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Harnessing biophilia to design magnetic office landscapes – A case study

Behnaz Avazpour[a*], Dorsa Fatourehchi [b], Christhina Candido[b], Iva Durakovic[a], Samin Marzban[c] and Jordan Smith[b]

[a]*School of Built Environment, Faculty of Art Design and Architecture, University of New South Wales, Sydney, NSW, Australia.*
[b]*Melbourne School of Design, Faculty of Architecture, Building and Planning, The University of Melbourne, Melbourne, VIC, Australia.*
[c]*School of Civil, Mining, Environmental and Architectural Engineering, Faculty of Engineering and Information Sciences, University of Wollongong, Northfields Ave, North Wollongong NSW 2500 Australia.*
** Corresponding author contact details: b.avazpour@unsw.edu.au*

ABSTRACT

The importance of a connection with nature has been recognized to boost workers' satisfaction and productivity. Providing data about spaces people want to be in within an office is so important, particularly in the post-COVID era to bring back workers to the workplaces. This can attract talents in the competitive job market while they are looking for flexible offices to accommodate various activities, and positively support their health and wellbeing. This study aims to explore the value of biophilic design (BD) in attracting workers to the workplace, increasing employees' satisfaction with space, and investigate its potential to inform future workplace design. The Space/Nature Syntax and lighting analysis, combined with observation, and computational image analysis with python is used to analyse the workplace's spatial configuration and identify design elements that enhance user experience and encourage interaction with nature and natural light. According to the findings, BD can boost space utilization by catering to employees' needs and increase their satisfaction with their working environment. The results of this study have implications for architects, designers, and policymakers interested in creating workplaces that are attractive for workers, and more likely to enhance their sense of wellbeing and productivity in office.

Keywords: Biophilic design; workplace; office utilization; health

INTRODUCTION

Biophilic design (BD) aims to create environments that connect people to nature, thereby supporting human health and wellbeing (Kellert & Calabrese, 2015a).Research has shown that by incorporating elements of nature into interior spaces, BD can help to reduce stress, enhance creativity, and improve cognitive function (Yin et al., 2020; Yin et al, 2019), whilst promoting

a higher quality of spaces and creating aesthetically pleasant environments (Kellert, et al., 2011; Kellert & Calabrese, 2015b; Ryan et al., 2014). The uptake of BD principles in workplaces has increased over time and there is a growing body of research that supports the positive effects of BD on workers' wellbeing (Yin et al., 2020; Yin et al, 2019), mental health (Alhammadi & Amer, 2022; Gritzka et al., 2020), productivity (Hähn, et al., 2021; Lohr et al., 1996; Khan et al. 2005; Nieuwenhuis et al., 2014) job satisfaction (Gray & Birrell, 2014; Marsh & French, 2020; Voordt & Jensen, 2023) and satisfaction in general (Lei et al., 2021; Hähn et al., 2021.

BD contributes to enhancing Indoor Environmental Quality (IEQ) from the adoption of natural materials and indoor planting, access to natural light and views of nature (Moya et al., 2019; Sanchez, Ikaga, & Sanchez, 2018; US-EPA, 2003). According to Kellert et al. (2011), the essential criteria for biophilic design initiatives include access to natural light, outdoor views, and the incorporation of natural elements such as plants, water features, and materials that mimic nature (such as wood and stone). Spence (2020) also indicated that the design should promote sensory experiences that engage our senses encouraging a connection to nature at multiple levels. Azizah et al. (2025) highlight the impactful role of BD in providing flexibility and adaptability to accommodate a range of activities, ensuring that the space enhances both individual and collaborative work. A study by Wallmann-Sperlich et al., (2019) clearly demonstrates the impact "active" biophilic-designed surroundings can have on the use of space and increase in physical activity. Further, there is also evidence about the potential of biophilia when designing spaces that can cater the diverse needs and preferences of workers, whilst enhancing wellbeing and productivity in the workplace (Appel-Meulenbroek et al., 2022; Maltseva et al., 2023). By embedding these criteria into workplace design, the BD initiative supports the overarching goals of enhancing worker wellbeing and optimizing space utilization.

Organizations have been leveraging design in general as a way of providing people with spaces that aligns with the needs of their employees that they want to work in (Elsbach & Bechky, 2007; Earle, 2003). Design of workplaces includes a wide array of elements, including office layout, interior design, ergonomic considerations, and the integration of cutting-edge technology, greenery and natural elements. These factors are used to create environments that enhance comfort, collaboration, and productivity. Post-pandemic, this is even more important considering low utilization levels. The COVID pandemic has caused seismic adjustments to the mindset of knowledge workers regarding where, when and how they could work resulting in positive impacts on work-life balance and wellbeing in terms of flexibility (Marzban et al., 2021; Marzban et al., 2022) and negative impacts on mental health (Majumdar et al., 2020; Neilson, 2020, Westfall, 2020), isolation and overall connection with co-workers and teams (Durakovic et al., 2023; Gensler, 2020; Marzban et al., 2021). There is a renewed sense of understanding how space can be strategically (re)positioned and leveraged in the new workplace landscape where utilization continues to remain stubbornly low. According to the Reserve Bank of Australia (RBA) (2021), office occupancy rates have generally increased in line with decreasing social restrictions and transmission risk. However, occupancy rates

have remained 10–30 per cent below pre-pandemic levels. The shift toward hybrid ways of working has led to lower occupancy rates in offices (Hutson & Orlando, 2023) which urges revisiting the configuration and utilization of workplaces. This change has financial implications for organizations including the uptake of technological solutions for space monitoring and management, seamless connectivity and reconfiguration of office fit-outs that can properly support the evolving digital and physical ways of working (Ancillo et al., 2021; Maltseva et al., 2023; Pinnington & Ayoko, 2021). In this context, there is growing demand to understand why some workplaces seem to do better in terms of utilization and to use an evidence-based approach when remediating issues.

BD as an approach to enhance use of space and also contribute to improved well-being, reduced stress, and heightened creativity among employees has been recognized (Gray, 2017; Gritzka et al., 2020; Sanchez et al., 2020). But hard evidence quantifying by how much people will prefer to choose a location within a workplace over other where BD principles are not implemented is not clear. There are studies and reports on the impact of design of offices and use of natural elements such as lighting on employees' choice of companies. According to the Human Spaces global study report (Cooper, 2013), which surveyed 7,600 office workers across 16 countries, one-third (33%) of the workers indicated that the design of an office would impact their decision to work at a company. The "Employee Experience" survey of 1,614 North American office employees indicated that access to natural light and views of the outdoors are the first factors of a workplace environments, outranking other facilities, such as onsite cafeterias and fitness centres, and onsite childcare (Future Workplace, 2018). While it is widely believed that employees are more inclined to choose workspaces that embrace these principles over those that do not, quantifying this preference in concrete terms has proven elusive. This gap in knowledge is a challenge for organizations aiming to enhance the quality of their workplaces after COVID. Without a robust data to support the benefits of BD, there is a level of uncertainty for the decision makers to allocate resources in shaping workplaces. Thus, there is a need to provide some methods of measuring the impact of BD on employees' health and wellbeing and their satisfaction to attract them to their workplaces. This case study provides valuable insights into the types and qualities of space that might be preferential to workers to use when they are in office, as well as the types of activities, configurations and design elements best suited to achieving a new alignment between workplace environments and ways of working that are attractive to workers. The paper contributes to this conversation by demonstrating the value BD can add to fit-outs from a utilization of space perspective. The potential of BD to enhance workplace desirability is promising but not yet definitively quantified. This paper aims to measure the impact of BD within workplaces by quantifying the extent to which BD elements are integrated into the space and the utilization of the space. The outcomes of this paper can be utilized by organizations to make informed decisions regarding the allocation of resources for the design and integration of natural elements within their workplaces.

METHOD

This paper presents results from a case study workplace located in Melbourne. The building holds a 6-star Green Star rating, and the workplace aims to achieve WELL Platinum rating. The studied floors host one tenant and the space features three main types of spaces: individual offices, an open-plan area with assigned seating and landscaped open plan area with non-assigned seating designed to support a variety of activities (Figure 1). The landscaped office area is used by residents and non-residents of the tenancy, providing people with several zones they can choose to work from that suit and support their task at hand. Figure 1 shows typical zoning of a floor in the case study.

As the nature of the work and the different types of users can influence preferences for office layouts and the selection of suitable work environments, this selected case study hosts a diverse range of users, including academics and practitioners from various fields such as IT, architecture, and engineering. This diversity in users provides a broad context for examining the impact of BD across different professional environments.

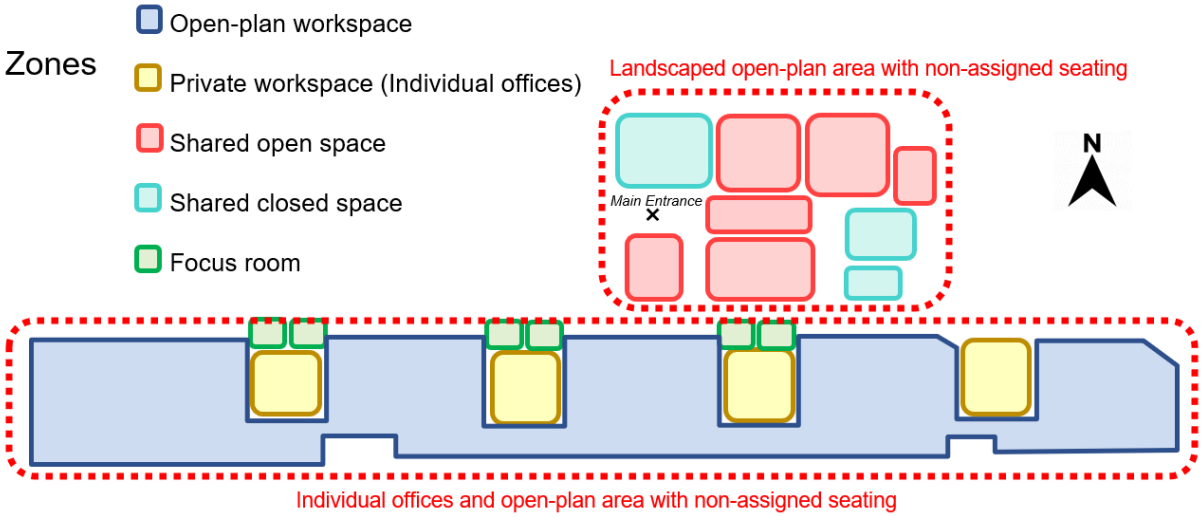


Figure 1. Typical work zones observed in a studied floor.

Site visit and observation

The site visit was used to understand the fit-out and base building provisions, use of space, access to views, greenery and furnishings. The site observation was then used to check results from the Space/Nature Syntax analysis. Site observations were conducted over two weeks between 1 Sep and 14 Sep 2022. The observation process was carried out twice during the day (Morning: 10:00~12:00 and Afternoon: 14:00~16:00) to understand how people use and engage with the non-assigned workspace area.

Space/Nature Syntax Analysis

Space/Nature Syntax is a design methodology that can be used to understand the relationship between space and nature (Hillier, 2007). By combining Space/Nature Syntax, the study aimed to gain a comprehensive understanding of the potential utilization of the studied workspaces and their relationship with BD elements. The Depthmap software was used for all analysis.

Space Syntax analysis uses a range of metrics and analysis techniques to explore the spatial properties of a built environment which could be relevant to understanding the potential for different activities in interior spaces (Penn & Turner, 2002). In this study, three Space Syntax variables were used to examine the possibility of workspaces to attract occupants to choose various activities based on the spatial layout – "Visual integration and connectivity", "Step depth", and "Agent-based simulation" (Table 1).

The first variable analysed, using visibility graph analysis, was the visual integration of the workspaces. According to Hillier (2007), this variable measures the visual distance from all spaces to others, while "connectivity" measures how connected a particular space is to other spaces in the environment (Hillier and Hanson 1984). Based on connectivity, the accessibility and possibility of a space to accommodate different types of activities can be shown. Spaces with high integration and connectivity values are typically more visible and accessible to other spaces and more conducive to utilization. The higher the values, the more likely a space is to attract occupants. On the other hand, spaces with low visual integration and connectivity are assumed to be underutilized based on their location and layout (Hillier, 2007).

The second variable analysed was "Step depth", which measures how far a particular space is from the main circulation paths or entry points in the environment (Turner, 2004). Spaces closer to these points may be more likely to attract workers, as they are more easily accessible. Therefore, spaces with a higher depth value could be directly proportional to the higher tendency of meeting and movement of people. It is worth noting that although both "Visual integration and connectivity" and "Step depth" are related to connectivity within space syntax analysis, they represent distinct concepts and measure different aspects of spatial configuration. The former focuses on the visual integration analysis, which assesses the degree to which a space is visually connected to other spaces within a given environment. It considers factors such as direct lines of sight and visibility between different locations, indicating the potential for spontaneous interactions and movement between spaces. The latter, evaluates the convex map analysis within space syntax, measuring the cumulative depth of steps required to access a location from all other locations within the environment. This variable reflects the ease of movement and accessibility between different points, considering the network of pathways and connections present in the spatial layout. Therefore, this research considered both variables to have a comprehensive evaluation of spatial configuration.

The third variable, "Agent-based Simulation", modelled occupant's individual movement behaviour in which agents choose their movement direction based on VGA values/scores. According to Penn and Turner (2002), agents were distributed into spaces of the environment and navigated using the visibility information directly available to them through the visibility graph. By default, Depthmap software displays the variable values with a colour scale from a blue-tinged magenta (lowest value) to light blue, green and yellow and up to a red-tinged magenta (highest value). The scale is continuous, with a value assigned to different colours.

Table 1. Space Syntax variables and the parameters to measure them.

Variable	Parameter	Relationship
Visual integration and connectivity	Visual graphic analysis (VGA)	The higher the value of integration of a space, the greater the tendency for unplanned activities (spontaneous activity) The higher the value of depth, the higher the value of space connections to be directly proportional to the tendency of meeting and the movement of people.
Step depth	Convex map analysis	Spaces that are closer to these points may be more likely to attract workers for unplanned activities, as they are more easily accessible.
Agent-based simulation	Visual graphic analysis (VGA)	Agents have access to pre-computed information about what is visible from any given location on the map.

The Nature Syntax methodology (Munro and Grierson 2016) was employed to assess the visual connection between the workspaces and nature. This approach aimed to evaluate the impact of biophilic elements on the utilization and behaviours of occupants in different task-based work settings throughout the workplace, in addition to considering their spatial configuration.

As an element of Nature Syntax, permeability calculation was used to indicate how visually permeable each space was. The parameter of *Visual Permeability* was calculated based on the equation below (Eq. 1).

$$VisualPermeability = (Total\ permeable\ surface\ area)/(total\ surface\ area)/100$$

Eq. 1

Where, the *Total Permeable Area* is the area of the openings on one side and the *Total Area* is the total wall area that contains the opening on that side. Permeability value shows the area of building envelop of a space that is visually connected to outdoor areas through windows. Permeability value ranges from 0 to 1. If the space is completely segregated from the outside the value is 0, whereas the value of 1 indicated the complete connection of a space to outdoors from all sides. To calculate the permeability, the AutoCAD drawings were used.

Computational Image Analysis

To quantitatively assess the presence of BD elements in studied spaces, this research employed computational image analysis techniques. Specifically, this study utilized the python programming language and associated libraries, such as OpenCV (Bradski, 2000) and NumPy (Harris et al., 2020) libraries to extract specific BD colours. The solution was customized based on the standard techniques for this research. This process allowed this study to derive an objective measure of design element prevalence. In terms of the approach, the raw images of workspaces were processed to enhance their quality and ensure consistency across the dataset. Through this approach, this study aimed to provide an objective measure of the prevalence of their impact on attracting workers. At the first step, the image was converted from BGR to RGB format to ensure compatibility with the analysis. Subsequently, masks were defined for each natural colour of interest, including green, blue, brown, and grey. These masks consisted of white pixels where the target colours were detected, effectively filtering the image data to extract relevant information and extract the percentage of indoor space containing the natural colours. The mechanism of using masks as filters for RGB images involved isolating specific colours associated with BD elements. This study utilized the OpenCV and NumPy libraries within Python programming language to implement this process. The pixels were calculated and printed as percentages as shown in Figure 2.

The selection of green, blue, brown, and grey colours for analysis was informed by the principles of biophilic design, which emphasize the integration of natural elements into built environments to enhance occupant well-being. These colours were chosen based on their relevance to common biophilic elements found in office spaces, such as vegetation, water features, wooden surfaces, and stone materials. By focusing on these colours, this study aimed to quantify the prevalence of biophilic elements within the studies workspaces and assess their potential impact on occupant satisfaction and productivity.

In this process, the different thresholds are considered when using masks. By changing the threshold value, it is possible to control which pixels are included in the mask, affecting the analysis results as there are various colours that need to be detected accurately. For green and blue colours, the lower and upper bounds were defined in the HSV colour space, while for grey and brown, the bounds were defined in the RGB colour space. In HSV green colour's bound is typically around (40, 40, 40) for lower and (70, 255, 255) for upper bound. While blue colour's lower and upper bounds are (90, 50, 50) and (130, 255, 255), respectively in HSV space. In RGB colour space, grey colour has lower bound of (100, 100, 100) and upper bound of (200, 200, 200) For brown colour the lower and upper bounds are (100, 50, 0) and (200, 150, 100), respectively.

Figure 2. Examples of BD elements analysis of the case study. Brown mask: natural material, green mask: greenery, grey mask: natural colour, blue mask: view to outdoor.

It is worth mentioning that for consistency and the constraints of the indoor environment, single perspective images were used to analyse the colours in this research. Moreover, to determine the location for capturing images, the insights from agent-based modelling simulation of space syntax were leveraged as the simulation identified the most frequently used spaces within indoor environment. Therefore, the selected spaces served as focal points for human activity and interaction, making them ideal for capturing representative images of biophilic design elements. Additionally, the camera height was aligned with standard human eye level, providing a perspective that reflects the typical experience of occupants within the space.

Lighting Analysis

As mentioned earlier, access to natural light can have a positive impact on workers, enhancing their satisfaction with their workspaces. In this case study, one of the main BD attributes is the amount of daylight in the interior spaces. To further explore this aspect, the study employed in-built lighting analysis using Revit to simulate the availability of natural light in the workspaces. The analysis was conducted for the date of observation across the duration of entire day from sunrise to sunset. The simulation used sun positions based on the specific date and geographical location of the building. Daylight Factor and Illuminance analysis were utilized to investigate the effectiveness of the layout in harnessing natural light in the workspace. Finally, the results of the observation and software analysis were compared to identify differences and similarities through a more quantitative approach. Overall, the implemented method is included in Figure 3 below.

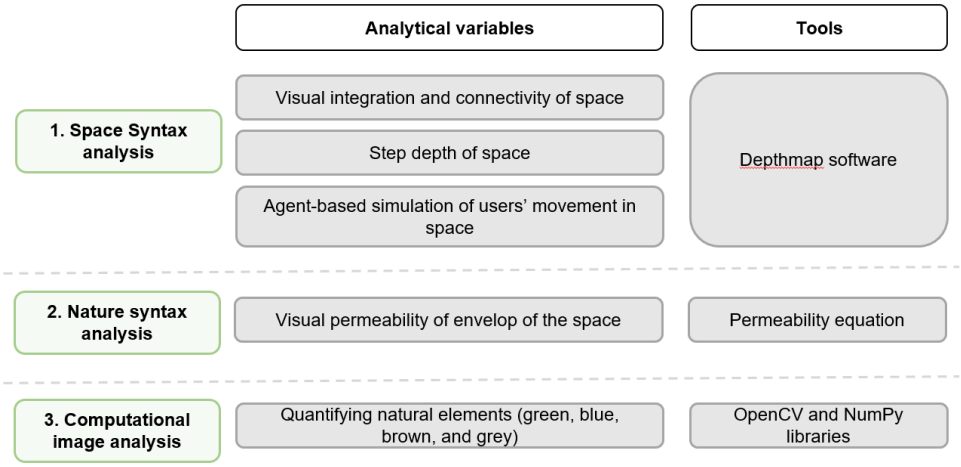


Figure 3. Summary of tools and variables for data analysis.

RESULTS AND DISCUSSION

BD Considerations observed in the fit-out

The analysis of the case study using Space/Nature Syntax and observation revealed that the spaces utilized by people incorporate BD elements. These elements include a view of nature, access to natural light, visual integration, easy access to main circulation paths or entry points, and the use of plants. These spaces not only support the intended activities but also encourage a diverse range of activities. Some BD elements that are particularly relevant for attracting workers for different activities in the workspace can be found in Table 2. On the other hand, the underutilized spaces identified in the case study were primarily characterized by a lack of access to natural lighting and nature, lack of natural materials, as well as uncomfortable furniture. For instance, the shared open space (Figure 2) might discourage workers from utilizing the space for extended periods or engaging in unscheduled activities. The lack of BD attributes as well as the presence of long fixed tables in a hallway-like layout with a door being

constantly open and closed for getting access to the floor might not effectively support the diverse needs of workers.

Table 2. Biophilic design attributes and data collection approach for each attribute (Klotz & Bolino, 2021; Zhong et al., 2022; Peters & D'Penna, 2020; Yaseen & Mustafa, 2023).

Attributes	Approach	Relationship
Natural light	Photo, observation, Lighting simulation	Exposure to natural light has been shown to have a positive impact on worker's wellbeing and productivity. By providing access to natural light in the workspace, a more inviting and energizing atmosphere can be created that may encourage workers to engage in unscheduled activities.
Natural materials	Photo and observation	Using natural materials such as wood, stone, or plants can create a calming and soothing atmosphere in the workspace, which may encourage workers to engage in unscheduled activities such as relaxation or contemplation. The underutilized spaces can also be boosted by natural elements and textures.
Green spaces	Nature Syntax, Photo and observation	Incorporating green spaces, such as indoor plants or living walls, into the workspace can create a connection to nature and help to reduce stress. Green spaces can also help to purify the air and improve indoor air quality which can have a positive impact on worker health.
Views of nature	Nature Syntax, Photo and observation	Providing views of natural elements such as trees, water, or sky can create a calming and inspiring atmosphere in the workspace. Views of nature can help to reduce stress and improve worker wellbeing, which may encourage workers to engage in unscheduled activities such as relaxation or contemplation.
Using natural colours and forms	Photo and observation	Incorporating natural colours such as greens, blues, and browns can create a calming and soothing atmosphere in the workspace. Natural colours can help to create a connection to nature and promote worker wellbeing, which may encourage workers to engage in their activities.

Space Syntax and observation results

The Space Syntax analysis and observation results revealed interesting relationships between space configurations and the unscheduled activities taking place in different zones of the

floors. Results of the Space Syntax variables/parameters (visual integration and connectivity, step depth and agent-based simulation) and site observations for all three levels are illustrated in Figure 4**Figure 3**Figure **7** and Table 3. Observation indicated different types of activities observed in the workplace (Figure 4 and Figure 5). Through Depthmap analysis, it can be hypothesized that VGA could provide a good indication of the way occupants might interact with space by using the space as a through route (Desyllas & Duxbury, 2001) or any other unscheduled activities, such as discussing, collaborating, standing, or generally occupying different spaces. Following this, according to Figure 6-Figure **8**, similarities were observed between the results obtained from Space Syntax analysis and observation. The illuminance analysis and daylight factor were also in line with the observations.

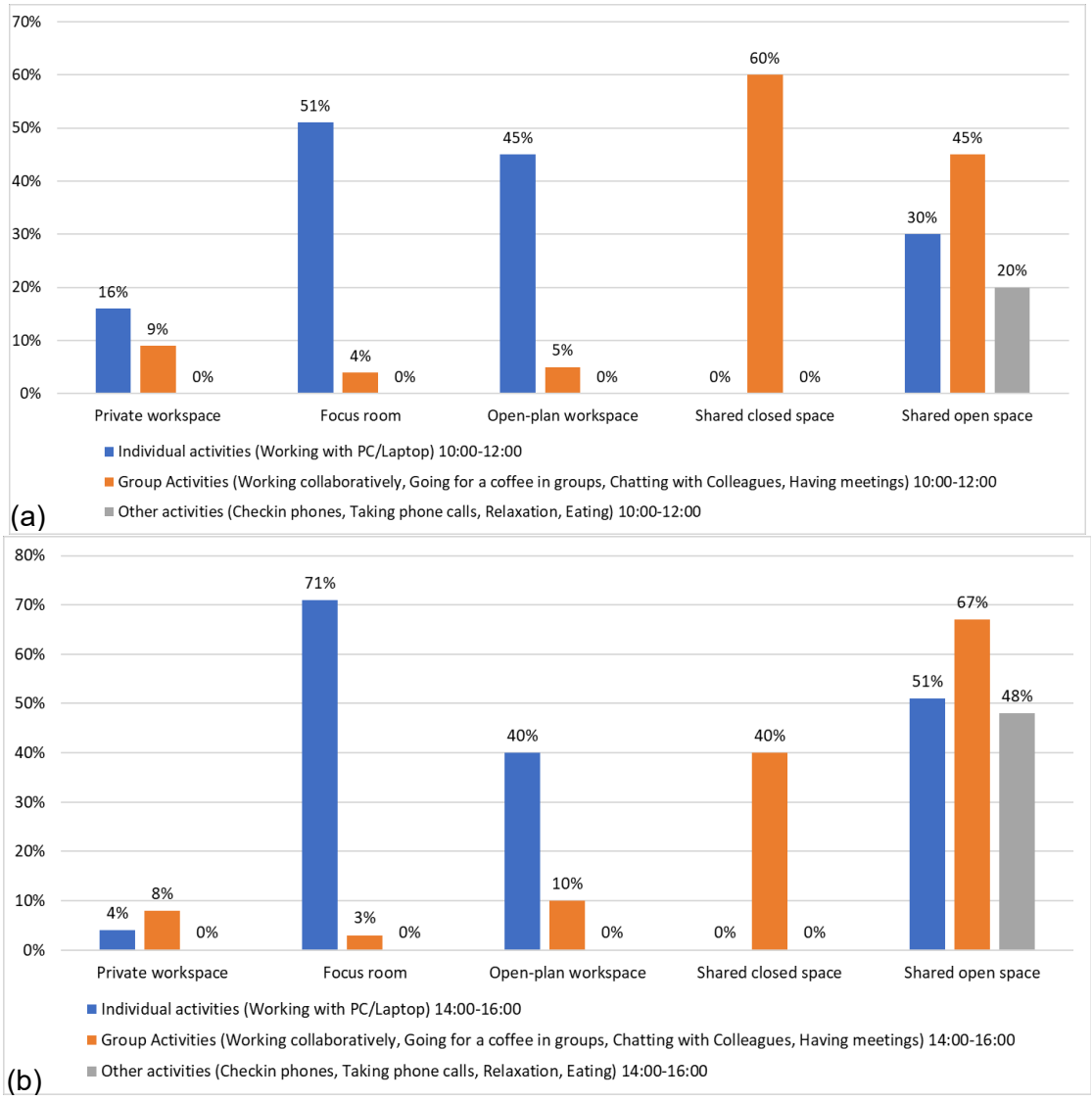


Figure 4. Percentages of activities observed in different zones of the floors: (a) Morning hours (10-12), (b) Afternoon hours (14-16).

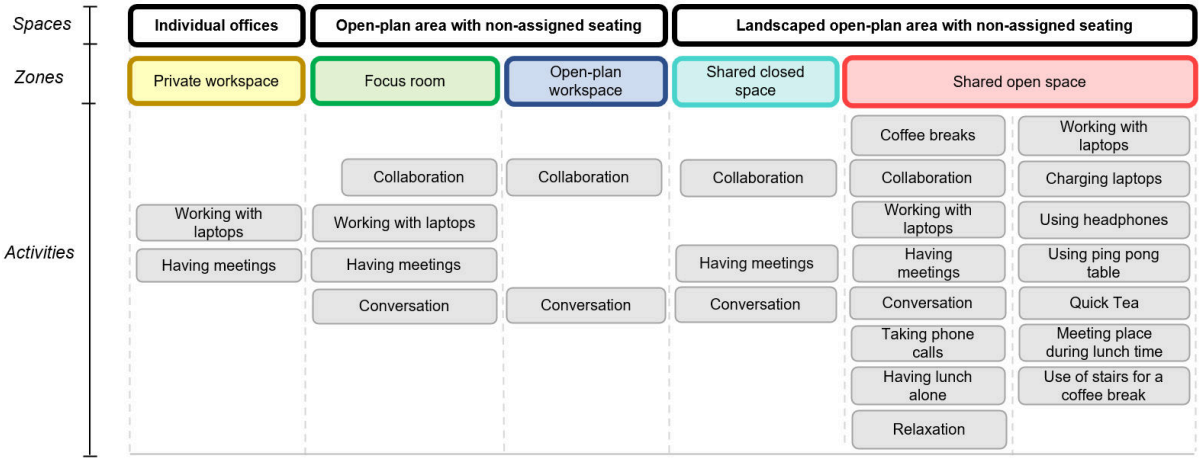


Figure 5. Diagram of observed activities in different zones.

The analysis of the individual offices and open plan area with non-assigned seating showed moderate to high values for visual integration and connectivity which should encourage high levels of collaboration and movement between different zones within these spaces. The agent-based analysis indicated movement of 29% in the open-plan workspace (Table 3). Also, as indicated Table 3, the step depth analysis revealed that the open-plan workspace in the corners were far from the entrance (80% step depth) and those that are in the middle are not far from the entrance which have lower step depth (40%) which demonstrates higher possibility of those spaces to be easily accessible for workers as also indicated in observation. In the observation, these spaces were used for different activities which could be the result of accessibility from the entrance and access to natural light through large windows. This space has high percentages of usage for individual work both in the morning and afternoon (Figure 4). In terms of private workspace (yellow areas in Figure 1), both VGA and agent-based simulation showed that these offices are not utilized frequently by staff with 39% and 19% respectively. These spaces show low percentage of usage with 16% for individual activities and 8% for group activities in the morning which changed to 4% and 8% in the afternoon (Figure 4). Similarly, the observation indicated that individual offices do not have access to enough natural light and are dim which can lead to lower utilization. These spaces also lack the natural textures and materials that can enhance their utilizations while the natural lighting lacks. While, due to the high visual permeability, workers in the open-plan workspaces (40-45% usage for individual activities and 5-10% for group activities) were mostly seen working with laptops while facing the south-facing windows or participating in collaborative activities in locations adjacent to south-facing windows.

The landscaped open-plan area includes two zones: shared open space with stairs and shared closed space. This area provides workers with a variety of formal and informal spaces for meeting, eating, relaxing and working. This area in each level is connected by internal stairs, encouraging vertical movement and unplanned encounters between workers. In terms of the shared open space such as the hallways and all the adjacent spaces, VGA analysis (Table 3) showed a high integration value (67%). Space Syntax also revealed high visual connection

(45%) as well as high incidence of activities and collaboration in the southern side of the shared open space (67% occupancy in the afternoon and 45% in the morning). Step depth analysis of the shared open space also showed that these spaces were within the proximity of the entrance, which demonstrates the easy access of these spaces for workers. In line with step depth and VGA results, the agent-based simulation illustrated higher movements (40%) in the shared open space (Table 3).

Similar to the results of simulations in Depthmap, observations showed that shared open space area was used for unscheduled activities such as collaboration and spontaneous meetings or even relaxation (Figure 5). These spaces have high percentages of occupancy for different activities both in the morning and afternoon (Figure 4). Design elements of large expanses of glazing as well as natural materials may have contributed to the occurrence and frequency of unscheduled activities in the shared open space. Natural light has been incorporated into various zones of the shared open space and retreat space through full height glazing, which simultaneously increases the visual accessibility of outdoor natural views, as demonstrated by the visual permeability in the previous section. Such opportunities could help workers reduce stress and improve wellbeing through activities of relaxation or contemplation as observed in the space. For instance, workers were observed eating, working with their laptops, chatting with other occupants, participating in online meetings while having lunch at a window side table within this space. In the north-east hallway with high integration values, higher unscheduled activities such as talking over the phone were observed. The retreat spaces adjacent to the north-facing façade, which were separated by a sheer curtain were also used by the workers to relax or sleep alone. The stairs and surrounding area were also used by a considerable number of workers for coffee in the upper floor, either alone or with their colleagues. Consequently, this central area was usually noisy due to the use of the stairs for a coffee break. The side stairs were also used, but not as much as the middle stairs. In line with the Space Syntax results of integration (67%) and connectivity (45%) in the upper floor's shared open space, activities such as chatting over coffee or food, resting, working from a laptop, private personal conversations, introductions, group discussions and spontaneous meetings were also seen in the sofa and café style seating zone on the plan's west side and the area north of the middle zone (kitchen).

The simulation of the shared closed space demonstrated moderate to high integration in these spaces (average 59%). However, the connectivity of shared closed space was low (22%) due to being a separate space from the surrounding open spaces. Observation indicated that these spaces have transparency which has contributed to accommodating unscheduled activities. This element was incorporated through glass-walled meeting rooms, enabling views towards natural materials of the adjacent shared open space (**Figure 6**). The activities observed in these spaces included resting, talking over the phone and chatting in small groups.

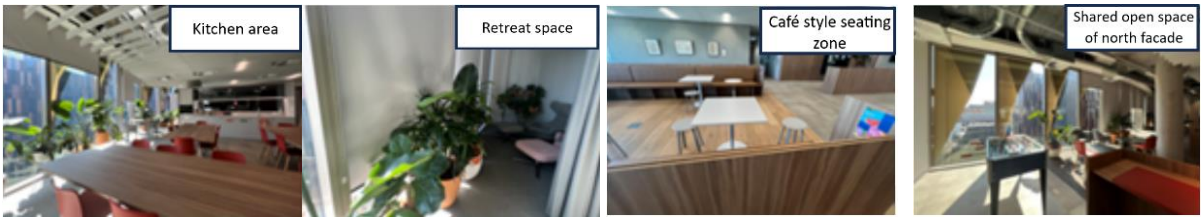
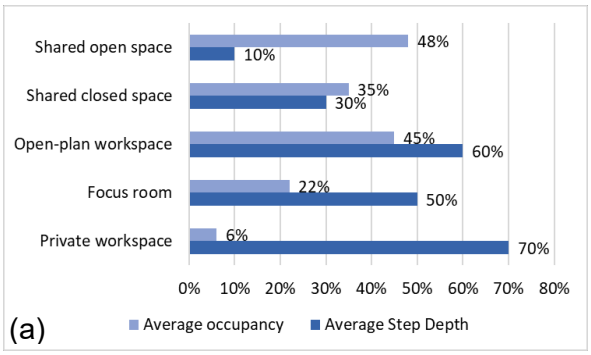
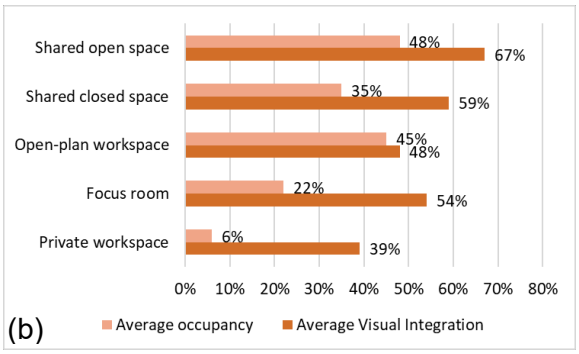


Figure 6. Photos of frequently utilized spaces that are characterized by plants, visual accessibility to nature, natural materials and light.

Table 3. Step depth, VGA (integration and connectivity), and agent-based simulation results from Space Syntax analysis for the case study.

Space type	Average Step Depth (Min:0, Max:5)	Average Visual Integration (Min:3.9, Max:13.1)	Average Connectivity (Min:9, Max:2026)	Average Gate counts (Min:0, Max:249) (Agent-based simulation)
Private workspace/individual offices	3-4 (70%)	5.1 (39%)	216 (11%)	46 (19%)
Focus room	2-3 (50%)	7 (54%)	366 (18%)	62 (25%)
Open-plan workspace	2-4 (60%)	6.2 (48%)	330 (16.2%)	71 (29%)
Shared closed space	1-2 (30%)	7.7 (59%)	437 (22%)	60 (24%)
Shared open space	0-1 (10%)	8.5 (67%)	858 (45%)	110 (48%)





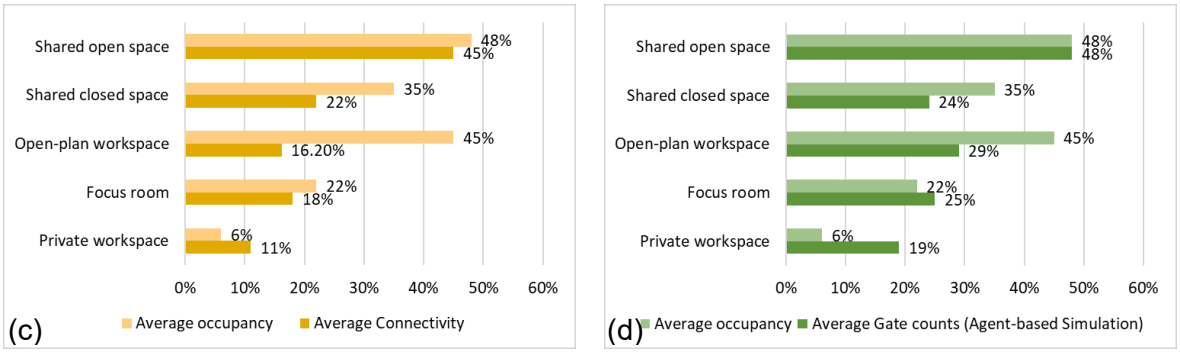


Figure 7. Comparison between Space Syntax Analysis and observation indicating percentages of observation with: (a) step depth, (b) visual integration, (c) connectivity, and (d) agent-based simulation.

Nature Syntax and observation results

For the aspect of visual permeability, calculations were used and tested by observation. Based on the permeability calculations of the floors, the north and south façades of the building are fully covered by windows, resulting in high visual permeability of 90% for the north and south sides of the three levels (**Figure 6**). Interestingly, the observation revealed that the areas where there was higher visual permeability (the northern and southern perimeter of the plan), were more frequently used by the occupants to implement their activities. Therefore, the permeability results were in line with the observation in this study. The permeability result was also in line with the Space Syntax analysis where perimeter parts of the floors showed higher integration, connectivity and agent-based modelling (**Figure 6Figure 9**).

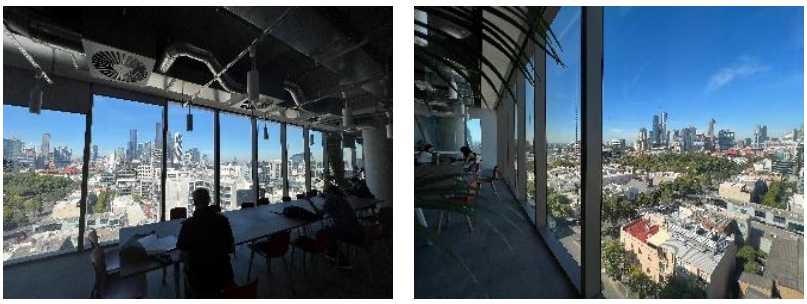


Figure 8. High visual permeability of the perimeter of the plan on north and south sides.

Overall, as indicated previously, the Space/Nature Syntax and observation analysis in this study revealed consistent findings regarding the significant integration, connectivity, agent-based simulation and occupancy/utilization of the spaces examined. This has further strengthened the possibility of the accommodation of unscheduled activities in the spaces where BD elements were observed. Therefore, it can be concluded that BD elements which have been implemented throughout the workplace could enhance the environmental quality of space, encourage different types of activities and higher utilization. In some cases where the Space Syntax analysis and observation showed higher integration or visibility of spaces (e.g., shared open space with 67% visual integration) showed in Figure 7b, more unscheduled activities and various types of activities were also seen in such spaces. Average of afternoon and morning occupancy for these spaces included 40% individual activities, 56% group

activities and 34% other activities. This study found higher integration of such spaces with BD elements. For example, the observation revealed that spaces with comfortable and flexible furniture, indoor planting and visual connectivity with natural outdoor or indoor green spaces appeared to contribute to attracting/enabling occupants to do their tasks in these spaces or use it for different activities. It can be concluded that such spaces with higher integration and connectivity, in which flexible furniture, natural materials, and natural views were provided, had more occupancy compared to other spaces.

Lighting simulation and observation results

Illuminance analysis and Daylight Autonomy showed high amount of natural light in the workspaces as one of the important BD elements enhancing occupants' satisfaction and the use of space (Figure 9) which align with the result of the Depthmap simulation and observations. The analysis of the illuminance levels and daylight factor in the building illustrates that most of the areas benefit from the natural light, except some central parts of floor plan, which may be a primary reason of frequent use of this building by users. The highest accessibility to daylight is in the perimeter of open-plan workspace and shared open space (89-100%) with highest occupancy of 67-68%. Table 4 indicates the range of daylight and illuminance of the spaces compared with usage of the spaces in Figure 9.

Table 4. Daylight autonomy and illuminance analysis throughout the observation date.

Space type	Average Daylight Autonomy (Min:0, Max:6000)	Average Illuminance (Min:0, Max:33)
Private workspace	500-750 (9%-13%)	1-3 (3%-9%)
Focus room	100-120 (17%-20%)	0-1 (0-34%)
Open-plan workspace	5300-6000 (perimeter) (89%-100%)	20-33 (perimeter) (61%-100%)
	3000-4000 (middle zones) (50%-67%)	9-14 (middle zones) (28%-43%)
	1000-3000 (inner zones) (17%-50%)	3-7 (Inner zones) (9%-22%)
Shared closed space	500-750 (9%-13%)	1-3 (3%-9%)
Shared open space	5300-6000 (perimeter) (89%-100%)	10-33 (perimeter) (30%-100%)
	4000-5300 (middle zones) (67%-89%)	6-10 (middle zones) (19%-30%)

1000-2500 (inner zones) (17%-42%)	3-5 (inner zones) (9%-16%)

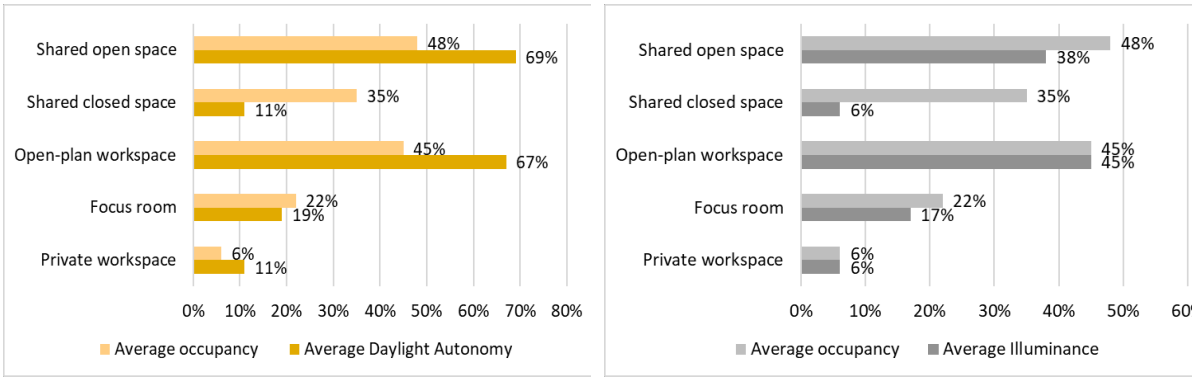


Figure 9. Comparison between Daylight simulation and observation.

Similar to the Depthmap results in areas less used by occupants, the natural light simulations support findings on the east side of the plan. It is worth mentioning that although the high amount of natural light in the perimeter of the floor plan could cause glare, through the availability of controllable elements such as blinds, the occupants can regulate the amount of natural light entering their workspace. Moreover, the layout of the workspaces provides the opportunity for occupants to choose their working area based on their preferred amount of light, without the need to close the blinds to benefit from the natural light. As revealed in observations and Depthmap analysis, the private workspace showed lower utilization rate (6%) which could also be the result of lack of access to natural light in these rooms (11% daylight autonomy and 6% illuminance) as one of the BD elements (**Figure 7** and **Figure 9**).

Although the majority of Space/Nature Syntax and lighting simulation results were in line with observations, in some areas there were differences between the outcome of each analysis. As a result, BD considerations based on the defined variables were analysed in these spaces to shed light on the reasons behind such discrepancies in results. While spaces with high integration in Space Syntax analysis may appear a more appealing choice for workers, they may not always be practical in reality. This is due to factors such as noise, privacy concerns, or other elements that may influence worker behaviour and activities. In spaces with lower connectivity or step depth, BD can create a positive emotional response encouraging workers to engage in their work and activities. For instance, the VGA of the lower floors showed low visual integration and connectivity for the seating area on the east side of the kitchen. However, it was observed that in this area, the occupants engaged in various activities, from quietly studying to interacting and collaborating with other students and academics. The BD elements in this area have provided direct experience of environmental features for the workers. This includes visual accessibility of natural light through windows' size and orientation in shared open space area in façade, presence of plants and visual accessibility to

nature through space and furniture arrangements in retreat space, kitchen and café style seating area with a consideration of natural materials (Figure 6).

Integration of BD with the workplace

A preliminary analysis of conducting Space/Nature Syntax analysis and observations, reveals several initial findings. Our data, aligned with previous research led by Cramer and Browning (2008), Nitu et al. (2022) and Ryan et al. (2014), demonstrated that BD integrates into the space through nature in space (such as use of plants, view to nature, natural light), natural analogues (such as use of objects, colours and materials that evoke nature) and nature of the space that refers to the configuration of the space (visibility, access, etc). However, the relationship between how the space is used, the frequency of the usage of space and BD elements has not been fully addressed in the literature. Also, a literature review study by Gillis and Gatersleben (2015) indicated that there are more studies supporting certain elements of BD (such as the presence of natural elements), while there is a lack of empirical evidence for other elements (such as the use of natural materials or processes). Thus, this study highlights the need for a more comprehensive approach to the intentional use of BD in designing workspaces that attract workers and can support different activities of occupants (Earle, 2003). It emphasizes the importance of BD elements, such as the integration of natural materials (Gray & Birrel, 2014), access to natural light (Sanchez et al., 2018), views of nature (Browning & Ryan, 2020; Cramer & Browning, 2008), and green spaces (Hähn, et al., 2021) in workspaces towards achieving increased engagement. BD in this study goes beyond greenery by incorporating three key criteria of nature in Space, natural analogues and nature of space. The case study of this research indicated that the implementation of BD elements led to integration and connectivity of workspaces, ultimately leading to an increase in the use of a space for different activities. It is recommended that future research should investigate the effects of BD elements on the integration and connectivity of activity-based workspaces in different contexts and settings. Furthermore, future research should consider other factors that may affect the use of space, such as personal preferences, organizational culture, and work practices.

The main finding of this study indicated that while space configuration is important for making a space visible and accessible to occupants, other factors can also have a significant impact on attracting them to engage in different activities within the workspace. Candido et al. (2019) have shown that designing workspaces with biophilia, organic layout, and blended break-out spaces can increase occupants' satisfaction by improving their overall experience of the space. BD can be a valuable tool in enhancing workers' experiences in their environment by promoting positive emotional responses and increasing wellbeing (Gray & Birrell, 2014; Lei et al., 2021; Rolfö et al., 2018), thereby inviting more organic unscheduled activities to occur within non-designated, open-plan, landscaped and activity-based workspaces. Understanding the design strategies implemented by workspaces with sustainability performance certification such as WELL/Greenstar ratings can provide an opportunity to

identify elements contributing to inviting and inspiring atmospheres in the workspace which may encourage workers to engage with space based on their various needs (Farahat & Alaeddine, 2020; Gray, 2017; Wallmann et al., 2019).

The relationship between step depth as one of the Space Syntax parameters and the use of space is another finding of analysis in this study. According to the Space Syntax, spaces closer to the main circulation points may be more likely to attract workers, as they are more easily accessible (Munro & Grierson, 2016). However, our findings showed that BD elements can have a great impact in attracting people even though the spaces are far from main circulation paths. Table 5 shows the BD elements and the average BD value for each space compared with the percentage of occupancy of spaces. As demonstrated, open-plan workspaces are not as closely situated to the entrances when compared to private offices. However, they are more frequently used than private offices due to their higher BD value (40%). Similarly, in this project, although the retreat space had less occupancy in the agent-based results, it was frequently being used by the occupants for group activity or individual working or even resting purposes. The lighting simulation also showed higher amount of natural light which could result in glare in this space. This could describe the reason of the closed blinds during the use of the retreat space and also indicates that controllability can enhance the use of space. Moreover, the availability of plants has contributed to the higher use of this space, demonstrating the important role of natural elements in attracting occupants to those spaces. These rooms had higher step depths than other adjacent spaces indicating higher privacy and lower visibility for occupants. Use of different plants in standing and hanging pots, a direct view outside and access to direct natural light were present in these spaces providing both visual interest and increased sense of privacy via screening. Occupants also had access to user adjustable furnishing elements such as blinds and reclining chairs. Therefore, according to the lighting analysis, although higher illuminance might result in higher glare in the perimeters of the workspaces, the availability of controllable blinds had resulted in frequent use of the space. There is also a shear curtain to draw across the entrance for privacy. This space and similar spaces in this project demonstrated that the way in which a social space is used can be influenced by the extent to which nature is visible from it or the natural elements are integrated with the space.

The results of the agent-based simulation demonstrated that BD elements and space configuration play a significant role in determining the movement of occupants and the way they use a space (Candido et al., 2021). The agent-based simulation predicted a low number of occupants in the shared open space located at the centre of the plan. However, observations showed that in this space occupants frequently worked individually or in groups, engaged in social interactions, studied, worked with laptops, and held academic meetings, contrary to the predictions of the Space Syntax analysis (Table 3 and Figure 4). As shown in Table 5, this area ranked with the highest BD value (59%), featuring BD elements such as plants (48% greenery),

natural materials (70%), natural colours (51%), natural light (69%), and direct views to the outside (43%). Occupants also had control of blinds in this area to moderate glare and light levels, providing an additional level of flexibility and user control to the space. Table 5 shows 80% flexibility of this space including furniture and blinds. The results of the agent-based analysis, therefore, support the importance of incorporating BD elements and flexible design strategies in workspaces to encourage use of space for different activities and accommodate diverse user needs. To understand the flexibility of the space, the percentages of flexible furniture and controllable blinds were calculated in this study (Table 5).

The observation approach used in this study sheds light on the limitations of relying solely on Space Syntax analysis and highlights the importance of considering multiple factors that address the needs of occupants when designing workspaces that support different activities (Candido et al., 2020; Nanayakkara, Wilkinson, & Ghosh, 2021). The findings of this study support those of Sanchez et al (2018), and Peters and D'Penna (2020) in demonstrating the beneficial effects of BD elements on the integration and connectivity of workspaces. In the case study, highly utilized spaces with high integration, also exhibited a greater integration of biophilic elements in their design approach. For example, the kitchen area on the east side of the building, which was adjacent to a table by the window, displayed high levels of integration, connectivity, and activity, and also offers view of the courtyard with natural light, uses natural materials and colours in furniture and finishing, and includes plants (**Figure 6**). This view of nature seemed to have a crucial effect on attracting occupants to spend time in that space. However, the case study showed that there are some contradictions in terms of the relationship between integration and the frequency of use of the space in reality. For instance, despite the results of the Space Syntax regarding the open-plan workspace with low agent-based simulation and connectivity values at 29% and 16.2%, respectively (Figure 6-Figure **8**), there were different activities taking place in this area, such as working with their laptop and group activities, which could be further explain the higher occupancy (45%) of such spaces by the transparency/visibility (48%) and view of nature (45%). Also, in contrast to moderate visual integration of the seating area located on the north side behind the kitchen, this area was regularly used for unscheduled activities which could be due to greenery of the spaces as well as high visibility of nature. The analysis showed that while underutilized spaces in this building lack natural light as the main BD element, it is possible to improve space utilization by incorporating natural textures and materials in the incidental spaces. For example, shared closed space has 11% access to natural light and 6% illuminance, but the use of natural materials (7%), greenery (10%), natural colours and forms (40%), flexible furniture (60%), along with 22% connectivity, 59% visibility, 70% proximity to the entries, and 24% ease of movement, have an impact on the Building Design (BD) value (28%) with an occupancy rate

of 35% (

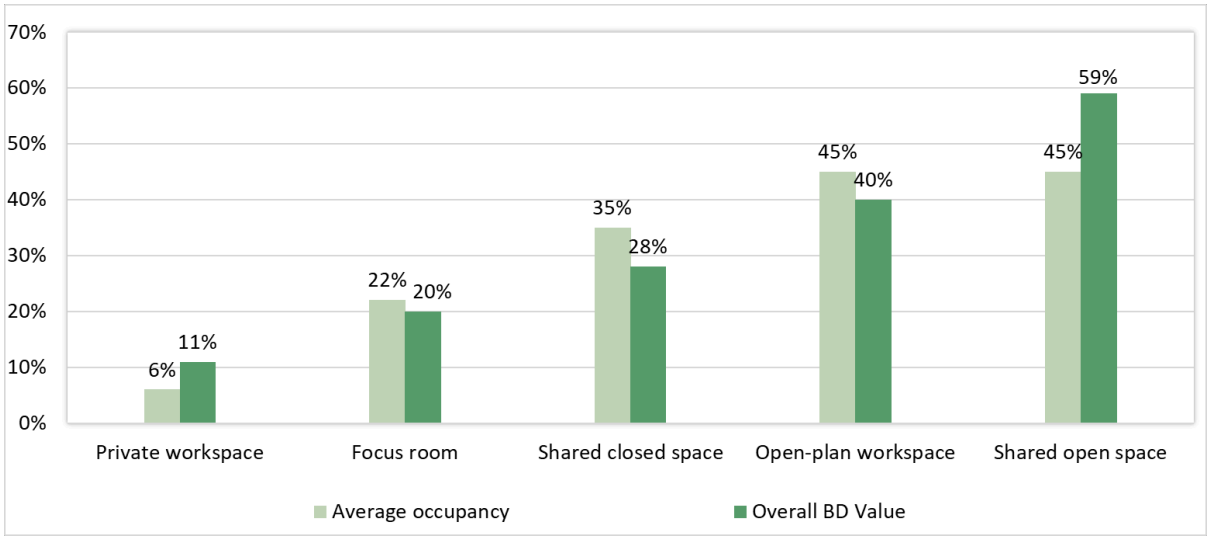


Figure **10.** Comparison between average occupancy and BD value., Table 5).

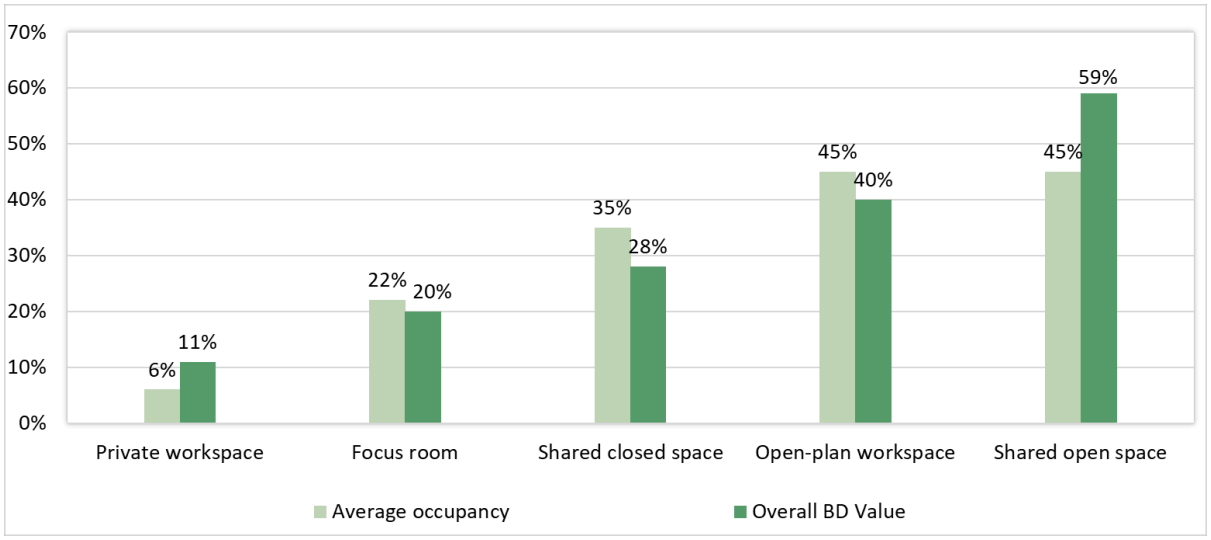


Table 5. Overall BD value in percentage for different areas based on the average of BD elements compared with occupancy rate which is highlighted in gradient.

Space type	Natural material	Greenery	Views of nature	Using natural colors and forms	Flexible furniture	Reverse score of Step depth	Connectivity	Visibility	Gate count (agent-based simulation)	Daylight autonomy	Illuminance	Overall BD value *

Private workspace	5%	<1%	<1%	<1%	<1%	30%	11%	39%	19%	11%	6%	11%
Focus room	<1%	14%	<1%	23%	<1%	50%	18%	54%	25%	19%	17%	20%
Open-plan workspace	<1%	20%	45%	50%	75%	40%	16.20%	48%	29%	67%	45%	40%
Shared closed space	7%	10%	<1%	40%	60%	70%	22%	59%	24%	11%	6%	28%
Shared open space	70%	48%	43%	51%	80%	90%	45%	67%	48%	69%	38%	59%

- Reverse score of step depth was considered as the higher amount equals to less accessibility and visibility and this lower value of BD value.
- The colored cells indicate the highest occupancy (dark green) to the lowest occupancy (light green) of the space.
- The items with the value of less than 1% were considered 0 in the calculation of overall BD value.

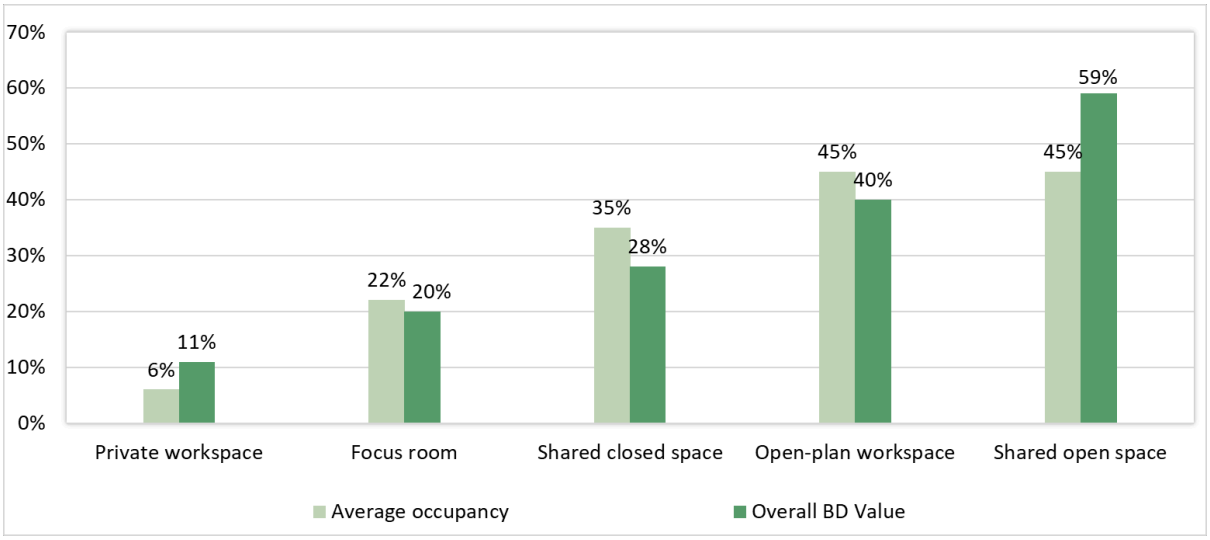


Figure 10. Comparison between average occupancy and BD value.

This paper aimed to highlight the significance of BD beyond space configuration in influencing the utilization frequency of a space. Our findings showed that although spatial configuration plays a critical role in encouraging the freedom of choice among the occupants, there are other important environmental qualities which can help the existing workspaces increase utilization. The changes brought about by the pandemic have shed light on the importance of workspace design in encouraging workers to return to their offices and use different spaces according to their preferred in office activities. Managers and organizations are struggling with these changes to articulate a clear purpose to bring back workers and

enhance use of space, and it has become evident that traditional working arrangements and environments may not be universally suitable. This research has emphasized the significance of BD and office configuration in influencing workers' use of space, particularly in the post-COVID period, by evaluating the role of natural BD elements through visibility, integration, connectivity analysis, lighting simulation and real time observations. However, the extent to which office design and biophilic elements can influence space utilization is still uncertain. This paper also introduced a novel approach by combining Space/Nature Syntax methodology in a building that accommodates both academic and knowledge workers.

CONCLUSION

This study shows the potential of using Biophilic Design for boosting office utilization. In particular, this study emphasizes the implementation of BD elements in spaces such as community hubs, and incidental spaces, to improve the functionality and adaptability of the office landscapes. These spaces can be transformed into multipurpose areas that support a range of activities, including work, rest, communication and collaborating. By prioritizing access to nature and natural elements in these areas, employees can experience the benefits of BD concept throughout the office space. The findings of this study have significant implications for office design and planning. By employing BD elements, offices can enhance the appeal of their spaces and create a more satisfying work environment for employees. Access to nature and natural elements such as use of plants, access to natural light and sounds of nature, use of natural materials, colours and forms of elements in nature can not only enhance the environmental and aesthetic quality of the office space but also promote engagement, physical and mental health of employees. The study also recommends that future research should explore the relationship between BD and the wellbeing of office workers, including physical health, stress levels, and job satisfaction. Also, this study acknowledges the role of job types and work styles in shaping spatial preferences. The utilization of certain spaces, such as focus rooms, may vary depending on the nature of employees' tasks and the level of concentration required. While this was considered in our analysis, future research could further investigate how different work tasks influence the use and effectiveness of workspaces, providing deeper insights into optimizing workplace design for diverse needs. It would be beneficial to conduct further research indicating to what extent BD can impact the utilization of workplaces and enhance the frequency of usage. This could lead to a wholistic understanding of the role of BD in office environments and provide additional direction for the development of effective office design approaches. Specifically, as this study showed, private workspaces and focus rooms of the case study have a lower percentage of BD elements and are used less (Table 5 and Figure 10). To increase the usage of these spaces, future studies could explore how varying levels of BD elements, such as increased daylight, natural materials, and views of nature, affect space utilization and user experience. In addition, while the observation periods in this study were limited to 10–12 pm

and 2–4 pm, as they represent typical working hours when office activity is generally steady and capture the peak of daily workplace routines, we recognize that these time slots may not fully reflect the variety of office dynamics throughout the day. Future studies are recommended to include additional timeframes to provide a more holistic understanding of workplace behaviour.

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