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Daylight autonomy as a driver for office building retrofitting

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Abstract

Daylight has always had a relevant part in design for architects and engineers since really ancient times. Even if light had such an important role in the design process, new methods for quantifying more precisely lighting levels have been discovered just in the last decade. In this research, issues related to daylight in office buildings - due to volume, structure, and orientation - have a key role. Lighting levels in workspaces are fundamental in order to estimate and optimize dimensions for an office building; the depth of the building in relation to the facade is one of the most common problems that always represent a struggle for designers that have to find a meeting point between intentions and performance. The research is particularly focused on the optimization of existing building shapes that, in accordance with new facades, optimize natural lighting levels in office spaces. The improvement of indoor comfort regarding natural lighting levels is nowadays one of the main topics in retrofitting interventions, especially in the case of office buildings environments where orientation, context and functions significantly change in relation to the orientation. The reduction of the thermal energy demand has been deeply investigated and the challenge to have nZEB retrofitting involves the reduction of energy for artificial light. Could the building depth change accordingly to a specific luminance level? How does the spatial quality of working spaces increase, if the building shape changes to get as much daylight as possible? Today, simulation software gives us the possibility to obtain precise information relatively to each environment on every single floor at any time of the year; the precision of the analysis results mostly depend on how accurate the study model is, and on how the settings have been given. Through the use of parametric software such as Grasshopper, together with potentialities offered by Ladybug and Honeybee, it is possible to obtain detailed natural lighting parameters and to explore the field of environmental analysis. In particular, starting from daylight autonomy simulations, an expansion based on daylight autonomy values has been made: the higher the percentage, the more the building extends its area. The idea is to get an extension of useful working space just in those areas in which luminance levels are acceptable for a longer time while, at the same time, buildings get slimmer where natural light conditions are worse. The concept has been tested on a study case in Rome, more specifically to the Ligini's Towers in the rationalist neighborhood of EUR.

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1. Introduction

1.1. Increasing of energy demand for light

In most industrialized countries, the proportion of retrofit activities in the construction sector has increased steadily during the past two decades. Today, a large number of buildings are being refurbished for different reasons, especially to increase indoor comfort conditions (air quality, visual environment, etc.), to reduce energy consumption, to counteract a poor state of repair, or to redefine the floor layout.

Daylight design is an important element of retrofitting interventions only when building components that affect the building's day lighting performance are replaced. Common retrofit measures include window replacement or, in some cases, the whole facade; old windows are often leaky and thus glazed surfaces a relevant source of heat loss. Refurbishment is therefore a chance not only to replace old building components with new ones, but also to redefine the functional concept of a building in order to meet today's requirements.

Retrofitting measures for administrative buildings are often oriented to reducing operative energy demand, whereas the aspect of reducing electric energy for lighting is getting an increasingly important aspect. In existing building, energy consumption for artificial lighting is not considered as a priority because its incidence is low in relation to the energy demand for air conditioning, heating and cooling. Whereas in retrofitted buildings with high-energy efficiency, the incidence of artificial lighting is very high in relation to thermal energy [1].

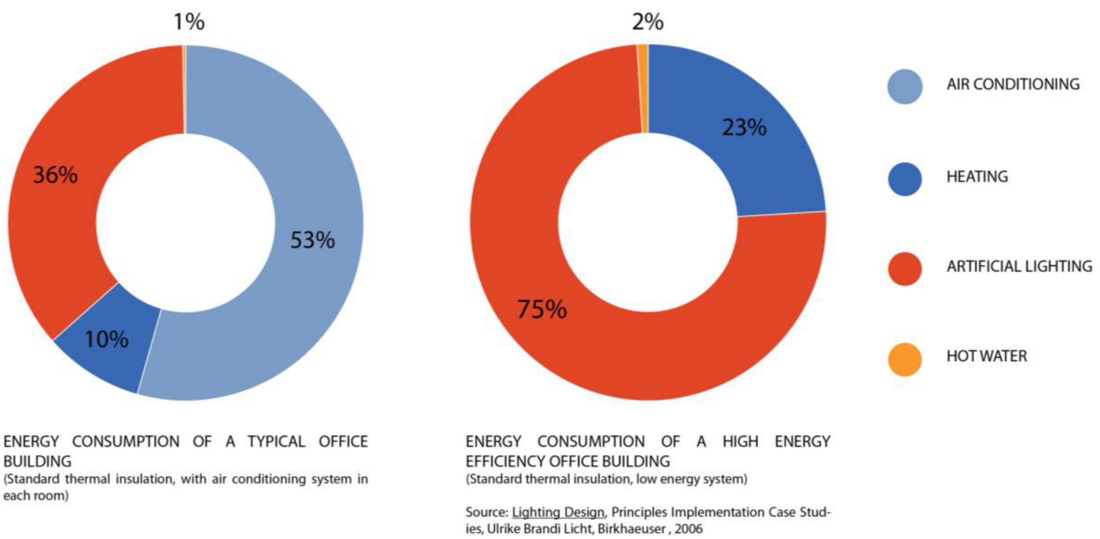

Fig. 1. In retrofitted buildings with high-energy efficiency standards, the incidence of artificial lighting is very high (up to 75%) in relation to thermal energy (up to 23%).

Further studies have shown that even using more advanced artificial lighting concepts and technologies, the energy demand for lighting has still a considerable impact on the overall energy demand of the building [2].

An increase of natural daylight conditions allows a reduction of artificial lighting to guarantee the requirements in terms energy demand and user comfort. The factors that determine the levels of natural day lighting are:

- At the urban level: latitude, sun shine probability, obstruction, building design scheme;
- At the room level: fenestration and height to depth ratio;
- At the window level: glass to frame ratio, glass LT factor, shading system.

1.2. Retrofitting

In the cases of interventions on existing buildings, the possible modifications are limited to the façade; nevertheless, it could be possible to modify, in some cases, also the original volumes by additions or subtractions.

In some cases, retrofitting measures can be combined with volume increase to reach better energy performances [3], a bonus that is conceived for investors to cover the costs for interventions that could be otherwise amortized very hardly.

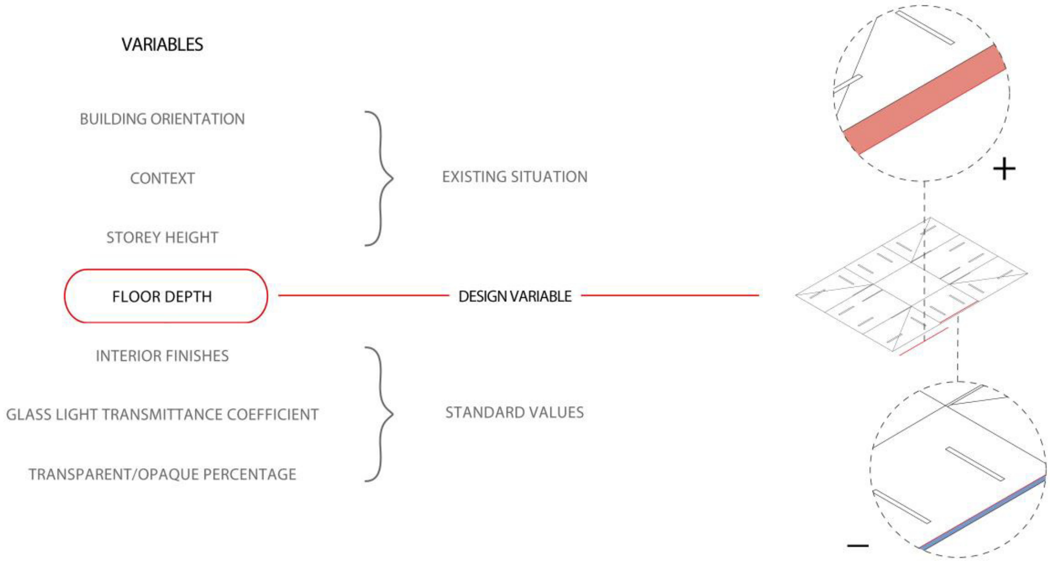

Fig. 2. When dealing with existing building, the floor-to-floor height is a not modifiable parameter, while the depth can be modified by adding or removing surface to the existing slabs. Our purpose is to test the daylight level in an existing building modifying the height to depth ratio.

An increased surface can be implemented with additional, overhanging structures that are structurally independent and that create a new layer on the external faces of buildings.

The object of the present research is the study of the morphological modification and how building transformation can be informed by natural daylight optimization. The surface increase is determined by the parameter of daylight to obtain optimal day light levels in the building. Furthermore, the modified geometry corresponds to an increased volume and floor surface and to a better interaction with the surrounding buildings in terms of daylight supply.

Among the different parameters that influence the level of natural daylight, we have focused our observation on the height to depth ratio that highly affects the building geometry. When dealing with existing building, the floor-to-floor height is a not modifiable parameter, while the depth can be modified by adding or removing surface to the existing slabs.

Most buildings have symmetrical floor plan layouts, that don't relate to the orientation and therefore to the light levels. As light levels are higher close to the façade, the presented method proposes to vary the depth of spaces in relation to natural daylight availability, to obtain a maximum surface increase by guaranteeing an optimal natural light supply.

2. Targets

Through the proposed investigation, the parameters to modify the existing building are set. By mapping the building floor plans, light entrance can be maximized depending on the given floor height.

This process is made possible by the use of daylight simulation tools.

Following specific targets can be further investigated:

- Homogeneous daylight supply levels for the entire building to reduce the use of electrical energy for artificial lighting;
- Optimized building shape to maximize daylight entrance;
- The choice of the most advantageous parameter to measure day light supply in office buildings;
- The definition of a calculation method using simulation tools;
- The correlation between daylight autonomy and height to depth ratio to maximize surface increase in the areas where the daylight supply is particularly advantageous;
- The validation of this method and its results on a real case study.

3. Method

In order to simulate the effect of building shape on daylight we combine a chain of software based on the Grasshopper capability to be programmed for specific task. The parameters we set are imported from the 3D model and the algorithm provides feedbacks: the algorithm produces analytic and graphics data that can be used from the designer to tune the project towards the best shape.

The overall method is based on a trial and error process, because the choose of a shape is always a design action, and our aim is to support the designer in the design process but not to generate shapes in an automatic way.

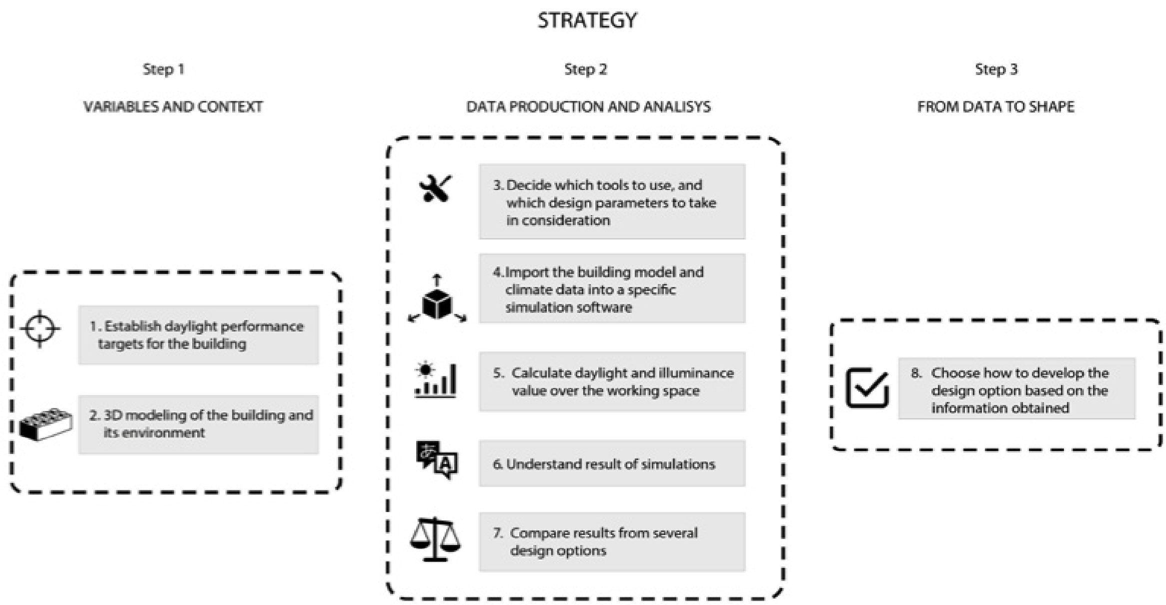

Fig. 3. The method is splitted in three steps: the choose of variables, the data production and analysis, the design interpretation of data.

3.1. Definition of a parameter to quantify day light

In our study, we decided to consider the Daylight Autonomy (DA) as a more effective parameter in zones with a high amount of radiation. Instead, the Daylight Factor (DF) refers to overcast sky conditions.

Daylight autonomy is a major innovation since it considers geographic location specific weather information on an annual basis. It is represented as a percentage of annual daytime hours that a given point in a space is above a specified illumination level [1,4].

3.2. Definition of a threshold

The threshold was at 300 lux on a horizontal plane at a height of 80 cm above the floor [1]. The aim is to map the floor plans in order to dedicate the most possible amount of surface to working activities that require specific day light levels during operations. Floor plan surface can be increased when the light level of 300 lx is guaranteed for more than 70% operation time.

3.3. Definition of simulation models

Daylight autonomy analysis produces a high amount of data. The necessity of quickly modifying the input data in a reiterative process has determined the use of the 3D Rhinoceros software [4] in combination with the parametric plug-in Grasshopper [4]. The three-dimensional parametric model has allowed to modify quickly the floor plan surface and to verify the consequences on the DA levels.

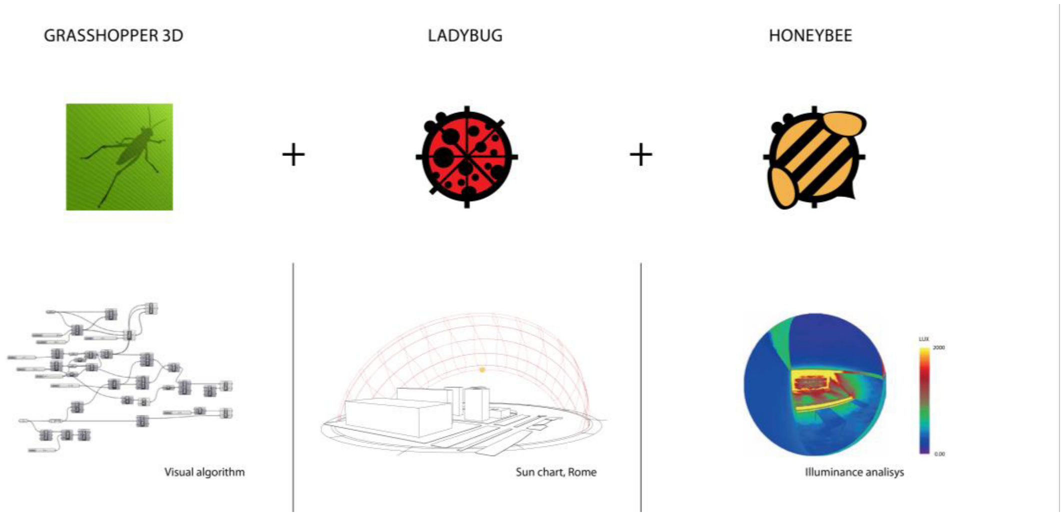

Fig. 4. By using different integrated software, it was possible to connect the variations of daylight supply to the dimension of the floor surface.

For importing the weather data of Rome, the Grasshopper plug-in Ladybug [4] was used. After importing the climate data of the study zone, (Energy Plus Weather files - EPW) in Grasshopper, Ladybug visualizes a shadow study of the buildings.

Honeybee [5], another Grasshopper plug-in, allows to connecting on a single platform different analysis software: Radiance for image visualization, Daysim for day light calculations, Energy Plus for climate data and Open Studio for running different programs. Daysim was used to generate DA data.

3.4. Building model and its context

The building chosen for the case study is part of an office building complex of the 1960's located in Rome, Italy. At present, the building is object of a retrofitting project. The building was modeled in its present shape with a façade with 85% windows-to-wall-ratio and a 0.5 value for light transmission of glazed surfaces. The building is located next to other buildings that were also modeled in their present dimensions and shape.

3.5. Calculation of the daylight autonomy levels for the entire building

The model was used to carry out a daylight autonomy simulation: the values were presented both in an analytic and a synthetic form in a grid of 50 x 50 cm for each level.

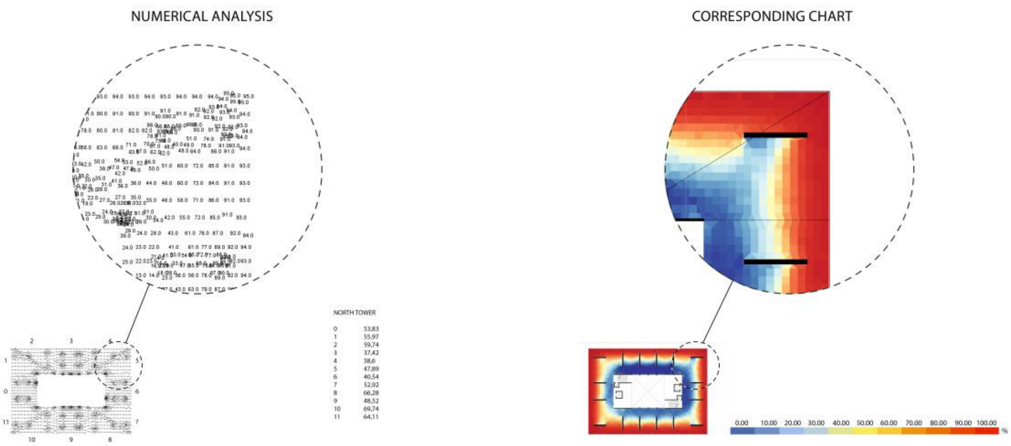

Fig. 5. The simulation of daylight autonomy level (DA) in each building floor. Left: analytic values; right: synthetic visualization. The chart provides the areas where the DA is over the threshold, then it is possible to increase the depth of spaces, and where is not, then the depth should be reduced.

3.6. Increasing floor plan surface where the DA levels are higher than the threshold and reducing it where DA levels are insufficient.

Depending to the exposition and the height, different DA values are reached. Each floor plan was divided into 12 sub areas in relation to the orientation. For these areas the DA level was calculated setting a minimal value of 300 lux for more than 70 % of operating time. If this condition is fulfilled, the slab length was increased with 50 cm towards the outside. This calculation was applied to all 12 subareas for all 16 levels of the building. Since the surface increase influences DA levels on the lower level, all modifications were included in the further calculation, in an iterative process.

3.7. Definition of a theoretical form that maximizes surfaces guaranteeing higher light levels

This iterative process determines a theoretical building envelope shape that is optimized in terms of DA. The shape has not necessarily an architectural sense, therefore it need a further optimization in order to obtain continuous surfaces and a reasonable envelope.

3.8. Interactions between buildings

The light level is affected by the shadows of adjacent buildings. Therefore, the case study has analyzed not only the single building but also the entire complex to verify how modifications in shape can influence the other buildings.

3.9. Shape modification to maximize the surface of all buildings

The shadow simulation shows that the south and east tower produce shades on the northern tower for long periods of time. The shape modification for these two towers has reduced the impact on the northern tower, guaranteeing better daylight levels for it. Simultaneously these modifications have determined better daylight levels for the southern and eastern towers.

4. Results

4.1. Shape optimization and surface increase

In the case of the northern tower, the surface increase on the 16th level was of 1,5 m on the east, south and west sides, producing a surface increase from 946 m^2 to 1062 m^2 that correspond to an increase of 12% of the floor plan surface. This increase is not equal for all levels; on the 11th level the increase is 31 m^2 that corresponds to 4%of the floor area, on the lower levels even a surface reduction occurs.

In fact, to guarantee DA levels above the set threshold, the depth on lower levels has to be reduced. On the 6th level the surface was reduced from 946 to 894 m^2 with a reduction of 52 m^2 corresponding to 6% and on the first level from 946 to 814 m^2 with a reduction of 131 m^2 that correspond to 11%. Summing up additions and subtractions an overall increase of 7% surface was achieved that correspond, in terms of surface, to one additional level. Beyond that, the daylight conditions in the building were substantially increased. For example, at the 16th level the amount of surface where the set threshold is guaranteed increased from 555 m^2 to 880 m^2.

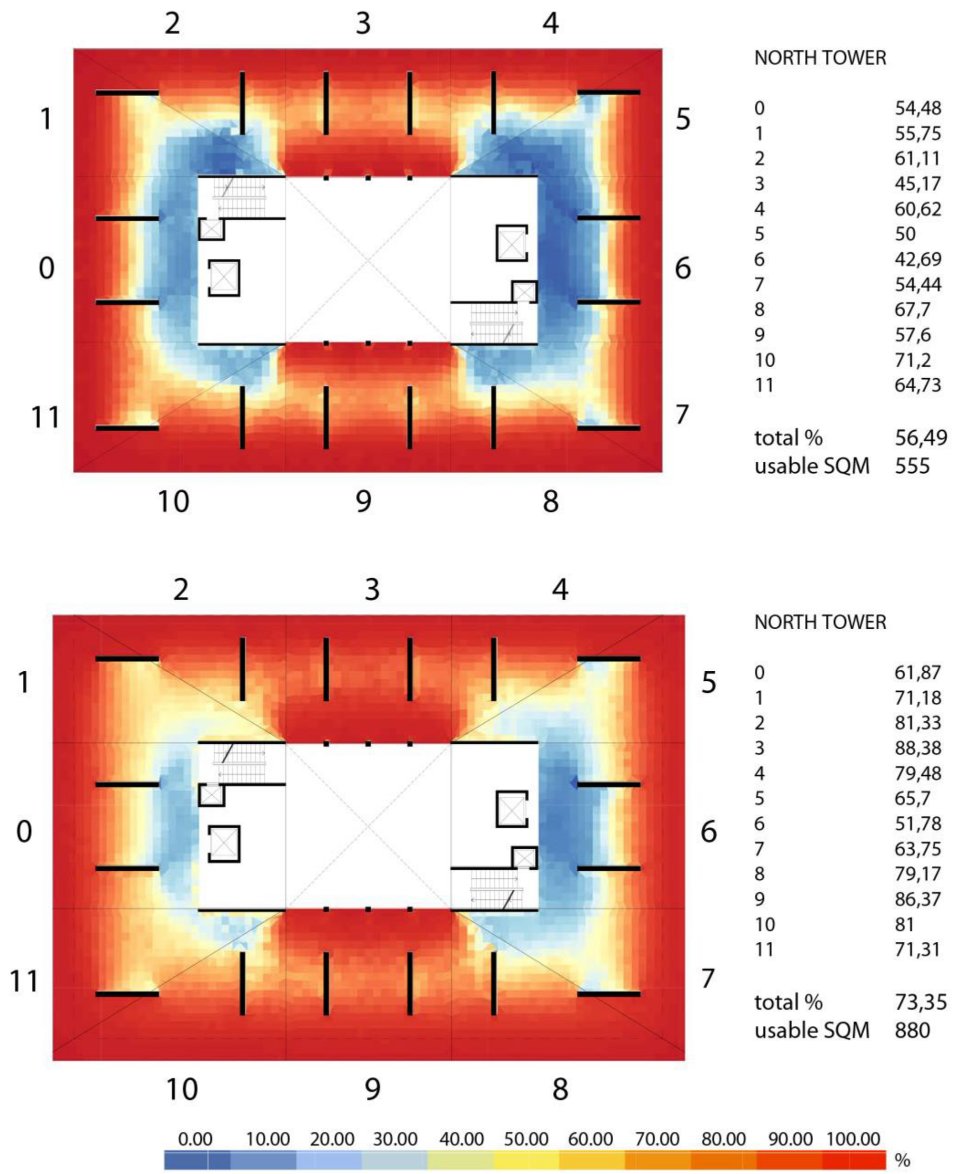

Fig. 6. Upper picture: before and, lower picture, after the floor surface increment. The increase of usable surface with a DA value (300 lux for 70% of operational time) higher than the set threshold.

5. Conclusions

The digital simulation tools allow to obtaining a large amount of data to map DA values within the building. This data was used to inform shape modifications in a transformation process of an office building in Rome. The resulting project produces an increase in floor plan surface by simultaneously increasing the day light supply within the building.

Two aspects that usually are considered in contrast, such as the building depth and the natural daylight quality levels, where connected determining an increase both in surface and in DA levels on every level of the existing building.

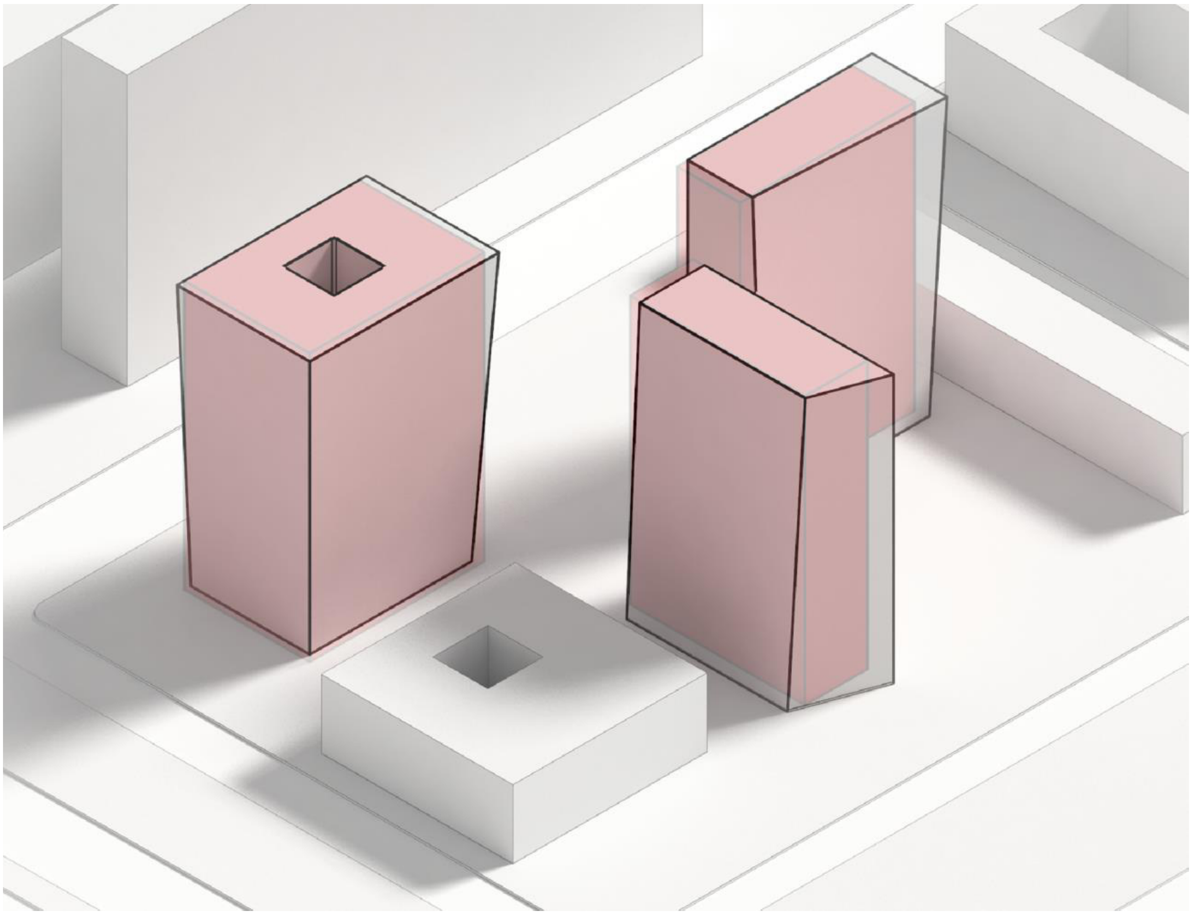

Fig. 7. It is possible to compare the existing shape (in rose in the picture) and the daylight optimized shape (in white). The shape modifications have determined a surface increase of 7% and simultaneously an increase of natural day light levels in the building.

In this specific case study, the described method has been applied to the refurbishment of an existing buildings, but it could be used to help designers to optimize the shape of new buildings in the early stages of the design process, by considering more variables e.g. The floor height.

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