AN URBAN GRAMMAR FOR THE MEDINA OF MARRAKECH

Towards a Tool for Urban Design in Islamic Contexts

JOSÉ P DUARTE GONÇALO DUCLA-SOARES AND LUISA G CALDAS
Instituto Superior Técnico, Portugal

AND

JOÃO ROCHA
Universidade de Évora, Portugal

Abstract. This paper describes research carried out to develop a parametric urban shape grammar for the Zaouiat Lakhdar quarter of the Medina of Marrakech, in Morocco. The goal is to create the basis for a system that could capture some features of the existing urban fabric and apply them in contemporary urban planning. The methodology used is described, from the initial historical analysis and fieldwork to the identification of three sub-grammars necessary to encode the complexity of the urban pre-existences: the urban grammar, the negotiation grammar, and the housing grammar. Top-down and bottom-up approaches to grammar design are analyzed and compared. The bottom-up urban grammar developed is then described, and a hand-derivation of the existing urban fabric is proposed.

1. Introduction

This paper describes research carried out to develop a parametric shape grammar able to capture, and replicate in a different context, some of the urban, architectural and morphological characteristics of the ancient fabric of the Marrakech Medina, namely its Zaouiat Lakhdar quarter. This research is part of a larger project that aims at incorporating shape grammars (Stiny and Gips 1972) with an existing generative design system based on genetic algorithms. The project's final goal is to develop a computational system able to generate novel urban and housing configurations that are more sustainable and energy efficient, while respecting certain cultural and spatial, as captured by the shape grammar. The final computational model should act

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at two different scales: the urban scale, where the layout of an entire neighborhood is outlined; and the architectural scale, where the interior organizations of individual houses are defined. The research described in this paper is focused on the development of a shape grammar to describe the urban features of the specific quarter of the Marrakech Medina referred to above.

The reason for choosing the Marrakech Medina as the case study for this experiment was threefold. First, this particular urban fabric was attractive because of the intricate connections between the urban configurations and the patio houses, Figure 1. Second, previous work (Rocha 1995) on the Zaouiat Lakhdar, aimed at characterizing morphologically and architecturally the urban and architectural patterns of this area, suggested that a stylistically coherent corpus of designs existed and that it had enough variety and richness to fit the research objectives. Third, the population increase that occurred in Marrakech during the last decades, as in most North-African and Middle-Eastern cities, has led to an uncontrolled urban growth that produced urban environments lacking the spatial richness found in historical vernacular districts. Thus, this research intends to provide a computational framework that can assist designers in the design of urban environments that maintain traditional spatial and compositional principles while satisfying the requirements of modern life.

This research draws on previous implementation of a generative system using genetic algorithms (Caldas 2001) and on the application of shape grammars to customized mass-housing (Duarte 2001), but the work presented here takes the Marrakech Medina as its architectural precedent.

2. Historic and Cultural Context

Cities of Muslim origin, such as Marrakech (13th century), share specific culture and social values which are embedded in their everyday system of social organization, and therefore, in architecture as well. In this section, we identify and put forward a succinct contextualization of these cultural and religious values, which have to be taken in consideration in any interpretation of Islamic architecture. Social and cultural characteristics of urban planning and architecture, as well as many aspects of Islamic social behavior are related to the Islamic law, shari´ah, and certain principles found in urban environments of Islamic cities are a tribute to shari´ah. They are clearly founded in the basic source of the shari´ah, the Qur´an and the sunnah (life of the prophet), while others stem from traditional building codes related to, inheritance and endowment laws.

This set of religious public values and rules determine many of the social patterns of Islamic society and its urban and architectural spatial configurations. An utmost Islamic condition is that a strong social relationship is underlined by the concept of brotherhood, which has frequently been mentioned in the Qur´an, and that family is the most fundamental element of Muslim society where strong family ties are expected to last.

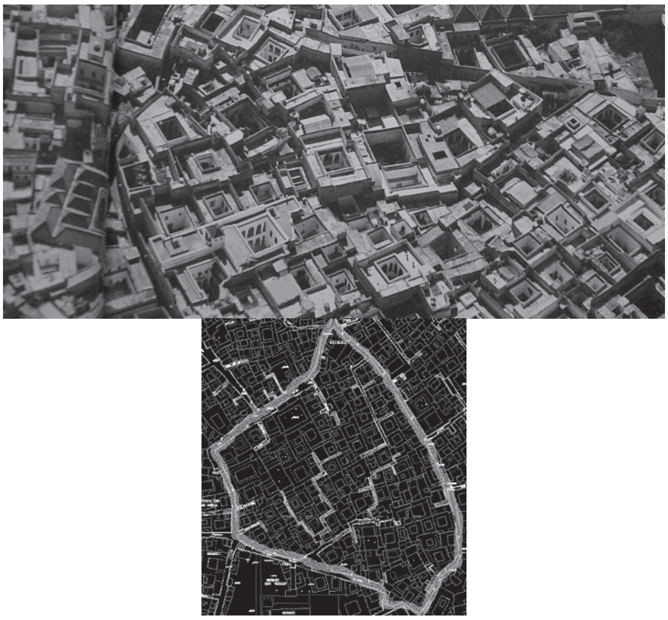


Figure 1. Aerial view (left) and plan (right) of Zaouiat Lahdar, the neighborhood selected as a case study.

This partially explains the organization of domestic architectural spaces which are close to each other and contain a multifunctional space surrounding a courtyard. It also partially explains the unsolved familiar tribal problems found in certain areas which can lead to spatial arrangements such as the closing of a Derb, the change of its direction, the destruction of a house for its division, or decisions about land division among family members and disputes of inheritance goods. Contrary to what happens in the Western world, Islamic societies do not have a precise urban code that guides the planning and design of urban environments. Islam through its shari´ah has provided principles that determine the way of life of Muslim communities and individuals, which in turn shapes the urban environment. Oleg Grabar says in his study on traditional Muslim urban environment: "it is Islam which gave resilience to the Muslim city and to its bourgeoisie, not because it was necessarily aware of all urban problems but because it had the abstract form in which all of them could be resolved (Grabar 1976)." These laws, which are constantly applied in everyday life, form a dynamic set of rules that actuate in a bottom up fashion to shape the urban tissue. This deserves to be preserved, but at the same time, encoded in more contemporary ways of living within the Islamic culture.

3. Methodology

The methodology used to develop the computer model of the Zaouiat Lakhdar quarter, particularly the urban grammar described in this paper, encompassed three steps described below: analysis of previous work carried out to infer basic shape rules; development of an experimental computer program encoding these rules; and field work to collect additional information to complete the rules.

3.1. PREVIOUS WORK

In previous work it was hypothesized that the Marrakech Medina urban tissue, as other Islamic cities, was organized as a progression from public space to progressively more private realms, until reaching the privacy of the patio house, the predominant urban type in this part of the Medina. (Rocha 1995) The patio is the place where the outdoor activities of the family take place. The patio is also the means to provide daylight and ventilation to the house, contrarily to traditional European configurations in which the main external space is the street, and buildings are lit and ventilated primarily through street-facing facades. External facades in the Marrakech Medina are mostly closed, with very little openings. Because privacy, lighting and ventilation requirements are not significant, street width can be considerably reduced. The street thus becomes mainly a device for physically accessing the house entrance, causing it to become very narrow and often covered with constructions from the first floor on, called sabbats, thereby generating corridor-like configurations called derbs.

3.2. EXPERIMENTAL PROGRAM

Following the initial hypothesis mentioned above, several conjectural attempts were carried out to simulate what could have been the urban growth of Marrakech. A simple shape grammar composed of ten parametric rules was developed. Then, it was encoded into a computer program implemented in AutoLisp to observe the behavior of the model simulating urban growth, defined by the successive and iterative application of rules. Finally, the program was run with 50, 100, 200, 500 and 1000 iterations, Figure 2. Four problems could be observed. The first was that growth became too slow preventing the polygon representing the neighborhood to be completely filled in. The program was implemented in a way that rules were blindly applied, that is, a rule was applied and then a test was carried out to check whether it yielded a valid result. As growth evolved, it became gradually slower to a point at which most rule applications were not valid. Consequently, it became gradually more difficult to fill in the whole polygon. The second problem was that derbs grew in all directions. Growth was constrained by restrictions imposed on the length and on the angles between rectilinear parts of derbs. Although angular values were restricted to intervals, the successive use of different values originated derbs that followed a wide range of directions, while in Zaouiat Lakhdar they tended to follow predominant directions. The third problem was that the distance between two "parallel" derbs was not controlled. In later versions of the program, a minimum distance was defined so that lots with adequate dimensions could be inserted. Results then showed that number of lots also had to be considered in determining the distance between derbs. The fourth problem was to guarantee that the limits of adjacent lots abutted. In the last version of the program, the growth of derbs was coupled with the placement of rectangles on both sides representing lots. Running the program showed that assuring that lots abutted posed a major challenge in the development of the grammar and its implementation.

3.3. FIELD WORK

To collect additional information that permitted to complete the grammar, a field trip to Marrakech took place in early 2005. Four sources of information were explored. The first consisted in surveys of the site based on laser measurements, digital photos, and hand drawings. These surveys permitted to acquire rigorous information regarding the length and width of the derbs, the height of the sabbats, and the location and size of windows and doors. The second source was documents and drawings obtained at the Agence Urbaine de Marrakech and at the Inspection Général des Monuments, such as an aerial photo of the city taken in 1950 and the plan of the Medina in digital format. The third source was interviews with local experts, which permitted to gather speculative information regarding the genesis of the neighborhood and the reasons for certain spatial configurations. Finally, the fourth source was a satellite photo of Marrakech acquired from QuickBird. The analysis of these sources of information led to the elaboration of a more accurate plan, shown in Figure 3.

4. Urban Grammar, Negotiation Grammar, and House Grammar

The view of the Medina of Marrakech suggested an organic and almost chaotic city growth. However, a close analysis unveiled a well-established order with repeated urban patterns. For example, the way lots are placed on derb corners are similar. Such patterns are not geometrically but topologically similar, meaning that they can differ in the values of parameters like the angles and dimensions of lots and derbs. Consequently, it was possible to capture the variety of patterns into a reduced number of parametric schematas to develop a parametric shape grammar (Knight 1998).

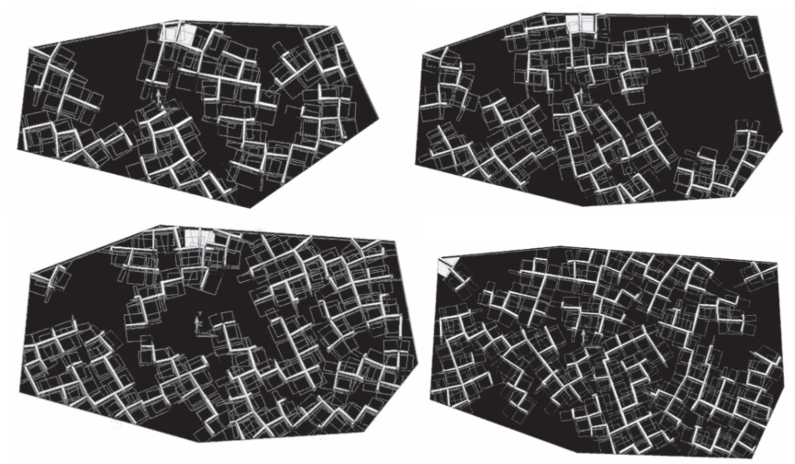


Figure 2. Output of an experimental computer program encoding a basic urban grammar for the Marrakech Medina after 100, 200, 500, and 1000 iterations.

Figure 3. Plans of Zaouiat Lakhdar based on collected information showing the main directions of the urban fabric, and the location of derbs, sabbats, lots, house entrances, and patios (left), and which lots are accessed by which derbs (right).

At the outset, it was considered that it was necessary to deal with both the urban scale and the scale of the house. As such, the development of two independent grammars was foreseen: an urban grammar that would account for the layout of the derbs and the definition of lots, and a housing grammar that would account for the functional organization of the houses. As the study evolved, it was realized that these two grammars could not be fully independent. In fact, the functional organization of the houses seemed to be partly responsible for the geometry of their perimeter. Moreover, the perimeter of different floors in the same house did not always match. Therefore, pre-established quadrilateral lots could not account for the generation of existing houses. This obliged to consider an interaction between the design of the houses and the urban layout and a third grammar was proposed as a result. This grammar, called "negotiation grammar," mediates between the other two grammars and regulates the permutation of spaces between adjacent lots according to the necessities of their owners. It is not certain that this "negotiation" between neighbors took place as not enough historical evidence was found. However, considering the close families ties that characterize Islamic society, to consider that it did exist seems reasonable. In fact, only a society with this tight-knit social environment could have produced such complex spatial configurations. Figure 4 illustrates the different stages reached by these grammars and the urban grammar will be described in this paper.

Figure 4. The three stages reached by the sub-grammars: urban grammar (left), negotiation grammar (center) and patio-house grammar (right).

5. Inferring and Structuring the Grammar

Given the scale of the Medina of Marrakech, the development of the grammar raised two problems, one related to the inference process, and the other to the structuring of the grammar.

In previous studies, shape grammars were developed based on a corpus of different designs within a given style. The type and scale of designs ranged from Chinese windows (Stiny 1977) to Palladian villas (Stiny and Mitchell 1978). In the current study, the goal was to develop a grammar that generated urban layouts, a design of a considerably larger scale. The Medina is composed of many neighborhoods and although these might look similar, they are quite varied in terms of morphology, street layout, urban culture, and way of living. Zaouiat Lakhdar, one of the oldest neighborhoods, has a relatively well-preserved urban fabric and its inhabitants seem to enjoy a healthy balance of safety, community life, and economic welfare. It has a derb-based configuration with two dominant orthogonal directions. It possesses two relatively small open-spaces that are used for socializing. The unique characteristics of Zaouiat Lakhdar made it the most appealing of all the visited neighborhoods, and so it was selected as the model for the development of the urban grammar. As such, the corpus of existing designs was restricted to a single design. To overcome this limitation, the strategy used to infer the grammar was to divide the neighborhood into sectors thereby creating a corpus of several partial designs.

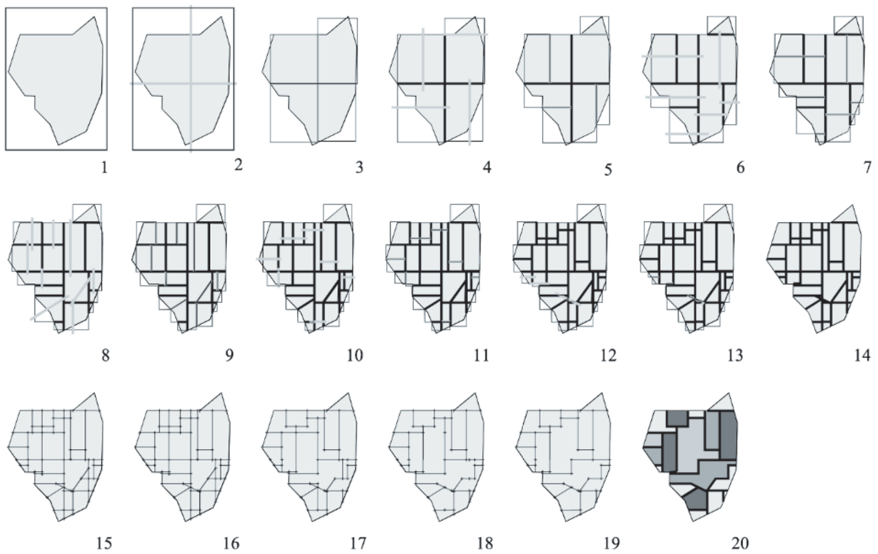
Structuring the grammar required a decision on whether to follow a bottom-up or a top-down approach as both seemed possible. The top-down approach provides a centralized form of controlling the design as it progresses from larger to smaller scales. In the specific case discussed here, one can imagine that a first step would be to divide the Zaouiat Lakhdar into smaller independent areas with access from the surrounding streets or from a derb. The advantage of this approach is that the relation between smaller parts is controlled from the beginning of the computation, with the shift to smaller scales only occurring when problems of larger scales are solved. This meant, for instance, that an eventual clash of derbs would be avoided because each had its pre-defined area of influence, provided that areas were defined taking the legal dimensions of lots into account.

The bottom-up approach offers a decentralized form of controlling the design, based on the independent behavior of its parts. In this approach, larger scale problems are solved by solving small scale ones. In the studied case, urban growth would be based on the individual, yet interdependent, growth of derbs coupled with the insertion of lots. Each derb would grow incrementally taking its surroundings into consideration. This approach raises some difficulties, namely, how to solve all larger scale problems, such as the clash of derbs, the alignment of lots, etc. The generation of a valid design might require an algorithm with considerable embedded intelligence. Its advantage is that it generates designs in an organic way, which might do better justice to the organic character of the urban fabric.

Not enough historical evidence was found to determine which of these approaches originated the Zaouiat Lakhdar, or whether they took place simultaneously, intertwiningly, or sequentially. Some historians (Wilbaux, 2003) do claim that the neighborhood's area was first divided into areas belonging to different families, and then each was divided into lots accessed by one derb. This would explain why many derbs are named after families (for example, derb شى, or derb ش). Other historians claim that urban growth was spontaneous and organic; new houses would adapt to the existing situation and derbs were the empty spaces left over for access purposes. Ideally, the generation process embedded into the grammar should replicate the actual evolution of the urban fabric.

5.1. TOP-DOWN APPROACH

The top-down approach requires the decomposition of the neighborhood into smaller areas. This can be accomplished in two stages as diagrammed in Figure 5: first by recursively dividing the neighborhood into smaller areas until some condition is satisfied (steps 1-13), and then by rearranging the limits of such areas so that all can be accessed from the exterior (steps 14-20). The problem with this approach is how to divide recursively irregular forms whose division can yield forms that are topologically different from the original ones. This can be overcome by inscribing irregular forms into rectangular frames. Then these frames are divided parametrically into two or four smaller frames using one or two orthogonal lines. Then the original frame is deleted and the dividing lines are trimmed so that they do not extend beyond the limits of the neighborhood and become the limits of smaller areas. The computation proceeds until some condition is satisfied, for example, all the zones have predefined areas and dimensions that guarantee they can be accessed through derbs and divided into "legal" lots. Two types of areas will result from the computation. In peripheral areas, lots are directly accessed from the surrounding streets and host commercial functions. In inner areas, lots are accessed from derbs and are reserved for housing.



1 2 3 4 5 6 7

8 9 10 11 12 13 14

15 16 17 18 19 20

Figure 5. Top-down derivation of the Zaouiat Lakhdar zone.

5.2. BOTTOM-UP APPROACH

The bottom-up approach emphasizes the notion of growth rather than division. It requires shape rules that define both the incremental expansion of derbs and the systematic insertion of lots, Figure 6. The basic idea is that entrance points are defined in the perimeter of the neighborhood (step 2), and then derbs grow independently from each one. Lots that have direct access from the surrounding street are defined at an early stage (step 3). Then derbs grow and fill in the empty space with lots until none is left and the whole neighborhood is packed (steps 3 through 16). The problem is that growth cannot be fully blind or independent, otherwise local voids of difficult access will be constantly created and the limits between neighboring lots will hardly ever be coincident. So, a certain level of intelligence has to be embedded in this system, both in the choice of rules to promote growth and in the way they are applied, particularly, in the assignment of values to rule parameters. There are two ways of solving this. The a priori solution requires performing local analysis to determine which rule to apply and the adequate assignment of values. The a posteriori solution implies applying a given rule with a given assignment of values and then to perform a test to check whether the inserted derb or lot clashes with existing forms; if not, it remains part of the design and the computation resumes; otherwise, it is deleted and another attempt is made using a different assignment of values or a different rule. If a bottom-up grammar is to be implemented and run automatically, it will be necessary to develop one of such higher level systems to determine whether and how growth rules can be applied.

Figure 6. Bottom-up derivation of the Zaouit Lakhdar zone.

5.3. MIXED APPROACHES

The top-down and the bottom-up approaches can be combined in two different ways to develop mixed approaches. The first, Figure 7, top, uses a top-down approach to divide the given site into different areas as described in Section 5.1, and then a bottom-up approach to pack each of the resulting areas with derbs and lots. The bottom-up stage also runs into the type of problems referred to above, but these are simplified. The second mixed approach, Figure 7, bottom, encompasses a bottom-up stage to insert derbs and their zones of influence, and a top-down stage to divide such zones into accessible lots. In this case, the problem is to avoid the clash of different zones, and so an intelligent algorithm similar to the one mentioned in Section 5.2 needs to be considered in the bottom-up stage.

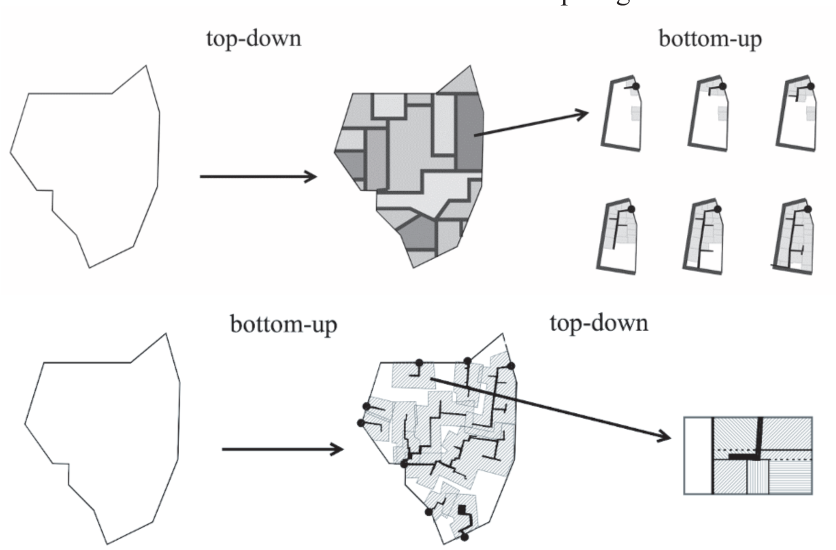


Figure 7. Top - down / bottom-up mixed approach (above); and bottom- up/top-down mixed approach (bottom).

5.4. SELECTED APPROACH

In the majority of shape grammars developed in the last thirty years, for instance the Palladian grammar (Stiny and Mitchell 1978) and the Queen Anne grammar, (Flemming 1987) designs are generated in a top-down fashion. Bottom-up approaches are more commonly used in genetic algorithms or cellular automata. Nevertheless, we believe that a bottom-up approach will reflect more honestly the organic character of the urban fabric and will eventually yield more complex design solutions. Moreover, the design of the grammar should become more challenging and interesting from a computational viewpoint. Consequently, a bottom-up grammar has been developed and is described in the next section.

6. Grammar

The proposed Marrakech grammar is a parametric shape grammar defined in the U12 algebra. The derivation of designs proceeds through six stages: (1) define the limits of the neighborhood, (2) insert entrances to derbs, (3) insert extenders and articulators forming derbs, (4) insert lots along derbs' extenders, (5) insert lots at derbs' ends, and (6) modify the layout of derbs and lots. These stages are not necessarily sequential as rules from different stages may be applied alternately. The remaining rules and further detail are available at http://www.civil.ist.utl.pt/~jduarte/dcc06/.

6.1. RULES

6.1.1. Stage 1: Define limits of the neighborhood

Stage 1 defines a polygon representing the limits of the neighborhood. This may vary in size, geometry and number of sides, but the edges should be, at least, twice as long as the minimum depth of a lot (i.e. 2 x 8 meters), and the internal angle between edges should be bigger than 60º. Two rules apply at this stage: 1.1 and 1.2, Figure 8. Rule 1.1 generates a basic triangular polygon that constitutes the initial shape and rule 1.2 introduces a vertex into an edge of the polygon so that more complex polygons can be obtained. By recursively applying rule 1.2 to the edges of an evolving polygon, a perimeter like the one that limits Zaouiat Lakhdar is obtained.

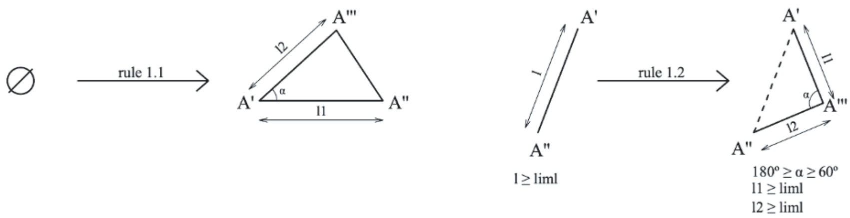


Figure 8. Rules for introducing the initial shape and defining the perimeter of the neighborhood.

6.1.2. Stage 2: Insert entrances to derbs

Rules 2.1, 2.2, and 2.3 apply at this stage, Figure 9. Each of these rules introduces an entrance point E in such a way that each edge cannot have more than two entrance-points. In rule 2.1, A'A'' is an edge of the polygon, and X' and X'' are the closest labeled points to A' and A'', respectively. They can be either other vertices of the polygon (An) or entrance-points (E). To guarantee that lots with adequate dimensions can be inserted later in the computation, the distance between two consecutive entrance points measured on the perimeter cannot be smaller than twice the length of the minimum lot depth (lim_e).

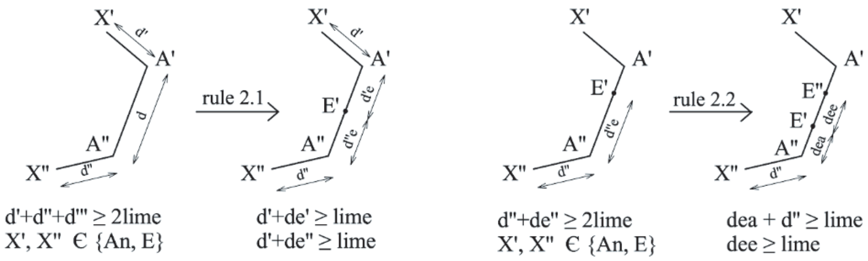


Figure 9. Two of the rules for inserting entrance points.

6.1.3. Stage 3: Insert extenders and articulators forming derbs

The third stage consists in the insertion of derbs and it encompasses rules 3.1 through 3.10. Derbs are composed of extenders that extend the derb in a pre-defined direction and are labeled with an empty triangle, and articulators that define new directions for the derb and are labeled with filled triangles. In the generation of a derb, rules that generate extenders and articulators are alternately applied, so that a extender is always followed by an articulator. Although the urban fabric inside the Zaouiat Lahdar is not orthogonal, derbs tend to follow two somewhat perpendicular directions. Therefore, the directions defined by the articulators are restricted so that the angle θ between a subsequent extender and one of the two perpendicular directions is within 20º, and the angle β between sequential extenders is between 30º and 150º. The combination of these two restrictions defines an interval – specific to each rule application and eventually composed of non-continuous sub-intervals – within which new directions for the derb can be chosen.

Rule 3.1 inserts the initial extender of a derb, Figure 10. In this case, β defines the angle between the perimeter of the neighborhood and the direction of the extender. Rules 3.2 through 3.9 insert an articulator after a extender. They differ in the type of the inserted articulators. Rule 3.2 inserts an articulator that permits to extend the extender without changing its direction. Rules 3.3, Figure 11, and 3.4 insert elbow-like articulators, and rules 3.5 and 3.6 t-like articulators. Rule 3.7 inserts an arrow-like articulator, rule 3.8 a y-like articulator, and rule 3.9 a cross-like articulator. Finally, rule 3.10 connects a extender to an articulator marked with a filled triangular label. The parameters in this rule are the length (l) and the ending width (w) of the extender.

6.1.4. Stage 4: Insert lots along derbs' extenders

In Stage 4, lots are inserted along derbs. In most cases, these are almost rectangular and, in the proposed shape grammar, this quadrilateral shape is captured by a general topological schema with specific constraints. The value of internal angles and the dimensions of their sides may vary between specified intervals. Furthermore, the proportion of the lot is confined to the interval between 1:1 and 2:3 meaning that its geometry may vary from a square to a rectangle in which the length cannot exceed 1.5 times the width. Not all lots are quadrilaterals as some may have more than four sides. However, it is possible to identify a main quadrilateral shape in such lots, which is then used for matching the schema on the left-hand side of rules. As lots follow the general topological schema just described, the internal shape parameters are not shown in the rules for inserting lots for simplification purposes.

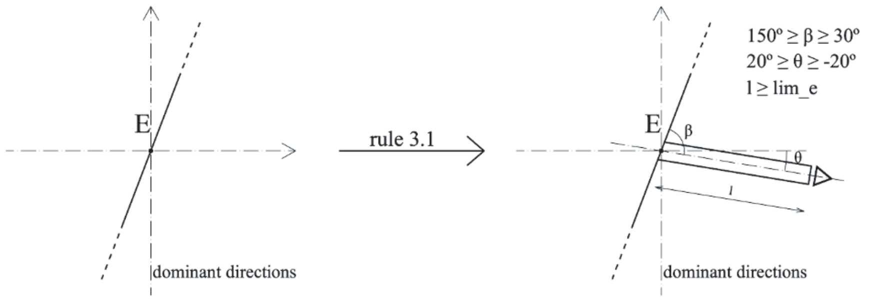


Figure 10. Rule for inserting the initial extender of a derb.

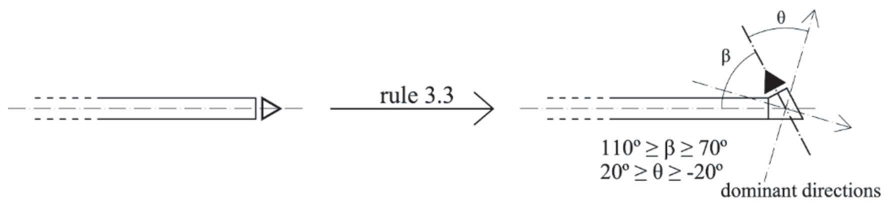


Figure 11. Example of rule for inserting an articulator.

Rules 4.1 through 4.5 define the insertion of lots along extenders. Rules 4.6 through 4.13 define different forms of inserting lots on the outer side of elbow-like articulators, and rules 4.14 through 4.16 do the equivalent on the inner side. Finally, rules 4.17 through 4.21, deal with the situations created by other articulators. Rule 4.1, Figure 12, top, is the seed-rule at this stage as it is responsible for the insertion of the first lot of the derb and it takes into account the perimeter of the neighborhood. The rule has five parameters: width w, distances d1 and d2, and angles $\alpha 1$ and $\alpha 2$. Rule 4.2, Figure 12, bottom, inserts a new lot along an extender that has not been completely filled in yet. An extender is identified as empty or full through labels E or F, respectively. Rule 4.2 only applies to situations where the extender has the label E and it keeps it unchanged. Rule 4.3 does the same as rule 4.2 except that it fills the extender, thereby changing the label to F. Rules 4.4

and 4.5 are applied when the extender' available length is smaller than the lot's minimum width. Rule 4.4 changes the label to F without adding a lot. Once an elbow-like articulator has been added to the extender, rule 4.5 introduces a lot that stretches beyond the limit of the articulator.

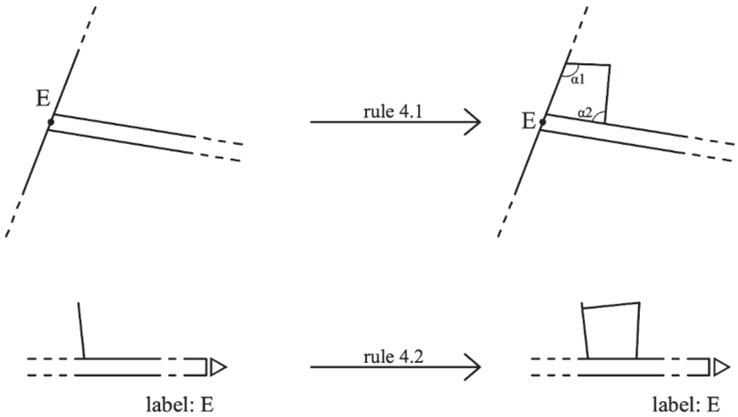


Figure 12. Example of rules for inserting lots along extenders.

Rules 4.6 through 4.13, deal with all the possible situations that can be created by the introduction of elbow-like articulators. In the application of parametric rule 4.6, Figure 13, three parameters, e, γ1, and γ2, need to be assigned values; e is the distance of the limit of the lot to the limit of the articulator. It is measured on an auxiliary axis, whose origin is O, with positive values on the left. Depending on the value of e, angles γ1 and γ2 can take one of two values to align the limit of the lot with the incoming extender or the out-going extender. If $e \leq 0$, then the angle γ1 is not defined and γ2 can have one of two values: 90° or 180° - β, with β defining the angle between the two extenders. If $e > 0$, then γ1's value can be either 90° or 180° - β. If γ1 = 90° (i.e. the limit is perpendicular to the in-coming extender), then γ2's value can be either 90° or β° (i.e. the lots' limit is either parallel to the in-coming extender or perpendicular to the out-going I-extender). If γ1 = 180° - β (i.e. the lots' limit is perpendicular to the out-going extender, then γ2's value can be either 90° or 180° - β (i.e. the lots' limit is either perpendicular to the out-going extender or parallel to the in-coming one). The closed polygonal shapes of the lots are not fully represented in the rule. As the rule specifies the relation between the lots and the extenders to which they are connected (in this case, an in-coming extender, an elbow-like articulator and an out-going extender) how the polygon is closed is not important. The remaining rules follow a similar scheme. Note that in all the rules, angle γ2 is such that the limit of the lot is parallel to the in-coming extender or perpendicular to the out-going extender.

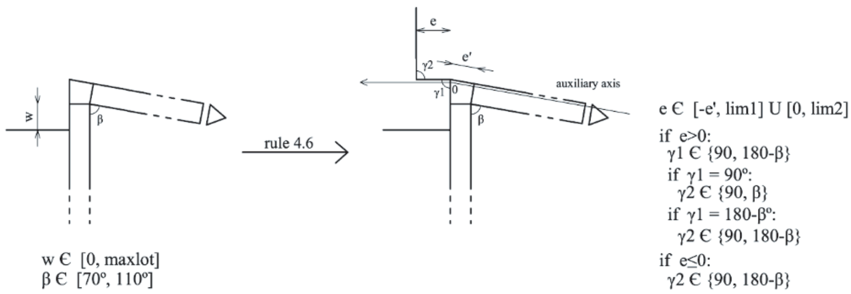


Figure 13. Example of rule for inserting lots on elbow-like articulators.

Rules 4.14, 4.15, and 4.16, are used to fill inner (concave) corners (corners defined by the intersection of one in-coming and one out-going extender) with lots, Figure 14. These corners need not be exclusively derived from the insertion of elbow-like articulators; any corner with an angle smaller or equal to 90° can be tackled with these rules regardless of the specific articulator involved. The problem is addressed in the following way. Rule 4.14, places a label P on the vertex of the last lot that is more distant from the corner between the in-coming and out-going extenders. If the distance d between point P and the out-going extender is larger than the minimum width of a lot, then rule 4.15 is applied to transform the lot into a corner lot. If it is smaller, then rule 4.16 transfers the label P to the last but one lot, and deletes the last lot. This rule is applied recursively until Rule 4.15 can then be applied.

Rules 4.17 and 4.18, Figure 15, insert a lot in an outer corner (corner defined by the intersection of two out-going extenders), which may be yielded by rules 3.5, 3.6 and 3.9. Four variables are involved in these parametric rules: w1 and w2 are the front dimensions of the lot and they can take any value in the interval defined by minlot and maxlot (respectively 8 m and 18 m in this case); and $\alpha 1$ and $\alpha 2$ are the angles between the limits of the lot and the extenders, which can vary from 70° to 110° each.

Rule 4.19 defines the insertion of lots in the specific case where the in-coming direction coincides with one of the two out-going ones. In this case, a continuity of extenders is observed and may be generated by rules 3.5, 3.6 and 3.10. For this rule to be applied, the distance e between the right most limit of the last lot and the articulator has to be inferior to a given lim. Then, the values of the parameters' on the right-hand side of the rule must be satisfied: $\alpha 1$ and $\alpha 2$ can vary from 70° to 110°, w1 must be positive, and w2 and d (width and depth) must be between minlot and maxlot. Finally, rules 4.20 and 4.21 handle the insertion of lots on the sector defined by the intersection of the out-going extenders, whenever rule 3.7 or rule 3.8 have been previously applied.

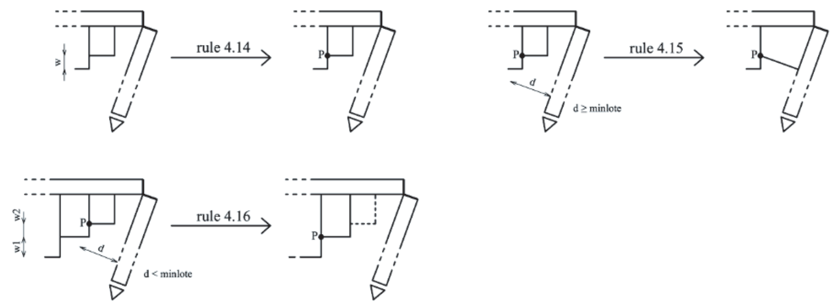


Figure 14. Rules to introduce lots in the inner corner formed by extenders.

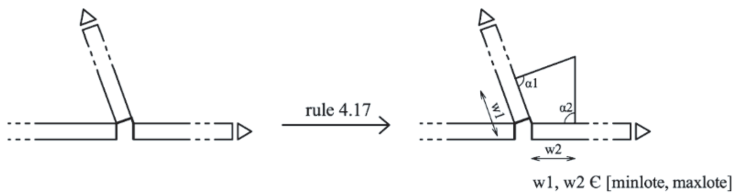


Figure 15. Example of rule to insert lots in the outer corner formed by extenders.

6.1.5. Stage 5: Insert lots at derbs' ends

Stage five deals with the insertion of lots in the ending extender of a derb. There are six possible layout configurations that can be found on the left-hand side of the rules in this stage. For each of these configurations, there are several ways in which lots can be placed at the end of the extender and these are encoded into the right-hand side of the rules. Rule 5.1 is shown in Figure 16. This rule inserts three lots at the end of the derb. For the rule to be applied, the positions of the last lots on both sides of the extender must be such that the distances between their limits and the end of the extender, respectively d1 and d2, are smaller then the minimum dimension permitted for a lot, minlot, which means that no further lots could have been placed using rule 4.2. The remaining rules (rules 5.2 through 5.19) work in a similar fashion.

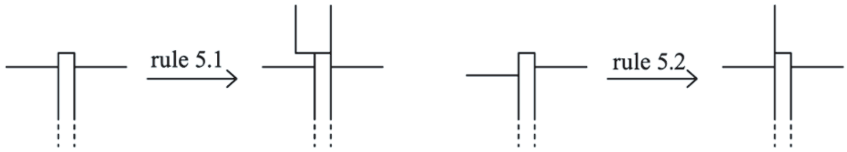


Figure 16. Example of rules for inserting lots in the ending extender of a derb.

6.1.6. Stage 6: Modify the layout of derb's and lots

Finally, stage six encompasses rules that modify the existing lots to create smaller or larger lots, to access locked lots, or to reach locked empty spaces to resume growth. The modifications introduced by these rules in the lots respect the general topological scheme described in Section 7.2. As such, the specific constraints on the shapes of modified lots are omitted in the rules. Rule 6.1 divides a larger lot into two smaller ones. Rules 6.2 and 6.3 expand a lot at the expense of an ending extender (literally a dead-end alley.) Rule 6.4 inserts an extender perpendicular to an existing extender at the expense of a lot to provide access to a locked lot or to an empty locked area. Rule 6.5 through 6.7 are similar, except that in rule 6.6 the new extender is aligned with the existing one, and in rules 6.6 and 6.7 a change of direction requires the introduction of an articulator. Rule 6.8 is similar except that its purpose is exclusively to provide access to locked lots and no further growth of the derb is foreseen. Rule 6.9 also provides access to a locked lot, but by modifying its topology at the expense on adjacent lot, instead of inserting an extender. Rule 6.10 provides access to a lot that is connected to a derb solely through a vertex. In this case the topologies of two lots are modified so that an entrance area is generated off the lot that is already accessible through the derb. Finally rule 6.11 connects two derbs by means of a diagonal direction.

6.2. PARTIAL DERIVATION OF THE EXISTING ZAOUIAT LAKHDAR

The grammar just described is non-deterministic and open-ended. In general, more than one rule can be applied at a given step in the derivation. Furthermore, a single rule can generate different solutions depending on the values assigned to parameters. This means that from the same perimeter different applications of the grammar rules will likely yield different solutions. Consequently, the application of the grammar generates unpredictable results. Figure 17 shows the last steps in the generation of the upper part of the existing Zaouiat Lakhdar neighborhood using stage 4 and stage 6 rules. Step 1 depicts the state of the design at the end of stage 5. Step 2 results from the application of rules 6.1, 6.2 and 6.3. Step 3 results from the application of these and rule 6.4. In step 4, additional lots are added using stage 4 rules. In steps 5 and 6, rules 6.5 through 6.11 are applied to complete the layout.

7. Discussion and Conclusions

The research described in this paper constitutes one step towards the development of a computational model of the Zaouiat Lakhdar neighborhood in Marrakech. The ultimate goal is to use this model in the planning and design of new neighborhoods that have similar spatial features and yet are improved from the environmental viewpoint. The model uses shape grammars to encode the underlying syntactic rules and genetic algorithms to “optimize” solutions. It encompasses three grammars: a grammar to generate the urban fabric, a grammar to generate the houses and a grammar to trade spaces among adjacent houses. This paper describes the first of these grammars. In the next sections the limitations of the current grammar are discussed and future work is outlined.

Figure 17. Different steps within stage 6.

The current grammar is bi-dimensional, but traditional urban environments in Islamic cities present three-dimensional complexity. In fact, the morphology of an Islamic city such as Marrakech cannot be described as the simple extrusion of bi-dimensional forms defined in plan. Its variety is just as rich in section as it is in plan. Consider, for instance, the Sabbats that cover the derbs. In addition to constitute a rich architectural feature of great formal plasticity, they exist for several reasons of which some are to provide structural stability to nearby houses, to create shade for environmental comfort, and to extend housing spaces to fulfill family needs. Another feature with similar impacts is the trading of spaces among adjacent houses which causes the perimeters of different floor plans not to coincide. Features like these cannot be fully described in two dimensions, but have important impacts on functional organization and environmental performance. Therefore, they are important for the type of "optimization" targeted with the model, and so future work will be concerned with the extension of the current grammar to include three dimensions.

One of the issues raised by the adoption of a parametric urban grammar concerns the criteria for choosing values for rule parameters. One interesting possibility is the drive to improve some performance indicators, thereby guiding the solution towards certain desirable characteristics. The shape grammar presented in this paper will be coupled with a genetic algorithm

(GA) to form a generative design system that performs guided search for improved urban patterns, a term we prefer to that of optimization.

This guided search may act at the urban scale, where potential fitness functions for the GA may be related to issues of density, ratio of public vs. private space, maximum length of derbs, and so on. Guided search may also act at the level of the private patio houses, by improving the environmental performance of the houses and providing modern living standards in terms of day-lighting, ventilation, thermal performance, and other environmental design parameters. Given a certain lot, determined after the application of the urban grammar, many design choices will have a deep influence on the future performance of the house, such as patio configuration, spatial layout, loggia design, type of façade and roof, openings design and layout, construction materials, colors and external finishes, among others.

Although the current study is based on the study of the Medina of Marrakech, the ultimate goal is that by introducing variations in the grammar rules, the model might be applied to new city districts not only in Marrakech, but also in other cities throughout the Arab world. Because of the demographic boom, the shortage of qualified personnel, and the scarcity of funds, we would argue that this tool is particularly appropriate for use in the design and planning of cities in this region.

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