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# Musical Morphogenesis

## A Self-Organizing System

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**Abstract.** We feel and seize the built environment through senses and body's interactive movement. During this process, our mind and physical status is processing solutions and methods of integration and adaptation that enable us to integrate and live with and in our surrounding environment.

In this paper, we provide an overview on "Musical Morphogenesis" interactive installation, which interacts through colour, light, movement and sound with the environment and its inhabitants. In addition, we intend to take visitors in a sensorial journey to explore the dynamic action of a network of genes during the development of an organism. Finding its roots in the Autopoiesis' theory (Maturana & Varela 1980), "Musical Morphogenesis" acts and interacts as a self-producing system. This installation results from a multidisciplinary collaboration of six main scientific disciplines: complex systems, computational biology, music, architecture, robotics, and science communication. During the design and implementation of the installation's components, the specificities of each discipline had to be taken into consideration, resulting in an extremely challenging project.

***Keywords.*** *Biomimicry; Morphogenesis; kinetic; nature-based-design.*

## Introduction

The concept of self-organizing systems was first introduced by Ashby in 1947. Self-Organizing Systems refer to a class of systems that are able to change their internal structure and function in response to external stimuli. (Ross Ashby 2004). By self-organization it is understood that the system's elements are able to manipulate or organize other elements of the same system, in a way that stabilizes either the structure or the function of the whole against external fluctuations (Banzhaf 2002).

## Project Scope

In the last decade, architecture brought to its agenda questions on performance and interaction as key factors of the design process (Hensel and Menges 2008). Current technologies linked to design and architecture such as digital fabrication and manufacturing resources enable architecture to become more responsive and performative. This achievement is made through the use of technologies such as Non Uniform Rational Basis Spline (NURBS) programming, visual programming languages, Computer numerical control (CNC), laser cutting, 3D printing and scanning, among others fabrication processes and techniques. Over the past years, several contributions were made in the living systems study, and regarding the relationship between their components, co-existence and complexity (Hensel, Menges and Weinstock 2010). The Autopoiesis Theory (Maturana and Varela 1971) seems to contain the necessary knowledge to enable the creation of individual self-producing systems.

## Related Work

In 1978, Peter Pearce in his *Structure in Nature Is a Strategy for Design* book presented the concept of Minimum Inventory - Maximum Diversity. In general lines this concept can be summarized as: a minimum inventory/maximum diversity system is a kit of modular parts and rules of assembly. In a successful system, the rules of assemblage and physical components work as natural organisms where rules grow from modules and modules grow from rules, creating a relationship of interdependency and consequence.

Based on Füller's experiences on geodesic arrangement of hexagons and pentagons, Grimshaw developed the Eden Project, a horticultural building structure. The project finds its basis in clusters of bubbles for the general form and dragonflies' wings to solve the structural challenge. The diameter of the bubbles could be varied to provide the growing heights required in the different parts of the building, and a necklace line that could be arranged to suit the approximate topography of the site. Through these strategies, architects were able to minimize the amount of the required ground shaping and allow for the solar orientation of the building to be optimized. The result is one of the lightest structures ever created and a building that is largely self-heated making use of passive solar design principles.

In 2007, Philip Beesley presents at the Musée Des Beaux-Arts, in Montreal (Québec), the Hylozoic Soil installation. Custom-manufactured components were produced making use of parametric design and digital fabrication. Machine intelligence was embedded within a network of micro-controllers that coordinated groups of proximity sensors and kinetic actuators. Arrays of capacitive-sensing whiskers and shape-memory alloy actuators were used to create a diffuse peristaltic pumping, which pulled air and organic matter through the occupied space. The installation offered layers of intriguing individual and group behaviors. Building upon simple motions embedded within individual elements, turbulent wave-like reactions are produced. Using tendrils, fronds and bladders to lure the visitors into its seemingly fragile web of laser-cut acrylic matrices, this work was able to blur the distinction between organism and environment. Operating at the intersections of architecture, design, engineering, and art, Hylozoic Soil is a visceral experience of exploring the nuanced relationship between the biological and the artificial.

In order to design a periodic structure for a coffee shop, VFABLAB-IUL (ISCTE-IUL, Lisbon) develop the Discursive wall – a Living System in 2012. Using digital fabrication processes to develop and design an acoustical cork panel, the goal was to create a wall responsive to human interaction. The fundamental hypothesis supporting the system was the design of an architectural living system constantly being designed and re-designed through its inhabitants. Inspired in the behavior of an *Arabidopsis thaliana* flower, the target was to develop a 3m x 5m wall, that would physically respond to movement, interacting with the temporary space, establishing a direct dialog with the inhabitants, constantly reshaping their perception, minimizing acoustical problems of the space. (de Oliveira et al. 2012). (Figure1).

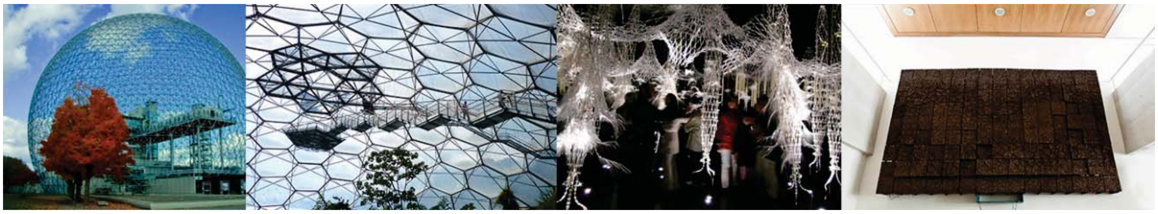

*Figure 1. From left to right: Montreal Bioesphere - Buckminster Fuller [1]; The Eden Rainforest Lookout, by The Grimshaw Architects [2]; The Hylozoic Soil installation, Montreal, by Philip Beesley [3]; Living System - a Discursive Wall, by VFABLAB-IUL [4].*

## Goal

The main goal of this project was the development of an itinerant installation with which the visitors could interact and learn. It models an *Arabidopsis thaliana* flower at a human scale, and its development should obey to the mathematical model of the gene-regulatory network responsible for its growth. The installation is composed of (i) a robotic model that mimics a flower, and whose kinetics reflects the temporal progression of the genetic network as it controls the flower growth development, and (ii) an interface for the visitors to interact with the installation. Through the interface, the visitors are able to select which of the flower's genes are expressed, steering the network towards the formation of different organs - petals, sepals, carpel or stamens. Finally, in order to facilitate the comprehension of the network, each gene is associated to a specific sound (Figure 2).

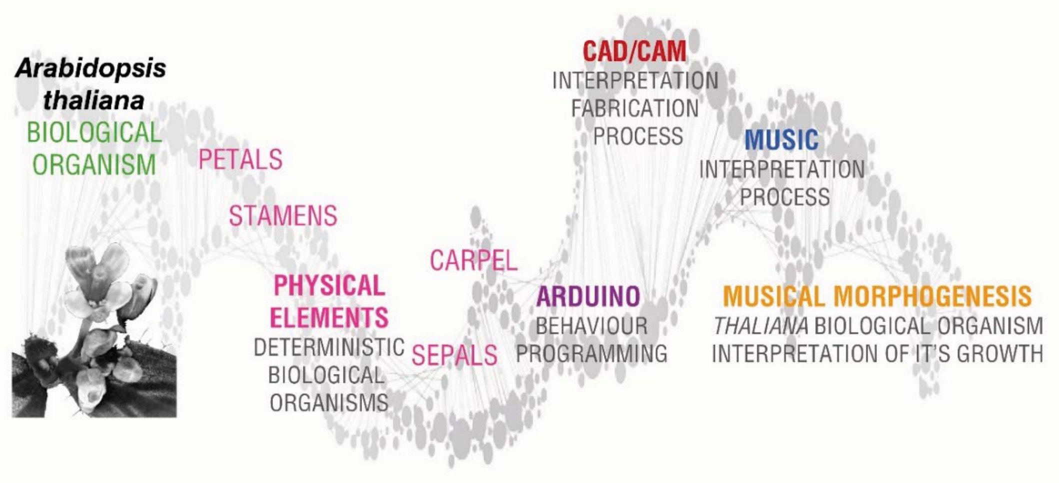

*Figure 2. Strategic diagram of Musical Morphogenesis composition.*

## Methodology

Projects combining science and art have the potential to address difficult scientific messages to the general public, resulting in enriching experiences to the visitors. But how easy is it to create a multidisciplinary project with a strong scientific message? In the development of this project, the following methodology encompassing five stages was followed:

## *Stage one – Study of Arabidopsis thaliana*

The first stage of this project privileged the research and understanding of the chosen living organism, the *Arabidopsis thaliana* flower. This is an important step where the essential genes are identified and their functions and relevance on the growth process are determined. The mathematical model proposed by the team members showed that just 15 genes are sufficient to lead to the development of all organs of the flower. Synthesizing the flower's genetic information, it was possible to describe its regular growth, as well as the influence of possible disturbances in it. The project was (re)draw with all the elements of the multidisciplinary team (Architects, Computation Biologists, Science Communicator, Computer Engineers and a Musician), in way that each member was able to interpret and input several data from its own field of knowledge (architecture, engineer, music, computational biology and science communication).

Every living system is a self-organizing system. Every living organism has a predetermined route, composed of genes and proteins, draw for its well growth, but biological disturbances could force the system to readjust this route. In such cases, the organism has to adapt its internal organizational growth and find new hierarchies, routes, eventually culminating in different physical expressions, in order to react and compensate the external disturbances.

Computers are based on a central processing unit that execute a set of instructions programmed by a user. They are also able to read and collect information from several devices such as memory banks keyboards, mice, and even our voice, information that is used during instruction's execution. What takes place in nature is similar to a computer working process. Cells read the information from genetic memory banks (which in this case corresponds to the DNA) as well as receives signals from the environment and from their own state. With the collection of all this information, cells are then able to produce different kinds of proteins. Unlike computers which typically have a central processor, in cells, information processing and computation of required tasks is done in a distributed way through networks of genes, proteins and other biochemical components.

In nature, when an organism start developing a tissue or organ, several genes and proteins start to interact. All cells of an organism contain the same set of genes, but these can be in an active or in an inactive state, conducting to the production or not of proteins. The configuration pattern of active and inactive genes determines the type of tissue or organ that is formed. This is Musical Morphogenesis main scientific message.

To simplify the scientific message to be apprehended by the visitors, the software that served as interface with the installation was programmed to reproduce the most common pattern of the genetic network, which leads to the formation of petals. However, the final result of the interaction with the installation could be other than the physical expression of petals. The visitor could steer the network, activating and de-activating different genes, which eventually conducts to the expression of another organ other than the petals (sepals, stamen or carpel).

*Arabidopsis thaliana* mathematical model is composed of fifteen genes, which can be either active or inactive. The specific configuration of active and inactive genes at each instant defines a state. The gene-regulatory network rules define which genes are active or inactive on the next time instant. This new configuration represents the next state that the network has reached. The sequences of states along time corresponds to a paths. Each path leads to a final state , an attractor, that represents the expression of the organ. The network rules specify several paths that end in different attractor states that will lead to the expression of a different organ. When at a given instant an interference is made on a state, by flipping a gene from ON to OFF or from OFF to ON, there is a change on the current state. This new may belong to a different path that will lead to the expression of a different organ.

## *Stage Two – Design, scale, structure and material*

The design of a self-supporting installation with sufficient mechanical resistance to be assembled and disassembled by only three to four people was one of the challenges in Musical Morphogenesis project. The first step of the design process consisted in the replication of *Arabidopsis thaliana*'s shape. Following stage one, the design team had to project a self-supporting installation that served as base to the four essential flower's organs – sepals, petals, carpel and stamens. The installation had to be prepared to allow movements from the different organs. The decision on the material to be used in the construction of the installation main structure and key components presented as an important milestone in the design process., The chosen material should aggregate a set of characteristics namely durability, resistance, and friendly cutting properties. Achieving all these requirement, Valchromat [5] was the chosen material. It consists in a type of MDF with the added characteristic of being produced in several different colors, essential for the expressiveness of the model and eliminating the necessity to be painted afterwards.

*The organs*

Musical Morphogenesis main structure was designed to mimic a flower's button, the initial physical shape of a flower's growth. This structure is composed of eight vertical elements, working as pillars, linked through five horizontal circular elements which contain the entire electronic components as well as the compressed air system. The complex net of electric cables and air tubes were thought and assumed freely in the installation as representation of a living vascular system. The five circular elements are associated to location of the different organs of the flower during its normal development.

To represent the possible genetic transgressions and deviations of the natural growth pattern, minor sizes and misshapen sepals and stamens were fixed at the installation, in a non-natural site-specific location. These elements express the pattern growth deviation of the flower, exhibiting genetic deviations and deformations. The complete amount of organs resulted in twelve petals, eight sepals, eight stamens and one carpel. The petals, the most iconic organ of the flower, assume an imperialistic shape being the longer organ and being represented by the red color. The petals are positioned at the second, third and fourth structural levels. The sepals assumed a shape of 'inverted' petals not only because genetically they have the same initial gene, but also because formally they are the first petals that protect the flower in its button stage. The sepals were represented by the blue color and were positioned at the first and fourth structural levels providing a clear expression of an organ that is being wrongly expressed, in the latter case. Both petals and sepals embrace the vertical pillars and produce a open/close movement driven by compressed air.

The stamens, like in the natural *Arabidopsis thaliana*, rises inside the flower through the shape of very delicate and sleek profile. Long, sleek yellow elements were designed as well as small mechanism that enable it to produce a 45º angle movement. Stamens have an influence in the structure all the way to the fourth level of the installation. The open and close movement of the organs is generated by a compressed air system.

The carpel, the majestic central element of the flower, was represented through a continuous acrylic cylindrical element, assuming its formal and functional difference. It is the only organ that influences the five levels of the installation, and unlike the remaining ones, it contributes to the installation through changes in light colors, instead of movement (Figure 03).

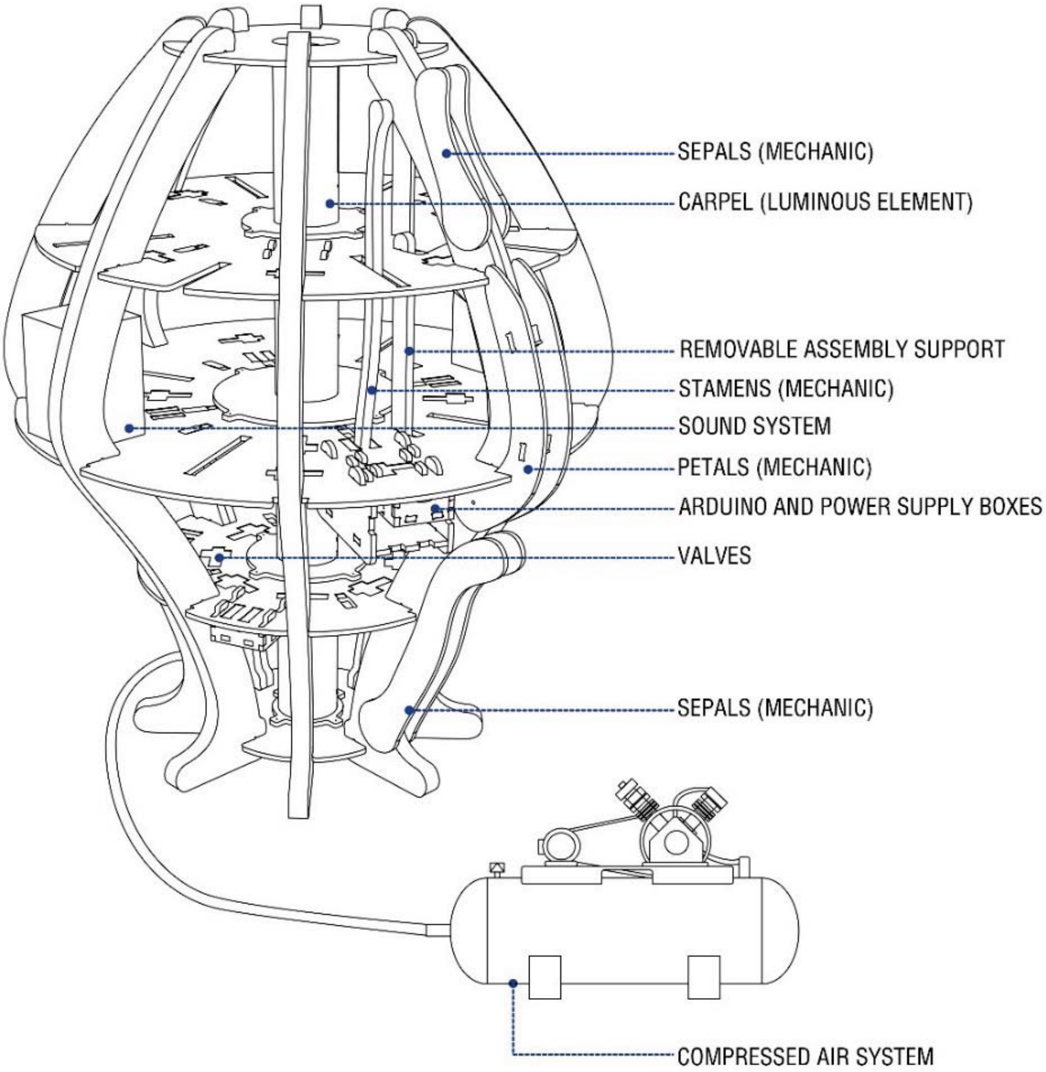

*Figure 3. Musical Mophogenesis blocks and components diagram.*

## *Stage Three: Fabrication and Assemblage*

Musical Morphogenesis was thought and conceived to be assembled and disassembled several times (a limited). To achieve this goal, the elements were designed to produce volumetric impact using bi-dimensional strategies, and the entire installation had no fixed elements. This strategy also enabled us to optimize the use of material and the fabrication time. All the joineries, from the button structure to the different elements were made to fit each other through male/female fittings to form a three-dimensional object Some metallic parts were also used, such as screwed rods - used to fix organ elements to the main structure, or screws - to fix the valves to the circular levels, but all the installation can be disassembled in twenty-five separated sections.

All the elements were organized in 1850 mm X 2500 mm colored Valchromat boards, with 16 mm and 30 mm in thickness, and in black, yellow, blue and red colors. All the structure was conceived in black boards with 30 mm thickness for the vertical pillars, and black boards with 16 mm thickness for the horizontal circular elements. The twelve petals were produced in red boards of 16mm colored Valchromat material, the eight stamens in yellow boards of 30mm and the eight sepals in blue boards of 16mm.

The assembling process starts with the vertical organization of the horizontal circular levels, sustained by removable pillars and the carpel sections that connect and link the structure between levels. The second step is to engage the vertical pillars of the structure, in a total of 8 of them. The petals and the sepals are already assembled in the pillars, reducing the assemblage complexity. There are two different versions of the pillars, accordingly to the organs that are assembled in each of them, in a quantity of 4 pillar of each version. The first pillars' version is composed of both sepals and petals and the second version ones only have petals assembled. The two versions are alternately installed around the levels. The third step consists in securing the Stamens to the horizontal elements and connect them to the corresponding compressed air cylinders. The fourth step compromises several tasks:  the connection of all electric cables (both control, power and sound), and the installation of the compressed air tubes. The electromagnetic valves that control the air flow to the cylinders are already installed in both sided of the different levels, along with the necessary control electronic hardware. In this step, there is the necessity to install the plumbing that provides compressed air to the valves, and the one that conducts the air from the valves to the cylinders, which actuate the different kinetic parts. The sound speakers also come separated from the levels and are installed in this step. The final step consists in the calibration of both the sound level and the opening and close time of the different elements, making use of a calibration program. In parallel with these steps, the interface both and unit is also assembled. It contains the main computer, a touch screen and a sound mixer, along with a subwoofer.

## *Stage Four: Choreographing through motion*

The behavior of the Musical Morphogenesis is expressed through motion, light and music and is controlled accordingly to *Arabidopsis thaliana*'s mathematical model of the gene-regulatory network. The model is executed in the interface's application, and at each step of the model, a combination of motion, light and music is defined. This combination is then sent from the computer to a control unit installed in the third level of the structure, which receives the information related to the different elements state (open or closed) and to the carpel's color. The control unit is composed of an Arduino Mega stacked with a custom made printed circuit board (PCB). To control the carpel light, which is composed of 5 individual rows of LEDs per section, in a total of 20 rows, a custom-made control circuit based on TLC5940's integrated circuit is used.[6] The intensity of the music and the range of motion is inversely proportional to the distance in the path to the final state. For each different path, leading to the expression of a different organ, a specific motion pattern was design and a specific musical theme was written. Each theme is composed of fifteen different sub-themes each corresponding to a gene. The active sub-themes at given moment are controlled by the active genes. Once the final state is reached an ending sequence is executed and a new interaction with Musical Morphogenesis starts. (Figure 4).

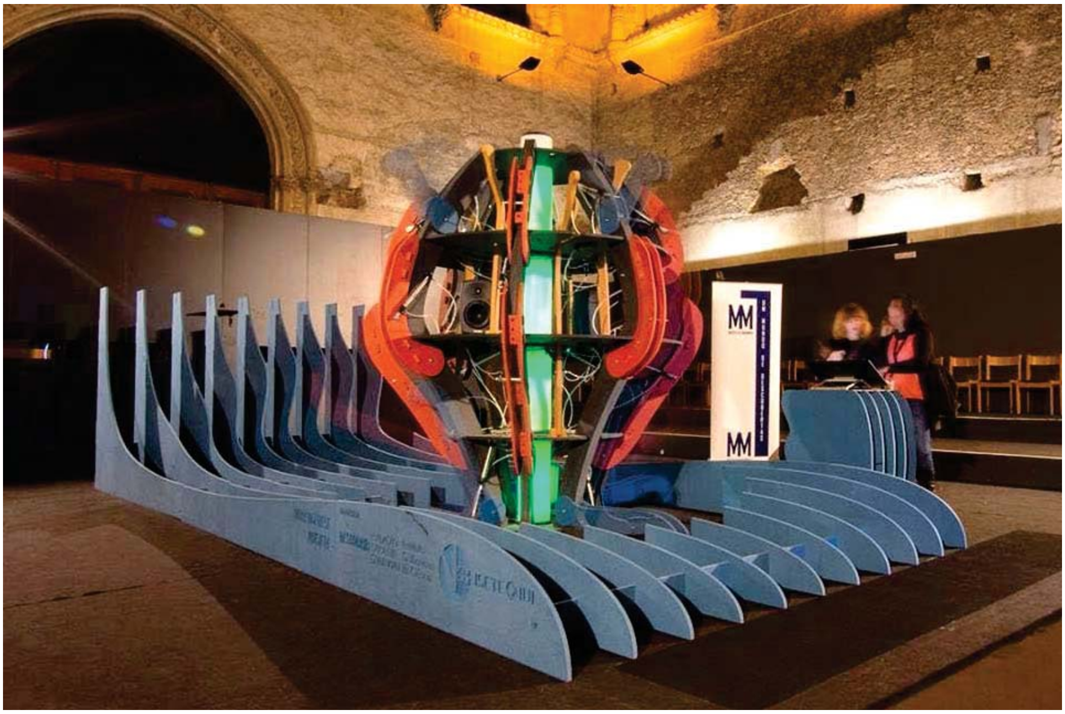

*Figure 4. Musical Morphogenesis in exhibition at Jerónimos Monastery, Belém, Lisbon, 2016. (Photography by Vasco Costa)*

### *Stage Five: Human/installation Interface*

The goal is to essay and visually experience the growth process of the flower and its organs. The human role is to set the state by defining the configuration of the 15 genes, during the process of growth. By defining the state the user is changing the path and consequently the final state (gene or protein) that will influence and determine the growth of one specific element and, as consequence the entire development of the flower. During the growth progression, fifteen genes and proteins interact with each other, enabling the evolution and change of the development path. In addition to the activation state determined by the mathematical model that runs this installation, the user may turn on or off one or more genes at different times of the interaction. When the regulatory genetic network of *Arabidopsis thaliana* finds a potential deviation from the path, the visitor may try to find the genetic path that will lead to the development of a desired organ, looking for the attractors underlying it. For instance, if the visitor wants to force the growth of the petals, s/he has to select proteins or genes that are closer, or that could improve the probabilities of development of that organ.

Physically, the Musical Morphogenesis interface is composed of a touchscreen application, that runs the gene regulatory network's mathematical model. Visually, the interface exhibits a gene and a protein 'keyboard' containing the live combination that is running at the moment of the flower's growth. Every time there is a chance for an external intervention, the possible genes start to blimp in the monitor. This is the moment in which the visitors are called to interact. The 'pause' state is also expressed in the installation: it starts to move unnaturally, with a confusing combination of colors and sound.

The application has also several elements to guide the visitor through the interaction with the installation. (Figure 5) The visitor can interfere with the genetic program by pressing a panel of fifteen buttons that represents the fifteen genes, located at the bottom of the screen (the gene and protein 'keyboard'). The central panel shows the organ that is being formed by the present configuration of the genetic network. Each organ is represented by an icon with similar color to its counterpart in the installation. On the top, there is a timeline that shows the historical of the visitor's interactions, i.e. which organs were closer to formation at a certain moment of development and internal clock of the software. The visitor may also choose to pause the development process or mute the sound, as well as to further explore the sound associated to each gene. A tutorial with the biological background underlying this installation was also created, in the format of an animation accessible through the interface.

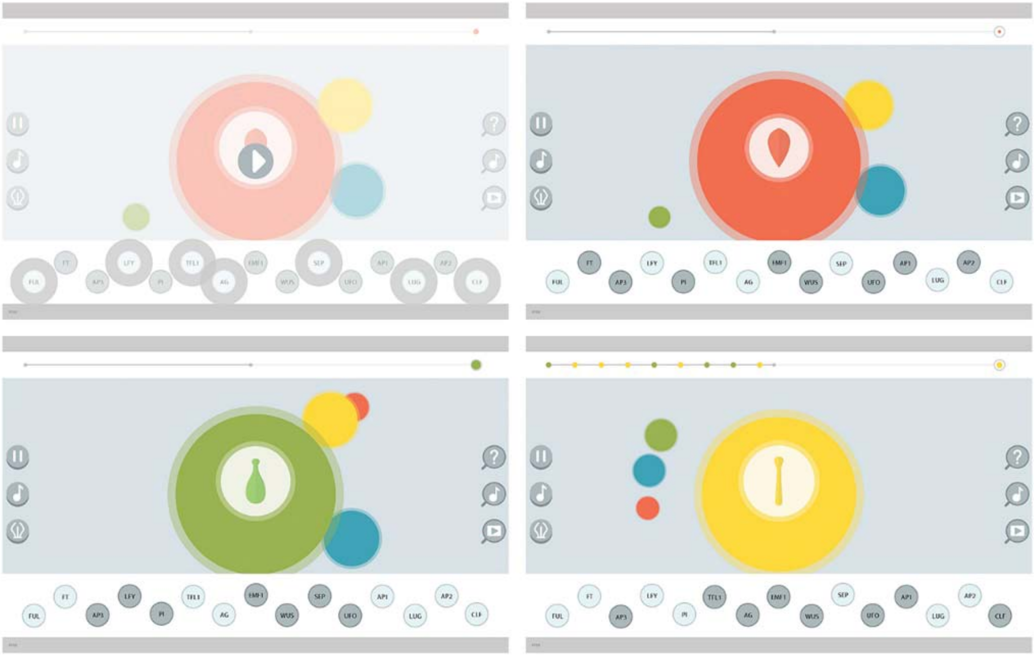

*Figure 5. Musical Morphogenesis interface application screen shoots.*

## Conclusions

'Musical Morphogenesis' is an interactive installation that translates into sound and movement the dynamics of a flower's development process. The development of an organism, or even a tissue or organ, is controlled by a system of genes and proteins. The behavior of the system is collective, in a way that it is not predictable from the individual behavior of each gene. The logic of this genetic control system can also be decoupled from the original organism, as a model. It can then be used not only in other organisms, but also to create message transmitting installations similar to the one exposed in here.

In this installation, we can visualize and interfere with the dynamics of the genetic regulation process by turning activating and inactivating genes and proteins. Doing so, there is a likelihood of developing a mutant type organism instead of a wild type strain.

During the process of creation, design and assembly, many issues appeared and conducted us to redesign the installation for better convey the scientific message underlying Musical Morphogenesis. This installation was exhibited in six different venues in Lisbon metropolitan area, reaching over 2 500 visitors. The feedback received from the visitors that interacted with the installation was overall positive, with different visitors highlighting different aspects of the installation, from its grand appearance and engineer complexity, to the scientific message and the music. (Figure 6).

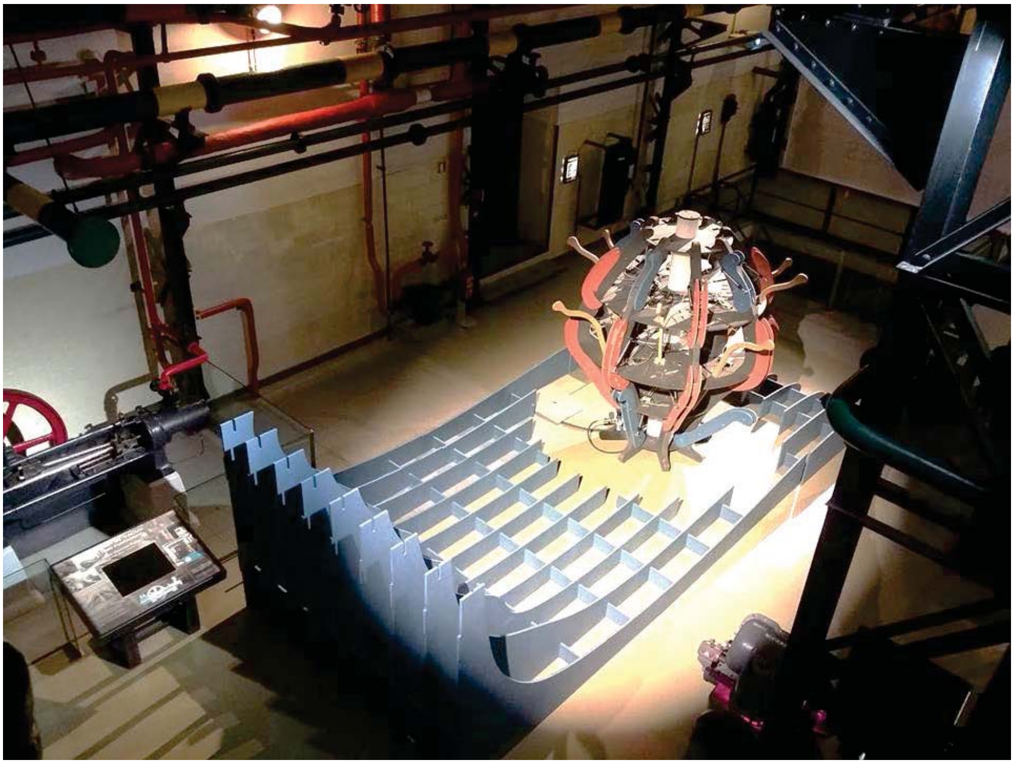

*Figure 6. Musical Morphorgenesis in exhibition at MAAT MUSEUM, Lisbon, 2017 (Photography by Vasco Costa).*

## Acknowledgements

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## References

Banzhaf, W., *Self-organizing Systems*. Encyclopedia of Physical Science and Technology, pp.589–598, 2002.

De Oliveira, M.J., Paio, A. & Rato, V.M., "Fabricating a Living System - Uploading the Design Process into Materialitt Performance", *ICONARCH I*, Konya, Turkey, pp. 294–302, 2012.

Hensel, M., Menges, A., "Versatility and Vicissitude: Performance in Morpho-Ecological Design", *Architectural Design* Vol. 78 No. 2, Wiley Academy, London, 2008.

Hensel, M., Menges, A., Weinstock, M., *Emergent Technologies and Design. Towards a biological paradigm for architecture*. USA and Canada; Routledge, 2010.

Kolarevic, B., Klinger, K., *Manufacturing Material effects. Rethinking Design and Making in Architecture*. USA and Canada; Routledge, 2008.

Maturana, H., and Varela, F., Autopoiesis and Cogni-tion. The Realization of the Living. Boston Studies in the Philosophy of Science, v.42, Boston; D. Reidel Publishing Co., 1980.

Ross Ashby, W., "Principles of the self-organizing system", *Principles of Self-Organization: Transactions of the University of Illinois Symposium* E:CO Special Double Issue Vol. 6 Nos. 1-2 2004 pp. 102-126, 2004.

[1] http://www.archdaily.com/572135/ad-classics-montreal-biosphere-buckminster-fuller (last visited 05.02.2017)

[2] http://www.thethinkinghandstudio.com/mies_portfolio/edenrainforestlookout/ (last visited 05.02.2017)

[3] http://ounae.com/hylozoic-soil-bosque-artificial-interactivo/(last visited 05.02.2017)

[4] https://www.revarqa.com/uploads/docs/dossier/arqa-106-Dossier-2.pdf (last visited 05.02.2017)

[5] http://valchromat.pt/ (last visited 05.02.2017)

[6] http://www.ti.com/lit/ds/symlink/tlc5940.pdf (last visited 05.02.2017)