A morphological generator of urban rules of solar control

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ABSTRACT: This paper aims to develop a morphological generator of urban rules of solar control based on a modeling approach of the Solar Bounding Box SBB. This is the optimum volume conditioned by both the urban rules of form and solar envelope rules. The urban rules are defined by the urban zoning regulations of a city. The solar envelope defines the largest volume that doesn't cast its shadows on neighboring buildings during critical periods of sunshine. The object here is to develop a digital tool for urban planning. This tool will assist planners for the drafting of urban morphological rules of solar control.
Keywords: solar control, solar envelope, Solar Bounding Box, urban rules.

INTRODUCTION

Energy consumption in the building sector is currently an important part of the overall energy consumption (about 40%), and continues to progress in a sustained manner. To this end, public policies are increasingly looking for new solutions. Acting upstream of urban planning in order to improve the energy efficiency of buildings is a frequently asked question in architecture and urbanism.

In Tunisia, the sun is a major source of energy. Several programs aiming to exploit this energy have been developed. The emergence of these new challenges needs the revision of the legislation and urban regulations used in most cities.

This paper presents a morphological generator of urban rules of solar control based on a modeling approach of the Solar Bounding Box (*SBB*). This is the spatial delimitation of the volume respecting both the urban rules of form and solar envelope rules.

The urban rules are defined by the urban regulation of a city. The solar envelope rules define the maximal limits of a volume that doesn't cast its shadows on neighboring buildings during critical periods of sunshine. This concept protects *solar rights* in urban areas and at the same time is a useful instrument for urban planning [1]. In fact, it allows achieving high ranges of density while preserving solar access [2, 3]. This has a direct impact on energy consumption of buildings, thermal comfort and quality of life as well.

Computational modeling of solar envelope has been a center of interest of several studies [4, 5, 6, 7, 8, 9, 10, 11]. The proposed approaches have shown difficulties to manage the forms complexity. Graziotin presents an approach for the modeling of the solar envelope and the urban reglementary volume [12]. However, it does not directly produce the constraints volume (urban and solar envelope constraints). The user should proceed by successive trials and experiments to find the urban reglementary volume and include it in the solar envelope volume. The approaches mentioned above stop at computational modeling of the solar envelope.

Indeed, the solar envelope fixes the geometric limits of a volume of restriction of the shadows projection. We propose here to use this concept to produce solar control rules in urban areas (height limits, set back, distance between buildings...). We assume here that the solar envelope is a concept that preserves the *solar rights* and this according to the particular climatic characteristics of each region. We conduct an experimentation of this approach in the case of a regulatory subdivision in Nabeul (Tunisia).

URBAN RULES AND SOLAR CONTROL

The urban rules controlling buildings morphology can be divided into 10 fields: the implantation rules (set back from roads and common limits, distance between buildings on same lot), the alignment, the maximum height of buildings, the floor area ratio (FAR), the plot ratio, the view servitude, the servitude of clear of the day, constructability context, the patio size and the roof slope

An urban rule has several purposes (goals). We set the following purposes: (1) Aesthetic purpose: search for harmony of the urban fabric, (2) Solar access purpose, (3) Lighting purpose: Ensure a minimum natural lighting in buildings (4) Ventilation purpose (5) Public safety purpose: Ensure practicable passages and prevent the spread of fire to buildings, (6) Practical purpose: rainwater drainage (7) Proximity purpose: Avoid neighborhood contact.

We propose a classification of these rules according to their purposes. We assign the value 1 to the urban rule if there is a direct relation with the purposes stated above and 0 if there is no relation (Table.1).

Table 1: Classification of urban rules according to their purposes

Urban rules \ Purposes	Aesthetic purpose	Solar access purpose	Lighting purpose	Ventilation purpose	Public safety purpose	Practical purpose	Proximity purpose
Alignment	1	0	0	0	0	0	0
Setback from roads	1	1	1	1	0	0	0
Setback from common limits	0	1	1	1	1	0	0
Distance between buildings on the same lot	0	1	1	1	1	0	0
Maximal height	1	1	1	1	0	0	0
Plot ratio	1	1	1	1	0	0	0
Floor area Ratio	1	1	1	1	0	0	0
View servitude	0	0	0	0	0	0	1
Servitude of clear of the day	0	0	1	0	0	0	0
Constructability context.	1	1	1	1	0	0	0
Patio size	1	1	1	1	0	0	0
Roof slope	0	0	0	0	0	1	0

The urban rules in direct relation with the issue of solar access are the implantation rules (setback from roads and common limits, distance between buildings on the same lot), the plot ratio, the floor area ratio, the constructability context and the patio size.

THE SOLAR ENVELOPE RULES

The solar envelope rules, as defined by Knowles [13], are the *cut-off time* and the *shadow fences*.

The cut-off time is the period of time T of assured solar access. Each time limit, defined by the hour, the day and month, determines a precise position of the sun. The position x of the sun is determined by its altitude angle H and its azimuth Az. Therefore, we have:

$$T = [T_{xi}(A_{zi}, H_i), T_{xf}(A_{zf}, H_f)] \text{ and } T = [t_1 \cap t_2 \cap t_3]$$

Where i = initial time limit, f = final time limit

t_1 is the useful time of sunshine depending on climate specifications of each region. This prevents overexposure of constructions to sunlight and therefore avoids the problems of overheating in summer. t_2 is the useful time of sunshine based on the balance of the different requirements of sunshine throughout the year. This idea was first developed by Pereira [9] and it is based on the user satisfaction or dissatisfaction with the solar radiation. This is represented by a ponderation system of the solar radiation as a function of the difference in magnitude between *the external air temperature* and *neutral temperature*. The method determines the beneficial hours of sunshine in winter and undesirable radiation in summer. Finally, t_3 is the useful time of sunshine according to the building function.

The shadow fences are the restrictive limit of casting shadows. A construction should not project shadows above this limit. The definition of shadow fences depends on surrounding environment (road, residential parcel, warehouse…). This affects significantly the solar envelope size. A warehouse, a parking or a taxiway does not need as much hours of solar access as a residential construction.

THE SOLAR BOUNDING BOX

The solar bonding box (*SBB*) is a spatial delimitation of the optimum volume conditioned by both the urban rules of form and the solar envelope rules

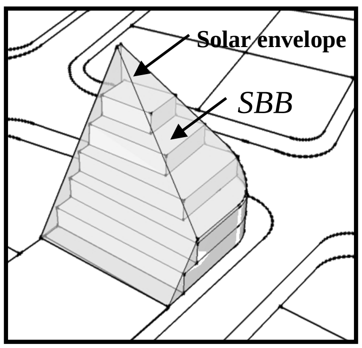
We distinguish two situations of production of the *SBB* (1) a unique maximal *SBB* satisfying the target values (maximal value to reach) of the urban constraints and the solar envelope constraints, (2) multiple-optimal *SBB* satisfying at best the urban constraints and the solar envelope constraints.

A unique maximal SBB is a volume that satisfies the target values of the urban constraints and the solar envelope constraints. However, several studies show that it is difficult to reach the limits of the solar envelope by applying the conventional urban regulations [14, 1]

In Argentina, Casabianca and *al.* [14] explored the merits of solar envelope in urban planning in different regions of Argentina. They show that it is possible to define solar access criteria according to the climatic characteristics, latitude and energy needs of each region. The solar envelope is, for Pereira and Nome Silva [1], a form of control of solar access in urban areas and an effective way to manage the land use.

It is possible to calculate a solution of the unique maximal *SBB* corresponding to an "ideal" volume that we seek to achieve and where all targets values are satisfied. Firstly, we generate the solar envelope volume (which always has a unique solution). We use here the method proposed by Stasinopoulos [7]. Then we note, from the geometric model (unique maximal *SBB*), the corresponding values of the urban rules of solar control (the setbacks, the plot ratio, the floor area ratio...). Finally, we compare these values with those implemented by the urban specifications of El Mrazka in Nabeul (Tunisia) (Fig.1).

Unique maximal *SBB*



Urban rules		Solar enveloppe rules	
Setback from roads	3m	Setback from roads	0m
Setback from common limits	4m	Setback from common limits	2.8m
Maximal height	12m	Maximal height	15m
Plot ratio	0.3	Plot ratio	0.9
Floor Area Ratio	1.0	Floor area Ratio	**2.6**

Figure 1: Comparison between the urban rules and the solar envelope rules for the case of a parcel from the subdivision of El Mrazka in Nabeul (Tunisia).

From this result, we find that the unique maximal SBB improves urban rules of solar control (implantation rules, maximal height, Plot ratio and Floor Area Ratio). Thus, it is possible to achieve a FAR of 2.6 compared to a standard value of 1.0. The unique maximal *SBB* allows, in this case, achieving higher levels of density. This volume offers an interesting alternative for the control of urban densities while ensuring an urban growth that preserves *sun rights*. The *SBB* can renew the existing urban rules and this according to the specific climatic requirements of each region.

In this perspective, the unique maximal SBB (based on the concept of the solar envelope) allows to formulate urban morphological rules of solar control. This volume overcomes the difficulties of *solar rights*, integrates the specific requirements of each region and confronts conventional urban rules to solar access rules. Thus, it can serve as a medium to assist planners in drafting urban specifications (Fig. 2).

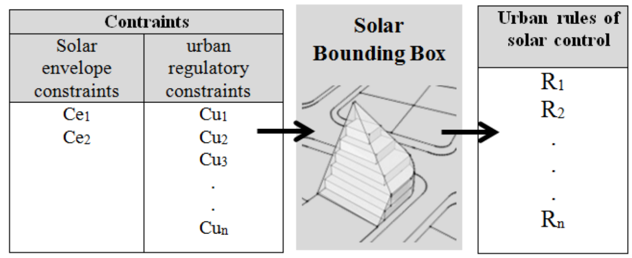


Figure 2: Management of the urban regulatory constraints and the solar envelope constraints for morphological generation of urban rules of solar control.

DISCUSSIONS

This paper introduces the concept of morphological generator of urban rules of solar control based on a modeling approach of the Solar Bounding Box. The concept proposed here allows to formulate urban rules according to the climate characteristics of a considered region. A precise analysis of solar envelope constraints (the *cut-off time* and the *shadow fences*) allows to have accurate results (values of urban rules) that are best suited to the climatic context of a specified region. Their variation involves changes in values of urban rules of solar control.

Impact of the variation of the *shadow fences* plane

The *shadow fences* plane is a a limited zone of restricted shadow projection. We can assign different levels of the *shadow fences* plane (Lvl.0, Lvl.1,.... Lvl.n) according to the needs of sunshine or shade for a concidered region (Fig. 3).

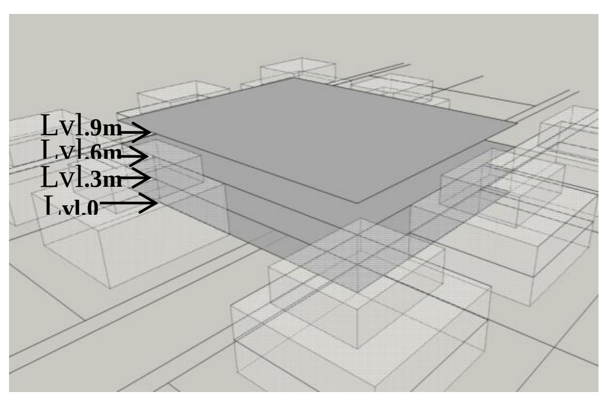


Figure 3: Different levels for shadow fences plane of a parcel from the subdivision of El Mrazka in Nabeul (Tunisia).

The Lvl.0 of the *shadow fences* plane is set by the neighboring buildings bases. This level delineates an envelope called minimal solar envelope SE_{min}. The Lvl.n of the *shadow fences* plane is determined by the highest level of neighboring buildings facades and delineates an envelope called maximal solar envelope SE_{max}. The minimal solar envelope ensures maximal access to sunlight to neighboring buildings. This envelope is suited to temperate climates. The maximal solar envelope ensures access to roofs and solar panels of neighboring buildings. This envelope is suited to hot and sunny climates characterized by a frequent need for cooling (air conditioning, refrigeration, ventilation) and where the need for solar tracking is essential. Its main objective is not to hamper the capture ability of surrounding buildings.

In what follows, we study the effect of the variation of the *shadow fences* plane on urban rules (rule of maximal height) for the case of a parcel from the subdivision of El Mrazka in Nabeul (Tunisia) (Fig. 4).

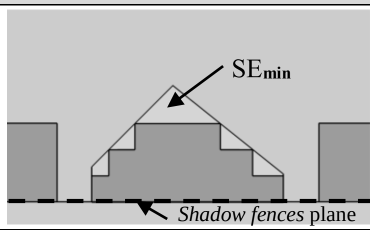
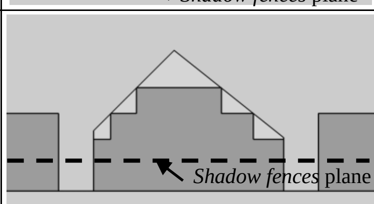
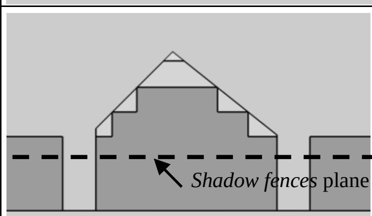
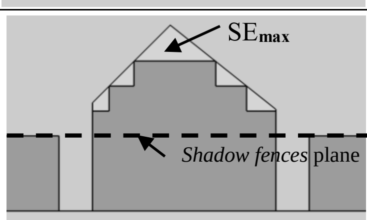
***shadow fences* plane**	**Solar envelope and Solar Bounding Box**	**Maximal height**
Lvl.0m		H_{max}=9m
Lvl.3m		H_{max} =12m
Lvl.6m		H_{max} =15m
Lvl.9m		H_{max} =18m

Figure 4: Variation of the maximal height rule according to the shadow fences plane for the case of a parcel from the subdivision of El Mrazka in Nabeul (Tunisia).

For each level of the *shadow fences* plane we can generate diffrent values of the maximal height rule. Higher levels increases the authorized height of constructions. This is applicable to other urban rules (location rules and Floor Area Ratio).

The levels of the *shadow fences* plane describe different properties of shading or sunshine between the winter solstice, the summer solstice and the equinox. We study this variation for the maximal solar envelope with a parcel belonging to the subdivision of El Mrazka in Nabeul (Tunisia) (Fig.5).

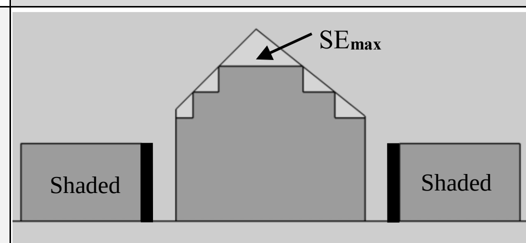
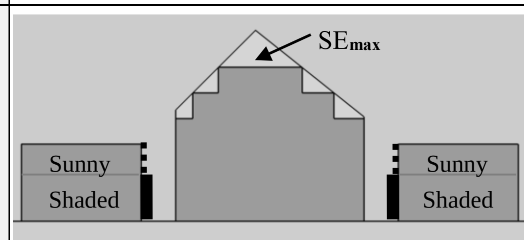
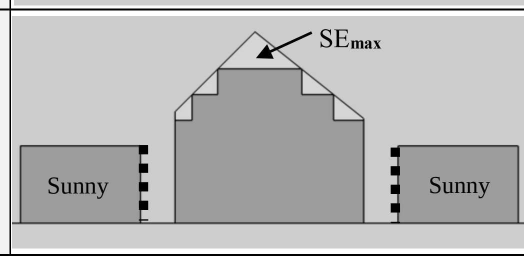
	Shade and sunshine
Winter solstice	
Equinox	
Summer solstice	

Figure 5: Variation of Shading and sunshine for the maximal solar envelope

The levels of the *shadow fences* plane are defined according to the need for sun or shade in a given region. This allows giving greater freedom to the planner for the application of urban rules under various climatic conditions (temperate or hot climates).

Impact of the variation of the *cut-off time*

The duration of the *cut-off time* is chosen according to the need for sunlight in a given region. In what follows, we study the effect of varying the duration of the *cut-off time* on the value of urban rules and in particular the Floor Area Ratio for a parcel belonging to the subdivision of El Mrazka in Nabeul (Tunisia).

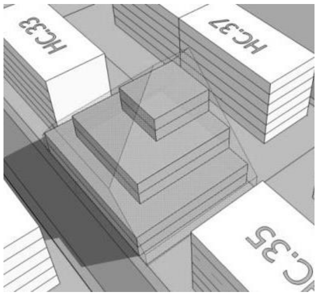
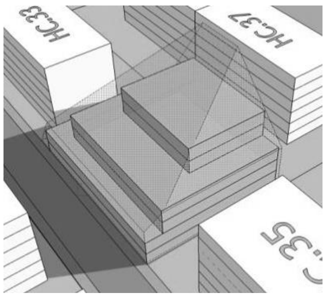
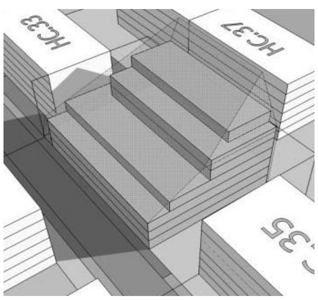
Duration of solar access	Solar envelope and Solar Bounding Box	FAR
2 hours		3.10
3 hours		3.60
4 hours		4.30

Figure 6: Variation of the Floor Area Ratio rule according to the solar access duration for the case of a parcel from the subdivision of El Mrazka in Nabeul (Tunisia).

From the above results we note that the variation of solar access duration implies the variation of the volume of the solar envelope and therefore the variation of the Floor Area Ratio rule. Indeed, when the *cut-off time* duration is reduced the size of the envelope increases and consequently the size of the Solar Bounding Box increases. This has a direct effect on the rate of urban density (FAR). Thus, we can note that when the need for solar access decreases (hot climates), the urban fabric will be more dense.

Prioritisation of urban rules of solar control

We set the urban rules which are in direct relation to the purpose of solar control. However, these rules do not have the same degree of relation with the issue of solar control in urban areas. We propose to quantify this relation with a weighting coefficient attributed to each rule. This quantification will prioritize urban rules of solar control.

We set different link degrees (very strong, strong, medium weak, absent) of a rule with its purpose. We assign to each purpose of the rules the following weighting coefficients; (a) the value 1 for a very strong link, (b) the value 0.75 for a strong link (c) the value 0. 5 for a medium link (d) the value 0.25 for a weak link, (e) the value 0 if there is no link to the rule with one purpose. Then we proceed to the data analysis using the seriation tool "BSK". This tool allows to group classes of rules according to the link degree attributed to purposes.

Table 2 : classification of urban rules of solar control using the seriation tool "BSK"

	Purposes / Urban rules	Aesthetic purpose	Solar access purpose	Lighting purpose	Ventilation purpose	Public safety purpose
Class A	Setback from roads	0,25	1	0,75	0,5	0
	Maximal height	0,25	1	0,75	0,5	0
	Floor Area Ratio	0,25	1	0,75	0,5	0
	Patio size	0,25	1	0,75	0,5	0
Class B	Setback from common limits	0	1	0,75	0,5	0,25
	Distance between buildings on the same lot	0	1	0,75	0,5	0,25
Class C	Plot ratio	1	0,75	0,5	0,25	0
	Constructability context.	1	0,75	0,5	0,25	0

We distinguish three classes of rules; Classes A and B are composed of rules highly attributed to solar access purpose. This is the urban rules of the *hygienic triplet* (solar access, lighting and ventilation) with a fourth purpose of aesthetic or public safety; Class C is composed with rules moderately attributed to solar access purpose and highly attributed to aesthetic purpose.

The classification of urban rules according to their relation to the solar access purpose, allows guiding the system for the generation of urban rules of solar control. These rules are generated with the notion of order, ranging from the rules of class A to the rules of class B and finally the rules of class C.

CONCLUSION

In this paper we developed an approach for a morphological generator of urban rules of solar control. To achieve that end, we have based on a modeling approach of the Solar Bounding Box.

The proposed system allows renewing the current urban regulations while ensuring a sustainable urban growth. A precise analysis of the solar envelope constraints permits to generate urban rules in accordance with the climatic context and shading or sunlight needs for a given region. This system gives a greater freedom to the planner in achieving the goal of preserving the *solar rights*.

Thus, the aim of this work is to assist planners to draft urban rules of solar control by providing them an urban specifications document in the form of an interactive 3D volume.

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REFERENCES

1. F. O. R. Pereira and C. A. Nome Silva, (1998). A proposal for the implementation of the solar envelope in urban planning as a concept for regulating the occupation of urban area, In *the 15th International Conference on Passive and Low Energy Architecture*, Lisbon.

2. I. G. Capeluto, A. Yezioro, T. Bleiberg and E. Shaviv, (2006). Solar Rights in the Design of Urban Spaces, In *the 23rd Conference on Passive and Low Energy Architecture*, Switzerland.

3. L. R. Knowles, (2003). The solar envelope: it's meaning for energy and buildings, *Energy and Buildings*, vol. 35, p. 15-25.

4. M. Schiller and Y. Uen-Fang, (1993). Solvelope: An interactive Computer Program for defining and drawing solar envelopes, In *the American Solar Energy Society Conference*.

5. J. F. Cotton, (1996). Solid modeling as a tool for constructing solar envelopes, In *Automation in Construction* N°5, Amsterdam.

6. K. Kensek and R. Knowles, (1997). Solar Access Zoning: Computer Generation of the Solar Envelope, In *ACSA Southwest Regional Meeting,* Mexico.

7. T. Stasinopoulos, (2000). Solar envelope: a construction method using AutoCAD 2000, [Online]. Available: http://www.oikotekton.net/solenvelope/. [20 December 2009].

8. I. G. Capeluto and E. Shaviv, (2000). SustArc: a model for the design of urban fabric with solar rights considerations, In *the 17th international conference on Passive and Low Energy Architecture,* London.

9. F. O. R. Pereira, C. A. Nome Silva and B. Turkienkz, (2001). A Methodology for Sunlight Urban Planning: A Computer based Solar and Sky Vault Obstruction Analysis, In *Solar Energy*, vol. 70, n° 13, p. 217–226.

10. M. Juyal, K. Kensek and R. Knowles, «SolCAD: 3D Spatial design to generate Solar envelope», *ACADIA22: connecting the cross roads of digital discourse*, Muncie, Indiana, 2003.

11. C. Ratti and E. Morello, (2005). «Sun Scapes: extending the 'solar envelopes'concept through 'isosolar surfaces'» In the *22nd international conference on Passive and Low Energy Architecture*, Beirut.

12. P. Grazziotin, B. Turkienicz, C. M. D. S. Freitas and F. O. R. Pereira, (2002). Visualization Techniques in a Building Potential Simulator Using Sunlight Access Control, In *SIACG: Ibero-American Symposium in Computer Graphics*, Guimaraes.

13. L. R. Knowles, (1981). Sun Rhythm Form, Cambridge: MIT Press.

14. G. Casabianca, J. M. Evans and S. Schiller, (1991). Solar right and planning codes, In the *9th international conference on Passive and Low Energy Architecture*, Seville.