Thermal Performance Associated with Materials in Early Stages of the Design Process

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This work is part of a research on decision-making processes in architecture involving computer programs in the early stages of designing the building envelope. The research involves two steps: (1) intuitive processes analysis during the handling of the building envelope components - floor, roof, walls, windows, solar protection elements - and (2) generative processes analysis of building envelopes supported by performance models. This article is the first step, analyzing four housing prototypes, designed and built for the Solar Decathlon competition. First, the building envelope elements and thermal characteristics of these prototypes were modeled; then different materials that make up the envelope were tested, aimed at assessing thermal performance against the modifications proposed in six different scenarios. The results showed that it is possible to obtain intuitive solutions that equalize temperature changes in the early stages of design with computing environments even without the use of detailed data on the characteristics of buildings, features of the later stages of the project.

Keywords: Building Envelope, Thermal Comfort, Design Process, Intuitive Process, Generative Strategies

INTRODUCTION

Architects are usually required to associate different bodies of knowledge such as environmental comfort, construction materials, scale, proportion, among other skills right at the early stages of the architectural design process. Architectural design processes generally undergo a series of tasks leading to alternative solutions to the same problem. Therefore architectural design problems can be characterized as ill-defined problems or wicked problems - in that part of the problem specification is unknown (Lawson 2005). In this sense, architectural problems do differ from well-defined problems - where solutions and tasks have an operative solution. In the early stages of the project, the architect defines some aspects and shows others, allowing future interpretations and arguments (Bueno 2014). This flexible character of the architectural activity constitutes an important strength for the profession and, at the same time, it develop to: it increase the level of uncertainty of the proposal to such a degree that it might well cause serious problems. If a proposal does develop itself with "holes" in objective parts it might be quite costly to change the proposal at its final stages. This is particularly true when the architect develop its proposal with limited knowledge about the impact of
environmental variables.

Buildings are environmentally modelled in a later stage of the design process as to not offer resistance to shape alterations. The architect need to keep its intuition (fed by objective knowledge and skill) as to keep control over different variables. In the early stages of the design process, the architect, faced with environmental conditions, seeks to intuitively reduce the need for active systems and to reduce energy costs. The optimization of thermal conditioning by passive strategies involves the adequacy of building materials in the local climate and the choice of forms and architectural elements that allow the reduction of discomfort. Temperature changes, leading to discomfort are controlled by the building envelope, thermoregulatory and primary element for measuring the thermal performance of the building (Lovell 2010). In the early stages of the project, the perception on the temperature exchanges between inside and outside from the impacts of the building envelope, throughout the different seasons of the year, is traditionally on intuitive criteria.

Lamberts, Dutra and Pereira (2014) describe passive thermal conditioning strategies for the building envelope in each of the eight Brazilian climatic zones, defined by NBR 15220-3, the regulation that provides guidelines for summer and winter and defines thermal transmittance (W/m²K), thermal delay (hours) and solar factor (%) parameters for roof, wall and opaque components, of the building. Based on NBR 15220-3 parameters, the architect can set initial design strategies involving the choice of shapes and materials for the climate zone of the building being built. Such standards and guidelines on the thermal parameters, however, don’t necessarily help establish the initial form of the building envelope. In other words, in the early stages of the project, when the envelope is defined, the structured and quantitative evaluation of their thermal performance is usually not required. The structured and quantitative evaluation often occurs in the final stages of the design process when the building envelope shape is already consolidated and committed deeply into the different components of the building. Computing environments capable of supporting such an assessment require data that emerges only in the final stages of design, thus hindering the implementation of performance models of initial form. As a result: initial design decisions do not involve the performance of materials and shapes defined by the party.

The introduction of generative strategies of architectural form from the data on climate and materials in the early stages of the project would help create a series of objects (Fischer and Herr 2001), creating sets of potentially viable solutions for a given climate and supply constructive materials. Generative strategies, such as the Shape Grammars, consist of the systematization of a vocabulary of forms associated with a set of rules, resulting in combinations and relationships between forms (Stiny 1980). The Color Grammars complement the Shape Grammars, adding the possibility of defining attributes to the vocabulary - such as color, texture, material, function, dimensions, performance - encoding the rules of composition (Knight 1994) and enabling the assessment of population generated solutions.

The anticipation of the structured and quantitative assessment process in the envelope thermal performance in the early stages of project is characterized as a possibility to be tested from two instances: the first aims to shed light on the intuitive dimension of the intervention by the architect on the building envelope involving its perception on the impact of shapes and materials used as thermoregulatory elements between the inner and outer temperatures of the buildings; the second consists of the structured and automatic intervention on the envelope shape associated with its thermal performance.

The both stages of the research begin from the analysis of the influence of thermal transmittance (U = W / m²K) from the materials and the shape of the envelope in Zero Energy Buildings. This article dwells on the first stage of the research and aims to correlate objectives of the Brazilian standard thermal performance, NBR15220-3 with intuitive characteristic processes in the early stages of the envelope design by
using computational tools. The article is divided into three parts. The first part describes the materials and methods used in the evaluation of intuitive processes in understanding the impacts from the Building Envelope on its thermoregulatory function. The second part will discuss the results, and the third and last part will elaborate on the preliminary conclusions of the results from the experiment.

MATERIALS AND METHODS
The intuitive process evaluation related with the building envelope thermoregulatory function reaches cognitive aspects covered, in an equivalent manner, recently with graduated architects and undergraduate architecture students at their graduating year. This work evaluate the perception about the impact of the building envelope on final year undergraduates in Architecture at Federal University of Rio Grande do Sul, divided into four groups, having Solar Decathlon (SD) projects with corpus. The prototypes (See Figure 1) analyzed during the experiment and their respective groups were:

- Group 1 - DALE House (developed by the Southern California Institute of Architecture and California Institute of Technology for the Solar Decathlon 2013, held in Irvine, California)
- Group 2 - EMBRACE House (developed by The Technical University of Denmark (DTU) for the Solar Decathlon Europe 2014, held in Versailles, France)
- Group 3 - PARA-EKO House (developed by Tongji University for the 2012 Solar Decathlon, held in Madrid, Spain)
- Group 4 - RHOME House (developed by Università Degli Studi Di Roma TER, for the Solar Decathlon Europe 2014, held in Versailles, France)

Groups of students modelled the elementary geometry of the prototypes in the computing environment: SketchUp, in attempt to simplify the model and to represent open, closed, opaque and translucent planes, separated from each other by layers that characterize the components of the envelope. Subsequently they imported the model to the software Ecotect Analysis by Autodesk, identifying the envelope materials in accordance with the characteristics, originally used by SD teams.

The experiment linked the thermal transmittance to the time required for the internal temperature to reach a comfortable level, in six different scenarios, with five changes of building envelope components. The first scenario has kept the characteristics of envelope materials offered by SD teams changing only the geographical location to the city of Porto Alegre. When changing the geographical location of the models to Porto Alegre, it resulted in mirroring the geometry, given the passive strategies of cooling and heating, towards the north and south poles. The measurement of the thermal comfort of the generated alternatives in both scenarios was simulated in

Figure 1
Corpus analysis: housing prototypes designed and implemented for the Solar Decathlon competitions.
Degree Hours, representing the amount of discomfort by the cold and heat. Degree hours consist of the number of degrees above or below the comfort level of the internal temperature for the months of the year, indicating the level of discomfort, and not just the evaluated period. The established range of the comfort zone in the experiment was between 18 °C and 26 °C, pondering for thermal calculation: passive ventilation system (natural), occupancy of two people in light activity (80W); sensitive and latent internal gains, respectively, 5.02 W/m²; infiltration rate: 0.50 hr of air change rate and 0.25hr wind sensitivity; 1.0 clothing (clo), relative humidity 60%, air speed 0.5 m/s and lighting level 300lux.

The following five scenarios changed components of the envelope, suggesting the increase or decrease in the thermal transmittance from the layer, in search of more efficient results in the new weather conditions. Scenario 2 changed the floor keeping the other properties. The third scenario maintained the floor from the original scene, as well as other components, modifying only the cover. In the fourth scenario, we tested the change of opaque vertical planes closure (walls), and fifth scenario measured the modification of fenestration, and the both scenarios kept the components and SD characteristics. Finally, in the last scenario, all the modifications offered in previous scenarios to Porto Alegre, have been integrated, while keeping the geometry of the prototype (See Figure 2).

RESULTS
The results show that between the first and last scenarios, the level of discomfort from the heating in the four analyzed models decreased. The Dale group suggested the improvement in the building performance for heating and cooling while the other groups decreased the level of comfort in cold periods and improved in warm periods.

In the last four scenarios of the Dale House, it is confirmed that the thermal transmittance of the envelope components decreased, improving the thermal behaviour of the prototype and reducing the hours of discomfort due to cold and heat. The students were surprised by the opposite role to the other planes of the envelope in terms of the increased thermal transmittance of the floor that resulted in the decrease in the total average annual discomfort (heat and cold). The last stage of this analysis showed a decrease of 42% in Degree Hours of average annual discomfort, finalized the process by 9.466 DegHrs, with 1.067 DegHrs of discomfort for heat and 8.399 DegHrs to cold (See Table 1) being a strong control indicator on the influential factors in thermal performance.

The second group has measured and adjusted components of Embrace House, testing the decreased thermal transmittance of the floor and raising the transmittance of the roof, walls and fenestrations respectively. Most of the changes increased the overall coefficient of transmittance, exploring different compositions between layers of insulation, sealing, internal and external. The changes proposed by the students kept the translucent areas and increased temperature exchanges between domestic and external environment. The increased thermal transmittance of coverage planes, walls and fenestration resulted in the prototype to cool down, reducing the
discount period on hot days and increasing discomfort in cold days. The only scenario that decreased comfort on hot days and increased comfort on cold days was the first, due to the decrease of 16% transmittance of the floor. The performance of the last scenario after all the changes resulted in increased discomfort to the cold and decreased discomfort in the hot environment, with 11.016 DegHrs of total annual discomfort, with 759 for heat and 10.257 for cold (See Table 1). The results showed that the students were able to obtain a high degree of thermal performance for the summer, but had difficulty equalizing the discomfort period in the cold.

The team of students from Para-Eko House opted to the decreased transmittance of the floor, wall and fenestration, only increasing the temperature exchanges between the cover. The result was an increase in discomfort in the first scenario, due to the difficulty to establish temperature exchanges between floor and soil; the decrease in total comfort while increasing exchanges between coverage and external environment, however considered a small decrease in hours of discomfort in the summer. The increased insulation of vertical opaque planes showed an increased in comfort in the inner zone, in contrast, the increase in the isolation of the apertures proposed by students, increased the comfort level in hot days and decreased in cold days, totalling more hours of discomfort throughout the year. Finally, the union of all changes, decreased only 3% of the average thermal comfort, increasing the discomfort in the winter while maintaining the performance during warm periods. The initial assessment totalled in 6.597 DegHrs of annual discomfort while the last scenario presented 6.795 DegHrs of discomfort, showing the control between temperature changes and manipulation of materials exercised by the students.

Table 1
Thermal Characteristics of building envelope components and performance captured by the four groups during the six proposed scenarios for the analysis in Porto Alegre / RS.
The low thermal transmittance of Rhome House led the students to propose an increase in temperature exchanges between interior and exterior. Increased in the floor transmittance as in the other groups showed a performance improvement while the temperature changes in coverage and fenestration increased the comfort on hot days, the comfort on cold days went down. Increased thermal transmittance of walls caused the decrease in thermal comfort in both hot and cold weather conditions. Even with the rise of temperature changes, the form had less discomfort in warm periods, clashing with the increased discomfort in cold periods. The result of DegHrs 8.989 measured in the first stage compared to the 9.848 DegHrs from the sixth stage represented the increase of 10% in prototype thermal discomfort. This result shows that the students were able to gain control over passive strategies for warm months, but did not know how to control the passive strategies for the winter very well.

CONCLUSIONS

The impact of the building envelope equalizing temperature changes in the early stages of design tested the perception of the materials by the designer. The results show that between the first and last scenarios, the students confirmed the reduction of discomfort from the heat in the four models. As such, the first group promoted the improvement on building performance for heating and cooling, and other groups decreased the winter comfort and improved in the summer. The group that tested the Dale House quickly identified that the glass areas of the prototype implied a high degree of transmittance and modified them to improve the overall performance. The other teams did not undergo drastic changes as they associated the proposed materials to the high thermal inertia and a few hours of discomfort.

Increased floor thermal transmittance resulted in the decrease in the total average annual discomfort (hot and cold), allowing the students to see that the temperature changes can be favourable in certain circumstances. The reduction of thermal transmittance floor proposed by the groups 2 and 3 confirmed the finding of the group 1 and 4, since the increase in the thermal inertia represented proposed increase in the discomfort of the tested prototypes. The same hypothesis was not confirmed in other components of the envelope, thus allowing students to conclude that the contact with the ground is essential to equalize the temperature changes and to measure the insulation required for the floor.

The components: coverage, walls and fenestration behaved inversely to the floor because when students proposed the reduction of thermal inertia, they found the increase in average annual discomfort. In some cases, there was a reduction in discomfort by the heat, but the annual balance sheet declined due to the significant increase in discomfort when away from the cold periods. Through these results, the students concluded that the surfaces in contact with the external air behave in a similar manner, and a caution should be exercised in relation to the thermal insulation of these components. The only situation against such a finding was the fifth stage of the Para-Eko House, which reduced the thermal transmittance of fenestration, increasing the period of discomfort as a result of the high degree of thermal inertia. The case of Para-Eko demonstrated that when the thermal inertia of fenestrations is extremely low, the heat reduction can occur through translucent planes.

The results show the relevance of the anticipation of the evaluation process that contributes to the intuitive process by the designers in the early stages of the project. The evaluation of the building envelope and the handling of the materials demonstrates the potential to create methods that link the performance models and generative strategies to the objective to assist decision-making to reduce the use of passive strategies in later stages of the design process.

FUTURE WORKS

Performance models associated with the early stages of design can help the design decisions to make the most efficient architectural solutions, while decreas-
ing the use of active strategies and consequently, excessive energy expenditure. The manipulation of materials associated with generative strategies, such as the Shape Grammar and Color Grammar, could enhance the exploitation of the envelope form and its properties to decrease the need for implementation of passive strategies in subsequent stages of the design process. The evaluated parameters can be expanded, including analysis of natural and artificial lighting, ventilation, and power generation, among others. The generative strategies can convert the methodology in a parametric system that generates efficient alternatives through a set of analyzes: thermal, lumen and energy. The inclusion of other building elements such as structure, functions and furniture, also strikingly displays to complement the proposed methodology.

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