

The Solar Block Generator: an additive parametric method for solar driven urban block design

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Abstract. This paper addresses the limitations of existing Solar Envelope (SE) methods to explore the trade-offs of solar radiation and urban shading, and to simultaneously account for several different Key Performance Indicators (KPIs). It offers an alternative parametric workflow - the Solar Block Generator (SBG) - which is based on an additive voxelization method by which multiple solar-driven massing alternatives are generated and evaluated for a given site, corresponding to a set of user-defined environmental KPIs. This method is tested here on an urban redevelopment case study in the Mediterranean (Tel Aviv). The results help achieve a more holistic approach for solar driven urban design.

1. Introduction

Designing the built environment based on solar positioning can be traced back from ancient history to the pre-air conditioning era. With recent rapid global urbanization, especially in hot regions where solar radiation and shading are the main driving forces for environmental performance, came the need for new methods to effectively explore the tradeoff between urban form and environmental performance through solar-driven approaches. An important milestone in this respect was reached in the mid-70s, when Knowles introduced the Solar Envelope (SE) concept- a spatial boundary which accounts for the solar access of the built environment for a given time frame [1]. Following the SE concept, several methods and tools were introduced: *SustArc* [2]- a computational tool which calculates the Solar Volume - a combination of both the Solar Rights Envelope as well as the Solar Collection Envelope; the *Residential Solar Block* (RSB) concept [3]- a harmonized approach which accounts for both winter exposure and summer shading; and the *RSB Envelope* [4]- in which through a sequence of computational steps, the spatial inputs for the solar calculations are based on the outputs of energy simulations. These methods can be regarded as ‘static’ i.e., they can only generate the largest theoretical spatial boundary for each building, defined by the solar angles for a specific analysis period and site morphology.



Recent advancements in digital workflows allow for more adaptive approaches: the *Parametric Solar Envelope* (PSE) [5] and the *Solar Envelope Tools* (SET) [6] are both Grasshopper-based workflows which enable an automated SE generation by users modifying weather data, geometry or programmatic requirements, in relation to different ordinances; the *Reverse Solar Envelope* method (RSE) [7] utilizes advanced subtractive methods combined with reverse raytracing to ‘carve’ out the built form in dense urban contexts to ensure solar access of the surrounding environment. These recent studies correlate well with recent trends in architectural design practices in which voxelated forms, driven by solar considerations, among others, are becoming more and more common.

Despite these recent advancements powered by the integration of digital tools into SE workflows, the application of the SE concept still has several limitations: (1) the outputs of current SE methods include a theoretical spatial boundary (space of solutions), rather than an actual building mass which is more useful for designers; (2) the SE boundary gives a very rough estimation of the tradeoff between the desirable and undesirable impacts of solar radiation for a given boundary; and (3) it usually accounts for only the worst case solar exposure and does not include other Key Performance Indicators (KPIs) such as energy consumption, daylight and outdoor comfort, or the tradeoffs between those metrics.

The overarching aim of this study is thus to address these shortcomings by capitalizing on the abilities of parametric geometry generation and optimization tools. This paper offers the *Solar Block Generator* (SBG) method as an alternative parametric workflow in which multiple solar-driven designs are generated for a given site - either a building addition or a new building mass - corresponding to a variety of environmental KPIs which can be defined and selected by the designer. In turn, the results of the analytical process are seamlessly streamed and can be post-processed visually by the user to achieve a more holistic solar driven design outcome. The following sections describe the analytical workflow and KPIs which were applied here on an urban regeneration case study in Holon, Israel, discuss the results of this study and conclude with some of its limitations and possible future developments.

2. Methodology

The SBG methodology consists of three main modules which interact seamlessly in Grasshopper - a parametric interface for the 3D CAD (computer-aided design) program Rhino (Figure 1):

2.1. The geometrical generator

The geometrical boundary is defined based on the following user inputs: the building’s footprint, the height limit, and the module (voxel) size. These inputs are automatically channeled in Grasshopper to a custom-made component in which the height of each corner of the building contour is used to generate a morphed box which then serves as a subtraction boundary to generate the solar masses. Here, a courtyard layout is considered, the height limit is set to 24 floors (corresponding to the surrounding context), and the voxel dimensions are set to 3.3 m. The dynamic corner height inputs (phase C in Figure 1), which are automated to modify within a certain range, trigger the parametric study of 6500 variations. For each iteration, the Floor to Area Ratio (FAR) is calculated - which is the ratio of the total building floor area to the site area. Corresponding to the local urban demographic needs, the motivation here is to double the existing density with the new solar driven block design. Thus, for each iteration, the corner input height values are factored to fit a total FAR of 5.2 (to double the existing density of FAR 2.6).

2.2. The analytical module

As a pre-analysis phase, a radiation study is performed for the maximum spatial boundary, to determine the context surfaces which are affected by the evaluated mass. The output context surfaces- roofs, south façades and outdoor surfaces (sidewalks and all private and public outdoor spaces), from this pre-study, are then used for the next analytical phase. Next, both the context and the proposed mass geometrical data are streamed to Ladybug [8] components in Grasshopper in which five different solar exposure and shading metrics (Table 1) are calculated for each iteration (approx. 10 sec per iteration). Exposure metrics include- (1) the Context Exposure Index (CEI), the New building Exposure Index (NEI) based on the Israeli green building code’s thresholds (SI 5281 [9]), and (3) the Sky Exposure (SE) metric [6].

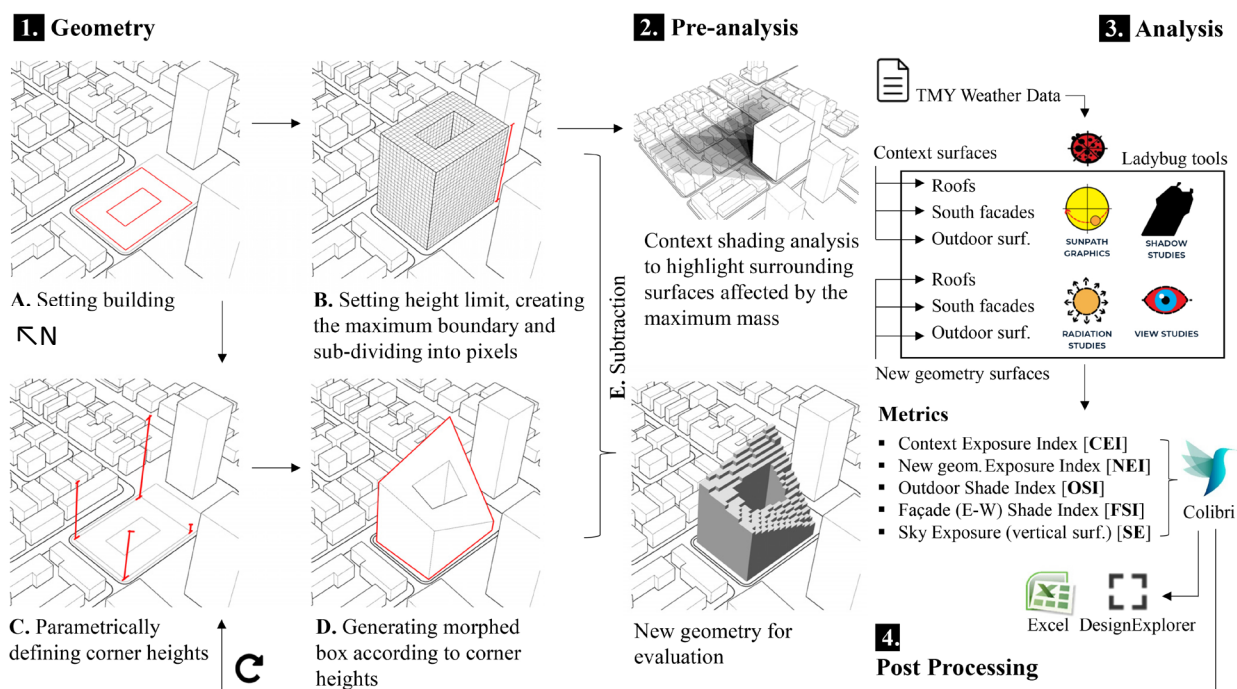


Figure 1. Analytical workflow

Shading metrics include - (4) the Outdoor Shading Index (OSI) [10], and (5) the East-West Facades Shading Index (FSI) [11]. The examination of these metrics allows the user to expand the performative perspective to various environmental performance considerations as well as to explore the balance between the different impacts of solar exposure, e.g., the tradeoff in higher density between visual comfort (SE), outdoor thermal comfort (OSI) and energy efficiency (FSI).

2.3. Post-processing and visualization

Finally, the results are recorded and streamed using the DesignExplorer platform [12], through which the tradeoffs between design alternatives and the resulting performance metrics are evaluated.

Table 1. Evaluation metrics used for the performance evaluation of each iteration.

metric	definition	Calculation method	Analysis period	units
CEI	Context Exposure Index	The average solar exposure compliance percentage of the following surfaces according to the respective thresholds taken from SI 5281 [9]: <u>Outdoor surfaces</u> - 0.9 kWh/m ² solar irradiation on at least 30% of surfaces <u>South facades</u> ¹ - 1.26 kWh/m ² solar irradiation <u>Roof surfaces</u> ¹ - 4 hours of solar exposure on at least 50% of each roofs surface	outdoor surfaces \ south facades - 21 st of December 08:00 – 16:00 roof surfaces - 21 st of December 09:00 – 15:00	[%]
NEI	New Building Exposure Index			
SE	Sky Exposure	The average percentage of the sky visible from each of the test point across all the <u>vertical surfaces</u> - averaged between existing and new masses.	N/A	[%]
OSI	Outdoor Shading Index	The average of the annual irradiation ratio between exposed and obstructed configurations of each point across the <u>outdoor surfaces</u> (in and around the site), subtracted from 1	Annual	[/]
FSI	East – West Facades Shading Index	<u>East and West facades</u> ' summer irradiation values (in MW/m ²), subtracted from 1 - averaged between existing and new masses.	1 st of June – 31 st of October	[1- MW/m ²]

¹ Additional condition for south and roof surfaces in CEI calculation- new mass should not compromise more than 20% of the exposure time of existing context surfaces.

The SBG workflow was tested on an existing urban block in Holon 32.0158° N latitude (Figure 2), situated in the greater Tel Aviv metropolitan area in Israel. This site, like many others, is being considered for redevelopment (i.e., demolition and new construction), through which its existing FAR is expected to double to meet the local demographic needs. Tel Aviv is categorized as a Hot-summer Mediterranean climate, in which solar radiation plays a pivotal role in energy demand, energy generation potential as well as indoor and outdoor environmental quality. Hence, this urban and climatic context is a suitable test bed for a harmonized approach which brings the above-mentioned indicators together.

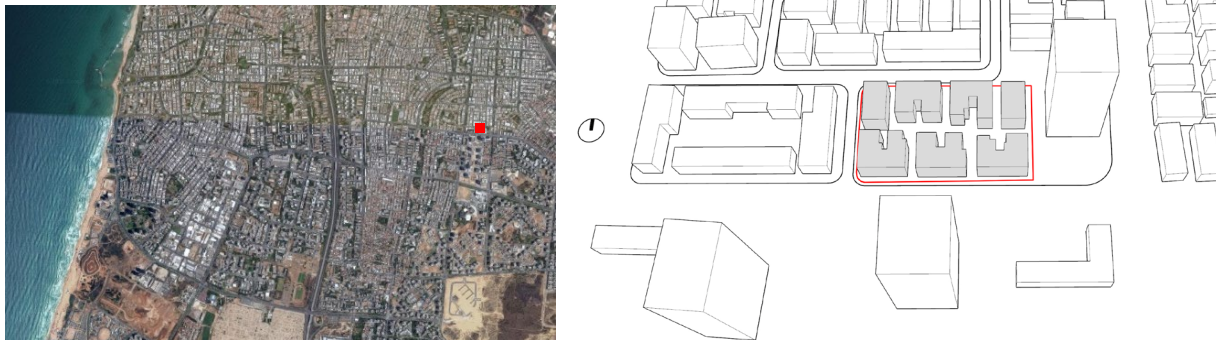
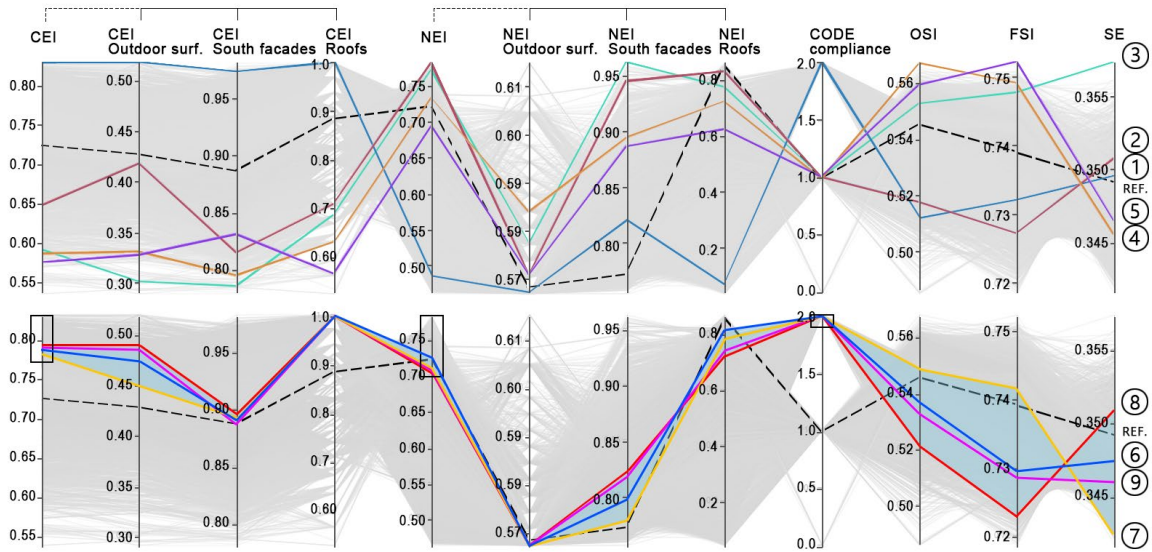


Figure 2. Redevelopment case study site in Holon, Israel (existing FAR- 2.6)

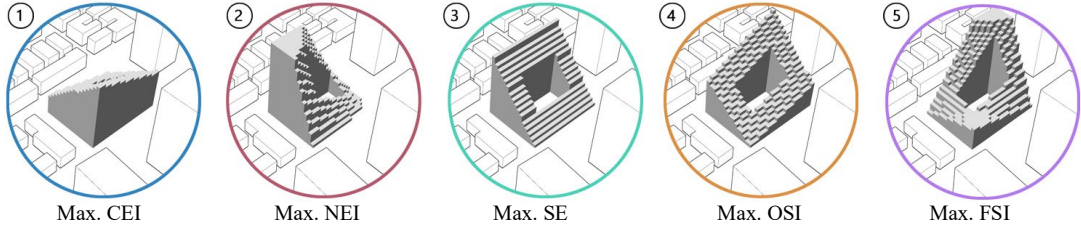
3. Results and discussion

Figure 3 shows two plots of the 6500 results recorded in the analysis using the DesignExplorer online platform. The top plot shows the entire range of results and highlights five different options among them (1-5), corresponding to five maximum values for the five evaluated metrics. The 3D visualizations of these options reveal interesting variability despite the constant FAR: the max. CEI (option 1) slopes towards the north as it is driven by the southern surfaces' exposure of the context while the max. NEI (option 2) slopes towards southeast, maximizing the new mass exposure (while disregarding the context exposure). Option 3 maximizes the SE metric which is disconnected from the solar positioning (driven by the sky hemisphere visibility of vertical surfaces). It results in a sharp inclination towards the south, different from the NEI, as it represents the sky exposure average between both the new mass and the context buildings, in this case the neighboring high rises south of the site. When considering annual shading of outdoor surfaces (OSI, option 4) and summer east and west façade shading (FSI, option 5), an examination of the numerical results shows the close correlation between the two metrics. These insights should be applied when selecting objectives for a multi-objective optimization study based on the SBG workflow. The bottom graph in Figure 3 reveals a selective range which reflects the boundary of results which achieve both the highest context and new mass solar exposure (CEI and NEI), as well as the highest possible solar exposure CODE compliance (in this case 2 pts.). Within that range, results 6-8 show different design configurations, each showing a different result when considering the three other solar exposure and shading metrics evaluated here (OSI, FSI and SE). Clearly, the design diversity diminishes, but even at this level of resolution, this plot enables the user to browse through different design alternatives (e.g., option 9), with both high context and self-exposure, as well as higher code compliance, while indicating the tradeoffs with other important environmental considerations. As the reference 'flat' option can be regarded as a mixture between the north sloping high CEI (option 1) and the south sloping higher NEI (options 2-3), this option offers a reasonable tradeoff, in this specific context, with surprisingly good performance in OSI, FSI and SE metrics.

Figure 4 describes the results obtained by running the six-metric evaluation workflow on three different masses generated by the three SE methods introduced earlier (PSE, SET and RSE) – based on the solar exposure thresholds indicated in Table 1. Note that the SE masses in Figure 4 represent the most stringent compliance with the code (3 pts.) and hence achieve lower FAR compared to the solutions



Design options from **full range** of results (top graph) -



Design options from **selective range** of results (high CEI, NEI and solar exposure CODE compliance) (bottom graph) -

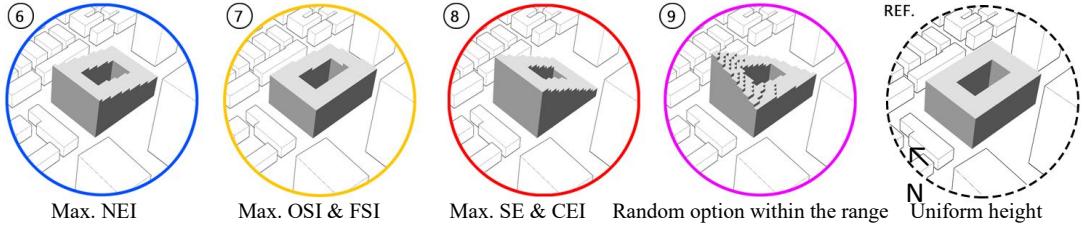


Figure 3. Nine design alternatives in two different ranges of results – full range (top) and selective range - highest CEI, NEI and CODE (bottom). All results correspond to FAR 5.2.

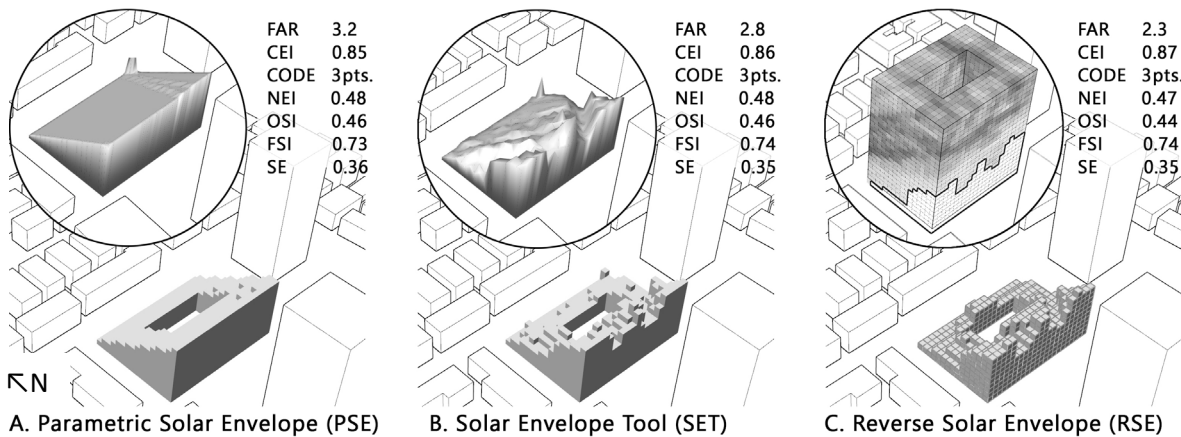


Figure 4. The results after running the analysis for the maximum boundary generated by three different solar envelope workflows for the site: PSE [5], SET [6] and RSE [7].

highlighted in Figure 3. The comparison between Figures 3 and 4 demonstrates how in contrast to the definitive masses described in Figure 4, which represent a self-contained maximum boundary, several spatial alternatives can be explored by applying the generative SBG method (Figure 3) – each representing a different trade-off between several solar-driven environmental objectives. In other words, the SBG allows the designer to obtain quantitative and spatial performance indications on a range of solutions within any given boundary rather than the representation of the boundary itself.

4. Conclusions

This paper presented the Solar Block Generator (SBG) workflow – a parametric generative approach to explore the environmental trade-offs of solar driven block designs. The application of this methodology on a case study in a coastal Mediterranean climatic context showed its potential to seamlessly generate a large design space, perform several analyses on each variable, based on the thresholds of the local code, and plot the results for visual selection by the designer. The SBG method adds a new perspective to the single boundary offered by the traditional solar envelope workflows and is suitable for a parametric design workflow in which multiple considerations interact and enrich the solar driven design outcome. In future research, we will test the SBG method in different climatic contexts and apply it to larger districts where several solar blocks interact using multi-objective optimization.

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