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Visible outside view as a facilitation tool to evaluate view quality and shading systems through building openings

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A R T I C L E I N F O

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A B S T R A C T

Viewing the natural environment from inside homes and workplaces has been recognized by a range of scholars as having an impact on improving health and well-being. Research has shown that a combination of outdoor elements – such as blue sky, sea view and greenery – is highly preferred as these elements are therapeutic for human wellbeing. However, installing shading systems is an important strategy for passive building cooling but it could affect our sense of connection to the outside environment. Most researchers evaluate view quality using qualitative questionnaires or quantitative methods by analyzing the geometry outside using 2D and 3D software which needs the outdoor environment to be fully built in the simulation accurately takes more time and may cause a system crash to run. This paper presents a new facilitation tool to quantify the visible outside view (VOV) by analyzing the outside view image by converting the view content into red, blue, and green (RGB) pixels using image processing technique. VOV measures the occupant's ray tracking percentage to the visible outside view content taking into consideration the blind factor of shading. An indicator start from 0 % to 100 % is given to quantify the outside view content including shading systems which then the overall VOV is related to the visible outside view quality as a factor of well-being potential (WP). The study found that the shading strategy should not be the same at all levels and shading devices in primary design stages considering the view to the natural elements positively affects occupants' wellbeing potential. These findings suggest that the proposed algorithm needs to be implemented with building energy and daylight simulation to produce more holistic systems. This will be the only way to get efficient and sustainable buildings highly connected with the human dimension.

Abbreviations

WP	Wellbeing Potential
VOV	Visible Outside View
FOV	Field of View
DLS	Direct Lines of Sight
$DLS_{greenery}$	Direct Line of Sight to greenery
DLS_{sky}	Direct Line of Sight to sky
$DLS_{context}$	Direct Line of Sight to context

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DLS_{blind} Direct Line of Sight to blind; i.e., shading
VOVsky Visible outside view to sky
$VOV_{greenery}$ Visible outside view to greenery
$VOV_{context}$ Visible outside view to context

1. Introduction

In current building standards, the introduction of the WELLv2TM standard is one of the most crucial aspects or additions that aim to enhance occupant health and well-being [1] compared to sustainability rating systems [2]. WELLv2 indicate that many factors could affect occupant subjective well-being in a space such as view quality, thermal comfort, noise impact and daylighting [3]. WELLv2 also recommends that the occupant's ability to interact with the outside view through windows has a psychological impact. This connection with the outside environment can contribute to the comfort and well-being of occupants because the interaction with direct sunlight and natural landscape elements can reduce stress and improve worker performance [3]. View quality as a component of well-being factors in the building rating system is measured based on three metrics related to window design: (i) view access, (ii) view clarity, and (iii) view content [4]. View access is defined as the sight angle to the outside environment; view clarity is defined as the visible transmittance for the window material (tent glaze or shading); and view content is related to how many layers are seen from the outside. Several studies evaluated the outside view quality based on subjective assessments using questionnaires that asked participants to rank photos to different outside views [5–8]; others evaluated view access by running a simulation process to measure sight line ratio to sky view through building opening [9–11]; and yet others assessed view content by ray-tracking occupant sight lines to outside view elements [12] or by rendering photorealistic views of the visible outside environment through windows opening with shades [13].

A new metric was developed by Konstantzos et al. (2015), to measure the view clarity through any fabric shading system [14]. The results indicated that darker fabrics usually scored higher view clarity when they had greater openness or porosity. There are two limitations in this study, the first one is that the study only used fabric shading devices to measure the view clarity, however vertical and horizontal shading systems is the most preferred systems in hot regions [15]. The second limitation is that they developed a metric only measure the view clarity through the shading device without referring to the impact of the visible view content to the outside environment (greenery, sky, context).

In this paper, we tested these missing pieces, assessing the impact of view content and clarity in vertical and horizontal shading design. Interestingly, to the best of the authors' knowledge no method and metric have been found to measure the visible outside view (VOV) content ratio, which refers to the outside view content and clarity ratio (greenery, sky, context) that occupants can see through a window with a shading device installed at the same time.

Multi-criteria approaches take into account the impact of shading systems on daylight availability, visual comfort, and other performance objectives [12,16].

The shading systems can affect not only view quality but are determinant aspects for passive building cooling strategies. Thus, a combined approach taking into account the obscuration of outdoor elements, building energy efficiency and occupants' thermal and visual comfort is needed. Although passive cooling shading is an important consideration it was an element to deal outside the current scope of the research undertaken. Several researchers focused only on assessing daylighting and view access using computational methods [13] considering view access percentage [11], shading device parameters [12], and glare issues [13]. Although these approaches optimize daylight and view quality, only view access and view clarity have been considered [13]. Moreover, existing tools are sometimes too complicated and need the outside environment to be fully built using three-dimensional (3D) modelling software [12], and some tools are not designed to simultaneously optimize between the optimal shading device and view quality.

This paper is structured into six main sections, following this introduction. Section 1 provides a general overview for those who are not deeply involved in the topic through a critical review of the assessment criteria found in building rating systems and standards to measure view quality followed by a critical review of previous research to define the research gap. Section 2 is an explanation of the parametric algorithm method to assess outside view quality (i.e. VOV) by using the image sampler technique. Section 3 provides an analysis of applying the algorithm to different outside view scenes and presents the associated WP. The algorithm is applied to a case

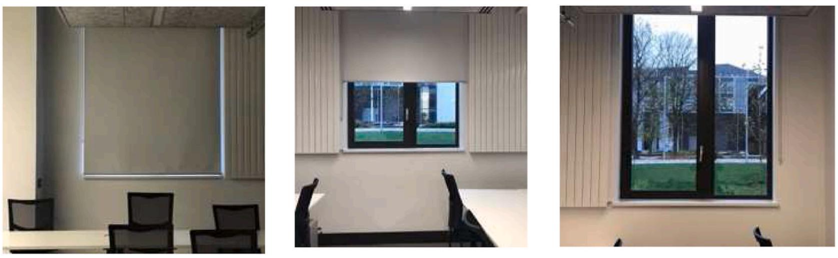

Fig. 1. The impact of view clarity and picture window frame on our sense of connection towards the outside environment. (Hall SEE17 at the new School of Science, Engineering and Environment (SEE) building at University of Salford, UK. Source: Authors.).

study in Egypt, Cairo to test the system process. Outcomes and discussion are presented in Section 4. Section 5 provides the limitation for applying the proposed facilitation tool. The final Section 6 provides a summary of the article, highlights the main knowledge contributions, and provides future research recommendations.

1.1. Picture window and view quality definitions

According to information design researcher Rune Pettersson (1987), 'a picture is a multidimensional representation of an inner or external reality depicting the physical structure of the objects or events they represent' [13]. A picture can be described as a sense of vision and awareness of the stimulation to the eye's vision perception cells by specific content [13]. The term 'picture window' was established by the architectural ornamentor Kent Bloomer, who stated that a picture window and window frame panels could affect our sense of connection towards the outside environment [17]. For example, in traditional window design, occupant view quality is affected by the small grid of many mullions that divides the outside view into frames [17] (Fig. 1). Views can be described as 'what you can see from a particular place' [6]. View quality has three main factors: (i) view access, which is defined as how many views the occupant can see from the viewing position [18]; (ii) view clarity, which refers to how an occupant can see the outside view content clearly [18]; and (iii) view content, which is related to layers found in the outside view such as sky, greenery and context [4].

WHO stated that the natural environment has a direct impact on our health and well-being [18]. In addition, Green and New Evidence and Perspectives for Action (2021) [19] stated that most green spaces have positive effects on overall mental health, quality of life, and subjective well-being. A study conducted by Mourato and MacKerron [19] revealed that over 20,000 self-reported responses from the United Kingdom and overseas participants thought that view quality to nature has a significant and direct impact on occupant well-being and happiness [20]. According to WHO [18] and LEED [21], three factors have been proposed for analysing view quality: view access, view clarity and view content. In the following sections, a critical overview of view quality measurements found in standards and building rating systems is provided for deeper understanding of view quality assessment.

1.2. View quality assessment methods

1.2.1. Methods defined by standards

View quality has been investigated through different building rating systems, such as LEED, WELLv2, and the Building Research Establishment Environmental Assessment Method (BREEAM), and with different standards, such as the Chartered Institution of Building Services Engineers (CIBSE) and the European norm (EN), with given some guidelines and metrics used to measure view quality in a space. CIBSE illustrates three metrics for measuring occupant view quality according to the occupant's position in a space [22]. These three metrics are (i) window-to-wall ratio (WWR), (ii) the distance from the view and (iii) the number of layers received by the occupant, such as sky, landscape and foreground. A score was given to rank the view quality: unacceptable, acceptable, good and excellent.

According to BREEAM [23], a good view quality credit can be achieved when 95 % of the floor space areas fall within 7 m from a window that enables the occupant to view the outside environment. The WWR must be more than 20 % in the open external environment and more than 10 % if there is an external solid block such as surrounding buildings or fences.

ASHRAE [24] along with the International Green Construction Code 2021 [25] state that view quality could be achieved if at least 50 % of the occupied floor area has a direct line of sight (DLS) to the outside environment with 1.07 m above the floor level and 6 m away from the window. Also, for view clarity, the WWR should be more than 7 % of the floor area. In addition, European standard EN 17037 [26] presents a new method to measure the view clarity index for any shading device based on the visible visual contact to the outside in case this shading is installed for the worst scenario. The view clarity index was defined by two metrics: (i) direct visible transmittance (VT, n-n) and (ii) diffuse visible transmittance (VT, n-dif). The EN standard provides a metric to measure the view clarity of different shading systems based on the VT factor, but it does not show the acceptable levels of the VOV content that will be affected by installing the shading system.

In the European standard EN 17037 [26], three general principles have recently been introduced regarding horizontal viewing angle distances and visibility. For view access, the sight-seen angle should be at least 14° and not more than 54° related to the minimum and maximum FOV. In addition, a clear view to the outside within at least 6 m away from the opening window for the view credit score is achieved if at least one of the outdoor layers sky, landscape or ground is visible [21,26].

LEED is the most widely used green building rating system in the world [27]. The definition of a view quality differs between LEED versions 4.0 and 4.1. In version 4.0, a view quality credit could be achieved by two of the three view types that follow (Types 1–3). For view Type 1, a view quality score could be achieved if at least 75 % of the regularly occupied building floor area complied with Type 2 and Type 3 view recommendations. For view Type 2, the design should achieve at least one of these elements: nature/art/urban landmarks, or objects at least 25 feet from the glazing. For view Type 3, credit could be achieved if the unobstructed views are located within a distance of three times the head height of the vision glazing [21].

1.2.2. Methods defined by previous literature studies

View quality could be measured based on some metrics related to view access, view content, and view clarity. Among all these measurements, no tool connects the view clarity and view content to quantify the VOV content received in case the view clarity is affected by any shading system because the greater the view clarity index, the more view content will be received.

Most related studies, standards, and recommendations emphasize view quality research on measuring three factors: view access, view clarity and view content; however, qualitative research studies [4–7,28] confirm that following the recommendations and guidelines does not guarantee the subjective evaluation of the view quality and suggest further research on the impact of installing any kind of shading on view quality that will affect the well-being of occupants. Researchers generally divide view quality research into quantitative measurements and subjective assessments. Quantitative measurements analyse how much view (access, content and clarity) is present. In contrast, subjective assessments evaluate how the view quality is perceived and how it affects occupant satisfaction, perception, cognition and behaviour.

Some researchers used subjective methods to quantify view quality [4–8]. Abboushi et al. [4] investigate daylight and the outside view content to identify the impact of daylight conditions and outside view quality on employee well-being. Their study used a different picture from a different location and 98 full-time employees to assess outside view quality by asking them to rank 12 photographic images of different outside views surrounding the working area according to their preference. After that, a questionnaire was administered to find out what employees prefer to see while sitting in offices on campus, ranging from forest views to urban greenery and street view scenes. The researchers found that workplaces with a natural outside view, such as a forest or urban greenery scene, had a lower sick leave ratio (days per year). Similar to research by Abboushi et al. [4], Matusiak and Klöckner [5] investigate the outside view quality by asking occupants to rank some images of the outside view scenes according to their preferences. A qualitative metric was given to each view: not satisfactory, satisfactory, good and very good. Boubekri et al. [28] conducted a study to illustrate the advantages of a clear view of the outside environment on occupant productivity. Their experiment revealed that outside view quality can enhance occupant well-being by increasing sleep time by 37 min. Their approach was based on a verbal questionnaire to occupants to rank different outside view photographic images in order of preference based on their feelings. In addition, a new study conducted by Ko et al. [6] states that 'the views that windows provide from inside a building affect human health and well-being'. Their study provides a new framework for a conceptual index that can evaluate the quality of a window view by combining the three primary variables: view content, view access and view clarity:

$$View\ quality\ index\ (VQI) = V_{content} \bullet V_{access} \bullet V_{clarity}.$$

Some other researchers used a quantitative approach based on simulation and optimization results to quantify view quality [9–13]. A new method was developed by Hellinga and Hordijk [10] to describe the relationship between daylight and view access through a window by showing the view through a window to the outside environment and referring to the sun's position using the 180-degree equidistant projection technique. A view quality score was calculated by answering a series of questions related to different outside view scenes. Li and Samuelson [8] examined the urban and environmental fields, but they used a new digital method to quantify the outside view content using Cesium platform (version 1.78), Tensorflow (version 2.4) and Python (version 3.6). Their study opened the gate to the wide benefits of analysing view content using digital tools that are considered a missing part in previous research. New research conducted by Pilechiha [29] provided a method of optimizing outside view access with daylight quality received using a multi-optimization simulation technique. The results revealed that several factors should be considered simultaneously when measuring view quality, including view access, view angles, FOV and view depth.

Table 1
View quality evaluation techniques in related studies.

Researcher	Methodology	Method	View quality assessment
Hellinga and Hordijk [10]	Quantitative: simulation		View quality score ranges from 0 to 12 ≥8: high 5–7: medium ≤4: low
Abboushi et al. [4]	Mixed method: experimental (HDR), questioner and survey methods		Subjective assessment to measure: satisfaction with content
Matusiak and Klöckner [5]	Qualitative: questioner and survey methods		Subjective assessment: 1 not satisfactory 2 satisfactory 3 good 4 very good
Boubekri et al. [28]	Qualitative: questioner and survey methods		Subjective assessment to the view clarity
Li and Samuelson [8]	Quantitative/Qualitative: computer-aided design (CAD) tools		Subjective assessment to view content: • 100: undesirable views • 100: undesirable views • 50: remained views
Pilechiha [29]	Quantitative: simulation		View access and view content to the sky
Turan et al. [11]	Quantitative: simulation		Ray-tracking method to all outdoor environment elements; a full 3D model is needed
Ko et al. [6]	Qualitative: questioner and CAD tools		Subjective assessment: view quality index (*VQI*), ranges from 0 to 1
Lin et al. [7]	Qualitative: questioner and CAD tools		Quantitative element analysis, Layer ration % Greenery, sky, building, far objects
Lee and Matusiak [12]	Quantitative: simulation		Rendering images, subjective evaluations to render output; view clarity
Method proposed by authors of the present study (2023)	Quantitative: Image sampler using series of visual scripting analysis		Visible outside view (VOV) content • VOV greenery ratio • VOV context ratio • VOV sky ratio • VOV blind ratio (for shading)

Lin et al. [7] provided a new mixed method for measuring outside view content based on quantifying three different factors: (i) view composition, (ii) horizon layers and (iii) far elements of the landscape to be at a distance of no more than 50 m. Their study used a qualitative approach and asked participants to rank some outside view images according to their preference. Their method was based on desktop analysis using computer-aided design (CAD) software to calculate the view content area in each picture without taking into consideration the shading configuration.

Turan et al. [11] proposed a spatially distributed view access metric for open unobstructed floor plans based on calculations from viewpoints throughout an indoor space. An extensive computer simulation process is required to trace rays to all outside elements; therefore, the outdoor environment needs to be fully built, which will take more time and cost more to be finished and more work is needed to get accurate results. In another study to tackle this issue, Lee and Matusiak [12] proposed a new approach to quantify view quality based on rendering photorealistic views of the outdoors for windows with shades. However, this method seems to be not simple; the results rely on participant opinions to rank the rendered images and rendering virtual images needs the outside environment to be fully built using 3D models (trees, context, ground), same as the method by Turan et al. [11]. Lee and Matusiak [12] also recommend that future research is needed to better understand how shading can affect view quality and discomfort glare, which are related to occupant comfort and WP.

1.3. Research gaps

1.3.1. Gap in method

It is evident in the reviewed literature that outside view content has been measured using quantitate and qualitative methods (Table 1). The review showed that evaluating the outside view content is often based on results of questionnaires that ask participants to rank pictures to different outside views based on their subjective feelings and preferences [5–8,28]. In other cases, an indicator is given to each natural element to assess the quality of outside view content using computational methods [8–12,29]. A few studies provide a qualitative method to measure outside view quality based on ray-tracking simulation methods or rendering photorealistic views [19,20]. Most researchers evaluate view quality by analysing the geometry outside using 2D CAD tools. In our perspective, there are drawbacks to each method; using ray-tracking methods needs the outdoor environment to be fully built in the simulation software, which takes more time and may cause a system crash to run the simulation depending on the machine's capability. Also, the measurement accuracy is still based on the outside build accuracy matching the real environment context, such as tree scale and position and also the surrounding buildings. The recently proposed method by Lee and Matusiak [12] evaluates the outside content based on rendering the internal scene and then evaluates this internal scene by asking participants to rank outside view photos based on their feelings and preferences. In Lee and Matusiak's study [12], rendering photorealistic views replaces the ray-tracking method provided by Turan et al. [11], but both methods have the same drawback related to the time consumed and the level of accuracy needed to build the outside view environment (trees, context, arts, and objects) (Table 1).

To the best of our knowledge, there is no research yet to combine outside view content and clarity in one evaluation process. However view clarity and view content are related to each other as conflicted targets, but most researchers only focus on assessing view quality factors (content, clarity and access) separately. This study produces a new facilitation tool that aims to quantify the outside view quality by combining view content and view clarity in one evaluation process called VOV. The provided tool VOV is inspired by the European standard EN 17037 [26] recommendation about the visible visual contact with the outside.

1.3.2. Gap in application used

There are few applications and software in the market that are designed to be used by engineers and architects to assess view quality. Each application is designed to assess some elements using a different platform. For example, DIAL + software developed by Estia SA [30] is separate software that aims to assess view quality based on the ratio of visible sky area available through the opening window ratio, such as the Integrated Environmental Solutions Virtual Environment (IES VE) [31]. The difference between DIAL+ and IES VE is that DIAL + can optimize between shading parameters and view to sky ratio, and thermal and daylighting levels, but this optimization is limited to application capabilities (Table 2).

The lack of consideration of obstruction elements such as shading devices to outside view may be explained by the difficulty of measuring this factor. Currently, few software in the market, such as ClimateStudio [32] and CoveTools [33], measure view quality according to LEED version 4.01 [21] and EN 17037 [26], with the function to measure blind factor via the visible view access to the outside, but it is not connected to the VOV content (greenery, art, context, sky).

Table 2
Application used to assess daylight and view quality.

Application	Developer	Type	Platform	Elements	Outside view input
DIAL + software	Estia SA	Software	Application	Only sky	Sky ratio
ClimateStudio	Solimane	Plugin	Rhino and Grasshopper plugin and Revit	Greenery, sky, movement, art, landmark	3D modelling
IES VE	IES Ltd	Software	Application	Only sky	3D modelling
Cove.Tool	Covetool Company	Software	Application	Sky, context, unobstructed view	3D modelling
Holistic system	Author	Visual programming scripting workflow	Rhino and Grasshopper plugin	Greenery, sky, art, landmark	Image sampler

2. Definition of visible outside view quality indicator (VOV)

For view quality assessment, a new parametric algorithm workflow is established to measure the connection with the outdoor environment using two metrics: (i) Direst lines of sight (DLS) that presents view access to the outside and (ii) view content by calculating the percentage of FOV of the visible outside view ratio content and clarity through any obscure physical element such as shading device.

To address the challenges mentioned, we introduce a new facilitation tool to quantify the view quality that combines view content (greenery, sky, context) and view clarity (shading system) in one indicator called VOV. This algorithm applying the Image Sampler plugin and Isovist Ray-Tracking technique found in Grasshopper, a cutting-edge parametric modelling tool that works with Rhino software to allow a new powerful and efficient way of designing [34]. This plugin will be used to create a complex series of parametric and mathematical relationships to quantify occupant sight lines through the shading device as a blind element to the outside view content. VOV at any test point is percentage that present the view clarity and view content together taking in consideration the blind factor of shading devices installed as follows: VOV content + clarity (VOV sky, greenery, mass - blind ratio). A parametric analysis between the internal field of view (FOV) and outside view content was performed by importing the outside view image and converting the view content into red, blue, and green (RGB) pixels using the image sample modifier. These pixels were connected with the occupant's FOV and the shading device was defined as a blind element to the outside view clarity. This new tool measure the ray tracking percentage starting from 0 % to 100 % which related to promote the view content quality related to (blue ratio from sky view and green ratio from landscape elements) as a factor of well-being potential (WP) by measuring the overall percentage of VOV content + clarity (VOV sky, greenery, mass − blind ratio) where blind ratio is defined by the pixels obscured by installing a shading device. A two-dimensional (2D) map is provided showing the WP associated with the view quality credit recommended by the Leadership in Energy and Environmental Design (LEED) programme.

The first objective of using this method is to quantify VOV taking into consideration all barriers focusing on shading devices. The proposed a facilitation tool (VOV) combines view access and view content to better evaluate the actual view quality received. The second objective is to create a 2D map showing the WP score by importing an image taken with a phone or camera from a specific position inside the workspace, which can be used to identify the view quality related to test points internally.

2.1. Import image sampler

The basic logic of the image sampler technique in the Grasshopper plugin Rhino software is that the user can load an image into Grasshopper, which then analyses the image in terms of colour, pixel brightness and saturation. The results of the image analysis can be used to perform operations on geometry in Grasshopper. In computer graphics, a sample is an intersection of a channel and a pixel [35]. Fig. 2 depicts a 24-bit pixel, consisting of three samples for red, green and blue related to the outside view content sky, greenery and context.

This method starts with taking panoramic shots of the outside environment from different positions 7 m away from the window, as recommended by LEED [22], WELLv2 [1] and CIBSE to assess view quality [23]. This panoramic view represents the picture frame of the visible outside environment. By using the image sampler method found in the Grasshopper plugin for Rhino software, we can analyse the imported image and convert its content into RGB pixels. A series of complex mathematical analyses occurred to split all pixels into RGB clusters to present the sky, greenery, and context ratio.

2.2. Visual fields

This stage aims to determine the suitable test point location to establish the algorithm (Fig. 3). These test points were created in two levels related to the FOV limitation by EN, LEED, and WELLv2. As shown Section 2.2.1, different rating systems have different requirements for testing view quality. One of these requirements is the distance from the window, which affects the occupant's FOV.

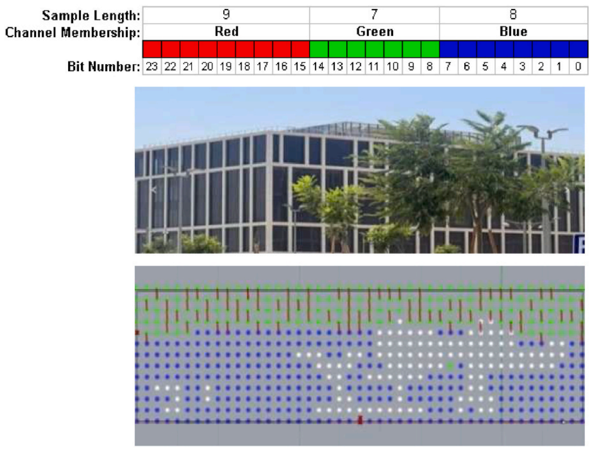

Fig. 2. Image sampler to the outside view scene (commercial building in New Cairo, Egypt).

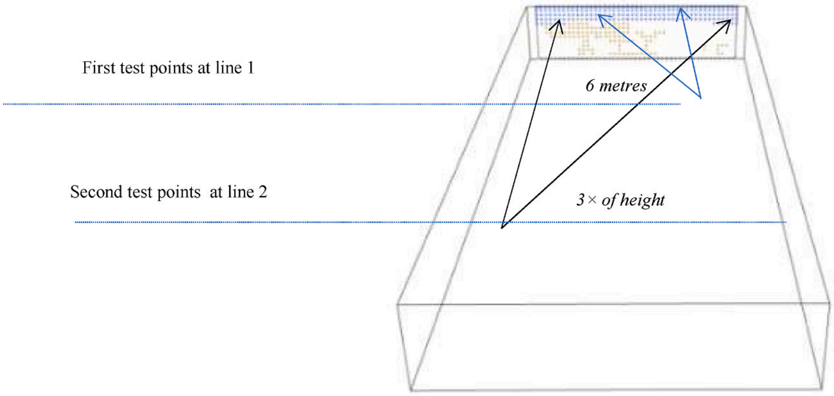

Fig. 3. Demonstrate test-point location.

European daylighting standard EN 17037 and EN 14501 [27,36] states that the sight-seen angle should be at least 14° and not more than 54°, related to the minimum and maximum FOV. In addition, a clear view to the outside within at least 6 m and a maximum of 50 m is related to the standard visual acuity of 25 feet. WELLv2 [1] and LEED [22] state that view Type 3 could be achieved if the unobstructed views are located within a distance of three times the head height of the vision glazing.

To comply with these recommendations, two test point edges are established, the first set of test points away from the window by 6 m and the second set within three times the head height space of the floor space.

2.3. Quantifying DLS

DLS represents two indicators, the first one is related to VOV pixels ($DLS_{greenery}$, DLS_{sky} or $DLS_{context}$) and the second one represents the blinded pixels (DLS_{blind}) in case there is a shading device or anything obscure (Fig. 4). The process of computing the 2D viewing angles is established by using the isovist ray component from Grasshopper. The overall view quality is defined by:

$$VOV = [DLS_{greenery}, DLS_{sky} \text{ or} DLS_{context}] - [DLS_{blind}]$$

2.4. VOV framework

A new parametric design approach was developed in Rhino/Grasshopper to quantify WP associated with the outside view quality. This algorithm consists of the following eight consecutive stages (see Fig. 5).

- *Stage 1*: Import the picture frame image to the algorithm.
- *Stage 2*: Parametric modeling of the case study using Rhino/Grasshopper plugin

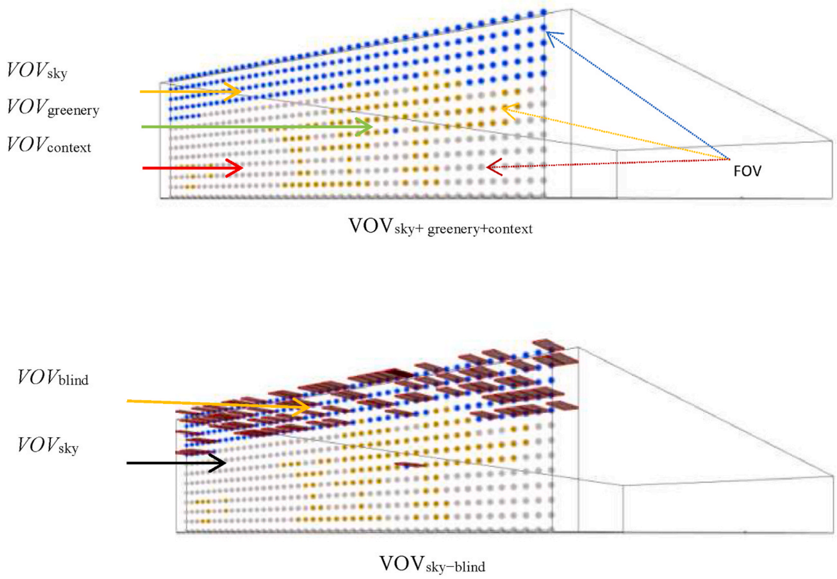

Fig. 4. Defining shading location.

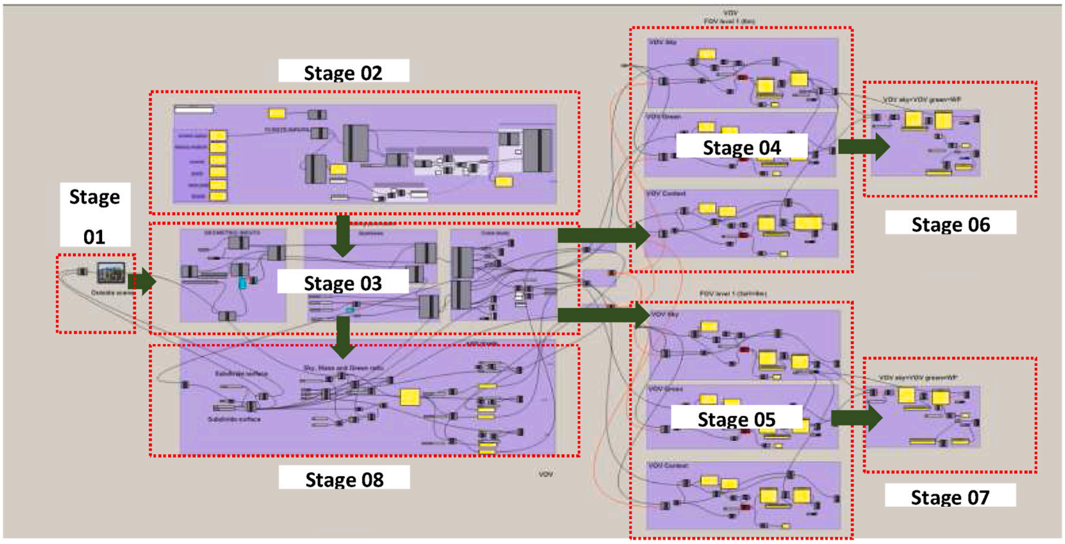

Fig. 5. VOV algorithm stages.

- *Stage 3*: Carry out a parametric analysis of the outside view image by converting its colours to RGB pixels by using the image sampler and isovist ray-tracking technique found in the Grasshopper plugin Rhino software to quantify occupant sight lines through the shading device as a blind element to the outside view content.
- *Stage 4*: Propose a percentage to measure the outside view quality based on the number of sight-seen rays from the test points located in Line 1 (6 m away from the opening) internally.
- *Stage 5*: A proposed a percentage to measure the outside view quality based on the number of sight-seen rays from the test points located in Line 1 (three times clear internal height away from the opening).
- *Stages 6 and 7*: Measure the WP score by counting VOV to natural elements related to the picture content (green pixels for greenery, blue pixels for sky) as follows:

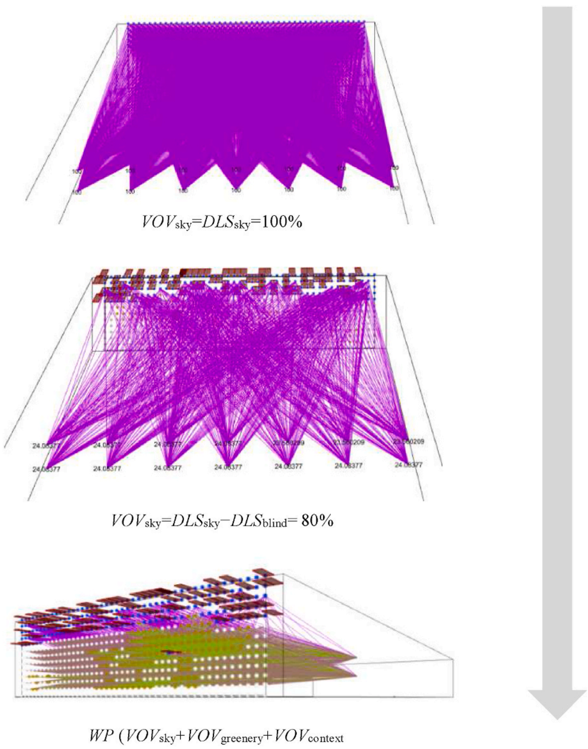

Fig. 6. Defining WP.

$$WP\% = \frac{\sum\left[VOV_{\text{sky}} + VOV_{\text{greenery}}\right]line1 + 2}{2}$$

- *Stage 8*: Test how the proposed algorithm can be integrated with two types of shading systems (vertical and horizontal louvers) that are the most common shading devices used in Egypt. Finally, conduct a comparison between the three models to show the impact of using shading device on visible view content and the view content quality as a factor of well-being potential (WP).

3. Quantifying of WP index

3.1. VOV algorithm

Previous studies have demonstrated that viewing natural elements from a residence or workplace is desirable and therapeutic for human health and well-being by reducing anxiety [36] and stress [37] and increasing creativity [38]. Studies have also shown that outside view content has a direct impact on occupant well-being [39–47]. In the present study, to quantify WP, a parametric algorithm was established to calculate VOV content inside the space by tracing the occupant sight lines to the outside view content; three sets of lines were found related to sky view, greenery view, and context. These sight lines present the occupant's FOV: green rays for natural view, blue rays for sky view and black rays for the outside context (Fig. 6).

A parametric analysis was carried out by importing the outside view image and converting it into RGB pixels using an image sampler. After that, the algorithm connected these pixels with the test points that represent the occupant FOV internally, corresponding to 0.7 m for seating position inside the working space as recommended by LEED [20]. VOV was measured by deducting the pixels used to set the shading device to achieve daylight quality and reduce visual discomfort to be generated in the particular area determined as having a fitness value (sky zone, greenery zone, context zone). This new algorithm evaluate the view quality by giving a percentage showing the WP of test points inside the workspace to measure the overall percentage of VOV as follows (see Fig. 5):

$$VOV_{\text{sky}} = DLS_{\text{sky}} - DLS_{\text{blind}}\%$$

$$VOV_{\text{greenery}} = DLS_{\text{greenery}} - DLS_{\text{blind}}\%$$

$$VOV_{\text{context}} = DLS_{\text{context}} - DLS_{\text{blind}}\%$$

3.2. Wellbeing potential (WP) index

WP index will be identified by measuring the FOV to the outside content related to (blue ratio from sky view and green ratio from landscape elements) as a factor of well-being potential (WP). A set of test points recommended by LEED [20], WELLv2 [1] and EN

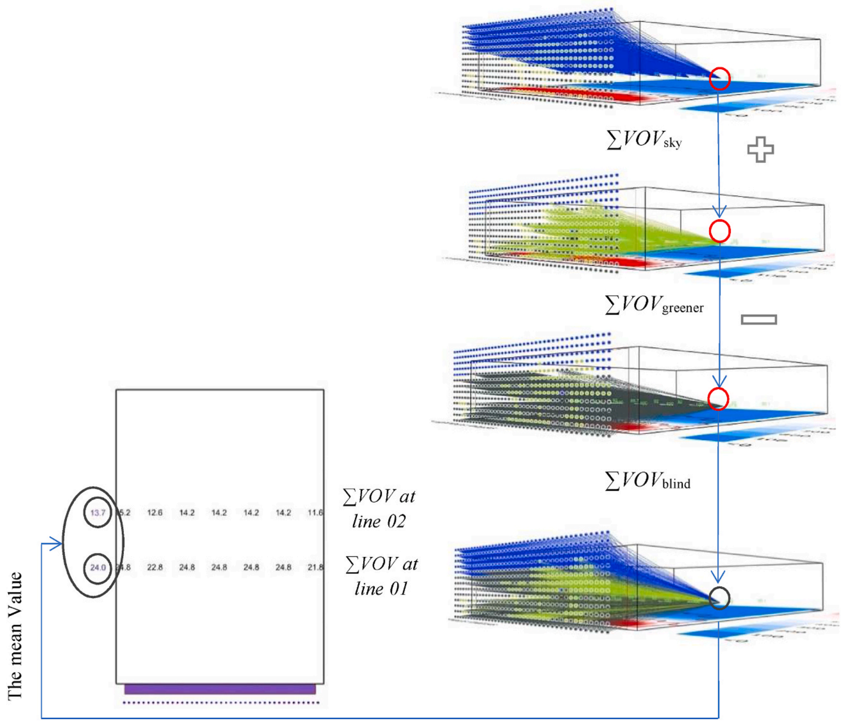

Fig. 7. Defining visible outside view (VOV): blue pixels for sky, green pixels for greenery and black pixels for context.

standards [27,36] were located in two lines (Fig. 3): the first line presents the FOV away from the opening by 6 m, and the second line is located within three times the space head height. A combination of elements in a coherent scene, such as blue from having a sky or sea view and green from the greenery elements that predominate nature scenes, is highly preferred as the elements are therapeutic interventions for human well-being [21,24,25].

To measure the WP score, the mean value of all VOV to natural elements related to the picture content (green pixels for greenery, blue pixels for sky) set in two lines is calculated (Fig. 7). The area with a high VOV percentage and located in the visual comfort zone recommended by LEED, WELLv2 and EN standards will have the most WP.

The WP% equation is defined as follows:

$$WP\% = \frac{\sum\left[VOV_{\text{sky}} + VOV_{\text{greenery}}\right] line1 + 2}{2}$$

3.3. Case study location

The case study location was a multi-storey office building in New Cairo, Egypt, consisting of seven levels with dimensions of 12 m × 8 m × 3 m (Fig. 8). A three-picture window for three levels was taken from inside the space at a distance of 6 m from the façade, as recommended by building rating systems (Fig. 9). To comply with the view quality requirements in rating systems, the glaze is assumed to have visual transmittance of 0.7 to provide a clear image of the exterior, not obstructed by frits, fibres, patterned glazing or added tints that distort colour balance, as recommended by LEED and WELLv2 on view quality. A 3D modelling of the case study location was built in Rhino and then imported into the Grasshopper plugin (Figs. 10 and 11). Our study started by quantifying the VOV score to the base model (clear glass without a shading device). Three views were imported into the algorithm, the first view taken from the first floor, the second view from the third floor and the third view from the fifth floor (Figs. 12–14).

4. Results and discussion

This section presents the results of applying two kind of shading systems on a case study in Egypt to assess view quality and WP. The algorithm proposed using two sets of test points recommended by LEED [22] and WELLv2 [1] to assess view quality; the first test point presented by Line 1 was away from the window by 6 m and the second at a distance of three times the head height space of the floor space (discussed before in Section 3.2, Fig. 3).

Initially, three levels were assessed for comparison – first, third and fifth floors –by taking a panoramic photo of the outside view from the nearest point to the window to have a clear image without any obstructions (Figs. 13–15).

The VOV algorithm analysed the view content by splitting any photo content into three pixels (sky, green and context). By tracing FOV from all the test points to these pixels, the algorithm evaluated the view quality based on the VOV ratio taking into consideration the shading configuration that obscures some area to the outside. In our study, this is called 'VOV blind'. WP is presented as the VOV ratio of sky and green pixels; the greater the ratio, the higher the WP. To find the impact of each shading device on view quality, visible view content ratio and WP ratio are introduced and discussed (Tables 3 and 4).

4.1. VOV

According to the ASHRAE 90.1 standard [25], in this case study the maximum WWR is achieved with the detail of input parameters of the case study dimensions (Fig. 7). The ray-tracking to the outside view and the VOV from Grasshopper are generated to quantify the view content ratio (Fig. 11). The large window size allows sufficient view to the outside but shading devices can obscure the view clarity. Two kinds of shading systems (horizontal and vertical) were tested for the first, third and fifth floor to evaluate the view content and clarity and the WP (Fig. 12). According to LEED [22] and WELLv2 [1], view content can be assessed if at least two of the following are achieved: (i) flora, fauna or sky; (ii) movement; and (iii) objects at least 25 feet from the exterior of the glazing, which is presented

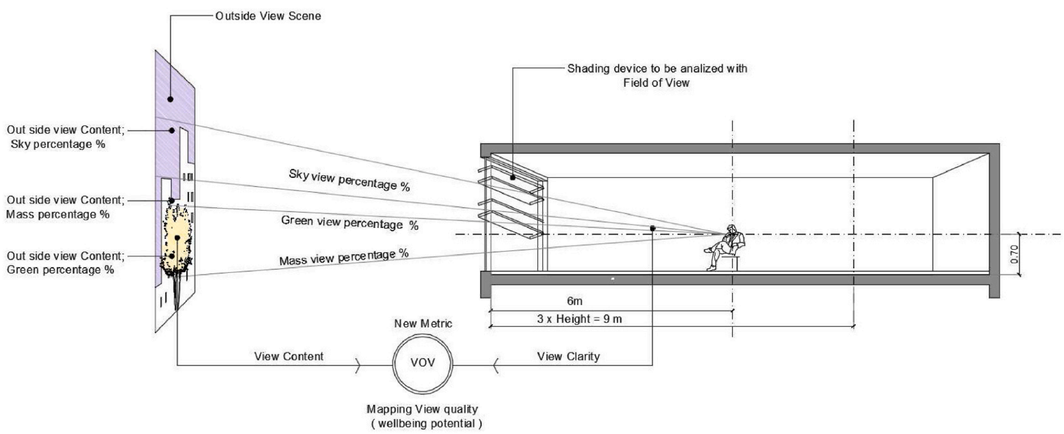

Fig. 8. VOV assessing process.

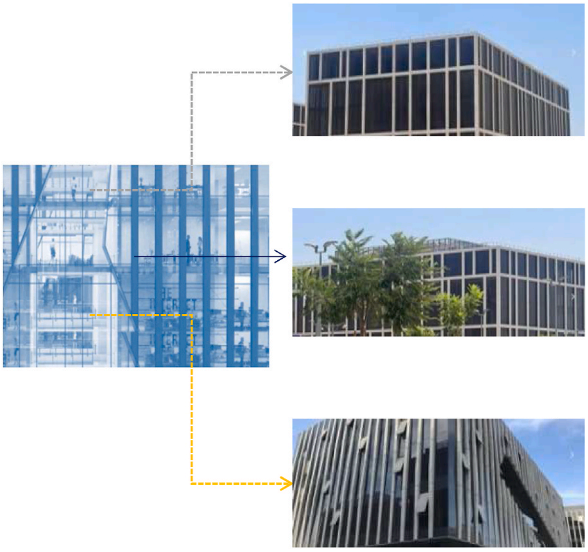

Fig. 9. The outside view photos taken from the first floor, third floor and fifth floor.

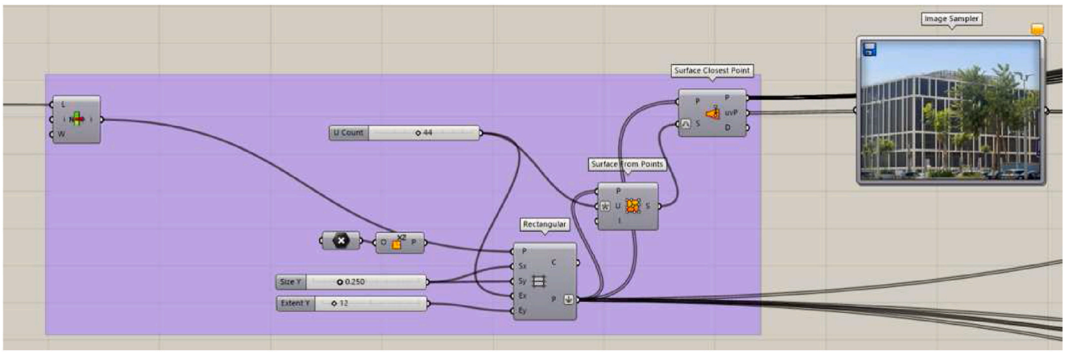

Fig. 10. Insertion of the outside view image to be analysed.

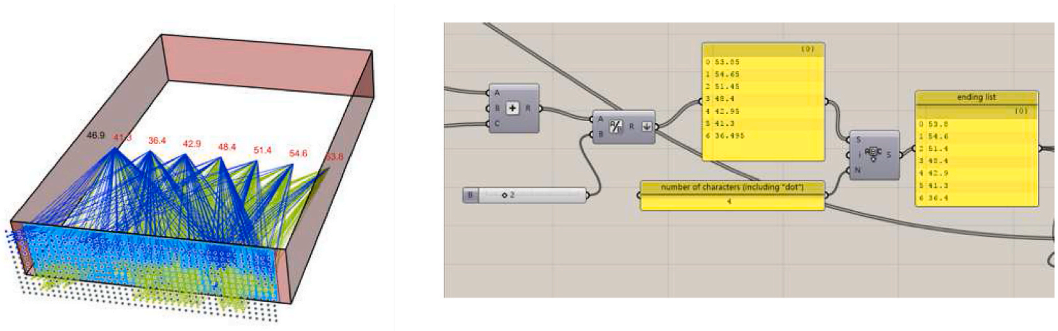

Fig. 11. Defining the sight line percentage for each outside view content (sky, greenery and context).

in our study by test points located in Line 1 (Fig. 3). Regarding view clarity, LEED [20] and WELLv2 [1] also define it by the unobstructed view ratio located within a distance of three times the head height of the vision glazing. View performance in the case study satisfied the recommended value by LEED and WELLv2, as all of the space has view access to the outside without shading devices.

The view content analysis in the case study reveals that at the first floor (i) 90 % of test points at Line 1 are located at a distance of three times the window head height; and (ii) 80 % of multiple lines of sight to vision glazing have at least 90° (Fig. 5). Accordingly, 80 % of the office room has satisfactory view quality without installing any type of shading system since the majority of test points have

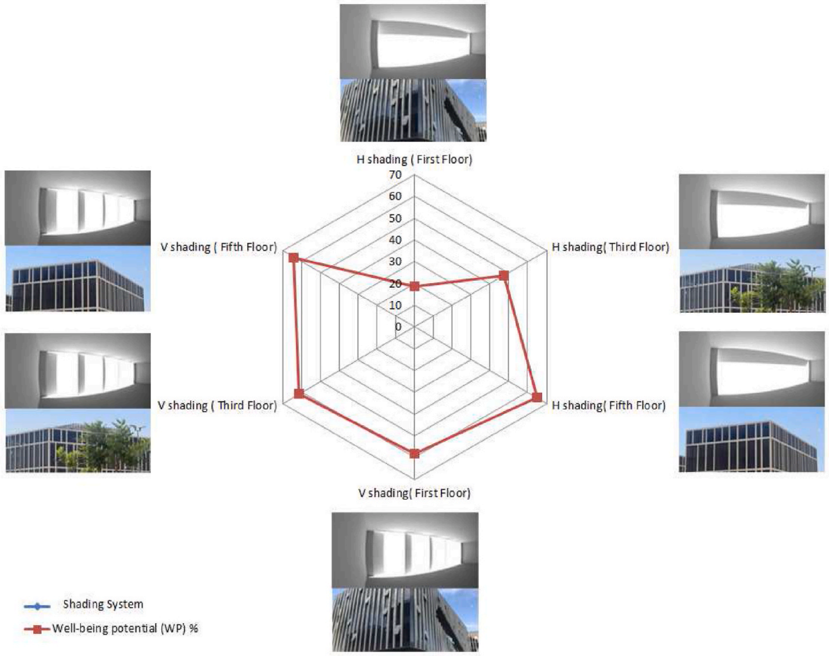

Fig. 12. The impact of horizontal and vertical shading system on well-being potential.

passed two out of three off view quality credit.

As recommended by WELLv2 [1], the views to naturally occurring blue and green colours have a good potential to increase occupant well-being. The horizontal shading system used on the first floor obscures the view to the sky by 38.45 %; therefore, the WP reaches the minimum level of 18.85 % (Fig. 5). The lower levels do not have a clear view to the sky as the higher floors, and also the view to the greenery landscape is greater on the ground floor than on the higher floors. These results demonstrate that shading design strategy should not be the same at all levels. Although shading devices are a preferred strategy for achieving the recommended daylight levels internally, shading needs to be incorporated with the view quality in mind. The VOV algorithm proposed in this study can be used to evaluate the view content and clarity in parallel with a daylight simulation. The best shading devices will be the ones that allow building occupants a well-balanced VOV - lighting condition - energy saving potential in the extreme summer season. Thus, daylighting simulation and the current algorithm need to be implemented with building energy simulation to consider this crucial aspect. This will be the only way to get efficient and sustainable buildings highly connected with the human dimension.

4.2. Improvement in WP

In this section, WP results from quantifying the view content and clarity to the outside view are compared with the objective results of the three levels (first, third and fifth floors) to demonstrate improvement in WP related to the vertical and horizontal shading devices used.

These three views were compared to test the best shading device that gives good view qualities. High values of 0.68 VOV and 0.64 WP were obtained for the fifth floor score by using a horizontal shading device (Fig. 15), whereas the high 0.68 VOV score for the first floor was obtained by using a vertical shading device (Fig. 13). The parametric method presented in this study can integrate with other parametric workflows to create a holistic system by integrating daylight quality, outside view quality and shading system.

The average WP of the studied models is 52.1 % (Fig. 13). This improved to 57.3 % for the first floor by using a vertical shading device rather than a horizontal shading system, because horizontal shading obscures the sky view more than vertical shading.

An improved WP of 12.8 % was noted for the third floor by using a vertical shading device (Fig. 14) because the view to the sky and to the greenery landscape was clear from all the test points. For the fifth floor, WP increased by only 0.8 % when applying the vertical shading system because the sky view pixels ratio was nearly the same as the greenery pixels ratio.

Given the impact of shading design on view quality and daylight internally and the lack of any uniform practical quantitative tool to measure this impact on occupant wellbeing, we believe that the findings presented in our paper will appeal to architect and planning designers and different decision-makers in many sectors that focus on the role of shading system that is considered one of the most preferred strategies to enhance building performance. Most researchers evaluate view quality using qualitative questionnaires or quantitative methods by analyzing the geometry outside using 2D and 3D software. In our perspective, there are drawbacks to each method; wellbeing is a subjective matter and the study needs to be objective to be more scientific; therefore, there is a need for both qualitative and quantitative data. In addition, using ray-tracking methods needs the outdoor environment to be fully built into the simulation software, which takes more time to complete the simulation and iteration process. Although prior research has identified a few methods that could be used in assessing view quality, such as Lee & Matusiak, 2022 and Turan et al., 2021, both methods have the

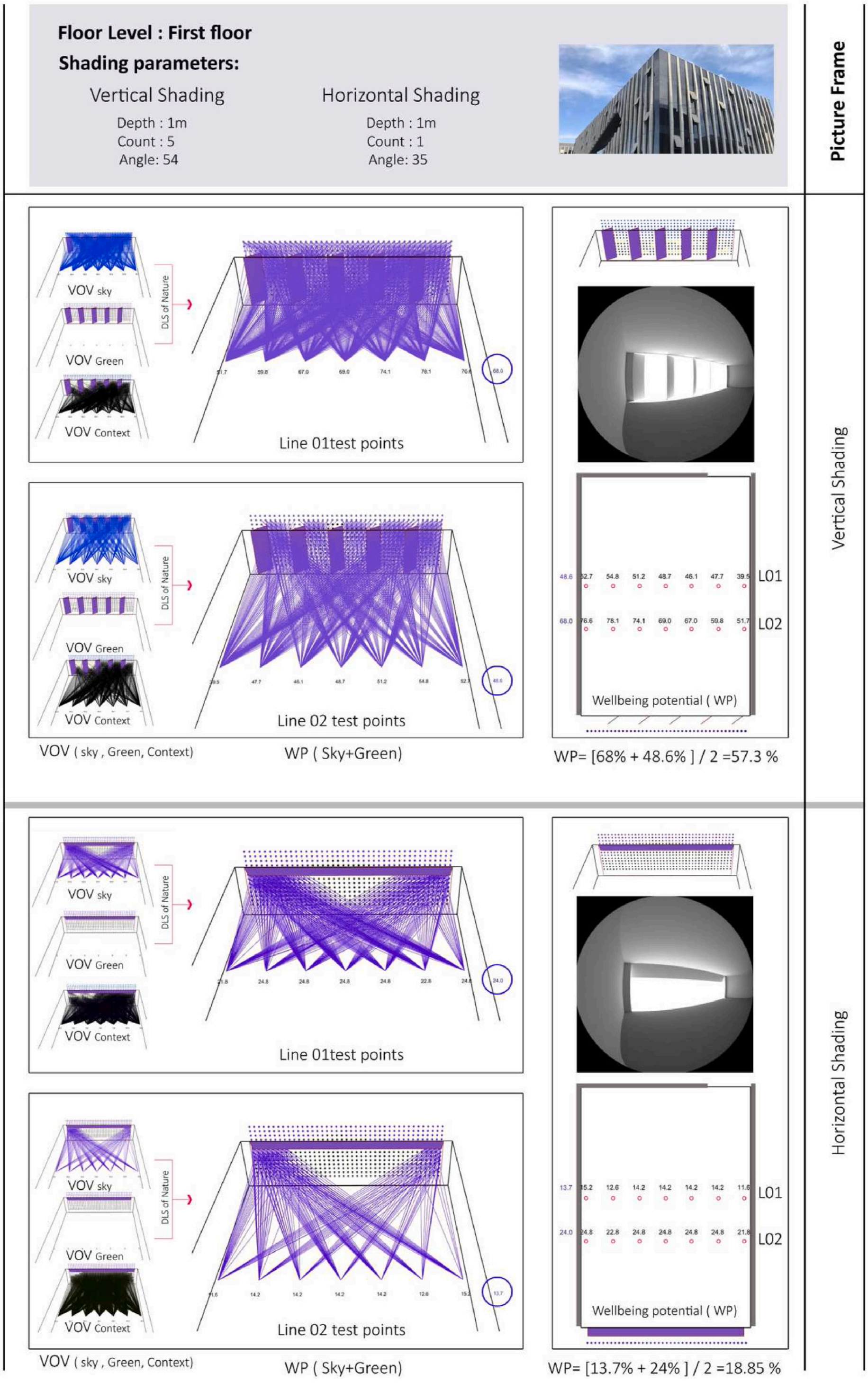

Fig. 13. First floor outside view assessment.

same drawbacks related to the time consumed and the level of accuracy needed to build the outside view environment (trees, buildings, and other objects).

In this paper, we produce a new facilitation tool using an image processing technique to evaluate both view content and clarity and the impact of installing two kinds of shading systems (horizontal and vertical) with indicated parameters for testing. The proposed facilitation tool presented in this paper is considered the missing part for producing more holistic systems that take into consideration

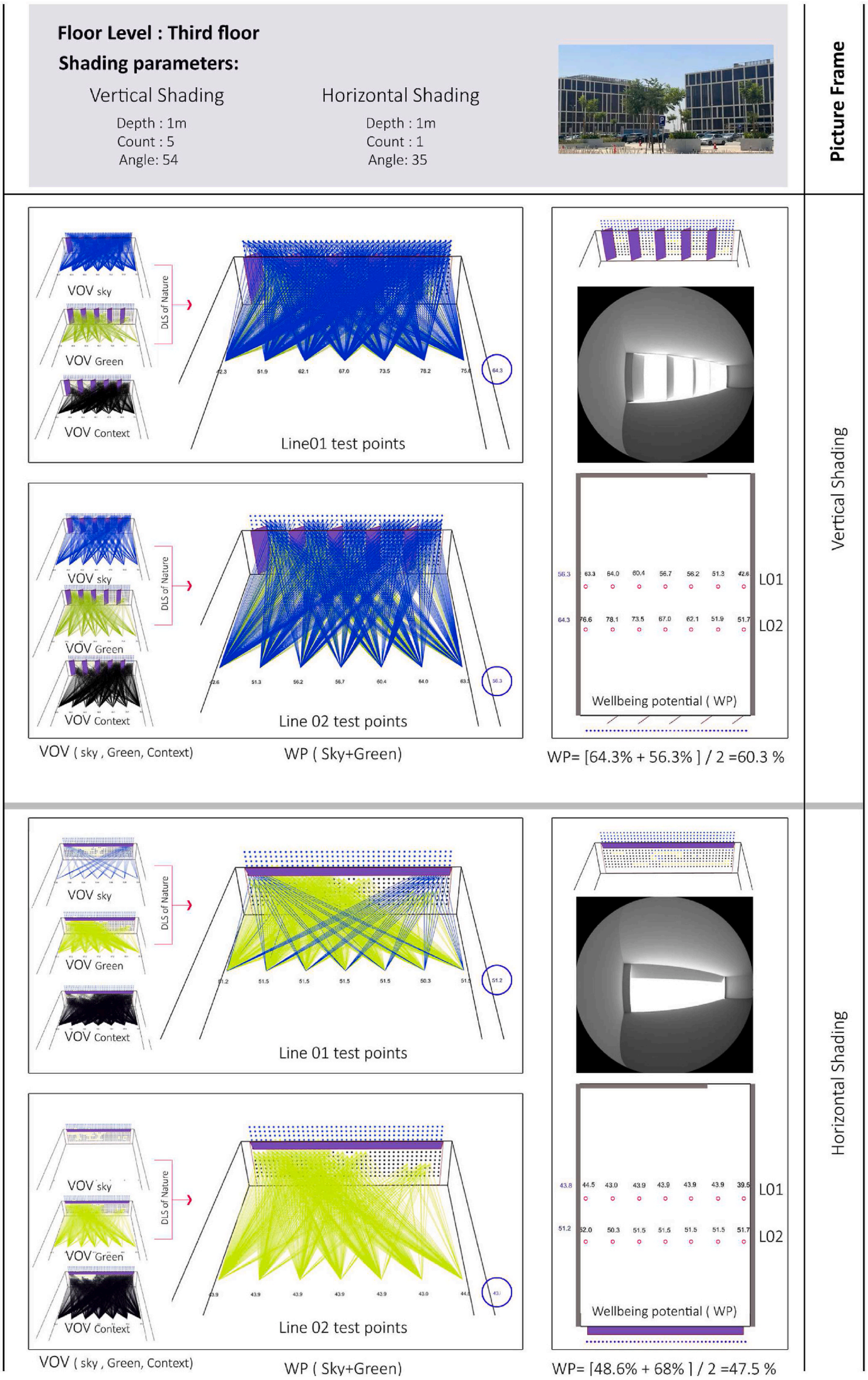

Fig. 14. Third floor outside view assessment.

different objectives such as energy, daylighting and view quality. To our knowledge, this is the first paper to produce a quantitative tool to assess the visible outside view quality VOV using an image processing technique. Therefore, the wellbeing potential indicator WP needs to be validated and correlated with subjective assessment in a real experiment.

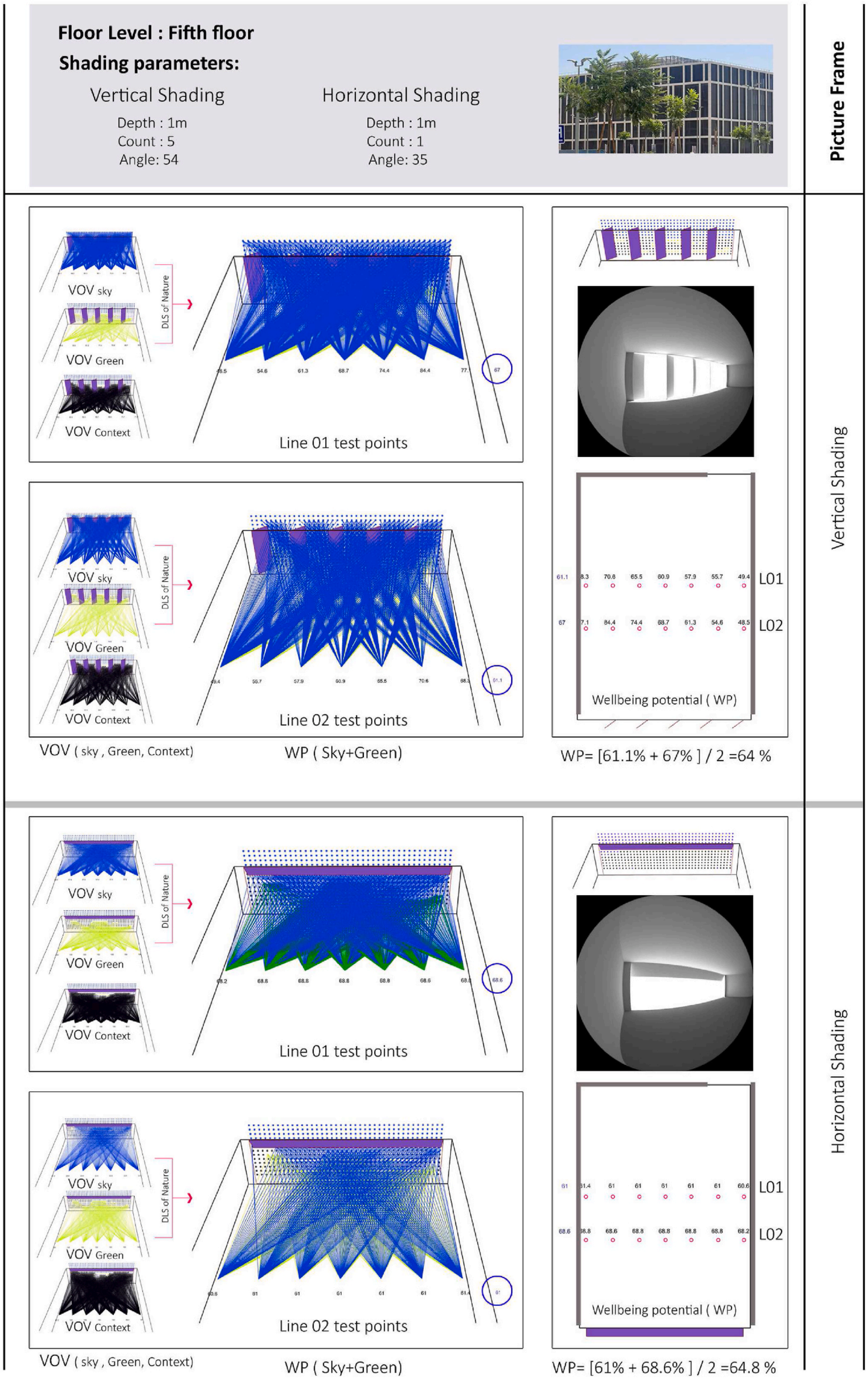

Fig. 15. Fifth floor outside view assessment.

5. Limitations and future work in this study

The method might be miscalculated if the buildings' colour were green or blue. Therefore, the saturation level should be adjusted inside Grasshopper to make sure that the selected pixels are related to only sky and green landscape. In addition, weather and time of day were not considered when selecting static photos. The method proposed can only be used for Venetian blinds, mullions, overhangs, or fins but does not work for roller shades since the openness (holes) is very small and hard to model in Rhino. However, it does provide

Table 3
VOV using the horizontal shading system.

Shading type		Horizontal shading								
Percentage		DLS for test points %							Well-being potential (WP) %	
Test points		T1	T2	T3	T4	T5	T6	T7	VOV	WP total (%)
Picture frame 1	Test line 1 (6 m)	21.8	24.8	24.8	24.8	24.8	22.8	24.8	24.0	18.85
	Test line 2 (3 × h)	11.6	14.2	14.2	14.2	14.2	12.6	15.2	13.7	
Picture frame 2	Test line 1 (6 m)	51.2	51.5	51.5	51.5	51.5	51.3	51.5	51.2	47.5
	Test line2 (3 × h)	43.9	43.9	43.9	43.9	43.9	43.0	44.5	43.8	
Picture frame 3	Test line 1 (6 m)	68.2	68.8	68.8	68.8	68.8	68.6	68.8	68.6	64.8
	Test line 2 (3 × h)	60.6	61	61	61	61	61	61.4	61	

Table 4
VOV using the vertical shading system.

Shading type		Vertical shading								
Percentage		DLS for test points %							Well-being potential (WP) %	
Test point		T1	T2	T3	T4	T5	T6	T7	VOV	WP total (%)
Picture frame 1	Test line 1 (6 m)	51.7	59.8	67.0	69.0	74.1	78.1	76.6	68.0	58.3
	Test line 2 (3 × h)	39.5	47.7	46.1	48.7	51.2	54.8	52.7	48.6	
Picture frame 2	Test line 1 (6 m)	42.3	51.9	62.1	67.0	73.5	78.2	75.6	64.3	61.15
	Test line 2 (3 × h)	42.6	51.3	56.2	56.7	60.4	64.0	63.3	56.3	
Picture frame 3	Test line 1 (6 m)	48.5	54.6	61.3	68.7	74.4	84.4	77.0	67	64
	Test line 2 (3 × h)	49.4	55.7	57.9	60.9	65.5	70.6	68.3	61.1	

views of the outdoors but it will minimise the view clarity. This study applied LEED assessment criteria, which states that view glazing should provide a clear image of the outside environment. Therefore the study was limited to use only clear glass and not working with the transparent blinds and small meshes which takes more time and may cause a system crash to run the iteration.

In the proposed tool, the view content quality as a factor of well-being potential (WP) obtained from sky and vegetation is considered the sum of all VOV to sky and greenery without any consideration of the impact of sky and greenery separately. As stated by LEED: "The design should achieve at least one of these elements: nature/art/urban landmarks". According to WELLv2TM "The number of layers received by the occupant, such as sky, landscape and foreground. A score was given to rank the view quality: unacceptable, acceptable, good and excellent". In addition, the European standard EN 17037 stated that "the view credit score is achieved if at least one of the outdoor layers sky, landscape or ground is visible". Therefore, the proposed tool takes the overall percentage of VOVsky and greenery. In future work, there is a need to establish a real experiment to compare both WPsky and WPgreenery measured by the proposed tool and participants' satisfaction level to the outside view content to quantify the impact of the sky view and greenery view separately.

The concept of Wellbeing is a subjective matter widely used in psychology to describe a sphere of feelings that refers to what is intrinsically valuable to an individual. In this paper, WP % could be an objective measure based on the visible outside view VOV percentage that occupants can see from inside a space taking into consideration the blind factor of the shading system that could obscure the view quality. To validate the proposed indicator, a real experiment is needed to involve the human factor in the workflow process to understand the correlation between the quantitative and qualitative results regarding the occupants' subjective perception of the view quality. However, real case studies are not feasible due to time and cost-consuming research activities and they did not allow for evaluation in the early design stages that are needed to design efficient and supportive buildings. Thus, a preliminary assessment of occupants' perception is needed in the future using Virtual Reality and Immersive Virtual Environments, starting from the 3D model.

6. Conclusion

This study provides a new facilitation tool to evaluate the impact of installing vertical and horizontal shading systems on visible outside view contents that could improve the well-being (WP) potential inside the working environment. Several studies indicate that sky and greenery view to the outside environment significantly to occupants' health and well-being. Recent research on view quality has focused on quantifying the outside view content using questionnaires to rank some images to the outside view based on occupant preferences and feelings. Other techniques use the computational ray-tracking method, which needs the outside context to be fully built in three dimensions with a sufficient level of accuracy to match the real environment context in scale and position. Little attention has been given to the impact of shading devices on the view quality and how it can contribute to WP.

A new algorithm is proposed in the current study using an image processing technique to evaluate both view content and clarity and the impact of installing two kinds of shading systems (horizontal and vertical) with indicated parameters for testing. This study provides a new facilitation tool for evaluating WP by quantifying the overall ratio to VOV content (VOV sky %, VOV greenery %) to all test points shown, as recommended by LEED [20] and WELLv2 [1]. These test points are located in two lines (Fig. 3). A new formula is produced to measure the mean value of WP for the space:

$$WP\% \frac{[VOV_{\text{sky}} + VOV_{\text{greenery}}]}{2}$$

The proposed algorithm was tested on a case study location in Egypt, Cairo. The results demonstrate that designing shading devices considering the view to natural elements (sky and greenery) positively affects WP. Therefore, building orientation is very important at the primary design stages has a significant impact on the ratio of natural elements and how many layers can be seen from windows.

The proposed algorithm can be integrated into a holistic system to achieve more sustainable shading devices. It could investigate the possibilities of using different shading system parameters to compromise between different objectives such as; daylight quality, energy consumption and view quality. In addition, this approach could be used to determine building shape positioning and the priority of creating views as part of urban master plan development.

Corresponding credit author roles

Mohamed Abdelrahman: Conceptualization, Methodology/Study design, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization.

Paul Coates: Writing – review and editing, Supervision.

Tanja Poppelreuter: Writing – review and editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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