The aim of these workshops and conference is to help transfer and spread newly appearing design technologies, educational methods and digital modelling supported by information technology in architecture. By organizing a workshop with a conference, we would like to close the distance between practice and theory.

Architects who keep up with the new designs demanded by the building industry will remain at the forefront of the design process in our information-technology based world. Being familiar with the tools available for simulations and early phase models will enable architects to lead the process. We can get "back to command".

The other message of our slogan is Back to command.

In the expanding world of IT applications there is a need for the ready change of preliminary models by using parameters and scripts. These approaches retrieve the feeling of command-oriented systems, DOWKRXJKZLWKPXFKJUDWHUHFWLYHQHVV

Why CAADence in architecture?

"The cadence is perhaps one of the most unusual elements of classical music, an indispensable addition to an orchestra-accompanied concerto that, though ubiquitous, can take a wide variety of forms. By GHȴQLWLRQDFDGHQFHLVDVRORWKDWSUHFHGHVDFORVLQJIRUPXODLQZKLFKWKHVRORLVWSODVDVHULHVRI personally selected or invented musical phrases, interspersed with previously played themes – in short, a free ground for virtuosic improvisation."
CAADEnce in architecture
Back to command
Edited by Mihály Szoboszlai
CAADence in Architecture
Back to command

Proceedings of the International Conference on Computer Aided Architectural Design

16-17 June 2016
Budapest, Hungary
Faculty of Architecture
Budapest University of Technology and Economics

Edited by
Mihály Szoboszlai
Theme

CAADence in Architecture
Back to command

The aim of these workshops and conference is to help transfer and spread newly appearing design technologies, educational methods and digital modelling supported by information technology in architecture. By organizing a workshop with a conference, we would like to close the distance between practice and theory. Architects who keep up with the new design demanded by the building industry will remain at the forefront of the design process in our IT-based world. Being familiar with the tools available for simulations and early phase models will enable architects to lead the process. We can get “back to command”.

Our slogan ”Back to Command” contains another message. In the expanding world of IT applications, one must be able to change preliminary models readily by using different parameters and scripts. These approaches bring back the feeling of command-oriented systems, although with much greater effectiveness.

Why CAADence in architecture?

“The cadence is perhaps one of the most unusual elements of classical music, an indispensable addition to an orchestra-accompanied concerto that, though ubiquitous, can take a wide variety of forms. By definition, a cadence is a solo that precedes a closing formula, in which the soloist plays a series of personally selected or invented musical phrases, interspersed with previously played themes – in short, a free ground for virtuosic improvisation.”

Nowadays sophisticated CAAD (Computer Aided Architectural Design) applications might operate in the hand of architects like instruments in the hand of musicians. We have used the word association cadence/caadence as a sort of word play to make this event even more memorable.

Mihály Szoboszlai
Chair of the Organizing Committee
Acknowledgement

We would like to express our sincere thanks to all of the authors, reviewers, session chairs, and plenary speakers. We also wish to say thank you to the workshop organizers, who brought practice to theory closer together.

This conference was supported by our sponsors: GRAPHISOFT, AUTODESK, and STUDIO IN-EX. Additionally, the Faculty of Architecture at Budapest University of Technology and Economics provided support through its “Future Fund” (Jövő Alap), helping to bring internationally recognized speakers to this conference.

Members of our local organizing team have supported this event with their special contribution – namely, their hard work in preparing and managing this conference.

Mihály Szoboszlai
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Solar Envelope Optimization Method for Complex Urban Environments

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Abstract: Planning requirements in terms of energy efficiency and daylighting strongly contribute to shaping the layout of cities. Direct solar access is the main requirement of the right to light in Estonia. Direct sunlight hours on building facades can be calculated by using environmental simulation software that also allows right-to-light analysis through the generation of the Solar Envelope. It is a method for calculating the maximum buildable volume that allows neighbors to receive the required amount of direct sunlight in a specific period of the year. The Solar Envelope can be determined on paper or more easily using simulations. The methods used by actual environmental software have significant limitations if used in complex urban environments. This paper discusses the potentialities of multi-objective optimization tools to generate Solar Envelopes for multiple facades with different orientations and specific amount of direct solar access requirements. The results show the superiority of the developed method that integrates parametric design, environmental simulations and multi-objective optimization, compared to existing methods.

Keywords: Urban Design, Direct Solar Access, Solar Envelope, Environmental Simulations, Multi-objective Optimization

DOI: 10.3311/CAADence.1657

INTRODUCTION

Natural light is one of the main factors affecting the physiological and psychological well-being of inhabitants of living environments. Natural light enters buildings in different ways: as direct solar radiation, diffused by the sky and the clouds, reflected by the surroundings. Direct solar radiation is considered to be the most valuable source of natural light in residential premises for its quantity, quality and distribution potentialities. The quantity is the necessary illumination needed to perform specific tasks with ease and comfort. The quality is the property characteristic of natural light to illuminate the interiors with the full spectrum of the visible portion of the electromagnetic radiation [1]. The distribution uniformity is guaranteed by a sufficient quantity of natural light and by proper interiors and windows layout that diffuse it first where it is more necessary [2]. Planning requirements, different from country to country, are set to guarantee sufficient natural lighting in residential premises.

The present work is based on the necessity to tackle specific problems encountered during a research conducted using computational and envi-
environmental tools to analyze the potentialities of in-fill of existing residential area located in the Soviet era quarter of Mustamäe in Tallinn (Lat. 59°26'N Lon. 24°45'E), Estonia. Direct solar access is regulated in Estonia by the standard “Daylight in dwellings and offices” [3]. The requirements state that new constructions cannot deprive the direct solar access of existing surroundings of more than 50% on a daily basis. The requirements concern the period from 22nd of April to 22nd of August. When designing the masses of new building that has to guarantee a required direct solar access on existing neighboring facades, the Solar Envelope method is an intuitive approach for the definition of the maximum volumes [4]. Differently than other regulations that use the setbacks method, the Solar Envelope is based on the characteristics of size, orientation and location of the building that will not cast shadows on the surroundings for a given timeframe and period of the year [5]. The calculations for the determination of the Solar Envelope can be done on paper using the data of the solar azimuth and elevation at the desired hours of the day and cut-off dates [6]. However, the calculation on paper is a long process and very imprecise for urban environments. Nowadays many CAD and parametric software that integrate environmental simulation tools include the possibility to calculate Solar Envelopes automatically [7, 8]. It is an easy procedure that requires few inputs, among which the main are: latitude of the area; boundaries of the neighboring buildings or baselines of the facades not to be shaded; boundary of the Solar Envelope; cut-off dates of the year and the desired start and end time of direct solar access that has to be guaranteed every day on the facades of the surrounding buildings. The result is a complex shape envelope that can be used as a volumetric limit to design one or more buildings with the desired layout, the mass of which does not have to exceed the Solar Envelope. A significant limitation of the above mentioned method to generate Solar Envelopes used by state-of-the-art simulation software is represented by the daily start and end time of the cut-off period to determine the required number of direct solar access hours. Although it works for a single façade without surroundings, it is not efficient if used in articulated urban environments where different facades need specific amounts of direct solar access. To guarantee the same right-to-light for different orientations’ facades it is necessary to consider different start and end time durations, one per façade, of the same cut-off period, or a method to generate the Solar Envelope based on the different actual quantities of direct solar access hours. Due to the complexity of the urban environment subject of the studies and the big difference of actual direct solar access hours on the different buildings’ facades (Figure 1), an alternative and more efficient method is developed. The author proposes a method to generate So-

Figure 1: Direct solar access hours simulation (min. values) for the main facades of the buildings in the whole area of study.
lar Envelopes that take into account multi-directional direct solar access requirements for complex urban environments. This method has been developed for the project of assessment of the potentialities of in-between construction in existing residential areas in Tallinn, integrating direct solar access hours calculations through computational environmental simulations, Solar Envelopes generation using parametric design and multi-objective optimization plug-in. The algorithm is designed using the visual programming tool Grasshopper for Rhinoceros 3D modeling software. The environmental simulations tool used for the calculation of the direct sun light hours in Grasshopper is Ladybug [9], based on the sun-path scripting function of Radiance, a validated lighting simulation tool [10]. The multi-objective optimization plug-in used is Octopus [11] that permits to apply evolutionary design principles in Grasshopper.

METHOD
The method described is applied to one group of four housing buildings of the whole study location. The four buildings of five floors of three meters each form an open boundary with an area in-between on which the Solar Envelope has to be calculated. The facades are oriented South, East, West and North-East. The area is 8 meters away from the buildings for fire security regulations. The buildings facades are divided in modules of 3x3 meters, each one with a window that in the simulation model is a node, i.e. a sensor for the computation of the direct sun light hours.

Actual Situation
First, the total direct solar access hours in the actual situation for the given period from 22nd April to 22nd August on the facades surrounding the area are determined through simulation of the sun-path and relative sun vectors. Second, after splitting the direct solar access hours for each of the 123 days of the analyzed period, the minimum, the maximum and the averages values are calculated for each façade/node/day. The minimum values are used in the development of the method because these are required by the standard (Figure 2). Since the Solar Envelope uses the baselines of the surrounding facades as the right-to-light start point and in a complex urban environment the lowest floors receive the least light, the minimum direct solar access hours values of the first floors nodes are used as the target. This guarantees that the least exposed portion of the façade also gets the necessary quantity of 50% of direct sunlight hours compared to the actual situation.

Having determined the minimum quantity of direct solar access hours on the first floor of each façade’s module in the actual situation, the values are reduced by 50%, which is the minimum required by the Estonian standard.

Figure 2: Direct solar access hours simulation (min. values) for the four facades surrounding the in-between area.
**Existing Method**

For comparison and evaluation of the proposed optimization method a Solar Envelope is generated with the existing method using two procedures. The required minimum number of hours previously calculated, is used to determine the different start and end time per façade in the cut-off period. Since the existing method requires only one time range, the time ranges of each facade are merged into one period. The baseline for calculation is one single contour for all the facades. The base of the Solar Envelope is the border of the area. The resulting Solar Envelope is a surface, defined by a three-dimensional grid of points, used to build the underlying volume of 18.115 m³ (Figure 3 left). This allows much more than the required 50% of minimum direct sun light hours on the surrounding facades, as exemplified by the deviation between the simulation with the Solar Envelope and the existing situation, done on the sample nodes on the first floor facades (Table 1). The second procedure is an advanced use of the existing method. It splits the generation of one single Solar Envelope into as many as the number of the surrounding facades and merges them in one resultant volume. For each façade its own time frame is used. The facades’ baselines are one line for each façade. The outputs are four three-dimensional grids of points, one for each Solar Envelope. Consequently the four grids are merged into one, selecting the corresponding points of the grid with the lowest Z coordinate through a selection algorithm. The lowest Z values guarantee that each facade node receives the minimum direct solar access required. The resultant grid of points is used to generate the top surface of the Solar Envelope with a volume of 45.995 m³ (Figure 3 right).

The resultant Solar Envelope is much larger than the one generated with the basic existing method. Nonetheless, the direct solar access hours on the surrounding facades are still significantly more than the target of 50%, as exemplified by the deviation of minimum direct sun light hours (Table 1). Therefore both the existing methods underestimate the buildable volume represented by the Solar Envelope.

**Multi-objective Optimization Method**

Due to the inadequacy of the existing method to generate Solar Envelope for complex urban environments and for different time ranges, a new method is developed that uses the actual amount of direct solar access hours on the facades and multi-objective optimization through the Octopus plug-in for Grasshopper. The evolutionary software looks for the best trade-offs between multiple fitness values (objectives), breeding multiple genes during a process of evolution through generations. It uses the Pareto principle that allocates optimal distribution of resources, in which one characteristic can be improved if another is degraded. This way, optimized solutions are generated. These present a range of trade-offs of the resources among which one can select the most efficient for the design task.

The developed method uses three objectives. The first derives from the Estonian standard described [3]. It is the deviation between the sun light hours obtained by simulation with each Solar Envelope and those required, which are 50% of the existing situation. The same cut-off period from 22nd of April to 22nd of August is used, but a start and end time per façade are not required. The objec-
Figure 4: The three dimensional grid of the multi-objective optimization method with the different objectives on the three axes: X the direct sunlight hours deviation, Y the volume of the Solar Envelope and Z the sum of the minimum direct sunlight hours. The items are the optimized solutions. A, B and C are the Pareto-front solution selected for the method evaluation.

The second objective is to maximize the volume of the Solar Envelope. The third objective is to maximize the sum of the minimum direct sunlight hours per facade/node/day calculated over the entire period on all the first floors nodes. These objectives have been selected because the scope is to find the biggest possible Solar Envelope shape that allows for the required minimum direct sunlight hours on the surrounding facades.

The Solar Envelope that the algorithm evaluates at each iteration of the multi-objective optimization solver is a Mesh built using the parameters of position and height of 9 points. These points are the four corners of the area, four points that can move along the edges and one point that can move in the two X and Y directions inside the area. The positions and heights of the points are the genes used by the evolutionary software.

The result of the evolution process after a number of generations is a three-dimensional grid of the optimized trade-off solutions, the fittest non-dominated Pareto-front, the elite ones and the last in the evolution history. The three axes of the grid represent each objective of the optimization: X the direct sunlight hours’ deviation, Y the volume of the Solar Envelope and Z the sum of the minimum direct sunlight hours. The fittest solutions are those closer to the origin of the grid and to each axis for every specific objective. For the evaluation of the method, three solutions are selected among the Pareto-front (A, B and C), with different objectives’ trade-off optimizations (Figure 4).

Solution A presents a direct sunlight hours’ deviation of 4, a maximum volume of 139.100 m³ and a total amount of minimum direct sunlight hours of 427. The corresponding values of solutions B and C are 6, 169.298 m³, 325 and 8, 202.725 m³, 267 respectively (Table 1). From the three-dimensional grid solutions’ items, the Solar Envelopes are re-instated in the 3D modeling software (Figure 5). All three Solar Envelopes selected present larger volumes compared to those generated with the existing methods (Table 1).
With the increasing volume size, the minimum direct sunlight hours’ deviation also increases (absolute values) and the sum of minimum direct sunlight hours decreases. The outcomes show that the Solar Envelope A is the most efficient. It presents the smallest deviation and is 7.6 and 3 times bigger than those generated with the existing methods (Table 1).

### CONCLUSIONS

The simulation tools for generating Solar Envelopes available in the actual environmental design software have significant limitations when used in complex urban environments and for specific requirements of direct sunlight hours. The limitations result from the use of a start and end time for the days of the cut-off period. The Solar Envelope generated to evaluate the maximum buildable volume on a designated area is smaller than what is allowed. This way, its mass allows more than the required minimum number of hours of direct solar access on the neighboring facades but the possible buildable floor area in the plot is underestimated. 

The method developed by the author using algorithmic parametric design and multi-objective optimization software has proven to be superior when compared with actual simulation tools. The advantage of this method is the possibility to use the actual amount of direct solar access hours for each façade of a complex urban environment. The improvement lies in not being bound to the start and end time used in the exiting methods that is a user input and not obtained by simulation. This way, the Solar Envelope is optimized for the shape, orientation, obstructions and specific direct sunlight hours requirements of each neighboring façade.

The utilization of the required amount of direct sunlight hours and the Solar Envelope volume as the multi-objective optimization software constitutes the big potentiality of the developed method. The three Solar Envelopes are more efficient because they permit a much larger buildable volume with small deviations of the values of the minimum direct sunlight hours required. Future work for the improvement of the method is the optimization of the objectives related to the direct sunlight requirements and the Solar Envelope volume, and to increase the number of control points of the Solar Envelope to generate a more accurate shape. This will eliminate the small discrepancy in the required direct sunlight hours, while still maintaining the possibility to generate maximized volume Solar Envelopes.

<table>
<thead>
<tr>
<th>Solar Envelope type</th>
<th>Existing method</th>
<th>Existing advanced method</th>
<th>Multi-objective optimization A</th>
<th>Multi-objective optimization B</th>
<th>Multi-objective optimization C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct sunlight hours’ deviation</td>
<td>21</td>
<td>18</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Volume of the Solar Envelope (m³)</td>
<td>18.115</td>
<td>45.995</td>
<td>139.100</td>
<td>169.298</td>
<td>202.725</td>
</tr>
<tr>
<td>Sum minimum direct sunlight hours</td>
<td>648</td>
<td>607</td>
<td>427</td>
<td>325</td>
<td>267</td>
</tr>
</tbody>
</table>

Table 1: Data comparison between the analyzed types of Solar Envelopes.
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The aim of these workshops and conference is to help transfer and spread newly appearing design technologies, educational methods and digital modelling supported by information technology in architecture. By organizing a workshop with a conference, we would like to close the distance between practice and theory.

Architects who keep up with the new designs demanded by the building industry will remain at the forefront of the design process in our information-technology based world. Being familiar with the tools available for simulations and early phase models will enable architects to lead the process. We can get “back to command”.

The other message of our slogan is <Back to command>. In the expanding world of IT applications there is a need for the ready change of preliminary models by using parameters and scripts. These approaches retrieve the feeling of command-oriented systems, although, with much greater effectiveness.

Why CAADence in architecture?

"The cadence is perhaps one of the most unusual elements of classical music, an indispensable addition to an orchestra-accompanied concerto that, though ubiquitous, can take a wide variety of forms. By definition, a cadence is a solo that precedes a closing formula, in which the soloist plays a series of personally selected or invented musical phrases, interspersed with previously played themes – in short, a free ground for virtuosic improvisation."