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The Shading Envelope: A morphology for climate change mitigation

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Abstract. This paper presents the Shading Envelope (OE) which outlines the smallest volume to shade neighbouring properties during summer overheating periods. The construction method of the OE, by means of a parametric visual programming tool, is presented. The solar geometry data required for its construction is deduced from energy simulations with respect to the climate needs. The study of the impact of the proposed model shows a significant improvement in terms of minimizing summer solar radiation and increasing urban density.

1. Introduction

For a number of scientists [1,2] climate change is increasing the frequency and the duration of heat waves and its related health threat. In fact, hot arid and even temperate regions tend to have hotter summers. A recent study [3] sounded an alarm bell about the fact that without an important reduction of greenhouse emissions, up to 75% of humans could be victims of deadly summer heat waves by 2100. Our carbon dependent cities are increasing risks of overheating and intensifying the urban heat phenomenon. It is therefore of critical importance to consider new urban planning strategies to deal with climate change mitigation and to avoid any adverse effects on the well-being of urban populations.

Although several factors such as construction materials and greening may influence the overheating risks as well as building energy consumption, shading is also likely to be important. Many authors [4–8] have demonstrated the importance of shading to decrease energy cooling use. However, these studies focused on the use of shading devices and vegetation to protect buildings from high summer temperatures.

This paper outlines the importance of shading morphologies. We propose to introduce the idea of “Shading rights” [9,10] in the urban planning process for arid and hot climates. This is made by introducing the Shading Envelope concept which purpose is to protect buildings from excessive sun exposure by mutual shading projection. This envelope outlines the smallest volume to shade neighboring properties during summer overheating periods.

We present in this paper a method, by means of a parametric visual programming tool, for determining the required data and constructing the Shading Envelope. This is transferable to different climatic conditions. A case study of the proposed method conducted in a hot arid climate demonstrates that the building morphology generated by the Shading Envelope outperforms by far the projected



Authorized Bounding Box ABB[11] in terms of minimizing undesirable solar radiation in summer as well as increasing urban density.

2. The Shading Envelope

The Shading Envelope OE is a derivative from the Knowles Solar Envelope concept [12]. It outlines a container generating shadows derived from the sun relative motion. Building over this container will protect neighboring properties during critical periods of high summer temperatures.

As the solar envelope, the Shading Envelope is conditioned in space and time;

First, this envelope outlines the smallest volume within time constraints, called *solar cut-off times*. The envelope cast shadows over a given limit at specified times of the day. We define this time period based on the intensity of the direct solar radiation during the cooling season in order to determine the time period of undesirable solar peaks. The reference day is the summer solstice where the sun is at its highest point which is a guaranty of shading projection all year around.

Second, it guarantees shading to the property surrounding a given site. The envelope accomplishes this by restricting undesirable sunrays inside a boundary delimited by neighboring property lines; these boundaries are called solar fences plane. Shading must reach at least the fences limit during the solar cut-off time at the reference date. It is however projected over this limit on other days of the year. We may have different levels of the solar fences plane depending on shading needs, for example one floor level.

3. The construction method of the Shading Envelope: Case study

In this paper, we present the construction method of a Shading Envelope to protect neighboring buildings facades from overheating summer sun. The case study is conducted for the climate of Tozeur (33°55'N 8°8'E), Tunisia. Tozeur has a hot arid climate. The weather is sunny throughout the course of the year with extremely hot summer temperatures often exceeding 45 °C in the shade. The technical guidelines of the 'Thermal and Energetic Regulation of New Buildings in Tunisia'[13,14] classify Tozeur into a climatic zone where cooling has an increased importance.

In this case study, the shading envelope is applied where streets and building blocks have their proper dimension and shape. We choose a trapeze plot surrounded by four buildings of mixed use with a commercial ground level and two office floors 'Figure 2'. This plot is projected to be constructed for a mixed-use building.

3.1. Determining the solar cut-off time

The determination of solar cut-off (ST) time is based on the intensity of the direct solar radiation in the cooling season which in Tozeur starts in June and ends in August. We use the Ladybug plugin [15] to calculate the hourly direct solar radiation received by the four surrounding building facades respectively named F1, F2, F3 and F4.

The results 'Figure 1' show that F3 facade is receiving a high radiation intensity during the 08:00-10:00 time period and F1 facade is receiving high radiation intensity during the 15:00 -17:00 time period. These two periods represent two pics of undesirable solar radiation for the cooling season. Therefore, the 08:00-10:00 and 15:00-17:00 periods are selected. However, because of solar geometry the solar cut-off time is extended from sunrise to sunset with $ST = [5:00-10:00] \cup [15:00-19:40]$.

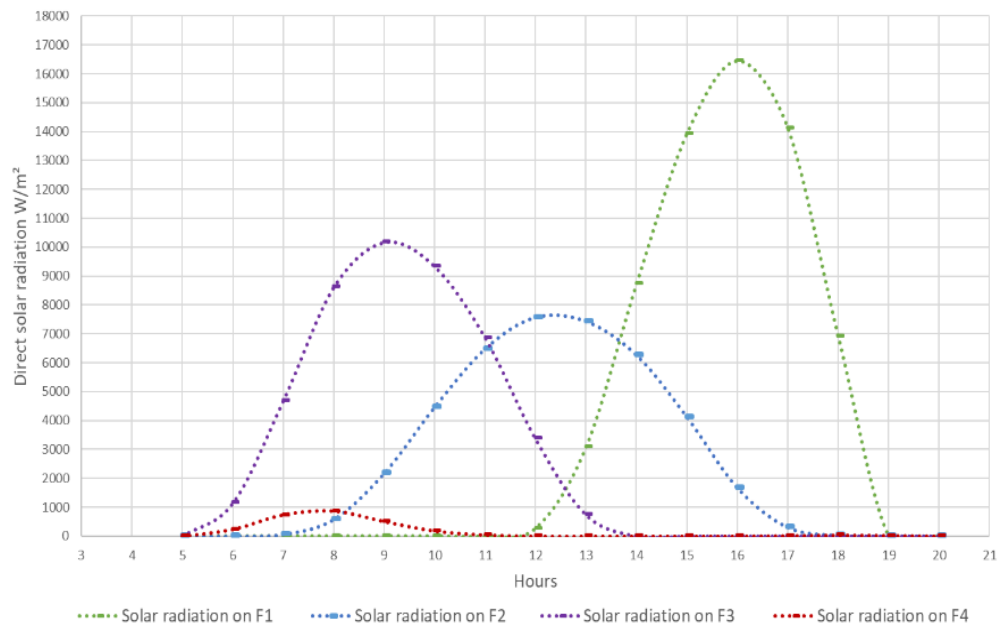


Figure 1. Hourly direct solar radiation received by F1, F2, F3 and F4

3.2. Determining the solar fences plane

The solar fences plane is delimited by the upper limit of facades receiving a high solar radiation intensity. In this case, these are the F1 and F3 facades which are the eastern and the western ones. These facades are with a height of nine meters 'Figure 2'.

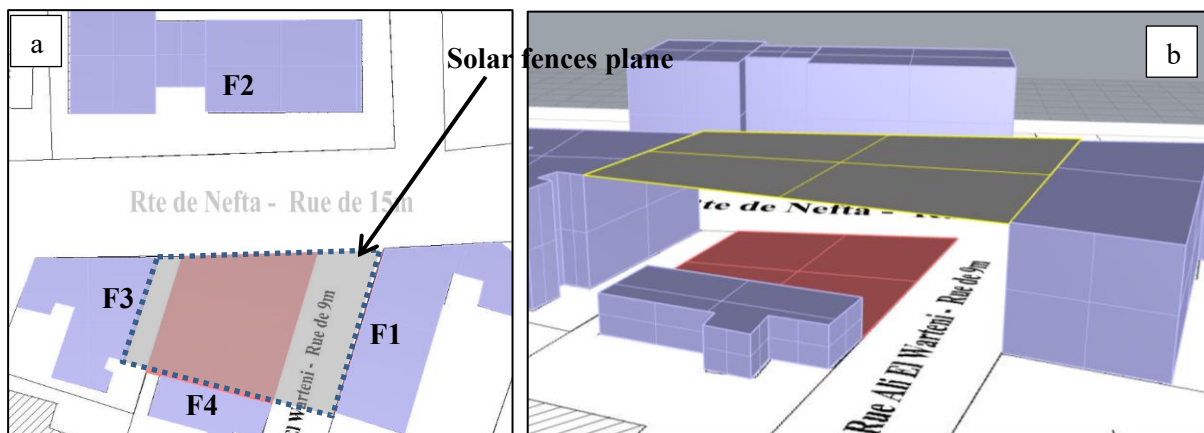


Figure 2. (a) Plot situation and (b) solar fences plane limit

3.3. Construction method

The construction method of the OE is an adaptation of the constructive method of Stasinopoulos [16]. The required data are: (i) the Solar cut-off time, (ii) the solar fences plane, (iii) the shape and dimension of the studied plot, (iv) and the location.

The construction procedure is the following: (1) generation of solar volumes by extruding the solar fences plane surface. The extrusion is performed twice one per each direction of the solar vectors at the two limits of the solar cut-off time. In this case study at 10:00 and 15:00 at the reference date of the summer solstice (2) generation of a volume by vertical extrusion of the plot surface. (3) Boolean intersection of the three volumes produced in step (1) and (2).

We build a Dynamo Component to facilitate the rapid construction and visualization of the Shading Envelopes within design-oriented software. Dynamo is a parametric visual scripting tool for the BIM

software Autodesk Revit [17]. The site location characteristics and the solar vectors are generated with Ladybug plugin [15]. The Shading Envelope that is generated with this component reaches a plot ratio of 8,4.

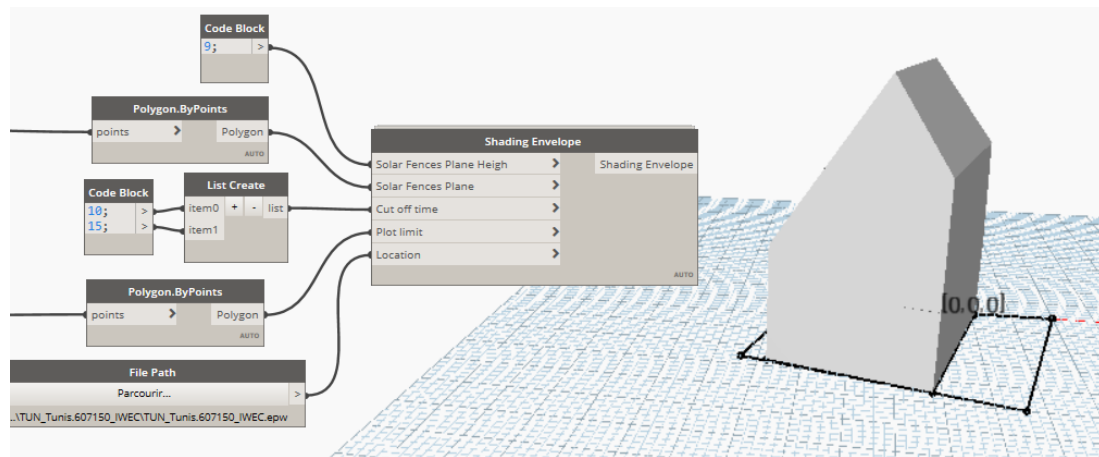


Figure 3. The Shading Envelope component

4. Study of the Shading Envelope impact

We study the impact of the Shading Envelope on the hourly direct solar radiation of F1 and F3 neighboring facades in the cooling season. This is achieved by conducting a comparative solar radiation analysis for two cases with different building morphologies. The first one is the calculation of a direct solar radiation received by the facades considering the Shading Envelope morphology. The second one is a scenario where the building morphology is created according to the local urban regulations. This morphology is called the Authorized Bounding Box ABB[11]. The produced ABB is lined up on the street without any setbacks from neighbouring buildings and with a plot ratio of 2,5. The comparison of the direct solar radiation intensity received by the F1 and F3 facades considering these two morphology cases is presented in 'Figure 4'.

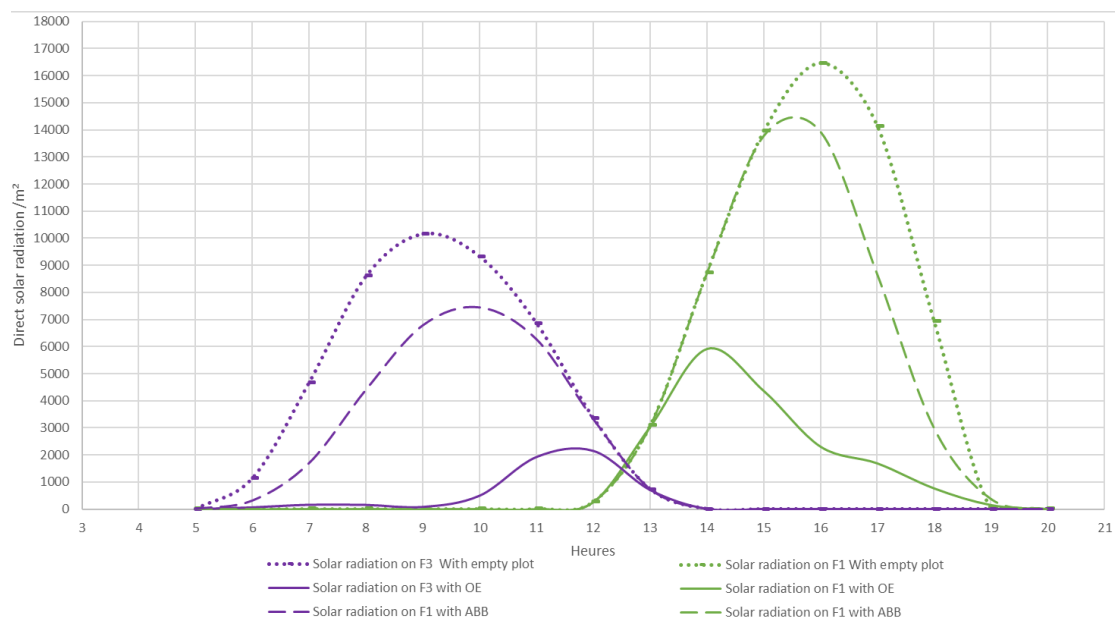


Figure 4. Comparison of the direct solar radiation received by the F1 and F3 facades with an empty plot, with the Shading Envelope and with the authorized bounding box

The Shading Envelope reduces significantly the solar radiation of the facades. Only 3% and 18% of the total radiation are received respectively by F3 and F1 in the period of the solar cut-off time. But, with the authorized bounding box these facades receive a high intensity of radiation over 60% of the total radiation for F3 and 78% for F1. The use of the OE as a building morphology outperforms by far the ABB in terms of reducing undesirable solar radiation during the summer. This heat loss would decrease evidently the amount of energy used for cooling. The created shading effect would help face the urban heat island phenomena and then would participate in climate change mitigation.

In terms of land use, the plot ratio for the ABB is 2,5 while the Shading Envelope is 8,4. The increase is important, more than three times the ABB plot ratio. These results provide an indication that the Shading Envelope is a suitable building morphology for similar hot and arid climates with considerably high developable densities.

5. Discussion

The case study presented in this paper evaluated the ability of the Shading Envelope to generate an urban morphology that protects buildings from overheating risks. This new building morphology with a high developable density could be an interesting framework for sustainable urban growth. Nevertheless, the proposed morphology should be tested in warm and cold climates. This is to show how, where, and in which conditions it could be transferable.

The impact of the Shading Envelope should be studied through additional environmental parameters, such as the natural daylight, the physical comfort and the Urban Heat Island so as to show how this morphology could interact with other important parameters.

Although the winter performance of the OE is not studied, it is safe to assume that the reduction of the eastern and western radiation doesn't impact significantly the southern facade solar radiation in winter. Thus, it would be interesting to examine its correlation with Knowle's solar envelope for the heating season. Could we model a morphology that should both preserve the winter beneficial solar radiation and avoid the summer undesirable one?

As mentioned above, the OE produces a high plot ratio. This issue may not arise for relatively small constructions, but development pressures usually require the largest practical volume. So, in order to reach the lowest volume for shading, it would be interesting to study how the OE could be transcribed in future urban policies. Could we face the "shading rights" concept to the "solar rights"?

Thus, future researches could focus on these discussed aspects of the proposed model, since that was not possible within the limits of this study.

6. Conclusion

This paper addresses building morphologies for hot summers and raises the question whether morphologies are suitable for limiting the cooling energy consumption. It proposes the Shading Envelope concept as the smallest volume for shadowing. The results of the case study show that, in terms of summer insolation and developable density, the OE morphology has an advantage. This concept would be useful to limit energy consumption for cooling and then to mitigate climate change.

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