Eco-envolventes\textsuperscript{1}: A parametric design approach to generate and evaluate façade configurations for hot and humid climates

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Abstract. This paper presents the current development of an in-progress academic research project where a particular design problem, that of building envelopes for tropical climates, is parametrically defined and its possible solutions assessed by means of data correlations and virtual simulations. In doing do so, the authors have devised a parametric structure based on factorial definitions whereby environmental, structural and life cycle analyses are taken into consideration to determine the design possibilities subsequently defined in terms of their physical configuration, constituent materials, construction processes and dynamic behaviour. Particular emphasis is placed on the embedded energy and functional performance of the resulting designs. The proposed methodological model is graphically presented, and its practical potential illustrated by a particular case of application. It should be taken into account, however, that this is a work in progress, and only the first step towards the construction of a simulation based methodology for architects and designers.

Keywords. Parametric design; building envelopes; green envelopes; tropical architecture.

INTRODUCTION

“Ecoenvolventes” is about the development of building envelope solutions for tropical humid climates involving passive control of thermal gains on their surfaces, allowing for better internal conditions and thermal comfort without the use of thermal machines. Environmental principles, design, and technological aspects are specifically defined based on the peculiar conditions (geo-climatic, technological, of biodiversity and economic) present in the Colombian low altitude regions, marked by constant high temperatures. Thermal and CFD simulations orient the process of experimental verification in a

\textsuperscript{1} Eco-envolventes is a multi-disciplinary research project developed at the Universidad Piloto de Colombia, where the authors have collaborated with Claudio Varini (Main Researcher), Tomás Bolaños (Biologist), Eduardo Rocha (Architect), Andrés Moscoso (Architect), Camilo Contreras (Structural Engineer), Paulo Romero (Industrial Designer and LCA expert) and Sara Luciani (Junior Researcher).
permanent laboratory counting on industry partnerships and available know-how. This paper presents only a small part of the project, that concerning the design component, involving the proposal of a parametric design structure to apply and support the general research findings.

Within the design component presented here, three different stages of development can be defined, of which the first has already been finalized. This first stage implied a study of the state of the art and further definition of the design problem. It involved a wide literature review and the analysis of various facade configurations, placing emphasis on those solutions of a local nature, and responding to the climatic conditions of our particular interest at this stage, i.e., hot and humid climates. A number of designs were compiled and sometimes 3D modelled, allowing for the production of summarized case studies. Following that, a general structure was proposed guided by three main determining factors: functional, technological, and environmental. Each group had specific factors and was translated into design possibilities by the changing parameters, their relative values, and simulation based evaluations producing a conceptual parametric structure.

Based on the information previously compiled and adapted to a specific environment, the second stage had to do with the development of a parametric design structure following a first set of assumptions given as results of the general research, and whose expected outcome is a parametric definition (still in development) that would embed a world of design possibilities and contemplate the particular performance of such possibilities in terms of the previously defined determining factors.

Having defined and developed the parametric design structure, the third stage looks for a particular implementation of such model, where the generic values given to materials and design typologies will be replaced by commercially available, low embedded energy components that showed high performance levels in pre-evaluations where carried on and are explained in the latter part of this paper.

DEFINING THE DESIGN PROBLEM

Conceptual approach
Following the general research line in which design results were intended to place particular emphasis on performance with low environmental impact, the design problem was defined in terms of three main groups of determining factors: functional, technological and environmental. The first defines the comfort levels that the envelope system would provide to the covered spaces, the second defines the structural and constructive efficiency of the system, and the third has to do with the impact that the system would have upon its environment at local and global scales; following that:

Functional factors are related to the manner in which the building envelope serves as a protective barrier and a provider of human comfort zones inside. These factors define the degree of comfort that the system determines to the covered spaces. We have identified four main factors requirements here: thermal control, light transmission, ventilation and soundproofing.

Technological factors have to do with the means and technologies used to realize the proposed building envelope, that is, what, and how is it built. We identified four factors that determine the degree of articulation of the proposal in terms of technological and constructive, and define how the performance of the proposed design may come to be evaluated: structural capacity, construction efficiency, safety and durability, and costs and maintenance.

Environmental factors are related to the global physical environment within which to locate the possible envelope, including energy issues and biodiversity (native plants and / or other living species). These factors define the system’s impact on the natural environment that surrounds it at local and global scales, which may imply requirements in terms of the following subjects: embedded energy,
absorbed-emitted thermal energy, support for local biodiversity and production of O2.

From such definition, we then defined three groups of design parameters that were to be implemented as design variables for the generation of design possibilities: General parameters, Structure parameters and Cladding parameters. These were groups of design variables, that were to produce a world of configurational possibilities to be subsequently tested by different types of analyses relative to the original determining factors.

Environmental conditions as first level design assumptions
The problem of physical categorization for the design of building envelopes could have a magnitude such that it is not clear how to approach a discussion about it. A literature review prior to the development of this research has shown that the vast majority of publications on the subject take the material type as the single parameter for classification, and are demonstrated through case studies. Some studies involve additional categories based on the configuration of layers in the envelope system, however, these were found specific to specialized double layer glass systems, typical solutions for high-latitude climates.

Even if there are plenty of recent studies regarding the design of ecologically efficient building envelopes, such problem can only be defined in its specificities by looking at a particular environment. The present study focuses on the climatic, geographical, ecological, and economic conditions found in a typical developing world tropical location, exemplified by the town of Girardot in Colombia, where the climate is common to great part of the Colombian territory. Located to 292 m asl, Latitude 4,16o N and Longitude 74,49o W, has
an average temperature of 27.4°C (minimum: 24.0°C, maximum: 32.3°C), a relative average humidity of 80%, 821 mm of precipitations with raining 76 days and 213 hours/month of solar brightness. The peaks of maximum temperatures reach to 40.0°C, whereas the minimum fall to 21.0°C. Generally, in 273 days/year (74.8%) temperature raises above 32°C. With an annual average 4,575 kWh/m²/day solar radiation, is evident that the sun is an agent who takes part strongly in the thermal economy of the envelopes contributing in 4°C (in average) up to 11°C to the air temperature.

A first step entailed the analysis of climatic data in contrast to ideal comfort conditions to define the main specific functions of the building envelope. Previous analyses using a common data visualisation and pre-analysis tool confirmed the high potential of passive strategies (facilitated by physical configurations) to attain reasonable comfort levels inside the covered building; the most prominent strategies were ventilation, thermal mass, shading and night cooling.

![Figure 2](General typology built in the model, a double layer cladding with the structure in between)

![Figure 3](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.)
Looking for the application of such promising strategies and guided by the requirements proposed by the determining factors, we considered only a limited number of physical, material and functional generic parameters, based on a preliminary assessment of the desired solutions. The generic parameters were relative to the general definition of the envelope, its structure and cladding; the proposed designs would be constituted by particular dual combinations of cladding, and would use the intermediate void to place the structure [FIGURE2], assuming at the same time that all possible configurations would offer the possibility of permeability, would allow for the use of vegetation, be made out of recyclable or renewable materials, and built from prefabricated components for easy and rapid assembly or disassembly.

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Figure 4
Surface morphology and size

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Figure 5
Relative position
DEFINING THE MODEL

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 eight design parameters whose functional and technological behaviour could be importantly influenced by their geometrical configurations.

As discussed above, the design parameters were circumscribed 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 [FIGURE3] 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 spread sheet, were 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:

**General Parameters**

These parameters define the general shape and conditions of the building envelope in terms of morphology, position 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 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.

**Structure parameters**

The lattice type has direct implications for the structural work, the construction process and particularly on the panelling 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.

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.

Defines the profile shape, depth and plate thickness used for the structural configuration of the structural system

**Cladding parameters**

Cladding parameters define how the system interacts with the surround environment surrounding the surface level, determining the types and levels of energy exchange of various kinds.

The physical configuration 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 Assuming as appropriate to include 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 to use vertical panels.

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.

**DESIGN GENERATION AND APPLICATION**

**Pre-evaluations as second level design assumptions**

The designs were analysed in terms of their performance as climatic barriers and providers of comfort.
For that we carried out temperature, lighting and ventilation evaluations using the software packages Ecotect and Design Builder [FIGURE 11]. The impact evaluations have been realized against the reference model as implemented in almost all of the constructions in Girardot: plastered or face brick facade and flat roof in concrete or fibro-cement. 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 performant 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

Figure 11
Examples of geometrical configurations produced from the parametric definition, and CFD analysis of an application to the selected building, half with the original cladding, half with a generated system using non coplanar elements in clay. The simulation for the 21st of June (hottest day) indicates a 4°C temp. difference in favour of the generated solution.
comfort from the interior of 10°C in the warmest
day and ≥5.8°C in 75% of the days. The generated
models were adapted to the particularities of such
materials-components.

**Particular application and performance simulations**
Using the material assumptions discussed above, the
parametric model is being used to “fine tune” the best
geometrical attributes to design a particular case, be-
ing 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 configura-
tions given by the proposed parametric definition.

**CONCLUSIONS**
This paper presented a particular case where para-
metric design definitions assist the development
of a research project that looks for appropriate
envelope solutions for buildings in hot and hu-
mid climates. The process involved the selection
of geometrical 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 if there is wide scope to de-
velop the processes involved in the generation and
evaluation of the designs carried out as part of the
present research, there are already results that can
guide the 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 processes.

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