DESIGN PROCESS FOR OPTIMIZATION OF BUILDINGS FAÇADES FOR SOLAR IRRADIATION IN THE BRAZILIAN CONTEXT

MORAES, Leticia Niero[1]; PEREIRA, Fernando Oscar Ruttkay[1]

1: Federal University of Santa Catarina, Brazil, letinierom@gmail.com

ABSTRACT

This paper shows the development of a process for solar potential optimization for non residential buildings in a high density urban area in the Brazilian context. Photovoltaic systems are generally installed on roof tops of buildings located in low density areas due to the availability of horizontal surfaces, but the developments of cities with tall buildings have encouraged photovoltaic integration on façades. A parametric solar design optimization is proposed, with the aid of the Rhinoceros 5.0 modelling tool, the plug-ins Grasshopper and Galapagos, which enable geometric transformations and optimized results and solar dynamic plug-in (DIVA for Rhino) for solar radiation analysis. The optimization criterion is based on the economic viability of the installation, through a minimum level of solar radiation that allows the investment return. The approach aims to maximize the solar access of a new building in existing urban area in Florianopolis – SC/Brazil, in the central area of the city. In this area, a reference building is chosen to analyze the influence of urban context on the solar radiation availability. From a reference shape, modelled in accordance with the occupancy limits from current Master Plan, different combinations of parametric transformations were tested: Twist, Slope, Rotation and Taper. The optimization process resulted in a larger area of the envelope with radiation levels above the fitness value.Through this process it was possible to identify the optimized building shape for solar radiation and to verify if façades can be exploited for energy production in dense urban areas in the Brazilian context. Due to the large energy concerns in Brazil and the great potential of using solar energy due to high solar radiation levels, studies that enhance the use of alternative renewable energy are fundamental to the dissemination of this potential.

Keywords: Urban environment, Brazilian context, Solar radiation, Optimization process

INTRODUCTION

In the context of increasing concern with regard to carbon emissions and global warming, interest in renewable energy sources has grown. Due to the significant contribution of buildings energy use, which corresponds to 47% of total electricity consumption in Brazil [1], there is a great interest to promote the use of renewable technologies integrated into buildings. Brazil is a country with high solar radiation levels, higher than those of developed countries, with great potential for solar energy use through photovoltaic systems (PV). With the inevitable verticalization of urban centres, there is a smaller area available on the roof. It is therefore possible to explore the potential of the façades for solar energy production.

Specifically for PV installations on facades, the condition of solar radiation exposure in urban areas is difficult to assess, especially in already established urban contexts. However, the literature discloses a wide variety of analysis tools and methodologies, which contributes to the verification of such conditions. Recent advances in computer science and performance requirements have driven the development of simulation methods to improve building performance, such as the approach known as generative systems, or parameterization and optimization processes. The more than two hundred articles review of major magazines referenced in the areas of renewable energy and computational optimization revealed that the number of research papers using optimization methods to solve the problems of renewable energy has increased dramatically in recent years, especially in the areas of solar energy and wind [2]. Among the tools available, the plug-in Grasshopper for Rhinoceros [3] allows the generation of parametric models. Simulations of daylight availability and internal loads are performed in Diva-for-Rhino plug-in [4], which integrates thermal simulations of Energy Plus with the daylight availability simulations of Daysim. Within Grasshopper, the optimization process can be performed through the Galapagos Evolutionary Solver [3] which is based on a genetic evolutionary algorithm of random sampling. Several studies have demonstrated the potential use of the tool to perform analyses of envelopes, focusing on optimizing energy or visual aspects [5, 6]; or in solar radiation availability assessments in urban environment [7, 8, 9, 10]. These last studies often use the ECOTEC tools or Diva plug-in for the sun exposure parameter.

In this context, this paper develops a procedure to optimize the building shape considering the impact of the built environment on availability of solar radiation in the Brazilian context, through an innovative parameter of economic feasibility of the installation as fitness value, which differs in optimization studies found in the area.

METHOD

A case study in the city Florianopolis – SC/Brazil is here presented, and an optimization process approach is described, in order to maximize the solar access and solar potential in an existing urban area. A current urban area was selected. The definition of this area considered as the main condition, besides the choice of non-residential areas, the central location area which allows greater height for the building - contextualizing the feasibility of implementation of PV systems on the facades, as more low-rise buildings are more influenced by the surrounding shading. In this scenario a reference building (OI_Reference) was selected to analyze the obstructions impact on solar irradiation levels in the facades. Figure 1 shows the location of the area and the site selected for the reference building. The Master Plan zoning defines much of the area as Mixed Central Area (AMC) - high density, complexity and miscegenation, aimed at, commercial and service. The site selected for the reference building is a corner site with an existing commercial building.

(a) *(b)*

Figure 1: (a) Perspective (b) Master Plan zoning – identifying the Impact Object (OI)

The selected program for modelling of urban setting was Rhinoceros 5.0, mainly due to the integration with plug-ins DIVA, Grasshopper and Galapagos, which will be used in steps of simulation and optimization. The first information used in the construction of scenario is the cadastral map, which features urban dimension information, as lots, streets and blocks. In the construction process, the height of the buildings is verified through field survey and Google Earth 3D.

The Optimization Process approach

The optimization process consists in consequential and iterative steps, using a combination of design and analysis tools, as shown in Figure 2. The identification, parameterization and optimization processes of the building shapes are composed by consequent stages.

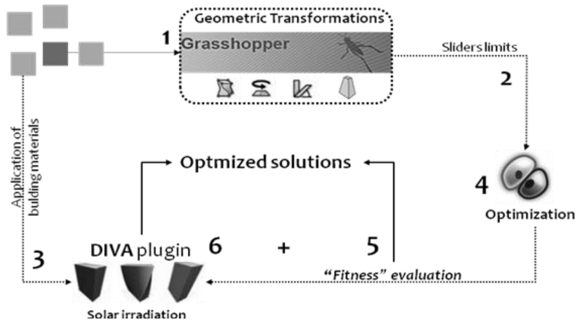


Figure 2: Development of the optimization process

Initially, from the definition and construction of scenario and reference building shape (OI_Reference), geometric transformations tools are applied (variables) within Grasshopper (Step 1), which are correlated with solar radiation levels. The simulations of annual dynamic solar radiation have been carried out using DIVA for Rhino, including the contributions of indirect solar radiation reflected by neighboring buildings. The reflectance of the external surfaces of buildings is set at 43.9%, which is obtained through study of the characterization of an average reflection coefficient for vertical surfaces in the central area of Florianopolis [11]. The reflectance of streets and sidewalks were set at 20%.

From a reference shape, generated in accordance with the occupancy limits from current Master Plan, different combinations of geometric transformations variables were tested: Twist, Slope, Rotation and Scale (Taper). Limits of values are defined for each type of variable, called "sliders", according to the limits observed in the city´s Master Plan (Step 2). Table 1 shows the ranges for each variable. The taper 1 is the normal setting the building, when the roof surface coverage is equal to the base. The length, width and height remain constant (17 x 35 x 42m) as well as the building volume.

	Twis	Rotation	Slope	Taper
OI Height: 42m Volume: 24990 m³	30° (range 5°)	20° (range 5°)	Axis x : -15 a 5° Axis y : -10 a 5° (range 1°)	0.75 a 1 (range 0.05)

Table 1: Summary of building's parametric transformation considered for analyses

The process within Grasshopper starts with modelling the base of OI_Reference, from the ground surface. The second stage refers to the modelling of geometric transformations, which are connected with the initial volumes. The building volume, defined by reference building, is kept constant for all proposed changes. Before the start of each simulation, a scale factor for the maintenance of the building volume is applied through the Scale component. The volume resulting from the combination of variables, for every interaction, is divided by the desired volume, referring to the initial volume of OI_Reference. This factor is applied twice, due to the modifications resulting of twist variable, as shown in Figure 3.

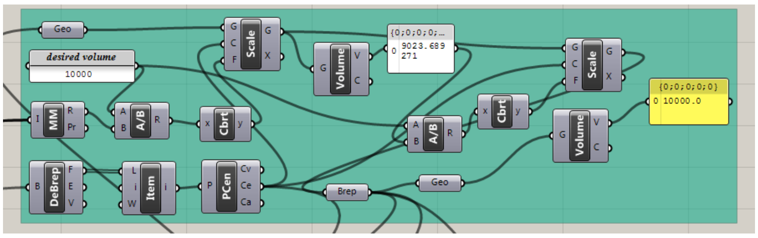


Figure 3: Volume maintenance process in Grasshopper

The limits for each slider are sent to the solver Galapagos, responsible for the optimization process of the building shape (Step 4). This tool allows the combination and evaluation of geometric transformations used from the definition of a value of solar irradiation desired, considered as "*fitness*". The premise adopted is the calculation of the minimum annual solar irradiation amount necessary to ensure an Internal Rate of Return of 6% for 25 years against the option of paying for the electricity distributor, having applied in the financial markets the value of the installation cost of the system [12], in this study regarding the Soliker opaque PV panel with initial installation cost of 1.81 \$/Wp for commercial application [13]. The minimum level of solar radiation required for the investment is economically viable is 630kWh/m².year, value adopted as fitness for the optimization process.

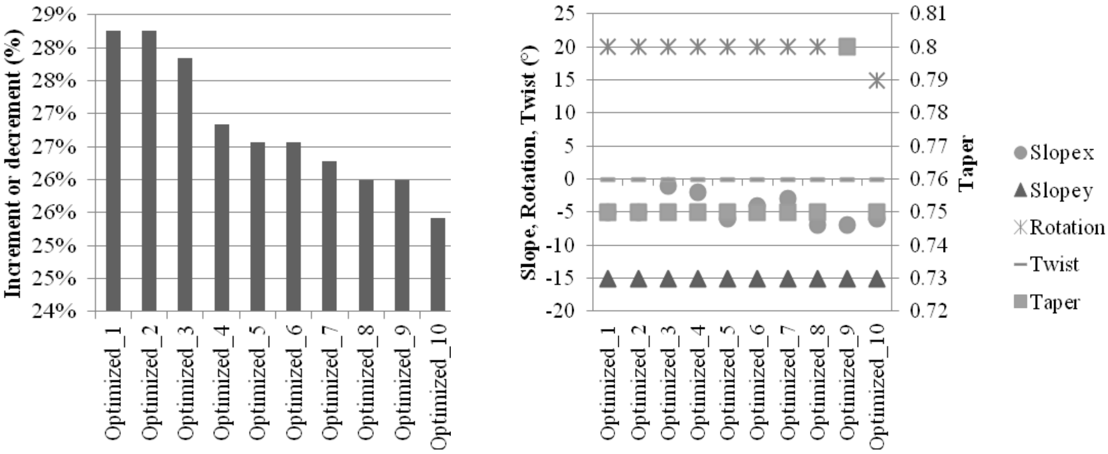
The solver Galapagos performs the optimization process by combining the transformations, along with solar radiation simulations with Diva (Steps 5 and 6). At the end of the process, the resulting solutions with the highest number of point analysis higher than in the "fitness" are considered the optimized solutions. The solver Galapagos allows the generation of a set of optimized shapes, defined by the number of stagnation. The configuration adopted considered to maximize the value of the fitness evaluation function, twenty individuals for each generation and the completion of code execution when it reaches the stagnation of twenty generations. Inbreeding rate, was considered 75%, and the individuals of stay from one generation to the other 5%.

For each step, the process starts with an initial shape of reference building. Applying the geometric transformations, together with the simulation of solar irradiation facade is generated a set of optimized shapes. At the end of the process, data is exported to a spreadsheet in Excel format, containing the variables of each transformation, the achieved fitness value (number of points analyses above fitness value) and the percentage of area above this value, for each façade.

RESULTS

This step shows the comparison of solar radiation on the new buildings designed in this case study, with the main objective to analyze formal variability and photovoltaic potential. The first step is related to an assessment of the reference building (OI_base) in Current Scenario, to assess the current urban situation for comparison purposes.

All the optimized results have been compared with the reference building and the percentage of variation has been calculated. The data collecting the ten most significant results of the simulation performed, showing the highest annual solar radiation values for different types of parametric transformation. As shown in Figure 4a, for all optimized solutions there are increments on the percentage of area above the fitness value, reaching values of up to 29%. In the Figure 4b is shown the main geometric transformations for each optimized result. As can be seen, Rotation and Slope y were the most variable transformations; the transformation twist was not used in this process.



(a) *(b)*

Figure 4: (a) Results of contribution of solar radiation (b) geometric transformations for each optimized solution

The optimization process resulted in a larger area of the envelope with radiation levels above the fitness value, but penalizes the area of facades that already had values above it. Figure 5 illustrates this condition for the Current Scenario. For example, in the North façade, the reference building has a percentage of area above the fitness value of 98%. For an optimized shape, as Optimized_1, these percentage decreases 9.3%, but the fitness value increases 28%.

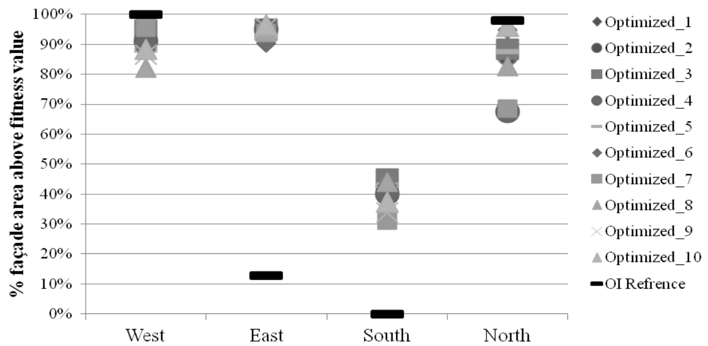


Figure 5: Results of percentage of façade area above fitness value.

Despite this consideration, the optimization process enabled facades that were not exposed to sunlight to increase the exhibition area to the fitness value, such as occurred in the South and East facades. Mainly for the South facade, the reference building did not have any area of the façade above this value. As shown in Figure 5, the optimal solution reached up to 45% of the South façade and 95% for East façade.

CONCLUSION

The analyses performed in accordance with the methodology demonstrate that the optimization process proposed is efficient in terms of achieving the optimized shape of the buildings according to a radiation amount based on economic viability. One aspect to note is that optimization algorithm can be easily applied to other surrounding conditions and fitness parameters, enabling a variety of analyses.

The results show the improvement of solar radiation envelope in the optimized solutions and the modification of exposure of the façades, increasing the solar irradiation of façades South and East and penalizing façades West and North, in order to increase the total exposed area. Thus, further analysis should be performed to see the influences of this result in the photovoltaic generation potential. Through this process it was possible to identify the optimized building shape for solar radiation and to verify if façades can be exploited for energy production in dense urban areas in the Brazilian context. Due to the large energy concerns in Brazil and the great potential of using solar energy due to high solar radiation levels, studies that enhance the use of alternative renewable energy are fundamental to the dissemination of this potential.

REFERENCES

1. BEN. Balanço energético nacional. [s.l: s.n.].
2. Baños, R. et al. Optimization methods applied to renewable and sustainable energy: A review. Renewable and Sustainable Energy Reviews, v. 15, p. 1753–1766, 2011.
3. Rutten, D. Evolutionary Principles applied to Problem Solving. Available in: <https://ieatbugsforbreakfast.wordpress.com/2011/03/04/epatps01/>.
4. Jakubiec, J. A.; Reinhart, C. F. Diva 2 . 0 : Integrating Daylight and Thermal Simulations Using Rhinoceros 3D , Daysim and Energyplus. Proceedings of Building Simulation, p. 2202–2209, 2011.
5. Gagne, j. M. L.; Andersen, M. Multi-objetive facade optimization for daylighting design using a genetic algorithmSimBuild. Anais...New York City, New York: 2010
6. Torres, S. L.; sakamoto, Y. Facade design optimization for daylight with a simple genetic algorithm. Building Simulation. Anais...2007
7. Giani, M. et al. A Design approach for the solar optimization of built volumesCISBAT 2013. Anais...Lausanne, Switzerland: 2013
8. Lobaccaro, G.; Frontini, F. Solar Energy in Urban Environment: How Urban Densification Affects Existing Buildings. Energy Procedia, v. 48, p. 1559–1569, 2014.
9. Lobaccaro, G.; Masera, G. A digital language for a new sustainable urban planning: Design and Simulation Tools for Solar Architecture. Proceedings of the Building Simulation and Optimization. Anais...London, UK: 2014
10. Vannini, V. C. Otimização geométrica de dispositivos solares de fachada. [s.l.] UFRGS, 2011.
11. Leder, S. M.; Pereira, F. O. R.; Moraes, L. N. Determinação experimental de coeficiente de reflexão médio para superfícies verticais em meio urbano. ENCAC. Ouro Preto: 2007.
12. Jakubiec, J. A.; Reinhart, C. F.. Towards validated urban photovoltaic potential and solar radiation maps based on lidar measurements , gis data , and hourly daysim simulationsSimBuild. Anais...Madison, Wisconsin: 2012
13. EPE. Inserção da Geração Fotovoltaica Distribuída no Brasil – Condicionantes e Impactos. [s.l: s.n.].