A LIVING PIECE OF ARCHITECTURE – A PROTOTYPICAL MODEL OF A SENSITIVE AND KINETIC ARCHITECTURE

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Abstract: The project "A living piece of architecture" is a conceptual design to thematize an intelligent architecture beyond smart homes. The starting point of this project was the observation that the use of evolutionary optimization algorithms, digital planning and fabrication processes end after completing the design and fabrication process. If these processes were also present during the life cycle of the built architecture, they would develop far greater benefits. In parametric design, processes such as daylight factor optimization to reduce energy consumption or structural optimization to reduce material in supporting structures are frequently used tools. Buildings are not fully optimized in every situation, since it is only possible to optimize towards energetic average values or a structural extreme condition and also because stresses and environmental influences constantly vary.
A physical model of a utopian architecture, which is capable of displaying a process of life, was built to illustrate this proposal. The attribution of life is supposed to exceed a symbolic character. Simultaneously, a digital model is shown as an additional layer of information. The kinetic, photosensitive and adaptive model represents an architecture that constantly changes its morphology to adapt, not only to the environment, but also to human emotions. The shape, size and speed of adaptation are controlled by an evolutionary optimization algorithm.
By this means it is possible to transfer biological criteria of life, such as physical irritability and growth, through tensile materials within a self-regulating system, into architecture.
Keywords: kinetic architecture, evolutionary optimization algorithm, utopian, interactive installation

INTRODUCTION

This work is located between the technical discipline of architecture[1] for inputs regarding optimization processes and parametric design, the scientific discipline of biology[2] for inputs regarding the attribution of life and the humanities discipline of psychology[3] for inputs regarding measuring emotions. This introduction will represent a theoretical approach on this topic and provide preliminary definitions of keywords such as nature, technology and bionics in the context of this work. It is an introduction to all of the "actors"[4] and their mutual interaction and behavior, followed by a broad state of the art and chapters documenting the technical implementation.

Nature is everything that was not created by human hands.[5] Wilderness, as the opposite of the cultural landscape, is that part of nature that is still untouched by human hands.[6] Since humans have been able to tame nature, wilderness is no longer considered a danger and the escape into the wilderness has been viewed as a romantic adventure. Western culture developed from views like the one "subdue the earth"[7] to the enlightenment principle "knowledge is power"[8] at the beginning of the natural sciences, down to today's advertising slogans glorifying nature as a gift. Floral ornaments have been found since the 16th century BC in architecture and other handicrafts of ancient Greece and later, historicizing epochs. Today's use of structures from nature is more holistic, characterized by fragmentation, organic shapes and a certain provisional appearance. Yet, natural and cultural landscapes are still understood as two different fields. Since they were conceived as distinct concepts, the notion of distinction has been transferred to architectural concepts as well. It is counterproductive to mimic the presence of nature solely from the outside. The very essence of life can be perceived in this ongoing process of evolution. Neither the adoration and imitation of all facets of nature, nor the fundamental rejection of technological advancement, however, would be adequate responses to future challenges. Kevin Kelly – writer and founding editor of the technology magazine Wired – describes in his book "Out Of Control: The New Biology of Machines, Social Systems, and the Economic World" how future technology will adapt to organic systems due to increasing complexity.[9] Further interpreted, he also sees the goal of human progress in learning from biological systems until technological prod-

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4 B. Latour, *Reassembling the Social. An Introduction to Actor-Network-Theory*, New York, 2007, 54ff.

5 C. Ort, "Kulturbegriffe und Kulturtheorien", in: *Konzepte der Kulturwissenschaften. Theoretische Grundlagen – Ansätze – Perspektiven*, eds. A. Nünning and V. Nünning, Stuttgart, 2003, 19–38.

6 T. Kirchhoff and L. Trepl, "Landschaft, Wildnis, Ökosystem: Zur kulturell bedingten Vieldeutigkeit ästhetischer, moralischer und theoretischer Naturauffassungen. Einleitender Überblick", in: *Vieldeutige Natur. Landschaft, Wildnis und Ökosystem als kulturgeschichtliche Phänomene*, ed. L. Kirchhoff, Bielefeld, 2009, 13–66.

7 S. Rappel, *Macht euch die Erde untertan. Die ökologische Krise als Folge des Christentums?*, Paderborn, 1996.

8 F. Bacon, *Religious Meditations. Places of Perswasion and Disswasion*, London, 2010, 180.

9 K. Kelly, *Out Of Control: The New Biology of Machines, Social Systems, and the Economic World*, Regensburg, 1995, 92–110.

ucts can naturally manage and maintain themselves at the highest efficiency level, as nature does.

Technology – the writing about rhetoric[10] or the teaching of the handicraft – is in opposition to nature being understood as everything that has been created by human hands and is considered a cultural asset. As a result, natural and cultural assets form the sum of everything that exists. The repercussions of the industrial revolution at the end of the 18th century provided the catalyst for rethinking how we deal with nature. Not until the 21st century didthe use of limited fossil fuels lead to scarcity of resources and pollution.[11] Life on earth had 4 billion years to adapt to nature, but through intelligence, mankind reached a tipping point at which it is able to adapt nature to itself through technology. Using the example of the wheel, it can be shown what can remain undiscovered through heuristic solution processes, such as evolution based on genetic algorithms.[12] If wheel-like forms had evolved in nature, they would not immediately have proven successful, as flat surfaces are needed to be able to use the wheel efficiently. Humans are capable of combining these circumstances to achieve results that might otherwise go undetected. In 1962, Ivan Sutherland developed the Sketchpad program. As the first CAD (computer aided design) program, it was the starting point for an architectural design service that works through data, which is inputted into the computer and digitally converted to simulations. Today, 3D printers and robotics enable further digital fabrication of architecture. As a result, no translation or visual presentation of this data to humans is needed. Individualized mass production becomes economical and enables new designs. Through technological progress, computing power increases and we are able to carry out more complex simulations, planning and fabrication, as our reality is increasingly digitized and created digitally as a virtual or augmented reality.

Bringing together the concepts of nature and technology, the following state of the art will list relevant bionic projects. Since the Bronze Age, technology has shifted away from nature. Now, in the Information Age, technology is being shifted back to nature through bionics. Bionics utilize biology and technology in interdisciplinary collaborations by abstracting, transferring and applying information based on biological role models to solve technological problems.[13] An increasing understanding of natural processes is therefore necessary to reapply its inherent principle to technical competencies. Examples of this are the lotus effect or the Velcro fastener. Surfaces created by natural evolution were transferred to technologically produced objects in order to take over their properties.

STATE OF THE ART

This state of the art will contain examples of bionics in architecture, as well as parametric and kinetic architecture. By reaching back to 1850 the evolution of bionics in architecture is shown, followed by a technical implementation explaining what this work proposes future bionics in architecture to be. Joseph Paxton, who was not

10 H. Menge and O. Güthling, *Langenscheidts Großwörterbuch*, Berlin, 2019, 683.

11 A. Gore, *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*, München, 2006, 22–28.

12 W. Domschke and A. Scholl, "Heuristische Verfahren", in: *Jenaer Schriften zur Wirtschaftswissenschaft. Arbeits- und Diskussionspapiere der Wirtschaftswissenschaftlichen Fakultät der Friedrich-Schiller-Universität Jena*, ed. Wirtschaftswissenschaftliche Fakultät Friedrich-Schiller-Universität Jena , Jena, 2006, 10.

13 VDI – The Association of German Engineers – Standard 6220, 2011–06.

only an architect, but also a botanist, was inspired by the support ribs of a lily pad when designing the Crystal Palace.[14] A certain irony is not lacking in the fact that the British figurehead for innovation and industrial power of this era was based on a bionic idea. If suggestions from nature are to flow into structural or architectural designs, then this cannot be possible without the intermediate step of abstraction.[15] These construction bionics deal with the implementation of natural phenomena to solve technological problems and interdisciplinary scientific work between biologists, physicists and other natural scientists and engineers, representing architects and designers.

Parametric modeling, which originated in digital animation technology, allows a number of form-finding techniques to be used in order to deal with the increasing complexity. To clarify the difference between complex and complicated structures,[16] deconstructivism can be taken as an example that relies on complicated solutions; parametricism on complex. Designs based on a script, define a new era of architecture which, according to Patrik Schumacher, is called the "New International Style".[17] Algorithms are understood as rules of actions for solving specific problems that are defined from a series of individual steps.[18] The aesthetics are ordered through the elegance of complexity and create the impression of seamless fluidity. These are some of the properties that also occur in natural systems.[19] Fractals, or self-similar patterns that generate a great deal of variation using a relatively simple code, are also common in nature. In the opinion of D'Arcy Thompson, numerical precision is the very essence of describing natural phenomenons scientifically.[20] Furthermore, according to Kas Oosterhuis, nature itself is a kind of computation.[21] Parametricism and generative architecture can both, therefore, be understood as bionic, since they are based on a code, like natural organisms are controlled by a DNA code. Accordingly, parametricism is often equated with organic manifestations. This is not, however, a requirement. In the Museum Plaza design by the REX Architects group, usage data will be implemented into the planning directly until the start of construction without the necessity of an organic design. This flexibility and adaptation to external circumstances during the planning phase is an essential quality of parametricism.

The pursuit of efficiency is a great impetus in the self-creation of nature. The profitability of simulated evolutionary optimization processes in architecture increases with the combination of digital planning and manufacturing methods. When it comes to structural planning, however, optimization is necessarily always based on extreme values. In order to reduce operating costs, buildings can be energet-

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14 F. Lodato, "Bionics in Action: The Nature of Invention", in: *Technology & Innovation* 12, ed. Cognizant Communication Corporation, 2010, 80.

15 W. Nachtigall and G.Pohl, *Bau-Bionik: Natur – Analogien – Technik*, Berlin/Heidelberg 2003, 1.

16 TEDxDelft – Kas Oosterhuis – We are changing your view on what is beautiful and what's not [Video File] https://youtu.be/8tvsQLeSK-U, 2011 [December 2nd].

17 P. Schumacher, "Parametricism. A New Global Style for Architecture and Urban Design", in: *AD Architectural Design – Digital Cities* 79, ed. N. Leach, 2009, 14–23.

18 H. Rogers, *Theory of Recursive Functions and Effective Computability*, Cambridge, 1992, 2.

19 P. Schumacher, "Parametricism. A New Global Style for Architecture and Urban Design", in: *AD Architectural Design – Digital Cities* 79, ed. N. Leach, 2009, 14–23.

20 D. Thompson, *On Growth and Form*, Cambridge, 2004, 2.

21 TEDxDelft – Kas Oosterhuis – We are changing your view on what is beautiful and what's not [Video File] https://youtu.be/8tvsQLeSK-U, 2011 [December 2nd].

ically optimized to an average. Currently, evolutionary optimization processes in parametric architecture are optimal examples for an implementation of bionics in architecture. Just as the flora and fauna undergo evolutionary development, our building typologies also change in the course of the ages. According to an evolution of building types and the assumption that we will build whatever is currently technically possible[22], a future of built architectures that act as intelligent biological machines is imaginable. The integration of robots is playing an increasingly important role not only in production, but also in built architecture and is therefore no longer a mere vision. Even the building itself becomes a robot.[23] By this means, technology enables a new benchmark for finding interactive or kinetic architecture.

Compared with the long history of architecture, the role of bionics in it is still relatively new. Examples such as facade elements that are based on the behavior of pine cones and open or close depending on humidity,[24] represent a form of architecture that reacts with morphology change in direct response to the climate. A process of change, similar to growth, can also be found in the kinetic facade elements of numerous built projects. The facade elements of the Thematic Pavilion for the Expo 2012 in Yeosu function like gills of a fish. The slats are made of fiberglass-reinforced, elastic plastic. A computer-controlled compressive force allows the slats to bend due to their material properties to open the interior space as required, enabling cross ventilation and sun protection.[25] On the other hand, some bionic systems can only be identified with a closer examination. In the Eastgate Center in Harare, Zimbabwe, cooling takes place exclusively through natural convection. The interior of the building is designed on the model of a termite mound and can both cool and heat via appropriate atriums and chimneys. In 1996 it was the first building that followed this idea in such a sophisticated way.[26] However, an organic appearance does not have to suggest a basic bionic idea. Complex and costly organic shapes can use nature as an aesthetic template, without using it as a source for abstract architectural solutions. The national stadium in Beijing is a visual reminiscent of a bird's nest. In this biomorphic design the ornamental adaptation has a purely aesthetic purpose,[27] as bionic thinking did not play a role during the design process.

The question of materials has always been a crucial point in the implementation of new architectural ideas. Smart materials become more efficient and economic through further research and prototypical, exploratory application. As "actors"[28] they open up and strengthen the architectural processing of intelligent, multifunctional and flexible materials. While kinetic facades are controlled by an additional

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22 M. Carpo, *The Alphabet and the Algorithm (= Writing Architecture)*, Cambridge, 2011, 35–44.

23 Ennemoser, Benjamin. The Robot as an Architectural Element of Today, 2015, January 25th, http://www.suckerpunchdaily.com/tag/benjamin-ennemoser, 2021, July 4th.

24 O. Krieg, "Hygroskin – Meteorosensitive Pavilion", in: *Advancing Wood Architecture*, eds. A. Menges and T. Schwinn and O. Krieg, Milton, 2016, 125–137.

25 J. Knippers and T. Speck. "Design and construction principles in nature and architecture", *Bioinspiration & Biomimetics* 7,1, (Berkeley), 2012, 7–8.

26 S. Turner and S. Ruper, "Beyond biomimicry. What termites can tell us about realizing the living building", in: *Proceedings of the 1st international conference on Industrialised, Integrated, Intelligent Construction*, ed. Leicestershire: Loughborough University, Department of Civil and Building Engineering, Loughborough, 2008, 222.

27 B. Brownell and M. Swackhamer. *Hypernatural. Architecture's New Relationship with Nature*, New York, 2015, 15.

28 B. Latour, *Reassembling the Social. An Introduction to Actor-Network-Theory*, New York, 2007, 54ff.

computer, there are also so-called intelligent materials that react to environmental conditions without an external control system. Nitinol, for example, is a nickel-titanium alloy that is able to return to its original shape over and over again.[29] If the material is bent, its altered shape remains until heat is applied and the material returns in its original state. Wood is a renewable raw material that has always been used, not only as felled timber building material, but also as a building material provided by living trees. A technique, often referred to as "tree shaping" or pleaching,[30] uses trees or tree-like plants to create functional structures. The German architects Ferdinand Ludwig, Oliver Storz and Hannes Schwertfeger are working on contemporary designs using this technology. An iron support structure is initially set up, around which young trees are then wrapped carefully. With the help of a computer-controlled tensile load system, the trees are forced into their position and strengthened over time. The iron structure is removed as soon as the mesh can bear the necessary load. Mitchell Joachim is also convinced that one day he will create living space from growing trees in order to obtain a holistically sustainable structure. The starting point of his work is the environmental impact of the construction and maintenance of conventional architecture. In his imagination, architecture and the environment merge.[24] The production work for this also takes place using a computer-controlled substructure, over which the organic material can be woven at an early stage and thus serving as a prefabricated component.

SCIENTIFIC RESEARCH QUESTION

Optimizing daylight factors, minimizing energy use, saving materials in support systems etc. can help to decrease material usage and expenses. The research question of this study is how evolutionary optimization algorithms can be included in the life cycle of built architecture, to develop a greater potential for building more economically. As optimization can only be made in the context of statistical factors for extreme or average values; structures are not fully optimized for every situation that can occur as loads and environmental influences vary constantly. Evolutionary optimization algorithms, digital planning and manufacturing processes are employed with the aim of achieving maximum economic efficiency – but coupled at the same time with aesthetic and functional diversity – but yet end at the completion of the design or fabrication process.

Accordingly, future architecture has to be sensitive and kinetic. These are among the biological requirements for determining whether or not matter is alive. Sensory and electrical systems can cause physical irritability via a conduction system. Motor skills and novel materials can adapt to the environment through movement and enable growth. Such an architecture is able to change depending on the situation and react intelligently to changing environmental influences, loads or needs. By moving beyond a conceptual character about the attribution of life,[31] this research aims to go beyond current examples of constructed bionic architecture.

29 I. Baker, *Fifty Materials That Make the World*, Hanover, 2018, 137–142.

30 B. Northey and P. Cook, *3 Methods of Tree Shaping every Aspiring Tree Shaper Should be Aware of*, Yangan, 2010, 15ff.

31 TEDxUW – Philip Beesley – Building living architecture [Video File] https://www.youtube.com/watch?v=L8AvW5CSvys, 2012 [January 8th].

Fig. 1

TECHNICAL IMPLEMENTATION

In the course of this work a physical model was built which was exhibited at Ars Electronica Festival 2017. The visitor's perception and the resulting discours are fundamental to this work. The model aims to take advantage of having qualities of parametric design within the built architecture by having an evolutionary optimization process as the main driver. To illustrate, experience and reflect these ideas, a physical model of a utopian architecture was built, which displays the process of life by constantly changing its morphology. Following this concept, evolutionary optimization algorithms, which lead to a constant adaptation, can be seen as the essence of life itself and the model described in this paper can be understood as a living piece of architecture. (Figure 1)

In addition to the physical model, a digital model is displayed extending the design for the observer to dissolve existing dualisms, such as the boundaries between natural and artificial, in the same way as those between the analog and the digital. The biological criterion of life is applied in such a way that a discourse on the question of what the term life in architecture could mean to us in the future is opened. The aim was to build a structure that is permanently optimized both intelligently and naturally for meeting changing conditions so that the point is reached where observers attribute life to it.

On the one hand, inputs for these processes are external environmental influences, such as solar radiation, air temperature and humidity, but on the other hand they also include the emotional state and the behavior of the person involved in them. A highly abstract architecture is to be shown in a model for this purpose. Functionally, the model can be seen as a pavilion; reduced to a single space, one material and with an individual person in it. Sensory impressions such as scents, acoustics, local context or constructive details are not considered. The model itself is not meant to be understood as a miniature version of a design to be built. Rather, it is designed in such a way that it transports the idea of a living architecture in the best possible and generally applicable way.

Software

A variety of different programs were evaluated in order to realize this model, as they not only had to perform their tasks well, but were also expected to be able to communicate with one another.

Rhinoceros 3D represents the software basis of the work. It is a CAD software that architects use primarily in free-form design, as 3D objects are not built on polygonal meshes,[1] but on mathematically described curves (NURBS Modeling, short for Non-Uniform Rational B-Spline). By this means organic free-form surfaces can be processed faster and edited more easily. A fast visualization was necessary for displaying an analog and digital model in parallel. Proprioception describes the sense of itself a body has, i.e. the knowledge of one's own body in the physical world. This property, which is usually reserved for living beings, is conceptually very important for the work in order to blur the line between analog and digital.

In the context of the input of the observer's emotional state, the psychology-derived model of the Self-Assessment Manikin (SAM) is used. The SAM process consists of a graphic with three dimensions. Joy, arousal and dominance (in the sense of social dominance). Depending on their emotional states, the observers can select a corresponding pictogram on a five-point scale.[32] The input of the emotional state is also done via the graphical user interface of Rhinoceros.

Furthermore, all programming of the model's control system was done in Grasshopper 3D plugin, a visual programming language for parametric or generative design within Rhinoceros. The final software setup consists of two Grasshopper definitions that are working in parallel. Grasshopper is mostly "single threaded", so it can only perform calculations on one processor unit. To increase the computing power, the task was split into one instance that reads and processes inputs (sender_input), and one output-writing definition (receiver_output).

"Sender_input" sends the processed input data to the receiver and controller for the output of the work "receiver_output". Communication between the two definitions takes place in text format .txt and contains only numerical values. The core of the work is an evolutionary optimization algorithm integrated in Grasshopper named Galapagos. The algorithm first initializes evaluations through random combinations of genes and learns to maximize or minimize a desired number, the so-called fitness criterion. The introduction of mutations – accidental changes in the sequence – is a barrier to prevent getting stuck and increases the available search space. An iteration of the algorithm therefore consists of: selection, recombination, mutation and evaluation. In this model, the algorithm's variable genes are different eccentric disks. Depending on the different rotation, i.e. the alignment, this rotatable structure is created in the exhibited model with a specific surface above it, which is then evaluated in the context of various specific criteria.

The Java platform Arduino Integrated Development Environment (IDE) was used to write and upload program codes for the Arduino hardware. The written codes only manage the data exchange between software and hardware. The entire processing and calculation of this data takes place, as already mentioned, in the

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32 M. Bradley and P. Lang, "Measuring emotion. The self-assessment manikin and the semantic differential", in: *Journal of Behavior Therapy and Experimental Psychiatry*, ed. A. Radomsky, Gainesville, 1994, 25, 49–59.

Grasshopper definitions, since the computing power of the Arduino hardware is only sufficient for very simple tasks. The communication takes place via the serial monitor of the Arduino IDE, which shows the values of the serial line between computer and Arduino by transmitting individual bits. Again, the logic is divided into an Arduino code for all incoming data from an analog sensor system (sender_input) and one for all outgoing data for one motor function (receiver_ouput).

Each iteration of the evolutionary optimization algorithm requires a new calculation of solar radiation. Ideally, this process takes less than a second. After testing various plugins capable of a direct interaction with Rhinoceros and Grasshopper, DIVA seemed to be the most viable solution simulating environmental influences in order to integrate them directly into the design. After some fine adjustments with the help of Jon Sargent, Co-Founder of Solemma and co-developer of DIVA, it was possible to calculate the solar irradiation for the particular surface in a very short time.

Control technology

The data of the observer's emotional state is the first set of inputs. Depending on which block of the SAM is selected by the user in the Rhinoceros viewport, the interface provides a respective value for further prioritizing of the calculations. Furthermore, a communication with the serial port of the sender_input Arduino is established, from which all inputs from the model, such as light intensity in lux values, air temperature and humidity can be read. The position of the light source is then determined geometrically using values of light sensors. The stronger the value of a sensor, the more it sets the light source – initially assumed in the center – in its respective direction. With five sensors, the position can be calculated very precisely. The position of the light source is assumed to be at a fixed distance from the model and projected onto a sphere. The method of finding a position using the base circle proved itself to be the fastest and most reliable method. After this calculation of the input data, the optimization algorithm sets a new orientation for the rotatable supporting structure to change the surface of the model. As a result of this step, each curve of this structure must be rotated around its specified axis and intersected with the zero plane of the model. The motors are installed with left or right rotating logic. Accordingly, depending on the motor and the maximum range, the value of the rotation must be subtracted or added to ensure that the analog and digital models match. The surface is created using a UV curve network. Via splines with differently weighted control points, the digital model closely approximates a textile behavior. In order to simulate the behavior of a textile membrane in the digital model, the elastic behavior was initially simulated in Kangaroo – a plugin that can simulate the real-time simulation of objects under the influence of physical forces. However, the simulation turned out to be too time-consuming. Different weightings make it possible to give more tension to the control points closer to the edge. The surface is created as a polygon network. The fineness of this mesh also determines the duration of the calculation of the irradiation. With a higher number of individual faces, the ray tracing algorithm needs more time. The finer the mesh, the longer the calculation takes and thus the iteration of the optimization algorithm. (Figure 2)

The arousal value previously entered in the SAM regulates the fineness of the mesh and thus provides more time for the servo motors to turn more slowly. The model becomes calmer and can produce more accurate results. On the other hand, a fast movement with high arousal only allows a coarse calculation of the solar

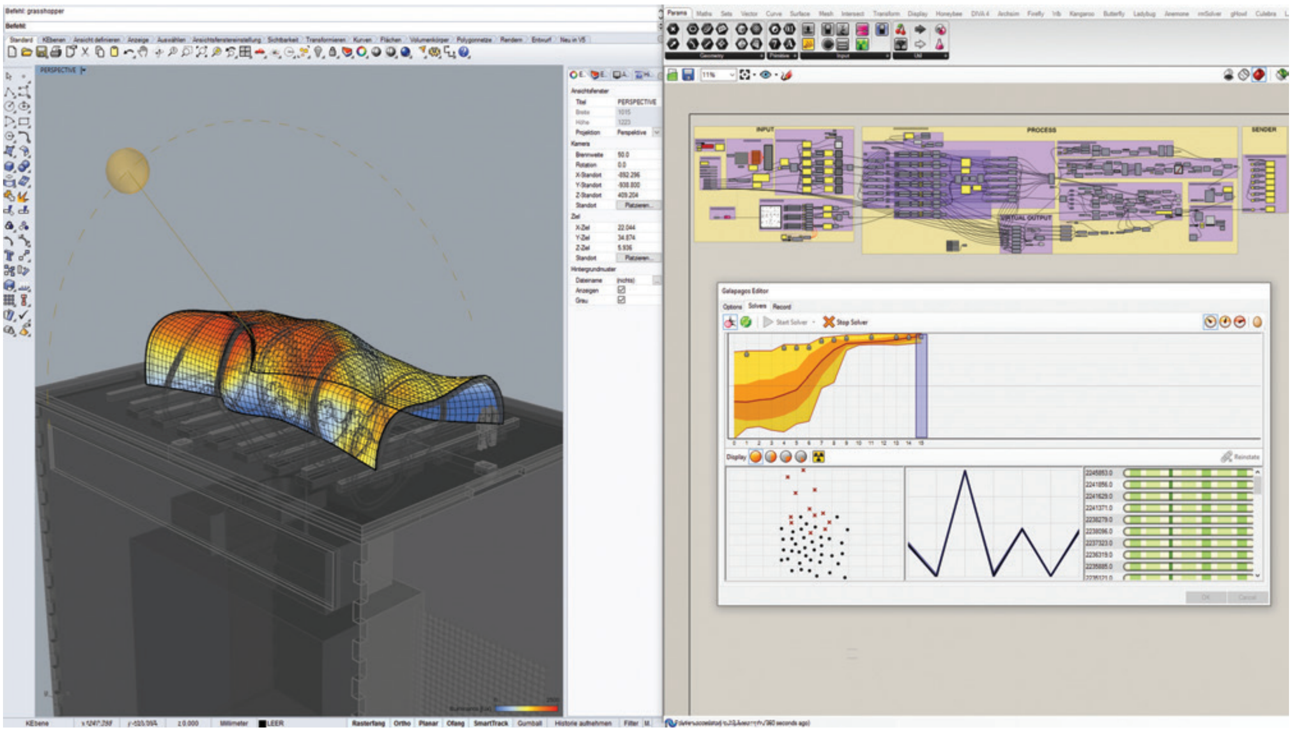

Fig. 2

radiation. The pleasure value controls whether the volume inside the model is prioritized or not. The higher the value for pleasure, the more a volume maximization of the model is forced. If the pleasure value is high, a larger volume is multiplied by a higher percentage, while a smaller volume is multiplied by a small percentage. These results, together with the other inputs, create a number that the optimization algorithm aims to maximize. The value for dominance in turn determines the prioritizing of human needs in relation to the needs of architecture, which are in this case maximizing the solar radiation. Referring to Marshall McLuhan's media theory, architecture can be seen as a technical extension of the human being.[33] Thus, when it comes to further architectural requirements, there are those that are necessary for the building to function, as well as those that make a room look comfortable and thus worth living in. When the dominance is set to a maximum, only the needs of the observer are taken into account. In the case of low dominance, these are multiplied by a low percentage. In this way it is possible for the algorithm to take different factors into account while maximizing a single number.

While the optimization algorithm works within the sender_input Grasshopper definition, the values for the rotation of the supporting structure are simultaneously sent to the receiver_output control system. The stream function of Grasshopper enables the exchange between two definitions via .txt file. The second half, receiver_output, has a structure that is comparatively simpler. It receives the numerical values for the rotation of the supporting structure and sends them through the serial port to the receiver_output Arduino. These values are continuously counted up or down, at different speeds, depending on the arousal value. The speed is matched by the arousal value to the duration of an iteration of the algorithm to have control over the movement speed.

33 M. McLuhan, *Understanding Media. The Extensions of Man*, Cambridge, 2002, 5ff.

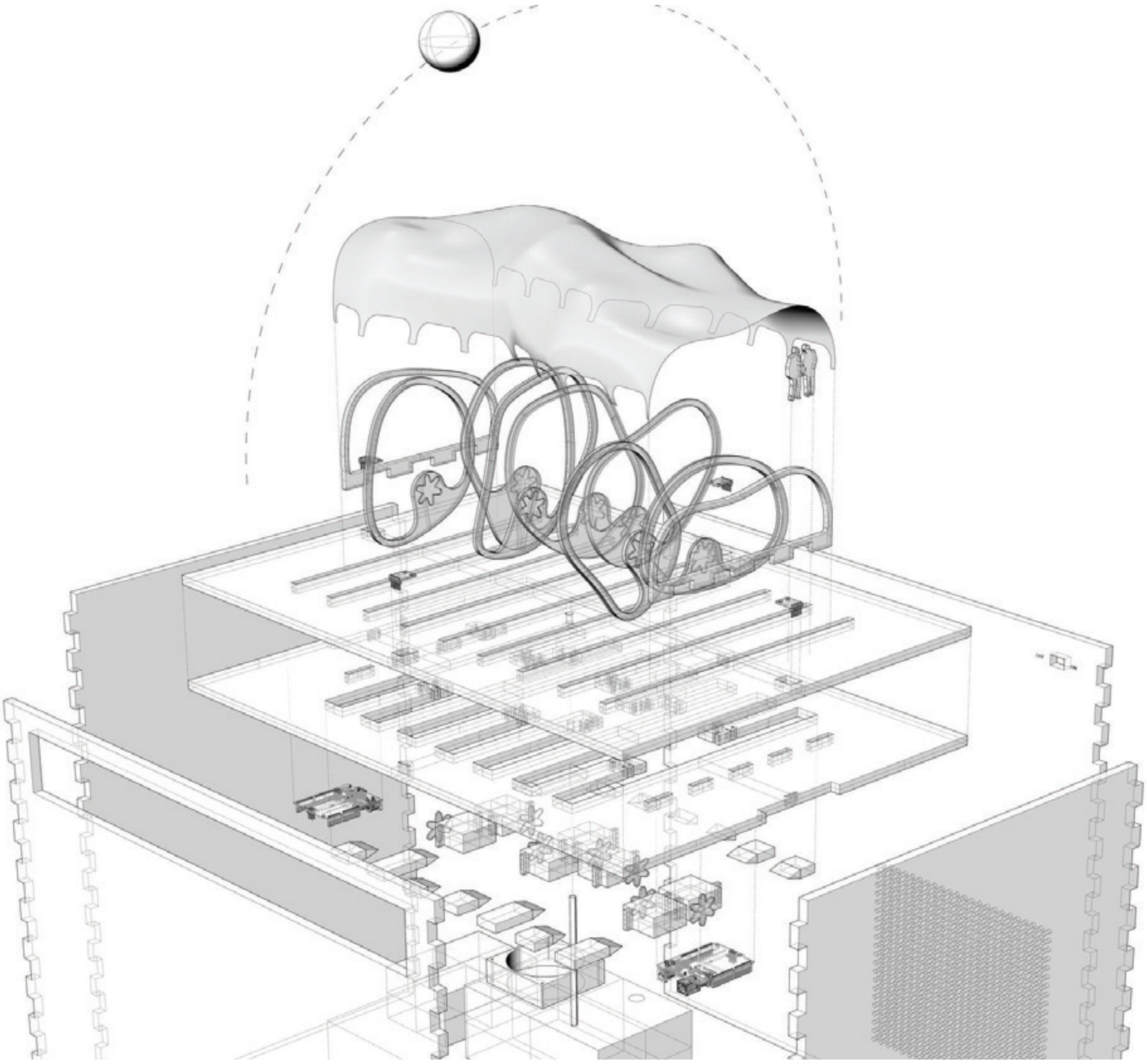

Fig. 3

Hardware

Briefly listed, the model consists of a base plate, a rotating structure and a stretchable membrane attached on top of it. The base plate consists of two glued 10 mm poplar plywood panels. Recesses for the components were precisely cut with a laser cutter. The entire electrical system is attached to the underside of the base plate. The model is presented on a 1,50 m tall base, which at the same time allows the supporting structure to be extended downwards and offers storage space for the computer and power supply units. (Figure 3)

Controller

Two Arduino Uno R3 serve as the hardware interface to the previous software chapter. Microcontrollers, such as the Arduino Uno R3, have a very low computing power due to their 16 MHz processor, which is completely sufficient for many tasks. In this work, however, complex simulations and geometric calculations are to be solved in real time. The microcontrollers thus only act as an interface via Firefly, an additional plugin to implement various hardware components and enabling control technology in Grasshopper to run on a powerful desktop PC. The sender_input program runs on the first Arduino. The digital outputs are used to address the sensors. The values are then read in via analog inputs. Power is supplied with 5 volts via USB. The second Arduino is controlled via the receiver_ouput program code. The positions of the servo motors are determined via digital outputs. The power for the motors is supplied via an external power supply unit. However, the Arduino must be grounded to the external circuit.

Sensors

Evolution requires environmental constraints. The better the sensor system, the better the adaptation can be. Therefore, the model has light, air temperature and humidity sensors, which enable perception and proprioception. The main focus here is on light sensor technology and the ability to track light sources. This property, which is also found in simple forms of life such as plants, immediately suggests lively behavior. In this respect, the phototropic design can also be understood as an analogy to a plant. The model has five digital ambient light sensors BH1750, which can measure in a range from 1 to 65535 lux. Four of the light sensors point outwards at a slight angle in the four cardinal directions. The fifth sensor is directed upwards in the middle of the base plate. The sensors are powered with 3.5 volts via USB. The values are then sent digitally in 16 bit via an I2C serial data bus to the Arduino. When voltage is applied to the ADDR pin, the sensor transmits the data via the address 0x5C. If there is no voltage on this pin, it transmits via the address 0x23. Accordingly, only two values can be read out in parallel on individual addresses. In order to be able to use all five values almost simultaneously, the sensors are addressed in series. This is done every few milliseconds using appropriate command lines in the sender_input program of the Arduino. Since each ADDR pin of the sensor boards is assigned its own digital output of the Arduino, they can call up the values one after the other and write them to the serial monitor separated by a comma.

As stated at the beginning, the aim was to loosen up dualisms such as analog and digital, as well as natural and artificial. This idea can be well illustrated using the interaction of the light sensors and the digital simulation of the irradiation. The human skin has millions of sensors that inform the brain where the light is hitting in and at what intensity. In the model on display, however, five physical sensors are sufficient to determine the position of the light source. The exact irradiation can then be calculated in the digital simulation for any point on the surface. On the other hand, this loop only works because the analog and digital models are identical and share data.

Motivity

The supporting structure of the model is driven by seven servo motors that can determine the rotational position of their motor shafts between 0 and 180 degrees. This leeway is sufficient to be able to give the model the desired orientation. The decision to choose seven motors was based on the optimization algorithm. Having more motors, and thus more variables for the algorithm, led to less useful results in an acceptable time period. The speed of these motors also has a significant impact. As described in the previous chapter, the speed of the motors cannot be controlled directly, but it can be regulated by continuously counting up and down the position values. The speed becomes an additional variable for the program and a new parameter when it comes to experiencing architecture. The TowerPro SG5010 servo motors are powered by a 5 volt power supply supplied with 2.2 amperes of current and thus can bear a maximum torque of 5.5 kg / cm at a maximum speed of 0.19 sec / degree. Due to these and other mechanical limitations of the components, the sizes for building the model have resulted by default. The motors are precisely embedded


Fig. 4

in their position on the base plate and elastically mounted in one direction so that they can evade in the event of overload to prevent damage.

Model making

A table lamp can be moved freely over the model to manipulate the position of the "sun". The most noticeable interactions occur when rotating around the longitudinal axis to observe how the difference between morning and evening sun is processed. The calculated position of the light source and the resulting radiation on the surface can be followed in a simplified formalized manner on a screen. The supporting structure of the model consists of nine planes arranged in a row. The centers of the rotations are slightly offset and have an eccentric free form exactly like the discs in order to keep the spanned surface as versatile as possible. In order to spare out any reinforcements and to keep the edge of the supporting structure as optically restrained as possible, it is cut from robust 6 mm beech plywood. The supporting structure is not present in the interior, putting the concept of a totally amorphous room front and center. The two outer panes are permanently installed and open the design on the narrow sides to provide insight. The rotation via the servo motors seemed to be the most feasible way to change the entire morphology repeatedly. While nature generates movement via muscles, rotary movement via rotating motors seems to be more practical with current means, as they can generate a large range of possible surface appearances and are much easier to regulate than pneumatic components. The supporting structure is made of deformed ellipses with a visible orientation. This means that, depending on whether the model is attempting to maximize or minimize the interior volume, all of the panes can either stretch clearly in one direction or give the model a distinct appearance. This comprehensibility is important when interacting with the model. The mechanism also had to allow the movement to come from within. Pulling or pushing from the outside was not acceptable in conceptual terms. (Figure 4)

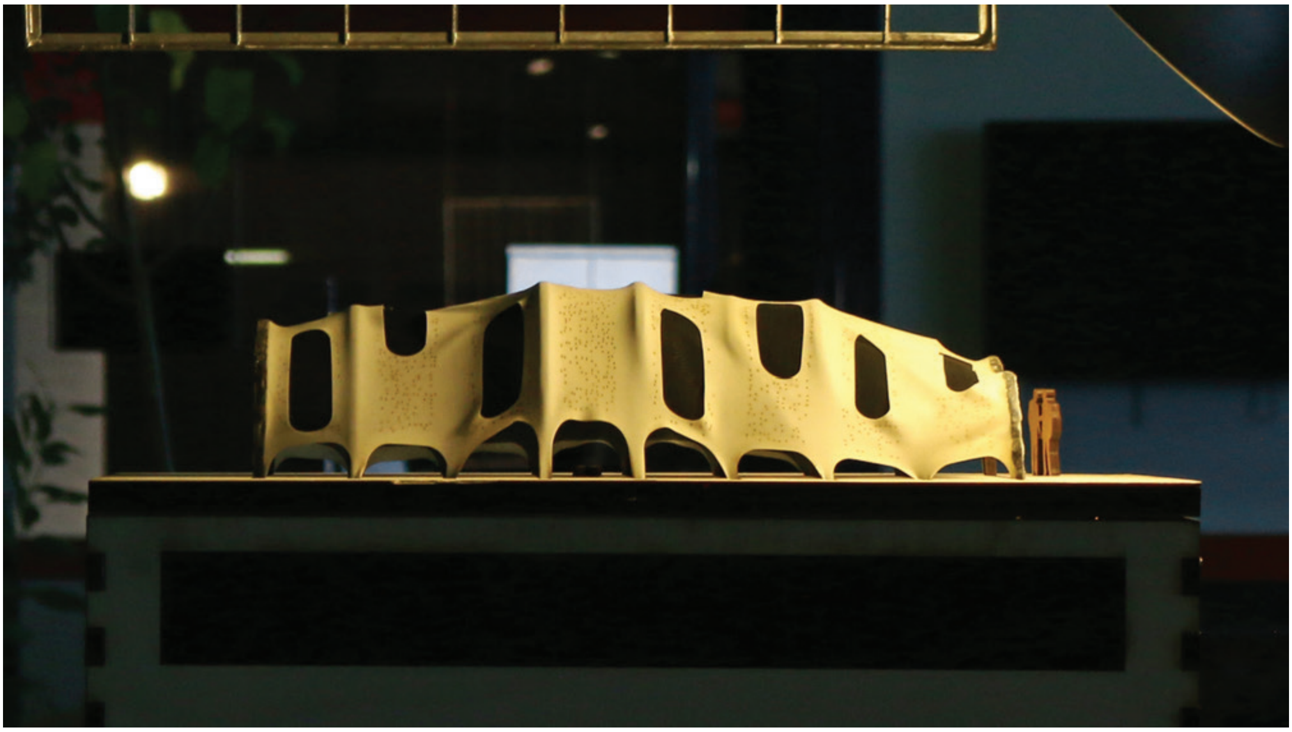

Fig. 5

The choice of material for the membrane, i.e. the external appearance of the model, and thus the aesthetics of the whole model, has a decisive effect on the ascription of life, in the same way as the model movement type supports an emotional coexistence between the observer and architecture. In the search for a highly stretchable, translucent or even transparent material, numerous fabrics in different thicknesses were tested.

A combination of bi-elastic nylon / spandex stretch and perforated, heat-treated natural rubber has proven to be ideal. Like the servomotors, the anchor points of the already elastic membrane are supported by elastic rubber bands. If there is too much friction due to an incorrect configuration, the anchor points will slip inwards along a felt-coated rail. The structure of the lower, inner layer of black stretch mesh minimizes the friction between the natural rubber and the supporting structure. The black mesh also contrasts well with the rest of the beige components. This layer has no openings whatsoever to visually unify the overall impression while still offering enough insight. The second layer consists of 0.18 mm thick natural rubber – an organic material which perfectly suits the aesthetic requirements of the model. Since natural rubber is very elastic, it can be influenced in terms of transparency without losing its shape or tearing over time. Heating the material once allows the elasticity to increase even further. However, like other types of rubber, it becomes slightly sticky once heated up. Talcum powder prevents the latex from sticking together. This effect is indicated in the model by the perforation of the facade. With greater stretching, the holes become larger and let more light into the interior. At the same time, the material is generally more flexible, so that the servo motors have more leeway. The perforation is also intended to underline the organic aesthetics of the model. Natural rubber or latex is already culturally charged for us and is closely related to human skin. The entire model is intended to be reminiscent of a living organism in its caterpillar-like appearance. (Figure 5)

CONCLUSION AND FUTURE WORK

The goal of explaining the concept of a sensitive and kinetic architecture model was achieved by making use of an evolutionary optimization algorithm as the driver for a computer-controlled exemplifying model. The ability of this interactive model is not to have control over the design, or to set it in such a way that it merely reflects the wishes of the observer. What is represented instead is a coexistence of the observer and the living architecture. Since the behavior of the model is based on the combination of all input options, empirical learning emerges from the observation of the interaction and the adaptation of the living architecture. On the one hand, the architecture is able to reflect the existing emotions of people, and thus support them, while on the other hand, it is also possible to counteract the emotional state. This results in the user not living "in"", but rather living "with"" this architecture. In this way, the architecture also allows meta-emotion in users.[34] This mood control idea relates to allowing oneself to be consumed by one's own misery, for example. Since architecture and humans are both systems that are constantly receiving and processing inputs, they also start to influence and balance each other out. Due to an interdisciplinary approach, it was possible to bridge the gap between the usage of artificial intelligence for architectural design[35] and the construction of responsive architecture.

Conclusions regarding the technical implementation of the control system have been made by building a small-scale model, while the creation of a full-scale model will largely be a materialization challenge in the future. The elaborated set of software is viable for processing information, simulating solutions and controlling the buildings movement. Building a full-scale model will necessitate the development of a waterproof and long-lasting elastic facade material. Interdisciplinary and artistic research in architecture endeavors to develop kinetic facades, smart materials, self-healing or shape-memorizing materials and flexible electrics. The product design of other markets shows how important the aesthetics of the objects and the type of movement are in creating an emotional relationship between people and technological products. According to architect Achim Menges, the material replaces the machine.[36] As in nature, the material will accordingly be pre-programmed to achieve a specific behavior. It is certain that more time is needed until building materials that are suitable for applications like the ones described in this paper are realized.

Nevertheless, an issue which might require further discussion is that today's architecture offers the security of being steadfast and lasting, which results in a physical and emotional state of safety. Is it advisable to exchange this security in the future, knowing that in the event of a storm, the intelligent building would protect itself and people by changing its shape? The idea of handing over this responsibility can already be seen in smart home concepts. An intelligent architecture of this kind will become our third skin after smart clothing. What if architectures such as this are able to generate knowledge through empirical values by means of machine learning? Does this make our everyday behavior predictable? Does this make us aware

34 W. Wirth and H. Schramm, "Emotionen, Metaemotionen und Regulationsstrategien bei der Medienrezeption", in: *Dynamisch-transaktional denken.Theorie und Empirie der Kommunikationswissenschaft. Ein integratives Modell*, eds. H. Stiehler and W. Wirth and C. Wünsch, Köln 2007, 153–184.

35 A. Imdat and P. Siddharth and B. Prithwish, "Artificial intelligence in architecture: Generating conceptual design via deep learning", in: *International Journal of Architectural Computing*, ed. A. Brown, Liverpool 2018, 306–327

36 Brüggemann, Michael. Wohnen im Pflanzenhalm, 2014, November 27th, http://www.sueddeutsche.de/wissen/baubionik-wohnen-im-pflanzenhalm-1.1975658, 2021, July 4th.

that our life is just a series of algorithms?[37] The perception of upcoming intelligent architecture is something that deserves to be explored further. Additional research has to be conducted regarding sensor technology to simplify the interaction between human and architecture. The use of thermal imaging cameras, face recognition and gesture recognition also need to be further elaborated.

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ILLUSTRATIONS

1: Photography showing the physical model (2017)
Фотографија која приказује физички модел (2017)
2: Visualization of solar radiation in Rhinoceros (2021)
Визуализација сунчевог зрачења у програму Риноцерос (2021)
3: Exploded-view drawing of the physical model (2021)
Цртеж расклопљеног изгледа физичког модела (2021)
4: Photography showing the substructure of the model (2019)
Фотографија која приказује подструктуру модела (2019)
5: Photography showing the physical model (2017)
Фотографија која приказује физички модел (2017)

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ABBREVIATIONS

ADDR – Address (Pin)
BC – Before Christ
AD – Computer-aided Design
NA – Deoxyribonucleic Acid
2C – Inter-Integrated Circuit
DE – Integrated Development Environment
URBS – Non-Uniform Rational B-Spline
C – Personal Computer
AM – Self Assessment Manikin
SB – Universal Serial Bus

Јулиан ЈАУК

ЖИВИ АРХИТЕКТОНСКИ ОБЈЕКАТ – ПРОТОТИПСКИ МОДЕЛ ОСЕТЉИВОГ КИНЕТИЧКОГ АРХИТЕКТОНСКОГ ОБЈЕКТА

Резиме: Пројекат „Живи архитектонски објекат" је концептуални пројекат који тематизује интелигентну архитектуру изнад паметних домова, намењен превазилажењу постојећих дуализама као што су дигитално и материјално, вештачко и природно. Процеси као што су оптимизација фактора дневног светла ради смањења потрошње енергије или структурна оптимизација ради смањења количине материјала у носећим конструкцијама, често су коришћени алати у параметарском пројектовању. Оптимизација је могућа само у односу на просечне енергетске вредности или екстремне грађевинске параметре. То значи да зграде нису потпуно оптимизоване у свакој ситуацији, јер напрезања и утицаји околине стално варирају. Почетна тачка овог пројекта била је чињеница да се употреба еволуционих алгоритама оптимизације, дигитално планирање и процеси израде завршавају након завршетка процеса израде. Да су ти процеси присутни и током животног циклуса изграђеног архитектонског објекта, корист би била далеко већа. Као илустрација ове идеје, изграђен је физички експонат утопијске архитектуре који одражава животни процес. Истовремено је приказан дигитални модел као додатни слој информација. Створена је визија интелигентне биолошке архитектуре, која није ограничена материјалним условима. Кинетички, фотоосетљиви и адаптивни модел представља објекат који стално мења своју морфологију како би се прилагодио, не само окружењу, већ и људским емоцијама. Облик, величина и брзина адаптације контролишу се еволуцијским алгоритмом оптимизације, који представља бионичку технологију инспирисану природом. Међутим, уместо целоживотног циклуса, једна итерација адаптације траје само неколико секунди. Учесници су позвани да стимулишу архитектуру уношењем расположења кроз тест самопроцене и променом почетног извора енергије и светлости, пошто зграда еволуира сходно унесеним подацима. Сензори и електрични системи стварају физички надражај путем система провођења стимулуса. Механика и еластични материјали се користе за прилагођавање околини кроз кретање и раст. На овај начин је могуће пренети биолошке критеријуме живота, попут физичких стимулуса и раста, преко растегљивих материјала унутар саморегулационог система, у архитектонску структуру. Приписивање живота на овај начин превазилази своје симболичко значење.

Кључне речи: кинетичка архитектура, алгоритам еволуционе оптимизације, утопијско, интерактивна инсталација