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The Utilization of Performance Based Simulation in from Generation to Optimize Daylighting

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Abstract: Daylighting provision gives a significant contribution to the enhancement of the indoor visual environment and user comfort. It has the potential to maintain the required illuminance level and to improve the space visual quality. This study aims to provide a parametric design approach to optimize the daylighting performance in buildings. It utilizes simulation techniques for identifying the most efficient daylight performance by incorporating parametric optimization tools in the preliminary design phase that has the potential to enhance the building daylighting performance and consequently improve the occupants' visual comfort as well as reduce the energy consumed for electric lighting. The proposed approach is examined over a case study office building on the 90th commercial street in New Cairo, Cairo, Egypt. Analysis was conducted using the Daylight Performance Metrics (DPMs) specifically Spatial Daylight Autonomy (sDA).

The approach redesigns an existing building while following the main design concept according to environmental and site constrains to eventually compare the daylighting performance of the resulting alternative with the original building. The results demonstrate that using the proposed optimization strategy produced a configuration that achieved Spatial Daylighting Autonomy of 87% which is 60% higher compared to the original building.

The goal of this research is to increase the utilization of the early stage design decisions by developing a simulation-based approach that enables designers to examine and optimize each design decision and the potentials of environmental strategies (e.g. building geometry, window-wall ratio, shading devices, etc.) using validated lighting simulation tools.

Keywords: Daylighting, Parametric Optimization, Form Generation, Schematic Design phase.

1 Introduction

Natural lighting is considered the best source of light that matches human visual response and required color, which has a substantial positive impact on the occupants [1].
Daylight has the potential to reduce the need for artificial lighting if the architectural design allows it to happen with the right quantity. According to the Egyptian code for energy Efficiency, the commercial building sector consumes around 46.2% of the overall energy consumption [2]. However, the incorporation of the energy and lighting simulation software at the last stage of the design process does not help to get the full benefits of the simulation process. So rather than analyzing whether a predetermined building design surpasses or fails a compliance requirement in the late stages of design development, designers are increasingly interested in obtaining rapid and iterative performance feedback on decisions in the early stages of design, where the largest impacts on building performance and occupant comfort are set. To effectively meet performance objectives, the building geometry, orientation, fenestration configurations, and thermal management strategies must become supporting pieces of the whole-building daylighting performance. Incorporating daylight simulation methods in the design process has rapidly developed to tackle the relationship between daylighting and architectural form [3], the use of complex geometries, as well as the special and dynamic lighting considerations in the design phase. This was shown through

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different researches where architects preferred to incorporate “DSADP” (daylight simulation integrated into architectural design process) from very early design considerations [4].

An early study conducted a parametric optimization process to find the most efficient form in the schematic design phase in terms of energy consumption [5]. Another one explored the uses of parametric design method to prove that its more advantageous than conventional design methods through testing different forms. The study presented a residential building that consists of five stories to find the best parameters which lead to the optimum performance in day-lighting and energy performance [6]. In a recent attempt, a case study of a small office building was conducted to test and verify the effectiveness of the optimization process. The geometry of the case study building was optimized in three different climates, Miami, Atlanta, and Chicago. The optimization process produced design alternative with better daylighting performance and less energy consumption [7].
There are many factors that affect the daylight quality in buildings, such as building orientation, shape, space between building, when it is taken into consideration it affects daylighting performance in the building (Abd EL-Montleb and Ali Ahmed, 2012, Amer and Attia, 2014). On the same approach (Suyoto, et al., 2015) optimized the building massing and utilized Grasshopper to find the most shaded and comfortable outdoor area.

The previous studies focused on enhancing the daylighting performance of a one-room-study-model, while this study aims at providing a workflow that can be used in the preliminary design phase to evaluate the daylighting performance of the proposed alternatives and guide the designers towards better decisions.

2 Parametric Modelling Tools

Parametric tools are relatively new to architecture design process because it is based on the ideas of exploring design variations [8]. By using this method, the computer generates many design variations satisfying the predefined ranges that satisfy particular conditions.

2.1 Simulation Tools

Computer simulation tools are increasingly used for the assessment of a building’s performance such as energy consumption, daylight provision, thermal or visual comfort of their occupants. They represent a powerful tool for studying the environmental performance of buildings, since they provide useful feedback for the on-going process of design [9]. The simulation software used in this paper is Diva for Rhino, which is a highly optimized daylighting and energy modelling plug-in for Rhinoceros [10].

3 Evaluation Criteria

The evaluation criteria is divided into two categories, the leading criteria that drives the optimization process to achieve the main objective of the simulation, and a secondary evaluation criteria that is only used when the resulting alternatives have convergent optimum results to obtain better performing designs.

3.1 Main Evaluation Criteria

The main criteria are set to contain the following aspects:-

3.1.1 Functionality

In architecture, functionality or ‘form follows function’ is the principle where buildings are being designed in accordance with their underlying purpose rather than aesthetics trends to determine the form.
Functional design should align human use with material and environmental aspects, so that all the building elements, from the smallest detail to the overall plan, work in harmony. To decide whether the generated alternatives are functional or not, the designer must develop a grasshopper definition that eliminates unfunctional depth ratios as well as sharp angles to maintain a proportional floorplan.

3.1.2 Daylight Availability

Daylighting design is a key aspect of building rating systems, such as Leadership in Energy and Environmental Design system (LEED). It uses metrics such as Daylight availability (DA), which is the percentage of annual work hours during which all or part of a building’s lighting needs can be met through daylighting alone [11]. It divides the space area into three zones and gives a warning when daylight exceeds the maximum threshold for more than 5% of the occupied hours. Those three zones are represented in the below table:-

Table 1: Daylighting Availability threshold.

Daylight Availability	Threshold	Occupied Hours
Daylit	300 to 3000 lx	For at least 50% of the occupied hours
Partially- Daylit	300 lx	Less than 50% of the occupied hours
Over-lit	<3000 lx	More than 5% of the occupied hours

3.1.3 Spatial Daylight Autonomy

Spatial Daylight Autonomy (sDA) represents the percentage of floor area having 300 lx of illuminance for at least 50% of the occupied hours (8:00 am – 6:00 pm in the case of the present study) throughout the year. A preferred minimum percentage of 75% of room area for sDA is recommended [12], [13]. Similarly the preferable daylighting conditions set by the IES committee for sDA 300/50% should be equal to or more than 75% of the room area.

3.2 Secondary Evaluation Criteria

The secondary criteria does not necessarily have to be the following aspects, as it varies according to each building, its design constrains as well as the environmental conditions. Thus, the secondary criteria could involve energy consumption, quality of view or even indoor thermal comfort. In other words, this part of the approach is left to the designer to decide according to his priorities and the main challenges the design needs to overcome.

3.2.1 Solar Radiation

Incident solar radiation refers to the total amount of solar radiation falling on a surface.

It predicts whether the space would be thermally comfortable or not through identifying the amount of radiation falling on the surfaces. It is mainly affected by shading, so the more the building has self-shading, shaded by adjacent buildings or even equipped with shading devices, the less radiation it receives and consequently less thermal heat gain on its envelope. Thus, the aim of this type analysis is to visualize and quantify the average annual intensity and distribution of solar radiation on various areas of the proposed alternatives. [14].

3.2.2 Airflow Simulation

This objective was included in the analysis based on the designer preference when the resulting configurations produces similar results since the form has a significant impact on the ability to ventilate a building using natural means. Moreover, the building is located on two main roads, thus, it has a potential of good ventilation if oriented properly towards the prevailing wind direction that comes from the north-west according to the Cairo wind rose (**Fig 1**). The simulation was carried out using Autodesk flow design, which is a validated virtual tunnel for simulating air flow around buildings.

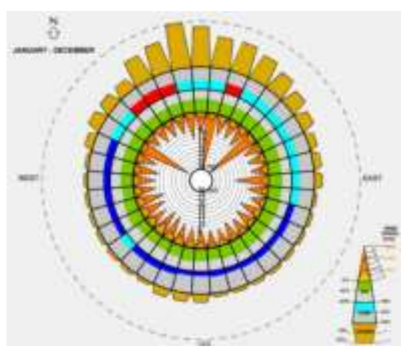


Fig. 1: Cairo wind rose.

4 Methodology

The purpose of the study is to prove that the proposed approach has the potential to generate alternatives with better daylighting performance. This is proved through implementing this approach over an office building located in New Cairo and shall be identified later on in the study. Since this building was designed using conventional design methods, therefore the study compares between the daylighting performances of the existing building vs using parametric optimization method. The approach includes three sequential phases each consists of multiple steps, the

first phase starts by having a conceptual layout idea developed by the designer. Afterwards, the idea should be translated in the form of a parametric layout. The parameters of the layout are set according to the site constrains as well as the allowable footprint. The layout must be kept functional through restraining the parameters with some limitations like minimum space dimensions and angles. The parametric layout goes through a daylighting optimization process to determine the profiles that achieve the best possible daylight. If the optimization process produced alternatives with convergent optimum results, then a secondary evaluation criteria set by the architect is utilized according to the design prerequisites to evaluate the performance of each alternative. This criterion could involve reduced energy consumption, quality of views or air flow as in this study. After reaching the layouts with the best daylighting performance, the second phase generate the form of the building using these optimized profiles after running a grasshopper script to generate all possible forms. The results are narrowed down to only the functional building forms. Once again, to determine the best performing model, another aspect of the secondary evaluation criteria is used to examine the performance of the different forms. The aspect used in this study was solar radiation. The aim was to evaluate the building forms in order to select the form with the least amount of solar radiation which, has a great impact on the indoor thermal comfort. The third phase uses the successful form along with the optimized floor plates to determine the exact WWR that achieves this optimum daylighting (**Fig 2**).
The simulation process was carried out for a building within its context, while in other attempts no surroundings were considered as they were applied on study models [9], [15], [16].

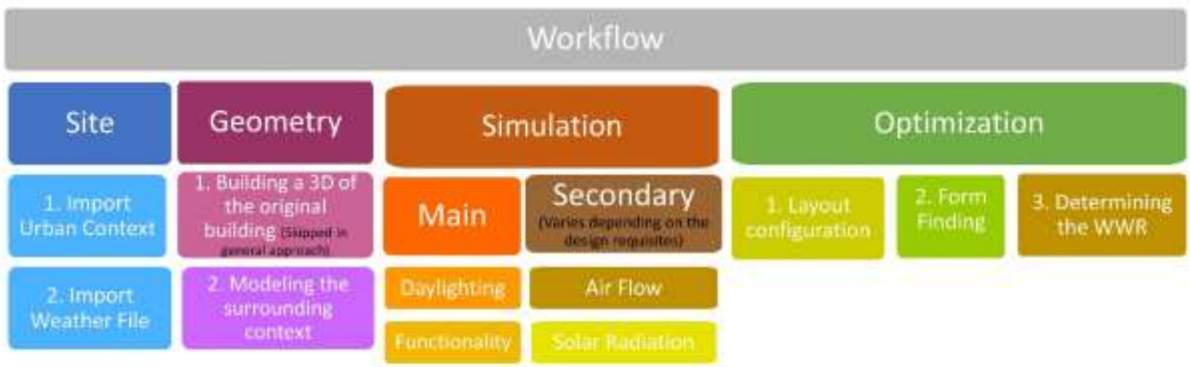


Fig.2: The workflow of the proposed approach.

4.1 Site Analysis

New Cairo, a newly developed urban settlement around Cairo (30° N, 31° E), has been selected as a study area due to its popularity and fast growing ratio. Moreover, it can be considered the most attractive area for new constructions in the Cairo metropolitan area over the last decade [17]. The study area is a linear raw of buildings that extends about 3 km along the southern 90th Street, which is the most important street in the city. A considerable number of corporations and institutions have recently established new headquarters or main branches in the commercial spine. Most of these buildings' facades include vast areas of glass ignoring their climatic region [17] (**Fig 3-5**). A glazed-façade-office building has been selected as the study model to evaluate its daylighting performance and apply the proposed optimization technique to enhance the occupants' visual comfort and increase workers' productivity and satisfaction. The building is surrounded by two buildings from both sides with almost the same height, while on the back there is an empty plot that is expected to be built any time. This context shall affect the simulation since surrounding buildings can cast a shadow over the chosen building, or even reflect the sunlight and cause glare.

Fig. 3: The site layout with the case study building highlighted.

Fig.4: The southern 90th street along with the office buildings.

Fig. 5: The actual building and a rendered shot of its 3D model

4.2 Modelling the Original Building with the Surrounding Context

The building floor plans were modelled in addition to the outer skin of the whole building with its curtain walls and window openings as measured from the actual building. Different studies have emphasized the influence of the surrounding context on the daylight availability and recommended considering it to secure adequate daylight exposure for the occupants [18]. Thus, the surrounding context has been modelled with its actual height and materials in Rhinoceros. Each element in the building was defined and assigned material in Grasshopper according to its function. Then, all elements were plugged in the Diva for Daylighting component. The grid size was set along at a 0.70m height from the floor finish level. Cairo airport weather file was used.

4.3 Daylighting Simulation of the Original Building (Base Case)

After modeling the whole building in Rhinoceros, each element is then defined in grasshopper according to its function (Walls, floors, Roof, Curtin walls, windows) and is given a material. Afterwards, all the elements are plugged in the Diva for Daylighting component while the grid size is set along with its height from the ground which was set to be 0.70 m. Last but not least, the Cairo airport weather file is inserted.

Finally, the daylighting simulation is carried out using the below script to examine the performance of the original building in order to compare the results later on in the study with the results of the optimized alternatives.

The building WWR were measured from the built model according to the original building to evaluate its daylighting performance, while the material reflectance was set based on the average reflectance values of these elements [19] [20] **(table 2).**

Table 2: Original building parameters.

Building Parameters		**Attributes**
WWR	North facade	Ratio = 50%
	South facade	Ratio = 80%
	East facade	Ratio = 55%
	West facade	Ratio = 45%
Material	Walls	Reflectance = 50%
	Floors	Reflectance = 20%
	Ceiling	Reflectance = 70%
	Glazing	Visual Transmittance = 80%

4.4 Building a Parametric Model for the Proposed Design Method

In this subsection, the main outline of the original building was traced to develop a simple parametric configuration that should go through the optimization process smoothly to eventually reach an optimized layout. The parametric model is created using a script that runs through all the parameters of the design variables in order to generate a huge number of alternatives. The 3D modelling phase is going to take the form of four steps as followed:

4.4.1 Layout Configuration

First, a simulation based design workflow is developed in Grasshopper that is capable of evaluating the daylighting performance of different alternatives of the floor plan generated by the parametric based definition. The design variables are set to be mainly related to the shape of the floor plan while parameters like window wall ratio and materials are fixed in this phase to limit the number of iterations in order to reduce the time consumed. For example, if the floor plan shape is designed as a rectangular shape it should have parametric length and width (X and Y).

Since the original building consists of two wings connected by the core of the building, therefore, the same concept was adopted in writing the grasshopper script in order to reach numerous number of alternatives derived from the original building (**Fig 6**). These alternatives are created based on some variables set to change the layout while maintain the main concept, like moving the two wings up and down, controlling their length and width and finally changing the distance between them through the width of the middle core and changing its length as well (**table 2**). One important constrain is that there is a minimum and a maximum width and length set for each of them. The minimum is set according to the minimum depth of an office space. The maximum is set based on the maximum allowable area and the minimum recesses from the boundaries of land plot (**Fig 7**).

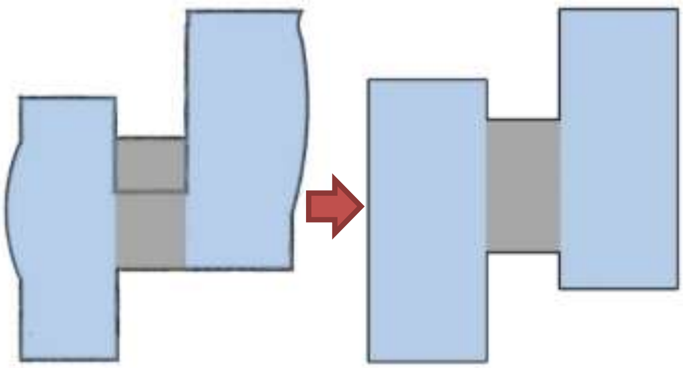


Fig. 6: The simplified layout derived from the original building.

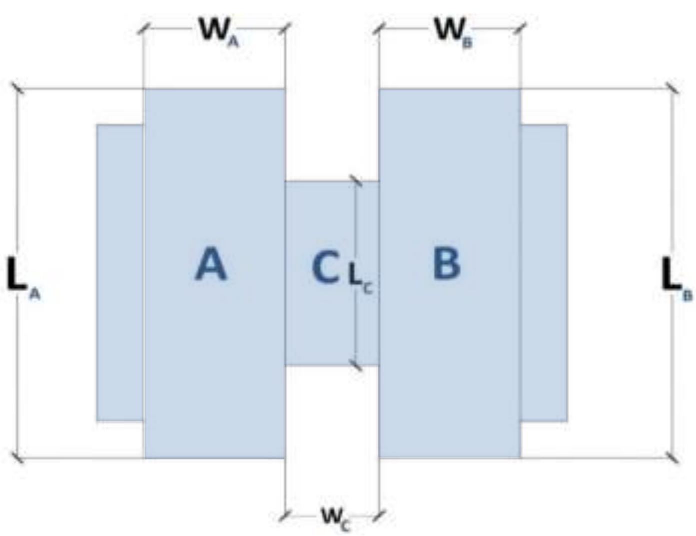


Fig.7: The parametric layout used in the layout configuration phase to produce alternatives.

Table 3: variable and fixed Optimization Parameters.

Building Parameters			Attributes
Geometry	Rectangle A Length (L_A)		(6 -36m with an increment of 6m)
	Rectangle A Width (W_A)		(4 -12m with an increment of 4m)
	Rectangle B Length (L_B)		(6 -36m with an increment of 6m)
	Rectangle B Width (W_B)		(4 -12m with an increment of 4m)
	Rectangle A Vertical movement (Y_A)		(0 -18m with an increment of 6m)
	Rectangle B Vertical movement (Y_B)		(0 -18m with an increment of 6m)
	Link C Width (W_C)		(0 -8m with an increment of 4m)
	Link C Length (L_C)		(0 -8m with an increment of 4m)
	Rotation angle (R)		-90° to 90° with an increment of 45°
	WWR	North	Fixed (75%)
		South	Fixed (50%)
		East	Fixed (60%)
		West	Fixed (60%)
Material	Walls		Reflectance = 50%
	Floors		Reflectance = 20%
	Ceiling		Reflectance = 80%
	Glazing		Light Transmittance = 80%

4.4.2 Form Finding

After selecting the alternative with the best daylighting performance, the form is generated using the optimized floor plate profiles. Grasshopper creates the massing of each building by blending the two profiles together. The profile from the base floor plate is lofted with its twin on the upper level and then joined together with the other pairs to create the generic form of the building (Fig 8).

The primary criticism of this massing type is that only two of the floors are truly optimal and that the remaining floors could potentially achieve a higher value. However, optimizing each floor individually becomes overwhelming due to restraints in time and processing power. Therefore, to overcome such an issue the optimization process is performed every two stories which means that it was done four times for a seven story building in order to get more accurate results while limiting the time factor. Each level height is based on the floor height of the original building. With the addition of two more floor plates, the multi-loft between matching sets of floor plates generates a significantly different massing type than the single loft. A third typology also exists by extruding these four profiles vertically, resulting in very abrupt shifts in the form of the building at each of these levels [21]

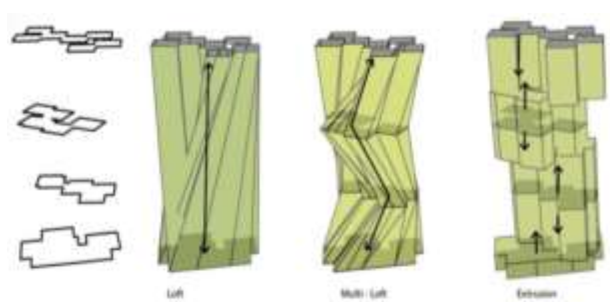


Fig. 8: Example of the different form typologies that can result from the same profiles [22].

4.4.3 Determining the WWR

The massing step is then followed by determining the WWR (Window Wall Ratio) to create the openings. Another optimization process now takes place to determine the window size and dimensions that allows maximum lighting while maintaining the glare amount within the acceptable range. This objective is not only about allowing as much light as possible otherwise, it would be a waste of time to perform this step and the largest WWR would be selected instead, but also it's all about the quality of this light. Besides, enlarging the window size too much reduces the

amount of useful lighting due to the high percentage of glare, which means that the overall amount of good light is now reduced.
The windows are created parametrically based on the window to wall ratio "WWR". Every facade has a specific WWR varied from 0.1 to 0.9 with 0.01 increments. Although WWR values of the six facades were isolated which consumes more time. However, it was necessary to reach the optimum value for everyone.

5 Results and Discussion

5.1 Daylighting Simulation of the Base Case

The simulation results show that the percentage of the partially daylit areas reached 50%, while the over-lit spaces that occurred mainly beside the openings reached 40%, which causes a high amount of glare. The sDA achieved only 27%, which strongly indicates that the majority of the office space has insufficient illuminance levels (**Fig 9**).

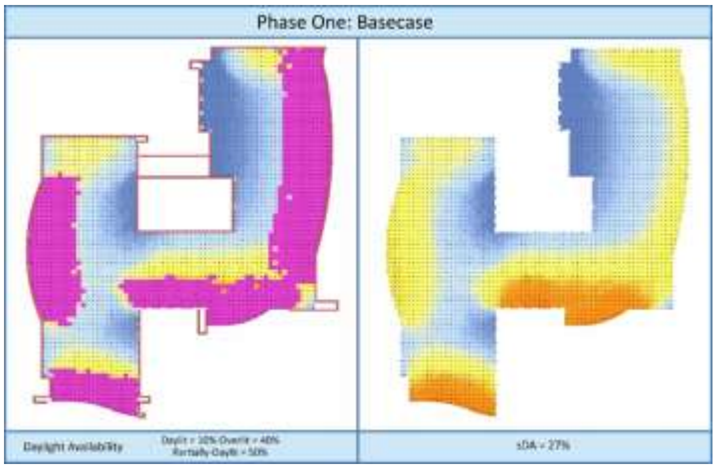


Fig. 9: The daylighting simulation results of the original building.

5.2 Building a Parametric Model for the Proposed Design Method

5.2.1 Layout Configuration

The form generation process produced about 750 design explorations. The elimination process was based on daylighting performance in the first place, followed by functional and structural factors. The below table shows a list of 21 configuration that achieved sDA from 45% to 77% (**Fig 10**). This range is considered acceptable since these values has the highest capability of achieving sufficient daylight. Values lower than 45% would be insufficient while values equal or higher than 75% are certified by the LEED rating system. Another optimization process is carried out and the results are narrowed down to a number of configurations that achieved higher than 70% (**Fig 11**).
In **Figure 11**, it can be noticed that layouts with rotation angles of 0°, 45° and -45° degrees in shapes L1, L2 and L3 achieved the best results; exceeding the 74%. However since there are some sharp angles that resulted from rotating link C, it was decided to adjust the angle to be 90° in order for it to be more functional.
After generating the layouts with the best daylight performance, the secondary evaluation criteria needs to be utilized over these three alternatives to evaluate the airflow around these configurations using Flow design wind analysis tool (**Fig 12**).
The 45° alternative was found to have the best airflow among the three. In addition, minimizing the rotation angle to 30° even showed better performance since it is oriented towards the prevailing wind direction that's coming from the NNW with 20° degrees. This orientation drives the wind to reach the leeward side allowing for better ventilation through and around the building. While the 0° alternative comes in second with an orientation that poorly ventilates the southern façade due to the negative pressure. As for the -45°, the orientation opposes the wind direction, which slows it down in the positive side, and completely blocks it from a considerably large façade area on the leeward side.

Therefore, it was decided to select the 0° and 45° alternatives to go through the form generation phase in order to achieve the best daylighting performance and have the potential to benefit from the natural ventilation.

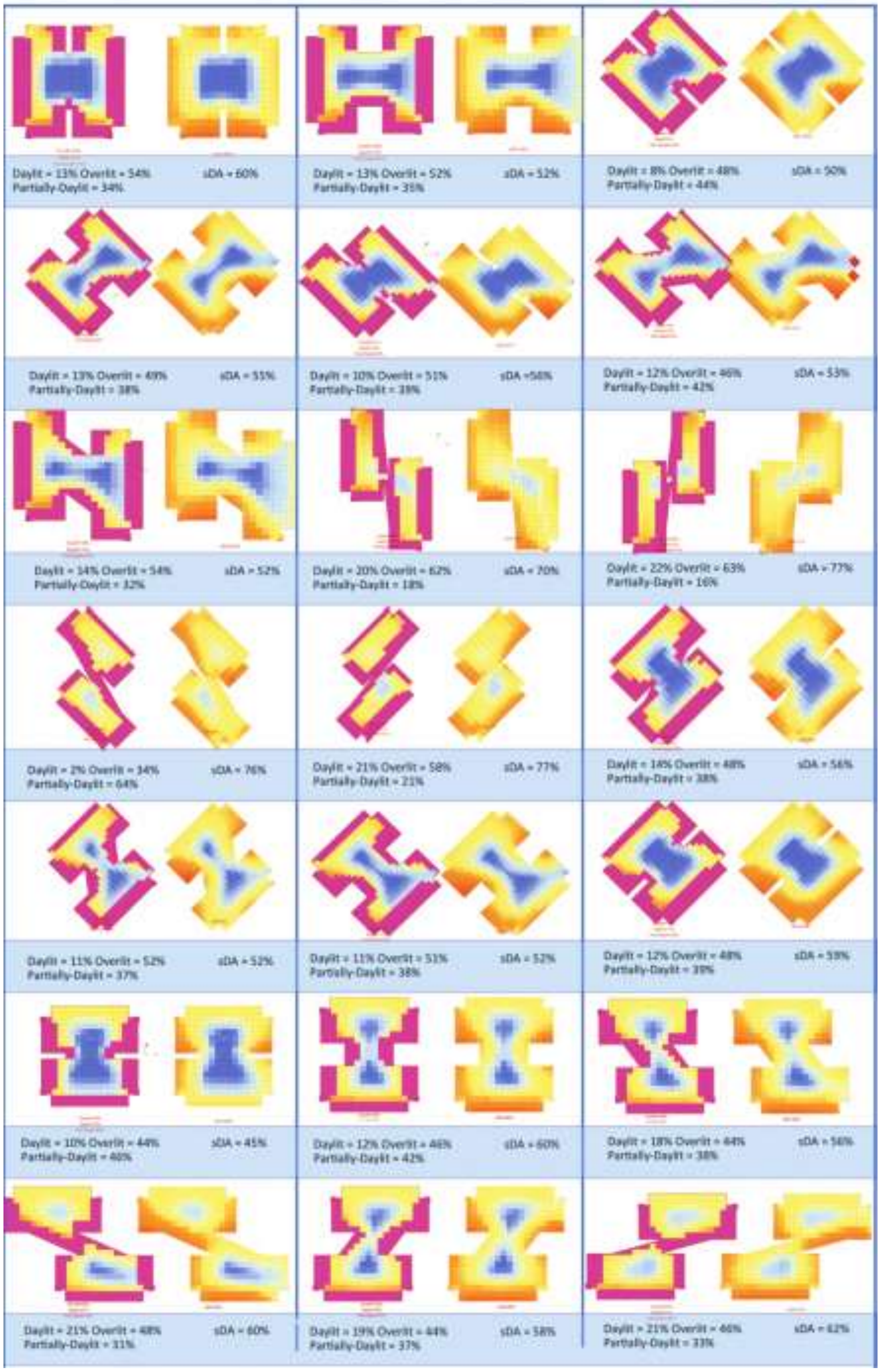


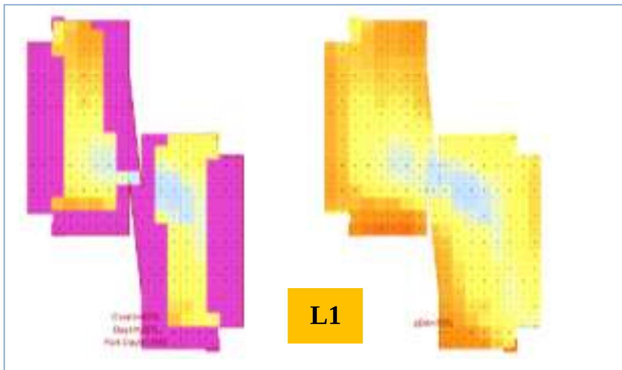
Fig.10: The configurations that achieved from 45% to 77.

5.2.2 Form Finding

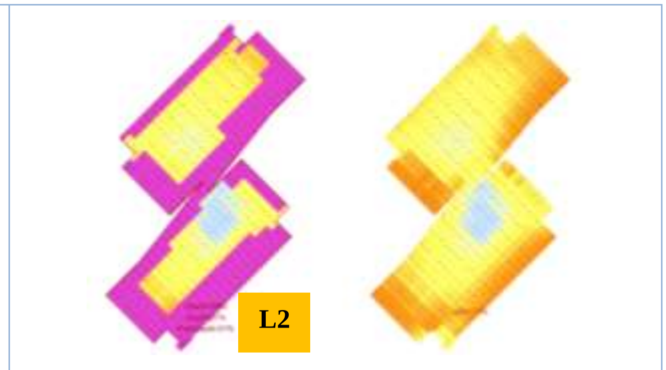
In this phase the 30° and 0° layouts were utilized to generate a diverse number of forms, from regular extrusion to blending the two optimized profiles together in the ground and the seventh floor to reach a distinctive yet functional building mass (Fig 13). The resulting configurations were as followed:-

(A) The basic extrusion of the 0° alternative.
(B) The basic extrusion of the 30° alternative.
(C) A basic loft that blends between the 0° and the tilted profile in the ground and the seventh floor.

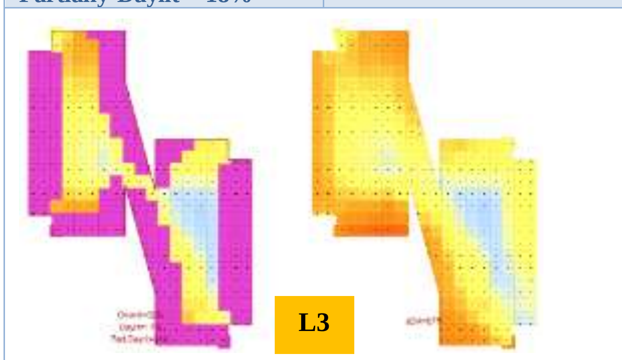
The previous results were filtered and the best cases that achieved above 70% were selected (**Fig 11**).



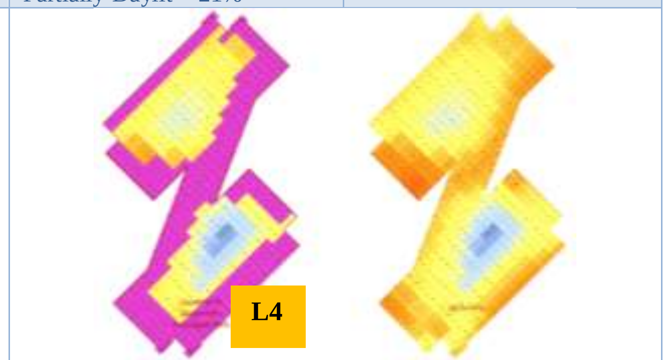
Daylit =20% Overlit = 62%
Partially-Daylit = 18%
sDA = 78%



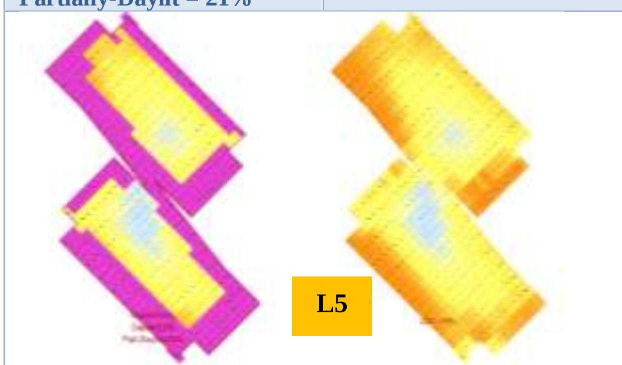
Daylit = 21% Overlit = 58%
Partially-Daylit = 21%
sDA = 77%



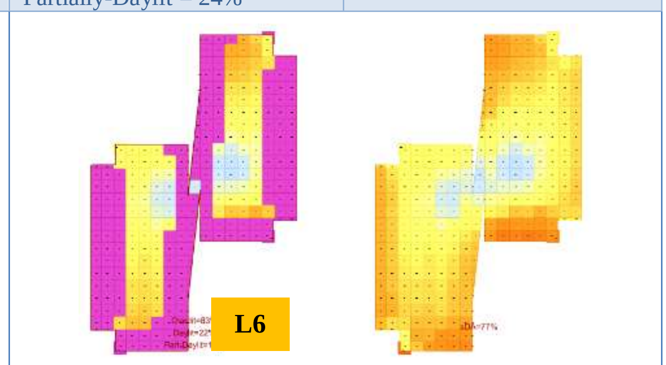
Daylit =17% Overlit = 62%
Partially-Daylit = 21%
sDA = 67%



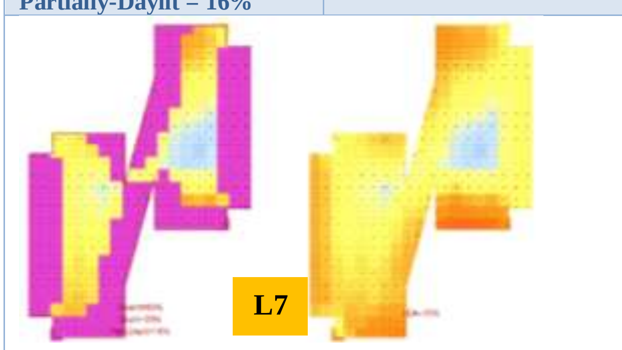
Daylit =15% Overlit = 61%
Partially-Daylit = 24%
sDA = 74%



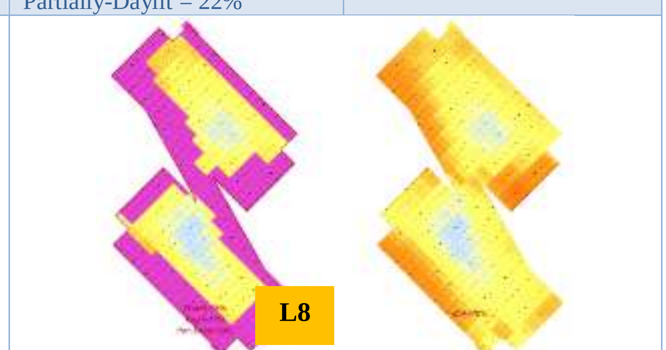
Daylit =22% Overlit = 62%
Partially-Daylit = 16%
sDA = 77%



Daylit =23% Overlit = 55%
Partially-Daylit = 22%
sDA = 75%



Daylit =20% Overlit = 62%
Partially-Daylit = 18%
sDA = 76%



Daylit =26% Overlit = 56%
Partially-Daylit = 18%
sDA = 76%

Fig. 11: The best cases that achieved above 70%.

(D) The extrusion of each floor profile vertically which results in very abrupt shifts in the building form. The levels in between will be gradually rotated to transform from the 0° to the 30° which, has the potential to create self-shading that can reduce the heat gain.
(E) The multi-loft between the floor plates generates a significantly different massing type than that of the single loft.
(F) The smooth loft that joins all floor profiles in a curvy smooth way.
(G) The organic loft.

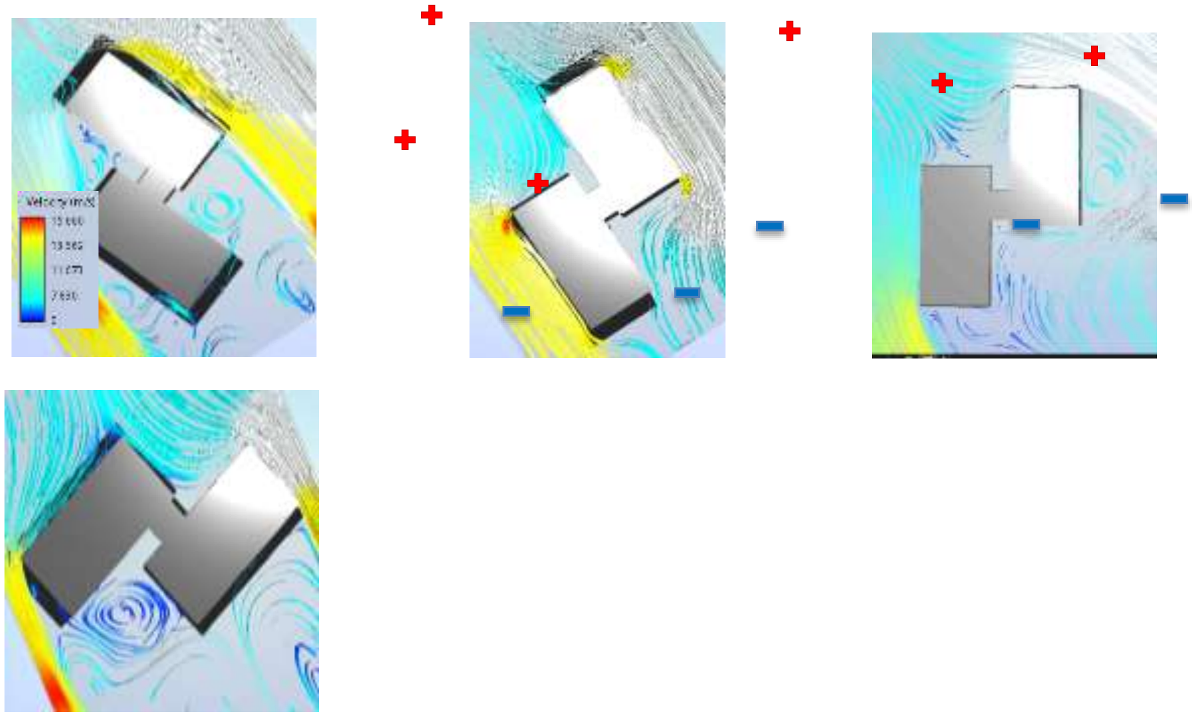


Fig. 12: Airflow simulation for the 45°, 30°, 0° and -45° alternatives.

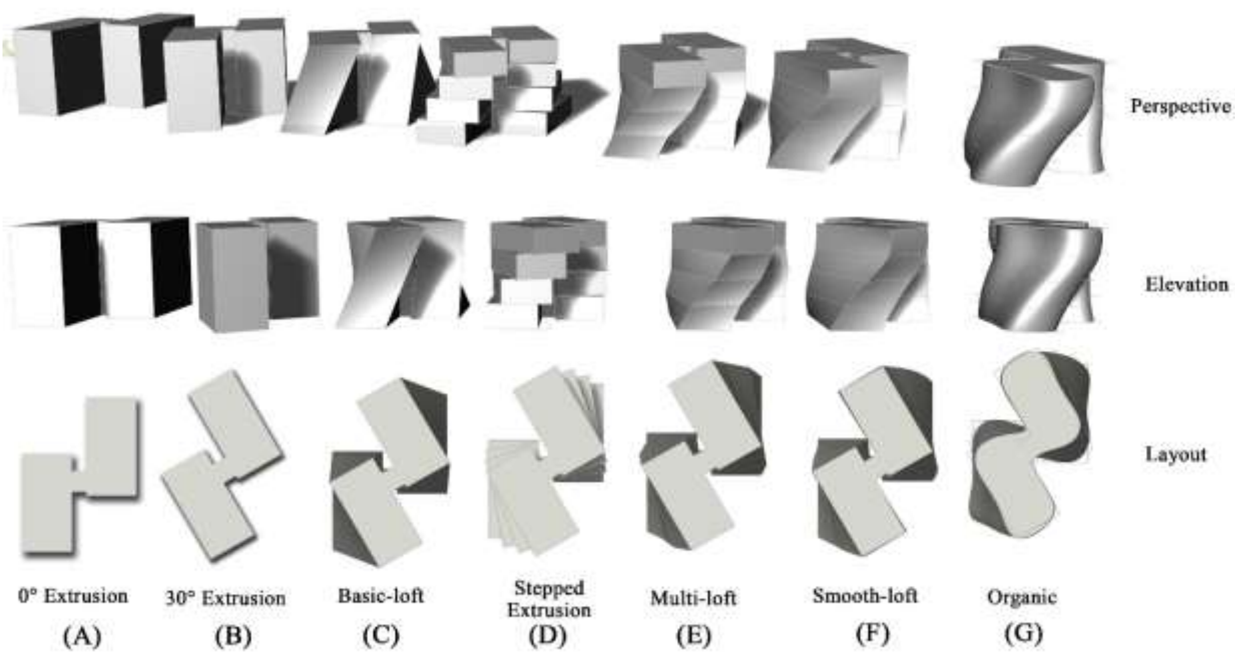


Fig. 13: The different formal typologies for generating a building mass from the floor plates.

To select one of these alternatives, other evaluation criteria should be applied by building designer. Structure and function are two key aspects when it comes to cost and usability. Solar radiation on the other hand can affect the performance of the building dramatically and its overall energy consumption. Although solar radiation is not the main objective leading the design in this case, it can also affect the indoor comfort level of the users, since the building is located in a hot arid climate with relatively large openings. Thus, an average annual solar analysis was conducted to select the form with the least solar radiation (**Fig 15**). The evaluation criteria may also include other aspects, such as site constrains, blending the model with the surrounding context or even the own vision of the building designer.

The below column chart compares between the solar radiation over the seven different forms (**Fig 14**). The results demonstrated that the stepped alternative received the lowest amount of solar radiation of 0.14 kw/m^2 due to its self-shading qualities followed by the basic and the multi loft receiving 0.15 kw/m^2. While the two basic extrusions along with the smooth and organic loft received values between 0.17 to 0.21 kw/m^2. Although the results were relatively close, however the stepped model of the lowest solar radiation value was selected.

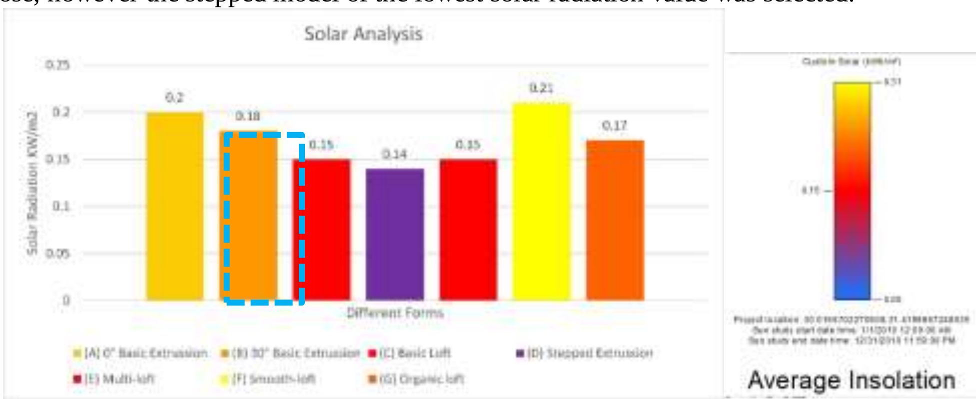


Fig. 14: Bar chat comparing the solar radiation over the five different forms.

3.2.5 Determining the WWR

After about 900 iterations, it was found that enlarging the window size increases the Daylight Availability percentage till some point where the high percentage of overlit areas starts replacing the daylit areas instead of replacing the partially daylit ones, which ends up reducing the DA percentage. However, **table 4**. shows the WWR of the four main facades and the two secondary ones.

Table 4: The WWR of the facades in each floor level.

Level	Facade	Value	Level	Facade	Value
Ground	North	0.88	**First**	North	0.85
	South	0.30		South	0.30
	East	0.55		East	0.55
	West	0.50		West	0.55
	Inner East	0.50		Inner East	0.55
	Inner West	0.55		Inner West	0.55
Second	North	0.85	**Third**	North	0.85
	South	0.30		South	0.30
	East	0.55		East	0.55
	West	0.50		West	0.50
	Inner East	0.55		Inner East	0.55
	Inner West	0.50		Inner West	0.50
Forth	North	0.85	**Fifth**	North	0.85
	South	0.25		South	0.25
	East	0.45		East	0.45
	West	0.30		West	0.30
	Inner East	0.50		Inner East	0.50
	Inner West	0.38		Inner West	0.45
Sixth	North	0.80		North	0.80
	South	0.25		South	0.25

	East	0.50	**Seventh**	East	0.45
	West	0.30		West	0.30
	Inner East	0.45		Inner East	0.45
	Inner West	0.38		Inner West	0.38

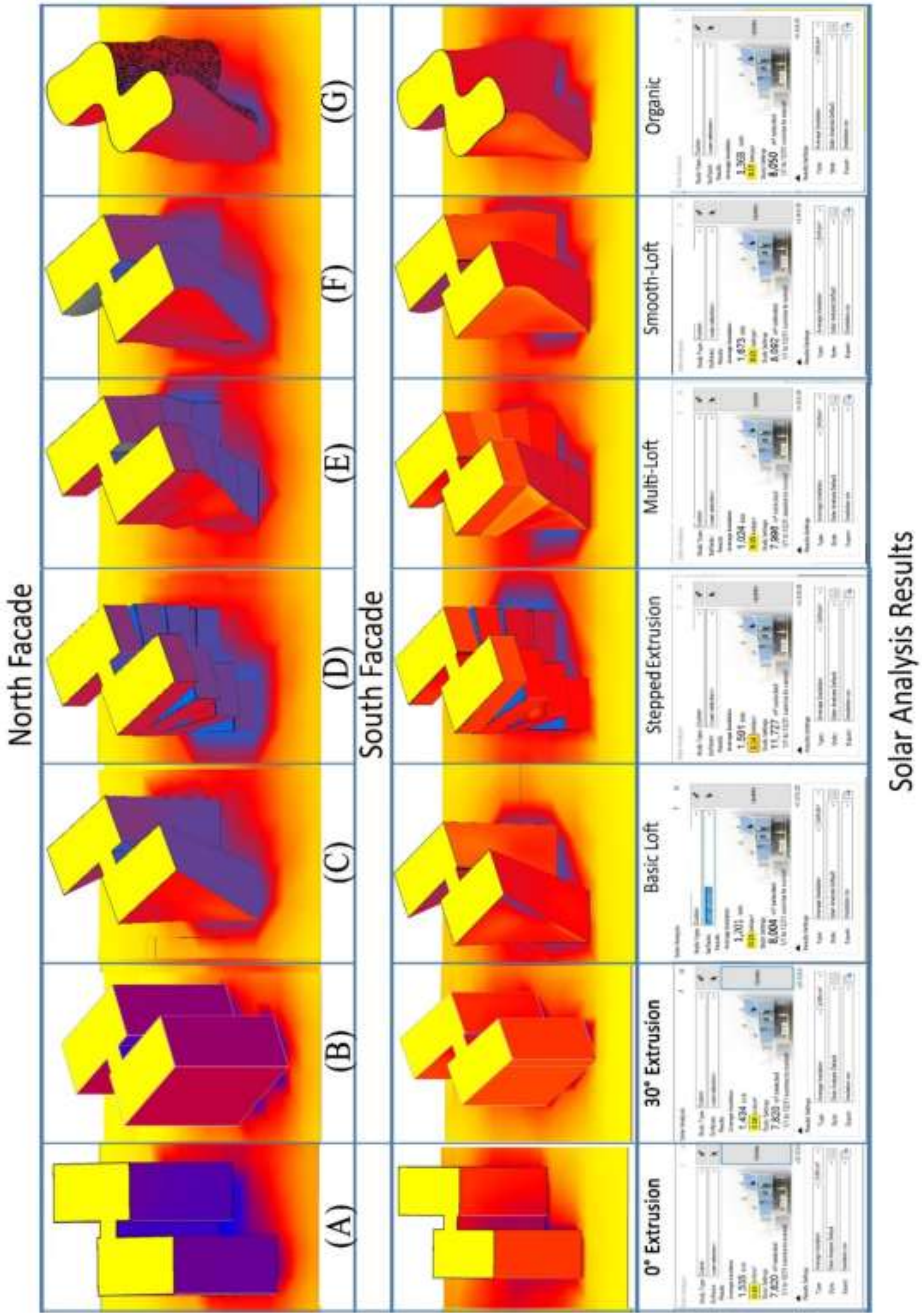


Fig. 15: The solar analysis of the seven generated forms.

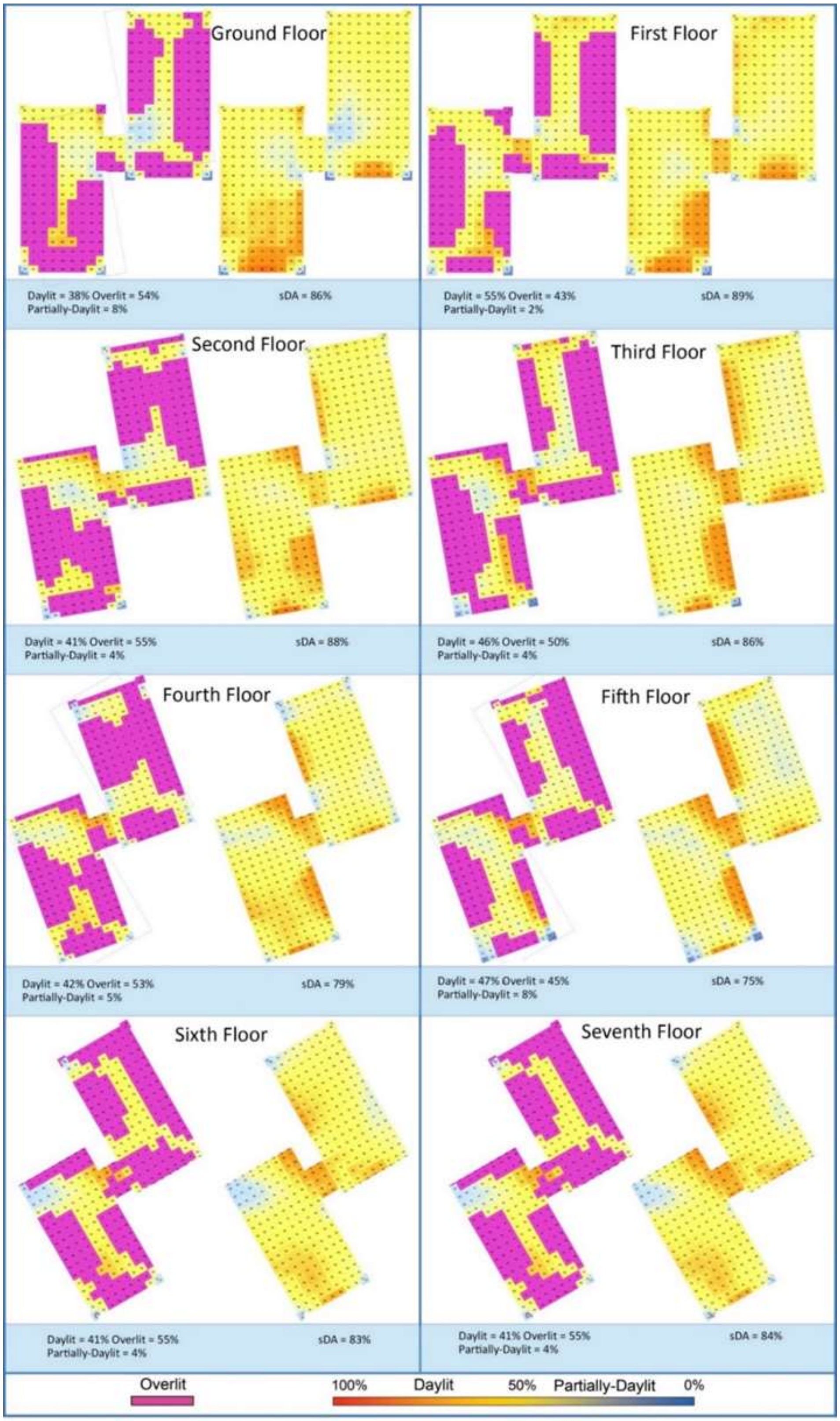


Fig. 16: Daylighting simulation results of the stepped model floor plans.

It can be noticed from the optimized values in (**Fig 16**) that the window size gets smaller the more we go up. It's mostly because of the surrounding context around the building which makes the higher levels achieve more light easily without enlarging the window size to the maximum, while lower levels especially the ground floor lacks lighting so it needs increased window sizes. There is also no doubt that the north façade allowed lighting without any notable glare while the South, East and West façade needs treatment due to the glare problem.

6 Discussion

It was concluded from this study that dividing the form into two separate masses maximized the number of facades that receives light while the vertical shifting between these two masses allowed even more light to penetrate. On the other hand, creating a link between the two also created a space that received sufficient daylight with minimum glare due to the shadow casted by the two masses. However, increasing the depth of the two rectangles more than 8m each creates an inner core that receives almost no light, Thus, the depth of link C was reduced to avoid having a gloomy core, while increasing the length of link C (LC) allows more light to reach the inner core of the building (**Fig 17**).

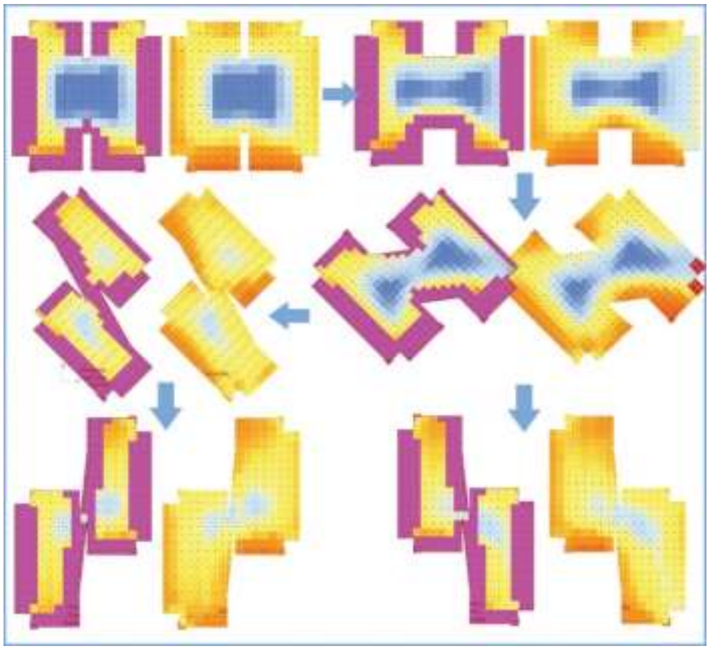


Fig. 17: The form development to enhance the daylighting.

7 Conclusions

The current study proposes an optimization approach that has the potential to generate designs with optimized daylighting performance. The study presents an approach to guide the designers in the preliminary design phase to utilize simulation tools to achieve more optimized design alternatives. The proposed strategy was examined over a case study office building on the 90th commercial street in New Cairo, Egypt. The results demonstrated that using the proposed strategy managed to produce a configuration that achieved sDA with 60% higher than the original building that was designed using conventional methods.

The study proves that performance-based design that integrates simulations that includes mainly daylighting in addition to other aspects (Airflow and Solar Radiation) in the design process has many advantages over traditional design methods because it allows many design variations to be evaluated against different daylight solutions. In addition, this approach has the ability to control many design parameters for each type of building geometry at any level of detail. It transfers the 3D modelling data to the daylighting analysis software without any technical problems, such as mesh topology or materials conflicts. It uses the analyzed data, evaluates them, and guides the architect towards the optimum solution providing a numerous number of alternatives. Ultimately, this approach could be upgraded in the future to involve different environmental factors, such as energy demand, indoor thermal comfort and quality views. Some conflicts may occur, but the proposed approach will help to trade-off and direct the final solution towards the main design objective, while taking into account the overall performance of the building.

The future domain integrations include taking the energy consumption factor in future studies into consideration which will affect the results of the simulation since adding such an objective will lead the designer to a balance between the two objectives; daylighting and energy consumption. In other words, this means that the results of the optimization process might not end up with an optimum daylighting solution, yet the best solution that can be reached so that it does not affect the energy consumption in a negative way. In addition, structural feasibility can be integrated as a factor for decision-making.

List of Abbreviations

DPMs	Daylight Performance Metrics
sDA	Spatial Daylight Autonomy
DA	Daylight Availability
WWR	Window to Wall Ratio
DSADP	Daylight Simulation in Architectural Design process

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