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Using building information modelling to optimise design quality of natural lighting in Iraqi school buildings

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Abstract: One of the most important aspects directly affecting a building's performance is the design quality of the natural day-lighting. The present research evaluates the effectiveness of daylight in school buildings in the city of Baghdad. It aims to ascertain how the characteristics of building windows affect the quality of day-lighting, the objective of this exercise being to improve educational processes in schools by making improvements in relation to the aspect of provision of satisfactory day-lighting levels. A building simulation approach was adopted, and using Autodesk Revit 2018 (Insight plug-in), a daylight analysis was conducted under the aegis of the Building Information Modelling (BIM) technology. For the case study, we selected the modern design of a 24-classrooms school building, which is part of a plan for the construction of 1,000 Iraqi schools. Leadership in Environmental and Energy Design (LEED v4) simulation was conducted on the school building design to provide the results, which were measured and analysed according to LEED v4 standards. The results demonstrated that opening dimensions and direction have an essential impact on natural day-lighting. The research concluded that using BIM simulation tools enhances the design quality of the natural lighting in such a way that compliance with LEED v4 requirements is achieved. The present study will assist in identification and assessment of the problems concerned with natural lighting levels in Iraqi school buildings as well as resolving these at an early design stage.

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1 Introduction

The school environment has a significant impact on students. Teachers and students often spend most of their time there conducting various educational tasks. Owing to a dearth in adequate day-lighting, individuals might have mental and physical issues that could occasionally lead to illness (Ruck et al. 2000). Various researches have revealed that productivity, performance and public well-being all significantly increase when sunlight is used as the main source of lighting (Carli and Giuli 2009). When compared with all other types of lighting, natural lighting is the most appropriate as judged based on the visual sensitivity of living beings, and thus it creates a better lighting environment than artificial lighting sources (Barzegar and Gerdroodbary 2022).

Since natural lighting performs many functions in school buildings and is one of the crucial factors that must be considered during the building design process, it has been an essential component of designing practice. The main factor for enhancing visual comfort and enabling teachers and students to understand their spatial environment is natural daylight. For increasing students' educational attainment in schools, architects and designers must include natural lighting in school buildings' construction designs. Natural lighting and accessibility to full sunlight are important design considerations for school buildings (Mangkuto and Koerniawan 2022).

Baghdad city has witnessed a school construction campaign as part of the governmental plan to build 1,000 schools all over Iraq. As an attempt to improve knowledge through the present research, it is crucial to note that the study's significance lies in the verification and detection of potential issues concerning building design and natural lighting level in the context of school buildings.

The study can provide local designers a database using which they would find it feasible to analyse and prevent design errors in natural lighting in buildings generally and school buildings specifically, mainly at the early stages of the design process.

The possibility of utilising building analysis simulations with building information models in the design process is illustrated by examples from research and practice (Schlueter and Thesseling 2009). By utilising the Building Information Modelling (BIM) capabilities, it is possible to prevent considerable design changes, errors and problems in school building drawings and/or specifications through BIM functions such as 3D visualisation (Ibraheem and Mahjoob 2022).

The purpose of the study is to utilise BIM technology to investigate the impact of opening area properties on the daylight performance of a school building during the project design stage using modelling simulation and solar energy analysis with the Autodesk Revit 2018 (Insight plug-in) tool. For the development of specific analytical simulations of complicated building designs, the present BIM software solution provides adequate modules.

2 Literature review

The design phase of the construction project is crucial because it establishes the project's final characteristics based on the specifications that the employer provides to the consultant to formulate during the design phase in the form of plans and specifications (Shadhar and Mahmood 2018). These specifications are then translated on the ground so that the shape of the completion satisfies those requirements. The central aspect of building design and sustainable built environment is natural daylight, which includes direct illuminance from the sun and indirect illuminance from the sky, constructional limits and building envelopes. Amin et al. (2019) conducted research pertaining to the natural day-lighting employed at school buildings in Erbil, Iraq. The study's findings demonstrated that case studies (with different plan layouts) underperformed when compared to the Leadership in Environmental and Energy Design (LEED v4) requirements for sunlight illuminance. As a result, it is crucial to further investigate and enhance the natural light level in the educational areas in terms of daylight illuminance in Erbil school buildings. The local educational space's south-facing location can increase daylight levels and enhance uniformity of natural light distribution.

Climate-based daylight modelling was applied by Mardaljevic et al. (2009) to analyse the realistic daylight performance in school buildings in England. The two distinct classroom designs have been studied for over 6 months. As part of a reliable method, the actual illuminance level has been determined by employing the high dynamic range (HDR) picture methodology. Since the study takes into consideration the unseen factors that influence daylight features, the research explores the significance of using reliable methods for determining the presence of realistic daylight in learning spaces.

The common relation between the local environment, natural daylight and design approach has been reviewed by Costanzo et al. (2017) in an extensive literature analysis of daylight consumption in educational facilities utilising innovative methods. There are a variety of efficient modern tools and technologies that have been researched and developed for improving the amount of effective daylight, including classroom design and glazing properties, exterior shade methods and redirecting systems of educational facilities. The study's findings demonstrated the difficulty and complexity of optimising natural light in educational spaces, and it is crucial to consider several climate-based metrics for evaluating the effectiveness of natural light.

Building performance analysis is one of the most crucial components in designing sustainable facilities. In order to forecast how buildings will perform in terms of their lighting environments as a result of the implementation of a suitable framework aimed at ensuring adequate day-lighting, building designers must conduct similar simulations. The methods of daylight analysis can be carried out either using computer simulation tools or by human calculations. The computer expert creates a simulation model for the implementation of the analysis once the designer specifies the architectural model of a building. Since most of the process involves manually converting architectural model data to simulation data, creating simulation models can be a time-intensive procedure (Bazjanac 2008).

In order to simplify the process of preparing the data input for simulation tools, as well as make it easier, graphical user interfaces for the defining of model geometry have been developed. Tools for modelling geometry have also been connected to tools for simulating natural lighting. Building design is utilising tools of BIM in this field (Young et al. 2008).

A procedure involving the development of a distinctive classroom design for ensuring adequate availability of sunlight was carried out for a proposed school in the US, and Koti et al. (2009) have documented and outlined this entire exercise to ascertain the degree of its utility in serving as an effective source of day-lighting performance.

A methodology was established to utilise BIM geometry from Autodesk's Revit Architecture software with very little intervention. Since there was no established process for utilising BIM geometry, some experimentation was involved. However, the overall efficiency and accuracy of the modelling development were greatly enhanced, compared to the reconstruction of 3D geometry.

The design of adequate natural light is related to a variety of factors, including building orientation and opening size. The present study investigates the use of BIM tools to recognise the impact of opening areas on natural daylight levels of a modern design of school building in Baghdad.

3 Natural day-lighting metric

Natural day-lighting metrics can be classified into static and dynamic. Dynamic daylight metrics are adopted for the purpose of the research because they represent climate-based metrics, and facilitate a simulation of a whole year rather than focussing on isolated climatic conditions (Mardaljevic et al. 2009). Spatial Daylight Autonomy (sDA) is selected in the present study as a dynamic metric that defines how much of a space receives sufficient natural daylight.

According to LEED v4 requirements, sDA must achieve 300 Lux for every 50% of the yearly occupied hours for at least 55% of the floor area; this measure of computation is used to determine the quantum of places receiving sufficient natural daylight, as shown in Table 1. To achieve 2–3 LEED points, the sDA percentage must be at a minimum of 55% or 75% of floor area.

4 Research justification

In school buildings, enhanced visual comfort improves educational performance as well as health and well-being. Due to the increasing demand for sustainable built environments, successful building design is becoming an increasingly challenging task. The justifications underlying the execution of the present study are the following:

1. The absence of a mechanism for assessing the design quality of natural lighting in Iraqi school buildings. Amin et al. (2019) confirm that it is crucial to further investigate and enhance the natural light level in buildings in Iraq that house educational institutions, particularly schools.
2. Integration of BIM tool with LEED v4 requirements to enhance natural lighting design quality.
3. Reduction of the consumption of electrical lighting energy by introducing natural day-lighting into Iraqi school building spaces, or enhancing the existing levels of natural lighting.

Tab. 1: Points for daylight floor area – sDA for schools, LEED v4 (Elkhapery et al. 2021).

sDA (for regularly occupied floor area)	Points
55%	2
75%	3

LEED v4, Leadership in Environmental and Energy Design; sDA, spatial daylight autonomy.

5 Research methodology

This section describes the approach adopted in the present study for the use of BIM tools such as Autodesk Revit 2018, which was employed as a modelling tool in this research. Additionally, a natural lighting analysis tool (Insight plug-in, Autodesk Revit 2018) was used as a simulation tool to evaluate the daylight optimisation performance. The present study will assess daylight performance according to LEED v4 requirements. Seyis (2022) believes that it is beneficial to evaluate LEED v4 requirements utilising BIM-based technologies while developing high-performance and green buildings (GB).

Figure 1 represents the developed methodology used in assessing the design quality of natural day-lighting for the school building. Concerning this methodology, in the present study, the integration between the BIM tool and the requirements of LEED v4 have been considered.

The case study selected was the construction design intended for application in the construction projects of 1,000 school buildings in Iraq, namely in Baghdad/Al-Karkh. The school building design prepared by National Center of Engineering Consulting (NCEC), using the 2D-CAD format without modelling, was adopted for this purpose. Figure 2 represents the architectural design intended for application in the construction of these school building projects, as designed and approved by NCEC using Autodesk AutoCAD 2021 (two-dimensional drawing).

For achieving the purpose of the natural day-lighting study, the school building was modelled using Autodesk Revit 2018, which can be considered the most powerful tool in context of BIM, as presented in Figure 3.

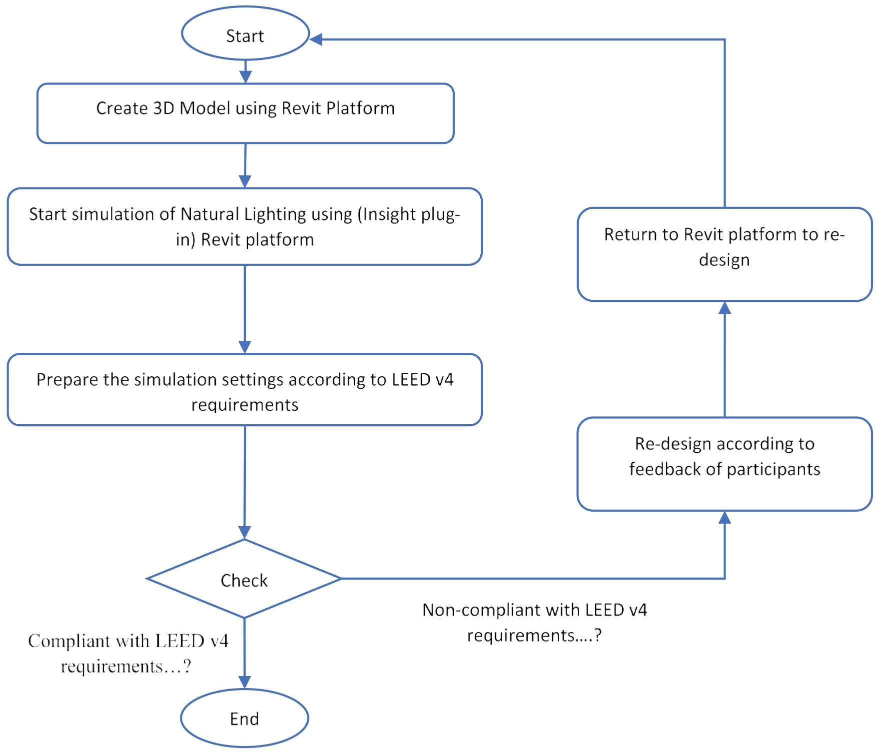

Fig. 1: The research methodology. LEED v4, Leadership in Environmental and Energy Design.

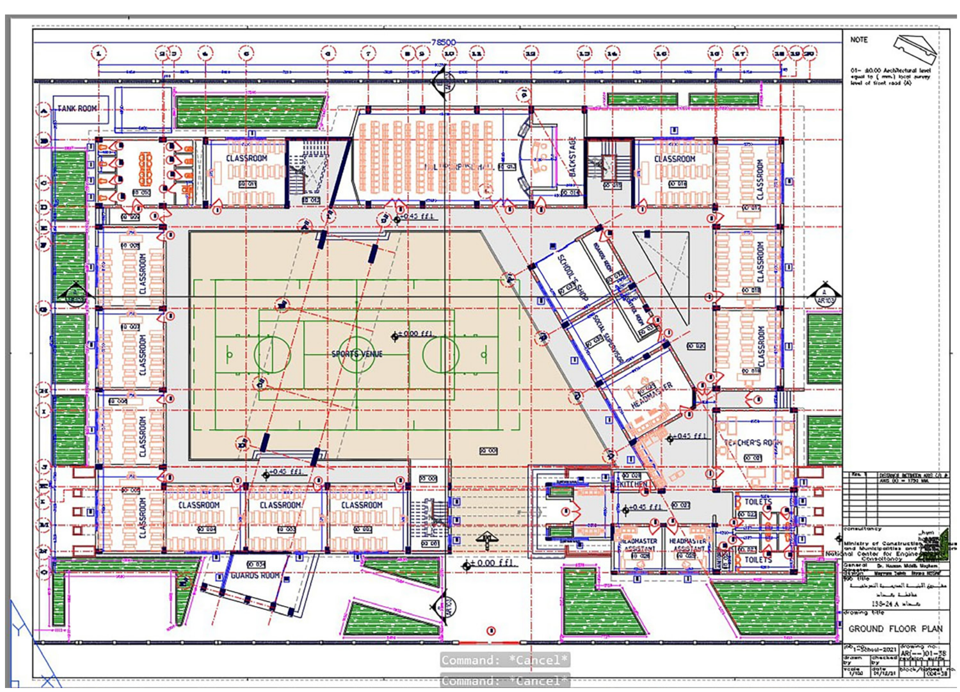

Fig. 2: The plan layout of the studied school building (case study).

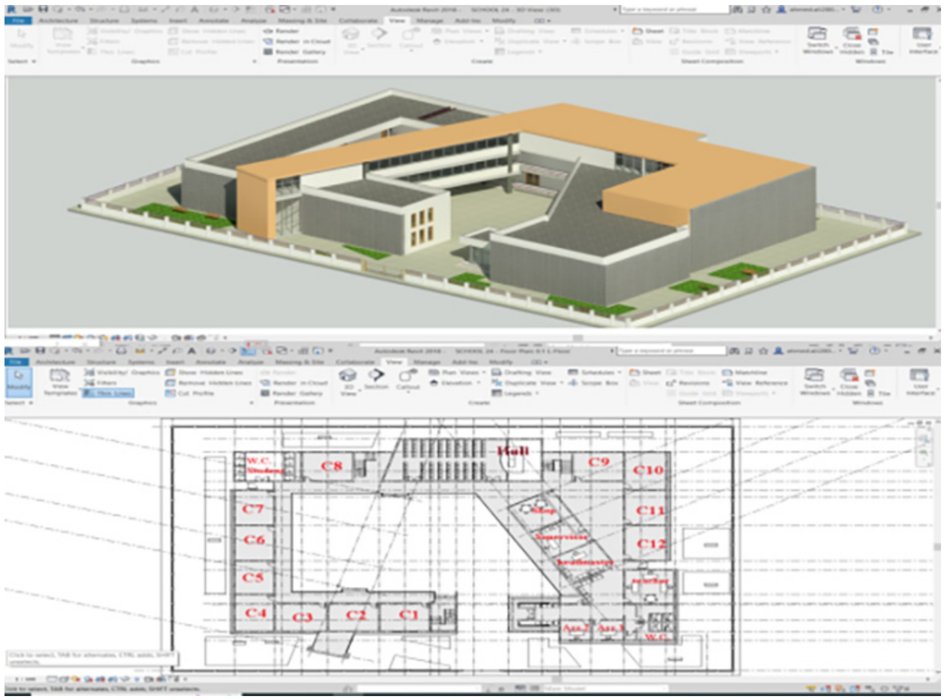

Fig. 3: Revit model of school building (as case study).

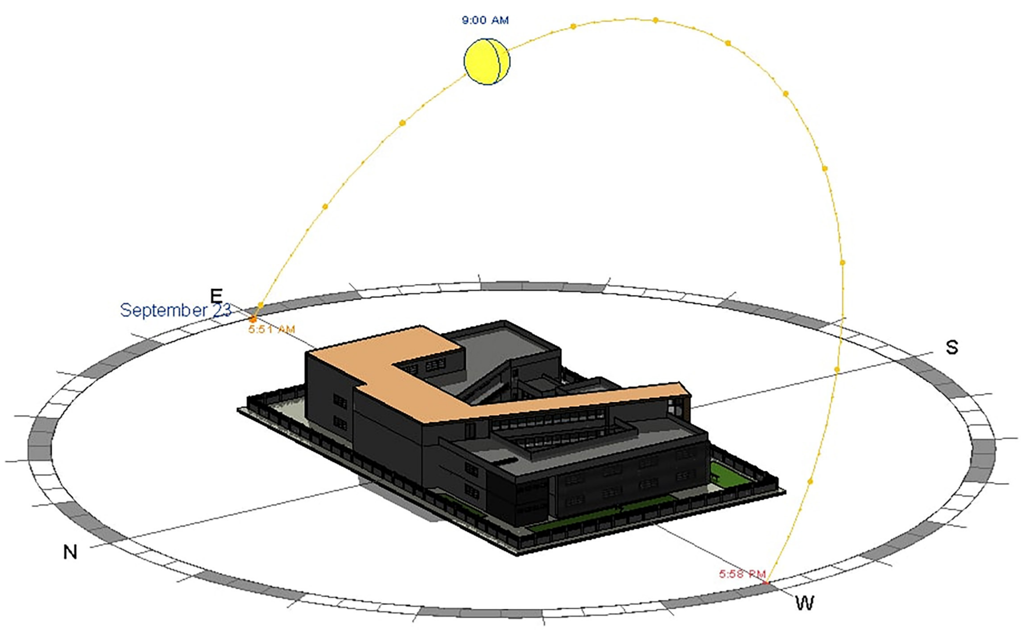

Fig. 4: School building orientation and sun path (case study).

According to the assigned/designed school location, the sun path and the orientation of the building masses of the school are presented in Figure 4.

The selection of the present case, from among more than six prepared designs of the governmental plan to build 1,000 schools, is backed by various different reasons, which are given as follows in the form of selection justifications:

1. The building design is different and distinct with 24 classrooms. The layout design is adopted for the governmental plan.
2. The building façade is designed as Glassfibre Reinforced Concrete (GRC) cladding, as represented in Figure 5; and although the façade is aesthetically striking, it will reduce solar radiation.

6 Simulation and results of the natural day-lighting (as designed by NCEC)

All steps, from data gathering to final modelling, can collectively be seen as a preparation for the simulation stage, which follows once these stages attain completion. The simulation was run for the ground floor of the school, which included 12 classrooms and administration rooms according to the LEED requirements.

The Insight plug-in (Autodesk Revit 2018) settings for this run's LEED simulation are the following:

1. Location: Baghdad City – Al-Karkh (lat = 33.245579 and lon = 44.357729)
2. Time and date: 7:00 AM–6:00 PM, September–March/2022
3. Clear sky model is selected.
4. According to LEED v4, the threshold has been defined between 300 Lux and 3,000 Lux, for the daylight illuminance.

Figure 6 shows the simulation results arrived at using the Insight plug-in (Autodesk Revit 2018) for natural lighting distribution. The school layout and material properties are similar to those designed by NCEC.

Table 2 represents values of daylight illuminance (Lux) for all administration rooms, classrooms and rooms used for carrying out other services whose conduction is in vogue within the school building. The of Daylight Illuminance values ranked from the maximum to the lowest.

7 Simulation and results of the natural day-lighting (with window dimension modification)

For the purpose of representation of the window dimensions' impact on the level of illuminance within each

Fig. 5: School building GRC façade (3D Revit model).

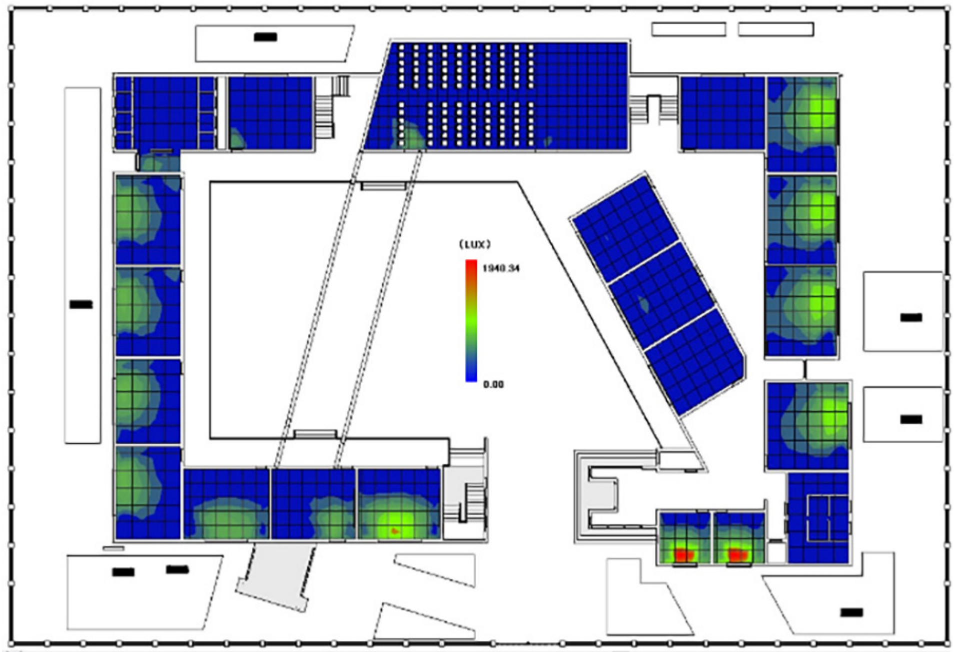

Fig. 6: Natural lighting distribution simulation results obtained with the use of Revit (Insight plug-in).

Tab. 2: Daylight illuminance values according to the simulation results.

Classroom No.	Area (m²)	Windows' properties				Daylight illuminance (Lux)	Compliance with LEED v4 requirements
		L (m)	H (m)	Orien.	Nr./room		
Assiss. room 1	16.79	1.80	1.40	South	1	468.23	Within 300–3,000 Lux
Assiss. room 2	16.79	1.80	1.40	South	1	468.14	Within 300–3,000 Lux
C1	39.18	3.60	1.40	South	1	426.24	Within 300–3,000 Lux
C11	39.18	3.60	1.40	East	1	396.25	Within 300–3,000 Lux
C12	35.05	3.60	1.40	East	1	389.35	Within 300–3,000 Lux
C10	37.52	3.60	1.40	East	1	375.66	Within 300–3,000 Lux
Teachers' room	42.87	3.60	1.40	East	1	362.87	Within 300–3,000 Lux
C3	39.43	3.60	1.40	South	1	297.53	<300 Lux
C7	39.43	3.60	1.40	West	1	238.11	<300 Lux
C5	42.87	3.60	1.40	West	1	237.70	<300 Lux
C6	39.43	3.60	1.40	West	1	236.19	<300 Lux
C4	42.87	3.60	1.40	West	1	231.92	<300 Lux
C2	39.48	1.20	1.40	South	1	214.49	<300 Lux
C8	39.96	3.60	1.40	North	1	67.25	<300 Lux
School's shop	53.07	3.60	1.40	West	8	47.91	<300 Lux
C9	39.48	3.60	1.40	North	1	44.40	<300 Lux
Supervisor room	39.48	3.60	1.40	S/W	1	43.01	<300 Lux
Headmaster room	39.96	3.60	1.40	S/W	1	40.22	<300 Lux
Main hall	173.52	-	-	-	-	32.51	<300 Lux
W.C. students	39.48	0.90	0.50	S/W	1	21.74	<300 Lux
W.C. teachers	53.55	0.90	0.50	East	4	17.12	<300 Lux

LEED v4, Leadership in Environmental and Energy Design.

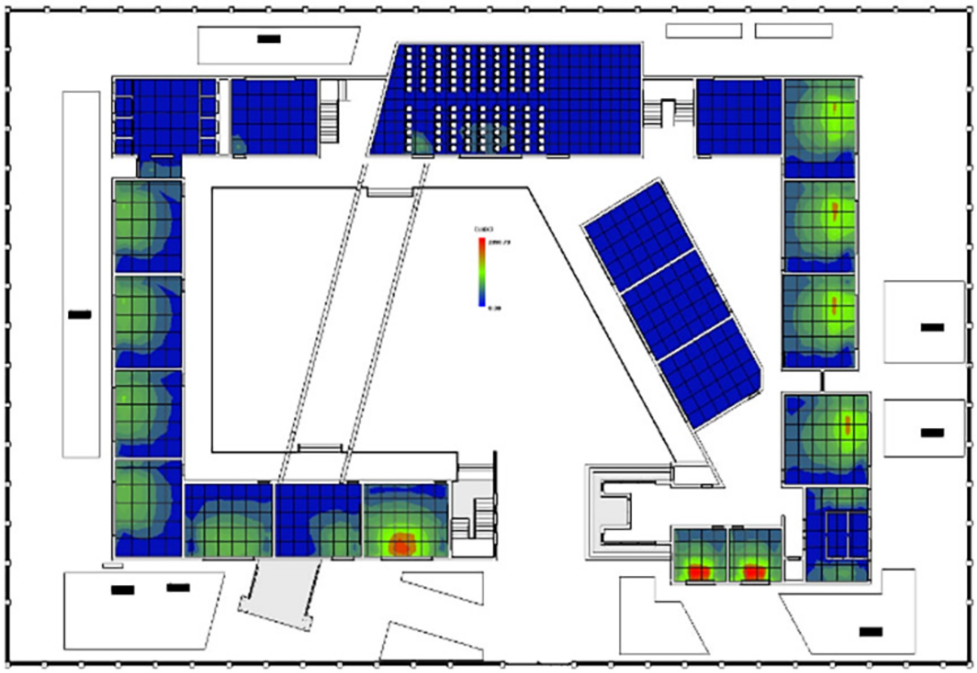

Fig. 7: Natural lighting distribution simulation results using Revit (Insight plug-in) after modification of windows' sizes.

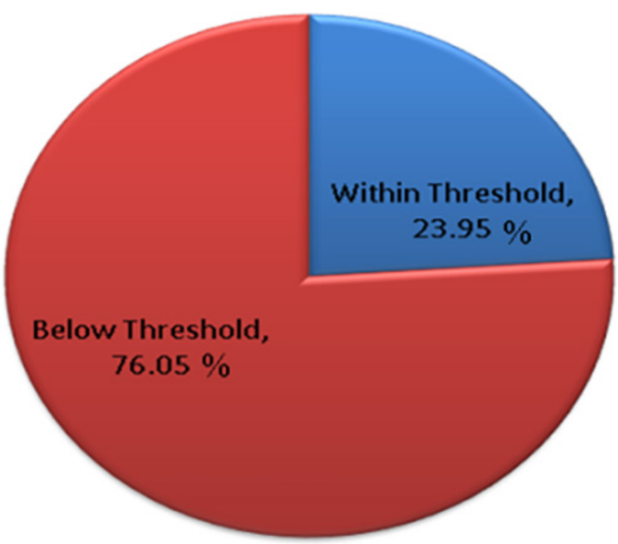

Fig. 8: Natural daylight availability percentage according to LEED v4 threshold. LEED v4, Leadership in Environmental and Energy Design.

space, the length and height of the windows were increased, as presented in Table 3.

Figure 7 shows the results of simulation of natural lighting distribution (after modification of windows' sizes), the simulations having been made with the use of Autodesk Revit 2018 (Insight plug-in).

8 Discussion of the results

With reference to the basic school layout design prepared by NCEC, the simulation results obtained from the use of Autodesk Revit 2018 (Insight plug-in) indicate that 23.95% of the studied floor area is within the threshold 300–3,000 Lux of natural lighting, whereas 76.05% is below this threshold; Table 2 and Figure 8 represent these results.

The east-, south-, west- and north-facing spaces receive natural lighting availability with 16.29%, 7.66%, 0.00% and 0.00% of the studied floor area, respectively. The total natural lighting availability within the threshold is 23.95%, which is less than the 55% of floor area mentioned as part of the LEED v4 requirements, as shown in Table 1 and illustrated in Figure 9. Accordingly, we may infer that the obtained daylight availability percentage is not compliant with the LEED v4 requirement. The main cause of this non-compliance is the widow dimension in comparison with classroom floor areas. Also, the

Tab. 3: Daylight illuminance values (after modification of window dimensions).

Classroom No.	Area (m²)	Windows' properties (modified)			New daylight illuminance (Lux)	Illuminance percentage increased (%)	Compliance with LEED v4 requirements
		L (m)	H (m)	Increased percentage of window area (%)			
Assiss. room 1	16.79	2.30	1.90	73.4	745.11	59.13	Within 300–3,000 Lux
Assiss. room 2	16.79	2.30	1.90	73.4	745.11	59.16	Within 300–3,000 Lux
C1	39.18	4.10	1.90	54.6	630.81	47.99	Within 300–3,000 Lux
C11	39.18	4.10	1.90	54.6	574.73	45.04	Within 300–3,000 Lux
C12	35.05	4.10	1.90	54.6	554.79	42.49	Within 300–3,000 Lux
C10	37.52	4.10	1.90	54.6	525.85	39.98	Within 300–3,000 Lux
Teachers' room	42.87	4.10	1.90	54.6	510.05	40.56	Within 300–3,000 Lux
C3	39.43	4.10	1.90	54.6	357.45	20.14	Within 300–3,000 Lux
C7	39.43	4.10	1.90	54.6	354.33	48.81	Within 300–3,000 Lux
C5	42.87	4.10	1.90	54.6	342.98	44.29	Within 300–3,000 Lux
C6	39.43	4.10	1.90	54.6	342.40	44.97	Within 300–3,000 Lux
C4	42.87	4.10	1.90	54.6	328.63	41.70	Within 300–3,000 Lux
C2	39.48	1.70	1.90	92.2	312.51	45.70	Within 300–3,000 Lux
W.C. teachers	53.55	0.90 1.00	0.50 1.90	0 422	301.20	347.88	Within 300–3,000 Lux
C8	39.96	4.10	1.90	54.6	81.24	69.57	<300 Lux
School's shop	53.07	4.10	1.90	54.6	61.03	37.45	<300 Lux
C9	39.48	4.10	1.90	54.6	59.88	39.22	<300 Lux
Supervisor room	39.48	4.10	1.90	54.6	45.50	13.13	<300 Lux
Headmaster room	39.96	4.10	1.90	54.6	35.93	10.52	<300 Lux
Main hall	173.52	4.10	1.90	New window	22.16	1.93	<300 Lux
W.C. students	39.48	0.90	0.50	0	17.12	0.00	<300 Lux

LEED v4, Leadership in Environmental and Energy Design.

architectural design used GRC cladding on the building façade to ensure the availability of an aesthetically striking effect, without taking natural lighting needs into consideration.

After the modification of window dimensions, as represented in Table 3, 55.65% of the studied floor area falls within the natural lighting threshold, in compliance with the specifications contained as part of the LEED v4 requirements, as represented in Figure 10.

As a result of that modification, the daylight availability percentage (55.23%) of floor area is rendered compliant with the LEED v4 requirement (2 points), as can be inferred by referring to Table 1. Out of the studied floor area, 44.77% is below the threshold (<300 Lux). The non-compliant floor areas are: C8, C9, School's shop, Supervisor room, Headmaster room, Main hall and W.C. students, because of the direction and other design requirements of layout characterising these areas. Figure 5 shows that, because of the sun path with regard to Baghdad City, the north-facing classroom receives 0% of the floor area within the threshold 300–3,000 Lux. Using the advantages of Autodesk Revit 2018, it has been possible to simulate and render the impact of the difference between the basic window dimension and that modified for the classroom C2. The original dimensions of the window, specified according to NCEC design, are 1.40 m height by 1.20 m width, which are modified to 1.90 m height by 1.70 m width, i.e. an increase of 92% has been carried out in the resultant window area vis-à-vis the window's original state, to ensure that a greater quantum of sunlight is admitted. Figure 11 shows the difference between the two cases.

Regarding teachers' water closet, the original dimensions of the window, according to NCEC design, are 0.50 m height by 0.90 m width, which are modified to 1.90 m

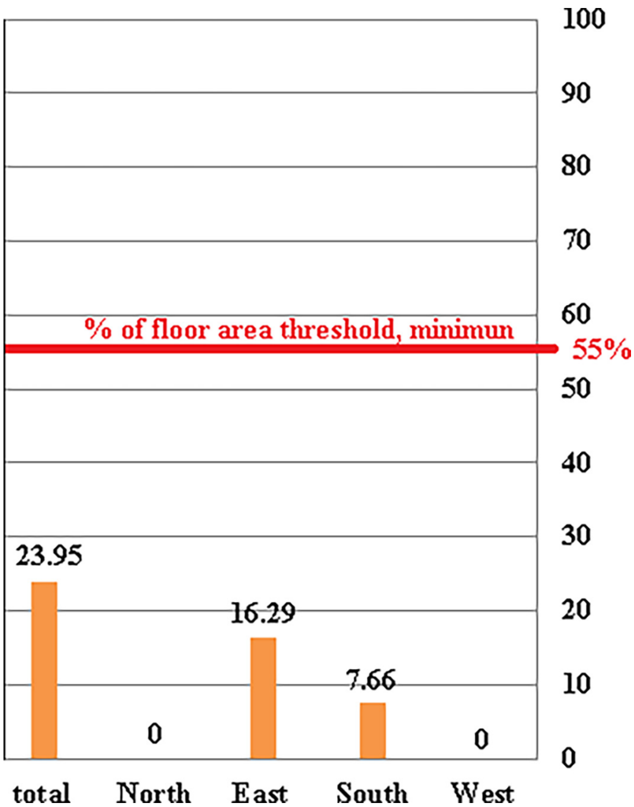

Fig. 9: Natural daylight availability percentage according to basic layout design.

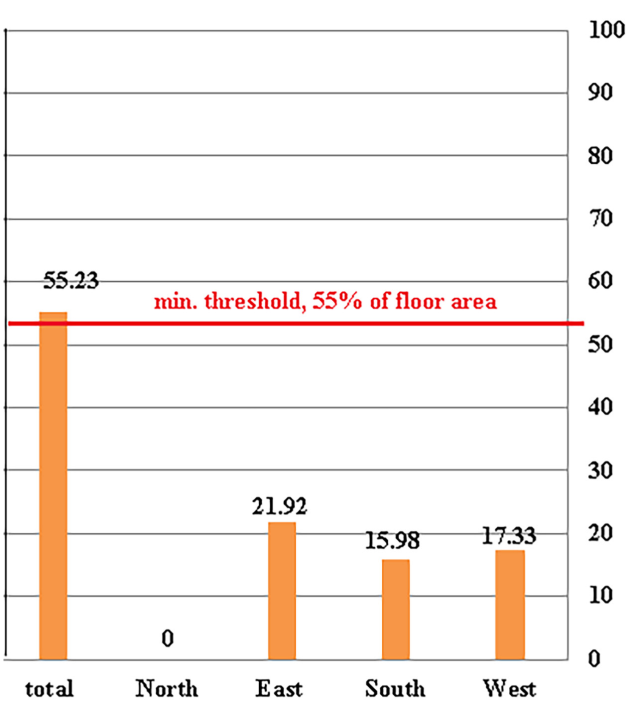

Fig. 10: Natural daylight availability percentage after window dimension modification.

Fig. 11: Revit rendering of natural lighting of classroom C2, for window dimensions: (A) 1.40 m x 1.20 m and (B) 1.90 m x 1.70 m; an increase of 92% is performed in the area.

Fig. 12: Revit rendering of natural lighting of teachers' water closet, for the window dimensions: (A) 0.50 m x 0.90 m and (B) 1.50 m x 1.00 m; an increase of 422% is performed in the area.

height by 1.70 m width, i.e. there is an increase of 422% in the window area, aimed at increasing the extent of passage of sunlight. Figure 12 shows the difference between the two cases.

9 Conclusion

The study reveal that the use of BIM tools to simulate the received extent of sunlight can enhance the design quality of the natural lighting in school buildings, resulting in the extent of this lighting reaching a level wherein it would be in compliance with the relevant LEED v4 requirements. The case simulation results demonstrate that classrooms/

spaces with south- and east-facing windows receive sunlight to a greater extent than those with north- and west-facing windows, which requires a design review of the school plan layout. Additionally, the results show that natural day-lighting provided sufficient daylight availability after the proposed modification but insufficient daylight uniformity. To provide students the perception of uniform daylight, a higher percentage of day-lighting spaces is required, especially in classrooms with a northern orientation; alternatively, electrical lighting may be employed to resolve this issue. The present study will assist in evaluation and addressing of the problems pertaining to natural lighting levels in Iraqi school buildings and represents an attempt to resolve such problems in the early stages of design using BIM tools.

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