-device element [11]

Fig. 20 Honeycomb-façade, elements partially opened + partially closed [11]

Fig. 21 Interior perspective: full shading is active – peak solar collection [11]

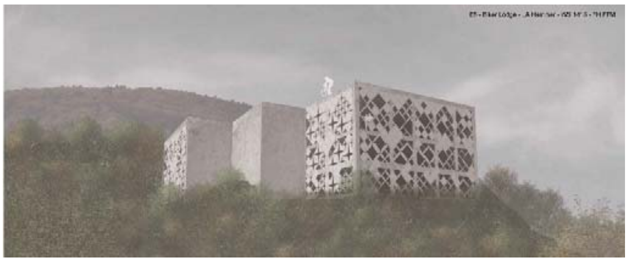


Fig. 22 Aubertin"-Design, Biker-Lodge Bingen [6]

Fig. 23 Different aperture- states of the flectofin-flaps [6]

### *E. Construction Principles for the Building Shell*

As this technology of the "flectofin"-mechanism is based on carbon and fiberglass- materials the detailing work within the students' range was very limited because of still unknown or undeveloped knowledge of how to merge an aluminum or concrete-substructure with a carbon-like material. The proof that these new technologies can be fitted to the most common building materials and construction techniques have already been proofed by Foster and Partners "Walbrook-Project" in the London City which used carbon-fiber lamellas to build, for the first time in the world, a complete shading-structure for a facade made of this new material.

Fig. 24 Vertical section and partial elevation [6]

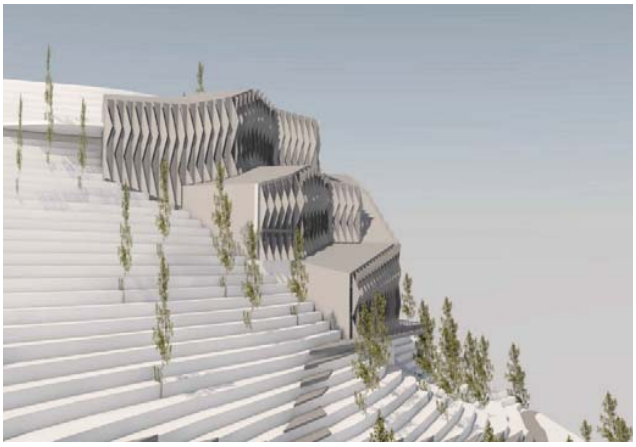


Fig. 25 "Frischholz"- Design, vertical flectofin- lamellas adapting to sun [8]

Fig. 26 Triangular flectofin-elements in upright arrangement [8]

*F. Detailing Work*

All relevant architectural details with horizontal and vertical sections in a large scale, as well as partial elevations that show the understanding of the adjustment and the working principle had to be provided by every student [see Fig. 9]. The principles that have been outlined in this document will need to be proofed by mock-up testing and furthermore detailed refinement.

Together with the involvement of research institutes in Germany, the hope for a better understanding of the described mechanisms and its adaptability under "real conditions", triggers the enthusiasm to aim for a buildable solution in the near future.

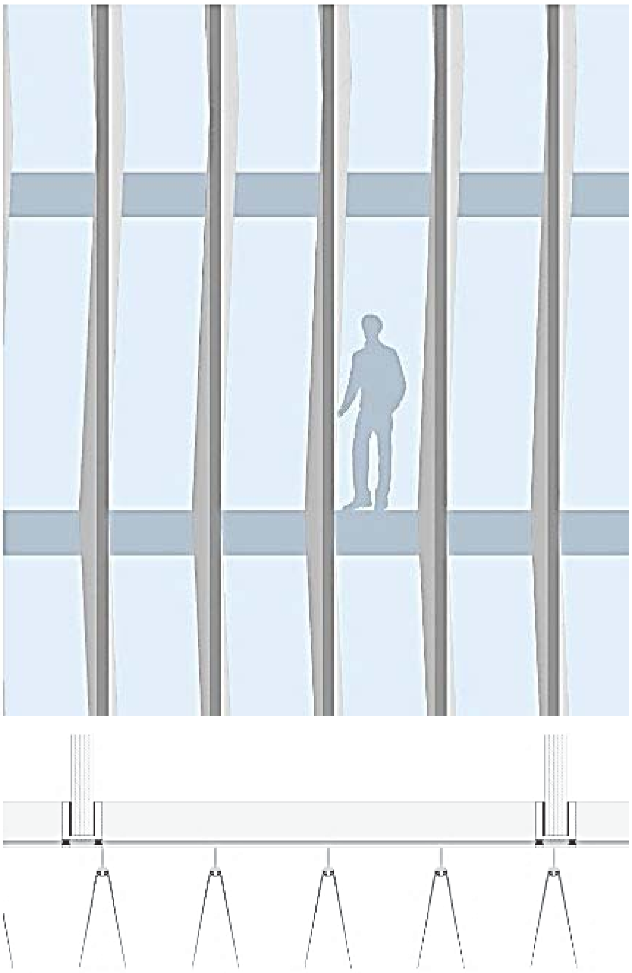


Fig. 27 Horizontal section and partial elevation – façade open [8]

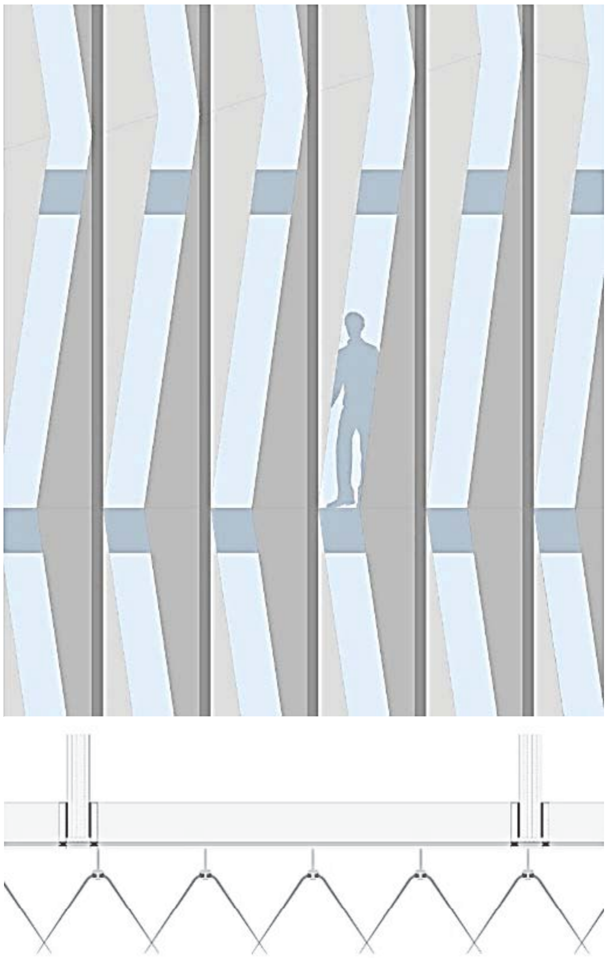


Fig. 29 Horizontal section and partial elevation – façade half-opened [8]

Fig. 28 Interior view -façade open, "Frischholz"-Design [8]

Fig. 30 Interior view -façade half-opened, "Frischholz"-Design [8]

The detailing work for the hinge-less flaps and their attachment to the building will be part of the research in the next years. Especially the material crossover between the "classical materials" (aluminum, wood, steel, glass) and the "new materials" (carbon and fiberglass) does need a much deeper understanding and development of knots and technical junctions [see Fig. 27-30].

*G. Perspectives*

Climate adaptive Building facades in the future will not only work with regard to shading-devices but with regard to an overall adaptability by using multi-tasking layers as has been outlined in the dissertation by Prof. Dr. Henning Braun [13] and his ideas for completely new material and surface-combinations to meet different functionalities that are needed for highly adaptable and energy-minimizing building shells [see Figs. 32 and 33].

## III. TARGET

The development of an enhanced design strategy according to this paper- proposal, as a shadowing device, will be needed to clarify and verify the basic principles, in order to prepare the ground for mock-ups and testing series to proof practicability. The relationship of the human factor with its need for natural daylighting, transparency, intimacy, physical comfort and its interaction with technical systems ought to be balanced with accuracy. Further unsolved questions regarding fire-resistance and the shut-down capabilities of facades entirely covered with electricity inducing flexible pv-systems, are one of the many questions that need to be answered in the near future.

In future research steps the question of how this can be applicable and of how the gap between research and real construction can be bridged, will be an essential one. Highly interesting proposals show a sensitive shading device according to the surface-specifications of the species "snake-star-*Ophiocoma wendii*" [see Fig. 31] or the vasomotoric and thermo-regulating multi-layered system of the "Rete Mirabile" [see Fig. 32] derived from the seal- skin [13].

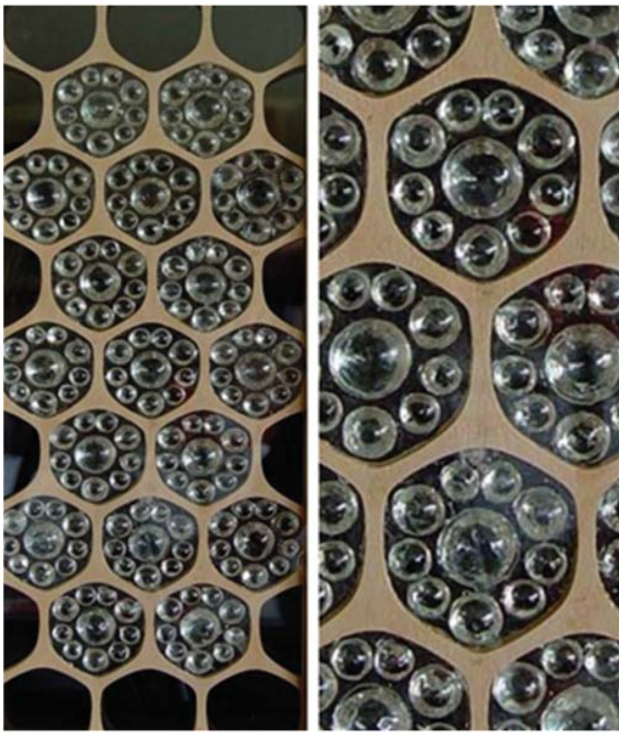


Fig. 31 Surface analogy to bionic principle of *Ophiocoma wendii* [13]

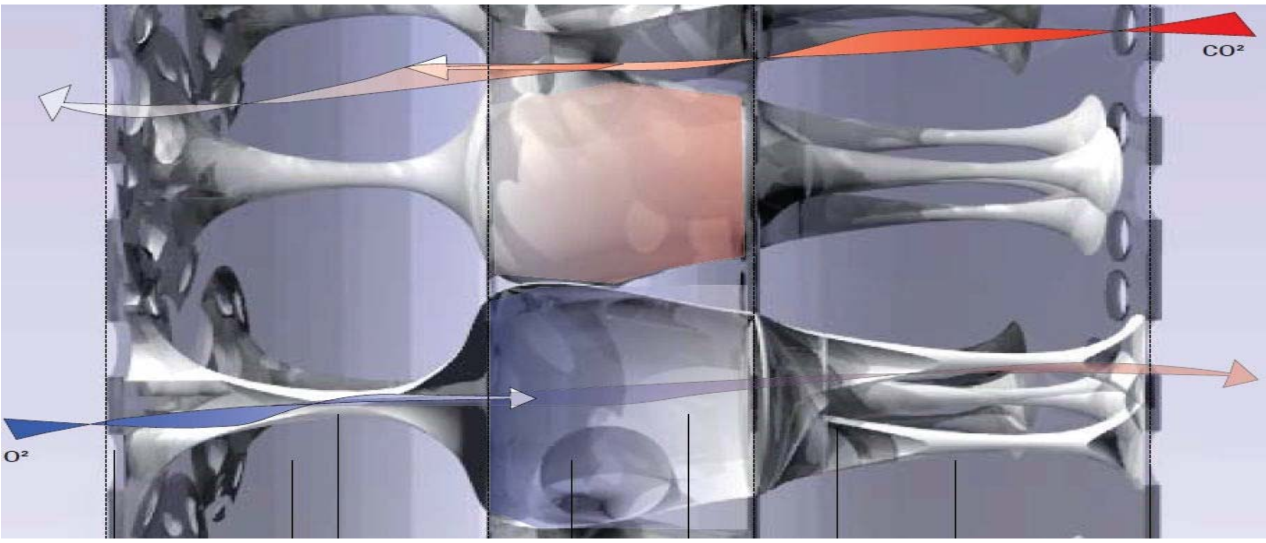



Fig. 32 Proposal for multi-layered façade according to "calliphoridae" [13]

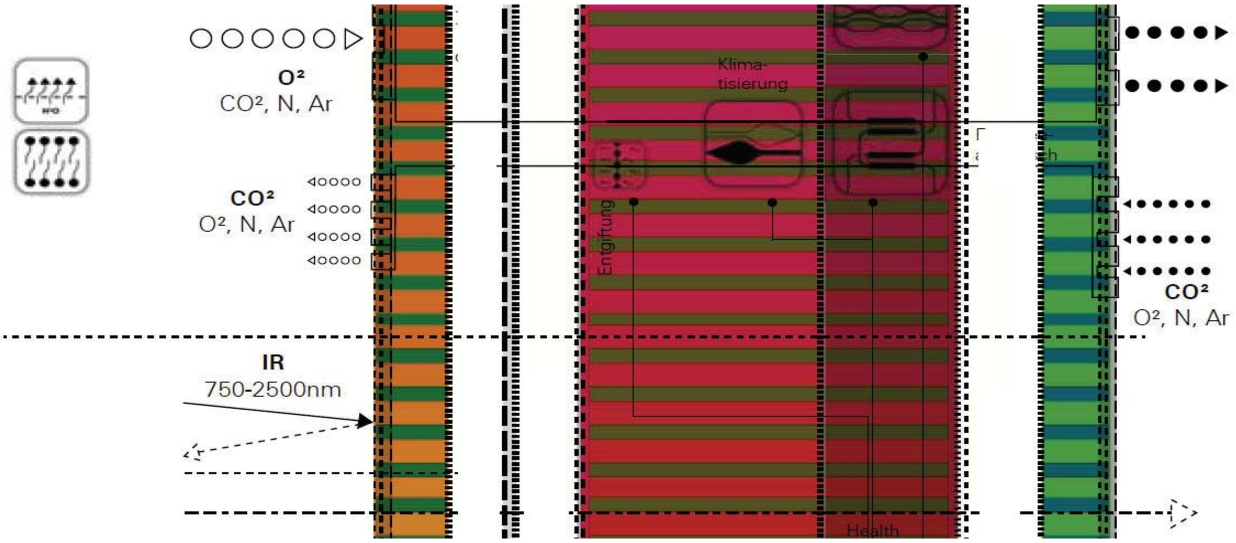



Fig. 33 Analytic diagram showing multi-functional requirements, [13]

## IV. Conclusion

As we need to collect energy in future buildings, to shift those manmade artificial objects towards plus-energy-buildings, the complete building envelope has to work like the human skin, adapting at the right time [of the day, of the season, to the weather and the climate] to the right functional need, with the minimum amount of energy-input or physical power. As we find these concepts already hidden in natural systems [flowers close at night and open up at day [see Fig. 15], clover at daytime [a] and clover at nighttime [b]], it is our task to unveil them and transport these brilliant ideas, evolved during centuries, into our building concepts. The challenging task has just started.

## Acknowledgment

The author wishes to thank the Frankfurt University of Applied Sciences and the University of Mainz for their support, as well as all students listed in the references, for using and discussing their work in this paper.

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