Anke Pasold :author
Isak Worre Foged
AREA Applied Research in Environmental Architecture :organization
Department of Architecture, Design & Media Technology, Aalborg University
Denmark :country

Performative Responsive Architecture Powered by Climate

This paper is to link the thermonastic behavior found in flower heads in nature with the material research into bimetallic strips. This is to advance the discussion of environmental responsive systems on the basis of thermal properties for advanced environmental studies within the field of architecture in general and in form of a responsive building skin in particular. :abstract

1 Introduction

The integration of computational systems into architecture allows for a new scale of information transfer and processing which covers a wide range of complex setups from the morphogenetic generation to the morphodynamic alteration of form.

Some of the more recent efforts link such approaches to the idea of architectural systems being an integral part of their surrounding environment with the proclaimed need of upholding a constant exchange with the same rather than being a closed system trying to separate itself from it. This gave rise to the thought of architecture as a responsive body, one that communicates with its surroundings and interacts with or adapts to specific environmental factors.

1.1 Responsive architecture

Within the context of such environmental responsive architecture, potentials of information processing have become a source for influencing and actively displaying the transfer and the effect of streaming information between any given environment and a defined model. Furthermore, the development of responsive architectures has extensively grown through the recent work of ORAMBRA *(Sterk 2006, 2009)* and the Kinetic Design Group, MIT *(Fox 2008)* to name just a few.

Such systems allow for a wide range of interactive information analysis and accordingly for an adaptation of the resulting model and its parameters and therewith are a step towards seeing architectural structures as subjects that are effectively integrated into a network of environmental information exchange.

1.2 Research approach

This paper therefore illustrates a research agenda aiming at understanding architecture through dynamic elements found in nature that adapt to the specific environment they have been created within, rather than regarding buildings as fixed bodies without location specific conditions.

Approaching architecture as a changing element over time caused by environmental alterations is deeply connected to the processes in nature (Weinstock, 2008) and opens to informed responsive systems and dynamic feedback (Hensel, 2006) in architecture that can be based on an integral flow of information in form of translated data.

Figure 1. Opening and closing of flower heads

Whilst extensive material assemblies and complex electronic setups are dominating the field of responsive architectural systems (see the above reference to Sterk and Fox), the presented research focuses on simple material systems that through their specific material properties are creating performance and expression triggered by the environment's existing energies.

Physical material properties with embedded sensoring and actuation function thereby as a complete system. This makes them comparable to flower heads that open and close to adapt to the environmental conditions in accordance with their needs and by means of their integrate thermonastic material *(Wood, 1953)* (Figure 1).

This process makes them display an open information cycle in the form of an effective feedback system that can give information about both the environment and the system at the same time. The setup thereby becomes an essential inspirational source to architectural practice with regards to implementing information into a responsive system and the resulting potential of guiding performative behavior.

1.3 Research targets

Accordingly, the research is targeting a responsive architecture that is similarly powered by climate, achieved, as in nature, through material properties rather than the integration of additional sensoring in order to create a structure that is responding through a difference in thermal expansion, relying on the diverse coefficient in a selection of metal components.

Within that frame, the potential of a climatic data transfer in form of a direct information flow from environment to built mass is to be explored in order to achieve a performative quality that has direct effect on both the internal spaces and the external expression simply through the innate material properties.

The created system should therefore display a performance-based design (Oxman, 2008) that results from a simple feedback system between the elements of an architectural system and their specific environment.

As the first in a row of environmental experiments, that each concentrate on a different phenomena, it is to explore the potentials of integrating thermal information into the set up of such a responsive architectural environment.

2 Responsive environments

The starting point for the research is therefore an exploration of responsive environments as a whole. The aim is to understand the dynamic feedback as an integral part of such a network system that according to the data received can react and adapt through its own sensitivity *(Beesley, 2006)* and therefore become part of a complex interconnected eco-system.

Taking thermal conditions of the environment as an initial information basis, they will provide data to the established architectural system, which in turn will translate it accordingly in form of an altered physical expression and adapted internal conditions.

2.1 Dynamic feedback

Focusing on the setup of a responsive system that relies on its own internal feedback processes to trigger an innate material change in its architecture - in accordance with the climatic information received from the external environment - allows a more refined approach to the information transfer between a specific system and its influencing environment.

Dynamic feedback is thereby employed as an effective method for researching adaptive behavior that, as a result, enables the system to dynamically adapt to different environmental conditions via internal feedback loops.

This, in turn, effecting the resulting system behavior and expression, establishes a system that produces several different versions of the same startup configuration of a set of components; each version using a varied optimization policy in order to create the optimum state for the received information.

The cause and effect relationship therewith created allows the system's configuration to become predictable with accordance to the external changes and will as a result exhibit repeated patterns of behaviors mirroring the changing environment.

Each generated constellation becomes the result of dynamic feedback that automatically determines the best formation policy, with each singular formation having a significant impact on the overall performance of the system as a responsive environment.

2.2 Responsive environments

Responsive environments resp responsive architecture first termed by Negroponte in 1975 is an evolving field of architectural practice and research commonly concerned with the sensor-based measuring of actual environmental conditions to enable an actuator-based adaptation in a building's expression: shape, color and formation and/ or a building's performance: shading, opening, solar exposure, ventilation.

This process would ideally improve the building's energy performance and is currently predominantly achieved by incorporating 'intelligent' and responsive technologies into the core elements of a building's fabric or structural systems that then in turn can reflect the specific environmental conditions the building is surrounded by, essentially establishing a direct communication between building and environment through the creation of a responsive system that receives environmental information and displays a concrete reaction within the built mass.

The aim with such a responsive environment is to create a system that can physically adapt its shape to meet changing needs with regards to the quality of the spaces inside, leading to thinking responsive architecture in scenarios of varied performance levels.

3 Methods and models

In order to achieve such a responsive thermal environment, research into the thermonastic behavior of flower heads that open and close their petals with the rise and fall of outer temperatures served as a valid source of thermal adaptation in nature. The flower heads' movements are due to different growth-rates on the two sides of the perianth members, an outer and an inner surface that respectively react to the temperature information received from the environment and react on an inner molecular level to achieve a formal outer adaptation *(Wood, 1953)*. (Figure 2)

A similar phenomenon can be found in the behavior of bimetallic strips, whose difference in thermal expansion coefficient cause them to expand at different rates and thus perform a correlated reaction at the occurrence of a change in temperature. Degree, range and speed of movement are determined by the combination of the specific samples, which, resulting from the different thermal expansivities of the two metals joined react in differing measurable degrees.

The idea of the performative system presented here relies on precisely that physical material property of metal taking advantage of their different thermal coefficient and corresponding expansion, 'enforcing' a predetermined shape change according to the specific metal inherent data. (Figure 3)

The metal having the largest thermal expansivity is known as the active element, while the metal having the smaller coefficient of expansion is known as the passive element. Within such a bimetallic actuator, the changing temperature will cause the active element to expand more than the passive one, resulting in the joint device bending out of the plane (Stephenson et al 2000), typically into an arch, much in the same way as observed in the flower's petals.

3.1 Experimental models

Translated into a case-specific, responsive architectural system, the material property stimulation by climatic alterations is based upon those material physics instituted into parametric models for high precision simulated formations (Figure 4). These models implement material phase-change properties or the arrangement of explicitly defined isotropic materials and are the digital representation of the physical prototypes.

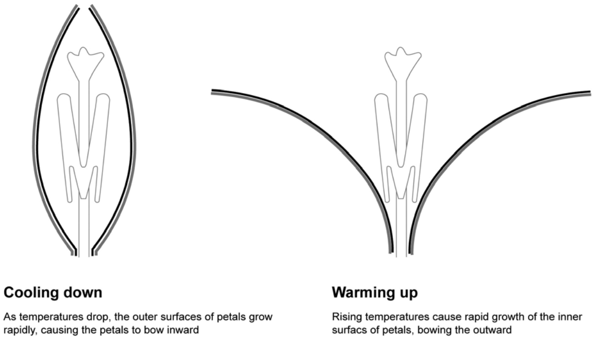

Figure 2. Thermonastic behavior in flower petals

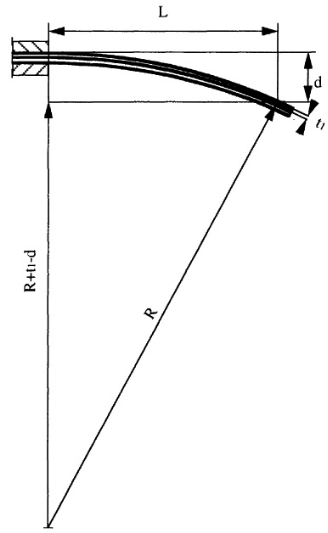

Figure 3. Bending of a bimetallic strip fixed at one end

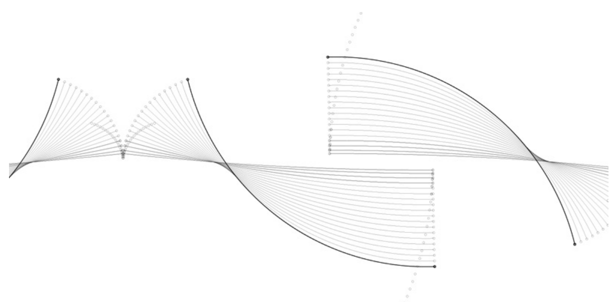

Figure 4. Parametric setup in Grasshopper/ Rhino

This means that the parametric digital models include such material properties as expansion coefficients, material elasticity - described through Young's modulus - and flexitivity - defining specific curvature - as integral parameters in an open system that is informed by temperature variations and thereby drives the adaptive behavior. (Figure 5)

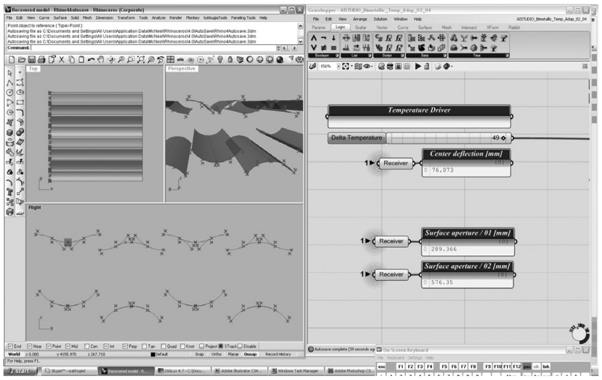

Figure 5. Changing formations according to temperature range

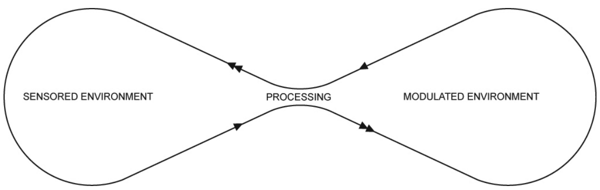

Figure 6. Information flow: Diagram

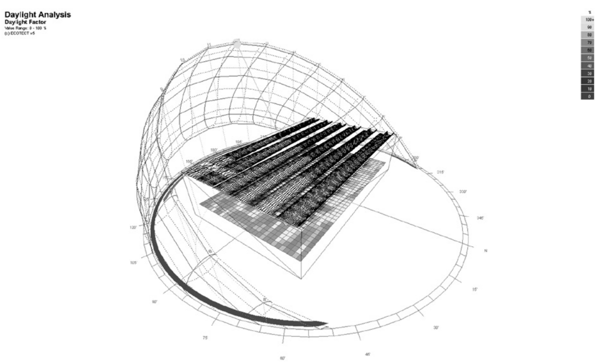

Figure 7. Daylight analysis of resulting internal environment of each of the configurations

This 'processor' combined with the environment's dynamic energy values of temperature levels and solar radiation allow explorative iterative studies of both, analytical performance criteria as well as the alterations in expression, changing the perception of material and space according to the information received from the environment. The former is thereby analyzed through daylight and temperature simulations, identifying the effects of the system's ability to support improved physical comfort conditions, while the latter is examined for its ability to connect internal environments with the external through induced formal changes.

3.2 Information flow

A change in temperature in the environment will be received by means of the material's integral information receiver, namely the metal's molecules, where the climatic data is 'processed' and, in accordance with the specific thermal coefficient, will react by means of a reversible change in shape.

As a result, one of the surfaces of the strip will expand more than the other forcing the whole component into a new physical state that is causing the component to open or close for light, temperature flow, ventilation etc. The building envelope and therewith both expression and internal climatic conditions change, which gives the basis for differentiated design and performance parameters.

The information is obtained through real-time sensors that are part of the material's properties to be processed in the material's own control system.

The external response is thereby the direct result of the responses inside the material that are formed according to the processed information.

Reversely, the ambient temperature can be measured by the related degree of bending as an extension of the integrated feedback resp. information flow within this responsive system.

3.3 Responsive models

The digital information flow from environment to model to regulated resulting environment allows extensive empirical studies in each of the phases thereby providing useful input to optimize material and geometrical configurations supported and verified within simulation environments for daylight levels and radiation studies. (Figure 7)

Each configuration can thereupon be studied and categorized according to specific properties of openness, enclosure and outer expression as each change in component set up will result in a change of pattern created, which conclusively will change the spaces' environmental performance. (Figure 8)

Reconfiguring the original layout of the components, their positioning to each other, their distance and the combination of materials will create a wide range of possibilities each resulting in an altered performance as a network system (Figure 9 & 10), in which, contrary to systems where the bimetallic strips are used as actuators, the metal components perform the shape change as a direct response of the façade to the change in information obtained from their environment. (Figure 11)

This allows for a multitude of design solutions further developing the strips into alternative configurations, that each displays a different behavior with regards to internal climate, shading and openness. An entire catalogue of input data and responses can be created that display the possible changes in performance to be achieved and help in selecting the appropriate solution for the existing environmental data. (Figure 12)

3.4 Concrete Impact of suggested models

Contrary to auxiliary systems, this direct embedding of sensors and actuators within the material properties ensures a minimum of translation errors within the information flow whilst being open to the designer's influence via geometrical arrangements or diverse component design and the calibration of responsive effects through material dimensions and combinations enabled by knowledge within architecture, engineering and natural sciences.

Rather than in-built sensors acting as moderator between human needs and environmental conditions by responding to the changing input data (Fox, Kinetic Design Group), using such a material innate characteristic results in a number of positive implications such as the precise predictability, the reduction in energy for use of conventional sensors as well as the occlusion of mechanic noise and maintenance requirements.

The result is a façade that, applied to an existing structural system, through its components' material properties, responds according to the received climatic data in form of changing temperature levels by displaying a more open or closed state in direct response. It thereby forms an architecture that demonstrates the ability to alter its porosity for spatial optimization in an attempt to continually reflect the environmental conditions that surround it *(Sterk, 2003)* and therefore essentially is in a continuous communication with its own ecosystem.

A building with such an envelope will lower its environmental input while at the same time improving the conditions for the users.

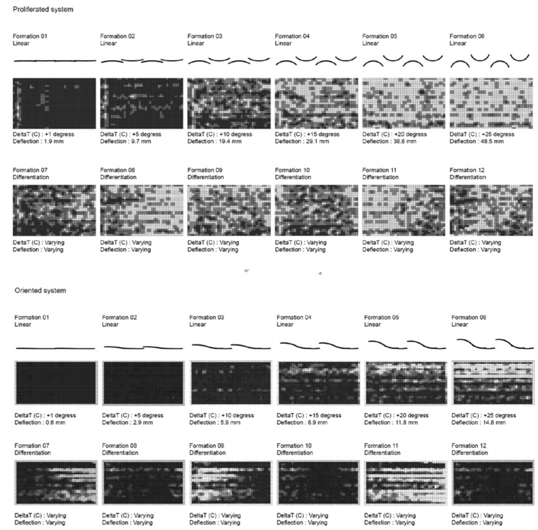

Figure 8. Ecotect analysis of various configurations

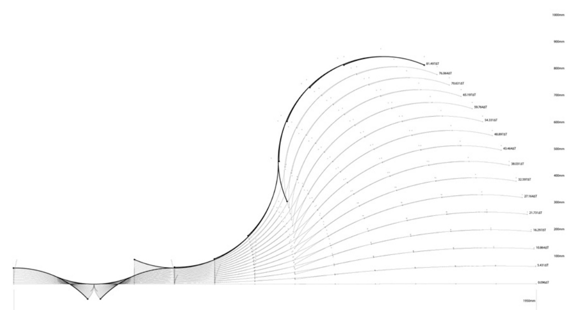

Figure 9. Components set up into a connected system

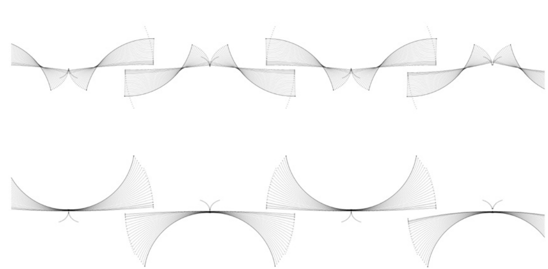

Figure 10. Extended setup and related expansion

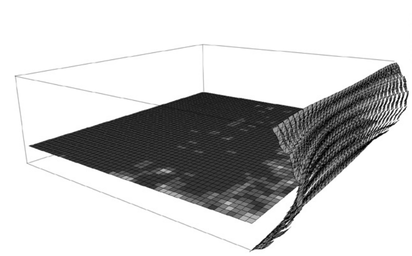

Figure 11. Façade application of an arrangement of bimetallic strips as responsive building envelope

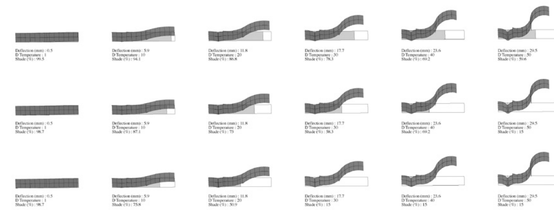

Figure 12. Catalogue of shading properties in summer, winter and equinox for the geographical location of Berlin displaying the results of change in deflection and temperature

4 Conclusions

4.1 Potentials of the approach

The research clearly shows that material configurations with explicitly defined physical properties merged with architectural environmental strategies support performance for continuously improved spatial conditions through regulation of daylight and temperature levels, radiation exposure, the enclosure of spaces and a diverse visual expression achieved through subtle and silent movements. The physical properties of bimetallic strips have been advanced to perform as the actual component design as part of a building's envelope rather than being used as a mere actuator. This results in the creation of a direct response that can be measured, cataloged and employed in a case-specific manner to achieve the desired localized performance level in individualized expressions.

4.2 Future direction

The predominant goal was to conduct a material investigation that seeks to generate a responsive structure with the ability to adapt to specific climatic conditions through a material-based information transfer. The experiment therewith stands exemplary in a possible development of a series of contextualized strategies that respond to local conditions and thereby argue the way in which environmental-climatic issues should be taken into consideration in form of an explicit integrated information transfer within architectural design practice.

The focus of the research is thereby aimed at the fundamental understanding of the material performance as the physical entity, which corresponds and reacts with its environment and displays a direct performative alteration of the architectural design in accordance to its surroundings creating a local adaptation that is highly feasible.

It is thereby to develop a number of physical prototypes to support the developed parametric model in form of a series of formation iterations that display the potential and possible variety in design while at the same time investigating its structural strength in relation to wind loads, snow and other environmental forces the structure is subjected to in order to complete the catalogue of implications.

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