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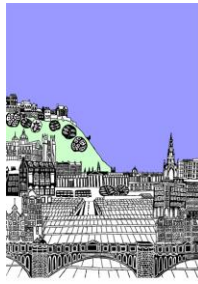
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Design to Thrive



Limiting the buildings' envelopes in order to prevent the surrounding mask effect: towards an efficient implementation in the context of SketchUp

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Abstract: The rise of technological advancements has come at a time of heightened awareness of the importance of analysing our cities' environmental impact, as well as the buildings which constitute them. One criteria for evaluating the quality of life may be the assessment of one's access to direct sunlight and of its optimization through architectural form. The attention to solar benefits was highlighted by Knowles in 1980, who defined the concept of "solar envelopes" in which an individual building's maximum volume is calculated depending on its direct impact on neighbouring buildings' solar accessibility. This approach produces an empathetic architecture, conceived with consideration for pre-existing or potential developments and their inhabitants, yet maintaining the goal of creating a dense urban environment. Originally implemented on hand-built models, we presently propose a new software implementation of Knowles' concept, integrated into a well-known, pre-existing ergonomic Computer-Aided Architectural Conception (CAAC) program, and made possible due to the democratization of available 3D urban GIS models. This tool also incorporates factors such as building usage and the corresponding productive periods of direct solar irradiation for its occupants.

Keywords: Solar Envelopes, T4SU, CAAD, Urban Form

Introduction

Initiated in 2014, the T4SU plug-in exploits SketchUp's built-in ray-casting feature to act as a "place of implementation" of concepts pertaining to human visual perception in the urban environment, such as the isovist or isovist field (Benedikt, 1979). T4SU can be used to describe the complexity of the representation of perception of urban space (Hartwell & Leduc, 2016).

Yet as Groleau (2000) states, the techniques used for the simulation and study solar radiation and lighting are identical to those used in the aforementioned study of (co)visibility, that is, the study of photon paths. Thus: *"Recognizing whether we are in the sun or in the shade is to be able to say if we can see the sun or not. Determining a level of luminance is to be able to identify the visible parts of the sky and evaluate their incoming radiation. Measuring the visual impact of a building comes down to determining from where and how we see it"* (Groleau, 2000).

It is therefore within this software environment that we wished to integrate amongst other elements, the sky view factor (Steyn, 1980), sky maps (Dupagne & Teller, 1999), and direct solar irradiation assessment (Littlefair, 2001; Littlefair, 1998). We discuss

here the implementation of R. Knowles' Solar Envelope in a vectorised simulation within the T4SU plug-in.

After detailing R. Knowles' concept of solar envelopes, we will delve into T4SU's framework and methodology for building such an envelope, after which we will give a concrete example and draw conclusions on the impact and pertinence of the criteria selected (i.e., the timeframe selected).

Solar envelopes

Solar Envelope Zoning is an approach to solar access protection (Knowles, 1974), originally conceived as a legal framework for city development in the same sense as traditional zoning plans. The solar envelope can be defined as a: *"space-time construct [...] defined by the parameters of land parcel size, shape, orientation, topography, latitude, and the urban context. Its time limits are defined by the hours of each day and season for which solar access is provided to neighboring land parcels, and the time interval will vary according to land use and community attitudes towards the value of solar irradiation"* (Knowles, 2003).

Its goal of establishing a necessary compromise between a city's development potential in terms of height and density and the inhabitants' right to sunlight at their homes or workplaces has a two-fold implication:

1. Protecting city dweller's right to direct sunlight, allowing a level of well-being and reducing the risk of property devaluation due to future surrounding developments;
2. Ensuring an even repartition of potential passive and active solar energy usage, thereby reducing heating costs and increasing the areas of potential renewable energy production such as rooftop solar panels.

Concretely, the solar envelope designates a maximum building volume for a specific parcel of land, constrained by the cited spatiotemporal criteria, as well as by local city regulations such as maximum building heights. The neighbourhood's urban morphology will also be a determinant, as street patterns, orientation, and size will greatly modify the envelope's dimensions.

Calculating the solar envelope defines the maximum volume available whose shadow does not impede on the surrounding buildings' footprints at a specific date and time. As such, the solar envelope's size is inversely related to time constraints: a longer time period or a time period closer to sunrise or sunset when the sun is low on the horizon will necessarily imply a large shadow area which will greatly constrain the envelope's maximum height.

Determining adequate time periods must therefore depend on a case-specific compromise between desired solar access and urban development needs. Moreover, surrounding buildings' functions, uses, and occupancy may indicate adequate timeframes. In effect, office buildings need only receive sunlight during their operating hours. Inversely, housing requires sunshine at least during the early mornings and evenings, when the building is most likely to be occupied.

Further this pragmatic, rational approach to urban planning, this model of maximizing solar benefits initially embodied an urban "utopia" intrinsic to its age (Siret, 2011). Today, utopian objectives show a regain of interest due to the increasingly recognized climatic urgency. Regardless of the legal and political considerations of such zoning, it is important to note that Knowles' work on low- and mid-density urban tissues (Knowles & Berry, 1980) have helped prove the theoretical feasibility of such a concept at certain latitudes, in terms of design, housing density, and commercial use.

Context

Although the practical application as a city-wide regulation has not yet been implemented, Knowles' work has drawn a renewed interest, especially with the renewed will to create a "post-carbon society" (Vartholomaïos, 2015). This dynamic has led to several different recent implementations of Knowles' solar envelopes based on varying media (Freitas et al., 2015), for example by utilizing Digital Elevation Models (DEMs) (Ratti & Morello, 2005). Expanding the original notion of solar envelope, the "solar volume" is the combination of a "solar right's envelope" (SRE), equivalent to Knowles' solar envelope, and a "solar collection envelope" (SCE), the lowest height at which a point will be shaded by its environment during the summer and exposed to direct sunlight during the winter (Capeluto & Shaviv, 1997).

The "residential solar block" (Vartholomaïos, 2015) is inspired by the concept of the "urban block", which integrates the concept of solar envelopes on a larger scale instead of a single building (Okeil, 2010). "iso-solar models" (Morello & Ratti, 2009) replace the binary system (sun or shade) by a quantification of the direct solar irradiation, therefore taking into consideration the sun's angle of incidence but removing the concept of "adequate timeframes" within a day.

This particular implementation is set in SketchUp which enables rather direct importation and exportation of geometries to/from other CAAD or simulation softwares, including those produced by the solar envelope analysis presented in this paper. Furthermore, T4SU enables importation and exportation of geographic data (shapefiles, csv, well-known text and binary files) as well as triangulated geometry such as terrain models, in order to facilitate the setting of the correct pre-existing built environment. As such, T4SU acts as a 3D GIS extension – in opposition to classical 2.5D GIS systems – which is necessary for the precise evaluation of environmental factors.

Use case

Site presentation

This case study focuses on the solar impact of a building recently constructed on the university campus of Nantes, France. Members of the CRENAU laboratory have a pronounced interest in this construction building, as the amount of sunlight available in the staffroom has noticeably decreased at times when it was most occupied, i.e. our adequate timeframes of coffee breaks (10:00, 16:00) and lunch breaks (13:00). As shown in Figure 1, this new building, indicated in green, is found to the south-west of the CRENAU laboratory, shown in the upper right-hand corner.



Figure 1. 3D Map of the area, with the new building in green and impacted buildings in red. Green Axis leading north, red axis leading east. The yellow arrow figures the point of view of the Figure 3.

Simulation results

Figure 2a displays the resulting ratio, over the second half of the year and for the three aforementioned times, between the maximum volume, which depends on criteria such as local zoning plans and guidelines, and the calculated solar envelope. As we can see, during nearly one third of the year, the newly erected building has no impact on its surroundings, as shown by the ratio of “1” during that timeframe (days from 174 to 234, also implying days 113 to 173), and drops to less than 40% of the original volume nearing the winter solstice (days 324 onwards, for the 16:00 timeframe). This relatively high ratio is in part explained by the width of the road (13.5m) separating it from its northern neighbouring buildings, and the lack of buildings in the direct proximity to the east and west.

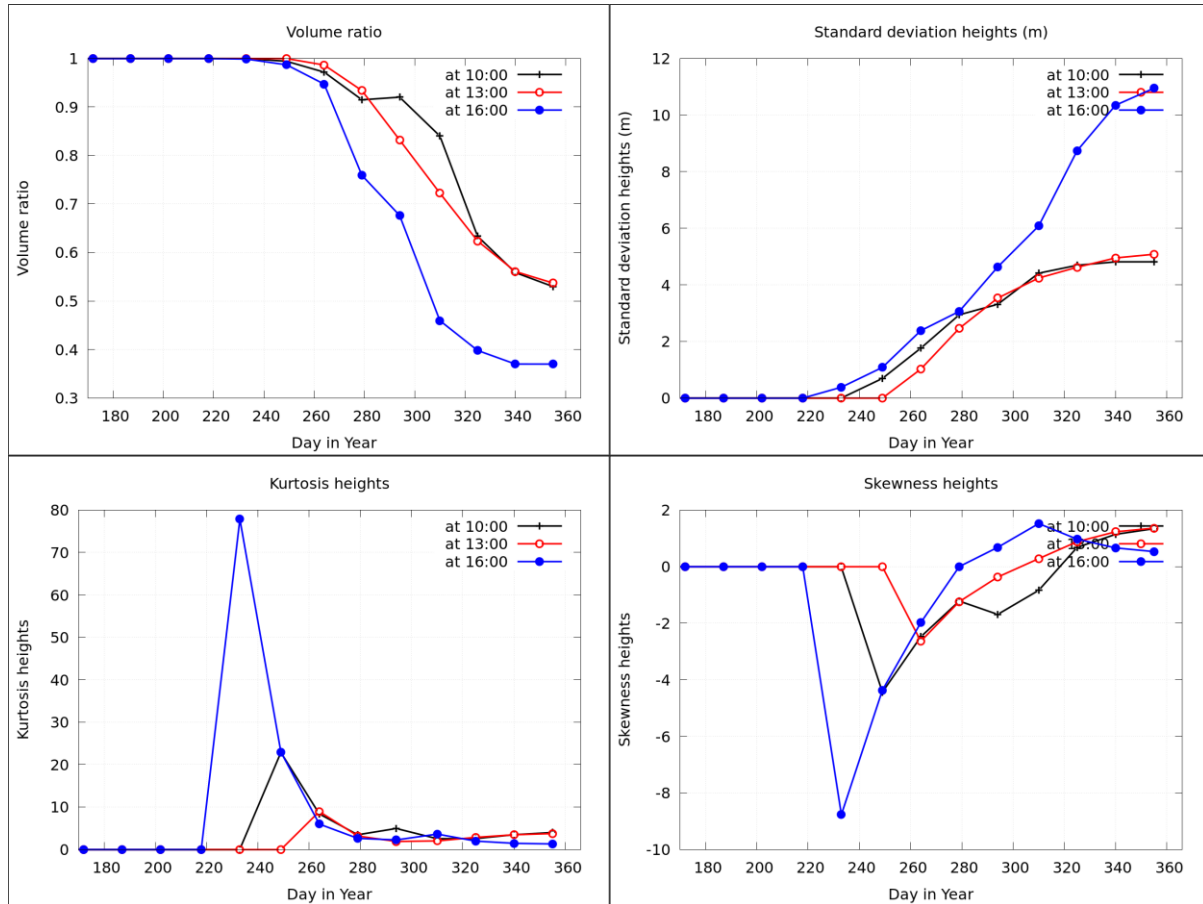


Figure 2. Statistical results of the Solar Envelope for three different timeframes between June and December: a. Size of the Solar Envelope relative to the maximum constructible volume, b. Standard deviation of the heights of the Solar Envelope, c. Kurtosis of the distribution of heights of the Solar Envelope, d. Skewness of the distribution of heights of the Solar Envelope.

When analysing the qualitative state of the resulting envelopes (Figure 3), one may notice the difficulty of deducing a form which would fulfil all adequate timeframes completely, as morning hours create west-facing slopes, and afternoon hours create mainly eastern-facing slopes. Nevertheless, the maximum height can still be reached at certain specific areas of the envelope, even when the sun is extremely low on the horizon. As the building's shadow crosses the street and hits the adjacent buildings footprints, the average height decreases dramatically and the standard deviation increases (Figure 2b). This is visually verifiable (Figure 3), as we notice the formation of tower-like structures reaching maximum height, surrounded by increasingly low and decreasingly slanted plateaus. This is the result of neighbouring cross-streets or indents in the streets' alignments: as the sun approaches the horizon, longer shadows will either be stopped prematurely, resulting in very low envelope heights, or fall along a road, resulting in near-maximum heights. Therefore, as the cast shadows grow longer at the approach of the winter equinox, the standard deviation is more likely to be higher. Conversely, closer to the summer equinox, much more of the shadow is likely to be cast on the street than on the adjacent buildings, leading to a lower chance of a high standard deviation and a more uniform solar envelope.

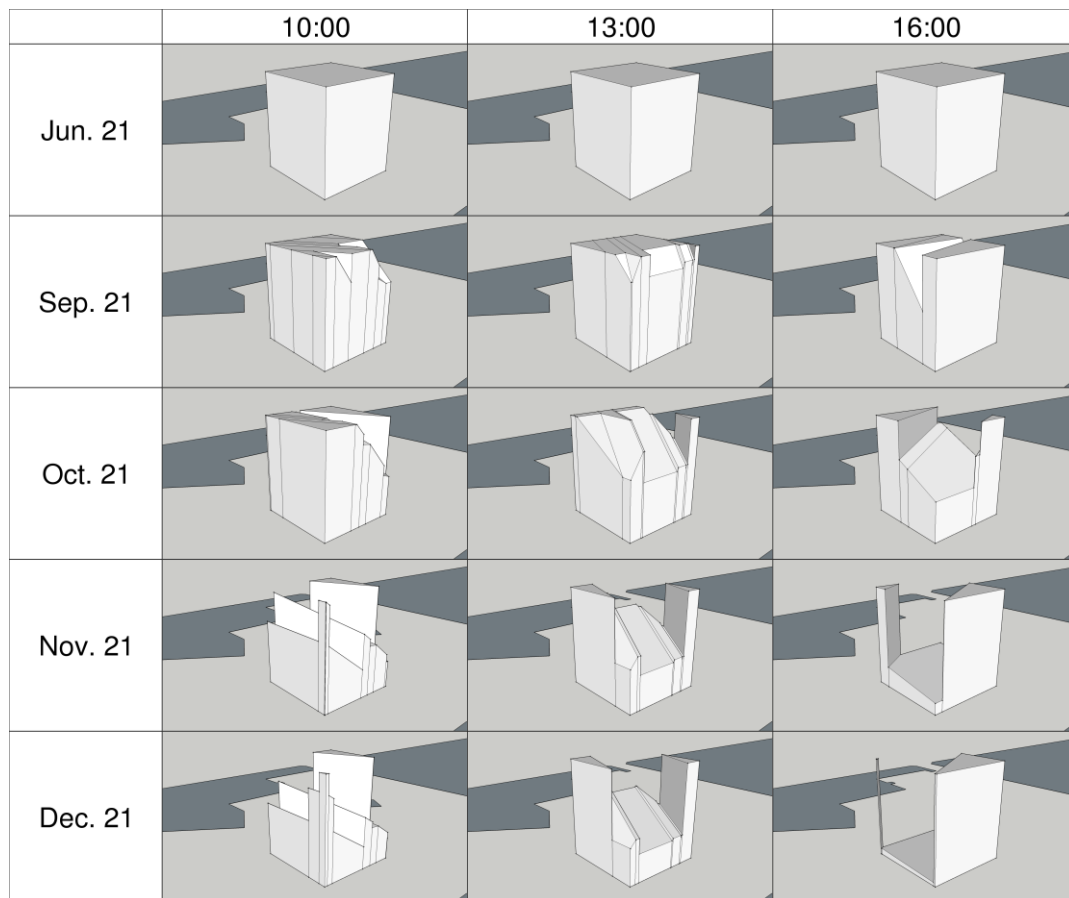


Figure 3. Examples of resulting Solar Envelopes' evolving forms throughout the year, for adequate timeframes.

A careful analysis of the skewness (Figure 2d) and kurtosis (Figure 2c) of the different timeframes taken into account allow us to make certain connections between the distribution of values and the resulting form. A negative skewness (found on October 6th at 16:00, October 21st at 13:00, and November 5th at 10:00) gives the impression of a chiselled block (e.g. Figure 3, September 21st), as a uniform rooftop is created, permeated by small, varyingly deep, angled sections. Inversely, solar envelopes with a positive skewness (e.g. Figure 3, November 21st) tend to have a low plateau with certain small sections – resembling towers – reaching maximum height. The higher the kurtosis, the more pronounced and visible the difference is between “tower” and “plateau” (positive skewness) and “chiselled block” (negative skewness).

Discussion

As previously mentioned, building use is of importance for selecting initial adequate timeframes. If the surrounding buildings are mixed-use, where, for example, the ground floor is occupied by retail and the upper floors are residential, this might require multiple time constraints. If maximizing passive energy reception is the main objective, setting the shadow limits to the footprint (i.e., ground level) of the surrounding buildings would yield the best results, as it implies that these building are completely devoid of shade. Yet, if the objective is to ensure direct sunlight infiltration into surrounding buildings, the aforementioned shadow limit may be considered too constraining and could be re-evaluated to match the building's ground floor window height (Littlefair, 1998), which would produce a larger available solar envelope.

Several problems originate from the binary nature of this solution to the question of urban environments.

The produced shapes - which respect the solar access of the surrounding buildings - may be chaotic or even inoperable. As such, the envelopes have much more to do with the modelization of new building constraints for information visualization and respectful planning, than with morphogenesis engines and the production of architectural form.

The aim is here to reduce the building envelope according to the savings in potential solar resource, but one can note that this resource preservation is absolutely not exhaustive and mainly arbitrary; we could also embed other criteria such as aeraulics, acoustics, or thermal potentialities of the studied site for legislation that may pertain to, for example, increased air circulation in street canyons.

Given the goal of solar potential maximization, several problems may arise. Prolonged direct irradiation may cause neighbouring buildings discomfort, such as glare or overheating, especially during canicular season. By reducing architectural masks, there is also a potential reduction of local cool island areas. Although the street is more exposed to sunlight, it is not yet sure if this produces a greater heat island effect as the sky view factor is also increased locally by the reduction in building height.

Conclusion

A concise presentation of the evolution of the concept of Solar Envelopes engenders a more complete perspective of solar impact. The implementation within T4SU, inscribed in a wide range of other solar potential modelizations, helps in calculating and visualizing these yearly impacts at given timeframes. In contrast to Knowles' model, the solar envelope is here seen as more of a design guide than as a potential constraint. In pair with increased solar access, the concrete implementation of techniques such as these should also increase the potential for sun-based urban energy production. It may be noted that very few cities have implemented such legislation, but various cases do exist in France and elsewhere: Saint Nazaire, Marseilles, Amiens, Milan, Tokyo and Hong Kong all have different planning regulations regarding the solar access of neighbouring buildings. This case study was detailed in order to demonstrate the variability of the results, explicating the need for data interpretation, informed decision-making, and respectful architecture.

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