KINETIC ARCHITECTURE AS A RESPONSE TO ADAPTIVE BEHAVIOR TO CLIMATE, A CASE STUDY THROUGH VIRTUAL MODELS

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In the current global context, two critical challenges are being faced: the need to take advantage of renewable energies, as well as a technologically advanced architecture to deal with climate variability that has a direct impact on buildings, demanding, therefore, new adaptable proposals, in which the connections between these two variables are strengthened. As an answer to these questions, this research is based on kinetics in architecture, with its capacity to respond to different environmental scenarios through the integration of dynamic elements in buildings. In this sense, the aim of this work was to evaluate how the architectural proposal of a kinetic envelope in an existing building responds to climatic conditions. To achieve this, the methodology used was a case study, integrating simulation as a technique to imitate the behavior of the system, creating virtual models in the process using programs such as Rhinoceros and Grasshopper. The results demonstrated the potential of integrating movable architectural elements into the building envelope and their ability to regulate thermal conditions, with certain exceptions, especially during the colder months of the year, leading us to the conclusion that static façades, while providing a basic level of energy efficiency, lack the ability to adapt to climatic variability, compared to the kinetic envelope proposal which provided an effective adaptive response to climate, leading to the creation of more sustainable and livable built environments in the future.

Keywords: Kinetic façade, Energy simulation, Comfort, Parametric modeling.

1 INTRODUCTION

Currently, the development of sustainable construction, efficiency in building design, incorporation of kinetic elements in building facades leading to improvements in terms of energy efficiency, environmental quality, and potential enhancements in the lives of users and society (Seyrek et al. 2021), has enabled the search of new ways to optimize energy consumption and reduce carbon emissions has led to the development of technological systems that can assist architecture to adapt responsively to the environment, where building envelope plays a decisive role (Heidari Matin and Eydgahi 2019). For the environmental conditioning of conventional buildings, envelope design is often conceived to achieve 80% effectiveness in response to external environment, however, variations in human activities within the building, and the inconstancy of climatic elements such as wind speed, radiation, temperatures and humidity; affect this adaptive projection, becoming insufficient (Ibrahim and Alibaba 2019). Considering that contemporary society demands attention to new needs, kinetic facades contribute to enhancing user comfort by providing buildings with appropriate lighting while also enabling the use of the same, thereby allowing in self-sufficient
architecture (Gil-Mastalerczyk 2023). In this scenario, the motricity of envelopes that can offer different ways of responding to their environment is an option that is studied from an energy perspective, and buildings accommodating a significant number of users can provide the space for the application of recent technologies that can subsequently be transferred to other types of small-scale structures. Studies on kinetic façades become common in contexts of hot-dry climates, and to a lesser extent in temperate and cold climates (Hosseini et al. 2019), such as those found in the Andean cities. Moreover, due to the complexity of the systems involved in the operation of these kinetic applications, the integration of a BIM environment is not only an interesting but also a convenient step to take (Kavuncuoğlu et al. 2022). The BIM methodology allows interoperability between different software’s that, in addition to modeling, interrelate energy analysis in different design variations, examples of these tools include Rhinoceros and its engines Grasshopper/Ladybug (de Sousa Freitas, Cronemberger, Soares, Naves, & Amorim 2020). The case study presented in this communication, provides an experimental scenario for implementing a kinetic façade using a platform with adjustable parameter information thus seeking to provide methodological contributions that can be used by designers and constructors to test their technological systems, improving the response of the building to its context.

2 METHODOLOGY

Through a case study, the objective is to analyze the thermal performance provided by a kinetic façade compared to the original static façade, in addition to studying the influence of ventilation. Given the nature of the kinetic typology that is proposed, that is, to generate changes and evaluate their influence, it is proposed to use software that allows making modifications between the parameters of the architectural model and observe its impact on the energy simulation, this will allow understanding how the building interacts with the climate and determine what physical aspects the facade should have to improve its performance.

![Diagram of digital tools workflow in Rhino/Grasshopper/Ladybug Tools environment.](image)

Figure 1. Overview of the digital tools workflow in the Rhino/Grasshopper/Ladybug Tools environment.

The selected digital tools are Rhinoceros 3D V7 and Grasshopper, where an information environment is recreated from the editable 3D model of the original building, including the attributes and climatic and thermal parameters, the optical properties of the envelope materials, the
number and characteristics of the users, as well as the passive heating and cooling loads. The final simulation data is obtained through virtual programs such as Honeybee and Butterfly, extensions of Ladybug Tools, a simulation engine integrated in Grasshopper. The model is simulated on the coldest day (November 11) and the hottest day (July 28) between the hours of building use (8H00 to 18H00). The methodological process can be summarized in Figure 1.

2.1 Case Study

The building under study is located in the city of Loja-Ecuador on the Eastern campus of the Universidad Técnica de Loja. It is a five-floors block with a built area of 69056.52 m², accommodating various uses. The building was built around 2013, in a Steel structure, concrete slabs on a composite floor deck, external vertical enclosures in a single-leaf masonry walls made of hollow concrete blocks and tempered glass glazing with UV coating on the outside, the internal partitions are composed of aluminum frames and laminated glass, the floors are polyurethane floor coating; finally, the building is crowned with a sloping of galvanized metal sheets. The planning of the building does not include environmental use characteristics, nor does it have a mechanical heating/cooling system. The main orientation of the building is east-west, leaving one façade highly exposed to afternoon radiation with a window-wall ratio of 50%, while the other façade is mostly shaded due to the proximity to another campus building, with a window-wall ratio of 50%. The height of the floors exceeds 3 m, the user density is 1.5 persons/m². The building is occupied for a period of 12 hours. Users’ perception of climate comfort reaches 10% experiencing a cold sensation most of the time. The summary of climate characteristics is shown in Table 1.

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Climatic Characteristics</th>
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<tbody>
<tr>
<td>Building IX of the UTPL campus</td>
<td><strong>Medium Temperature:</strong> 13 – 20.5 °C</td>
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<tr>
<td></td>
<td><strong>Average Relative Humidity:</strong> 61 – 93 %</td>
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<tr>
<td></td>
<td><strong>Wind Speed:</strong> 0.6 – 4.5 m/s</td>
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<td></td>
<td><strong>Direction of the Wind:</strong></td>
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<td></td>
<td>E – NW (12 m/s) y NW – SE (14 m/s)</td>
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<tr>
<td></td>
<td><strong>Solar Radiation Annual Average:</strong></td>
</tr>
<tr>
<td></td>
<td>4574.99 watts/m²/day</td>
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<tr>
<td></td>
<td><strong>Altitude:</strong> 2160 m.a.m.s.l.</td>
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</table>

The simulation of the thermal behavior can be seen in Figure 2. On the coldest day, the building does not reach the comfort ranges, while on the warm seasons it exhibits irregular behavior on each floor, requiring specific actions to each level, something that the current façade cannot perform. In this regard, a ventilated façade would provide convenient movements, that is, by allowing floor-specific openings, thus generating an air chamber that can capture and retain heat in cold weather and release it when temperatures rise, this will be the starting point to propose the new kinetic façade.
2.2 Modeling the New Kinetic Façade

The proposal fits ventilated façade model, as a set of modules separated from the current façade plane, in which the opening of these modules may establish the conditions for solar collection or cooling, the rotation arrangement of the panels in summer is 90° and in winter it was considered 0°, with respect to the vertical plane. For the design process, based on the original model established in Rhinoceros, panels are modulated according to the dimensions of the original building structure. The proposed façade, as can be seen in Figure 3, is divided into aluminum modules measuring 1.70 m width, 2.80 m in height, and 1.65 m in depth, assembled on a steel grid attached to the main structure. These modules enable panel displacement within the range of 0° to 90° relative to the horizontal axis.

Figure 3. Module and its opening, with the axonometry and some design patterns of the envelope.

3 ANALYSIS OF RESULTS

The proposed proposal was simulated under conditions of closing (coldest day) and opening (hottest day) of the façade modules, results can be seen in Figure 4 and 5. The proposal more effectively in warm seasons, remaining within the comfort zone even during peak solar exposure hours (11H00-17H00), however, despite testing various scenarios, the façade does not enable
passive building climate control on the coldest day. To explain these results, solar capture must be taken into consideration, due to surfaces facing east and north, which should collect heat in the morning, remain in shadow due to their proximity to neighboring buildings, making them less susceptible to storing heat. Furthermore, the higher floors have better solar gain conditions, as they gradually lose the influence of neighboring buildings’ shadows that do not reach the height of the building under study. Another crucial aspect observed in the simulations, is the accumulated insolation, which ranges from 0 to 6793 Wh/m²/day on the hottest day and from 0 to 5479 Wh/m²/day on the coldest day, as a result, the variation in radiation between seasons is not significant; instead, the shading conditions play a more significant role in achieving air conditioning.

Figure 4. Representation of the current building and the kinetic façade in the linear flow diagrams of temperature (comfort) in relation to degrees and hours, on the warmest and coldest day.

Figure 5. Simulation of winds on the hottest and coldest day.

The wind simulations reveal specific differences in two sections, east and north façades, bordering a building and a residence in the orientation of the prevailing winds, they register a higher presence of cold air and an increase in wind speed at the lower part of the façade (Figure 5). In addition, it is observed that the separation between the building and the nearby structure creates a wind tunnel effect towards the east. The original building enhances cooling on this façade, preventing thermal accumulation in the morning, however, the proposed envelope design allows
regulation of the influence of this wind current. Regarding the simulation of internal illuminance, this simulation was conducted under cloudy sky conditions. Depending on the opening of the envelope panels, illuminance levels between 300lx and 500lx can be achieved.

4 CONCLUSIONS

The quality of modification of the façade based on the movement of its panel prove to be more effective than current static façade, and the understanding of this behavior of the façade was facilitated thanks to the design and simulation platform based on Rhinoceros and Grasshopper, in which the values of accumulated insolation, winds, lighting and temperature were interrelated to adjust the influence of each factor on the overall performance. The morphology of the envelope plays a crucial role in significantly protecting the façade wall against solar radiation, wind and direct heat transmission. The air chamber generated by the envelope offers the possibility of accumulating or dissipating energy, which extends the thermal transmittance and makes it possible to delay or limit the impact inside the building depending on the weather season, whether is winter or summer. After the analysis conducted it was determinate that during the hottest day, approximately 50.83% of operating hours provide optimal comfort, while the remaining 49.17% experience a period of discomfort. In contrast, on the coldest day, around 34.17% of operating hour offer the desired comfort, while the remaining 65.83% are characterized by a period of discomfort. Thus, the proposed façade improves the overall thermal performance and is more convenient than the conventional envelope system. The applied methodology made it easier to diagnose the performance of the static envelope system to subsequently make changes and transform it into a kinetic system, while the adjustment of parameters in the virtual model allows testing alternatives that are validated in the energy simulation. Currently, kinetic façades are proposed for buildings that house large numbers of users; however, the application of this type of construction systems in smaller scale buildings would imply a significant investment, however, the use of the interrelated methodology between design and simulation programs allows testing different scenarios to select the most convenient physical characteristics of the envelope. Finally, the Grasshopper environment used in this study provides a versatile field of exploration, even with several applications beyond energy analysis, which could be used to test proposals in case studies with a greater diversity of technical qualities in future research, making it easier for designers to understand and propose integral solutions in their projects.

References