

Parametric and Automated Brise-Soleil Prototype Using Digital Technologies

Alessandra Teribele¹, Rodrigo Marques de Figueiredo², Felipe Vinícius Stein³, Felipe Arnhold⁴ and Izabele Colusso¹

1. Programa de Pós-graduação em Arquitetura e Urbanismo, Universidade do Vale do Rio dos Sinos, São Leopoldo, RS 93022-750, Brazil

2. Programa de Pós-graduação em Engenharia Elétrica, Universidade do Vale do Rio dos Sinos, São Leopoldo, RS 93022-750, Brazil

3. Departamento de Engenharia Elétrica, Universidade do Vale do Rio dos Sinos, São Leopoldo, RS 93022-750, Brazil

4. Departamento de Engenharia da Computação, Universidade do Vale do Rio dos Sinos, São Leopoldo, RS 93022-750, Brazil

Abstract: The solar protection systems avoid direct sunlight shafts incidence contributing to the luminous, thermal and energetic performance of edifications. In some regions, like the south of Brazil, where the variation of temperature is wide, the control of solar radiation incidence is even more required. Besides, the use of the vertical and mobile brise-soleil in facades which radiations affect with larger angles, as east and west facades, is more appropriate. The possibility to make this automatic movement would make its utilization and manipulations easier, adjusting the opening angulation according to the user desire and the environmental criterion of the period as well. In this way, the main goal of this work is the development of a parametrical and automatized brise-soleil prototype, aiming its application in architecture and construction. The relation between elements of solar protection and automation can contribute to a greater environmental efficiency and user convenience.

Key words: Automatization, parametric architecture, digital fabrication, Arduino.

1. Introduction

Brise-soleils emerged in the early 1900s, designed to protect buildings from direct sunlight by considering modern architectural language [1]. Being elements of sun shading, they must have a suitable dimensioning to the sunshine that is desirable to protect [2] while participate in the composition of the building and contributing to the definition of the building's character [3].

The brise soleil can be fixed and provide good environmental results with the right planning for the sunshine that should be protected. However, mobile brise soleil allows greater gains in illumination and visibility, since it allows angular variation, closing or

opening the plane to which it is fixed [4]. Otherwise, solar protection systems interfere with the luminous, thermal and energetic performance of buildings [2], as they avoid direct incidence of solar rays by altering the lighting conditions and the thermal comfort of the interior [4].

The mobile brise soleil depends on a control, manual or not, to carry out the predicted movements. This can be done with the help of automation, which is increasingly present in the architectural reality. While automation allows management with minimal human intervention, automatization that has become a system automatic allows movement control, but man must interfere with the process. Domotic [5] is the term used for automation and automatization in buildings for civil use allowing to control and monitor various equipment through sensors and management software. Systems of automation of a building can also be called responsive

Corresponding author: Alessandra Teribele, professor, research fields: architecture, digital technologies, generative process.

architecture, kinetic architecture, dynamic or interactive buildings, among others, with a small variation of meaning between them [6]. Digital technologies can help buildings to adapt better to the environment by optimizing the use of resources [7].

The relationship between solar protection elements and automation can contribute to greater environmental efficiency, since responsive buildings can adapt dynamically to the environment [7]. The use of mobile brise may be interesting because it allows the user to control the opening during the day and different seasons along the year. The need for selective control is present where the climate consists of a cold and hot period [3].

Currently, the new mobility tools contribute to the brises being more efficient [1]. Automation helps in this process of mobility, because it is possible to move a brise soleil with minimal human intervention or with computer-driven programming.

The automated control of a mobile brise soleil allows the control of the input of natural light and direct sunlight, whether for heat control, lighting and/or visibility. In addition, the aperture control helps ventilation as well as the choice of the angular variation of the brise soleil during the course of the day and time of year. It also contributes to the environmental comfort of the environment related to (a) clarity of environment from external lighting; (b) control of solar incidence for thermal comfort and; (c) increase the ventilation in the environment, as it allows turning the blades to increase the opening when desired.

Considering that the mobile brises are efficient for radiations with higher angles of incidence, as it happens with the east and west facades [4], it was chosen to develop the prototype with vertical brises, which are more suitable for incidences oblique in relation to the facade. Another important factor is the exploration of brise soleil as an aesthetic element incorporated into the building and “(...) can be an element of valorization and compositional dynamization valuing the technological character of

the built building [3]”. A parametric design can contribute to the aesthetics of building to the extent that an idea can be devised so that the form is explored while being tied to answers to the necessary requirements.

The objective of this work is to construct a generative and automated brise soleil prototype based on digital technologies and joining automatization with generative architecture. Other prototypes of facade protection elements were made as presented by Vaz et al. [6] that, despite having experimented with digital models, aspects of automation were little explored. Vertical brise prototype with automation was performed by Silva and Menezes [8]. They used different software to simulate the shadowing and lighting due to solar incidence and they applied sensors to aggregate automation [8]. Despite advances in automation, this study did not use a printed circuit board for the assembly of the final circuit. The aesthetic issue also was not explored. Studies with prototypes for other applications are also found in the literature such as the prototype based on polyhedric modular frame, considered as a possible habitable shelter that would move through sensors according to the degree of lightning. In this case, the servo motor was applied on some dismembered faces of the polyhedron to allow the movement [9]. Modifiable spaces through kinetic architecture are also proposed by Silva and Eloy [10].

Digital technologies are changing the way buildings are designed and produced and the professionals involved could contribute by integrating their services around these technologies [11]. This can be deepened when professionals from different areas integrate and contribute to the construction, as in this case of study where there are professionals and students from architecture, control engineering and automation as well as electrical engineering. It opens the way for application and expansion of these items in the civil construction contributing to the use of technologies to improve environmental comfort. Interdisciplinarity is

capable to integrate modes of thinking from various disciplines to produce an advance in knowledge [12].

2. Theoretical Framework

The brise-soleils contribute to environmental comfort while integrating the architectural language of the building that employs it. This type of sun protection can be fixed or movable, occupying vertical, horizontal and/or mixed position [13]. The movable brises soleil provides greater or less natural light and/or ventilation because your blades (or profile) can be positioned according to the solar movement.

The movable brises soleil can be moved by manual or automated actuation. The building Londrina road, by the architect Vilanova Artigas, is an example that has a mechanical movement, whose mobility occurs through cranks [1], activated by a person, when desired.

Although mobile brise soleil can have its movement performed by human force, automation and automation, within the domotics field, it comes with the proposal of providing comfort [5] and user-friendly functionalities [14].

Automation would be the act of making an automatic process, that is, performing an action without a real participation in it. However, automation involves automatic control, in which a device can be able to perceive changes in a system, analyze possibilities, make decisions, and finally act in that same system without the need for human intervention [15].

In this work, the automation was performed to move the blades of the brise soleil. The user does not need to perform mechanical force to rotate a blade around its axis, because the installed motors perform this work when the user executes the respective command. The application of automation, as the future goal of the project, would have the function of making user intervention unnecessary, since the management of the system would be in an automatic control.

Both automatization and automation are processes within domotic, which is a term that brings together

two French words, “domus” (home) and “imotique” (automatic), which can be easily related to what we now understand by automation [14]. In practice, domotic refers to automation applied to civilian buildings.

The goal of any domotic system is to provide comfort in various aspects in any environment [16], as comfort in relation to external clarity and insolation control, with the least possible intervention by the user.

Although domotic is not a new subject, there is still a lot of space for improvement that offers convenience in the simplest demands [14] and existing technologies for automation of more diverse technologies. The processes within the residences and environments allow its expansion of use and application.

Brise soleil, in addition to protecting facades against solar radiation, also has an important aesthetic character, because it is an element used to compose buildings. The prototype uses parametric strategies to allow shape exploration in the profiles forming the sun protection.

Prats et al. indicate generative principles can be used to inspire designs [17]. This can be achieved through the parametric exploration of the form, allowing creating and exploring new sets of projects. Using computer technologies that support the design and manufacture of products (CAD/CAM technologies) allows to design and generate complex shapes that in the past could only be generated manually [18].

In this work, the aesthetic part was explored through a parametric programming, performed in Grasshopper software. From the requirement to combine the blades (profiles) when closed, the folds can be explored. Because it is parametric, it propagates the changes in the set, because the dimensions of the programmed object are related to each other [19]. Parametric design is a process based not on fixed metric quantities but on a consistent relationship between objects that relate the parts to the whole [20], allowing the generation of alternatives between which the architect/designer chooses the most appropriate.

Although the parametrization was present in the protection elements (brise soleil), the prototype considered the device as a full structure and protection elements, coupling the parts of the automation, because it was necessary to think of the structure for the support of the blades and step motors, as described below.

3. Method and Materials

Based on action-research aiming at the practical knowledge [21], this study proposes to apply the concept of domotic in the issue of environmental comfort through the execution of an automated mobile brise-soleils prototype. This control allows the profiles to be opened and closed at specific angles to control the incidence of sunshine in the environment and, consequently, the lighting, ventilation and heat.

In order to construct a parametric and automated sun shading prototype, the methodology was divided into 3 parts, as shown in Fig. 1:

- Parametric architecture for creating profiles;
- Laser cutting and assembly of the device;
- Electronic prototyping.

3.1 Parametric Architecture for Creating Profiles

The parametric architecture was used in the

construction of the profiles, which were drawn from plug-in Grasshopper that works together with the software Rhinoceros.

The profiles were drawn and handled formally considering the open profile, i.e., 90 in relation to the open plane. A vertical plane leaning to the profiles was put parallel to the aperture where the control points were defined. When these points are changed the plane curves and its curvatures are transferred to the blades, similar to what was demonstrated by OM EGVO [22] when generating in the grasshopper brise curved from vertical plane but does not show rotation of the same for closing combining the blades.

This side of the modified blade is passed to the opposite side of the adjacent blade. When the device pieces are closed, they are combined in the same plane and shut the protected aperture. Fig. 2 shows the plane with the curvatures and the brise-soleil modeling from this curved plane manipulated by control points.

The parametrization of these pieces occurs through the change of control points, accomplished in the plug-in Rhinoceros. This manipulation automatically feeds the programming done in Grasshopper that captures this curvature at the end of the blade and transfers it to the opposite end of the adjacent blade. Each modification

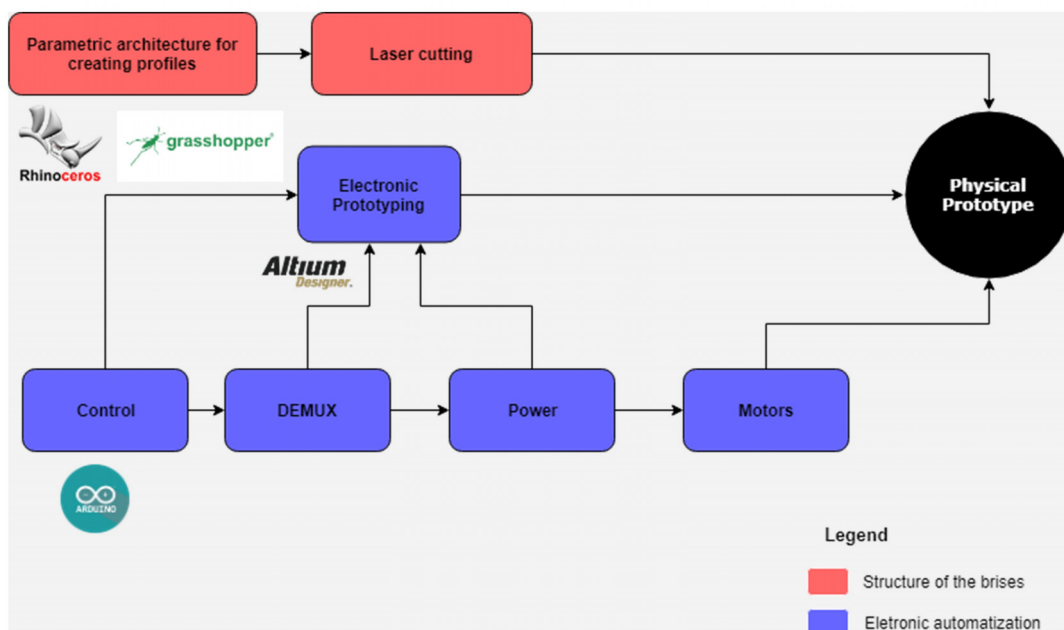


Fig. 1 Graphical scheme of the methodology.

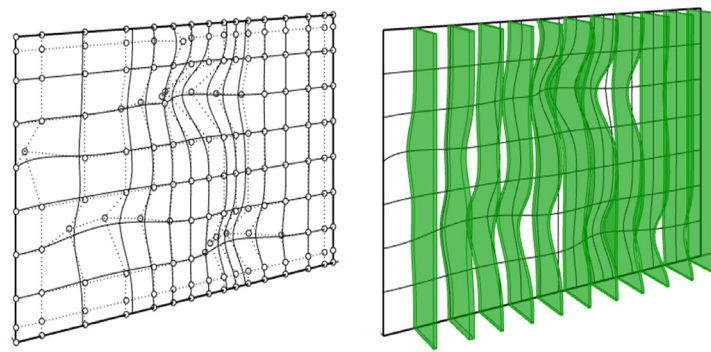


Fig. 2 Plane with active control points and blades suitable for the modifications in this plane.

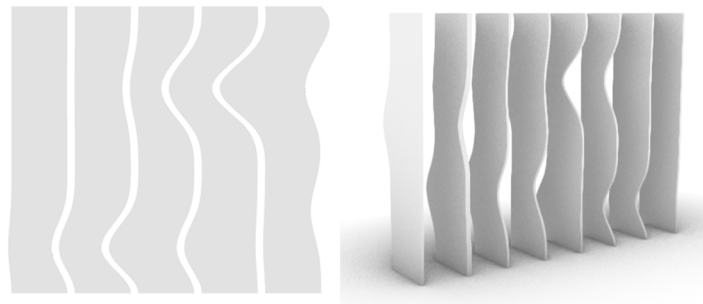


Fig. 3 Open brise-soleil and closed brise-soleil demonstrating the combination between the blades.

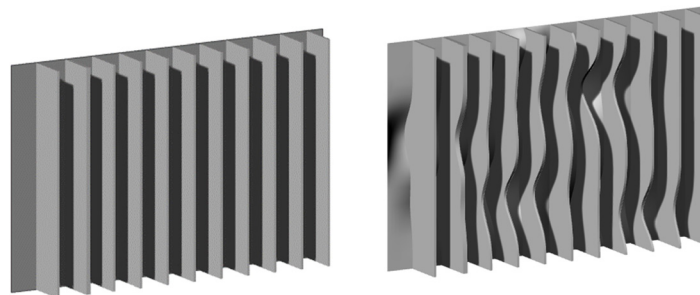


Fig. 4 Comparison between the brise-soleil with rectangular blades and the parametric brise-soleil with curvatures.

that is made changes the profiles doing the adjustment between the sides that meet. Fig. 3 illustrates the combination between the blades.

It is a parametric design, where changing a part changes the geometry of the set. In this specific case, the brise-soleil shape can be freely explored through the blades side and the algorithm that is developed allows these changes to be automatically transmitted to the side of the adjacent profile. This way the meet of the blades is guaranteed when the set is closed. Fig. 4 shows a comparison between the vertical brise-soleil with rectangular blades and the brise-soleil with parametric blades.

3.2 Laser Cutting and Assembly of the Device

After the aesthetic adjustment of the profiles through the manipulation of the blades and the definition of the desired shape, the Bake command was used in the Grasshopper so that the defined profiles became objects in the software Rhinoceros. So, these blades were flattened. The other device pieces which make up the outer frame and the base to receive the motors were drawn at the Rhinoceros and prepared for laser cutting. They were drawn without parametric programming.

The frame is formed by the upper base, by two sides, and by two lower bases that keep enough

distance from each other to accommodate the motors. The prototype was planned to receive 8 profiles and 1 motor for each blade totalizing 8 motors.

The mechanical part for rotation of the brise-soleil was made in the profile itself. A cutting was added at the bottom of the profile to put it at the motor pin and to allow the rotation along with it. The upper part of the frame was perforated for posterior pin placement that will fix the profile and allow its rotation. The outer frame parts received teeth to fit into each other without the need for any other means to secure them together.

The draw of these pieces is sent to the machine that will do the laser cutting. However, for better control of the cut order and the power that is used it is necessary to make the drawing with different layers. It is possible to choose the function the machine will perform for each layer.

First the inner cuts and then the external cuts are made. This ensures precision in manufacturing, because when a part is at first cut externally it falls into the machine and it leaves its place. If the laser needs to be cut inside it will not find the piece in place to ensure accuracy. Moreover, the power control only allows marking the parts rather than cutting them. This was made on each profile that received a numbering for installation in the correct order and the combination of the blades when the device is closed.

The green color was used for marking the red color for the first cut and the black color for the second cut. Fig. 5 shows the drawing sent to the laser cutting machine (item a) and demonstrates the 3 mm-MDF pieces cut in the laser cutting (item b). After this step, the physical structure of the brises prototype was assembled, and it was ready to receive the automation.

3.3 Electronic Prototyping

After the laser cut, the pieces of MDF were mounted and the equipment for the automatization was added, as Fig. 6 shows. This structure received one stepper motor for each profile, enabling its individual control. The

automatization of the brises, with respect to the matter of its movement around its very axes was performed in three stages: control, demultiplexing and power.

For its control was used the Arduino Nano prototyping platform for the general control of the system, due to its availability at the university, being user-friendly—both in software and hardware, have an open source license and low cost. In the project, the Arduino Nano controls the movement of eight stepper motors, which are electromechanical devices that convert electrical pulses into angular displacement [23] commonly used in control application, where movement accuracy is required [24].

The device was programmed to accomplish the assignments of: (a) drive the movement of the stepper motors, by performing the correctly and synchronized activation of the coils for the both sides; (b) control the rotation speed of the motors and; (c) determine which would be activated, taking into account that the activation of the motors is individual, therefore the drive of the electromechanical devices should not be simultaneous.

Of the three Arduino's assignments in the project, only the rotation speed control of the motor is not available to the user to configure through the physical interface—a printed circuit board, with command buttons. That control is only available by line program editing, because there is no need of constant adjustments of this characteristic.

To control a unipolar stepper motor, through the Arduino platform, it is required four digital channels (two channels for each coil, in a total of two coils). To control the eight motors used, in a simultaneously way, it would be necessary thirty-two digital available channels in the platform. Arduino Nano does not have such number of channels (twenty-four channels, including all kinds of channels), and because that was used the demultiplexing principle, in order to perform the control of each motor individually. In this way it is possible to select the motor to be controlled by using the physical interface.

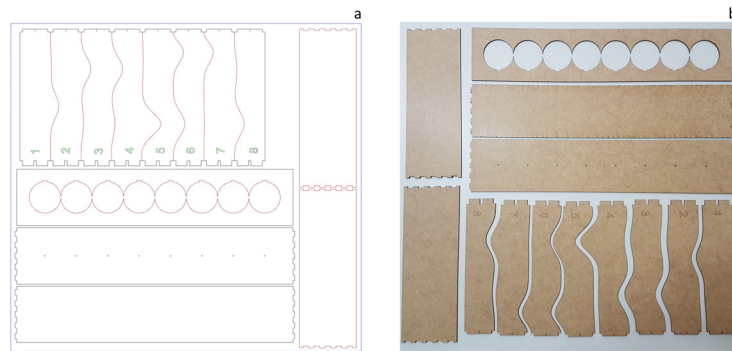


Fig. 5 (a) Drawing sent to laser cutting where each color corresponds to the action that will be done by the machine, and (b) pieces for the prototype after laser cutting.

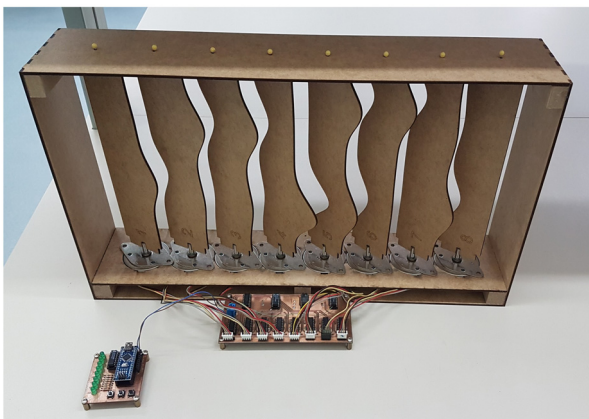


Fig. 6 Pieces for the prototype were mounted.

The demultiplexed communication is a technique used to allow that a same message could be sent to more than one previously intended destination [25]. The demultiplexer element (circuit integrated 74138, from Texas Instruments) acts as a decoder, because it receives the message and the device address that this message should be sent.

The stepper motors used in the project (23BB-H002-14, from Minebea), which are commonly used in the axle of the printers, need a supply of 1 A as indicated in the body of the device, such current that Arduino are incapable to provide (maximum current of 40 mA). Thereat, after the demultiplexing stage is performed an amplification of the current provided by the digital channels of the prototyping platform—which is retransmitted by the demultiplexers—through the SN754410 driver, from Texas Instruments. This driver has been chosen due to

its easy implementation, low cost and meets all the project requirements.

The SN754410 driver retransmits the very same logic level sent by the control platform, now with an increased current, in order to be able to supply the coils of the motors thereafter, enabling the movement of the motors.

The circuit was assembled originally in a protoboard and it was verified its fully functioning. However, the circuit was built again in two printed circuit boards in order to add sturdiness. In one board it was placed the control stage and in the other the demultiplexing and the power stages. The three stages were divided in two boards to allow that the power stage could be placed inside of the structure of the project and the control stage was located within reach of the user, in a future use. Besides, in any case of adding more features at the control stage it would be necessary just to rebuild this stage, taking into consideration that the other stages hardly would be modified. The connection between the two boards was made through wires.

The boards' layouts were designed with the Altium Designer (version 17) software, being manufactured in a dual layer fiberglass board with the PCB-PROTO 2 prototype machine, which is available at the university.

In the control stage was added a visualization system of the motors selection, through eight LEDs (one LED for each motor). It was used a 7445 decoder, from Texas Instruments, to perform the LEDs trigger according to the command of Arduino.

4. Discussion

This article demonstrates the construction of a prototype of mobile brise soleil whose mobility is done through automatization supported by digital fabrication and by parametric process in the exploration of plasticity. It was decided to work with a vertical brise soleil, which is more appropriate to the east and/or west facades. As in these facades, the angular variation of the solar incidence is bigger; the possibility of mobility becomes interesting and adequate.

Towards the manufacturing, a few parts were initially cut out to test the engine docking on the bottom base, the blade fitting on the motor pin and the size of the pin fixing hole. These pieces had to be redone, because the teeth had to be shortened in order to make the fit more even, without any slack. In the circles cut out in the base for the insertion of the motor was necessary to make a rectangle, besides the circumference, to allow the passage of the wiring. It is important to emphasize that the upper part of the external frame, with the holes for the pins, was adequate.

After the frame mounted with the MDF parts and the motors inserted, it was observed the need for adjustment in the prototype structure. The sides of the board showed signs of buckling and reinforcement with a piece of wood placed on the MDF was necessary.

The project was designed with the intention of being versatile and modular, in order to eventually add new features and make it even more complete and autonomous. In this case the term modular is understood as “product architecture”, in which several modules have specific functions. Initially, the control part was developed with the intention of the motors being driven by the user through a physical interface. Nevertheless, Arduino, in this same programming, could receive information of an intelligent control, as for example an artificial intelligence, to realize the movement of brises without the necessity of the human interaction.

Subsequently, automation can be added to the prototype, providing it with sensors and software and hardware devices to manage the system and perform the brise soleil movement according to the solar incidence, without the need to program by hour of the day/year. In addition, a programming can be included that aims at optimizing the amount of solar incidence with some other attribute, such as increased illumination.

Blades may be designed to move laterally when opened, creating overlap between them, if necessary. In addition, independent planning for each blade can occur, following the course of the sun and closing the aperture, if desired, facilitated by the speed provided by automated drive. It can satisfactorily meet the control of solar radiation while maintaining ventilation, visibility and lighting issues.

These possibilities justify the working solution of a mobile brise soleil, precisely because it presents itself as a more advantageous solution in relation to a fixed brise soleil during the several hours of the day, allowing this flexibility of control of incidence of direct solar radiation. Thus, the development of a mobile brise soleil and adding its automatization possibility, allowing the change of position of the same throughout the day, without that a manual position modification is necessary, is presented as a desired solution [8].

In the current conjunctures, the project automates the process of moving the brises, however it counts on the intervention of the user to activate the engines that carry out this movement. In spite of this, the project makes room for future adaptations and customizations that would reduce the level and frequency of user action needed to manage the domotic system.

5. Conclusion

This work demonstrated the construction of a parametric and automated brise soleil prototype through the integration of professionals from different fields of the knowledge: architecture, control

engineering and automation as well as electrical engineering. This allows a broader view where involved areas complement each other.

The development of a prototype has the objective precisely to prove the possibilities of the system, as well as its possibilities of application in real situations and study. In this experiment it was possible to explore plasticity in the architecture as well the automatization possibilities supported by digital fabrication.

Activities such as natural and artificial light performance, which can previously test the application of brises of different natures, can be widely benefited in the area of architectural and engineering projects, demonstrating a gain in efficiency in the execution thereof, since the automated prototype can guarantee that the environment always presents the desired degree of illumination, thus avoiding the use of electric energy in lighting.

For the time being, no tests were carried out to confirm the incidence of insolation, but for future work, it can be pursued the integration of parametric modeling with environmental simulation and also the optimization of area for balance between insolation and ventilation.

The prototype received the automatization of a process—the movement of the blades around its axes—however, it is suggested the use of automation to move the device without the need for human intervention. In this new stage it should integrate sensors to monitor the solar radiation and the temperature of the environment, as well as devices to monitor and manage the system, creating a building responsive, by reacting intelligently to the environment [6].

References

- [1] Atem, C. G., and Basso, A. 2005. “Apropriação e eficiência do brise soleil: o caso de Londrina (PR).” *Ambiente Construído* 5 (4): 29-45.
- [2] Leitzke, R. K., Da Cunha, E. G., Da Silva, O. M., Da Silva, A. C. S. B., and Beltrame, C. M. 2017. “Avaliação de dispositivos de proteção solar fixos e automatizados para edifício residencial.” *PARC Pesquisa Em Arquitetura e Construção, Campinas* 8 (1): 59-72. doi: 10.20396/parc.v8i1.8649657.
- [3] Da Cunha, E. 2011. “Mitos e verdades sobre o brise-soleil: da estética à eficiência energética.” *Arquitetura Revista* 7 (1): 73-80. doi: 10.4013/arq.2011.71.07.
- [4] Maragno, V. G. 2001. “Eficiência e forma do brise-soleil na arquitetura de Campo Grande—MS.” Presented at VI Encontro Nacional e III Encontro latino-Americano sobre Conforto no Ambiente Construído.
- [5] Hernández, S. P. 2010. “Consideraciones para la aplicación de la domótica desde la concepción del diseño arquitectónico.” *Arquitetura Revista* 6 (1): 63-75. doi: 10.4013/arq.2010.61.06.
- [6] Vaz, C. E. V., Souza, J. P. M., De S. Pinto, H. R., Cardoso, A. R. B., and Queiroz, N. 2016. “O desenvolvimento de elementos de fachada responsivos-exploração e controle de um processo.” *Gestão & Tecnologia de Projetos* 11 (2): 73-87. doi: 11606/gtp.v11i2.118141.
- [7] Henriques, G. C. 2015. “Sistemas responsivos: relevância, estado da arte e desenvolvimentos.” *SIGRADI 2015: Project Information for Interaction*, 200-6.
- [8] Silva, S. M. C., and Menezes, J. P. C. 2015. “Desenvolvimento de brise vertical com posicionamento automatizado orientado pela movimentação solar.” *Revista Eletrônica de Educação e Ciência (REEC)* 5 (1): 1-7.
- [9] Fonte Boa, C. R. M., and Do Vale, C. M. 2017. “Investigação De Geometrias Aplicáveis À Responsividade Em Arquitetura.” *Cadernos de Arquitetura e Urbanismo* 23 (32): 30-41. doi: 10.5752/p.2316-1752.2016v23n32p30.
- [10] Silva, J. L. S., and Eloy, S. 2012. “Arquitetura flexível: movimento e sistemas cinéticos.” *Arquitetura e urbanismo* 8 (2): 190-9.
- [11] Kolarevic, B. 2003. *Architecture in the Digital Age: Design and Manufacturing*. 1st ed. New York: Taylor & Francis, 2-12.
- [12] Leis, H. R. 2011. “Especificidades e desafios da interdisciplinaridade nas ciências humanas.” In *Interdisciplinaridade em Ciência, Tecnologia & Inovação*. 1st ed. Manole, 107-8.
- [13] Gutierrez, G. C. R., Labaki, L. C., Cristina, G., and Gutierrez, R. 2005. “Considerações sobre o brise-soleil na arquitetura moderna brasileira.” Encontro Nacional e Latino-Americano de Conforto no Ambiente Construído (ENCAC/ELACAC), pp. 874-81.
- [14] Antunes, D., De Matos, D. M., and Gaspar, J. 2011. “Improving Domotic Services Combining a Dialog System and a Resident Tracking System.” Presented at IEEE EUROCON International Conference on Computer

- as a Tool.
- [15] De Camargo, V. L. A. 2014. *Elementos de Automação*. 1st ed. São Paulo: Érica.
- [16] Dobrescu, L. 2014. “Domotic Embedded System.” Presented at 6th IEEE International Conference on Electronics, Computers and Artificial Intelligence (ECAI).
- [17] Prats, M., Earl, C., Garner, S., and Jowers, S. I. 2006. “Shape Exploration of Designs in a Style: Toward Generation of Product Designs.” *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 20 (3): 201-15. doi: 10.1017/S0890060406060173.
- [18] Figueiras, J. I. B. 2005. *Forma Resistente*. 1st ed. Santiago, Chile: Ediciones Arq. Escuela de Arquitectura de La Pontificia Universidad Católica de Chile.
- [19] De Souza, A. F., and Coelho, R. T. 2003. “Tecnologia CAD/CAM—Definições e estado da arte visando auxiliar sua implantação em um ambiente fabril.” Presented at XXIII Encontro Nac. De Eng. de Produção.
- [20] Meredith, M. 2008. *From Control to Design: Parametric/Algorithmic Architecture*. 1st ed. Barcelona, Spain: Actar-D.
- [21] Tripp, D. 2005. “Pesquisa-ação: uma introdução metodológica.” *Educação e Pesquisa* 31 (3): 443-66.
- [22] OM EGVO. 2017. “Grasshoper Tutorial. Mountain View: Google, 2017.” Accessed January 10, 2020. <https://www.youtube.com/watch?v=F-AL9xCOHmI>.
- [23] Mahdavian, M., Shafaghi, P., Janghorbani, M., Ganji, E., Eshaghpour, I., and Javadi, S. 2017. “Analysis and Simulation of Behavior Dynamic in Permanent Magnet Stepper Motor.” Presented at 14th IEEE International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON).
- [24] Melkebeek, J. A. 2018. “Stepping Motors.” In *Electrical Machines and Drives*. Springer Verlag, 523-35.
- [25] Capuano, F. G., and Idoeta, I. V. 1997. *Elementos de Eletrônica Digital*. 41st ed. São Paulo: Érica.