Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 3 (2024)

Optimizing Building Form for Daylight Access in Dense Urban Areas in the Early Stages of Design

Fatemeh Yazdandoust
Ph.D. candidate, Morgan State University, Baltimore, MD, USA

Abstract: The urgency to address climate change, the energy crisis, and indoor air quality underscores the importance of utilizing daylight as a renewable energy source in urban environments. This study delves into passive design strategies to facilitate access to sunlight and daylight within urban contexts and architectural designs, aggregating essential parameters identified in the existing literature to improve building forms for daylight accessibility. The study then develops a multi-scale, multi-objective framework integrating these passive strategies to optimize building performance in densely populated areas. Suitable approaches for incorporating daylighting at both building and urban scales are identified by examining existing passive form-finding strategies and rules of thumb. Given the implications for dense urban areas, floor area is used as an evaluation criterion, with energy use intensity (EUI) and carbon footprint serving as additional criteria in the optimization process through manual analyses and computer-based tools. By adopting a workflow that considers multiple objectives and parameters, this study aims to guide designers in integrating optimal daylighting strategies during the initial design phases.

Keywords: *Building Form, Daylight, Renewable Sources, Sunlight*

1. Introduction

A. Background

The need to address climate change, energy efficiency, equity, health, and indoor air quality has heightened the emphasis on daylight in urban environments. The US Department of Energy reports that the building sector accounts for 40% of energy use and greenhouse gas (GHG) emissions. Reducing energy consumption in buildings is essential for addressing climate change, as heating, air conditioning, ventilation, and lighting are the primary energy consumers (Department of Energy, 2023). For instance, in commercial buildings, lighting accounts for almost 35% of total energy consumption, with 60% of this energy used in perimeter zones within 40 feet of windows during working hours (8 am to 6 pm) [1], [2]. Practical urban configurations and building forms are crucial for harnessing these natural resources.

Historical vernacular settlements across various geographic locations illustrate the integration of urban design with sun and wind considerations. Although these concepts have been neglected for some time, there has been a recent resurgence in the awareness of the importance of urban fabrics and building forms that facilitate access to daylight. Zoning plays a pivotal role in the initial design stages, directly impacting the availability of daylight and fresh air in urban contexts [3], [4]. For example, the 1961 zoning law in New York City mandated building setbacks to ensure street-level access to sunlight and fresh air [5]. In 1978, Professor Ralph Knowles proposed solar zoning, known as the solar envelope, which guarantees specific hours of sun exposure for building masses without casting shadows on neighboring structures [6]. Various researchers and designers have explored this concept in different urban contexts. While Knowles' concept is effective in medium-density urban areas, it may not suit densely populated regions [7]. To address this, DeLuca and colleagues introduced the Reverse Solar Envelope (RSE), which ensures sunlight access for neighboring buildings in dense urban areas.

In addition to zoning regulations ensuring sunlight access for groups of buildings, individual buildings can benefit from daylight through proper design rules. Daylight feasibility tests, considerations of daylight penetration, skylights, and atriums are commonly used to determine the appropriate building form that maximizes daylight availability. Designers can achieve more efficient and effective solutions by evaluating and incorporating these strategies in form-finding.

Existing examples of the application of daylight are often site-specific and lack a comprehensive workflow for effectively implementing daylighting and natural ventilation. Furthermore, these examples may not consider all relevant aspects, including required metrics and targets, to facilitate the form-finding process during the mass design stages. Developing a workflow that optimizes building form for daylight application and includes the necessary metrics and targets is essential. By adopting an integrated approach, designers can streamline the form-finding process and achieve optimized solutions that meet daylighting requirements. This research study aims to develop a systematic process for identifying appropriate forms that integrate daylighting within dense urban contexts. The study proposes two primary levels of analysis: urban and building. Established rules and computer tools, such as Rhino-based software, Climate Studio [8], and Grasshopper plugins Solar Toolbox [9], are utilized for daylight simulations. The study aims to provide designers with a practical framework for integrating daylighting in urban contexts by utilizing established rules and computer tools. The developed process considers urban-scale and building-scale requirements to guide the form-finding process effectively. Overall, this research seeks to contribute to the understanding and application of daylighting strategies by offering a systematic approach that can be applied in dense urban contexts [10].

B. Daylight definition and most used metrics

Daylight has been utilized as a primary interior lighting source for centuries, encompassing direct and indirect sunlight. Its availability is influenced by location, time of year, and sky conditions [11]. In architecture, daylight integrates natural light and building forms to create visually stimulating, healthy, and productive interior environments [5].

Daylight within buildings is a combination of direct sunlight, indirect sunlight, and reflected light from surrounding spaces and surfaces. To facilitate measurement, daylight is quantified using relative metrics rather than absolute values, as its characteristics vary based on factors such as time of day, weather conditions, and seasonal variations throughout the year. Two commonly used metrics for quantifying daylight are the daylight factor (DF) and daylight autonomy (DA). The daylight factor represents the ratio of indoor to outdoor illumination on an overcast day and is dimensionless, typically expressed as a percentage or decimal [3], [12]. It is position-specific, meaning that different areas within space can have varying daylight factors.

Daylight autonomy, on the other hand, measures the availability of daylight in terms of the duration that a given space meets a target illuminance level [13]. The Illuminating Engineering Society of North America (IESNA) sets a target of 300 lux with a 50% threshold to fulfill daylight autonomy requirements [11].

In daylighting, "Annual Sunlight Exposure (ASE)" refers to the fraction or percentage of the horizontal work plane that surpasses a specific illuminance level from direct sunlight for a designated number of hours per year. This assessment considers a predetermined daily schedule, assuming all operable shading devices are in the retracted position. ASE provides insights into the extent of direct sunlight exposure on the work plane throughout the year [14]. Illuminance measures the total luminous flux on a surface, expressed as the amount of light energy per unit area. It quantifies the brightness or light intensity level at a specific surface point. It is measured in lux [15].

2. Passive Design Strategies for The Application of Daylight

A. Daylight on an urban scale

The presence of daylight within a building is influenced by a multitude of factors, including the urban context, building form, orientation, façade characteristics, size and location of openings, geometry, and interior space features such as color, material, and glazing types. Achieving access to daylight requires careful consideration of these elements in the building design and site selection. This study focuses on finding the appropriate building form that facilitates daylight access.

To clarify and streamline the form-finding process, two scales are used for assessment: urban and building. Different daylight standards are available worldwide, such as solar zoning, daylight factor-based approaches, and window size-based criteria, which may vary from country to country. These standards can be used to set criteria in the form-finding process. While solar zoning is the initial step, it should be noted that it does not guarantee daylight access to interior spaces. Its primary purpose is to ensure sufficient light availability around the building while minimizing obstruction of sunlight to the surrounding context.

The concept of solar rights, first established in New York City in 1916 for buildings in Manhattan, restricts building height and mass to ensure access to daylight and air for the surrounding area. San Francisco also implemented solar rights in 1985 to provide solar access to open spaces such as parks and specific streets throughout the year [16]. In 1978, Ralph Knowles introduced the solar envelope concept for urban buildings. The solar envelope establishes volumetric limits for a building to prevent overshadowing the surrounding environment at specific times. The shape of the envelope is determined by site geometry, sun movement over time, and the shadow fenestration line, which marks the level on the surrounding façade where shadows are not projected (Fig.1) [6].

Figure 1: The solar envelope [6]

By considering these principles and concepts, this study develops an understanding of the form-finding process, enabling the design of buildings that optimize daylight access while harmonizing with the surrounding urban context, allowing solar access to adjacent buildings. The solar envelope can be calculated and visualized using various methods, including manual calculations, charts, and computer algorithms. Rhino, a 3D computer graphics software developed by Robert McNeel and Associates in 1969, has plugins incorporating algorithms to generate solar envelope surfaces. These plugins can be integrated into Grasshopper, an extension of Rhino that facilitates visual programming using Python [17].

The solar envelope concept has been widely utilized in a variety of research studies to determine appropriate urban configurations. For example, researchers employed the solar envelope in Bandung, Indonesia, to analyze vertical settlement (Fig. 2) [18]. Similarly, in Nabeul, Tunisia, the solar envelope was used to establish urban regulations for solar control (Fig. 3) [19]. In Izmir, Turkey, the solar envelope created a solar cityscape (Fig.4) [20]. Additionally, a study focused on solar access and natural ventilation in downtown Chattanooga, Tennessee [21]. The study regulates the shape of buildings on a block o to ensure access to daylight and sunlight. It uses the Solar Envelope concept, which ensures adequate daylight access based on a specified sky view angle, with the Solar Envelope concept, which ensures access to direct sunlight during specified times. By applying this concept and considering strategies for natural ventilation to the existing pattern of blocks and buildings, the research demonstrates how the urban fabric can be configured to maximize daylighting potential while allowing for increased development density compared to existing conditions. (Fig. 5).

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 3 (2024)

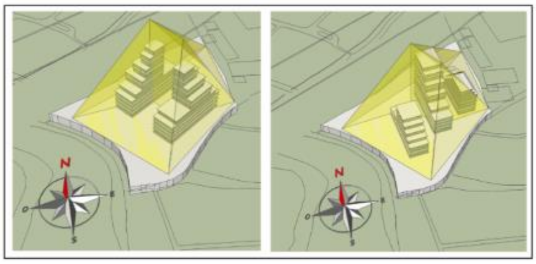
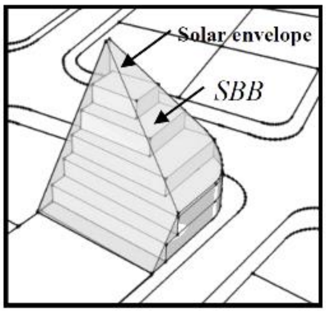


Fig. 2: Solar envelope for vertical development, Indonesia [18]

Unique maximal *SBB*



Urban rules		Solar enveloppe rules	
Setback from roads	3m	Setback from roads	0m
Setback from common limits	4m	Setback from common limits	2.8m
Maximal height	12m	Maximal height	15m
Plot ratio	0.3	Plot ratio	0.9
Floor Area Ratio	1.0	Floor area Ratio	**2.6**

Fig.3: Solar envelope rules, Tunisia [19].

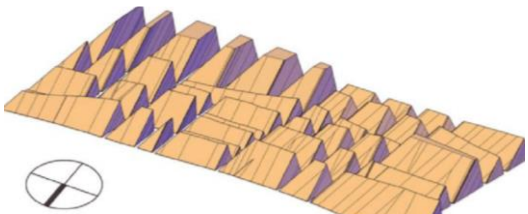


Fig.4: Solar city scape, Izmir, Turkey [20].

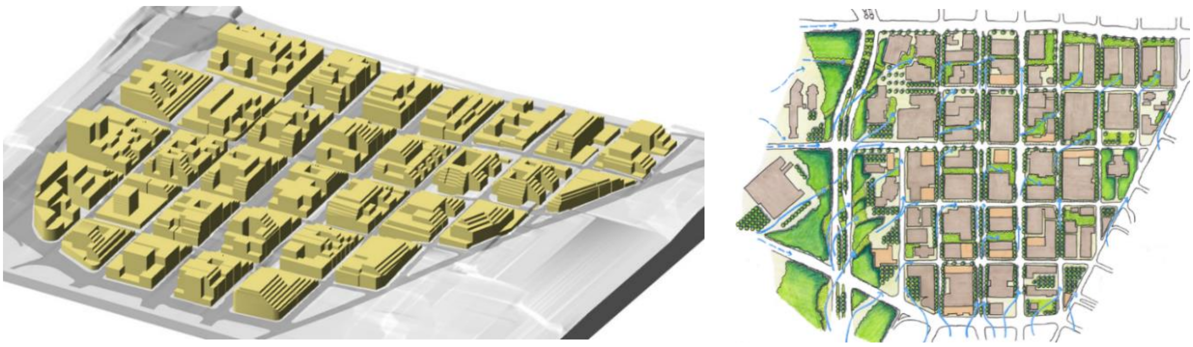


Fig. 5: Sunrays intersecting with the building volume and sunrays that do not intersect with the volume and core (left), sunrays reaching a window in the back of the volume shown in red (right) [21]

However, Ralph Knowles' method, associated applications, and tools have demonstrated effectiveness in low building density. However, when applied to dense urban environments, where optimizing the building floor area is of utmost importance, the strict enforcement of a solar envelope can inadvertently encourage urban sprawl rather than promote sustainable development. In such densely populated areas, it becomes necessary to balance solar access considerations and efficiently utilize available space to ensure responsible urban growth and design. Knowles' traditional solar envelope method may need to be more practical in densely populated areas. De Luca et al. (2021) introduced the Reverse Solar Envelope (RSE), specifically designed to address this limitation in the early design stages. The RSE employs the discrete solid geometry method, which divides the building volume above grade into three-dimensional cells. By subtracting these cells from the overall volume, the RSE ensures that solar access to the surrounding façade is not obstructed. Rhino and Grasshopper scripts are utilized to implement this method, and a plugin called Solar Toolbox, developed by DeLuca and colleagues, helps streamline the workflow.

The RSE process involves five steps, each serving a specific function within the workflow sequence. These steps include:

1. Volume/Facade Discretization.
2. Sun Rays Generation.
3. Sun Rays Selection.
4. Hit-or-Miss Analysis.
5. Reverse Solar Envelope Generation.

This method offers the advantage of creating an optimized building form driven by solar considerations (Fig. 6,7, 8) [7].

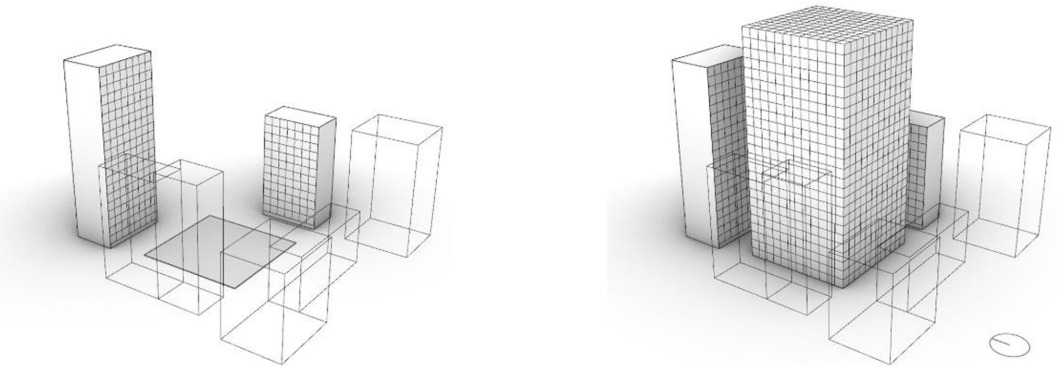


Fig. 6: Discretization of the surrounding buildings' facades (left) and the building mass above the ground (right) [7].

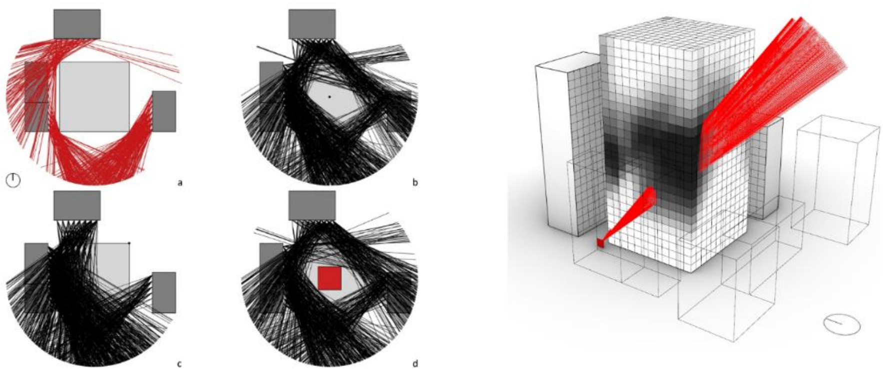


Fig. 7: Sunrays intersecting with the building volume and sunrays that do not intersect with the volume and core (left), sunrays reaching a window in the back of the volume shown in red (right) [7]

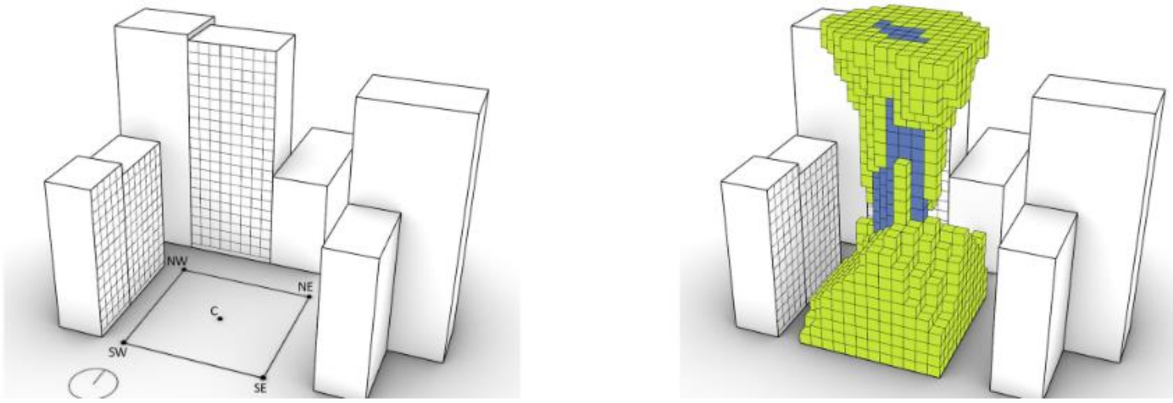


Fig 8: Façade subdivision, and plot (left), RSE generated (right) [7]

B. Daylight in the building scale

Historical standards and regulations aimed to ensure access to daylight in interior spaces. However, these regulations only sometimes guarantee optimal daylighting due to dynamic daylight characteristics, obstructions in the surrounding context, and permanent shading. For example, LEED v4 requires a daylight factor of 2% (excluding all direct sunlight penetration) in 75% of all spaces occupied for critical tasks. However, Reinhart's examination of 2304 spaces with a daylight factor over 2% demonstrates that the percentage of floor area that meets this requirement will never reach 75% for all spaces, even though a large portion of these rooms have an average daylight factor of 2%. As a result, daylight regulations must consider different rules, criteria, and methods to make informed decisions based on site and building requirements. These regulations must be adapted to address the complexities of dynamic daylighting and the surrounding context to ensure optimal daylighting in interior spaces [16], [22].

This study thus considers several rules of thumb to guide the design process. On the building scale, the entry of sunlight depends on unobstructed openings such as windows and skylights. Shaded facades may experience reduced daylight penetration. The daylight penetration depth, which ensures sufficient light, is often determined as a multiple of the distance from the floor to window head height, ranging from 1.5 to 2.5 times. Sky lighting, achieved through light wells connecting the ceiling plane to the roof plane, is another method to access direct daylight. The amount of light depends on the size, location, and proportion of the light well, with a desirable width-to-depth ratio larger than two-thirds.

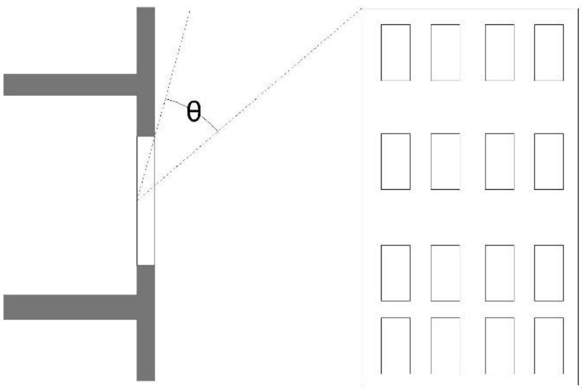


Fig. 9: Sky view angle (θ).

Additionally, indirect light reflected from surfaces can serve as a daylight source when direct sunlight is obstructed, provided it meets the feasibility factor calculation. The feasibility factor considers the window-to-wall ratio (WWR), glazing area visible transmittance (Vt), and obstruction from neighboring buildings. Professor Reinhart and his colleagues refined the feasibility factor. They introduced a rule of thumb called the Daylight feasibility test (θ * WWR > 2000), where θ represents the vertical sky angle between the building and the obstruction (Fig. 9). As per the equation proposed by Reinhart in Section Five of the Daylighting Handbook I, which outlines massing studies if window to wall ratio has its maximum, which is 80 % since windows also include mullions, a minimum sky view angle of 25 degrees is required for effective daylighting. The atrium design is another passive strategy to provide indirect daylight, with a rule of thumb suggesting a maximum height of fewer than 2.5 times its width [5].

$$WWR > (0.88\ DF / V_t) * (90^{\circ} / \theta)$$

In the early design stages, computer tools can assist in assessing form and daylight availability. Climate Studio, a Rhino-based platform, offers a user-friendly tool for simulating daylight availability and calculating related factors such as annual sun exposure (ASE), illuminance, and artificial lighting. It is also available as a plugin on Grasshopper, providing easy-to-use and customizable daylight simulation templates. Those are now the basis for LEED certification of daylighting design.

By considering these rules of thumb and utilizing computer tools like Climate Studio, designers can make informed decisions regarding building form and optimize daylighting in the early design stages.

3. DEVELOPMENT OF THE FRAMEWORK FOR THE FORM-FINDING PROCESS IN THE APPLICATION OF DAYLIGHT

A. Summarizing the Daylight Strategies

Based on the literature review, access to daylight in and around a building is influenced by these key factors, which can be divided into two categories:

- *Urban Context and Site:*

The proportion of open space: Unobstructed open space prevents significant shadowing caused by nearby structures. It also ensures that the building does not cast shadows on adjacent properties.

Massing and Relation: The overall massing of the building and its relationship to surrounding structures play a crucial role. Optimized massing improves daylight by considering solar exposure.

Building Orientation: Orienting the building to maximize exposure to diffused daylight based on the local climate conditions is essential.

- *Building Geometry, Floor Plan Layout, Fenestration, and Room Design:*

Building Floor Aspect Ratio: The floor plan of the building and its aspect ratio impact the overall form. These factors significantly affect the distribution of daylight within the building.

Façade Characteristics: The design of the building's façade, including the arrangement of windows, shading devices, and glazing types, influences the amount and quality of daylight entering the interior spaces.

Room Design Characteristics: Interior space arrangements, proportions, room dimensions, materiality, reflectivity of surfaces, and relationships are crucial in determining access to daylight.

The literature review suggests that building and urban context features utilizing daylight can be categorized into similar groups [23].

B. The Form-finding Framework for the Application of Daylight

This study proposes optimizing the form-finding process for access to sunlight and daylight in urban contexts and individual buildings. Due to the parameters involved in incorporating daylight, a multi-phase framework with a multi-objective approach is deemed most suitable. The form-finding process is conducted at the urban and building scale. Each scale consists of interconnected steps considering the building's overall shape and characteristics while comparing and evaluating optimized forms to determine the most appropriate design. The final steps aim to identify the most efficient form that meets predefined performance goals for accessing sunlight daylight within a dense urban environment (Fig. 10). The subsequent sections describe the proposed framework, which optimizes daylighting.

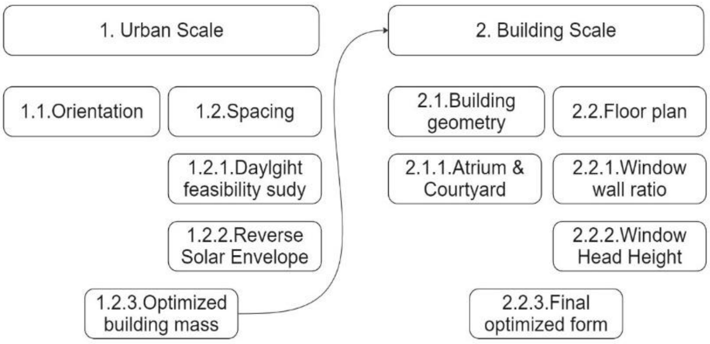


Fig.10: Workflow of design process framework

1) Urban Scale

The first stage of the design process focuses on the urban scale and primarily involves orientation (1.1) and spacing (1.2) considerations. The goal is to determine the optimal orientation of the building toward the sun and the spacing between buildings to avoid shading on the building and its context. This process begins by identifying the most suitable orientation for the sun throughout all seasons.

1.1 Orientation to the sun

The initial step in building design involves determining the optimal solar orientation. Sun path diagrams, available online or through tools like Climate Studio, can assess the building's location with the sun's path throughout the year [24].

Ideally, the most favorable orientation for a building is achieved by aligning its longest side towards the south, with a slight deviation of up to 15 degrees. This orientation maximizes sun access to the building in winter when the sun angle is low, while the exposure can be controlled by building features like sunshades in summer when the sun is high in the sky (Fig. 11) [25]. However, in cases where the site extends from north to south, aligning the long side of the building with the south direction can pose challenges. In such situations, the east and west sides, the longest sides, receive more sunlight during the morning and afternoon, which is not ideal for daylight access, but it can be viable through thoughtful design features such as sunshades and blinds.

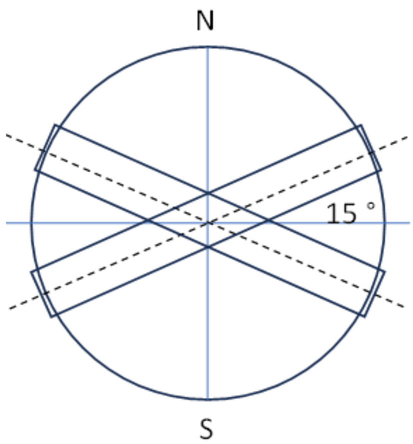


Fig. 11: The ideal building orientation toward the sun is the south with up to 15 degrees deviation.

1.2 Spacing of building mass in an urban context to access daylight

Step 1.2.1. Daylight feasibility study

Once the optimized orientation is determined, the next step involves justifying the spacing of the building within the context. A daylight feasibility study is conducted to assess which parts of the building may be shaded by adjacent obstructions and to identify areas that receive sufficient daylight. The key parameters for this feasibility study are the façade orientation and surrounding obstructions. The sky angle θ is manually calculated to assess the degree of obstruction, and the daylight feasibility formula (explained above in the Daylight in building scale) is used to determine the degree and distance required to mitigate the obstruction. This information helps adjust the building's distance from its surroundings to ensure adequate daylight on desired surfaces and zones.

Step 1.2.2.: Applying the Reverse Solar Envelope (RSE) concept to the building mass

Another aspect of this stage is to design a building form that does not block the daylight access of neighboring buildings. Reverse Solar Envelope (RSE), described in Daylight on an urban scale section, can be employed to find an appropriate form, especially in dense urban areas. The Solar Toolbox includes components that generate alternative building forms based on the input data. The Grasshopper component, called the RSE generator, eliminates 3D building blocks to create options for building form. For example, varying daylight access hours can significantly impact cell elimination numbers in a building. The RSE approach identifies the portions of the building mass that need to be eliminated to ensure sunlight reaches the windows of surrounding buildings. To facilitate this analysis, a script is developed using the Solar Toolbox plugin within the Grasshopper environment. The geometries of surrounding building volumes, their windows, and the building plot curve are exported from Rhino to Grasshopper interface. The surrounding buildings are represented as poly surfaces, while their windows are defined as surfaces. A rectangular curve defines the site. Subsequently, the RSE component generates an optimized building volume shape, allowing sun access to the surrounding buildings.

2) Building Scale

This stage encompasses two primary objectives: building geometry (2.1) and floor plan (2.2). Building upon the preliminary mass study from the urban scale (1.2.3), the aim is to determine the optimal geometry for the building. The daylighting strategies can be approached from two perspectives: perimeter strategies, which focus on side-lit windows, or central strategies involving features such as atriums and courtyards. This leads to including a central void, such as an atrium or courtyard, or limiting access to daylight through the external shell. Alternatively, a combination of these two scenarios may be chosen. Here, the rule of thumb for atrium calculations suggesting a maximum height of fewer than 2.5 times its width explained in the Daylighting in Building scale can be used to calculate the volume of the atrium. The Floor Area Ratio (FAR) is a reliable decision criterion in dense urban areas while also considering the spaces that must be daylit according to the building program requirements. Therefore, the optimized geometry should allow access to daylight while maximizing the floor area ratio compared to other alternatives. Other criteria are energy use intensity (EUI) and operational carbon. These criteria can be studied using computer tools such as Climate Studio. The ultimate objective is to determine the floor plan's dimensions and the proportions of the rooms. Rules of thumb like window-wall ratio (WWR) and window head height (WHH) are used to estimate the optimal window surface and floor plan depth for daylight penetration 1.5 to 2.5 times the window head height. Spaces with less priority to daylight can be in zones away from the windows with daylight access.

3) Final form with access to daylight

Integrating daylighting objectives in the form-finding process leads to optimized building design. By incorporating the RSE method and considering the specific context, the proposed framework enables the development of building masses that provide access to daylight and positively contribute to the surrounding urban fabric. The framework offers flexibility in considering different objectives and requirements, allowing for variations in the resulting form based on specific project needs.

4. Conclusion

The building and construction industry is widely recognized for its significant negative environmental impacts, making it crucial to find solutions to mitigate them. One promising design approach for creating a sustainable environment is passive design strategies that leverage renewable energy sources such as sunlight and wind. Strategies like daylighting and natural ventilation can reduce energy consumption and achieve additional benefits like improved indoor air quality. Therefore, the primary focus of this research study was to optimize the form-finding process for the application of daylighting while considering both urban and building scales.

To accomplish this objective, the study thoroughly examined the major passive building form design strategies for daylighting at urban and building scales. It involves evaluating the massing of buildings during the early design stages, progressing from macro to micro scales. This sequential workflow allows assessing the building mass before delving into finer details. Furthermore, it enables the consideration of the surrounding context to leverage its advantages and ensure unobstructed access to daylight. An objective-based approach facilitates the optimization of the building form, leading to an efficient and effective design process. By setting specific daylighting goals within each objective, designers can identify appropriate metrics and strategies to achieve those objectives—moreover, goal setting streamlines the work process, enhancing the efficiency of designers.

During the decision-making process, the floor area ratio, a critical factor in compact neighborhoods, was identified as the primary criterion. The study also demonstrated the impact of form with access to daylight on carbon emissions and energy use intensity. The framework is valuable for designers, enabling them to make informed and efficient decisions during the initial massing design stages, ensuring optimal daylighting.

Future work aims to expand the scope and generalize the findings. Such as incorporating automation through parametric computational tools such as Grasshopper, allowing the framework to be applied to diverse locations and scenarios. Grasshopper scripts can be developed using the built-in components or by creating new components as required. The input components in the Grasshopper, such as EPW file readers, BREP, and Geometry components, enable the exporting of relevant weather data, context models, and plots. Furthermore, simulation and transformation components can be coded using programming languages to facilitate the analysis and visualization of results.

References

[1] K. Konis, A. Games, and K. Kensek, "Passive performance and building form: An optimization framework for early-stage design support," Solar Energy, vol. 125, pp. 161-179, 2016.
[2] F. Yazdandoust and D. Mirrindi, "Rethinking sustainability: towards an open system approach," *DARCH - 5th International Conference on Architecture*, Apr. 2024, doi:10.5281/zenodo.11088501.
[3] A. Kwok and W. Grondzik, The Green Studio Handbook: Environmental Strategies for Schematic Design. Routledge, Taylor & Francis, 2018.
[4] F. Yazdandoust and D. Mirrindi, "Harvesting alternative energy: exploring exergy, human power, animal body heat, and noise as sustainable sources," *5th International Conference on Architecture and Design*, Apr. 2024, ISBN: 978-605-72065-4-1, doi:10.5281/zenodo.11088585.
[5] C. Reinhart, Daylighting Handbook I: Fundamentals Designing with the Sun. Christoph Reinhart, 2013.
[6] R. L. Knowles, Sun, Rhythm and Form. The MIT Press, Massachusetts, 1981.
[7] F. De Luca, T. Dogan, and A. Sepúlveda, "Reverse solar envelope method: A new building form-finding method that can take regulatory frameworks into account," Automation in Construction, vol. 123, 2021.
[8] Climate Studio. [Online]. Available: https://www.solemma.com/climatestudio. [Accessed: May 2022].
[9] Food4Rhino.com. [Online]. Available: https://www.food4rhino.com/en/app/solar-toolbox. [Accessed: May 2023].
[10] F. Yazdandoust, "Decision support for the design of a building form coupling daylight and natural ventilation consideration in a dense urban context," [Online]. Available: https://doi.org/10.31274/td-20240329-200. [Accessed: 2023].
[11] Velux.com. [Online]. Available: https://www.velux.com/. [Accessed: Mar. 2023].
[12] U. Passe, Course ARCH 551, College of Design, Iowa State University, Spring 2022.
[13] C. Reinhart, Course 4-430. [Online]. Available: https://ocw.mit.edu/courses/4-430-daylighting-spring-2012/6b02f502c8b6101f9c34d5eebbd5ded1_MIT_430s12_lec02.pdf. [Accessed: Apr. 1, 2023].
[14] Ies. [Online]. Available: https://www.ies.org/definitions. [Accessed: Jul. 2023].
[15] Wikipedia, "Illuminance." [Online]. Available: https://en.wikipedia.org/wiki/Illuminance. [Accessed: Jul. 2023].
[16] M. Boubekri, "An overview of the current state of daylight legislation," Human Environmental System, vol. 7, no. 2, pp. 57-63, 2004.

---

[17] Rhinoceros. [Online]. Available: https://www.rhino3d.com/. [Accessed: Dec. 31, 2022].
[18] B. Paramita and M. Donny, "Solar envelope assessment in tropical region building case study; vertical settlement in Bandung, Indonesia," Environmental Sciences, vol. 17, pp. 757-766, 2013.
[19] K. Raboudi and A. Ben Saci, "A morphological generator of urban rules of solar control," in PLEA2013 - 29th Conference, Sustainable Architecture for a Renewable Future, Munich, Germany, 2013.
[20] T. Stasinopoulos, "A survey of solar envelope properties using solid modelling," Green Building, vol. 13, 2018.
[21] M. DeKay, "Climatic urban design: Configuring the urban fabric to support daylighting, passive cooling, and solar heating," in WIT Transactions on Ecology and the Environment, The Sustainable City VII (2 Volume Set), vol. 155, pp. 619-630, 2012, doi:10.2495/SC120522.
[22] C. Reinhart and V. LoVerso, "A rules of thumb-based design sequence for diffuse daylight," Lighting Research & Technology, vol. 42, no. 1, pp. 7-31, 2010, doi:10.1177/1477153509104765.
[23] F. Yazdandoust and U. Passe, "Decision support for the design of a building form coupling daylight and natural ventilation consideration in a dense urban context," presented at the 8th International ICARB Conference on Carbon Accounting, UK, 2023. [Online]. Available: www.icarb.org/2023-conference/.10.13140/RG.2.2.26546.21442
[24] Andrew Marsh. [Online]. Available: https://andrewmarsh.com/apps/staging/sunpath3d.html. [Accessed: Aug. 2022].
[25] H. Fathy, Natural Energy, and Vernacular Architecture. University of Chicago Press, 1986.