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Impact of Building Typology on Daylight Optimization Using Building Information Modeling: Apartments in Erbil City as a Case Study

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Abstract

Daylight represents one of the crucial factors that affect directly on the building performance and its occupants. This study assesses the daylight performance in the multi-storey residential buildings (apartments) in Erbil city. It aims to find out the impact of building typology on daylighting quality and quantity. The endeavour of this research is to determine the optimal plan typology in providing sufficient daylight levels. A simulation method has been used with an academic licensed Revit Architecture 2019 with plugged insight daylight analysis as one of Building Information Modeling (BIM) tools for achieving this goal. Five multi-storey residential buildings were selected as cases of study. Three types of simulation were run on each project: Illuminance, LEED, and Daylight Autonomy to achieve results. The results were analyzed and compared with daylight standards levels. The results demonstrated that the point typology is the best type of plans among all cases in terms of providing optimal daylight performance, while the double-loaded plan typology was the worst. The study concluded that the plan typology has an obvious impact on achieving daylight performance in the multi-storey residential buildings. The current research can contribute to identifying the shortcomings of daylight levels in buildings seeking to overcome it in the early phases of design.

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1. Introduction

The home environment is of great significance to human beings. It is a place where people typically spend most of their time performing various social and life activities [1-3]. Without proper daylighting, they may have physiological and psychological problems, which in some cases can cause sickness [4]. Many studies have demonstrated that if daylight is the primary source of lighting, there is a great improvement in productivity, performance and wellbeing in general [5,6]. Daylight provides a better lighting environment than electrical lighting sources because daylight is most compatible with the visual response of humans by comparing it with all other types of lighting [7]. The majority of humans prefer a daylight environment because sunlight consists of a balanced spectrum of color, with its energy peaking slightly in the blue-green area of the visible spectrum [8,9].

Daylight has been an integral part of architecture studies because it serves many purposes in the building, as it is one of the vital aspects to be taken into account during the building design process. Natural daylight is the key component to allowing users/occupants to perceive their spatial surroundings as well as improve their visual comfort. Daylight provides an essential element to the architecture experience. It provides visual and personal attention that helps to form the space in the human mind. Without daylight, space will be free of any personality and deepness. It is important that architects and designers incorporate daylight into their designs for the convenience of the occupants' wellbeing and the quality of the experience. This, in turn, affects their behavior, work style, life, emotion etc. Moreover, daylight plays an essential role in achieving a healthy and sustainable living environment.

Daylighting and access to direct sunlight play prominent roles in residential building design. Bringing natural light to buildings is, therefore, one of the most important aspects of design. Designing the optimal level of natural light inside a building is complicated by many factors that may affect the distribution of light. One of these parameters is the building typology and its potential effects in achieving optimal daylight levels within its

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interior spaces. The city of Erbil has witnessed in the last two decades a big boom in urbanization and development, housing sector representing the largest share of this prosperity. From this perspective, the importance of this study lies in the verification and detection of the possible relationship between building design and daylight level in the context of multi-storey residential buildings, in an attempt to contribute to the field of knowledge through such research trends. This may provide local architects with a database to review and avoid deficiencies in daylight levels in buildings in general and residential buildings in particular, especially at the early beginnings of the design process.

1.1. Definition of typology

Linguistically, typology is taken from the word 'type' which is defined by Cambridge International Dictionary of English as a particular group of things or people sharing similar features and forms a smaller division of a larger set" [10]. In this sense, 'type' is related to categorization based on the similarity of characters or features [11]. McHenry [12], as cited in [13], defines it in more detail as: "a system of groupings, usually called types, the members of which are identified by postulating specified attributes that are mutually exclusive and collectively exhaustive - groupings set up to aid demonstration or inquiry by establishing a limited relationship among phenomena. A type may denote one or several kinds of features and must include only those types that are important for the problem in question. This definition is used to differentiate typology from classification by emphasizing the former's role as a system of grouping of types to aid demonstration, or investigation, by establishing a limited relationship among phenomena [14], as cited in [11].

1.2. Configuration of residential buildings

Typological classification of residential building configurations is becoming increasingly more relevant for solving complex housing-related issues, especially in the current conditions in highly urbanized areas [15]. Prominent theorists in the field of building typologies such as Quatremère de Quincy, Giulio Carlo Argan and Aldo Rossi emphasize the theoretical considerations of the importance and necessity of typology in architecture. Sherwood [16] highlights the role of the typology of forms in the course of clarifying architectural issues and defining solutions. As Sherwood [16] explains the benefits of the use of prototypes in housing, he defines the types of housing units according to their orientation and the types of residential buildings according to access to dwelling units [17], as cited in [15]. Tibermacine and Zemmouri [18] classified building shape and layout based on an analysis made to bring out the most common typologies of a residential apartment in an average-sized building in hot and arid regions. Their analysis revealed five common typologies include slab configuration, L floor layout, pavilion configuration, U floor layout buildings as well as courtyard configuration, as shown in Fig. 1.

Ju et al. [19] classified the block plans (building plan typology) into mainly four types: the single-loaded corridor type which is a form where units are arranged only on one side of the common corridor, the double-loaded corridor type which is a form where units are arranged in rows on both sides of a corridor, tower type and atrium type (Fig. 2).

1.3. Daylight definitions

Daylight is the natural light that there is during the day before it gets dark [20]. Daylight is defined as "the combination of all direct and indirect sunlight during the daytime". This comprises diffuse sky radiation and direct sunlight. Both of these often reflected by the Earth and terrestrial objects, like buildings and landforms. Sunlight which is reflected or scattered by objects in outer space is generally not considered daylight. Thus, despite moonlight is in direct sunlight, daylight excludes it. The period of time each day when daylight occurs is called daytime. Daylight occurs as Earth rotates, and either side on which the Sun shines is considered daylight [21].

1.4. Daylight and residential buildings

There are many advantages for daylighting in enhancing the building design, in that good distribution of natural daylight in the space within the design reduces the need for artificial electric lighting and improves the visual comfort [22]. High rise residential buildings have the characteristic of placing circulation in the middle of the building and the apartment units on the side. This distribution leads to increasing artificial lighting usage that causes

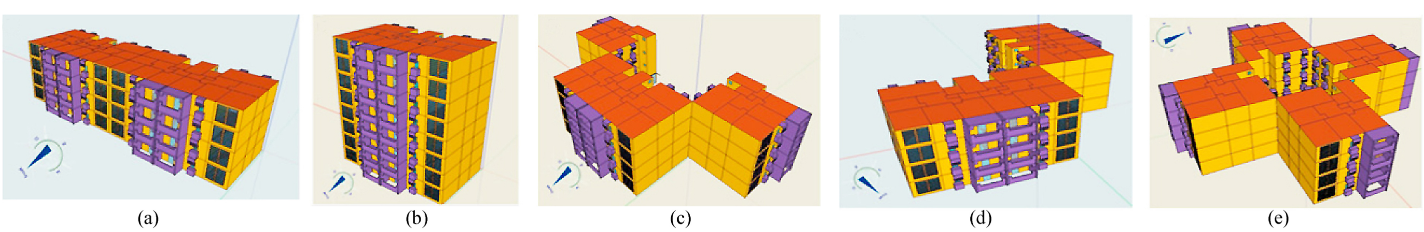

Fig. 1. (**a**) Slab configuration, (**b**) pavilion configuration, (**c**) U shape, (**d**) L shape, and (**e**) courtyard configuration [18].

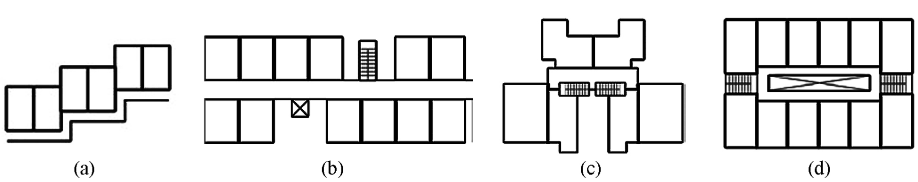

Fig. 2. Typologies of block plans - building plan typologies [19]: (**a**) single-loaded corridor type, (**b**) double-loaded corridor type, (**c**) tower (point) type, and (**d**) atrium type.

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increasing in high energy consumption because of the low illumination level in the room especially in the rear room and restricted penetration of daylight. More energy can be saved by the use of the right daylight technologies [23] and have a good impact on occupant's health, productivity and satisfaction [24-27]. Daylight is a significant element for residential spaces that can contribute to maintaining the minimum illuminance level required to improve indoor environmental quality and user comfort. The benefits of a carefully planned daylight concept range from an enhanced lighting quality for the inhabitants to reduced artificial lighting consumption [28,29]. When the process of design comprises daylight strategies integrated into the building design process in the primary design phases, significant energy savings can be attained [30-32].

1.5. Daylight effects on human

Daylight is significant to people's wellbeing and health; in a recent study presented by [33], it seriously affects the emotion, mental alertness and mood of humans. The benefits of daylight and sunlight in buildings for the health and well-being of occupants have been recognized by many researchers. These benefits include its necessity for the regulation of daily rhythms [34]. Daylight is one method to offer healthy lighting in buildings; it is efficient in terms of energy, rich in short-wavelength light and obtainable much of the time at great concentrations [35]. Using lighting in the right way in buildings means mainly to study the possibility of using daylight [36]. According to [37] there is a common agreement that space with good daylighting is one that minimizes visual uneasiness and gives high levels of visual quality under exclusively or predominantly daylight conditions regularly throughout the year. Daylight remains the main factor in how space is revealed and perceived by its users [38]. In general, daylight existence has an important positive influence on the quality of lighting and makes a more attractive interior space [39]. Daylight has a natural variant brightness and intensity and carries data about the time of day and the world outside; the season and weather. The continuous alterations in daylight have a positive effect on mood and stimulation [36]. Bluish morning light has biologically an activating (alerting) effect, while the red sky that we see more often has a relaxing effect in the early evening. A good daylight space should host a stimulating interplay of light and building form that keeps occupants comfortable and satisfies their needs [40].

2. Daylight metrics

2.1. Static metrics

2.1.1. Daylight factor

The daylight factor expresses the ratio of illuminance at a specific point in a space as a percentage of the total illuminance from the whole, unobstructed, overcast sky. It is the simplest and the most common metric to quantify the daylight allowed by a window, as it expresses the potential illuminance inside a room in the worst possible scenario under overcast sky conditions, when there is less exterior daylight [41].

2.1.2. Daylight illuminance

Daylight Illuminance is the incident light, where the “incident” is the beam of light actually landing on the surface, it is also known as the amount of light striking a surface, [42]. Illuminance is the amount of light falling on a surface and luminance that of the light reflected from it or emitted by it in some cases [43]. In photometry, illuminance is the total luminous flux incident on a surface, per unit area. It measures how much the incident light illuminates the surface, wavelength-weighted by the luminosity function to correlate with human brightness perception [44]. It is the most extensively acceptable and simplest daylight metric which has been used by regulations and standards [45]. Illuminance has been defined as “the ratio of the luminous flux, incident on an infinitesimal surface in the neighborhood of the points, to the area of surface” [46]. The range of acceptable illuminance threshold has been limited between 300 - 3000 Lux [47].

2.2. Dynamic daylight metrics (DDM)

Building regulations and certification systems are moving away from the DF model due to its intrinsic limitations. The DF metric is replaced with the so-called dynamic daylight metrics (DDM); often referred to as Climate-Based Daylight Modeling (CBDM) [48] because it results from the development of CBDM, which is the ‘prediction of various radiant or luminous quantities (e.g. irradiance, illuminance, radiance and luminance) using sun and sky conditions that are derived from standardized annual meteorological datasets’ [37]. CBDM thus allows a whole year simulation instead of looking at single sky situations. The most common DDM used in practice are defined below. DDM require advanced computer simulations [49].

2.2.1. Daylight autonomy (DA)

Reinhart and Walkenhorst [50] have defined the daylight autonomy as the percentage of the occupied hours of the year when the minimum illuminance requirement at the sensor is met by daylight alone. Unlike the daylight factor, the DA method is climate dependent, consequently being more likely to give a better daylight evaluation of the studied space.

2.2.2. Useful daylight illuminance (UDI)

A development of DA is the UDI which also is based on work plane illuminance. It adds another demand on what is considered adequate daylight to work in. This is added as an upper threshold so as to avoid glare and overheating issues. The thresholds proposed being below 100 lux and above 2000 lux, where below 100 lux would be to dark and above 2000 lux would lead to visual and/or thermal discomfort. UDI is the percentage of the occupied hours of the year when illuminance lies within one of the three illumination ranges: 0-100 lx, 100-2000 lx, and over 2000 lx [51]. It provides information not only on useful daylight levels, but also on excessive levels that could be the cause of glare or unwanted solar gains.

2.2.3. Spatial daylight autonomy (sDA)

Spatial Daylight Autonomy describes how much of a space receives sufficient daylight, which is for residential spaces must achieve (sDA 300 lux / 50% of the annual occupied hours) for at least 55% of the floor area as shown in Table 1. It has no upper limit on luminance levels. It calculates the percentage of analysis points that exceeds a specified Illuminance level (300 lux) for at least 50% of the total occupied hours from 8am-6pm over the year

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Table 1. LEED v4 - Points for daylight floor area: Spatial daylight autonomy [53].

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

[52], while the percentage of sDA should be at least 55% or 75% to achieve 2 to 3 LEED points.

2.2.4. Annual sunlight exposure (ASE)

It is defined as the cumulative amount of visible light incident on a point of interest over the course of a year. Annual light exposure is measured in lux hours per year. ASE is used to describe how much of space receives too much direct sunlight, which can cause visual discomfort (glare) or increase the cooling loads. In LEED v4 ASE measures the percentage of floor area that receives at least 1000 lux for at least 250 occupied hours per year, which must not exceed 10% of floor area [53]. ASE is the number of hours per year at a given point where direct sun is incident on the surface. In other words it is the second metric used by LEED, which searches for any potential source of visual discomfort, particularly the presence of direct sunlight. This metric calculates the percentage of the analysis points that exceeds a specified illuminance level, 1000 lux, for at least 250 hours of the occupied hours without any contribution from the sky [54].

2.2.5. Daylight performance index (DPI)

Other metrics for daylight have started to emerge. It prescribes thresholds with a minimum and maximum daylight factor. The maximum value here is thought to avoid over-illumination and problems that follow, such as glare and overheating. The DPI only accounts for the area of the building which has a daylight factor between these two values. Instead of using a standard diffuse sky, the prevailing sky of the location is used; although still diffuse [55].

2.2.6. Continuous daylight autonomy (cDA)

It is another set of metrics that proposed by [56]. In contrast to earlier definitions of daylight autonomy, partial credit is attributed to time steps when the daylight illuminance lies below the minimum illuminance level. For example, in the case where 500 lx are required and 400 lx are provided by daylight at a given time step, a partial credit of 400 lx/500 lx 0.8 is given for that time step. The result is that instead of a hard threshold the transition between compliance and noncompliance becomes softened. This change to the metric can be justified by field studies that indicate that illumination preferences vary between individuals, and that many office occupants tend to work at lower daylight levels than the commonly referred 300 or 500 lx [57].

3. Daylight performance according to LEED

To incorporate new metrics, LEED v4 has updated the "Daylight" credit under the Indoor Environmental Quality (IEQ) category and in order to achieve daylight credit, LEED 2009 provided a prescriptive compliance path. By using the window design, this compliance option facilitated calculating daylight in space. Yet, these calculations were inaccurate as they did not account for project-specific performance factors such as exterior conditions, building orientation, time of day and year or interaction with interior finishes. This prescriptive compliance method is no longer permitted by LEED v4. Instead, the focus will be on using simulations for daylight analyses and actual measurements for the estimation of daylight levels and quality [58].

4. Previous related research and studies

Many studies have adopted residential buildings in an attempt to study the performance, quantity, and quality of natural lighting entering their interior spaces. Each one of them has pursued a different research approach in addressing the problem of daylighting. These studies can be reviewed and discussed according to those approaches, visions and methods adopted. Of these studies, some can be referred to, for example, Sarvani & Kontovourkis [59] studied a proposed residential building in Cyprus that was designed based on the climatic and functional issue. The design method of the building depends on solar radiation and daylight in this location. The study was based on how simulation can help improve the performance of this design in providing sufficient daylight in all the building's spaces. Within the same context, Lauridsen and Petersen [60] used Grasshopper to generate different fenestration systems for a room that fulfils performance criteria regarding daylight, energy-saving and indoor climate. The study concluded that the method can generate an almost optimum solution based on designer concepts, which can achieve indoor environmental requirements. Reaching 60% of daylight autonomy in the midpoint of the room is acceptable range but this will cause less in the other interior points behind this point which will be not acceptable according to standards. Not far from the previous context but within office buildings, Qingsong and Fukuda [61] applied simulation in their study to optimize heat gain and daylight inside an office building in Beijing. The study method depends on finding the best size window area on each wall to minimize energy consumption and maximize the useful daylight illuminance. The study found that south-oriented window is the best orientation, followed by north as an optimum solution in 63% of the time, with height 3.063 m and width 1.959 m, in order to improve daylight illuminance to be greater than 300Lux. The resulting dimension in this study may not be acceptable for most types of residential units and buildings in particular because the ceiling height is usually less than three meters.

At the level of building typology, Hammad Amin et al., [47] conducted a study on school design daylighting analysis in Erbil City to assess its natural light performance. For this, six foundation schools with different size, shape, and layout have been selected. The daylight illuminance level and daylight autonomy have been simulated and compared with design standards for sufficient daylight. Revit with insight plug-in has been adopted as a simulation tool. The results showed that the illuminance level in most of the case studies is below the satisfactory range depended on architectural standards. The sDA and ASE have reached what is needed in three different school layouts. In contrast, sDA and ASE performance was below the required levels in other cases. The study showed a marked variation in the amount and level of daylight performance depending on the building typologies. Likewise, Montenegro et al., [62] explored the effect of typological variations of school buildings on their visual, thermal, indoor air quality and energy performance by using the IES-VE software. To analyze their bioclimatic potential in two different climatic contexts, nine typologies of school buildings were

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modeled using three recurring proportions of classrooms (2:3, 1:1 and 3:2) cold (Montreal, Canada) and temperate (Santiago, Chile). According to the DA index, the visual performance was assessed. Results showed that the best performances are consistently related to linear typologies under both climates.

Realizing the importance of the building typology but within the urban context, Sattrup & Strømann-Andersen [63] conducted a study seeking to answer a logical question: how does urban form and density, as expressed in different building typologies, affect energy use and daylight? They developed a framework for urban analysis for examining the potentiality of passive solar energy and daylight and their impact on the total energy performance of typical urban typologies in Denmark. A comprehensive suite of climate-based dynamic thermal and daylight simulations showed how the passive energy properties of buildings are affected by increases in urban density and urban form design choices. The study analyzed both traditional and contemporary typologies. The results demonstrated that the relative impact of choosing a specific typology may affect up to 16% of the total energy performance and up to 48% of the daylight autonomy in buildings at similar urban densities. On the other hand, Li et al., [64] aimed in their study to simplify a procedure for determining indoor daylight illuminance using daylight coefficient concept in Hong Kong. The study focused on daylighting performance and energy use for residential flats facing large sky obstructions via computer simulations. The daylighting performance for typical interior rooms was investigated in terms of daylight factor and illuminance level. The study explained that the daylight levels of residential flats can be greatly reduced by neighboring buildings and hence the externally reflected component would be the principal source of natural light. Mass public housing designed with optimization approach of natural lighting was studied by Suriansyah [65]; she focused on daylight quality potency at mass public housing in Bandung Indonesia. Apartment Sarijadi Bandung (ASB) was intended as mass public housing for the lower middle income. ASB designed as cluster typology with one staircase lined to four dwelling units. The study aimed to determine the extent of natural lighting at ASB that is designed with optimization approach of natural lighting. Field surveys conducted in obtaining data of (1) illuminant of the residential units, and (2) physical spatial configurations of architectural elements, which was used for analyzing how much the natural lighting available in the residential units at ASB. The importance of this study lies in the innovations of disclosure of influence factors of the architectural physic-spatial configuration to daylighting potential in vertical residential building typology as in the ASB. It is a useful new finding to be applied in supporting the development of science and technology and procurement related to vertical housing that provides opportunities for better life quality and energy efficiency in urban areas. Chatzipoulka et al. [66] have aimed to explore relationships between urban geometry and solar availability on building façades and at the pedestrian level, with implications for buildings' passive potential and outdoor thermal comfort, respectively. The study was based on the morphological and solar analysis of 24 urban forms of London, covering a wide range of built density values found across the city. Apart from the strong, negative effect of density, the analysis of this study revealed that solar availability on ground and façades is significantly affected by urban layout.

Compliance with current developments of multi-family housing is a hot topic, for instance, Bournas and Dubois [67] investigated the daylight regulation compliance of existing multi-family housing developments located primarily in Sweden. To test their compliance with the current Swedish daylight regulation, Radiance simulations were used to evaluate a representative sample of 54 buildings constructed from 1926-1991. The studied buildings were selected according to their relevance to main architectural typologies of Swedish urban planning. The assessment was based on a point Daylight Factor scheme (DFP), which stipulates that for the room to be sufficiently lighted, a specific point in a room should achieve a Daylight Factor DFP ≥ 1%. Results showed that specific architectural typologies consistently yield poor DFP levels compared to other ones. Moreover, the study concluded that the daylight performance of multi-family houses was affected by different planning practices during Swedish urban planning history in a specific period.

Also at the level of residential buildings but within a specified range of spaces, Angeraini [68] studied the influence of the balcony and actual sunspace on the daylight performance in the adjacent living spaces (workshop, kitchen and living room) in multi-family housing in Malmö, Sweden by the use of simulation programs. The results showed that the daylight received in the neighboring spaces was reduced by at least 50% compared to the apartments without balcony and sunspace. The study showed that the least depth and the shortest length of balcony and the sunspace gave the highest average daylight autonomy (DA) and average daylight factor (DF) in all living spaces of the four studied apartments. The relationship between lighting illuminated to interior spaces through windows in an apartment building was investigated by Al-Shurafa [69]; she highlighted the situation of daylighting in multi-storey residential buildings at the Gaza Strip, Palestine to propose design guidelines. The study concluded with a set of recommendations such as confirming the direct relationship between the illuminance level that reaches inner spaces through the window with window design, and the illuminance level that reaches lower spaces with light well design. The study found significant effects of plan orientation, area, light well surfaces material reflectance, and opening area passes the light to the spaces on the illuminance level in the tested spaces. It has been revealed that light shelf has effective results on improving the quality distribution of light. Although the study reported some factors that affect daylight inside the building, it did not determine the amount of effect produced by each factor on daylight.

Notably, daylighting within residential buildings as a topic has occupied a great deal of research work, but from different points of view. Syed Husin and Harith [70] focused on the numerous materials and kinds of window and the glass, in order to identify the quality and quantity of daylight that penetrates into the residential buildings. Based on a series of measurement, it was identified that the type of glazing and window gives major significant on the performance of daylight and thermal performance in residential buildings. Another important topic related to daylighting is energy-saving and consumption within buildings. Line with this context, Li and Tsang [71] have studied energy implications and the daylighting performance for office buildings. A total of 35 commercial buildings have been chosen in the survey. Based on RADIANCE simulation program, two

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typical office blocks were further analyzed. The daylighting performance was assessed in terms of room depth, glare index and daylight factor. It has been found that the daylighting performance for office buildings is quite effective. About one-third of the office areas that are near the perimeter regions have an average daylight factor of 5%. For the inner region of deep plan offices, some innovative daylighting systems such as the light pipe and light redirecting panels could be used to improve the performance of the daylighting. The study concluded that the office building envelops designs are conducive to effective daylighting and proper daylight linked lighting controls could save over 25% of the total electric lighting use.

The studies reviewed emphasized the importance and role of simulation programs in studying and measuring the quality, quantity, performance and level of daylight entering the interior spaces of buildings in general and residential in particular. These studies differed in the way they approached the subject of daylight. Some studied daylight quantities and compared them with energy consumption levels. Other studies have gone on to come up with a set of suggestions, guidelines, conceptual and practical frameworks for the development and repair of the defect in the level of daylight penetrating into the buildings. A few of these studies have adopted residential building typology as a basis for research. A handful focused on a part of the spaces and neglected the other spaces, while some of them adopted multi-storey residential buildings in one or limited cases, as they did not cover all the types recognized by architects and designers. Therefore, the present study is considered to fill the gap that exists at least within the cognitive and research contexts discussed and reviewed in advance in this research effort. The importance of the current research lies in the adoption of multi-storey residential buildings and for all known and common typologies. What distinguishes this study from its predecessors is that it linked the type (plan layout typologies) of multi-storey residential building specifically, without focusing on a particular part with the neglect of the rest of the other parts and spaces. Hence, this research contributes to supporting architects specializing in the design of multi-storey buildings, especially in the early stages of design.

4.1. Research problem

A search through the literature shows that much of current daylighting research is mainly focused on office spaces, whereas residential architecture is rarely taken into consideration. A keyword search across academic search engines reveals that only 35% focus on residential architecture out of 6865 publications, whereas the rest 65% focus on office spaces [72]. It is clear from the literature reviewed that there are several factors parameters that affect the distribution of daylight inside buildings as well as many tools are available for design and simulation. However, none of these studies addressed the relationship between multi-storey residential building typologies and the level of daylight performance within their interior spaces.

The pursuit of energy-saving and reduction of increases in energy consumption rates requires increased utilization of daylight; this problem has become an important issue in the design and construction of buildings. Providing natural light in residential buildings specifically has always been a challenge for architects and building designers. As daylight is one of the most important factors in the apartments, this question is come to mind: How does building typology affect the optimal daylight level in interior spaces of apartment buildings? The multi-storey residential building includes many different plan typologies that may provide a different amount of daylight, which generate a shortfall in daylight performance in certain cases more than others. According to scenario compiled above, the research problem can be formulated as a verification of the relationship between the architectural plan typologies of multi-storey residential buildings with daylight (natural lighting) level in its interior spaces.

4.2. Research aim and objectives

The aim of this research is to investigate the impact of the plan typology on the building daylight performance in the multi-storey residential building (apartments) in Erbil city by using the building information modeling (BIM). In order to achieve this aim, the following objectives are formulated specifically.

1. To measure the impact of plan typology on daylight performance level in multi-storey residential building.
2. To determine the optimal plan typology in providing sufficient daylighting.
3. To identify the optimal daylight distribution within the interior spaces of multi-storey residential buildings.
4. To provide specific design guidelines of daylight performance in multi-storey residential buildings.

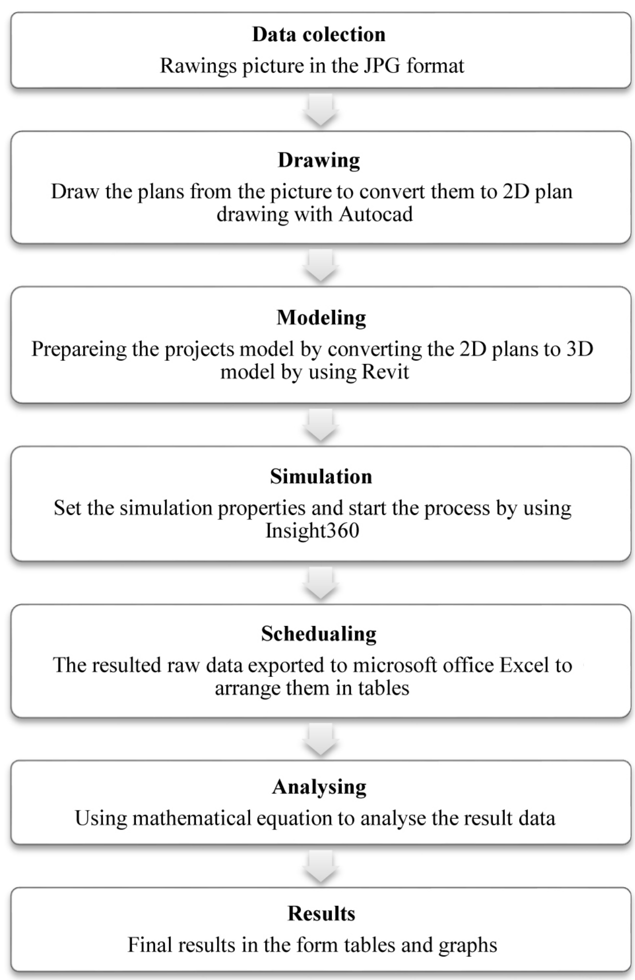

Fig. 3. Methodology stages.

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5. Research methodology

5.1. General method

One of the most important aspects of designing sustainable buildings is building performance analysis. Architects have done such analyses done to predict how buildings are performing in terms of their luminous environment as a result of daylight. Computer simulation tools or hand calculations have been used to perform the programs of daylight analysis. For simulation, once the architect states the architectural model of a building, the simulation expert makes a simulation model for the execution of the analysis. The preparation of simulation models can be a very lengthy and resources consuming process as the work mostly consists of manual translation from architectural model data to simulation data [73]. Graphical user interfaces for the definition of model geometry have been created for simulation tools to ease the process of creating the input files. In addition, geometry modeling tools have been linked with daylight simulation tools. In this field, BIM is being used in building design [74]. This section presents a methodology of using BIM tools such as Autodesk Revit which has been applied as a modeling program in this research; in addition, daylighting analysis tool such as Insight360 as a simulation tool has been used to find the relation between daylight optimization performance and plan typology. The simulation process allows for choosing the optimum design typology among the defined groups of typologies. This could be achieved through simulation of the case studies to find the final daylight performance of each type (Fig. 3). Daylight performance will be assessed in this study according to Daylight Illuminance, LEED, and Spatial Daylight Autonomy. This is to get a more accurate and reliable results about each case study of multi-residential building.

Table 2. Case studies classification.

	Project name	**Plan Typologies**				
		Point	**Single-loaded corridor**	**Double-loaded corridor**	**Large-scale development**	**Mixed**
1	Golan tower		✓			
2	Kamarany city	✓				
3	Lebanon Village			✓		
4	Mamostayan city				✓	
5	Empire world					✓

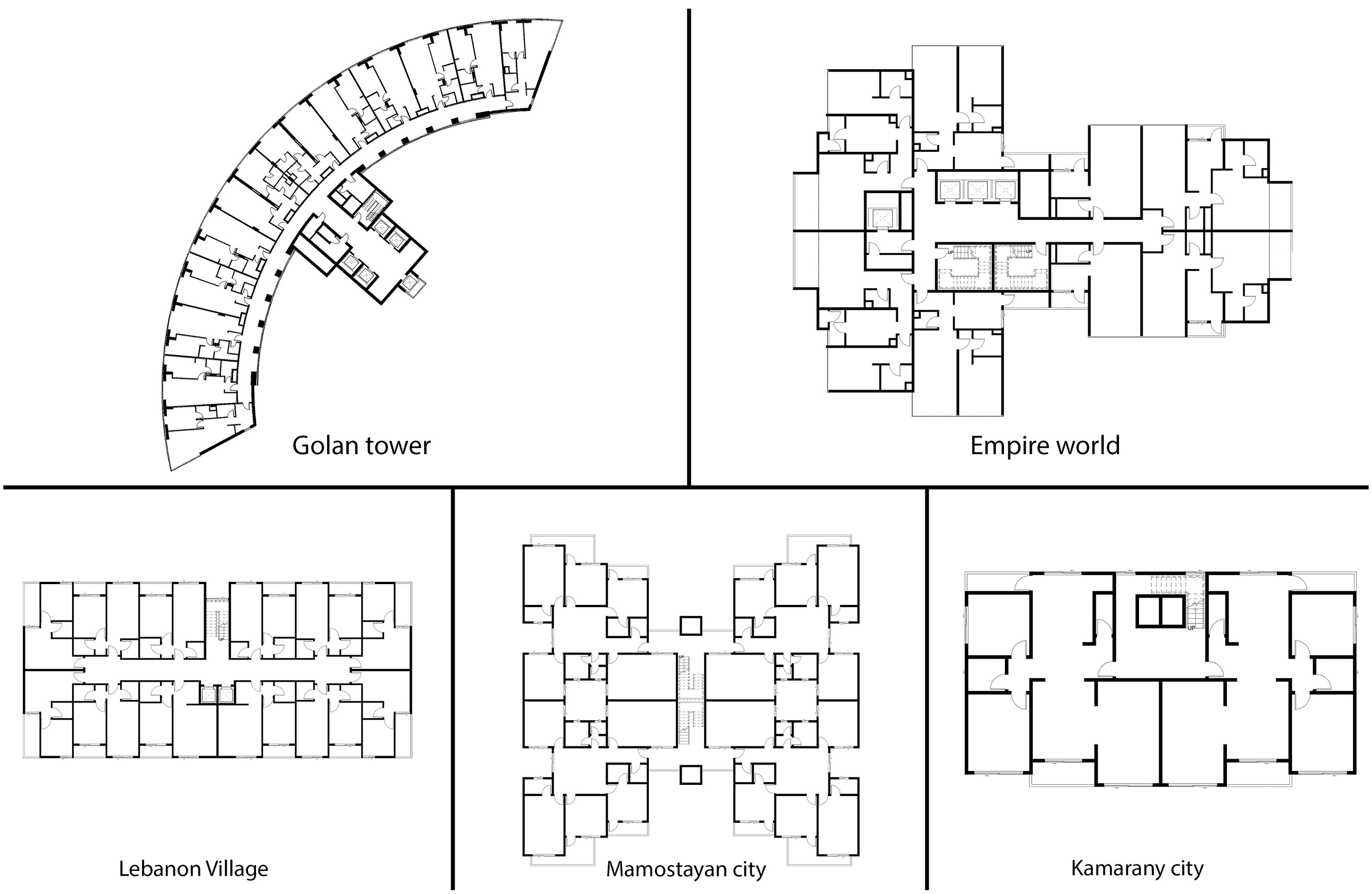

Fig. 4. Case studies plan layout.

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5.2. Case studies classification

After drawing all the cases were selected, the next stage is to classify them according to the plan typologies. The selected multi-storey residential projects have been classified based on five categories of plan typology as follows:

A. Point: consists of the projects that have one central vertical circulation where all the entrances to the apartments are located near it.
B. Single loaded corridor (Gallery): consists of the projects that have one or more central vertical circulation connected with a long corridor where all apartments are located on one side of it.
C. Double loaded corridor: consists of the projects that have one or more central vertical circulation connected with a long corridor where all apartments are located on both sides.
D. Large scale developments (Segment): consists of the projects that have one or more central vertical circulation where the same shapes are repeated two or more than two times but those parts are connected to each other by joints to produce the final shape of the building.
E. Mixed: one or more of the previous typologies were mixed in the same building corridor with a segment and so on.

For the purposes of analysis and comparison, five case studies of multi-storey residential buildings (apartments) in Erbil city were selected as a sample (Table 2), i.e. one case to represent each of the types mentioned above. Plan layouts of the case studies are presented in Fig. 4.

6. Results and discussion

All processes from data collection to the final stage of modeling can be considered as preparation for the last stage which is a simulation. At this stage, three types of simulation were conducted on each case study to produce three different results according to the type of simulation (Illuminance Analysis, LEED v4 option 2, and Daylight Autonomy (sDA preview)). The simulation was performed using the Insight360 version (3.1.2.1 educational license) as a simulation tool. The following results were obtained from running the simulation:

6.1. Daylight illuminance results

The first type of simulation which is Illuminance Analysis was run on all the projects one by one to achieve results. The simulation setting of this running was as follows:

A. Location: Erbil city, Iraq.
B. Date/time: 21 September/two simulation time first at 9 am and the second at 3 pm. The sky model selected for daylight calculations is a clear sky.
C. Illuminance setting: Threshold between 300 lux as lower point and 3000 lux as an upper point.

Table 3 shows that apartments of Kamarany city which represent point typology achieved the highest percentage of daylight availability with 84% (the sum of within threshold and above threshold) followed by apartments of Mamostayan city with 80%, while apartments of Gulan Towers, Lebanon Village and Empire World achieved a lower percentage of daylight availability with 68%, 65% and 64% respectively. Obviously, the results of all plan typologies vary with each other, ranging from the lowest 64% for apartments of the mixed typology to the highest 84% for apartments of the point typology in terms of achieving daylight levels. However, this result cannot be considered alone because there is another simulation performed at 3 pm.

Table 4 shows the results of simulation at 3 pm on 21/September, the best case is Kamarany city achieved the highest average of daylight availability with 84% from the point type, while the worst case was Lebanon Village with 65% representing double-loaded typology. At the 3 pm simulation, the results were changed very slightly and the double-loaded is the worst typology and the single point typology was the best in terms of daylighting performance.

Figure 5 shows the final results of this stage of simulation, which is the average percentage of the results of both times (9 am and 3 pm) for daylight availability based on plan typologies. In both times, with about 63% of the total floor area within threshold between 300-3000 lux plus 21% as above the threshold 300 lux, accounting a total daylight availability of 84% of the total floor area for apartments of Kamarany City representing the point typology were recorded the best compared to other cases. Whereas, the apartments of Lebanon Village representing double-loaded plan typology and apartments of Empire World are the worst in

Table 3. Simulation best results according to typology at 9 am for all cases.

Project	Plan Typology	Within threshold	Above threshold	Below threshold	Daylight availability
Kamarany City	Point	63%	21%	16%	84%
Mamostayan City	Large sc. developments*	66%	14%	20%	80%
Lebanon Village	Double-loaded	54%	11%	35%	65%
Empire World	Mixed	37%	27%	36%	64%
Gulan Tower	Single-loaded	54%	14%	32%	68%

*Large scale developments.

Table 4. Simulation of the best results according to plan typologies at 3 pm for all cases.

Project	Plan Typology	Within threshold	Above threshold	Below threshold	Daylight availability
Kamarany City	Point	63%	21%	16%	84%
Mamostayan City	Large sc. developments*	66%	14%	20%	80%
Lebanon Village	Double-loaded	54%	11%	35%	65%
Empire World	Mixed	33%	34%	33%	67%
Gulan Tower	Single-loaded	51%	17%	32%	68%

*Large scale developments.

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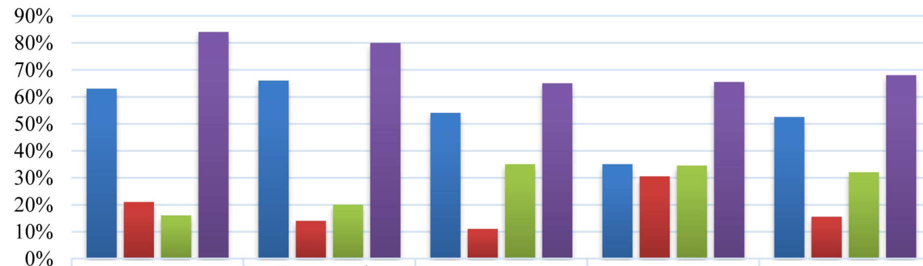
term of daylight performance with a total of 65% and 65.5 respectively in terms of daylight availability.

Furthermore, Fig. 6 demonstrates the graphical illuminance simulation results for all spaces in overall case studies. The areas above the threshold have been revealed in yellow color, while the red color indicates the daylight areas bellow threshold and other gradual colors refer to the areas within threshold with values ranging between 300 to 3000 lux. It is noticeable that apartments' corridors and deep interior spaces have the lowest daylight performance among other spaces. The simulation program also



	Point Kamarany City	Large scale developments Mamostayan City A	Double-loaded Lebanon Village A	Mixed Empire World	Single-loaded Gulan Tower
Within threshold	63%	66%	54%	35%	52.50%
Above threshold	21%	14%	11%	30.50%	15.50%
Below threshold	16%	20%	35%	34.50%	32%
Daylight availability	84%	80%	65%	65.50%	68%

Within threshold Above threshold Below threshold Daylight availability

Fig. 5. The average percentage of the results of both times (9 am and 3 pm) for daylight availability based on plan typologies.

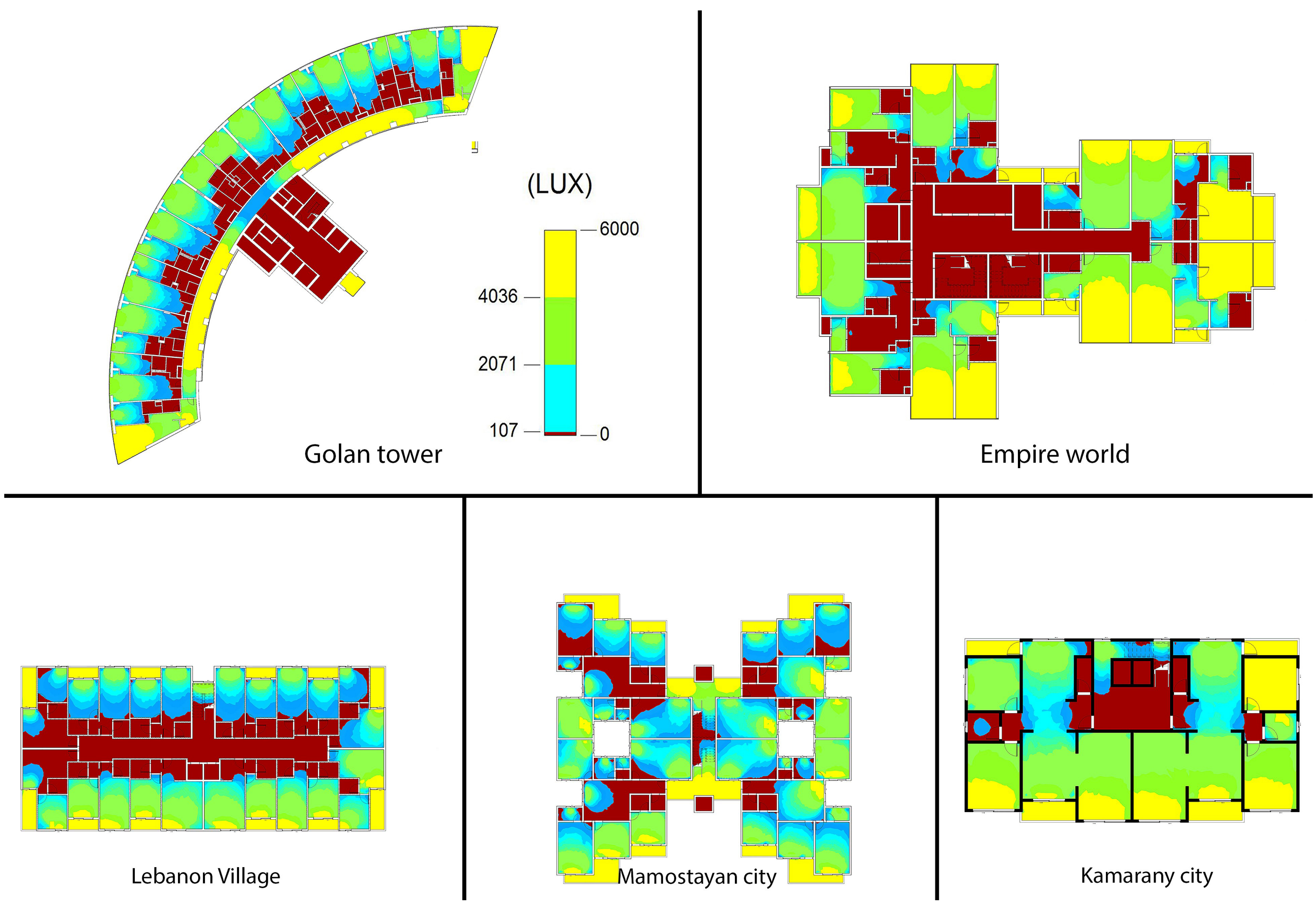


Fig. 6. Daylight Illuminance distribution results for overall case studies.

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provides the daylight details for each individual space in all case studies.

6.2. Results of daylight performance according to LEED

LEED v4 opt2 is the second type of simulation was run for all cases to produce another type of results according to the LEED standards. Insight360 setting for LEED simulation of this run was as follows:

A. Location: Erbil city, Iraq.
B. Date/time: The average weather data of two clear sky days within 15 days of 21- September and March from 9 am to 3 pm have been selected. The sky model selected for daylight calculations is a clear sky.
C. Illuminance setting: For the daylight illuminance, the threshold has been determined between 300-3000 lux according to the LEED v4 option 2.

Table 5 shows the simulation of the best results according to LEED v4 option 2 at 9 am. It is clear that apartments of Kamarany City which represent point typology achieved the highest percentage of daylight availability with 84% followed by apartments of Mamostayan City with 80%, while apartments of Gulan Towers, Empire World and Lebanon Village achieved a lower percentage of daylight availability with 67%, 66% and 65% respectively. It is clear that the results of all typologies are varied with each other, ranging from the least 65% for apartments of the double-loaded typology to the highest 84% for apartments of the point typology in terms of achieving daylight level. This result, however, cannot be considered alone as there is another simulation to be done at 3 pm.

Table 6 shows the results of LEED simulation at 3 pm. Results of this type of simulation at the mentioned time reveal that the best case is Kamarany city achieved the highest average of daylight availability with 84% representing point typology, whereas the worst case was Lebanon Village with 65% representing double-loaded plan typology. In the 3 pm simulation, the results were changed very slightly and the double-loaded is the worst typology and the single point typology was the best for daylighting performance compared to other typologies.

Table 5. Simulation of the best results according to LEED v4 option 2 at 3 pm for all cases at 9 am.

Project	Plan Typology	Within threshold	Above threshold	Below threshold	Daylight availability
Kamarany City	Point	63	21	16	84
Mamostayan City	Large sc. developments*	66	14	20	80
Lebanon Village	Double-loaded	54	11	35	65
Empire World	Mixed	38	28	34	66
Gulan Tower	Single-loaded	53	14	33	67

*Large scale developments.

Table 6. Simulation of the best results according to LEED v4 option 2 at 3 pm for all cases.

Project	Plan Typology	Within threshold	Above threshold	Below threshold	Daylight availability
Kamarany City	Point	62	22	16	84
Mamostayan City	Large scl. developments*	66	14	19	80
Lebanon Village	Double-loaded	54	11	35	65
Empire World	Mixed	33	33	34	66
Gulan Tower	Single-loaded	50	18	32	68

*Large scale developments.

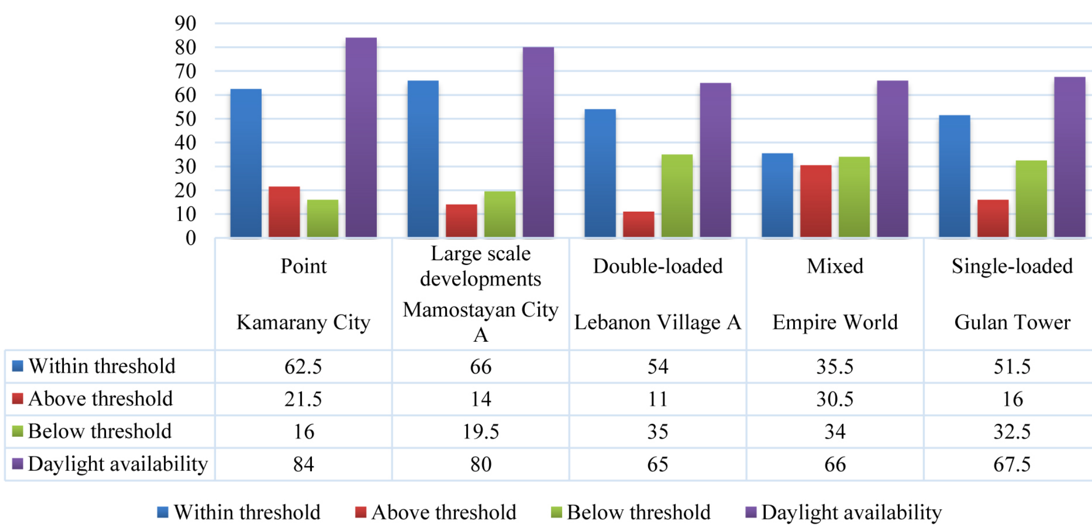

Fig. 7. The average percentage of results in both times (9 am and 3 pm) for daylight availability based on LEED simulation.

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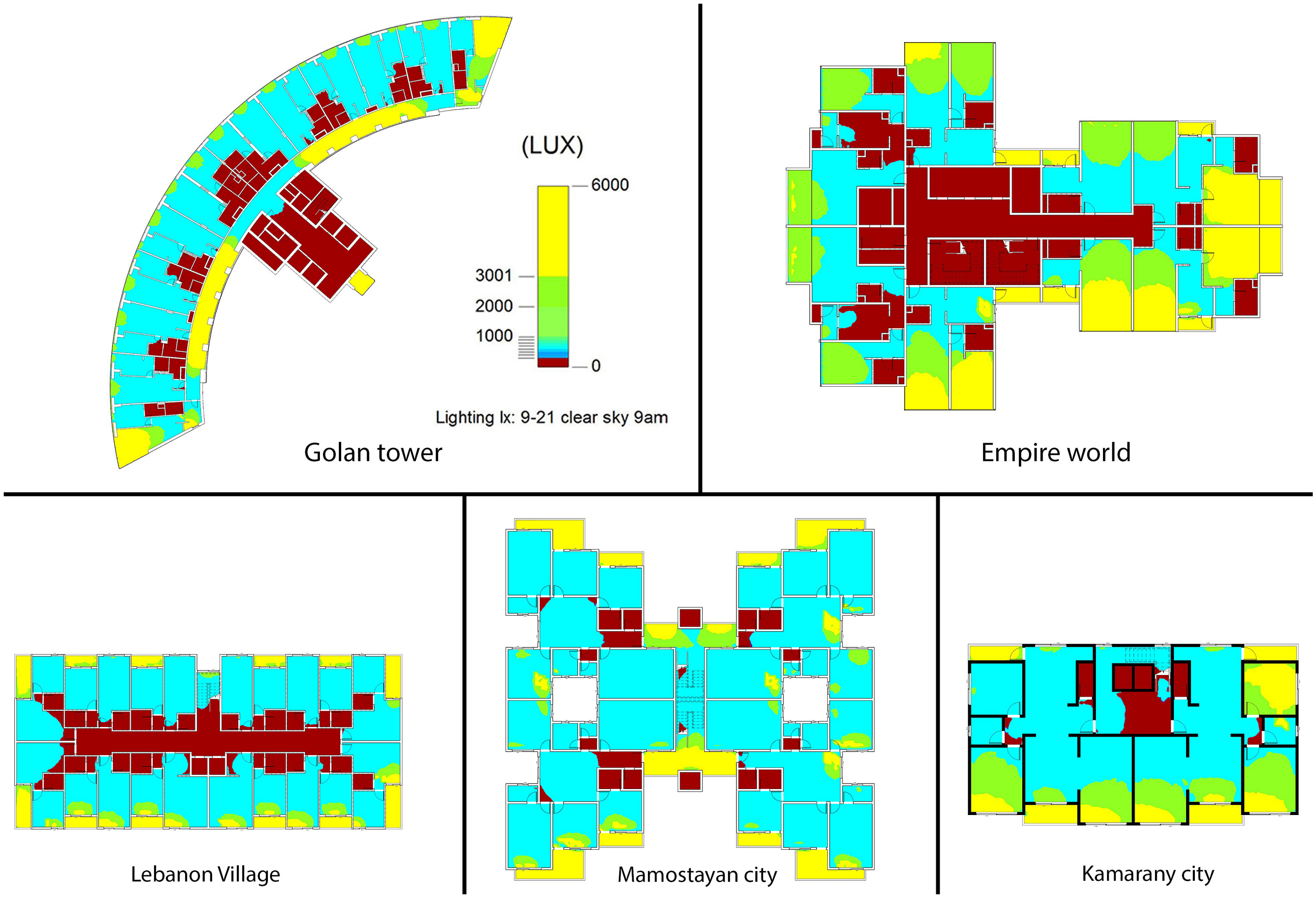

Fig. 8. Graphical presentation based on LEED simulation for all cases.

Table 7. Daylight Autonomy simulation results at 9 am for all cases.

Project Name	Typology	Floor area	sDA 300/50 %	sDA 55% >of room area	sDA 75% >of room area	ASE 1000/250 %
Kamarany City	Point	273 m²	85	85	83	24
Mamostayan City	Large scale developments	766 m²	76	81	68	17
Lebanon Village	Double-loaded	565 m²	62	68	56	13
Empire World	Mixed	742 m²	63	72	60	29
Gulan Tower	Single-loaded	1190 m²	67	81	55	19

Figure 7 shows the overall results of this stage of simulation, which is the average percentage of the results in both times (9 am and 3 pm) for daylight availability according to LEED simulation. In both times, with about 62.5% of the total floor area within threshold between 300-3000 lux plus 21.5% as above the threshold 300 lux, accounting a total daylight availability of 84% of the entire floor area for the apartments of Kamarany City representing the point typology which was recorded the best compared to other cases. Whereas, the apartments of Lebanon Village representing double-loaded plan typology are the worst in term of daylight performance with a total of 65% of daylight availability. Figure 8 presents a graphical presentation for all cases and typologies according to LEED simulation.

6.3. Daylight autonomy results

The third type of simulation is Daylight Autonomy, which was run for all projects to produce another type of results according to LEED standards. In this simulation, the building achieves two LEED points if the result is more than 55% in the simulation and three LEED points if it attains more than 75%. The annual daylight performance in terms of sDA and ASE varies from one case to other case studies. Insight360 setting for Daylight Autonomy for all cases was run based on the following steps:

A. Location: Erbil city.
B. Date/time: The simulation covered the period from January 1 to December 31, from 8:00 am to 6:00 pm which includes 3650 hours of daylight simulation. The sky model selected for daylight calculations is a clear sky.
C. Illuminance setting:

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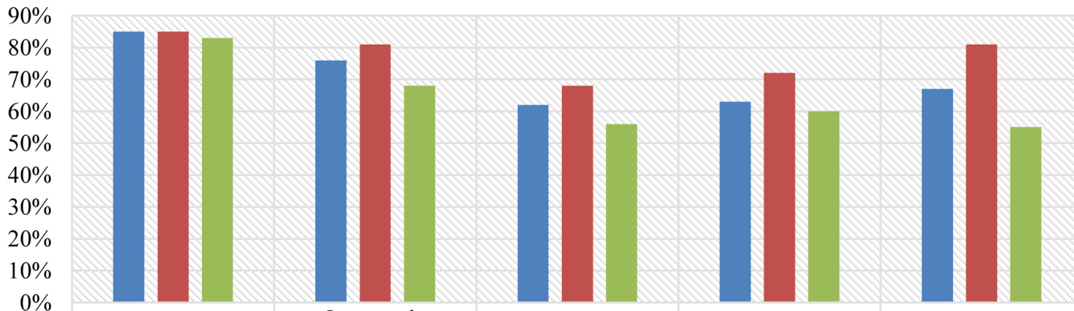
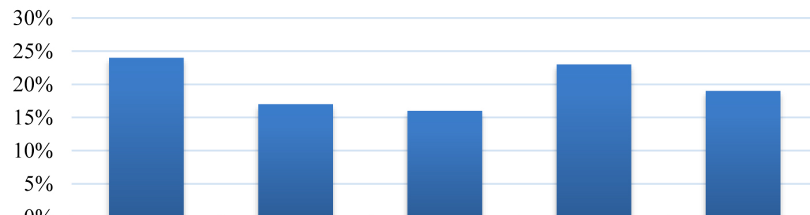


	Point Kamarany city	Large scale development Mamostayan City A	Double-loaded Lebanon Village A	Mixed Empire World	Single-loaded Gulan Tower
sDA 300/50	85%	76%	62%	63%	67%
sDA 55% >of area	85%	81%	68%	72%	81%
sDA 75% >of area	83%	68%	56%	60%	55%

sDA 300/50 sDA 55% >of area sDA 75% >of area

Fig. 9. The average percentage of results for daylight autonomy (sDA) according to plan typologies.



	Point Kamarany city	Large scale development Mamostayan City A	Double-loaded Park View B	Mixed Empire World	Single-loaded Gulan Tower
ASE 1000/250	24%	17%	16%	23%	19%

ASE 1000/250

Fig. 10. Annual Sunlight Exposure (ASE) best simulation results according to plan typology for all cases.

1. sDA300/50: The percentage of floor area that receives over 300 lux for at least 50% of 3650 annual hours. LEED points are earned for 55% & 75% of Building area.
2. ASE1000/250: The percentage of floor area that receives over 1000 lux for more than 250/3650 annual hours. Only areas in Rooms with ASE < 20% Room area can be qualified.

The data resulted from this type of simulation were sDA and ASE percentages according to building area. Table 7 shows the result of simulation regarding Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) for all cases and typologies.

Figure 9 shows the highest simulation results of daylight autonomy according to plan typologies for all cases. Obviously, Kamarany City, which represents the Point typology, got the best results, as the overall sDA reaches 85% of the total building area, 85% of this area reaches more than 55% of sDA which means 2 points according to LEED standards, 83% of the total area achieves more than 75% of sDA, which means three points according to LEED. The second best results achieved by Mamostayan City, which represents a Large-scale development typology reaches 76% as overall sDA of the total area of the building, 81% of this area reaches more than 55% of sDA which means 2 points according to LEED, 68% of the total area achieves more than 75% of sDA which means three points according to LEED. On the other hand, Single-loaded, Mixed and Double-loaded typologies got the worst results with 67%, 63% and 62% respectively. Figure 10 presents the highest results of Annual Sunlight Exposure simulation according to plan typologies for all case studies.

Annual Sunlight Exposure simulation results show that Kamarany city representing Point typology got the best results with 24% of the building area got more than 1000 lux of daylight for 250 hours per a year, followed by Empire World apartments representing mixed typology. In contrast, Single-loaded, Large scale development and Double-loaded typologies got the worst results achieving 19%, 17% and 16% respectively. Based on three types of simulation (Illuminance, LEED, and Daylight Autonomy) among all case studies, it can be concluded that point tower apartments are the best typology in terms of daylight performance, while apartments in the Double-loaded typology are the worst. Figure 11 shows that the combination of results of all simulation types among the best cases.

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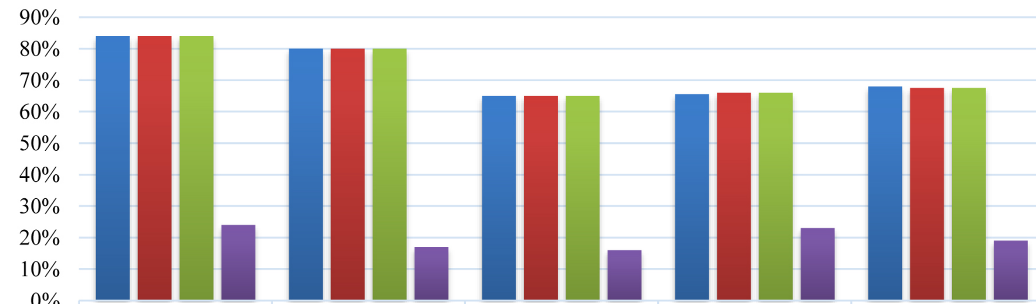

	Point	Large scale development	Double-loaded	Mixed	Single-loaded
Illuminance	84%	80%	65%	65.50%	68%
LEED	84%	80%	65%	66%	67.50%
sDA	84%	80%	65%	66%	67.50%
ASE	24%	17%	16%	23%	19%

Illuminance LEED sDA ASE

Fig. 11. Combination of simulations results.

7. Conclusions

Recently, building information modeling is widely used in architecture and construction field. One of the most important factors that BIM tools can help improve and evaluate the performance of a building is daylight within its interior spaces. Undoubtedly, the building layout shape affects the quantity and quality of daylight that penetrates the building. The relationship between building plan typology and the quantity, quality and level of daylight within the interior spaces of multi-storey residential buildings are important arguments that require verification. From this standpoint, the research adopted a verification approach to this supposed relationship. Information building modeling has been used as one of the most important and accurate methods developed to verify this research controversy. An academic licensed Revit Architecture 2019 with Plugged Insight360 for daylight analysis as one of BIM tools has been applied for achieving this goal. Five multi-story residential buildings representing different plan typologies in Erbil city were selected as cases of study. The plan layout of these cases were classified into various typologies, which consist of four main typologies: a point typology that has one central vertical circulation; a single loaded corridor also called a gallery, it consists of long corridor with apartments from one side; a double-loaded corridor has a long corridor rounded by apartments from both sides and it has one or more vertical circulation; and finally, the large scale development which also can be called as segments. Two or more of these typologies can be used to produce a mixed typology as a fifth category found in Erbils' multi-storey residential buildings.

To achieve results and to solve the research problem, three types of simulation were run on each case study: useful daylight illuminance, LEED, and spatial daylight autonomy. These types of simulation allow assessing the quantity and quality of the daylight availability and also the visual comfort inside the buildings reaching to determine the optimal situation. The results were analyzed and compared with daylight standards levels. The results of the simulation showed that the point plan typology provides the optimum daylight performance among all the typologies and also providing sufficient daylighting with an optimal daylight distribution inside the multi-storey residential building. This result is attributed to the fact that the apartments within the point typology are overlooking and open to the external environment in all sides and this contributes to the exposure of each apartment from more than one side to the sunlight. On the other hand, the central vertical circulation core of this type is a small ratio compared to the building area and also can be lighted naturally. As for other plan typologies, the double-loaded corridor achieved the worst results among all of the cases of its longitudinal shape which provides the apartment with one side of sun exposure to the sunlight in most cases. In addition, the corridor cannot be easily illuminated because it is surrounded by apartments on both sides, and the area of the corridor is not small compared to the total area of the building. Based on the most important findings achieved, the following are the main conclusions that can be referred to:

- The study concludes that the plan typology has an obvious impact on achieving daylight performance in the multi-storey residential buildings.
- The study contributes to the verification of the assumed relationship between the plan building typology and the level of daylight reaching the interior spaces within residential buildings.
- The use of information building modeling as a tool for measurement and analysis has provided a solid environment in achieving reliable and accurate results.
- The current research can contribute to identifying the shortcomings of daylight levels in buildings in general and multi-storey residential buildings, in particular, seeking to overcome it in the early phases of design.
- The study identifies the optimal daylight distribution within the interior spaces of multi-storey residential buildings represented by point typology.
- The outcomes of the current research can serve as a database to provide specific design guidelines for optimal daylight performance in multi-storey apartment buildings.

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Contributions

M. N. Majeed being a master student conducted the research in terms of literature review, data collection, establishing and generating a simulation model, interpreting the results and conclusions. F. A. Mustafa has developed the main idea and directly supervised the research, guiding its path through reviewing the writing of the research in addition to developing discussion of the results and drawing conclusions. H. A. Husein provided advise and information about case studies.

References

[1] H. Freeman, Mental health and high-rise housing. In: Unhealthy Housing, Research, remedies and reform, R. Burridge and D. Ormandy eds., Chapman and Hall, London, 1993, 168-190.

[2] U. Bronfenbrenner and G.W. Evans, Developmental science in the 21st century: Emerging questions, theoretical models, research designs and empirical findings, Social Development 9 (2002) 115-125.

[3] G. W. Evans, N. M. Wells and A. Moch, Housing and mental health: a review of the evidence and a methodological and conceptual critique, Journal of Social Issues 59 (2003) 475-500.

[4] N. Ruck, Ø. Aschehoug, S. Aydinli, et al., Daylight in Buildings - A source book on daylighting systems and components, Lawrence Berkeley National Laboratory, Washington, DC, USA, 2000.

[5] M. De Carli, V. De Giuli, R. Zecchin, Review on visual comfort in office buildings and influence of daylight in productivity, In: Indoor Air, 2008, Copenhagen, Denmark.

[6] M. De Carli and V. De Giuli, Optimization of daylight in buildings to save energy and to improve visual comfort: Analysis in different latitudes, In: Eleventh International IBPSA Conference, Glasgow, Scotland July 27-30, 2009.

[7] G. Franta and K. Anstead, Daylighting offers great opportunities, Window & Door Specifier-Design Lab., 40-43, 1994.

[8] J. Liberman, Light: Medicine of the Future, Bear Company, 1991.

[9] K. Al Omari, The impact of daylight on occupant's satisfaction: In the Residential apartments of Amman, Jordan, International Journal of Applied Environmental Sciences 11 (2016) 551-557.

[10] P. Procter, Cambridge International Dictionary of English (Cambridge Illustrated History), Cambridge University Press, New York, 1995.

[11] N. L. Nik Ibrahim, S. Hayman, and R Hyde, A typological approach to daylighting analysis, Architectural Science Review 54 (2011) 141-147.

[12] R. McHenry, The new encyclopaedia Britannica, Vol. 12, 15th edn, Encyclopedia, Chicago, 1993.

[13] S. Agyefi-Mensah, Functionality and adaptability of design solutions for public apartment buildings in Ghana: towards evidence-based design for sustainable lifespan building performance Eindhoven, PhD thesis Department of the Built Environment, Technische Universiteit Eindhoven, The Netherlands, 2013.

[14] J. Wojtowicz and W. Fawcett, Architecture: Formal Approach, Academy Editions/St., Martin's Press, New York, 1986.

[15] T. Mirko, New type of residential building configuration, Facta universitatis – series: Architecture and Civil Engineering 14 (2016) 47-58.

[16] R. Sherwood, Modern housing prototypes, Harvard University Press, Cambridge, 1978.

[17] Rossi, A., The Architecture of the City, The MIT Press, Cambridge, 1984.

[18] I. Tibermacine and N. Zemmouri, Effects of building typology on energy consumption in hot and arid regions, Energy Procedia 139 (2017) 664-669.

[19] S. R. JU, L. Lee, and S-Y Jeon, The typologies of block and unit plan in Malaysian apartments-Focused on middle cost houses supplied by the private sector, Journal of Asian Architecture and Building Engineering 13 (2014) 397-404.

[20] Collins Dictionary, Collins Online English Dictionary, available: https://www.collinsdictionary.com/dictionary/english/daylight, retrieved: 13/10/2019.

[21] Daylight, (2019). Daylight Appreciation Day, available: https://rich1698.wordpress.com/2019/06/21/daylight-appreciation-day/, retrieved: 12/10/2018.

[22] V. Mikler, A. Bicol, B. Breisnes and M. Labrie, Passive Design Toolkit: Best Practices, available: https://vancouver.ca/files/cov/passive-design-large-buildings.pdf, retrieved: 5/10/2019.

[23] M. Bodart and A. D. Herde, Global energy savings in offices buildings by the use of daylighting, Energy and Buildings 34 (2002) 421-429.

[24] W. M. C. Lam, Perception and Lighting as Formgivers for Architecture, 4th edition, McGraw-Hill, New York. 1977.

[25] P. Leather, M. Pyrgas, D. Beale, and C. Lawrence, Windows in the workplace: Sunlight, view, and occupational stress, Environment and Behavior 30 (1998) 739-762.

[26] L. Heschong, Daylighting and Human Performance, ASHRAE Journal (2002) 65-67.

[27] R.A. Achsani, S. Wonorahardjo, and F.X.N. Soelami, A Vision of Daylight Technologies for High-Rise Residential Building, In: Tropic HABITechno 3rd International Conference, IOP Conference Series: Earth and Environmental Science, 2018, 152.

[28] C. Reinhart and O. Walkenhorst, Validation of Dynamic RADIANCE-based Daylight Simulations for a full-scale Test Office with outer Venetian Blinds, Energy & Buildings 33 (2001) 683-697.

[29] Y. Elghazi, A. Wagdy, S. Mohamed and A. Hassan, Daylighting driven design: Optimizing Kaleidocycle façade for hot arid climate, In: Fifth German-Austrian IBPSA Conference RWTH Aachen University, Germany, 2014.

[30] M.E., El Sheikh and D.J. Gerber, Building Skin Intelligence: A Parametric and Algorithmic Tool for Daylighting Performance Design Integratio, In: Proceedings of the 31st Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA), 170-177. ACADIA. Calgary/Banff, The University of Calgary, Canada, 2011.

[31] P. O. Akadiri, E. A. Chinyio and P. O. Olomolaiye, Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector, Buildings 2 (2012) 126-152.

[32] V. R. M. Lo Verso, E. Fregonara, F. Caffaro, C. Morisano, G. M. Peiretti, Daylighting as the Driving Force of the Design Process: from the Results of a Survey to the Implementation into an Advanced Daylighting Project, Journal of Daylighting 1 (2014) 36–55.

[33] B. Iason , A. Stephanie Jenny, H. Ludvig, S. Maha, L. Therese, D. Marie-Claude, Innovative solutions for good daylighting and low energy use in multi-family dwellings, MKB Greenhouse, Swedish Energy Agency Project, Lund University, Malmö, Sweden, 2017.

[34] W.K.E. Osterhaus, Discomfort glare assessment and prevention for daylight applications in office, environments, Solar Energy 79 (2005) 140-158.

[35] J. A. Veitch, Lighting–to your good health = Lyset og det gode helbred, Arkitekten 9 (2007) 60-63.

[36] W. Van Bommel and G. Van Den Beld, Lighting for work: A review of visual and biological effects, Lighting Research & Technology 36 (2004) 255-266.

[37] J. Mardaljevic, L. Heschong and E. Lee, Daylight metrics and energy savings, Lighting Research & Technology 41 (2009) 261-283.

[38] M. Andersen, S., Kleindienst, L. YI, J. Lee, M. Bodart, and B. Cutler, An intuitive daylighting performance analysis and optimization approach, Building Research & Information 36 (2008) 593-607.

[39] M. Boubekri, Appraisal of the lighting conditions in an office building: Results of a survey, Indoor Environment 4 (1995) 162-169.

[40] C., Reinhart, D. Bourgeois, F. Dubrous, A. Laouadi, P. Lopez, and O. Stelescu, Daylight 1-2-3–a state-of-the-art daylighting/energy analysis software for initial design investigations, In Proceedings: Building Simulation 2007, available: http://www.ibpsa.org/proceedings/BS2007/p233_final.pdf, retrieved: 20/10/2019.

[41] W. Hee, M. Alghoul, B. Bakhtiyar, O. Elayeb, M. Shameri, M. Alrubaih, and K. Sopian, The role of window glazing on daylighting and energy saving in buildings, Renewable and Sustainable Energy Reviews 42 (2015) 323-343.

[42] S. Baier, Illuminance: exploring 'incident light', 2012, available: https://lumenistics.com/illuminance-define/, retrieved: 20/09/2019.

[43] D. A. Snow, Plant Engineer's Reference Book, 2nd edition, Elsevier, 2001.

[44] W. F. Long, Luminance exitance, 1994, available: http://www.drdrbill.com/downloads/optics/photometry/Exitance.pdf, retrieved: 20/09/2019.

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[45] P. R. Tregenza, and J. Mardaljevic, Daylighting buildings: Standards and the needs of the designer, Lighting Research and Technology 50 (2018) 63-79.

[46] V. Costanzo, G. Evola and L. Marletta, A review of daylight strategies in schools: State of the art and expected future trends, Buildings 7 (2017) 1-21.

[47] A.B. Hammad Amin, F.A. Mustafa and S. Swar, School design daylighting Analysis: A study of Foundation schools in Erbil Governorate, Sulaimani Journal for Engineering Sciences 6 (2019) 21-34.

[48] J. Mardaljevic, Climate-based daylight modelling and its discontents. Presented at the Simple Buildings Better Buildings? Delivering performance through engineered solutions, CIBSE Technical Symposium, London, April 16-17th. 2015.

[49] P. Rogers, M. Tillberg, E. Bialecka-Colin, M. Österbring, and P. Mars, En genomgång av svenska dagsljuskrav (SBUF ID 12996). Svenska Byggbranschens Utvecklingsfond (SBUF), Stockholm (Sweden), 2015.

[50] C.F. Reinhart and O. Walkenhorst, Dynamic RADIANCE-based Daylight Simulations for a full-scale Test Office with outer Venetian Blinds, Energy & Buildings 33 (2001) 683-697.

[51] A. Nabil, and J. Mardaljevic, Useful daylight illuminances: A replacement for daylight factors, Energy and Buildings 38 (2006) 905-913.

[52] IES,Illuminating Engineering Society of North America, & Daylight Metrics Committee, Approved method: IES spatial daylight autonomy (sDA) and annual sunlight exposure (ASE), Illuminating Engineering Society of North America, NewYork. 2012.

[53] USGBC, The U.S. Green Building Council, Inc., LEED Reference Guide for Building Design and Construction v4. USGBC, Washington DC., 2019.

[54] Y. Elghazi, A. Wagdy, S. Mohamed and A. Hassan, Daylighting driven design: optimizing kaleidocycle facade for hot arid climate, in: Fifth German-Austrian IBPSA Conference RWTH Aachen University, 2014.

[55] N. Baker and K. Steemers, Daylight design of buildings: A handbook for architects and engineers, Routledge, 2014.

[56] Z. Rogers, and D. Goldman, Daylighting metric development using daylight autonomy calculations in the sensor placement optimization tool, Boulder, Colorado, USA: Architectural Energy Corporation, 2006, available: http://www.archenergy.com/SPOT/SPOT_Daylight%20Autonomy%20Report.pdf, retrieved: 18/12/2019.

[57] C.F. Reinhart and K. Voss, Monitoring manual control of electric lighting and blinds, Lighting Research & Technology 35 (2003) 243-258.

[58] Archecology, Daylight Credit – LEED v4, 2015, available: https://www.archecology.com/2017/03/15/daylight-credit-leed-v4/, retrieved: 11/09/2019.

[59] V. Sarvani and O. Kontovourkis, Parametric design of a high-rise habitation unit system through lighting and solar energy performances, Journal of Sustainable Architecture and Civil Engineering 3 (2013) 9-18.

[60] P. K. B. Lauridsen and S. Petersen, Integrating indoor climate, daylight and energy simulations in parametric models and performance-based design, In: Proceedings of the 3rd International Workshop on Design in Civil and Environmental Engineering, Technical University of Denmark, Kongens Lyngby, Denmark, 2014, 111-118.

[61] M. Qingsong and H. Fukuda, Parametric office building for daylight and energy analysis in the early design stages, Procedia-Social and Behavioral Sciences 216 (2016) 818-828.

[62] E. Montenegro, A. Potvin and C. Deners, Impact of school building typologies on visual, thermal and energy performances. In: Proceedings of the 28th International Conference on Passive and Low Energy in Architecture (PLEA), 2012, Lima, Peru.

[63] P. A. Sattrup, J. Strømann-Andersen, Building typologies in northern European cities: daylight, solar access, and building energy use, Journal of Architectural and Planning Research 30 (2013) 56-76.

[64] D. H.W. Li, S.L. Wong, C.L. Tsang, G.H.W. Cheung, A study of the daylighting performance and energy use in heavily obstructed residential buildings via computer simulation techniques, Energy and Buildings 38 (2006) 1343-1348.

[65] Y. Suriansyah, Daylight quality potency at Sarijadi mass public housing in Bandung Indonesia, Journal of Energy Technologies and Policies 3 (2013) 14-28.

[66] C. Chatzipoulka, R. Compagnon and M. Nikolopoulou, Urban geometry and solar availability on façades and ground of real urban forms: using London as a case study, Solar Energy 138 (2016) 53-66.

[67] I. Bournas, M.C. Dubois, Daylight regulation compliance of existing multi-family apartment blocks in Sweden, Building and Environment 150 (2019) 254-265.

[68] S.J. Angeraini, Sunspace design solutions based on daylight performance in a multi-storey residential building, LUP Student Papers, Lund University Libraries, 2016, available: https://lup.lub.lu.se/student-papers/search/publication/8896386, retrieved: 27/08/2019.

[69] A.Y. Al-Shurafa, A study of the daylighting performance in the multi-storey residential buildings of Gaza Strip. A study of the daylighting performance in the multi-storey residential buildings of Gaza Strip. MSc. thesis, The Islamic University of Gaza, Gaza, Palestine, 2016.

[70] S. N. F Syed Husin and Z. Y. H. Harith, The performance of daylight through various type of fenestration in residential building, Procedia - Social and Behavioral Sciences 36 (2012) 196-203.

[71] D. H .W. Li and E. K. W. Tsang, An analysis of daylighting performance for office buildings in Hong Kong, Building and Environment 43 (2008) 1446-1458.

[72] T. Dogan and Y.C. Park, A new framework for residential daylight performance evaluation. In: Proceedings of the 15th Conference of the International Building Performance Simulation Association-IBPSA, San Francisco, USA, August 7-9, 2017.

[73] V. Bazjanac, IFC BIM-Based Methodology for Semi-Automated Building Energy Performance Simulation, In: Proceedings of the 25th International Conference on Information Technology in Construction, Santiago, Chile July 15-17, 2008.

[74] N. W. Young, S.A. Jones, H.M. Bernstein and J. Gudgel, SmartMarket Report on Building Information Modeling (BIM): Transforming Design and Construction to Achieve Greater Industry Productivity, McGraw-Hill Construction, Washington, DC., 2008.

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