# Visualizing the Expressive Use of Technology in the Design of Parametrically Generated Eco-envelopes

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ABSTRACT: This paper illustrates how computational design has surfaced in the architectural discourse. One particular area of interest has been in parametric design. The authors argue against Parametricism, an avante garde movement which is limited to the issues of style and aesthetic fitness. Instead, an approach that uses parametric modelling, simulation and visualization in an iterative way to generate design solutions for complexities of contemporary design problems is favoured. The authors present a particular case study where parametric design is utilized in the development of a research project that looks for appropriate solutions for building envelopes in hot and humid climates. The process involved the selection of geometrically dependent parameters and their translation into variable fields, variable instances and range values. The parameters and the possible values were based on literature reviews and digital simulations (pre-evaluations) of different types, but categorized as functional, technological and environmental. Even though the project is ongoing, the generation and evaluation of the designs carried out as part of the present research have already yielded results that can guide designers towards informed solutions of the problem studied. More importantly, the study presents a methodology that, understood as part of so many other similar proposals, can assist in the construction of new and more efficient digitally driven design and research processes.

KEYWORDS: Parametric Design, Computer Aided Design, Simulation, Brise Soleil and Building Envelope

## INTRODUCTION: From the conventional understanding of design (analogue and/or digital) to an iterative systems approach facilitated by computation

> It appears to me that the age of tools has now given way to the age of systems, exemplified in the conception of the earth as an ecosystem, and the human being as an immune system. - Ivan Illich

Advancement in modeling and visualization was stagnant for hundreds of years until the drawing machines of the Renaissance gave way to a new type of machine just 65 years ago.[1] Following the invention of the 167 square meter (1800 ft2) ENIAC computer, Programma 101 followed twenty years later as the world's first desktop computer, and with the prophetic 1968 presentation of Douglas Engelbart, a new future reliant on computational technology was envisioned.

In spite of a relatively slow process which has spanned the past three decades, continual improvements in hardware and computing power paired with the rapid evolution in software have created a favorable condition for the absorption of computing into the practice of architecture. This has generated interest and inquiry by both practitioners and scholars in the field of architecture.[2] Organizations such as; the Association of Collegiate Schools of Architecture (ACSA) demonstrate the significance of the digital discourse as their centennial conference of 2012 concentrated on the theme “Digital Aptitude”. Attention of this sort is necessary because the architectural discipline, both in academics and practice, has grappled with the way to which computation should be absorbed as a tool in design processes for decades. At the commencement of the digital discourse and until recently, computation was just understood as a way to expedite traditional processes (a representational utilization of digital tools). However, what has surfaced is a growing interest in the possibility to use parametric tools which can facilitate an iterative systems approach to design that supplants the original notions of Computer Aided Design (CAD). (Bermudez and Klinger 2003)

## 1.0 PARAMETRIC DESIGN IN ARCHITECTURE

### 1.1 A glimpse at the trajectory of parametric design in architecture

Parametric design is one area of the discourse that has recently received significant attention though the term is nothing new. This concept was an important premise for Ivan Sutherland in the development of *Sketchpad* fifty years ago. Various architectural software has incorporated limited parametric functionality ever since. That being said, the general flexibility of the software and use has been limited to expediting representational notations. The explicit determination of designers to incorporate multidimensional parametric design thinking in their work flow and as a tool to explore design intent in an iterative way is a recent development. There has been a learning curve that has slowly revealed that a parametric approach requires that the mantra of the 'part to whole' is conceived as a system of relationships in which the author*(s)* must define the connections as well as the constraints. (Woodbury, 2010) This provides a clear break in the tradition of *apriori* design manifestation.

While the possibilities of developing parametric design methodology are virtually unlimited, an interest in geometric has become a focused area for exploration. In particular an organic aesthetic of non-Euclidean forms has become rather common as interfaces for scripting and programming have become more intuitive (as seen in the Grasshopper plug-in for Rhinoceros and Bentley's Generative Components). Intending to solidify and increase coherence for this new movement, Patrik Schumacher states:

> Contemporary avant-garde architecture is addressing the demand for an increased level of articulated complexity by means of retooling its methods on the basis of parametric design systems. The contemporary architectural style that has achieved pervasive hegemony within the contemporary architectural avant-garde can be best understood as a research programme based upon the parametric paradigma. We propose to call this style: **Parametricism**. (Schumacher, 2008, 1.)

After establishing the criteria and describing the characteristics of the evolving style which he calls *Parametricism* in a 2008 manifesto, Schumacher's ambitious agenda has involved an attempt to establish the validity of Parametric Design as an important movement within the history of architecture. In a chapter of the text *The Autopoiesis of Architecture, Volume II: A New Agenda for Architecture* (2012), the parametric paradigm is explained at conceptual and operational levels. In spite of these efforts to substantiate a new style in architecture, criticism of this proposal easily points out that the material wastefulness in virtuous form making exuberant aesthetic proposals have no place amidst the environmental crisis now being actively faced by the fields of architecture, engineering and in the construction industry.

> The new terminologies and procedures of designing and planning lose both their realism and their validity as soon as they cease to reflect the personal issues which matter most to the people who take decisions or are affected by them." (Jones, 1992, 73.)

Without the development of a more comprehensive strategy, *parametricism* might have a bleak chance of further development, whereas *eco-logically conscious parametric design* provides much potential.

### 1.2 Potential of eco-logical parametric design

Being that the parametric design process offers a systematic organizational structure to confront design problems, it lends itself as a powerful tool to address the complexities of the contemporary architectural design problem that not only must create form, but also involves providing solutions for; material, structural and environmental performance. Interest in computational design tools and processes in the architectural discourse has the potential to be of greater value if capable of expanding upon the *parametricist* scope of design as a research program and aesthetic theory to an agenda which includes other narratives that incorporate criteria of use and performance.

> Constructing narratives of utility provides an escape from tautological parametric solipsism without forsaking formalism by providing an instrumentality of form, which could include pragmatic performance, the visceral, as well as the intellectual, discursive, or meaningful.(Meredith, 2008, 8.)

Considering that those 'affected' by architectural constructions include 83% of North Americans polled by Gallup to be pro-environment, designing in an environmentally sensitive way through parametric modeling could be meaningful on many levels. (Americanprogress 2011)

## 2.0 RESEARCH INITIATIVE IN PARAMETRIC DESIGN: Developing a methodology that prioritizes environmental performance

### 2.1 Background

As architectural professors in the undergraduate program at the Universidad Piloto in Bogota, Colombia, we are involved in teaching and researching about facade systems. In our institution and as we have witnessed in numerous institutions, there continues to be difficulty with technology from a pedagogical perspective. Generally electives are offered as courses in software, but not in computational design thinking. Relegating computation to knowledge of software packages perpetuates ignorance in professional practice, as seen through practitioners that view *Building Information Modeling* as little more than an extension of drafting and modeling. Our belief is that the contemporary student must manage technology; nevertheless this skill set should be seen as secondary. Developing analytical problem solving should take precedence. Being that these tools are robust and that computing is much more than an instrument for drafting. The student should not only rationalize this, but be able to apply design methods to real world situations.

Due to a lack of literature related to design for the climatic conditions of Colombia, a research is being undertaken at our institution which looks to fill this gap. The activities of this project include modeling, simulation and comparative analysis with the performance of physical prototypes located in the hot and humid tropical climate. This project seeks to generate a useful body of knowledge for students and designers. Participants include biologists and architects and range from the level of student to full professor with doctoral degree.

### 2.2 Research question

Reflecting on the institutional agenda for this research, the authors have defined a line of inquiry that relates digital discourse with environmental performance. We have formed the following question:

> How might digital aptitude (and visualization) aid architects in the quest to develop solutions that mitigate negative environmental impact and strive to achieve maximum performance through the agency of parametric modeling? (Brakke and Velasco, 2012, 7.)

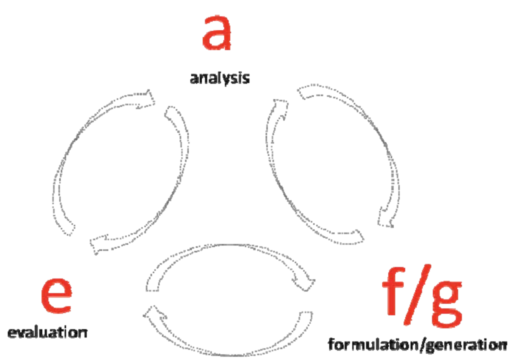



**Figure 1:** Iterative Design Process. Source: (Author 2012)

### 2.3 Case study: Eco-envelope research project

The Eco-envelope project is one example which we have created an integrated and iterative approach that defines, analyzes and considers a set of parameters which guide the development of a brise soleil system to serve as the building skin. This is currently a work-in-progress, so this article does not put forward the results as authoritative, but intends to present the development hitherto. Within this section of the article, the methodology used in the generation of the facade system will be explained. Three stages have been identified which include; 1) Formulation of the problem, 2) Development of a parametric model, and 3) The application of this model.

### 2.4 Geographic location and climatic data

The climatic, ecological, and economic conditions found in a typical tropical location near the equator are characterized by heat and humidity. This climate is common to great part of the Colombian territory, but the town of Girardot, Colombia was chosen as the exact location for this study. This town is located at 4.16º N Latitude and 74.49º W Longitude. This town has an average humidity of 80% and the average day time temperature is over 27 º C, though temperatures exceed 32 º C 75% of the year and peak highs surpass 40 º C. Obviously the mitigation of solar radiation becomes a primary task to consider in the design of the building envelope. Natural ventilation is also a priority as we seek to create solutions of low environmental impact that strive to provide internal comfort.

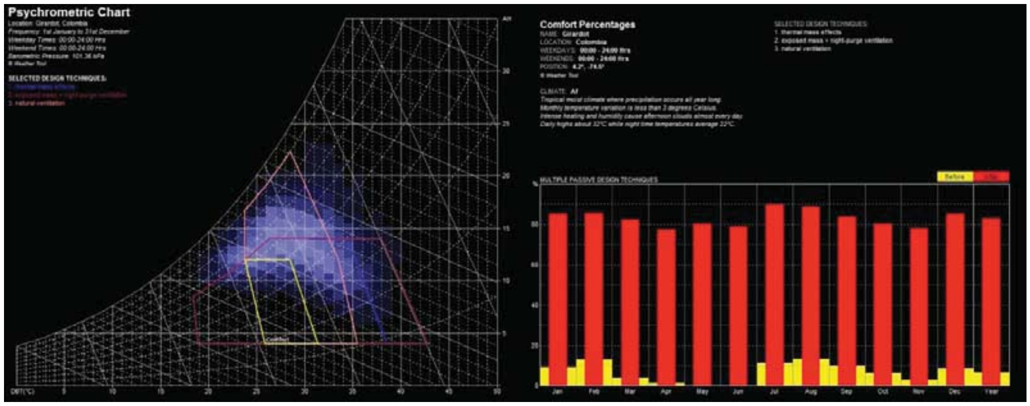



**Figure 2**: Psychometric Chart for Giradot and forecast rates of comfort with the use of selected passive strategies. Source: (Author 2012)

### 2.5 A literature review and subsequent definition of the design problem

The first stage was dedicated to the *definition and formulation of the problem* which involved a study of issues pertinent to state of the art facade design through a comprehensive review of special facade designs and existing literature. The literature review prior to the development of this research has shown that most of the publications on the subject tend to classify envelope systems based on a single parameter, the type of material used in the solution and demonstrate such categorization through case studies. There is a scarcity of information that documents methodical analysis based on the configuration of layers or integrated systems in the envelope system. The existing literature that complies with the scope of integrated systems is generally related to specialized double skin glass facade systems typical of solutions for structures that are situated in high-latitude climates. (Ulrich Knaack 2007, 2008)

In parallel with the literature review, several three-dimensional digital models were created and analyzed (simulations in Ecotect and Design Builder were conducted) to gain insight and provide preliminary data about the performance of particular solutions in hot and humid climates.

The analysis of the information in the literature review and preliminary simulations resulted in the identification of three types of major determinants necessary to understand in the creation of any type of building proposal, these factors include; *functional, technological and environmental*.

Functional factors relate to the way in which the skin of the building, working as a protective barrier, provides human comfort zones inside. These factors determine the degree of comfort that the system provides to the covered spaces. Four main criteria related to function have been identified: thermal control, light transmission, ventilation and soundproofing.

Technological factors deal with the means and technologies used to know about how the proposed building envelope is built. We have identified four factors that determine how the performance of the proposed design may come to be evaluated and control the degree of articulation of the proposal in terms of technology and construction: structural capacity, construction efficiency, safety and durability, and costs and maintenance.

Environmental factors relate to the global physical environment in which the possible envelope is located. This includes everything from energy issues to biodiversity (native plants and/or other living species).These factors define the impact of the system on the natural environment that surrounds it at local and global scales, which may imply requirements in terms of various subjects such as embedded energy, absorbed-emitted thermal energy, support for local biodiversity and production of O2.

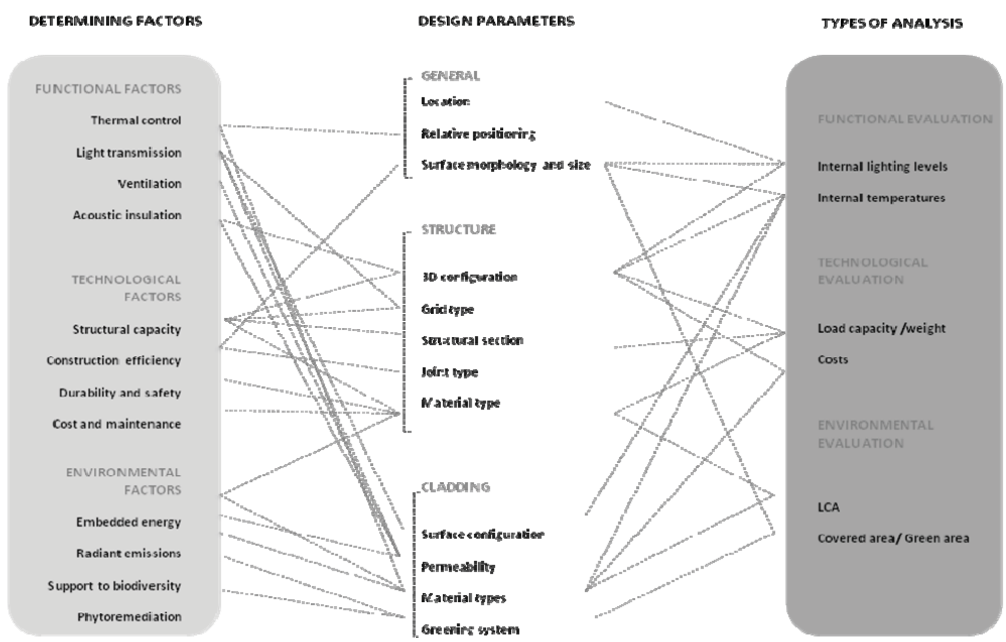
A series of factors that could be assimilated as groups of system requirements is included in each of these categories. These groups were classified into specific requirements having the potential to be evaluated, and thus incorporated as types of analysis and as feedback for the generated proposals. The first emphasis of the Eco-Envelope project is on the articulation of these systems and subsequently on the architectonic designs which are created through the enmeshing of these defining factors. In this study, design is to be understood as the integrator.

## 2.6 Design parameters

Three groups of design parameters that were to be implemented as design variables were then defined for the generation of design possibilities. These groups include; general parameters, structural parameters and cladding parameters. These groups of design variables formed a structure from which we were able to produce a set of configurational possibilities which were subsequently tested by different types of analysis relative to the original determining factors. [See Table 1]

We have identified 12 parameters to define the design and characterization of architectural envelopes for tropical climates: location, relative position, surface morphology, scale, structural configuration, grid type, sections of structural work, joints and anchors, structural material, type of closure, permeability, and materials for closure and plant support. The table below shows the relationship between the determinants and proposed design parameters for this research, defined into three main categories: general, structure and cladding.

**Table 1**: Definition and relationship between; Determining Factors, Design Parameters and Types of Analysis. Source: (Author 2012)



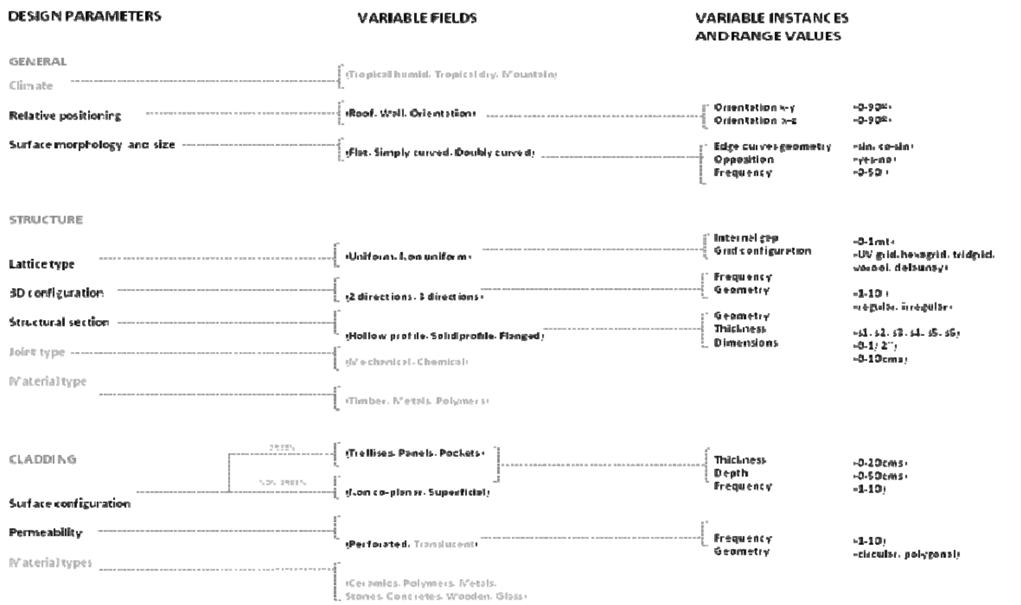

## 2.7 The development parametric structure and rules for configuration

A parametric structure is synonym of an inter-relational organization, where the parts are connected within a coordinated system, thus implying automatic recreation/reconfiguration of form as the variables are modified. (Woodbury, 2010, 11.) Accordingly, the following had to be defined; the parts of our model, the way and the ranges by which they change, and the general rules of the system. These parts have been called “design parameters” which generally involve particular configurable types (variation fields), where internal definitions (variables) can have differential values of specified ranges (values). The following section explains the general rules and the definition of the parametric structure providing the framework for the use of digital tools.

General configuration rules are given by previous analysis of research conducted within the frame, where passive strategies were explored in warm humid air to achieve reasonable levels of comfort within the covered building. As shown through basic pre-analysis, the most important strategies were ventilation, thermal inertia, solar protection and night cooling.

The proposed research involves the use of double-layer systems that may allow selectively indoor and cross ventilation. Thus, seeking the application of these promising strategies and guided by the requirements proposed as determinant factors, we have considered only a limited number of design parameters. These general parameters of design are related to the general definition of the envelope, its structure and enclosure: the proposed configurations would be constituted by double-enclosed particular combinations using the interior void as the cavity for the structure. This allows for the possibility of permeability, the use of vegetation, and the use of recycled or renewable materials. The current thinking is to develop panels that will be constructed from prefabricated components which will also allow for easy assembly and disassembly.

**Table 2:** This table shows the definition of structure and design parameters. The dark names indicate a direct relationship to geometrical, thus to be included in the 3d parametric model definition. Source: (Author 2012)




## 2.8 Design Generation

Following the above mentioned structure where the technological, environmental and functional factors that demarcate our particular space for physical configurations were integrated, we further defined the variable fields of seven design parameters whose functional and technological behavior could be importantly influenced by their geometrical configurations. As discussed above, the design parameters were constrained into three groups, the first corresponding to the general conditions, the second for the structure, and the third defining the cladding, this to be subdivided into external and internal.

The diagram above [Table 2] shows a further description of the proposed design parameters for this research, the geometrically related design parameters (in black) can be directly controlled from three-dimensional parametric definitions built on Rhinoceros-running Grasshopper, producing specific digital models to be evaluated using structural and environmental software packages. Material and functional parameters were to be defined using an Excel based spreadsheet, where options are linked to specific pre-determined values and computed with the incoming data resulting from evaluations of the three-dimensional model.

Here we shall briefly describe each of the general fields:

The first field is called *General Parameters*: These parameters define the general shape and conditions of the building envelope in terms of morphology, position and size. The first variable is called *Relative position:* The relative position is probably the main parameter determining the degree of influence of the external environment on the envelope surface. There are three possibilities for this parameter, vertical position,



operating strictly as a wall (whichever the orientation), horizontal position, operating strictly as a roof, and intermediate positions between the above two conditions. The second is called *Surface morphology and size:* The morphology and relative position of the surface defines the positioning of the surface relative to the external environment, involving, for example, higher levels of solar radiation, exposure to wind or rain. As for surface morphology, we defined three possible variations, flat, singly-curved, and doubly-curved. The main implications that each option entails, are structural and constructive. Size implies the magnitude of the envelope in 2 directions.

The second field refers to *Structural Parameters:*This category includes lattice type, 3d configuration and structural section.*Lattice Type*: The lattice type has direct implications for the structural work, the construction process and particularly on the paneling and modulation of the cladding elements in the system. We have identified two cases of lattice, uniform, and non-uniform. The first indicates a total modular standardization case; the second indicates a semi-standardization provided by the use of two or more modules. *3D Configuration:* The structural configuration is understood as skeletal-type construction, defining two degrees of connectivity between elements, and involving changes to the structural work sections of the elements. We have identified two possible variations to the structural configuration, a structure in two directions and in three directions. The higher degree of connectivity provides greater structural stability to the system, but usually implies more weight and more constructive assemblies. *Structural section:* Defines the profile shape, depth and plate thickness used for the structural configuration of the structural system.

The last field relates to the *Cladding Parameters:* Cladding parameters define how the system interacts with the surrounding environment at the surface level, determining the types and levels of energy exchange of various kinds. *Surface Configuration:* The physical configurations of the modular elements that cover the envelope system define the system relationship with the external environment. We have identified three major changes in this parameter; elements coplanar, surface, and mass. Type of greenery system and plant species were studied to find appropriate plant material in areas that make up the cladding. We have identified three possible configurations for positioning, the first would be given by a mesh of wires to support climbing species, the second would be given by receptacles forming horizontal hard pockets, and the third would imply the use of vertical panels. *Permeability:* The permeability of the surface elements is also (at a material level) defined by the modular configuration and/or type of material used, involving two types, perforated and translucent. We shall only translate the former into the 3d model.

## 2.9 Application and performance simulations

Improving Energy Retrofit Decisions by Including Uncertainty in the Energy Modelling Process by Alireza Bozorgi and James R. Jones

The designs were analyzed in terms of their performance as climatic barriers and providers of comfort. In order to run the simulations, temperature, lighting and ventilation evaluations were carried out using the software packages Ecotect and DesignBuilder.

The evaluations have been realized against the performance of the reference model which simulates the vernacular techniques of a plastered or face brick facade and flat roof in concrete or fibrocement as implemented in nearly all of the constructions in Girardot. The highest performance models have been compared with the referent construction and the Girardot climate in order to choose the best environmental and of thermal performance options. After a comparative analysis of 48 different cases, three models were identified as highly performing and environmentally friendly: ventilated envelopes of hollow flat bricks, with light coloration, green walls and roofs with native species of easy propagation and locally cultivated, supported by bio-plastic boxes reinforced with mineralized vegetal fibres, and laminated bamboo panels, immunized and preserved against the humidity and UV radiations. The three selected model solutions, even with different thermal curves, show an improvement of the thermal comfort from the interior of 10oC in the warmest day and ≥5,8oC in 75% of the days. The generated models were adapted to the particularities of such materials-components.

Using the material assumptions discussed above, the parametric model is being used to “fine tune” the best geometrical attributes to design a particular case, being that the west facing facade of the existing university buildings in Girardot. Thermal and CFD simulations were carried out to evaluate the original conditions, and to be compared with the performance of 60 design configurations given by the proposed parametric definition. [FIGURE 4

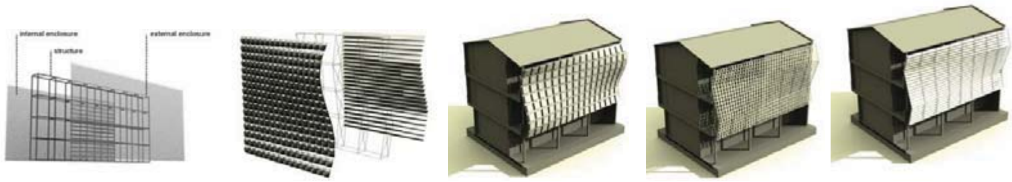



**Figure 3**: Diagram of enclosure and structural system chosen. Examples of three geometrical configurations produced from the parametric definition. Source: (Author 2012)

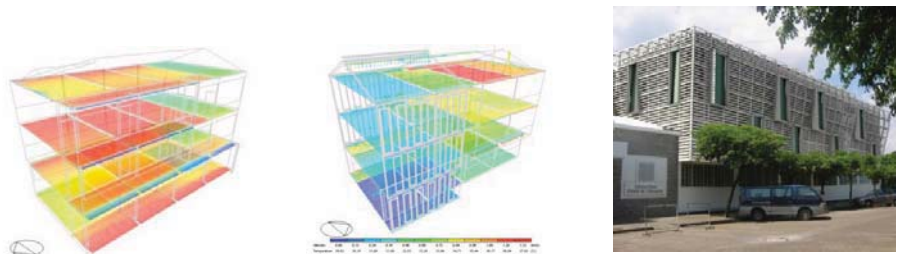


**Figure 4**: Left: The images on the left are visualizations and simulations of internal temperature of classrooms in an existing building at the Universidad Piloto in Girardot. The simulation on the right shows that the results with the proposed facade (modular ceramic and brick interior wall) achieves a decrease in internal temperatures close to 6º C (10º F). Right: A render of the existing building with the brise soleil solution on July 21st at 12 PM. Source: (Author 2012)

## CONCLUSION

This paper illustrates how the development and formulation of a parametric facade system has been created to address the specific climatic situation near the Equator. While digital tools continue to evolve, what becomes more important is how the architectural design process is approached. As design processes, such as; parametric modelling, building information modelling (BIM) and architectural visualization software are utilized, architects are encouraged to look beyond the surface and incorporate feedback from the physical and cultural contexts as parameters to design innovatively.

Architectural design is discursive and even though this document reveals an ongoing project, there are already results that can guide designers towards informed solutions for projects of similar characteristics. The parametric design process is one that relies on the visualization of models not only to understand form, but also performance. The culmination of research to date will not provide a defined equation which explicitly states the manner to which an ecological digital design process should be approached. Rather what is illustrated is how we have gone about using parametric modeling in our exploration of designing and developing brise soleil facade systems that seek a high level of performance. This study presents a methodology that, understood as part of a body of work along with other similar proposals, can assist in the construction of new and more efficient approaches to design. These approaches are digitally driven and strive to achieve maximum performance through the agency of parametric modeling. The *visibility* of the results is evidence that not only does our design solution mitigate the negative environmental impacts of building but is also able to achieve levels of internal comfort highly desired by the inhabitants.

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## ENDNOTES

[1] Though J.N.L. Durand's *Précis des leçons d'architecture données à l'École royale polytechnique* was a significant contribution to the methodology of the presentation of design drawings, no other advances in architectural drawing and modeling were made until recently.

[2]ACADIA (Association for Computer Aided Design In Architecture) was founded in 1981. This organization "facilitates critical investigations into the role of computation in architecture, planning, and building science. There is an international network of 5 sibling organizations which also provide an environment for research in computation and design matters.