AN URBAN FORM-FINDING PARAMETRIC MODEL BASED ON THE STUDY OF SPONTANEOUS URBAN TISSUES

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Abstract. This research paper investigates the peculiarities of unplanned urban fabrics known for developing in a spontaneous way. By studying the characteristics of their urban form, a set of rules, functions, and objectives used for an experimental urban form-finding model are explored. Based on these features, the development of a parametric model seeks to grasp certain characteristics of spontaneous urban tissues in old Islamic cities and incorporate them into an experimental social housing proposal. By the use of genetic algorithms, the model aims to offer better adaptability and more diversification which will be to while still keeping a degree of preservation to the distinctive aspects that define those settlements. The use of a genetic solver is expected to be a problem-solving method that can simulate and offer a wide range of objective-based spatial that are considerably adaptive to particular urban contexts. In this study, we discuss the defining aspects and constituents of the urban form of these settings before interpreting them into algorithmic components to be incorporated in a parametric model.

Keywords. Spontaneous Urban tissues; Urban form-finding; Genetic algorithms; Islamic cities; Multiple-objective optimization.

1. INTRODUCTION

An urban fabric could be considered as being similar to a living organism that is made up of an aggregation of intertwined and consolidated spatial components: It finds its morphological expression in its spatial layout, road networks, the typology of buildings, and the relationship between its public and private spaces. This research finds its footing on the basis of observations of unplanned urban developments in old North African Islamic cities, namely in Morocco. In the case of Moroccan medinas (historic North African quarters enclosed by a wall), these spontaneous urban tissues are characterized by their adaptability and incremental evolution through time without the intervention of any formal urban design as it is known today. Even though Moroccan medinas such as the medina of Fez City is nowadays mostly constituted of old and saturated urban tissues, its space is a historic telltale of city growth that reflects a local social and cultural identity to north African settlements (Bianca, 2000). While at first glance, the medina

of Fez may seem as simply like a manifestation of a chaotic and disorganized development that echoes an apparently aimless labyrinth, but a set of fundamental principles of Islamic culture actually defines its space, consequently making it more representative of an organizational logic to which its urban space abides by. This is especially evident when considering that north African countries, which share mostly the same socio-cultural and environmental setting, and hence the same set of spatial organization principles, have an essentially similar urban morphology (O’Meara, 2007).

1.1. BACKGROUND

The spaces that are produced by different types of societies follow different types of organizational logic, which in turn lead to the creation of distinct spatial patterns (Hillier et al, 1984). This assertion is especially relevant in the case of spontaneous urban settings, which are composed of the incremental aggregation of physical elements in a scalable sense. Accordingly, the medina-type city is produced in an intuitive albeit procedural manner. Describing a Moroccan medina is no easy task considering its morphological dimension is deeply entangled with a set of fundamental political, religious and cultural guidelines, that define the logic of its space (Duarte et al, 2006). Indeed, This type of traditional urban fabric reflects a living style that is ordered around the spatial interpretation of Islam, and the adaptation to local environmental and social factors. Blocks can be described as being of irregular shapes yet very compact in nature; they are also open on the inside through the use of interior courtyards that play a double role of preserving privacy and moderating the environmental comfort inside buildings. In this way, the individual and collective elements that compose the city are carefully articulated around locations of key interests, of which places of worship or of political power play a prominent role. The aggregation of other vital quarters that contain places of commercial and craft activities is also given certain close attention. For example, according to sanitary concerns, there can be a requirement for a degree of disconnect between areas that harbor certain types of commercial or manufacturing activities (e.g tanneries) and places of worship (see Figure 1).

Figure 1. Typical organization of a medina-type city (Left); High-density courtyard morphology of the medina of Rabat (Right).
The seemingly labyrinthine urban morphology of Moroccan medinas is established with an organizational layout that is essentially characterized by bare, continuous walls (see Figure 2). This physical separation is in turn defined by the basic element that is the housing unit, or “dar” in Arabic, which can be considered as being the fundamental unit or cell that in its aggregation defines the urban morphology. Coupled with a variety of other units such as alleys, neighborhood types of facilities etc. a diversification of shapes and functionality can be achieved. The interaction between these basic elements on a smaller scale is what allows for enough complexity for a larger scale urban coherence (Nikos, 2000).

1.2. STATE OF THE ART

In recent years, a number of researches discussed the subject of urban-form definition through the use of objective-based algorithms. One of the first projects to consider an urban form-finding model through an objective function algorithm is the Induction Cities project’s “Sun God City” (Watanabe, 2002) where an algorithm generates a cityscape that is optimized for sun exposure. A later study established an urban shape grammar that encapsulates the street layout structure and the patio-type housing units of the medina of Marrakech (Duarte et al, 2006). While the outcome was to develop an algorithmic model for housing in Islamic contexts which synthesizes the medina’s morphology, the focus was mostly on reproducing the said morphological structure rather than creating a model that interprets it for adapting to different conditions. Another study focusing on self-organized Architecture for housing (Ikeda et al., 2006) relied on the use of 3D cell-automaton to analyze and rearrange generated self-organized geometrical components. This form-finding methodology evaluates and optimizes the urban shape in the face of changing factors. It is also important to note recent research that focuses more on the methodology of genetic algorithms in the exploitation of objective fitness and the exploration of variation in urban form generation (Mekki et al., 2018) while taking into account a superblock of the ancient city of Fez as a base generic module for variations. While being part of this continuity of researches that approach the urban form question through genetic algorithms, our research takes the context for Moroccan traditional cities as its main focus. Thus, it explores context-specific characteristics to be incorporated into an adaptive methodology for the definition of the urban form.

1.3. PROPOSED APPROACH

Nowadays, cityscapes are often designed in a way that leaves little room for adaptability and diversification, though cities are still intrinsically a spatial expression of an evolving social complexity that manifests differently through time. Consequently, this research defines its main purpose as developing an approach for conceiving a city that can take into account dynamism and changeability. Indeed, one of the main features that can be observed when studying intuitive urban tissues is that they are highly adaptive to the evolution of social needs and environmental constraints. Such an approach, by offering a degree of flexibility, will allow users, to find, through a trial and error process, solutions
that address their issues by self-organizing and changing the usage typologies of the urban space. This process is done while always keeping in mind a number of social and functional directives that could be considered as flexible rules.

Although experimental, the use of self-organized models in architecture has thus far allowed for the development of rule-based forms that can allow for bottom-up design (Narahara, 2008). The application of such methods allows decentralization of the organizing system that favors the creation of spontaneously generated structures by way of feedback loops. This system can be especially fitting for our case, considering that our study is based on spontaneously developed urban tissues that have a tendency to build up from local interactions to form a global structure. Through the simulation, the algorithmic model should consequently show a suitable degree of responsivity in a dynamic setting. This capacity for the system to self-organize is described with three typical features.

- **Adaptability**: it reflects the ability of the system to be resilient in the face of both context-specific constraints and dynamic change. This proves the system strength as it allows to achieve the objectives in a variety of conditions.
- **Flexibility**: it expresses an intrinsic allowance for transformation which grants the system enough stability against complex constraints.
- **Diversification**: it indicates the capacity of the system to offer substantial variation in its spatial solutions. This capacity can not only increase the other characteristics but also ensure that there is enough interactivity between components of the system on a lower level to allow for the objectives to be attained on the whole.

### 1.4. RENDITION AND USE

On the basis of all of the above, the simulation will adopt a construction method that allows for diversification through standardized components. This can be achieved with the use of prefabricated modules that can be arranged in different possible combinations to form a variety of urban entities, thus aiming to create diversity through different forms of aggregation of the same basic unit (cf. cell and tissue). By being the smallest component of the system, those modules will be an interpretation of the dar, that when assembled together show a capacity for the system to adapt through bottom-upping. As for the plot definition method, it will have to allow for urban geometries with patterns that reinterpret the contiguous configuration of the medinas.

However, in order to refute any arbitrariness, it is necessary to evaluate the system behavior to assess the solutions adaptability. Accordingly, for our case, the use of an algorithm that applies a multi-agent genetic solver is deemed relevant to simulate an urban form-finding model for high-density, module-based housing.

### 2. THE EXPERIMENT

#### 2.1. CASE STUDY

The use of genetic algorithms has shown itself to be a promising way to solve constraints related to social housing layouts (Aksoy et al., 2014). For this research
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to be practical, the model was applied to a case scenario of social housing which provides a set of specific social, environmental and spatial constraints to be taken into account. This case takes place in the slum known as “Douar Al Garaa” in Rabat, Morocco. The reason for choosing this specific site is threefold. First, the slum is well integrated into its surrounding urban fabric that is comprised of the “Habitat Marocain” type of housing (Navez-Bouchanine, 2000), which is a modern economic housing typology. Second, by observing the spatial morphology of slums in Morocco, parallels can be drawn between its urban morphology (see Figure 2) and that of traditional medinas; although it was initially planned in a modern way, the organic nature by which urban growth is achieved in a spontaneous way, as well as the high density and intricacy that result from the incremental nature of its buildings, are some of the key points of analogy. Finally, strong demand for an on-site rehousing solution has been expressed by the inhabitants; in this way making it a fitting scenario for our experiment (Cheddadi, 2018).

![Figure 2. Street in Douar Al Garaa (Left); Bare-walled street in the medina of Marrakech (Right).](image)

2.2. SPECIFIC CONSTRAINTS AND PROSPECTS

For this case study, the solutions would have to guarantee a minimum degree of spatial comfort when compared to the surrounding urban fabric (cf. Habitat Marocain). Compared to the current situation, the improvements that this model aims to offer consist of a better ratio of public space per inhabitant, better accessibility for emergencies, both of which can be created by having a better-defined plot subdivision; an urban morphology that offers enough room for scalability since by relying on a modular and heterogeneously shaped construction approach; and also an improved environmental condition by equalization of sun exposure per housing unit.

Achieving these objectives supposes that some of the current characteristics of the site would have to be changed and others kept. The features that are kept include the locations of neighborhood equipment are landmarks for the population and also play an important role in social cohesion (i.e Mosques, public baths, water fountains etc.). Offering to house all the inhabitants also means that it will be
necessary to keep a least the same population density per surface area while also reaching for higher construction heights. However, street and plot subdivision will be changed in order to allow the algorithm enough flexibility to vary the output, as it is also an element of experimentation.

2.3. THE TOOLS
The simulation algorithm was developed with the use of Rhinoceros 3D (Rhino) and its visual parametric plugin Grasshopper (GH). Rhino was used for the CAD data whereas GH was used to establish the algorithmic workflow for the form-finding simulation by way of using a number of add-ons. The form-finding algorithm was carried out by the use of Octopus, the multi-objective solver add-on for GH, the environmental data (sun vectors) was incorporated by using the Ladybug add-on. On the basis of multiple-objectives evaluation functions, Octopus carries out an optimization algorithm that looks for the best combination of inputs to generate a best-fitting geometry (phenotype) and establishes a Pareto ranking.

2.4. SIMULATION METHOD
On the basis of the previously mentioned points, the parametric design algorithm is set to develop a self-organized model based on a number of factors including exposure to sunlight, physical accessibility, the number of floors, the urban population density and the randomness factor.

A number of GH components, which will be described in the workflow, are established as genes and coupled together with objective functions in order for Octopus to operate. The genes that are input include the random reduction seeds, the random 2D point population for plot subdivision, an integer range for plot subdivisions. As for the fixed input in the algorithm, which includes: the maximum building heights, the weather data; An integer range of population density; an integer number of fixed 2D population for plot subdivisions.

2.5. WORKFLOW OF THE ALGORITHM
Based on the aforementioned input, the GH model definition connects a number of components. We can divide these components into the following categories:

2.5.1. Plot subdivision
To subdivide the site into smaller plots, the algorithm takes its geometry as a reference before populating it with 2D points. A certain number of points are fixed as to refer to on-site neighborhood types of equipment, the rest of the points are randomly populated with a maximum cap. To ensure an organic shape, a Voronoi GH component is used to divide the plot, coupled with a surface offset that creates width for the streets (see Figure 3).
2.5.2. Grid definition
A 2D grid is mapped into the plot surfaces, its dimensions can be modified to suit different scenarios. Then, the 2D grid is coupled as an input with a height component in Z-direction that converts it to a 3D component. These represent the dimensions of prefabricated modules that are used for construction (see Figure 3).

2.5.3. Density definition
The 3D grid is connected to a Random Reduce component that deduces modules from it. It runs on two variable types of input: The rate of reduction which is the percentage of boxes to be reduced; A random seed that generates a number of user-set random factors for the random reduce component. For defining the density, two factors are taken into account. The first is the number of floors and the second is the reduction factor. The latter is relative to each floor and is not a global factor (see Figure 3).

2.5.4. Sun vectors definition
For defining the sun exposure (SE) data, the “Ladybug” environmental plugin within GH was used. The geographic weather profile for Rabat city is loaded into the GH definition in order to represent, depending on the scenarios, the sun vectors and sun path for the winter or the summer solstice.

2.5.5. Meshing and Color Mapping
To visualize SE, the resulting modules are merged and put together with a Mesh Union component (see Figure 4). The resulting meshes are then color-mapped by using a gradient component that visualizes SE by representing the exposure on any module surface throughout the day. The color gradient expresses values in a linear way by going from 1 to 10 hours of daily exposure.

2.5.6. Solver and fitness objectives
On the basis of two objective fitness functions that seek to maximize SE and accessibility (see Figure 4), in addition to its built-in diversification function, Octopus evaluates each phenotype of 3D geometry in order to seek better fitness. For this simulation, Octopus is set to a maximum of 50 generations with a population of 50 with the history option turned on.
The first fitness objective aims for better accessibility, its objective function calculates the distance between each module and the nearest street (shorter distance is better), thus evaluating the physical accessibility of each module and favoring the creation of open interior spaces. As for the SE objective function, it is set to reward the algorithm if the optimization results are equalized in a range that goes from 3 to 6 hours of sun exposure.

In order to check the reliability of the design algorithm, different scenarios (see Figure 5) were run to assess it in changeable conditions. These scenarios include different sets of density, different maximum heights and unit volumes (5x5 and 7x7 grid) and different plot numbers.

![Accessibility fitness (Left); Meshing and Color Mapping (Right).](image)

2.6. FINDINGS AND DISCUSSION

Inspection of the generation data of the Pareto front for the scenarios results (see Figure 5) indicates that the genetic solver has shown an overall potential for optimizing the urban form. As seen in the different scenarios, the generation number by which the solver reaches a stable Pareto front varies from situation to another. Judging by the nature of the genetic solver and the initial random condition by which the fitness landscape is explored, this could be considered as typical.

As was expected, higher SE scores are observed during summer, especially with a 5x5 grid. This might be due to the more intricate nature of a form generated by smaller volumes. Under similar settings, the results of simulations in which there were no fixed Voronoi points show better scores than those that do. this would suggest that more Voronoi points be dispatched by the algorithm, and subsequently, more subdivisions could be factored into having better SE and accessibility results. For the SE distribution, it seems that the result is close to expectations with a distribution approaching the bell curve in the most SE optimized phenotypes when compared with baseline results outside the Pareto front.
Analysis of the data shows that the algorithm is capable of sacrificing the global SE score for a better SE equalization result. As for the accessibility, in some cases, the algorithm might score better because there are simply fewer modules to take into account. In order to fix this issue, it would be more interesting to consider using an average score by the number of modules instead. The model has also shown a capability for resilience by withstanding unexpected changes in the results, a number of most optimized accessibility phenotypes in the earlier generations show up as empty surfaces where a Voronoi surface was not established. Although this could be considered as a limitation, Octopus has shown that it can recognize it as a non-viable solution on the Pareto front in later generations.

Overall, current results show that there is a certain lack of balance between exploration and exploitation of solutions. Indeed, the algorithm quickly favors the exploitation of better objectively fit results rather than more design variations, thus rapidly reaching its end results. This presents a certain challenge in the problem definition of the objective function in which a certain balance between exploration and exploitation should be aimed for. Although the methodology by which the simulation was approached does not necessarily reach a target solution as it continues to generate new, better-fitting phenotypes. it does show that there is potential in researching a high-density, self-organized model if the objectives of the algorithm and the variables are better defined and evaluated.

3. CONCLUSION

The use of an evolutionary problem-solving as a methodology in architecture and urban design became more prevalent in recent years. The present study follows on from these works and while not pretending to be completely groundbreaking, it finds its originality in contextualizing the problem-solving process with a cultural background study and a concrete footing in social issues. Through this experiment, contextualizing the issue meant that it was relevant to make a model inspired by
the traditional Islamic tissues, in all their intricacy and apparent randomness, while still taking into account the characteristics of modern economic Moroccan housing. Approaching the solution through a genetic solver in the form of a self-organized simulation has shown to have the advantage of offering enough adaptability and exploring a diversity of urban forms that break from the architectural redundancy of social housing. Potentially speaking, the use of modules can be a step towards achieving a balance between parametric diversity and mass production.

To better refine results, this experiment shows that further optimizations of the algorithm and studies of its behaviors under different constraints are necessary. Understanding how the algorithm works can allow for the integration of other environmental objectives such as airflow or heat island effect, thus making it more broadly adaptable. In the end, the study of self-organized architecture is more about the system-design of resilient and adaptive algorithms than it is about formulating a planning methodology.

One of the shortcomings of this research is not being able to fully take into account more of the social benefit factor of this approach, and not being able to measure it. Keeping social cohesion after rehousing the slums is what could be considered the most important factor to be taken into account besides the political ones. In future iterations of this model, we should look into methods that can keep local neighborhoods well-articulated and organized even after redefining structural subdivision factors such as the streets layout or facilities locations. In later iterations of the model, better defining the algorithm objectives also means to maximize social interactions through the connection between private and public space, while still keeping a certain degree of privacy that defines the principles of Islamic housing.

References

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