Parametric Study Method of Illuminance and Airflow in Building Architectural Design Phase

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Abstract

Today, the production of sustainable buildings has become one of the main objectives of the construction industry. This direction aims to meet the increasing demand for construction while minimizing harmful impacts on the environment, thus contributing to sustainable development. The indoor environment of sustainable buildings, influenced by various parameters such as lighting, air quality, thermal comfort, and materials used is of paramount importance. This environment requires in-depth research to effectively meet the needs of occupants, thereby ensuring their comfort and well-being. The quantity of light and the natural ventilation flow are therefore essential elements to consider in the architectural design process of buildings. This study explores a computational approach using a workflow between Revit, Dynamo, et Python to assess illuminance levels and airflow efficiency in a small house. To achieve this, our research is divided into three phases: firstly, creation of 3D model in Revit; secondly, extraction of geometrical and environmental data and thirdly, computation of radiation-based illuminance calculations and estimation of natural airflow rates based on simplified Bernoulli equations using Dynamo and Python. The results of this research provide actionable insights into illuminance exposure and ventilation rates for each room, enabling data-driven decision-making for architects during the design process. This approach establishes a workflow that eliminates the need for external simulation software by leveraging BIM's built-in calculation tools. The results demonstrate the method's effectiveness in analyzing early design stages.

Keywords: *BIM and air flow analysis, integrated design and illuminance, BIM and illuminance study, air flow architectural analysis, architectural illuminance study method.*

1. Introduction

In recent years, sustainable construction has become the main objective of those involved in the building industry, in order to reduce as far as possible, the pollution associated with this sector, which accounts for 37% [1] of the overall pollution emitted by human activity [2–5]. There is a growing amount of research being carried out in every sector of the construction industry, with the aim of improving the efficiency, resilience and zero-emission performance of buildings. In the original concept of sustainable construction, it was more related to emission reduction and energy efficiency. Recently, the International WELL Building Institute (IWBI) launched a rating system based on principles that set a new global benchmark for healthy communities. This rating system focuses more on the relationship between the building and the indoor environment, with human health and well-being as its main objective [6]. Several parameters influence the indoor environment in sustainable buildings: lighting, air quality, thermal comfort, and materials used [7–9]. Daylight is of crucial interest because building scientists have recognized its relevance to the health and comfort of occupants [10] and its role in the perception of space and the aesthetics of the work and for its energy-saving potential [11]. The aim of this research is to explore the possibility of studying the building's illuminance and ventilation during the architectural design phase, using Autodesk Revit, Dynamo and Python, in order to minimise the potential changes that may occur during coordination with Heating, Ventilation, and Air Conditioning (HVAC) engineers and thus optimise the architect's design.

2. Literature review

2.1 Literature Review on Illuminance and Study Method

Several building assessment methods such as WELL v2 [9] which is supplement to LEED (Leadership in Energy and Environmental Design) in the United States, BREEAM (Building Research Establishment Environmental Assessment Method) in the United Kingdom, HQE (High Quality Environmental standard) in France, CASBEE (Comprehensive Assessment System for Built Environment Efficiency) in Japan [12], offer frameworks for high-efficiency buildings. At the same time, there are studies that use a combination of daylight and electric lighting systems that make a significant contribution to reducing energy consumption in non-residential buildings; however, determining energy performance requires knowing the levels of daylight in the location where the maximum benefit is found [13]. Natural illuminance contributes to reduce the building's overall energy consumption and is an important strategy for improving the building's performance and the visual comfort of its occupants. [14]. Daylight is an important parameter and a determining factor in assessing a building's performance. [15]. There are three main parameters that affect the natural distribution of light in a room: the height of the building, the opening of the windows in the building envelope and the size of the windows [16] and the state of the sky. A great deal of research has made it possible to assess the different aspects of daylight, namely its availability [17], its glare [18], its aesthetics [19] and the visual effect of daylight.

Regarding external lighting in architectural design, Anastasia [20] developed principles of "tectonic" illumination and "decorative". Illumination was developed based on the analysis of the state-of-the-art experience of lighting architectural objects. But these principles were based solely on the literature review and did not incorporate parametric approach, which are increasingly important for providing

guidelines in the conceptual phase. He et al. [21] evaluated the influence of perforated facade panels on internal illuminance using parametric analysis and established an analysis method for immediately and practically assessing the internal illuminance performance of different design options at the earliest design stages in order to provide possible solutions to facilitate readjustments. The analysis was made using Autodesk Revit for BIM model Rhinoceros coupled with plug-in (Grasshopper3D) for daylighting analysis.

2.2. Method for determining illuminance inside buildings

The measurement systems and minimum recommendations in terms of the amount of natural light to be achieved in buildings are defined by standard EN 17037 [22] which classifies them into three performance categories: Minimum, Medium, High. These recommendations are intended to serve as guideline for architects, designers and developers to effectively improve their creations. They are useful for all types of buildings such as hospitals, offices, sport halls, schools and private residences, and are only excluded for rooms where natural lighting is not adequate for the function of the room. A summary [23] of EN 17037 on illuminance inside spaces likely to be occupied, whatever their specific function, states that a minimum illuminance threshold of at least 300 lux over 50% of the reference plane and, at the same time, minimum illuminance of 100 lux over 95% of the space in all interior spaces regularly occupied for more than half the day must be respected. With regard to the level of natural lighting inside the building, this standard sets the performance of average lighting at 500 lux and that of high lighting at 750 lux.

Tab. 1: Daylight factor (DT) and (DTM) required to ensure 50% of time target illuminance (ET) and minimum target illuminance ETM, according to the 3 levels of recommendations (case study of the city of Prague) [24]

Recommendation levels	**E_T (lux)**	**D_T (%)**	**Fplane,% (%)**	**E_{TM} (lux)**	**D_{TM} (%)**	**F_{plane} (%)**
Minimum	300	2.0	50	100	0.7	95
Medium	500	3.4	50	300	2.0	95
High	750	5.0	50	500	3.4	95

The levels of recommendation for exposure to direct solar radiation are organised in a graduated manner in EN 17037 and state that the minimum duration of exposure to direct solar radiation for a reference day in the year chosen between 1 February and 21 March under clear, cloudless skies must comply with one of the following categories [25]:

Tab. 2: Exposure to direct sunlight [26]

Recommendation on exposure to direct sunlight	
Level of recommendation for exposure to direct sunlight	Exposure to direct sunlight (hours)
Minimum	1.5
Medium	3.0
High	4.0

2.3 Literature review on air flow in building

Reducing the energy consumption of buildings and raising awareness of environmental concerns have drawn the attention of researchers and designers to the potential of natural ventilation and user control of the local environment [27]. “Indoor air renewal is based on a relatively simple general principle that mobilises natural and/or mechanical forces. Good indoor air renewal results from a certain quantity of air being moved between air inlets and outlets judiciously positioned in the building” [28].

A number of studies have evaluated the importance and role of airflow in saving energy and improving thermal comfort [29, 30]. Allard & Utsumi [31,32] instead evaluated specific design elements, such as airflow windows and large openings, and their impact on building thermal control and airflow prediction. They proposed a general solution to include large openings in the pressure network of a multizone model. This model is generally applicable in most of the large opening’s configuration.

Zhai [31] evaluates aspects and trends in the application of computational fluid dynamics in building design, including its roles, challenges, and emerging trends and found that combination of employing parametric design tools and fluid simulations allows designers to explore a large number of design alternatives prior to shifting to final validation with time-consuming and wave pools.

Cao et al. [33] Have carried out a review of the performance of the various ventilation and airflow distribution systems in buildings and consider that each task of a ventilation system makes it possible to determine the effectiveness or efficiency of the ventilation system.

Nimlyat et al. [34] prepared "a review of the literature on indoor air quality and sick building syndrome in the design environment of office buildings" and concluded that clean breathable air can be achieved by removing pollutants from inside the building and ensuring a sufficient rate of outdoor air renewal. A building interior design without adequate ventilation would have a significant impact on indoor air quality, temperature, humidity and airflow due to inherent pollution.

Natural ventilation is a useful means of diluting the contaminants present in the air inside the building. This type of ventilation is used as a bridging system and provides local ventilation. For natural ventilation to be effective, structural and environmental factors such as outdoor air quality, indoor and outdoor temperature and relative humidity, window location, opening mechanisms and wind speed must be taken into account. [35].

Indoor air quality as governed by European standard EN 16798-1:2019 is organised into four categories ranging from class 1 (high expectations) to class 4 (low expectations).

These studies collectively highlight the importance of airflow in building design and the potential for innovative solutions to improve it.

Further research will enable us to establish an architectural design approach that integrates the study of daylighting and natural ventilation, thereby optimising the architect's design.

3. Methodology

In this article, the trend in the study of illuminance and natural ventilation was first explored in order to obtain an overview and understanding of how illuminance and ventilation are taken into account in building design. It emerged that these concepts are taken into account in the building design process but are largely the responsibility of HVAC system professionals, as the architect, who has to ensure that the lighting and ventilation of the spaces designed are adequate, finds himself having to continually modify his design in relation to the requirements of the data received from HVAC system professionals, which generally affects his design and creates a lot of modifications and additional costs. In order to address this issue, the present study proposes a parametric method to assess illuminance and airflow at the

architectural design stage, in order to optimise the architect's design as much as possible and to reduce the potential changes that could affect the architect's design, and consequently reduce the costs associated with these changes.

The methodology of the research in 'Fig. 1' is divided into three phases: firstly, creation of 3D model in Revit and shared parameters; secondly, extraction of geometrical and environmental data using Dynamo script; thirdly, computation of radiation-based illuminance calculations and estimation of natural airflow rates based on simplified Bernoulli equations through Dynamo scripts coupled with Python.

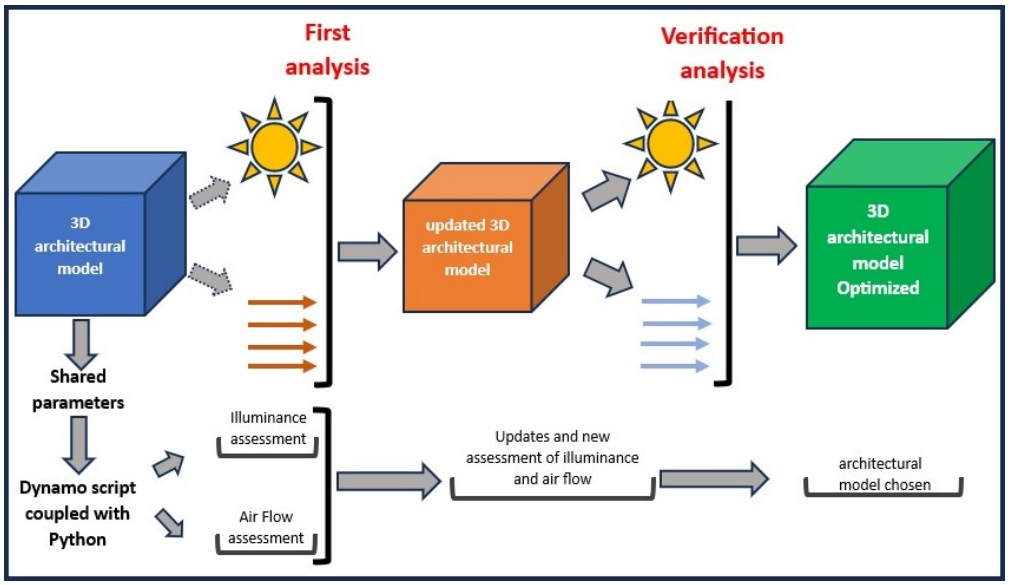

Fig. 1. Research methodology

In our method, everything starts with design of architectural model, followed by creation of shared parameters that are used to input or extract data related to rooms and windows, such as names, surfaces, volumes, different windows associated with rooms, reflection factors, window area, daylight factor and lux factor to input sunlight intensity. Once this first stage is completed, the data related to the rooms and different windows are extracted using Dynamo scripts. The final step is the creation of Dinamo scripts linked to Python, based on EN 17037 for the assessment of illuminance and on simplified Bernoulli equations for the calculation of wind incidence angle, air changes per hour, air flow rate in the room and effective wind speed.

The initial dynamo script linked to Python is based on the daylight factor formula, incorporating the angle of incidence of the external light relative to the vector normal to the window.

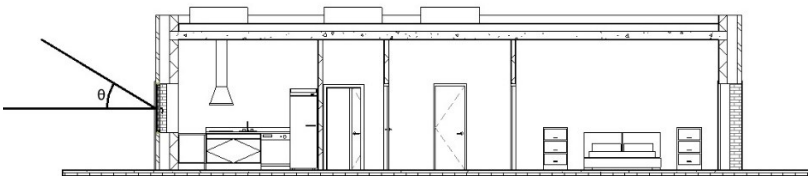

Fig. 2. Incidence angle on window

According to European Standard EN 17037 [36], the daylight factor (DF) is defined as such.

$$\boldsymbol{DF = \left(\frac{Eint}{Eext}\right) \times 100 \quad \rightarrow \quad DF = 0.9 \times \left(\frac{Aw}{Ar} \times T\right)}$$

The DF can be modified to incorporate the angle of incidence by employing:

$$\boldsymbol{DF = 0.9 \times \left(\frac{Aw}{Ar} \times T \times \cos(\theta)\right)}$$

This approach encompasses the following three physical possibilities [37]:

- When light arrives at an oblique angle (θ), its effectiveness in illuminating the interior of the room is diminished, hence the cos(θ) factor.
- If the light arrives perpendicular to the window (θ=0°), then cos (0) =1 and the equation reverts to the classic formula.
- Conversely, if the light arrives at a greater angle (θ=60°), then cos (60°) = 0.5, which halves the illuminance inside. The interior illuminance is, therefore, evaluated using the following formula. $\boldsymbol{Eint = DF \times Eext \times \cos(\theta)}$

These different formulae are used in Dynamo script linked with python to calculate the illuminance in the rooms.

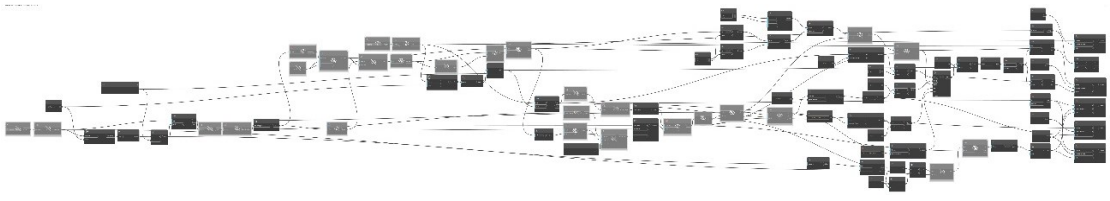

Fig. 3. Dynamo script linked with Python for illuminance assessment

The script for illuminance assessment has been developed; the dynamo script coupled with Python for airflow assessment is currently being developed.

The second dynamo script coupled to Python is based on Simplified Bernoulli equations [38], defined as follows:

$$\frac{P_1}{\rho g} + \frac{{v_1}^2}{2g} + h_1 = \frac{P_2}{\rho g} + \frac{{v_2}^2}{2g} + h_2$$

$$\Delta P = \frac{1}{2}\rho {v_2}^2 \rightarrow \quad v_2 = \sqrt{\frac{2\Delta P}{\rho}}$$

$$Q = C_d A v$$

The script on 'Fig. 4' was developed on the basis of these equations:

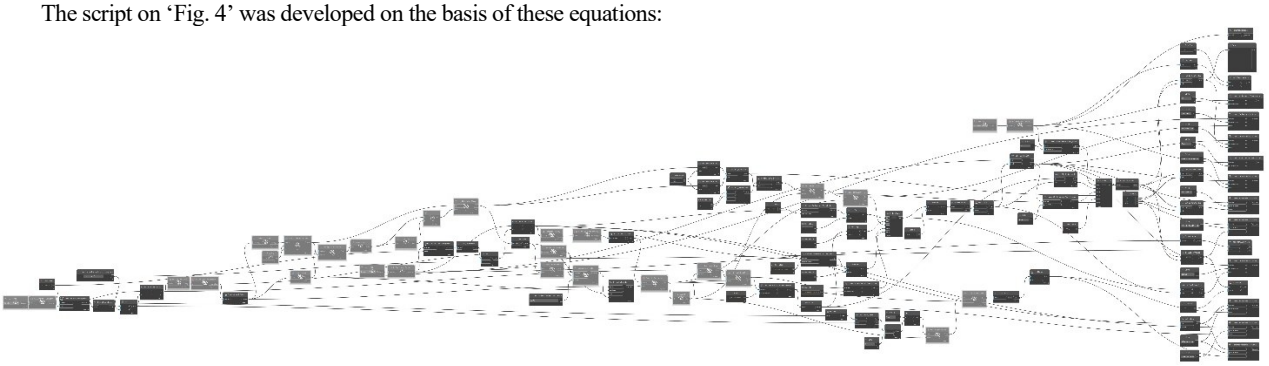

Fig. 4. Dynamo script coupled with Python for air flow assessment

4. Case study

4.1 Phase 1: Creation of 3D Model

Our study model is a dwelling house made using Revit 2024 consisting of an entrance hall, a living room, a bedroom, a kitchen, a garage and a utility room, and we incorporate architectural elements, such as windows, skylights, and ventilation openings, into the model. Let consider that we want to achieve high level of illuminance in the rooms.

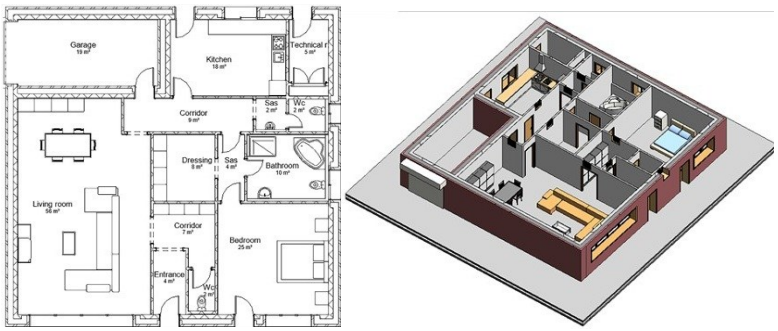

Fig. 5. Architectural study model (own study)

4.2 Phase 2: Study of illuminance in rooms containing attached window

In this phase, the 3D model produced in the previous phase is employed as the architectural design model. The illuminance is then assessed using the first dynamo script developed in our methodology. After running the script, different results are obtained, as demonstrated in 'Fig. 6'.

<Room Schedule>

A	B	C	D	E	F	G	H	I
Numb	Name	Area	Volume	Window_room	∑_Window area	reflection_factor	Sun_angle	Illuminance_In
1	Living room	56 m²	180.48 m³	W_(3500 x 1100),	3.85	0.7	18.434949	357.03
2	Corridor	7 m²	21.30 m³		0	0.7		0
3	Bedroom	25 m²	80.00 m³	W_1500x 1100),	1.65	0.8	18.434949	304.3
4	Bathroom	11 m²	34.05 m³	W_(800*1100),	0.36	0.35	71.565051	78.38
5	Dressing	8 m²	26.81 m³		0	0.7		0
6	Corridor	9 m²	27.97 m³		0	0.7		0
7	Kitchen	18 m²	57.71 m³	W_(900*1100),	0.99	0.1	18.434949	254.56
8	Wc	3 m²	8.66 m³	W_(600*600),	0.36	0.5	71.565051	347.31
9	Entrance	4 m²	13.36 m³		0	0.7		0
10	Wc	2 m²	7.10 m³		0	0.7		0
11	Garage	19 m²	60.72 m³		0	0.6		0
12	Technical r.	5 m²	16.13 m³		0	0.5		0
13	Sas	4 m²	11.52 m³		0	0.7		0
14	Sas	2 m²	6.07 m³		0	0.7		0

Fig. 6. results of the initial evaluation of Illuminance utilizing the script (own study)

Following a thorough evaluation of the initial calculation's outcomes, it was determined that the illuminance levels within the model's rooms fall short of the requisite minimum illuminance levels necessary for classification in the high category. This finding indicates that the existing window surfaces are inadequate for meeting the necessary illumination standards. Consequently, a recalibration of the existing window surfaces is imperative, necessitating the implementation of the script for the purpose of further evaluation.

Subsequent to the readjustment and recalculation of the model's window surfaces using the script, the results are illustrated in 'Fig. 7'.

Room Schedule illuminance | {3D} | Room Schedule airflow | Window Schedule

<Room Schedule illuminance>

A	B	C	D	E	F	G	H	I
Numb	Name	Area	Volume	Window_room	∑_Window area	reflection_factor	Sun_angle	Illuminance_In
1	Living room	56 m²	180.48 m³	W_(4700*1200), W_(1100*1200),	6.96	0.7	18.434949	871.71
2	Corridor	7 m²	21.30 m³		0	0.7		0
3	Bedroom	25 m²	80.00 m³	W_(2100*1200),	2.52	0.8	18.434949	929.5
4	Bathroom	11 m²	34.05 m³	W_(1350*1200),	1.62	0.35	71.565051	352.7
5	Dressing	8 m²	26.81 m³		0	0.7		0
6	Corridor	9 m²	27.97 m³		0	0.7		0
7	Kitchen	18 m²	57.71 m³	W_(1500*1220),	1.8	0.1	18.434949	565.69
8	Wc	3 m²	8.66 m³	W_(600*600),	0.36	0.5	71.565051	347.31
9	Entrance	4 m²	13.36 m³		0	0.7		0
10	Wc	2 m²	7.10 m³		0	0.7		0
11	Garage	19 m²	60.72 m³		0	0.6		0
12	Technical r.	5 m²	16.13 m³		0	0.5		0
13	Sas	4 m²	11.52 m³		0	0.7		0
14	Sas	2 m²	6.07 m³		0	0.7		0

Fig. 7. results of the second illuminance evaluation were obtained through the implementation of the script (own study)

Following a thorough evaluation of the outcomes from the second calculation employing the designated script, it was determined that the illuminance levels within the model's rooms meet the requisite minimum standards for the high category classification. This finding suggests that the existing window surfaces are adequate. To verify the reliability of the results, the current model parameters are retained and an illuminance study is conducted using the Autodesk Rendering cloud-based calculation engine to assess illuminance levels in rooms.

The parameters employed for this preliminary analysis are derived from the recommendations outlined in the standard EN 17037, which stipulates the selection of parameters as previously delineated in the review.

Fig. 8. Parameters used for illuminance study Rendering cloud-based calculation (own study),

4.3 Results

A comprehensive list of the various results obtained is provided herewith:

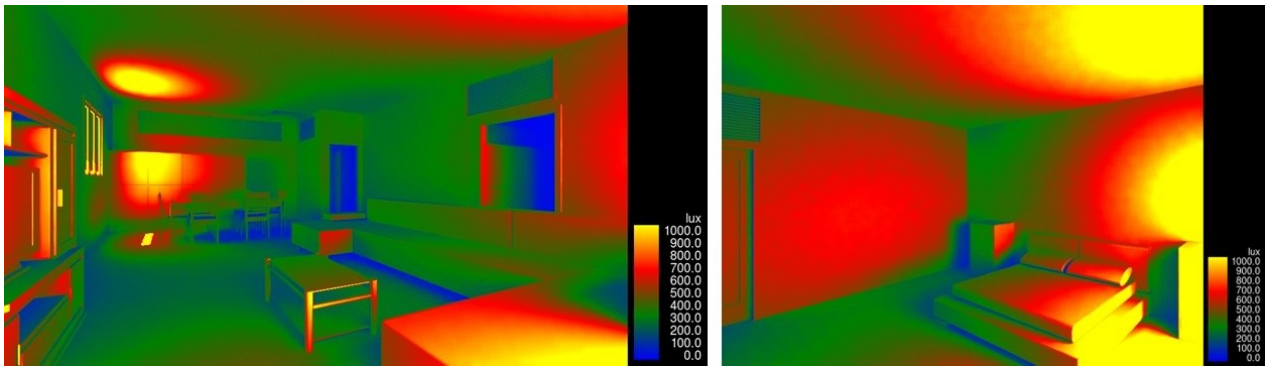

Fig. 9. study of the illuminance in the living room and bedroom after readjustment of the windows (own study)

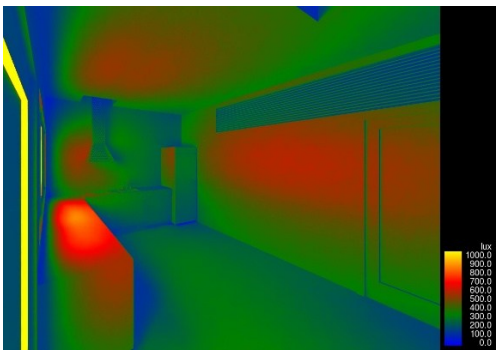

Fig. 10. study of the illuminance in the kitchen after readjustment of the windows (own study)

4.4 Phase 3: Simulation of air flow in the study model

In this section, assessment of the air flow in the model is conducted using the second dynamo script developed in the methodology section of this study. Subsequently, dynamic simulations will be conducted using Autodesk CFD to simulate the movement and circulation of the air in our study model. This will serve to validate our results.

The initial calculations employing the dynamo scripts are depicted in 'Fig. 11'.

Room Schedule illuminance | {3D} | **Room Schedule airflow** | Window Schedule

<Room Schedule airflow>

A	B	C	D	E	F	G	H	I	J
Numb	Name	Area	Volume	Window_room	∑_Window area	Wind Incidence Angle	Air changes /h	AirFlow Rate	Effective Wind Speed
1	Living room	56 m²	180.48 m³	W_(4700*1200), W_(1100*1200),	6.96	18.43	615.33	9.631	2.85
2	Corridor	7 m²	21.30 m³		0				
3	Bedroom	25 m²	80.00 m³	W_(2100*1200),	2.52	18.43	619.66	4.303	2.85
4	Bathroom	11 m²	34.05 m³	W_(1350*1200),	1.62	71.57	313.51	0.922	0.95
5	Dressing	8 m²	26.81 m³		0				
6	Corridor	9 m²	27.97 m³		0				
7	Kitchen	18 m²	57.71 m³	W_(1500*1220),	1.8	71.57	205.7	1.025	0.95
8	Wc	3 m²	8.66 m³	W_(600*600),	0.36	18.43	1875.5	1.383	2.85
9	Entrance	4 m²	13.36 m³		0				
10	Wc	2 m²	7.10 m³		0				
11	Garage	19 m²	60.72 m³		0				
12	Technical r.	5 m²	16.13 m³		0				
13	Sas	4 m²	11.52 m³		0				
14	Sas	2 m²	6.07 m³		0				

Fig. 11. results of the evaluation of air flows in the study model using the Dynamo script (own study).

The dynamic simulations carried out using Autodesk CFD to simulate air movement and circulation in our study model in order to validate our results produce the results shown in 'Fig. 12' and 'Fig. 13'.

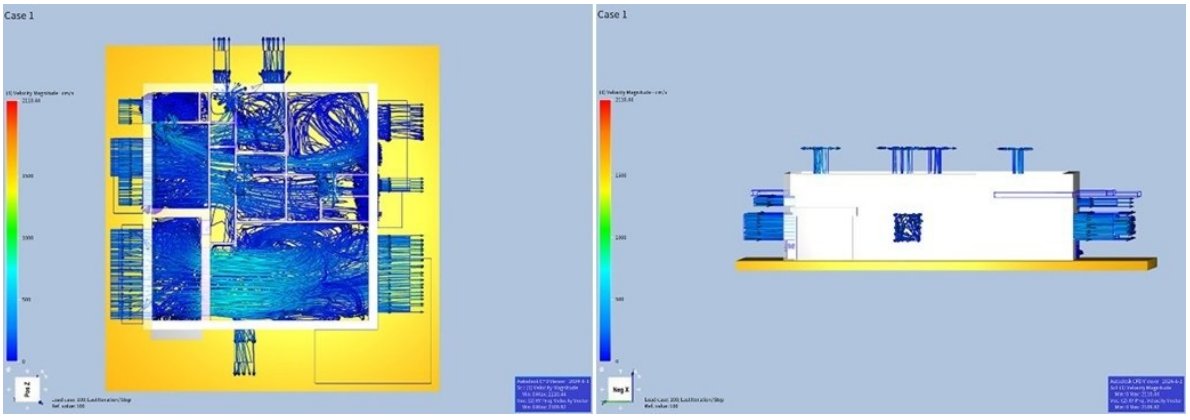

Fig. 12. Results of airflow analysis in the top and left view of the building (own study)

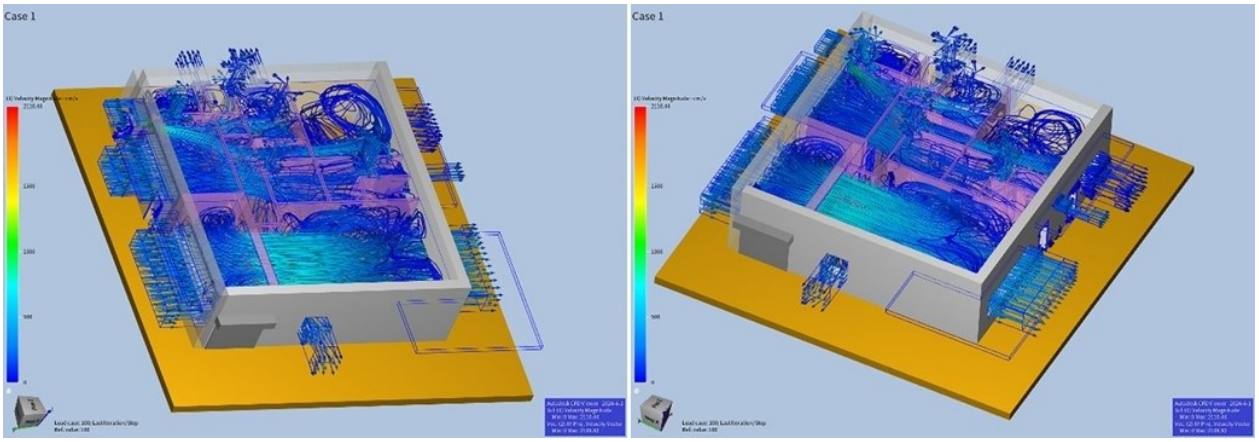

Fig. 13. Results of 3D view airflow analysis in study model (own study)

5. Discussion

This study demonstrates the practicability and usability of integrating parametric design tools early on in the architectural design process to analyze and optimize two significant environmental factors: illuminance and natural ventilation. Using Building Information Modeling (BIM) with Revit, visual programming with Dynamo, and scripted logic with Python, it is feasible to carry out detailed environmental simulations without needing to wait for late-stage coordination with HVAC professionals.

The daylight analysis, according to EN 17037, provided actionable data on which design changes could be made in real time, adjusting window size and location to meet high-performance lighting requirements indoors. Adding the cos(θ) term to the daylight factor (DF) equation enhanced light distribution simulation accuracy [37], taking into account the orientation and angle of incidence of sunlight, an element usually neglected in traditional design processes.

Similarly, airflow analysis using Simplified Bernoulli equations allowed the design team to simulate air exchange rates and wind flow in the rooms at initial design stages. Cross-validation by Autodesk CFD simulations confirmed the validity of results from the Dynamo-Python script, proving that predictions at initial stages could be very close to advanced fluid dynamics simulations.

These parametric designs significantly reduced the number of design iterations usually required to avoid architectural designs being subsequently altered to accommodate HVAC constraints. They also enable the human-centered design ideology promoted by WELL standards through providing sufficient lighting and indoor air quality from the early design stage.

6. Conclusion

This research highlights the effectiveness of a parametric, performance-based design strategy that enables architects to design and optimize illuminance and natural ventilation in early stages of the design process. The scripts produced using Dynamo and Python were viable means of embedding regulatory requirements like EN 17037 and principles of fluid dynamics into architectural modelling directly.

In integrating environmental performance analysis into the architect's workflow, the methodology enables:

- Increased design freedom for architects,
- Reduced need for redesigns at later stages, and
- Reduced additional cost due to HVAC coordination mismatches.

The case study confirmed that iterative simulation and tuning specifically of window surfaces and positions can successfully balance architectural intent and high-performance building standards. Moreover, the method is scalable and adaptable for different kinds of projects and regulatory regimes.

For future study, the addition of real-time weather data, to include thermal comfort simulation, and parametric optimization through Dynamo and Python would further increase the scope and power of this parametric approach.

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