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PERFORMATIVE DESIGN ESSAY FOR A PAVILION

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Abstract

This paper discusses the digital process in architectural design. It reflects on the collaboration of generative modeling tools, integrated with performance analysis, to construct information in the design process. The work approaches a design experiment, carried out by the Research Group Grupo SCP - Contemporary Design Systems (www.gruposcp.org)dedicated to the development of a multi-purpose pavilion for public use, inserted in an urban void of the city of Vila Velha, in the state of Espírito Santo, Brazil. The research sought to explore the methodological possibilities of generative and performative design to establish digital dialogues between the formal conception and the pre-existing information in context—social, cultural, environmental—through explicit and integrated processes. The method includes the use of computer programs and plugins as Revit Architecture for environment modeling; Rhinoceros and Grasshopper for generative modeling; the DIVA for Grasshopper plug-in and Kangaroo for design-integrated performance analysis; and the Galapagos plug-in to applying evolutionary algorithms in the formation process. The method enabled the optimization of a form according to local conditions and performance variables, automation of processes and reducing design time. The project mediated by the digital programs collaborated with processes of knowing-in-action and reflection-in-action, in which explicit knowledge, obtained in the act of doing, feeds back into the process, allowing testing, analysis and adjustment in the act of conception.

Keywords Digital design, generative design, performative design, algorithm.

1 Digital processes in architectural design: generative and performative design

Digital processes in architectural design enable new opportunities for conceptual and formal exploration, articulating architectural morphology to the adaptive properties of form. Oxman (2006) terms the formation process of the object which is highly mediated by digital technology "digital design". For the author, the evolution of digital design as a field of activity and producer of classes, that are exclusive to design, is a phenomenon that has been established in the last decades. Important contributions related to research and practice in digital design have been elaborated in recent years (Kolarevic, 2003, Kolarevic and Malkawi, 2005; Kolarevic and Klinger, 2008; Kolarevic and Parlac, 2015; Oxman, 2006, 2008a, 2008b, Oxman and Oxman, 2010, 2014).

Contemporary design methods explore the complexity and transformation of form by integrating performance analysis tools and generative mechanisms. The form, digitally generated in parametric and generative processes, are programmed by algorithms. These inform logical rules and procedures, making it possible to explicitly integrate the formal conception to design conditions and performance variables.

For Kolarevic (2003) the contribution of digital tools in architectural projects redefines building expectations, their processes and practices. The digital processes in the architectural conception surpass the mere possibility of representation and visualization, and evolve into processes of digital morphogenesis, in which the tool is used to generate the form from an internal computational logic. These highly interactive processes build information that feeds back[1] into the design act. They also allow explicit integration of context information and performance variables into the processes of form generation and analysis.

In generative design, the architect interacts with the generative mechanism and not with the model itself, and the form derives from pre-formulated generative processes. In this process, interaction is paramount. Through interaction modules, the designer controls and chooses the best solution. For Oxman (2006), the ability of digital models in establishing a greater connection between conception and materialization also enables greater depth of context and performance. More than any other concept, understanding and accommodating complexity seems to be one of digital design's chief characteristics. The author points to the fact that this transformation in the design process has contributed to the emergence of new roles for the architect, including that of a toolmaker.

In digital design, it is possible to generate and change the form, as well as simulate behaviors, integrating the formation process with the performance variables. In this process, called "performance-based design" (Oxman, 2008a) and "performative architecture" (Kolarevic and Malkawi, 2005), form generation is conditioned to the actuation of external forces (environmental forces, movements, site, program) that inform the logic of algorithmic programming. Performance is, at once, the determinant and the method for the creation of form. For Oxman, "performance-based design" is "an approach in which building performance becomes the guiding factor in design" (Oxman, 2008a, p. 4).

According to Oxman and Oxman (2010) digital technology enables a new order for design and construction. The available technology for digital modeling and simulation provides contemporary architecture with new work models for architects and engineers, as well as new design categories, which the authors call "design engineering." These models are characterized as highly collaborative and feedback-oriented, in which interaction between architects and engineers occurs in the early stages of design and form definition.

The use of information in digital modeling shifts the design emphasis from "form making" to "form finding". All information guiding the formation process enable complex transformations linked to performance management. Attention is focused not only on the generation of complex forms, but mainly on the possibility of generating form that can be transformed and dialogue with social, cultural, economic and environmental contexts, through explicit and integrated processes.

2 Knowing, reflecting, transforming in action

Traditional design processes are based on implicit knowledge, since it is not possible to formalize the assessment of what is conceived. They are usually associated with creativity and intuition. In digital design, knowledge is explicit, and decisions are mediated by the responses obtained through the use of digital tools. This process, fed by information and learning in action, contributes to the process of "knowing-in-action" and "reflection-in-action," advocated by Schön (2000).

For Schön, the "indeterminate zones of practice," that is, those that present a great deal of variables, uncertainty and conflicts of values, are the most present in professional practice. These are unique situations that escape linear technical solutions and assimilate systemic, chaotic and undetermined problems (Schön, 2000, p. 17). For the author, in undetermined zones, intelligent actions are driven by tacit knowledge—that which is generated through doing—in a process called "knowing-in-action" and "reflection-in-action."

Schön argues that knowledge acquired in action is sometimes difficult to describe (such as riding a bicycle, for example), but that through the exercise of observing and reflecting on actions it is possible to draw up a description of the tacit knowledge that is implied in them. "Whatever language we use, our descriptions of the act of knowing-in-action are always constructions [. . .] The process of knowing-in-action is dynamic, and 'facts,' 'procedures' and 'theories' are static" (Schön, 2000, p. 31, translated by the author).

The act of "knowing-in-action" involves another act that takes place simultaneously: "reflection-in-action." Knowledge gained through experience contains certain surprise elements, which occur at odds with expectations and lead to "reflection-in-action." The act of reflecting on action does not necessarily occur after the action, so that one can no longer act upon it, but during action, where "our thinking serves to reshape what we are doing while we are doing it" (Schön, 2000, p.32, translated by the author).

The process of "knowing-in-action" and "reflection-in-action" is a trial and error process, very common in design processes. It is a dynamic process that involves continuous error detecting and correcting through experience. For Schön, the attempts are not random, but relate to one another. "Reflecting on each attempt and its results creates conditions for the next" (Schön, 2000, p. 33, translated by the author).

This process of knowledge investigated by Schön can be described through a cybernetic[2], system, organized by information (obtained through the experience of "knowing-in-action"), detection and adjustment (through "reflection-in-action"), in a dynamic and interactive way that involves feedback processes (Marconsini, 2012).

Schön's work is signaled by Oxman (2006) as an important foundation in digital design models, especially in the author's reflection on the central role retained by the designer and his action, emphasizing the interaction between the designer and the representation of the problem, and characterizing the process as reception (perception), reflection (interpretation) and reaction (transformation). For Oxman, this conceptual terminology of the project as "interaction with visual media" to "inform the future design" is utterly relevant in digital design models and underscores the centrality of the designer, who controls the digital process (Oxman, 2006, p. 241).

3 Development

The experiment aimed to explore the methodological possibilities of generative and performative architecture in the design of a pavilion, inserted in an urban void of the city of *Vila Velha*, in the state of *Espírito Santo*, intended for multifunctional activities related to culture and leisure. The method for formal conception employed generative digital models, in which the logic of the algorithms establishes explicit dialogues between form, local conditions and performance variables.

The chosen site is located in the *Ilha dos Ayres* neighborhood in *Vila Velha, Espírito Santo*, Brazil, and has 8,279 square meters with a length of 350 meters and a width of 42 meters (figure 1). Owned by the city hall, it is part of an idle, wide and spacious median strip, which resulted from the construction of new roads for the Bigossi Corridor Project, planned by the city in partnership with the state government, with the premise of optimizing urban mobility (Obra, 2007). It is part of a context where land use is predominantly residential, and nearby are located institutions and social assistance projects.

Despite its proximity and connection to important roads, shopping malls, institutions, a bus terminal and hospitals, the Bigossi Corridor Project has provoked a large number of expropriations, causing problems of different levels of complexity. This long, empty and idle median strip was chosen for the installation of a multi-purpose pavilion which allowed for different appropriations of the underused area.

Fig. 1: Aerial view of the intervention area. Source: Google Earth, 2019.

The data survey for the site included mappings, images, photographs, and local visits that observed flows and uses on different days and times of the week (figure 2). The information collected about the nodal points, the high-flow roadways, the pedestrian crossing and permanence guided the programming of algorithms and generative systems in the design process.

The median strip's occupation by local residents is spontaneous and not planned, and it is used in a mixed way by all age groups. On weekdays, there is an intense flow of vehicles, especially during peak hours. In the morning, late afternoon and on weekends the place is used for spontaneous leisure activities. Despite its current use, due to low density and scarce variety of commercial activities, the place has low urban vitality, with little pedestrian traffic. Located in an essentially residential urban area, the site is subject to rapid transformations which may change the landscape due to the possible increase in building density and variety of uses when the Bigossi Corridor mobility project is completed.

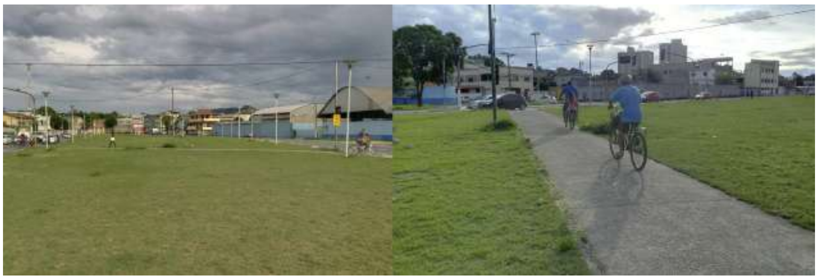


Fig. 2: ASpontaneous appropriations of the study area. Source: Research collection, 2018.

Mapped points show the spontaneous use that occur in the void. In the map (figure 3), activities are related to sports (1); pedestrian crossing (2); children's play (3), pet walk (4); and physical activities, such as jogging (5). Information collected was synthesized in maps and diagrams, identifying the main conditions of the site: road hierarchy, bike paths, uses and occupations, pedestrian flows, urban infrastructure, voids and buildings, height of buildings and environmental conditions (figure 4).

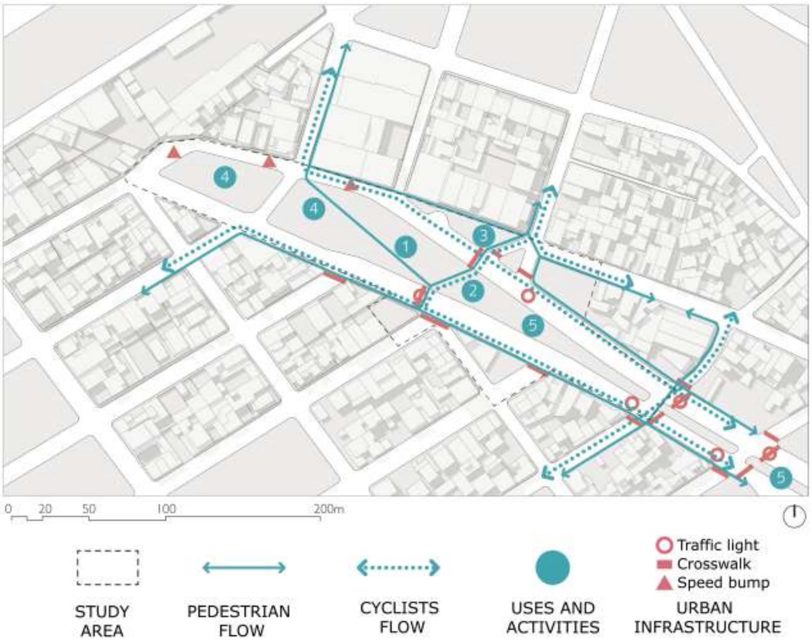
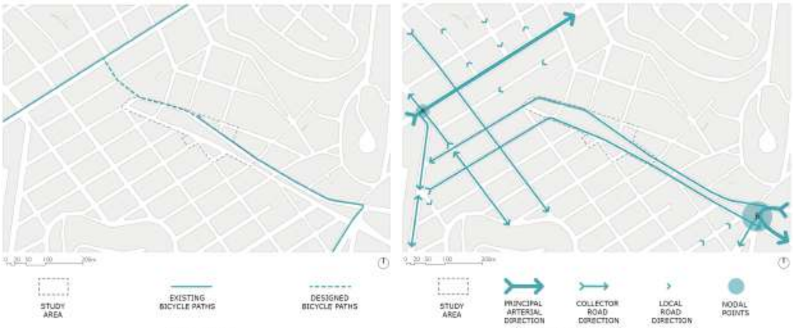


Fig. 3: Mapping of pedestrian flows, cyclist flows, uses and spontaneous activities. Source: Research archives, 2018.

Green areas, buildings, vegetation and empty sites.

Setting out line chart



Bike paths

Road hierarchy

Fig. 4: Mapping of local conditions. Source: Research archives, 2018

3.1 Programming and Tools

For the definition of the pavilion's volumetry, the guideline that has oriented the design's conception was to prioritize the pedestrian and enable a diversity of experiences related to the communal life. Departing from this premise, we sought to fulfill some conditions for the volumetric study: pedestrian flows, uses and occupations, environmental comfort, spatiality, structure and materiality. These conditions were incorporated with some degree of force or interference in the design process, which responsively implied the volumetry of the pavilion.

The pavilion was organized in three volumes: main pavilion, annex pavilion and pedestrian walkway. The division in sectors defines the usage territories, designed to house the predominant activities in the place and stimulate new uses, contributing to greater appropriation and permanence of pedestrians: community events, kiosks, farmers' market, sports, physical activities, spaces for permanence and sharing, playground, community fitness center, skate park, community garden. Due to the high flow of vehicles around the site, a pedestrian crossing bridge is proposed, thus widening the connections between the site and the surrounding roadways (figure 5).

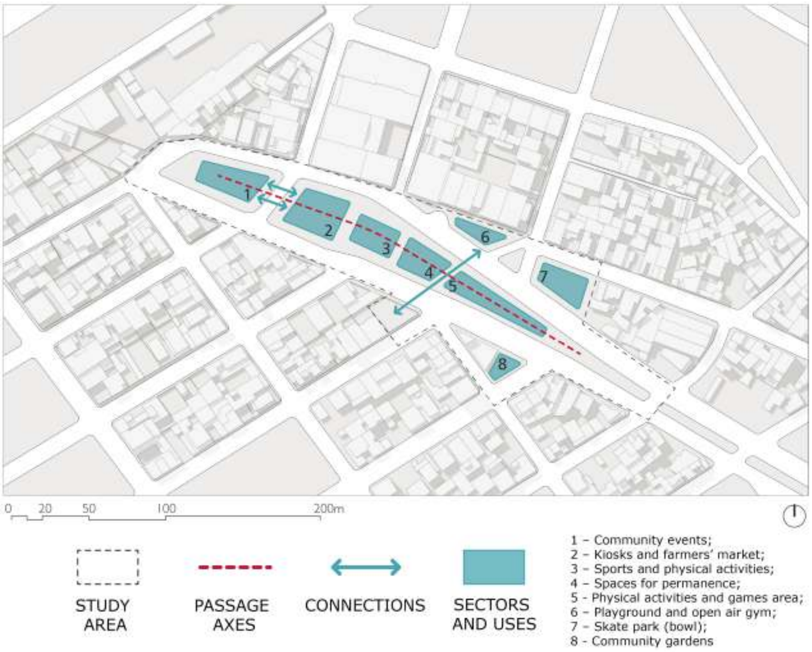


Fig. 5: Map showing the planning of the usage territories, according to the spontaneous activities observed and other potential activities. Source: Research archives, 2018.

The surroundings were modeled using the Revit Architecture software and imported into the Rhinoceros 3D software (figure 6), along with the diagrams with graphic and vector representations of the context analysis, presenting basic elements for form programming. A synthetic geometry for spacing boundaries, locations for sports activities and the main crossing flow was created.

Departing from the basic elements, generative codes were programmed with the Grasshopper software for each building composition: main pavilion, annex pavilion, pedestrian walkway and floor layout.

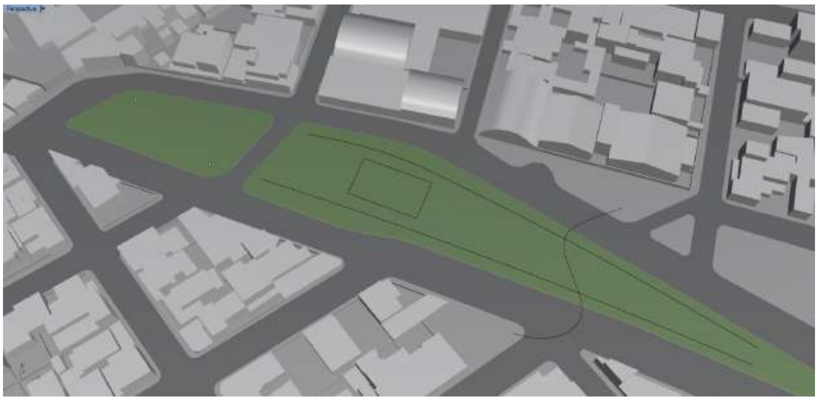


Fig. 6: Base imported into the Rhinoceros software for algorithm construction. Source: the authors, 2018.

The advantage of generative systems is that they can use different sources of information for better results. However, the larger the managed information, the slower and more delayed processing will be. Due to hardware, staff and time constraints, code programming was divided into steps.

Five codes were organized in the programming flow, for formal design and performance evaluation (figure 7). Code 01 defines the main pavilion; code 02 manages the volumetry and structure of the walkway; code 03 performs insolation analysis on the pavilion's volumetry, aiding in the choice of materials, optimized from UDI (Useful Daylight Illuminance); code 04 manages the volumetry of the annex pavilion; code 05 defines floor layout.

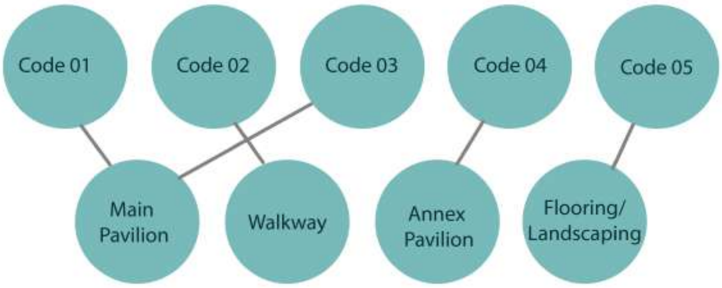


Fig. 7: Programming flow diagram for Grasshopper. Source: Research archives, 2018.

For solar radiation and daylighting simulations, the DIVA for Rhino software was used[3]. DIVA is a daylighting and energy modeling plug-in optimized for Rhinoceros and Grasshopper. It was initially developed at the Graduate School of Design at Harvard University and is now distributed by Solemma LLC. It allows environmental performance evaluations of buildings and urban landscapes, including radiation maps, photorealistic renderings, climate-based daylighting metrics, glare analysis and energy analyses.

The structure simulation and panel patterning were developed on the Kangaroo*Kangaroo*[4] plug-in developed by Daniel Piker. Kangaroo is a Live Physics engine for interactive simulation, form-finding, optimization and constraint solving. This tool was used to include information of flows and uses in form generation, operating in two different situations. The first operation creates the main surface and determines the pattern of the panels; the second operation generates the structure, which shares the same principles as the first operation, but is limited to the main volumetry, avoiding incompatibilities.

To define the volumetry of the annex pavilion the Galapagos[5],plug-in, incorporated into the Grasshopper plug-in, which generates evolutionary genomes to maximize results, was used. At this point of the project development, there happens a clear understanding of the process of "form-finding," in which the conditions are defined by the architect, but still the final form is unpredictable.

3.2 Algorithm construction

Code 01 (figure 8) was programmed to define the main pavilion's volumetry, and is organized in four parts, managing two results. The first part comprises the selection of the basic elements to define a projected two-dimensional form from which we extract the information that feeds the parameters and dynamics for the creation of the roof surface; the second part comprises parameters and dynamics such as anchor points—points with dynamic forces to affix geometry at a given coordinate—the force of gravity and size constraints, ensuring greater control at the moment of deformation, avoiding loss of optimization; the third part contains the Kangaroo2 tool, which calculates and manages data and information collected in the previous steps; the fourth step presents the results obtained through management and optimization. The code was designed to output two results that are justified due to the modulation differences between the surface panels (figure 9) and the spatial truss modulation (figure 10), and in which incompatibilities between both components are not allowed.

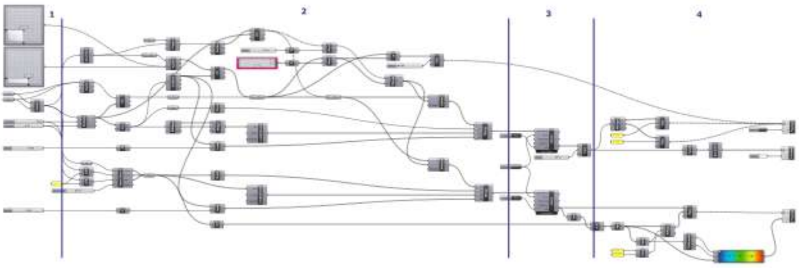


Fig. 8: Code 1 programmed on Grasshopper: It defines the main pavilion's roof and structure. Source: Research archives, 2018.

Fig. 9: Top view of the roof surface. Reference of the projected 2D surface (left) and roof surface with panel pattern (right). Visualization on Rhinoceros 3D. Source: Research archives, 2018.

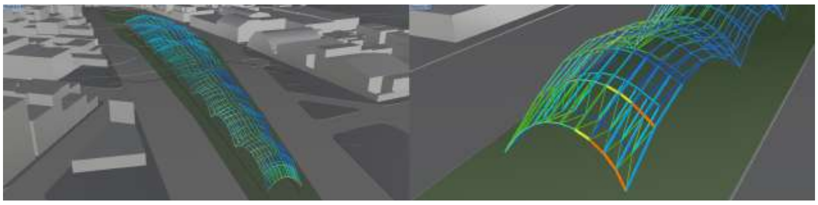


Fig. 10: Detail of the truss with the dimensioning of the sections of the profiles linked to a stress analysis. Visualization on Rhinoceros 3D. Source: Research archives, 2018.

Code 02 (figure 11) defines the walkway geometry and optimizes the openings. It was elaborated with the same step structure of code 01: definition of geometry, parameters, management tools and results. This code uses the solar radiation simulation offered by DIVA 4 (figure 12a), which optimizes the size of the openings of the walkway panels linked to the amount of insolation received (figure 12b).

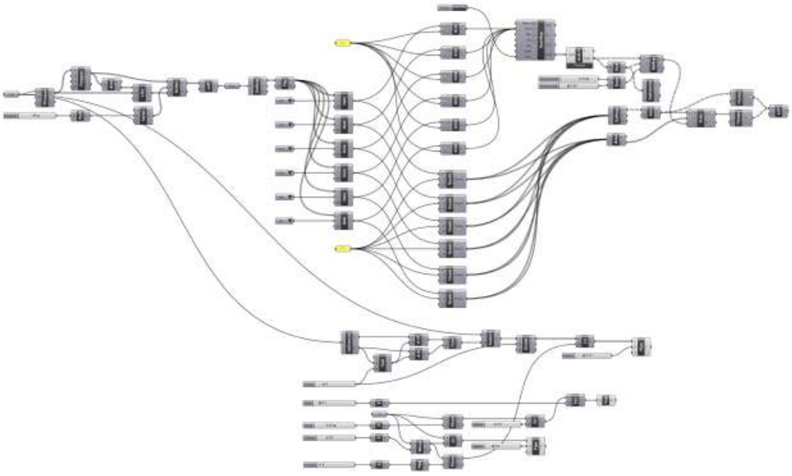


Fig. 11: Code 02 programmed on Grasshopper. Defines the panels and structure of the walkway. Source: Research archives, 2018.

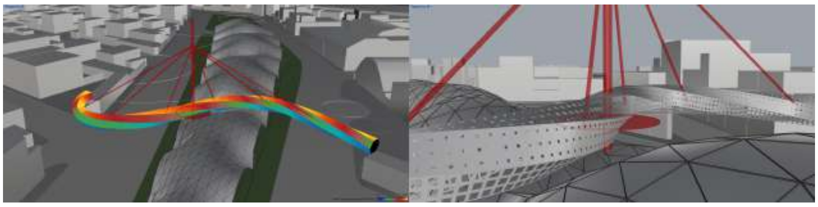


Fig. 12: (a) Solar Radiation Simulation on the DIVA for Grasshopper plug-in, (b) Optimization of the size of the openings linked to the amount of solar radiation received. Source: Research archives, 2018.

Code 03 (figure 13) was developed for insolation analysis on the roof surface and to obtain the pavilion's illuminance levels in order to guide roof opening points for lighting and ventilation. This code operates only as a method to analyze results through the Useful Daylight Illuminance (UDI) simulations on DIVA 4 (figure 14). In this case, the concept of "form-finding" does not apply but has as its principle the exercise of evaluation and management of results through programming.

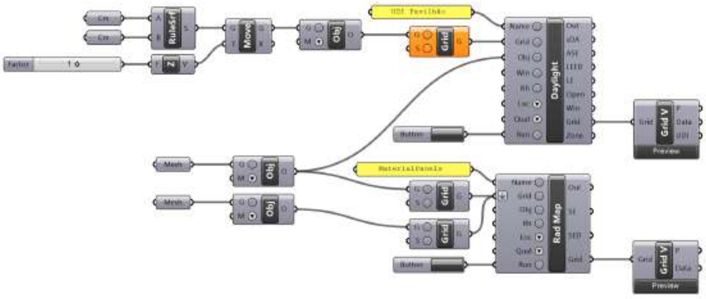


Fig. 13: Code 3 programmed on Grasshopper. Analyzes roof insolation and the pavilion's illuminance levels to guide opening points for lighting and ventilation. Source: Research archives, 2018.

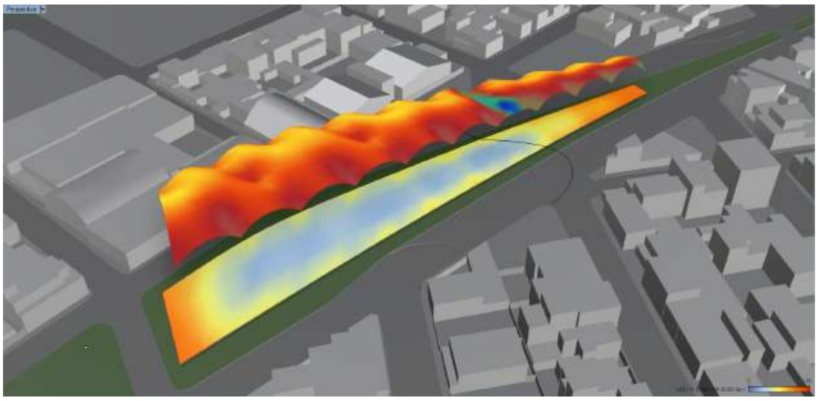


Fig. 14: Geometry view with insolation analysis and UDI, visualization in Rhinoceros 3D. Source: Research archives, 2018.

Code 04 (figure 15) defines a parametric volumetry designed to undergo genetic evolution, optimizing the amount of insolation within the enclosed pavilion. The Galapagos plug-in is used to generate evolutionary genomes and maximize results by combining different possibilities of algorithms and parameters to achieve the best results and filter them. This process is divided into five steps: the first step selects the base elements and initially defines a two-dimensional geometry; the second step is the parameterization of the volumetry, data that is used in the evolutionary gene process; the third step comprises the insolation analysis tools using DIVA 4; the fourth step collects the results; and the fifth step is responsible for combining the parameters distinctly, seeking the best solution (figure 16).

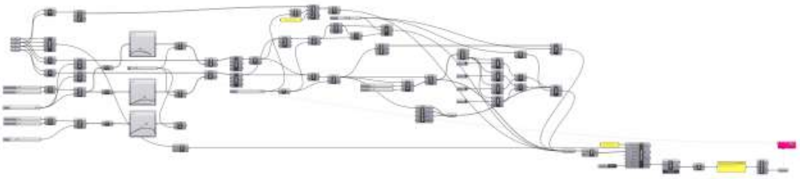
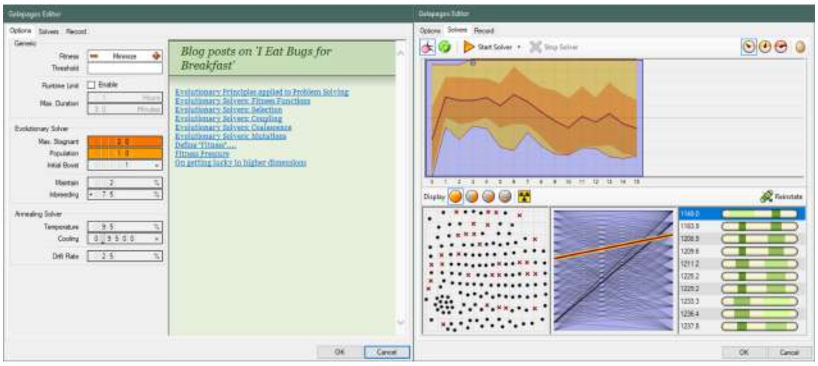


Fig. 15: Code 04 programmed on Grasshopper. It performs insolation analysis inside the pavilion and defines the best volumetry from the analysis of evolutionary genomes. Source: Research archives, 2018.

The Galapagos dialog box displays graphs of the figures obtained and organizes them in the priorities defined in the settings. Figure 16 shows the radiation data analyzed by DIVA 4 in ascending order. From these data, it is also possible to select which combination of parameters will be kept in the final definition of the form, also considering its aesthetic aspects (figure 17).



Generic
Fitness: Minimize
Threshold
Runtime Limit: ☐ Enable
Evolutionary Solver
Max. Stagnant: 20
Population: 10
Initial Boost: 1
Maintain: 2 %
Inbreeding: + 75 %
Annealing Solver
Temperature: 95 %
Cooling: 0.9500
Drift Rate: 25 %

Blog posts on 'I Eat Bugs for Breakfast'

Evolutionary Principles applied to Problem Solving
Evolutionary Solvers: Fitness Functions
Evolutionary Solvers: Selection
Evolutionary Solvers: Coupling
Evolutionary Solvers: Coalescence
Evolutionary Solvers: Mutations
Define 'Fitness'...
Fitness Pressure
On getting lucky in higher dimensions

Fig. 16: Screenshot of the Galapagos dialog box showing evolutionary genome configuration and management, based on the parameters defined in the code (left) and the process and outcome of the evolutionary genome (right). Source: Research archives, 2018.

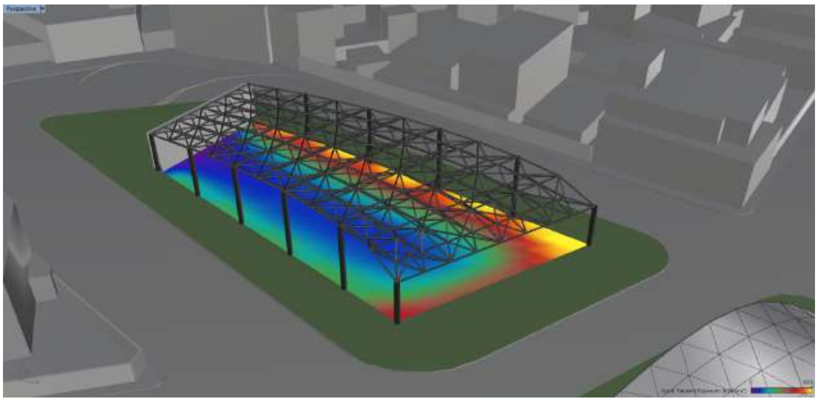


Fig. 17: View of the resulting geometry, shown with the insolation analysis, visualized on Rhinoceros 3D. Source: Research archives, 2018.

Code 05 (figure 18) contains a parameterization in which specific points—determined by the flow of people and uses of the pavilion—are considered that have a certain force field to act on the floor design layout. They generate dynamic designs, which help the visualization of the passage axes in the project and the permanence spaces. The force fields defined by the points guide, at the same time, small openings for contact with the ground, helping the runoff of rainwater, especially where there will be openings in the roof.

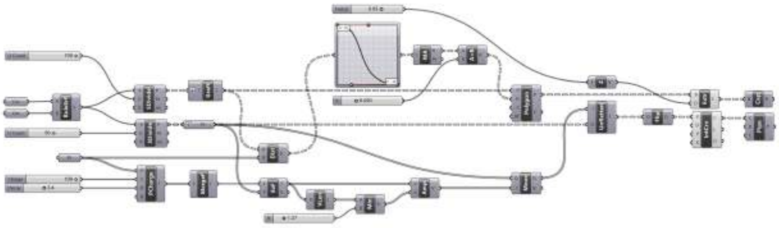


Fig. 18: Code 05 programmed on Grasshopper. It performs the parameterization of the floor layout inside the pavilion. Source: Research archives, 2018.

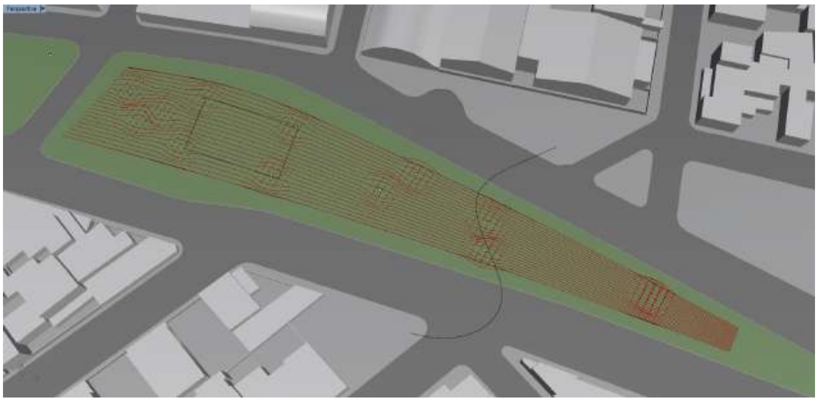


Fig. 19: View of the floor layout which resulted from force fields. Visualization on Rhinoceros 3D. Source: Research archives, 2018.

4 The pavilion

Given the volumetric results generated through the codes, a series of graphical contents for the representation of the project was elaborated (figures 20 to 24). This content seeks, through humanization, to reveal the spatialities, the uses, the observer's views, the aesthetics and scale.

The project considers surrounding land and vacant lots for better building/surrounding integration, and improvements in the flow of people. These vacant lots house ramps that provide access to the walkway, the skate park (bowl), and allow extensions to community gardens, playground for children and physical activity facility for the elderly. The parameters to establish the limit of roof height were programmed so as to not exceed the average height of the surrounding buildings, creating a new landscape in harmony with the volumetric forms of the surrounding buildings.

The perspectives show the flexibility of the generated components, with small kiosks, sports court, spaces with different types of furniture, and passage axes. The landscape design seeks to incorporate natural elements dynamically, as well as to provide better visual and thermal comfort. It is possible to understand the arrangement of the opening of the panels, generated responsively, according to the insolation.

Fig. 20: Rendering of the project's implementation. Source: Research archives, 2018.

Fig. 21: Rendering of the aerial view of the project. Source: Research archives, 2018.

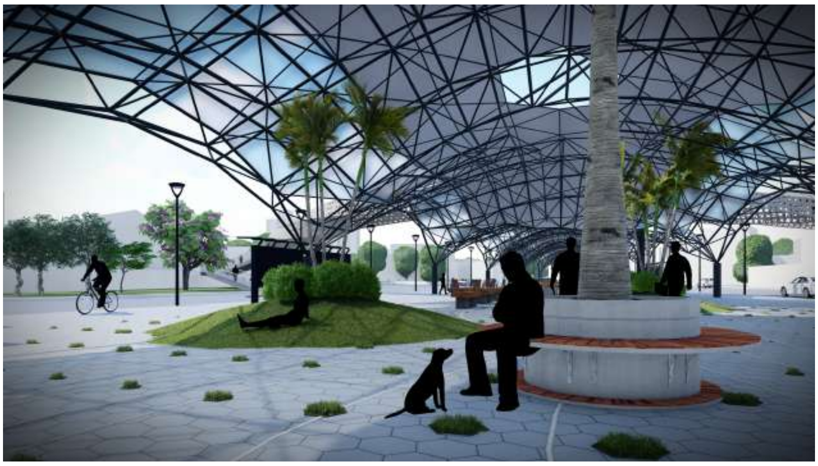


Fig. 22: Rendering of the observer's view, showing the internal spatiality of the main pavilion. Source: Research archives, 2018.

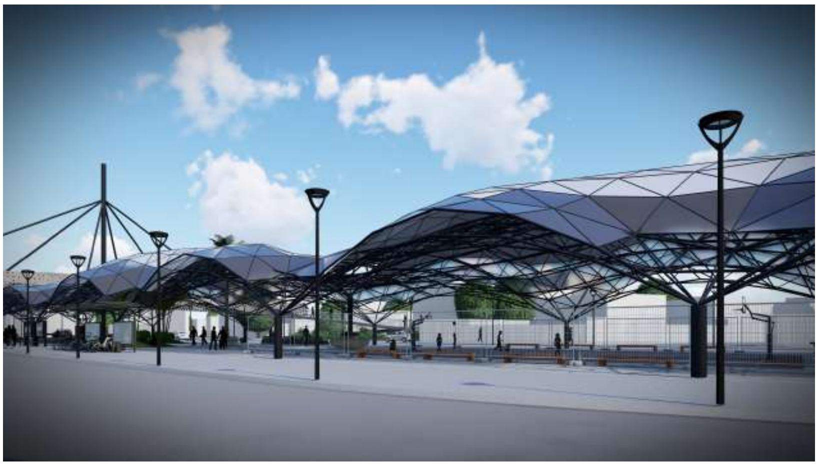


Fig. 23: Rendering of the observer's view showing the court, bike racks and bus stops. Source: Research archives, 2018.

Fig. 24: Rendering of the observer's view, showing the internal spatiality of the main pavilion. Source: Research archives, 2018.

5 Conclusões

The conducted design essay explored the generative modeling tools for the construction of the information in the design process. In the design conception, the interaction with the form occurred through the programming engines, which accommodated the context information and the desired performance variables. Once built, they made it possible to experiment with formal solutions. The generation and adaptation of the form occurred through feedback processes from the information obtained in the manipulation of generative tools.

In the employed method, the digital tools, used in form programming, collaborated to the process of knowing-in-action and reflection-in-action. Generative modeling enabled dynamic design integrated with performance analysis. It informed decision-making based on tacit knowledge, acquired in action, based on the explicit information made available by the tools in the act of conception.

Performance is paramount in form seeking, and is conditioned in the construction of algorithms, especially in two situations: in the definition of the walkway openings, whose dimensions are conditioned to solar radiation; in defining the form of the annex pavilion, generated by evolutionary genomes, adapted to allow for better availability of natural lighting. In other situations, such as the definition of the openings and trusses of the main pavilion, performance simulation, although not directly linked to the form-seeking engine, it acts as an important information for reflection, analysis and transformation during formal conception.

Form programming contributes to the reduction of modeling time compared to the conventional process, especially in more complex designs, facilitating changes, testing and quick visualization of results, in tandem with design conception. In this essay, the generative and performative design allowed the optimization of form as a function of the aspects related to environmental comfort, structure, materiality, functionality, viability, among other performance variables.

The digital project, conceived from generative and performative models, made it possible to approach the complexity of the design process through the integrated modeling of the object. In this process, mediated by digital tools, the designer has taken on a central role, from programming, experimentation, testing and assessment, including aesthetic judgment as well. Explicit information obtained in the practical process led to reflection on the action and, in turn, provided feedback in the process that favored the choice for the best solution.

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1 Feedback is a feature of systems in which the effects of responses inform the actions of the receivers, successively, in self-regulated systems. A wide variety of systems in technology and nature are regulated by feedback mechanisms. The feedback process is central to cybernetics, "theory of control systems based on communication (transfer of information) between systems and environment and within the system, and control (feedback) of the system's function in regard to environment" (Bertalanffy, 2010, p. 43, translation by the author).

2 Cybernetics is a transdisciplinary science that emerged in the mid-twentieth century and which investigates the flows of information in living and inanimate systems: information, control and feedback. Norbert Wiener originally defined it as "the science of control and communication in the animal and the machine" (Pask, 1970). Cybernetics pave the way for the emergence of information theory in the 1960s and influenced research in a wide range of areas, including psychology and pedagogy.

3 Available at: http://solemma.net/Diva.htm

4 Available at: https://www.food4rhino.com/app/kangaroo-physics.

5 Available at: https://www.grasshopper3d.com/group/galapagos.