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Parametric Urban Comfort Envelope An Approach toward a Responsive Sustainable Urban Morphology

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***Abstract*—**By taking advantage of computer's processing power, an unlimited number of variations and parameters in both spatial and environmental can be provided while following the same set of rules and constraints.

This paper focuses on using the tools of parametric urbanism towards a more responsive environmental and sustainable urban morphology. It presents an understanding to Parametric Urban Comfort Envelope (PUCE) as an interactive computational assessment urban model. In addition, it investigates the applicability potentials of this model to generate an optimized urban form to Borg El Arab city (a new Egyptian Community) concerning the human comfort values specially wind and solar envelopes. Finally, this paper utilizes its application outcomes -both visual and numerical- to extend the designer's limitations by decrease the concern of controlling and manipulation of geometry, and increase the designer's awareness about the various potentials of using the parametric tools to create relationships that generate multiple geometric alternatives.

***Keywords*—**Assessment model, human comfort, parametric urbanism, sustainable urban morphology.

I. Introduction

NOW, More than ever, as design enters the world of science, or as science enters the world of design, a harmonious mix of both processes is needed. Involving Parametric Design and Parametric Models within the design process in the early conceptual stages will affect the whole process and enhances the final product as the parametric tools empower the designer beyond the traditional framework of manual design.

Urbanism, by nature, operates with massive dynamic urban data. For that, various urban code systems have been implemented for data registration. However, compared with the huge amount of data accumulated, the capacity of processing and cross breeding these data is rather limited. This problem starts to become more crucial with the switch of urban planning culture from top-down towards bottom-up approach, which regards the urban fabric as a self-organizing complex system that exhibits great complexity and huge amount of internal interactions. Under this light, new urban question is legitimated: if it is possible to construct a common platform to cross breeding different kinds of urban data using computational and parametric techniques [1]?

Furthermore, the process of urban design involves working with quantitative parameters that define elements constituting the design (e.g. buildings, open spaces etc.) and relations between these elements. In order to find an optimal solution for the configuration and arrangement of these elements, multiple scenarios must be generated and evaluated. Using parametric design methods it is possible to declare parameters of the elements. By assigning different values to the parameters one can generate different configurations [2].

Reference [3] the author outlined that the parametric approach to urbanism is the *deep rationality* of parametric design by involving several parametric levels to produce powerful urban effects. Accordingly, the parametric approach to urbanism is defined as the ways in which associative design systems can control local dynamic information to affect and adjust larger urban life-processes by embedding intelligence into the formation, organization and performance of urban spaces, uses, activities, interfaces, structures and infrastructures [4].

Thus, parametric urbanism is based on parametric design systems, in which the parameters of a particular object are declared, and not its shape. In this context, the focus of interest is not the form itself, but the parameters which have generated them. Originally developed in aerospace and automotive industries, these technologies have presented a strong impact in the architectural design process, especially for improving the design of building components. In the last few years, parametric design techniques and technologies have been transferred to urbanism, in particular, to large scale urban design, as parametric design systems enable the generation of different alternatives of design by the adjustment of parameters [5].

This paper introduces an application on the interaction between parametric urbanism and environmental design. An application urban designer can use to direct the urban development to be more responsive in terms of environmental aspects, by helping designers in the conceptual phases to choose the optimum design scenario instead of generating a single snapshot by the traditional methods of urban design without exploring other possible solutions.. In addition, this application is reinforced by synchronizing it with real world

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implementation to elaborate on the potentials of parametric urbanism.

II. Problem

Traditionally, urban plans and detail plans have been developed with rigid and definitive design systems. To deal with the complexity and change that characterize contemporary urban societies a more flexible approach to design is required [6].

As a result, computers were needed to manage and express the increasing complexity of factors that affect the environmental optimization process of the urban morphology. In designing, a multitude of requirements and constraints have to be observed, that can often overwhelm designers. There are some problems whose complexity, level of uncertainty or range of possible solutions require a synergic relationship between the human mind and a computer system, while it is considered inapplicable for architects and urban designers to achieve the urban sustainability without using digital methods such as, simulation, evaluation or measuring the performance of the built environment to reach the human comfort values through indoor and outdoor spaces.

Accordingly, the *problem* of this paper is stated as following; the traditional tools of dealing with the complexity of parameters controlling the environmental aspects of urban morphology are no longer able to give the optimum design solution because they are considered static tools. Therefore, it is essential to consider a set of rules, parameters and generators during the design process that cannot be optimized, unless using dynamic computer systems represented in parametric urban models with a multi-criteria approach.

III. Why Urban Morphology?

As the majority of previous quantitative environmental studies in architecture and urbanism have mainly focused on isolated or relatively small clusters of buildings (microscopic level); it is advisable to look at the built environment as a whole (macroscopic level), especially the intermediate scale corresponding to the neighborhood or the morphology of a city block, in terms of efficient environmental and sustainable management and assessment [7].

Therefore, as difficult as it is to describe and to simulate the interactions between urban morphology and climatic conditions, at the microscopic level, in particular because of the complexity of the frame geometry, it seems attractive to work at a macroscopic level, allowing to get away from local heterogeneity, and to consider large enough volumes and mean effects of the interaction between urban shape and microclimate [8].

IV. Parameterization of The Urban Morphology

Optimum building forms vary according to climatic parameters and can have a profound impact on the form of urban spaces. In all climates, building design should aim to maximize day lighting, energy conservation, and shelter (solar or wind shelter, depending on the climate). In general compact building forms are preferable. By minimizing the surface to volume ratio, heat losses and gains can also be minimized [9].

V. Parametric Approaches of Urban Morphology

There are two primary approaches to the parametric and quantitative study of the urban morphology in terms of climatic aspects [7].

A. Morphometric Method

This method requires the advanced computation of geometric parameters through the analysis of urban statistical databases. Normally, databases containing information on shape, size, height, attribute, and arrangement of roughness elements such as buildings and vegetation are required for computation.

B. Morphologic Method

The *morphologic* method to study urban morphology relies primarily on the visual inspection of urban databases or aerial photography.

This paper has a scope limited to apply the first method only as it deals with the physical parameters of the urban morphology in order to constitute vibrant and desirable urban spaces throughout achieving the human comfort values by manipulating the geometrical aspects of the built environment.

VI. Components of an Environmental Parametric Urban Model

There are four main components that has been deduced by analyzing the previous implementations of parametric urbanism; and the traditional methods of generating urban morphologies based on environmental consideration. These components are used to construct an environmental parametric urban model as shown in Fig. 1.

A. Generators (constraints)

There are many quantitative factors to be considered in the urban design process. Zoning; program; density; solar gain; shadow projections; wind velocity, location to city service points for energy, water, and waste collection; traffic flow and projected economic revenue are just a few of the factors involved in the process [9]. In the parametric environment these factors are considered generators, as they are the environmental aspects the urban designers need to consider while applying the parametric approach to create environmental urban morphology. These aspects vary according the climatic differentiations of every site location. In this paper, a specific site is chosen which locates in a *hot-humid* environment.

B. Parameters (variables)

Computer-based analysis techniques and methodologies are applied to various datasets, including digitized buildings, land use/land cover, and other essential datasets for urban morphology. This effort uses a database of urban morphology parameters as following [10]:

1) Mean and standard deviation of building height and

vegetation height.
2) Building height histograms.
3) Area-weighted mean building height.
4) Area-weighted mean vegetation height.
5) Surface area of walls.
6) Plan area fraction as a function of height above the ground surface.
7) Frontal area index as a function of height above the ground surface.
8) Height-to width ratio.
9) Sky view factor.
10) Roughness length.
11) Displacement height.
12) Surface fraction of vegetation, roads, and rooftops.
13) The orientation of streets and networks.

C. Rules (relationships)

These rules can be established be linking addressed environmental generators by the designer with the desirable physical parameters in order to generate the optimum design solution regarding to the environmental performance. Parametric design sets up measurable factors of rule-sets to determine behavior. Within architecture, these rule-sets can be; program, site, exposure, views, floor to floor heights; or a curricular diagram [11].

Within each rule-set, parameters are established and a bandwidth of outcome is introduced. No single rule-set typically regulates until the author gives authority to one over the other. These rule sets can be either co-dependent or isolated from each other. The more overlap and co-dependency that exists the more integrated the outcome. Throughout this paper we will situate the parametric processes as a series of questions and not a formal driver or generator. This methodology establishes an emergent set of relationships removed from preconceived notions [11].

D. Tools (indicators)

Urban designers and decision makers, when faced with the task of designing urban morphology that is desirable and thus used rather than abandoned, will be better informed with a predicting tool that allows various design alternatives to be compared and tested in terms of attractiveness and effectiveness. In particular, a testing tool is needed that can provide both quantitative and qualitative understanding of the relationships among microclimatic environment, subjective thermal assessment, and social behavior [12]. Such a tool should have the ability to process detailed environmental information according to time and location variations and to generate analytical results to reveal the relationship. Environmental modeling tools such as Solar Envelope and Wind Tunnel analysis can provide an understanding of climatic conditions [12]. However, three types of indicators that can be used separately or combined together to better simulate and optimize these environmental parameters during the urban design in a computational environment

1) Scriptive Models, which is based on generating design options from using scripting languages. The designer in these models is designing a design system which can be based on a previous successful implementation by deducing its formula or script to reuse it again in further projects to achieve the same results.
2) Numerical Models, which is based on numerical equations as the design rules. These models in used in the mathematical approach of parametric design which depends basically on mutation formulas. This method is usually used in the evolutionary urbanism.
3) Visual Algorithms, which express the power of algorithms in a visual interface. Thus this type is considered the most practical for the majority of urban designers, as it doesn't need a previous knowledge on scripting languages or physical and evolutionary equations.

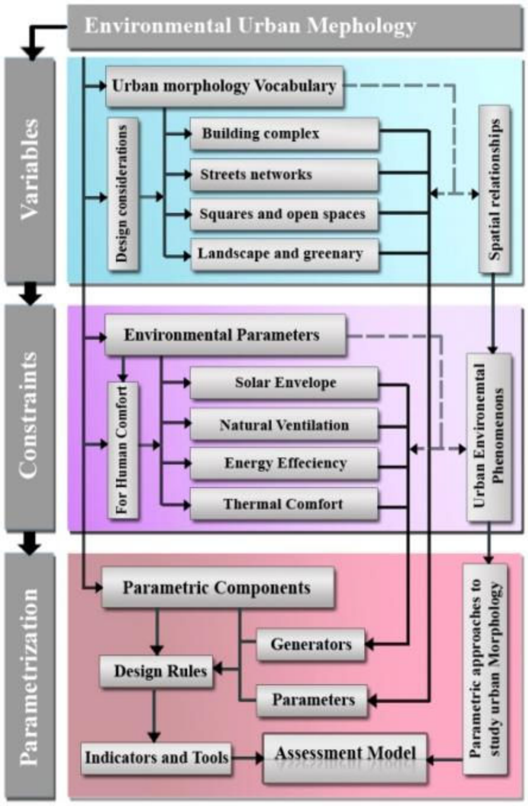

Fig. 1 The process of constructing a parametric assessment model for environmental urban design to achieve human comfort

VII. Parametric Urban Comfort Envelope Concepts

The parametric urban comfort envelope (PUCE) is a dynamic tool to help the urban designers and town planners during the decision making process to generate a more responsive environmental urban morphology, by taking advantage of the parametric potentials embedded in; the graphical algorithms such as Grasshopper; and the simulation tools such as Project Vasari.

PUCE is an assessment model in which the urban designer can enter rules to associate any changes in the physical urban fabric with achieving certain environmental qualities to ensure the human comfort values. In particular, the solar envelope analysis to ensure solar access and the optimum distribution of the natural ventilation. These concepts are introduced in detail in Fig. 2.

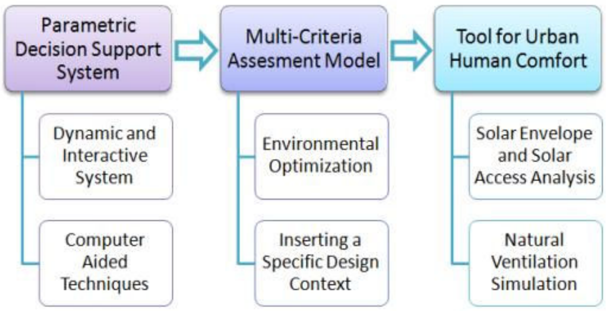

Fig. 2 The Primary concepts of the parametric urban comfort envelope (PUCE)

VIII. Parametric Platform of PUCE

Considering the above mentioned concepts, a parametric urban assessment model has been created using a NURBS-CAD environment using a parametric programming interface. The CAD environment used for this purpose was Rhinoceros® and the parametric interface was Grasshopper®. In addition, a simulation tool was used for wind analysis which is Project Vasari®.

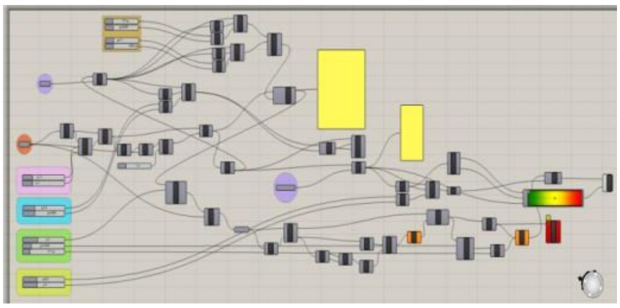

Fig. 3 Snapshot from the graphical algorithm in Grasshopper® used to generate the urban block in the case study of the application

Regarding the parametric approaches of the PUCE assessment model, this is defined using a diagram Fig. 4 that has been done by the first author based on previous research to explore all the different interaction between parametric design and urbanism showing that the designer will consider using the associative and performance-based parametric approaches to reach environmental qualities in the optimization stage; and to insert a specific design context in the optimization stage of the design process.

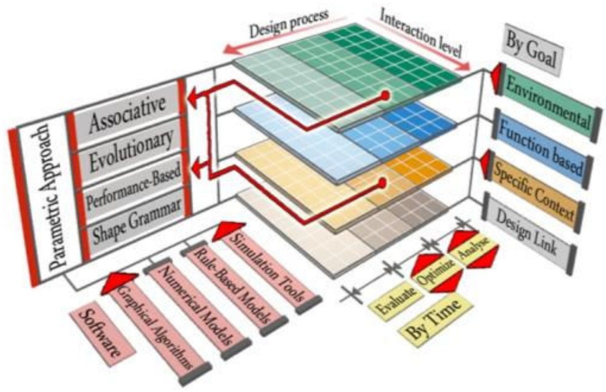

Fig. 4 Defining the parametric approaches and tools used in PUCE model to achieve the intended objectives

IX. The Case Study

A. Analyzing the Existing Condition

The current building regulations in Borg El Arab city are causing the urban design to be a rigid and static process, mostly, because every building block has to imply to the same fixed set of rules. As a result, the urban morphologies produced by these rules are suffering from a notable lack of environmental considerations and a harmonious distribution of land use.

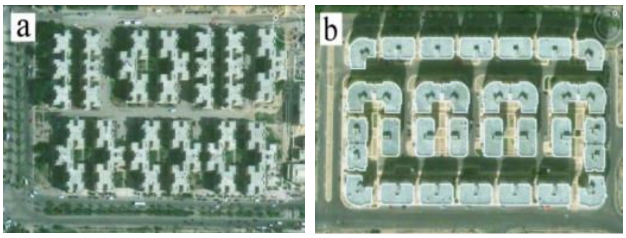

Fig. 5 Case studies (a) and (b) are two examples of the analyzed existing residential typologies in Borg El Arab city

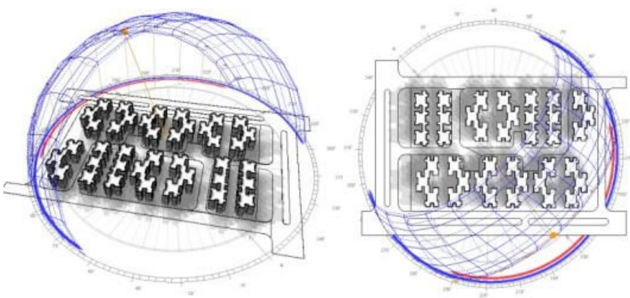

Fig. 6 Simulating the shadow range of case study (a) in the critical hours during daytime by using Ecotect® to measure the solar access to all building blocks

By analyzing examples of the existing residential typologies in the city as shown in Fig. 5 using climatic simulation tools such as; Ecotect® for solar access analysis Fig. 6, and Project Vasari® for wind quality analysis Fig. 7, it has been concluded that they aren't achieving the optimum environmental performance.

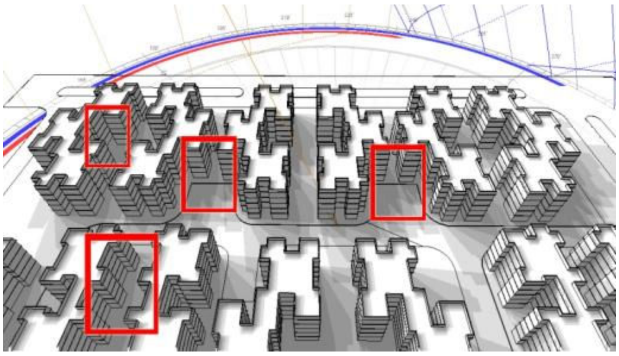

Fig. 7 Studying the shadow range in winter solstice from 10:00 to 14:00 O'clock, it can be proved that the existing fabric doesn't achieve the optimum solar accessibility in all building blocks as shown in the highlighted zones

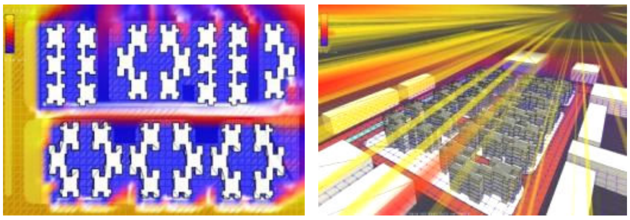

Fig. 8 Using Project Vasari® for wind analysis to show that the existent morphologies don't produce a proper distribution to natural ventilation within this existing buildings typology

From the above analysis of the existing condition, there was a great need for a more dynamic and interactive design methodology to be undertaken, a methodology allows the designer to associate any changes in the geometrical parameters with environmental performance of the final morphology, especially the human comfort values.

B. Deducing the Parametric Components

From the above analysis of the existing condition, there was a great need for a more dynamic and interactive design methodology to be undertaken, a methodology allows the designer to associate any changes in the geometrical parameters with environmental performance of the final morphology, especially the human comfort values.

The parametric components that have to be outlined in any parametric urban model are; the design generators (constraints) and in this case they are environmental generators; the parameters (variables) and in this case they are geometrical and functional parameters; the design rules which determine the relationship between the generators and parameters; and finally the tools and indicators used to construct this parametric model Fig. 1. In this case study, these components are outlined in Table I.

TABLE I
PARAMETRIC COMPONENTS USED TO APPLY PUCE MODEL

Component	Description		
Generators	Construct Solar envelopes to ensure solar access in indoor and outdoor spaces.	Create variation in building heights for natural ventilation.	Color map zoning for land use distribution.
Parameters	Position of city center point which has the maximum building heights and land use.	Position of FAR scaling point which is controlling the block size in the pattern.	Optimization to reach the maximum buildable volume.
Rules	Generate the block subdivision pattern and create attractor points to control the geometrical changes in design.	Associate solar envelopes automatically with any changes in the geometric or physical parameters.	Eliminate design scenarios with negative wind effects.
Tools	Using Voronoi method in Grasshopper® to create the desired pattern to fit with the existing network.	DIVA-for-Rhino® will be used to generate solar envelopes in a time range.	Project Vasari® will be used for wind tunnel simulation and analysis.

X. THE ASSESSMENT PROCESS

From the above mentioned concepts of PUCE assessment model, the assessment process consists of six main steps. Using the morphometric method to suit a particular physical design context with consideration to the environmental performance based on a multi-criteria method by dealing with more than one parametric approach and development goal to ensure the human comfort in the final design development. These steps and their deriving factors and tools is outlined in Fig. 5.

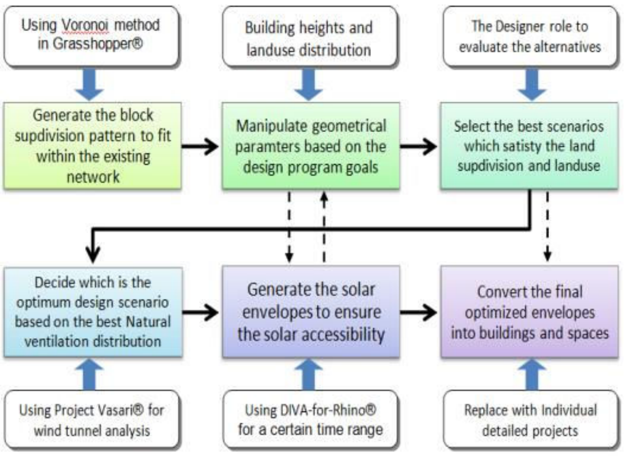

Fig. 9 Six simplified steps to generate the maximum buildable volumes for a certain design program in a responsive method with the environmental performance to achieve a sustainable neighborhood

XI. Applying The PUCE Model

Therefore, a specific site has been chosen in Borg El Arab city within the existing urban fabric with a total area of 270 acres Fig. 10. Then a design program has been assumed to be applied in this site to absorb a new mixed-use neighborhood that consists of residential, commercial and business typologies. According to the total area, the expected population is 10000 residents.

The general characteristics of this neighborhood have been derived from a previous application conducted by the authors in [13]. However, the main goal of the design program is different from this application. In this case the goal is to reach the maximum buildable volume which achieves the optimum environmental performance in a hot-humid climate, through associating any change in the physical geometry with the solar access and natural ventilation aspects to achieve human comfort.

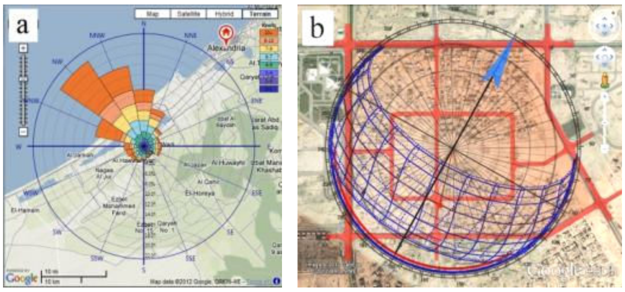

Fig. 10 The weather data of Borg El Arab city, (a) the wind rose analysis, (b) the annual and daily sun paths

After selecting the site location of the case study and gathering all the required data through site analysis and site inventory Fig. 10. Thus the six steps of the assessment model has been applied as shown in Fig. 9.

A. Step One

The Voronoi pattern system is presented as a method for parametric street network generation and block subdivision in Grasshopper. This system depends mainly on the distance between two points to vary the block size and shape through considering the center of each block as the first point and the neighborhood center as the second point. This method enables the designer to emerge his design goals and regulations with dynamic and parametric street and block generation.

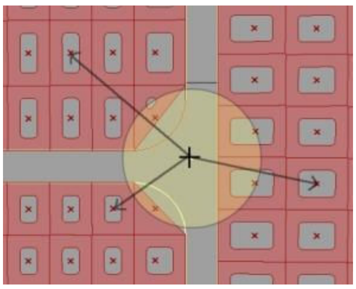

Fig. 11 Creating design rules through defining an attractor point to vary the land plots using Voronoi system

B. Step Two

In this stage the design rules should be outlined to satisfy the goals of the design program. These set of rules will manipulate the geometrical parameters to be associated later on with environmental parameters. The output of these rules should be a harmonized urban fabric with differentiation in building heights (maximum allowed number of floors), Floor Area Ratios (FAR) and land use distribution (color code). To simulate the effect of these differentiations, this output is presented in a distribution of uses or functions per block visually defined with colored block envelopes and pie charts for the numerical results of the total buildable volumes of each use.

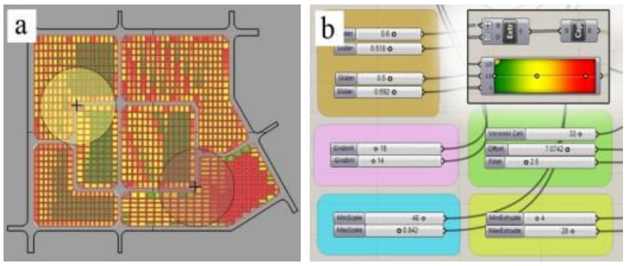

Fig. 12 (a) changing the attractor points' positions to reach the desirable results, (b) manipulating the geometrical parameters of the urban morphology and varying the assumed color gradient for the landuse distribution

C. Step Three

This step depends mostly on the designer role to evaluate the generated solutions by the parametric tools from the aforementioned steps to decide which of these solutions best fit with the design program goals, and in some cases the designer might need to manually manipulate the parameters to fine tune the output. For this purpose the 3D model shows graphic outputs of the parameters for designer visual assessment. Any change applied to the model including changing the attractor points' positions will automatically update the regulations in each block. As the model provides an empirical design interface which allows designers to see in real-time what the consequences of the design changes are.

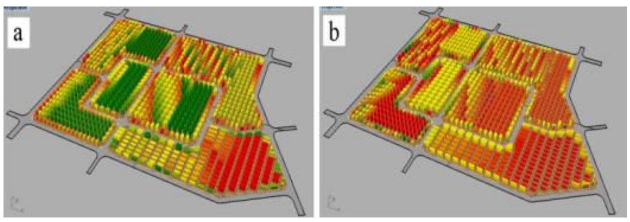

Fig. 13 (a) and (b) are two scenarios for landuse and buildings heights that satisfy the design program will be selected based on the designer criteria to evaluate the visual and numerical outputs

D. Step Four

The selected design solutions provided from the previous step will be evaluated based on the natural ventilation performance by using wind tunnel analysis in Project Vasari®. The distribution of natural ventilation will be measured to ensure the human comfort values for the wind pressure and wind velocity as it the Project Vasari enables the designer to evaluate each design alternative to decide which case achieve the optimum solution for the natural ventilation performance.

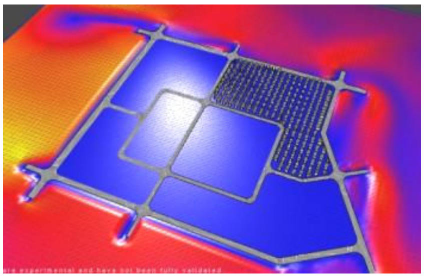

Fig. 14 Using Project Vasari® to simulate the wind behavior to evaluate the natural ventilation distribution of each design alternative

E. Step Five

In this step the parametric tool DIVA-for-Rhino® will be used to construct the solar envelopes of all the building blocks to guarantee solar access for all occupants in the critical hours of daytime by using the "*whole building"* solar envelope as a zoning policy in the design development. This will eventually result in increasing the opportunities of taking advantage of solar collectors and thus a notable energy savings.

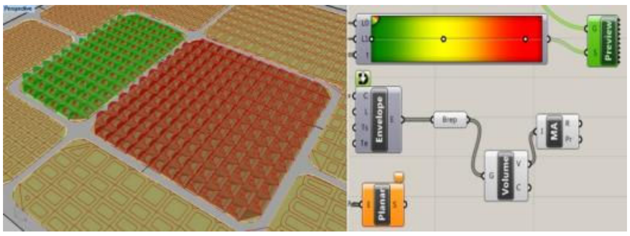

Fig. 15 Generating solar envelope using the Solar Envelope component in DIVA® to ensure the solar access to all the building

F. Step Six

In this step, the generated Solar Envelopes which are three dimensional envelopes or volumes will be replaced by buildings to guarantee the mutual opportunity for adjacent neighbors a specified minimum direct solar access time per day during the critical hours throughout the year [14]. The solar envelope of each building is considered a regulation rule instead of the existing regulation of fixed heights.

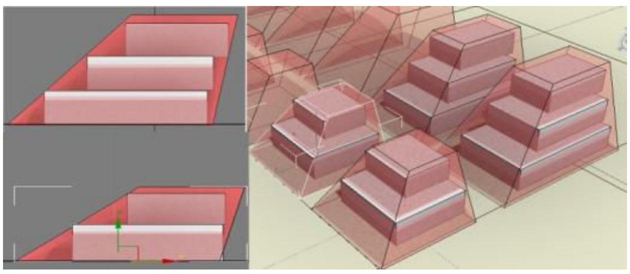

Fig. 16 Replacing the solar envelope with conceptual buildings

XII. RECOMMENDATIONS

The PUCE model is designated to enhance the environmental performance of the generated urban morphology to reach the optimum human comfort values. However, the parametric tools used to demonstrate the model's abilities were limited to simplify the operation and focus mainly on presenting the core concept of this research.

Hence, this model has more to offer the designer during the decision making stage regarding to the environmental optimization or the accuracy of the final results. As the software used to conduct this model have more tools that can expand the potentials of model notably. These additional potentials can be presented by pointing to the further tools that is already available in the software. Moreover, the link between the software used in the model and other software can be considered as further capabilities for the model. Therefore, these potentials are recommended as following:

1) Inserting the evolutionary power of the Galapagos® tool in Grasshopper® for optimizing the resulted design scenarios instead of designer preferences which can't be always accurate enough.
2) Using the additional library in Grasshopper for pattern and block generation to produce more pattern options besides the rectangular pattern such as the radial patterns and the recursive patterns.
3) Taking advantage of the thermal and energy analysis in Vasari® to include all the aforementioned environmental parameters that can control the human comfort.
4) Applying the Solar Fan tool in DIVA® to generate solar envelopes for squares and green spaces.
5) Linking the model with geospatial, demographic, traffic, economic data derived from GIS maps that can provides the trace of activity and event parameters of the urban life process.
6) Converting the generated design scenarios into physical models using 3D printers to be presented for evaluation by the future occupants to encourage the public participation in the decision making process of urban design.

XIII. CONCLUSION

In this paper an interactive decision support system has been structured providing the most common features for creating an environmental sound urban morphology for the scale of a small neighborhood. The system offers a parametric driven manipulation of a design whilst providing density measures about the total buildable volumes for a better assessment of the economical qualities of the proposed design. This assessment was based on commonly used urban indicators and parameters such as building heights; block size and buildable volumes, in order to provide a measurable comparison between the traditional methods and the proposed new method using the parametric tools. Thus, the paper has managed to highlight the importance of considering the parametric tools during the urban design process. particularly when optimizing the environmental performance to achieve a sustainable urban morphology.

Obviously, the benefits of such a system in the urban design process are, once the rules or relationships have been calibrated, different design options can be explored through the manipulation of parameters or inputs which generated through the system software, making it responsive, quick and dynamic to evaluate and explore varying design options, alternatives and *"what if?"*scenarios.

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