The impact of biophilic design in university study areas on students' productivity

Rolien Terblanche
University of the Witwatersrand Johannesburg, Johannesburg, South Africa and University of Cape Town, Cape Town, South Africa, and
Dorcas Khumalo
University of the Witwatersrand Johannesburg, Johannesburg, South Africa

Received 26 October 2023
Revised 3 February 2024
14 February 2024
Accepted 22 February 2024

Abstract

Purpose – The objective of this study is to determine how biophilic designs in study areas affect the productivity of students at the University of the Witwatersrand. The study also seeks to evaluate study areas at Wits in terms of biophilic design, determine whether biophilic design contributes to the preference of students and their study productivity.
Design/methodology/approach – This is a cross sectional study that used a mixed methodology. Five study areas were identified and evaluated in terms of biophilic design. At each study area, nine students participated in an open- and close-ended questionnaire regarding their perceptions on study areas and productivity.
Findings – The five study areas scored the following results according to the biophilic test: 29.09%, 34.55%, 36.36%, 80.00% and 85.45%, respectively. The students prefer to study in biophilic study areas as it prompts positive emotions and make them feel rejuvenated and energized. However, there are still students studying in the non-biophilic areas due to convenience or due to the biophilic areas that are noisy and lacks monitoring.
Research limitations/implications – With the small sample size, the generalizability of the findings are limited, but does create a foundation for further research.
Practical implications – Universities can learn from the findings and benefit greatly from many biophilic study areas. This could also encourage architects and interior designers to include biophilic design more so in general buildings/rooms.
Originality/value – Study areas at the University of the Witwatersrand was evaluated in terms of biophilic design, while determining whether biophilic design contributes to the preference of students and study productivity.

Keywords Biophilic design, Study areas, Study productivity, Academic performance
Paper type Research paper

1. Introduction

Robust research has been conducted on how the built environment can be manipulated in order to improve physical health among patients in the healthcare facilities, improve productivity in workplace environments and hospitality. This manipulation of the built environment is through the concept of biophilia. According to Barbiero and Berto (2021), biophilia is defined as the innate human instinct to connect with nature and other living things. There are three categories of biophilic design:

(1) Nature in the space whereby there is direct presence of nature in a space.

(2) Natural analogues which are representational presence of natural materials, patterns, shapes, etc.

Archnet-IJAR: International Journal of Architectural Research
Emerald Publishing Limited
2631-6862
DOI 10.1108/ARCH-10-2023-0288

(3) Nature of the space which is the incorporation of special elements commonly found in nature such as expansive views and lighting (Simarmata, 2023).

Furthermore, biophilic designs have been associated with restorative properties (Ryan *et al.*, 2014). When it comes to learning environments, designers and architects still have the same issue of not knowing the kind of environment that optimizes cognitive function: learning, emotion, memory, communication and social intelligence (Derterman *et al.*, 2019).

It is vital to understand the role and importance of the environment to students' mental and physical health. The relationship between study productivity; biophilic learning and/or the impact of biophilic designs on academic performance, has only been explored at an elementary school level. Students in elementary schools and tertiary institutions however have different academic pressure and stresses therefore the impact of biophilic design in university learning spaces should be researched further in order to prevent or reduce mental health issues and improve academic performance (Peters and D'Penna, 2020). Research has proven that nature can actively and passively improve human health, physiological and psychological, including improving cognitive function and academic productivity (Ryan *et al.*, 2014; Jimenez *et al.*, 2021).

Most studies have examined the extent to which a physical learning space enhanced with biophilic properties contributes to the well-being of students and improved learning outcomes, but only for primary school students in the 1st world countries (Determan *et al.*, 2019). These previous extensive studies do provide an idea of how biophilic designs in learning spaces affect student academic success but are very limited in nature as the research applies to specific demographic and environment. There is a large gap in knowledge of how biophilic designs in learning spaces of universities affect university students' academic performance, more so, students from South Africa, who are exposed to different challenges in comparison to the elementary students in the first world countries.

Studies have also established that classroom designs or environment can influence certain interactions within the classroom and support student attention, well-being, physical health, perceived environmental quality among other factors that improve academic performance within the classroom (Dillon and Osborne, 2006). University students encounter a lot of stress from socio-economic factors brought about by high expectations from themselves or from society, e.g. students from poor backgrounds are first in their families to attend university (Mofatteh, 2021). Biophilic designs have been closely correlated with boosting human health and creating a supportive environment towards those in distress (Burton, 2022).

The poor academic performance can affect a student's mental health, self-esteem and sometimes can lead the failures towards a life of drugs abuse and suicide. Annually, cases of suicide are reported in South African universities, with academic challenges cited as part of the root causes (Makhubela, 2021). To curb the academic challenges facing students, universities have implemented various interventions, i.e. providing academic support and mental health programs; however, the problem persists (Makhubela, 2021). Academic failure is the most common cause of suicide amongst students globally, including South Africa (Alabi, 2022). With these factors, suicide and poor mental health among university students is not a local phenomenon, but a global social concern which urgently needs to be eradicated (Campbell *et al.*, 2022).

There have been many studies proving that biophilic design is good for the environment (Bogerd *et al.*, 2020). Additionally, there were many studies testing physiological and phycological aspects of humans within a biophilic rich room and proving that it improves physiological health (Sayed and Nagy, 2020; Aristizabal *et al.*, 2021; Hung and Chang, 2021) and psychological health (Yin *et al.*, 2018; Tahoun, 2019). While Bogerd *et al.* (2020) and Peters and D'Penna (2020) made definite recommendations in terms of biophilic design in study areas at tertiary institutions, their findings were based on literature reviews. Furthermore,

Burton (2022) did a study on biophilic design within lecture rooms at a university in the United States. There were, however, no studies done at universities in South Africa, nor did they specifically look at the biophilic design within the study areas while collecting the perspectives of the students using these study areas.

The aim of this study is to determine how biophilic design in study areas affects the perceptions, preferences and study productivity of students at the University of the Witwatersrand, South Africa. This study has the following three objectives:

(1) To evaluate study areas at the University of the Witwatersrand in terms of biophilic design.

(2) To determine whether biophilic design contributes to the preference of students.

(3) To determine whether biophilic design contributes to better study productivity.

2. Biophilic design and academic performance

2.1 Biophilia

Biophilia is a term with the constituents, "Bio" which refers to "live" or the state of living whereas "philia" denotes an inclination towards nature, or a fondness and innate connection to elements of nature (Kayihan *et al.*, 2018). Kayihan *et al.* (2018) further explains that the term was first developed in 1964 by a social psychologist named Erich Fromm who described biophilia as the cognitive inclination towards living things that are fundamental to one's psychological well-being.

Wilson (1984) was the second to use the term "biophilia," which then lead to the generation of the "Biophilic Hypothesis," followed by an explanation that humans have an innate desire and tendency to gravitate towards nature and the biosphere at large (Elmashharawi, 2019). Xue *et al.* (2019) suggests that biophilia provides a solution that not only addresses the need for green building methods, but also goes beyond that and takes into consideration the needs of the occupants. Integrating an occupant-centric approach to green building techniques that already exists, to drive sustainability through improved engineering methods, would ascertain that a building holistically impacts and benefits the health and wellbeing of its occupants, and the natural environment (Xue *et al.*, 2019). Humans are naturally drawn to nature and have an inborn urge or rather trigger to be physically and mentally captivated by the natural environment, which in turn has proven to be essential to ones' physiological and psychological health and well-being (Kellert, 2016).

The phenomenon described above then gives rise to the term biophilic design and consists of several values that have the effect of improving overall health when adequately implemented (Kellert, 2016). Kellert (2016) identified the following eight biophilic values:

(1) Attraction: to find nature aesthetically pleasing

(2) Intellect: the ability to understand the natural environment

(3) Spirituality: building a deep connection with nature

(4) Exploitation: the material use of natural elements

(5) Dominion: the ability to manipulate nature

(6) Aversion: the act of avoiding nature

(7) Affection: the state of having full admiration of nature

(8) Symbolism: using nature as a symbol of expression

Benefits associated with the above-mentioned values are listed below, respectively:

(1) Improved intellect, innovation, curiosity and imagination

(2) Problem solving skills, cognitive development and critical thinking

(3) Awareness of one's significance and inspiration

(4) Security, contentment and efficient productivity

(5) Sense of self-reliance and proficiency

(6) Building coping and defence mechanisms as well as security

(7) Nurture, connection and cooperation

(8) Improved communication, language and design capabilities (Kellert, 2016).

2.2 Biophilic design

Biophilic design is an architectural design strategy adapted in recent years that is aimed at actively incorporating a number of natural elements in the built environment both directly and indirectly-by giving the illusion of being immersed in nature-in acts to drive sustainability, restore the environmental blueprint and most importantly reconfigure the connection between building occupants and the natural environment (Dewi *et al.*, 2020; Aristizabal *et al.*, 2021; Elmashharawi, 2019).

This concept is rooted from the fundamental ideas surrounding Biophilia, which prescribe that human-beings are positively impacted by exposure to nature-related components, as they have been proven to enhance overall health, productivity and well-being (Tahoun, 2019). Tahoun (2019) further outlines that this positive affinity towards nature is rooted from the evolutionary organic bond that exists between man and mother-nature, thus giving rise to theories developed by environmental psychologists of which are namely the attention restorative theory (ART) and the stress recovery theory (SRT). This is a grave requirement in the design of building envelopes as traditional architectural methods often neglected the importance of occupants' visual, mental and physical preferences, and it rather provides the opportunity to bridge this gap (Elmashharawi, 2019).

2.2.1 Definitive aspects of biophilic design. According to Aristizabal *et al.* (2021), there are three elements that make up biophilic design:

(1) ***Nature within a space:*** the introduction of physical greenery, acoustic elements of nature, natural scents and visual exposure to nature within a space, i.e. a landscape that encompasses greenery, trees such as the Jacaranda filling the atmosphere with hues of purple, a body of water with a fountain out of sight and panoramic views of the sky from the benches surrounding the area; reflecting the direct experiences of nature.

(2) ***Parallels of nature:*** indirectly provides exposure to nature by creating a parallel of it through natural patterns, prints, colours, symbols and materials, i.e. a circular roof/skylight structure made of glass and steel to mimic a spider web. It is found within the building, allowing natural light to infiltrate the space and providing occupants the leisure of having visual contact of the external environment, and in turn an indirect experience of nature; reflecting the indirect experiences of nature.

(3) ***Nature of the space:*** the mimicry of the natural environment, or even design through biomimicry. This can include, strategically organizing furniture and decorative elements in a way that elicits comfort and security in the occupants of

the building space (Aristizabal *et al.*, 2021), i.e. a building consisting of transitional spaces that allow for the occupant a full view and visual access (prospect) to activities, and other occupants within and outside of the building, whilst "out of sight" (refuge), giving them a sense of safety and security; reflecting the indirect experiences of nature.

2.2.2 Types of nature experience and qualities. In their extensive work on biophilic design, Kellert and Calabrese (2015) identified several notable qualities of biophilic design and created a criterion of these qualities and the experiences they fall under:

(1) ***Qualities linked to direct experiences of nature****:* UV-light, water, air, plant life, biological organisms, weather, geology, topography, natural habitats and ecosystems, scenic views, green facades and fire.

(2) ***Qualities linked to the indirect experience of nature:*** Images and paintings of nature, natural materials, colours inspired by nature; simulation of natural light and air; nature inspired patterns and geometrics; and an evocation of nature and biomimicry.

Another experience identified by the authors Kellert and Calabrese (2015) is the "experience of space and place." The qualities linked to this experience of nature include:

(1) Prospect and refuge theory.

(2) Organized complexities, integrating constituent parts to make up wholes.

(3) Transitional spaces.

(4) Mobility and ease of access.

(5) Cultural and biological attachment to space.

2.3 Biophilic design elements to improve the building envelope

Kellert and Calabrese (2015) stated that the incorporation of biophilic design elements to a building would in turn change the environmental conditions of that building. This then influences the overall building make-up, as adopting active efforts to curb the negative impact of buildings on the environment in general involves altering the structure or the elements within it. These structural alterations may include:

(1) Curtain walls, light reflecting material and skylights to improve lighting,

(2) Functional windows as a method of natural ventilation to improve the indoor air quality of the building envelope, balance temperature fluctuations, air-pressure and humidity, and

(3) Green walls and adequate landscaping would enhance the aesthetic appeal of the structure and address ecological concerns, whilst benefiting building occupants (Kellert and Calabrese, 2015).

Wijesooriya and Brambilla (2020), also supports the notion that building performance factors such as indoor air quality and thermal comfort are positively impacted by the implementation of biophilic design, and further provided that this result can be elicited through living walls to cool the internal and external environment, thus reducing overheating.

2.4 Physiological and psychological benefits of incorporating biophilic design within a space

Several studies on biophilic design have indicated that this philosophical approach to architectural planning and design may primarily be implemented to enhance psychological

and physiological well-being through adapting its attributes such as excessive daylight, adequate lighting, strategically placed windows to provide a connection to the external environment, the use of natural materials, introducing or increasing plant-life, opting for skylights and optimizing greenery in and around the building envelope (Peters and D'Penna, 2020).

2.4.1 Physiological benefits of biophilic design. In schools, biophilic design may improve students' physical health by improving their blood pressure, reducing signs of sickness and providing a sense of comfort and ease (Sayed and Nagy, 2020). Improved airflow through natural ventilation can reduce levels of humidity and carbon dioxide, thus improving comfort, ensuring that the respiratory health of learners is not compromised (Mallen *et al.*, 2020). Self-reports of occupants on exposure to nature through windows have indicated a reduced heart-rate recovery period after experiencing stressful conditions (Aristizabal *et al.*, 2021). When occupants in the study were exposed to a room with biophilic elements, their diastolic and systolic blood pressure was found to be lower (Yin *et al.*, 2018). Electro-dermal response was lower in a room with biophilic elements than it was in a room without biophilic elements (Yin *et al.*, 2018). Biophilic design was said to have an impact on the following parameters: cortisol levels, improved brain activity, body temperature, reduction in pain levels and frontalis muscle tension amongst other physiological parameters (Hung and Chang, 2021).

2.4.2 Psychological benefits of biophilic design. Aristizabal *et al.* (2021) cited that introducing actual and artificial plants reduced irritation of people in hospital waiting rooms, thus lowering stress levels in both instances. Improved brain activity or cognitive function results in optimized memory, critical thinking and enhanced learning ability (Sayed and Nagy, 2020). Tahoun (2019) noted a decline in stress levels, improved concentration, reduced anxiety, great proficiency of skills and other behavioural changes such as reduced aggression in the workplace. Yin *et al.* (2018) discovered that short-term memory improved by 14%.

2.5 Study efficiency

This study uses the phrase *"study efficiency"* to imply the effective or productive way of studying. This requires great attention/concentration, a healthy study environment and an effective study strategy. Concentration or mental effort, can be another obstacle to student learning, according to cognitive load theory (Szulewski *et al.*, 2022). Therefore, for a student to concentrate, he/she must be in a comfortable space which is conducive to cognitive mental behaviour. Studying effectively also means studying or reading with excessive attention and understanding (Bernard, 1957). This means, skimming through your paper or document does not demonstrate an effective way of studying, and therefore chances of you remembering main concepts about what you were reading about are very slim. Effective studying means studying to reach a specific goal, in this case, students study to pass assessments or to improve academic performance and to complete their degree. Among the criteria to study effectively, is to find a study area and to avoid distractions (Natalia and Roman, 2022).

2.6 Good academic performance

According to the Merriam Webster dictionary, the word *"academic"* is used in relation to school related matters, especially in tertiary/higher learning institutions. This word can also be expressed as "educational," it is a synonym of the word "academic." Therefore, academic performance, which can also be stated as educational attainment, is defined as the act of learning, and describes whether a person performed well or not in their learning endeavours. This is therefore classified between "poor academic performance" which means one did not do well in their studies, and "good academic performance", which is the opposite of poor performance.

Passing a module with a distinction is one great example of good academic performance. This is most acknowledged by awarding the students with a certificate of merit, scholarship or both. Students who perform well academically implement the strategies of effective studying mentioned above and study in a non-strenuous environment. A student's performance can be influenced by school environment and the facilities offered by the faculty and/or school, could be study space, availability of books, or consultations which in turn affects the performance and the student's accomplishments (Ali *et al.*, 2013).

There are many factors that can improve the academic performance of students. Some of them may apply to a single individual, whilst other factors have been proven to be universal. These factors include interest in the course studied, regular study and hard work, dedication and self-confidence, regular attendance, healthy mental and physical state, and support from family members and others (Islam and Tasnim, 2021). Moreover, poor academic performance can also affect the mental and physical health of the students; hence the two factors are directly related (Houri and Kincade, 2022). Familial and moral support also affects a students' mental state in such a way that, if support lacks, depression develops, which in turn negatively affects their abilities and learning processes (Mofatteh, 2021). Importantly, a biophilic environment could contribute to better academic performance (Burton, 2022).

2.7 Fundamental elements of biophilic design

According to Kellert (2016), there are six fundamental elements of biophilic design:

(1) Environmental features which are elements that relate to the characteristics of the natural world found in the built environment;

(2) Natural shapes and forms – elements that include the simulations or representations of the natural world to the built environment;

(3) Natural patterns and processes which focus on how the built environment is enhanced by including characteristics of nature in to it;

(4) Light and space goes to the many ways in which lighting and space can be incorporated into a space;

(5) Place-based relationships refer to the relationship between the community culture and their environmental ecology and lastly,

(6) Evolved human-nature relationships highlights how human relationships with nature can be reflected in the built environment.

Biophilic design can therefore follow the various fundamental elements listed above. Other factors however, to consider within study areas as well, are quietness, organized nature and comfort (Thermory, 2022).

2.8 Biophilic design and study areas at tertiary institutes

Students experience increased stress, depression and other mental health issues due to their academic performance (Bogerd *et al.*, 2020). Biophilic design in university study areas can improve the well-being of students as well as their academic performance. They have further been proven to reduce harm, e.g. the ability of plants to reduce air pollution through the absorption of carbon dioxide and production of oxygen which is a vital factor in the survival of the human body (Bogerd *et al.*, 2020). Biophilic design have been proven to have restorative abilities, meaning they have properties that can induce physiological (Sayed and Nagy, 2020; Aristizabal *et al.*, 2021; Hung and Chang, 2021) and psychological (Yin *et al.*, 2018; Tahoun, 2019) recovery from stress and mental fatigue. Moreover, these natural elements have

instauration abilities with which they encourage physical activity, socialization and a healthy lifestyle. Students spend an ample amount of time on their university campus including different study areas therefore being exposed to natural elements can prove to be beneficial towards their overall wellness and academic performance (Bogerd *et al.*, 2020).

While Bogerd *et al.* (2020) and Peters and D'Penna (2020) made definite recommendations in terms of biophilic design in study areas at tertiary institutions, their findings were based on literature reviews. Furthermore, Burton (2022) did a study on biophilic design within lecture rooms at a university in the United States. There were, however, no studies done at universities in South Africa, nor did they specifically look at the biophilic design within the study areas while collecting the perspectives of the students using these study areas.

3. Methodology

To understand how biophilic design in study areas affect the productivity of students and their preferences, we must firstly understand how biophilic the room is and secondly gather the perspectives of the students that use these rooms to study. Hence, this research was conducted using a mixed method approach, which is a method that consists of both quantitative and qualitative data collection and analysis (Saunders *et al.*, 2016). The data collection consisted of two sections. The first section involved the observation of five study areas (cases) at the University of the Witwatersrand, regarding the presence of biophilic elements. The second section of the data was collected by means of questionnaires that were answered by students that were studying at these five study areas. The data collected through the observations are considered qualitative data, while the analysis of the data was done in a quantitative manner. The questionnaire survey consisted of open ended and close ended questions to understand their perspectives, preferences and attitudes. The questionnaire was therefore a mix of qualitative and quantitative data (Leech and Onwuegbuzie, 2009). On average, each study area receives about 50 students per day. A total of nine students per study area completed the questionnaire, and therefore, a total of 45 questionnaires were completed. The data of both sections were collected simultaneously. Leech and Onwuegbuzie (2009), classified such a methodology as a fully mixed concurrent dominant status design.

On the sample size for the questionnaire, it must be noted that "data saturation, theoretical saturation, or informational redundancy" (Leech and Onwuegbuzie, 2009) may not have been reached due to the small sample size and makes generalizability limited. According to Saunders *et al.* (2016), a sample of five for qualitative data could be sufficient. From the given sample size, it was possible to make the necessary connections and relationships that the primary questions of the research are interested in. This study, however, did not focus on the degree of strength of these relationships. A power analysis, where the minimum number of participants is determined to improve the confidence level of the research would then be required.

To achieve the first objective, which is to evaluate the level of biophilic design present at each of the five study areas, a biophilic study area test was conducted and analysed. This test was adapted from the findings of Kellert (2016), and includes six categories, each being one of the six fundamental elements of biophilic design discussed earlier. Each category has various elements (see Table 1). Kellert (2016) compiled a detailed list of what can form part of biophilic design and is a good benchmark against which the study areas can be measured. The presence of each element was checked. The frequency of the elements in each category was calculated and expressed as a percentage. This percentage indicates which elements and types of nature experiences are most prominent in the study areas observed, and further provides the opportunity to measure what type of experience mostly impacts students' preference, productivity, mental well-being as well as their perception of the study areas.

Biophilic elements present in study areas (Total points = 55)		JMF	JMC	WWL	COM	WCL
Actual nature features (not images of real nature characteristics)	Air	✓	✓	✓	✓	✓
	Water	✓	–	–	–	–
	Plants	✓	✓	–	✓	–
	Animals	✓	–	–	–	–
	Natural materials	✓	✓	✓	✓	✓
	Views	✓	✓	–	✓	–
	habitats	✓	–	–	✓	–
	Fire	–	–	–	–	–
Natural shapes and forms/ representations of nature and simulations	Animal-like	✓	–	–	–	✓
	Shells and spirals	✓	–	–	✓	–
	Curves and arches	✓	–	✓	✓	✓
	Fluid forms	✓	–	–	✓	–
	Abstraction of nature	✓	–	✓	✓	–
	Inside-outside	✓	–	–	✓	–
	Botanical motifs	–	–	–	–	–
Natural patterns and processes- properties derived from natural features and processes	Natural ratios and scales	✓	–	–	✓	–
	Patterned wholes	–	–	–	✓	✓
	Linked series and chains	✓	✓	✓	✓	✓
	Integration of parts to wholes	✓	–	✓	✓	–
	Area of emphasis	✓	✓	–	✓	✓
	Complementary contrasts	✓	✓	–	✓	✓
	Bounded spaces	–	–	✓	✓	–
	Age, change and the patina of time	✓	✓	✓	✓	✓
	Sensory richness	✓	–	–	✓	–
	Dynamic balance and tension	✓	–	✓	✓	–
Colour and light (colour, light and material qualities and space relationships to nature	Composition	✓	✓	✓	✓	✓
	Communication	✓	✓	–	✓	✓
	Preference	✓	–	–	✓	–
	Response	✓	✓		✓	✓
	Pragmatics	✓	✓	✓	✓	✓
	Natural light	✓	–	–	✓	–
	Filtered light	✓	✓	✓	✓	✓
	Reflected light	✓	–	–	–	–
	Light pools	–	–	–	–	–
	Warm light	✓	–	–	✓	–
	Light as shape and form	✓	–	–	✓	–
	Spaciousness	✓	–	–	✓	–
	Spatial variety	✓	✓	✓	✓	✓
	Space as shape and form	✓	–	–	✓	–
	Spatial harmony	✓	–	–	✓	–
Place-based relationships culture together with ecology, rooted in geography	Geographic connection to place	✓	✓	–	✓	✓
	Historic connection to place	✓	✓	✓	✓	✓
	Ecological connection to place	✓	–	–	✓	–
	Cultural connection to place	–	–	–	–	–
	Integration of culture and ecology	–	–	–	–	–
	Spirit of place	✓	✓	–	✓	✓
Human-nature relationship paired biological needs of the human relationships to nature	Order/complexity	✓	✓	✓	✓	✓
	Prospect/refuge	✓	–	–	✓	–
	Curiosity/enticement	✓	✓	✓	✓	–
	Master/control	✓	–	–	–	–
	Attraction/attachment	✓	–	–	✓	–
	Exploration/discovery	✓	–	–	✓	–
	Fear/awe	✓	–	–	✓	✓
	Reverence/spirituality	✓	–	–	✓	–

Source(s): Table created by author

Table 1. Biophilic elements present in study area

Descriptive statistics were used on the results collected from each of the study areas to demonstrate what nature experiences were more present, and whether the space is directly, indirectly or abstractly biophilic. Once this has been configured, all the study areas were compared from the lowest cumulative percentage ratings to the highest.

Furthermore, this study used cross-case analysis (Ryan, 2012). The method was used for the purpose of gathering an in-depth understanding of the intersection between biophilic design and the impact it has on student productivity and preferences. The data collected from the individual students needs to be compared with that of the other students and across the different areas of interest, in the pursuit of enhancing the strength of the results. Stake (2000) referred to these designs as collective case studies.

The questionnaire responses from the students were grouped into four themes, assessing how students respond to a study area in terms of: (1) perception of the space; (2) preference, (3) studying practices and productivity in the space, as well as (4) how physiological and psychological aspects may or may not be affected by the space. Prior to any data collection, the robust ethical clearance of the university was followed and an ethical clearance certificate was obtained. Participation was voluntary, and all participants' personal details remained confidential.

4. Data analysis

4.1 Analysis of the biophilic elements present in the study areas

The first objective is to evaluate study areas in terms of biophilic design. If the areas/rooms are compared to a set benchmark, then we could have a clear understanding of how biophilic a room is. Each of the five cases were observed and each element on the list (Table 1) was checked whether it is present (or not). The five study areas/rooms were: Old John Moffat Foyer (JMF), Old John Moffat computer lab (JMC), Warternwailer Library (WWL), Chamber of mines (COM) and the Willium Cullen Library (WCL).

The old John Moffat study area is mostly characterized by "Human-Nature Relationships" as indicated by the maximum statistic of a 100%. The minimum statistic of 66.67% represents "Place-Based Relationships", which means that elements within this category were least implemented in the study area. Colour and light and actual nature features are equally implemented in the study area, both have high percentages compared to other categories, and contribute to how biophilic the space is. The high mean of 84.46% further demonstrates the high magnitude of biophilic elements present in the study area and this satisfies the deductive approach which prescribes that a data set that exceeds the 50% mark is significant, therefore making the study area highly biophilic. Students responded quite positively to this factor, which provides cause to believe that cognition is improved by the presence of biophilic elements.

Descriptively, the computed results indicate that the Old John Moffat Computer Labs do not consist of any natural shapes and forms such as animal-like features, fluid forms or even shells and spirals to name a few, this is clearly demonstrated by the minimum value of 0.00% allocated to the category. The mean of the results is a strikingly low 33.75%, which is below the biophilic study area Test base percentage of 50 and further demonstrates the ill-performance of the biophilic design categories within the study area. The maximum percentage is subject to a modal of 2 categories, i.e. actual nature experience and place-based relationships. This translates that the study area provides partially indirect experiences of nature to its occupants, although its overall performance is quite poor and does not satisfy the deductive approach, thus making it less biophilic.

The Wartenweiler Library data indicates that for the category of place-based relationships, approximately 17.00% of the 6 elements is present while approximately 50.00% of the elements from the category of natural patterns and processes are present.

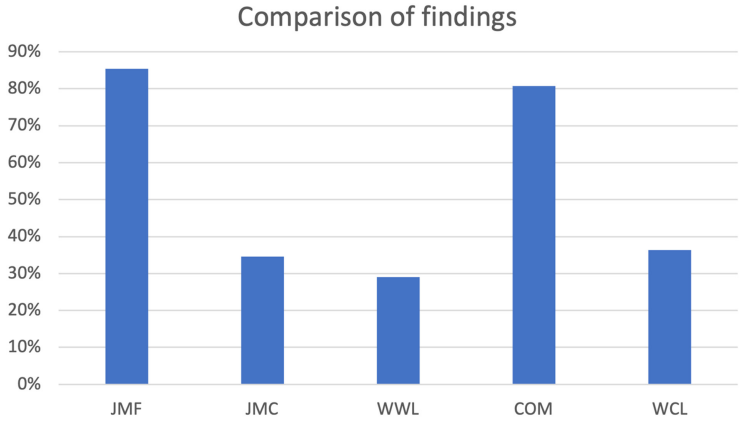
This emphasizes that since most of the categories failed to reach an average of 50.00%, it does not only indicate that the library is less biophilic, but it also contributes to the reasoning why the library cannot be classified as biophilic.

For the COM study area, the survey indicates a 100% presence of natural patterns and processes, which confirms that all the possible elements under the category are present. For example, there is a presence of natural ratios and scales patterned holes, linked series and chains, integration of parts to wholes, area of emphasis, complementary contrasts, bounded spaces, age; change and the patina of time, sensory richness, dynamic balance and tension. It further indicates a minimum of 62.50% for the elements implemented under the category of the actual nature features. This, according to the deductive approach indicates that since all the categories are over 50%, the study has proven to be biophilic.

The William Cullen Library possesses 55.56% of the natural patterns and processes, which is the highest from the different categories of the biophilic elements while it has a minimum of 25.00% of the actual features and the human-nature relationships. This emphasizes that the both the elements of actual nature and human-nature relationships are the least present in the area. Only air and natural material out of 8 elements are present for the actual nature elements, and only order/complexity and fear/awe out of eight (8) under the human-nature relationship. Therefore, according to the deductive approach, actual nature features (25.00%), human-nature relationship (25.00%), natural shapes and forms (28.57%), colour and light (37.50%) failed to meet an average of 50% which does not only make the study least biophilic but also fail to pass the biophilic study area test.

The minimum represents case study 3, and therefore indicates that the Wartenweiler Library is the least biophilic study area from those that have been observed. Although case study 5 (the William Cullen Library) performed slightly better than the Wartenweiler Library and the Old John Moffat Computer Labs, it is on the negative of the mean, below the 50% average required to satisfy the deductive approach and subsequently the biophilic study area test.

Failing to meet these requirements, the William Cullen Library is the third least biophilic study area identified. The maximum represents case study 1, with its focal point being the Old JMF, which is then tailed by case study 4 (COM). Both study areas performed exceptionally well on all tiers, as each category scored percentages of over 50%, thus fulfilling the requirements of the biophilic study area test. The Old John Moffat foyer is therefore the most biophilic study area, followed by the COM which is the second most biophilic as demonstrated in Figure 1 below.



Source(s): Figure created by author

Figure 1.
Comparison of the biophilic test results

Plate 1 consists of two photos: The WWL (lowest score) and JMF (highest score). At the JMF, the prospect and refuge theory is supported and consists of transitional spaces that allow for the occupant a full view and visual access to activities, and other occupants within and outside of the building. The building also happens to satisfy the "indirect experience of nature" as it consists of glazed walls that provide connection to the external environment. WWL on the other hand, does not allow for connection to the outside or any vegetated spaces.

With the clear understanding of the level of biophilic design of each study area/room, it can be used to understand how it affects the perceptions, preferences and productivity of the students studying there. The questionnaires were then implemented to understand the students' perceptions, preferences and productivity in terms of their choice in study area. This enables the objectives:

(1) To determine whether biophilic design contributes to the preference of students.

(2) To determine whether biophilic design contributes to better study productivity

4.2 Analysis of the attitude surveys

4.2.1 Old John Moffat Foyer. 4.2.1.1 Perception. On a broad spectrum, students' perceptions of the study area were quite consistent. Not only did a majority of them express that the type of environment they choose study in impacts on their productivity, but they also intentionally chose to immerse themselves in a study area that caters to all their needs, i.e. comfort, the ability to concentrate on tasks, minimal distractions and a rejuvenating atmosphere. Furthermore, the Old JMF consists of all the direct and indirect experiences of nature that the students perceived in it, of which they further expressed had an influence on their selection.

4.2.1.2 Preference. All the students shared the sentiments that how conducive a space is for their studying largely influences their productivity, with the bulk of the qualities selected such as comfort, multi-functionality, ease of access and a reviving natural space being some of the factors that make a study area conducive. A theme of biophilic elements was present across all the students' responses on what preferences compel them to be more productivity, hence making the Old JMF a highly preferred study area due to its biophilic design.

4.2.1.3 Study practices and productivity. The students within this space appear to thrive most in biophilic study areas than in less/non-biophilic study areas. They have adopted studying practices that contribute to their productivity, with most students vouching for acquiring an area designated for studying purposes as they strongly believe that this factor improves the effectiveness of their studying. The students further demonstrated their affinity for nature by gravitating towards spaces that possess more natural elements, whilst disapproving of those that had a lack thereof. Results from this study area strongly suggest that there is a relationship between students' preference, studying practices and productivity.

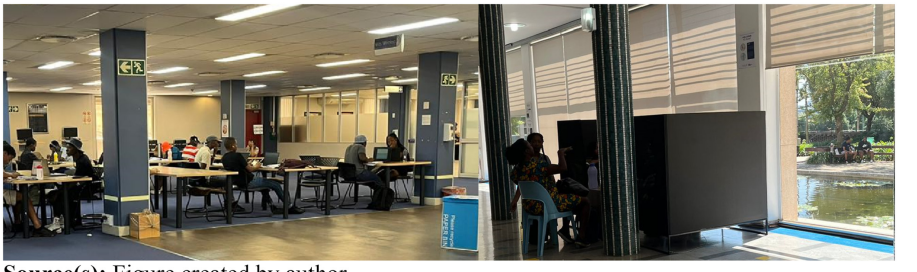


Plate 1.
Photos – WWL on the left and John Moffat Foye (JMF) on the right

Source(s): Figure created by author

4.2.1.4 Physiological and psychological aspects. The students expressed that the study area elicits positive emotions, provides an inviting and reviving space as well as one that contributes to their physiological well-being. This is further supported by how the space has respiratory benefits for the students as it largely harnesses ventilation from nature and students' reporting that their heart rate recovery is quite as they do not feel tense nor anxious in the environment. Therefore, the more biophilic the space is, the more its occupants' benefit from it.

4.2.2 Old John Moffat computer labs. 4.2.2.1 Perception. Although a reasonable number of students expressed the space they study in impacts on the effectiveness of their study sessions, a few of them had opposing views, expressing that the factor of location has no impact on their studying. The students' perception of the study area was alarmingly inaccurate, as most of them noted elements of nature that do not even characterize the space as found in the case study. The students then perceived the elements they selected as contributing factors to their choice of study area, which may suggest that the students may have rather expressed what elements they would prefer in a study area instead of those that were present in the study area they completed the questionnaires in. The students' responses may suggest that they would prefer being in a more biophilic space as they described but are content with the space they were in or unaffected by its lack of biophilic qualities.

4.2.2.2 Preference. Although students firmly expressed their preference of a study area that has sparing or no implementation of biophilic design, they equally expressed that they would prefer indirectly biophilic environments. The students went on to indicate that how conducive a study area is, could highly impact their productivity, but still had no intention to seek out a study area that would provide for this positive result, which is supported by a significant number of students expressing that they have observed no difference in their productivity and concentration within the Old John Moffat computer labs compared to other study areas.

4.2.2.3 Study practices and productivity. The students appear to have adopted good studying techniques following that they believe that such studying practices influence how much they benefit from their study sessions. The students expressed that they feel productive in biophilic and non-biophilic environments, thus making their preference for biophilic elements insignificant to their productivity within a study area.

4.2.2.4 Physiological and psychological aspects. The student's responses suggest that the heart rate recovery within the study area is slightly slow as majority expressed that they have to step out of the room for the tension to be eased. Physiological aspects also affected are discomfort and humidity within the space, of which a reasonable number of students expressed as undesirable characteristics of the space. Nonetheless, most of the students maintained that they are in a calm state within the study area and are able to focus, although they would feel the same way in study areas that possess more biophilic elements. It is therefore deduced that these students express feelings of contentment in circumstance as their productivity is unaffected by how they feel about a space.

4.2.3 Chamber of mines study area. 4.2.3.1 Perception. According to the analysis conducted on students studying in chamber of mine, students perceive the study area as somewhat most biophilic since they are able to identify and acknowledge the presence of natural elements in the study area.

4.2.3.2 Preference. The analysis further indicates that the student prefers the natural elements present in the study area, since they bring them comfort, emotional stability, makes them feel calm and very productive. These elements include daylight, natural plants, natural shapes and paintings that represent natural elements.

4.2.3.3 Study practices and productivity. Following the preference, students believe that their study productivity is influenced by natural elements present in the study area as they bring them comfort and calmness to enhance their level of productivity. Some of the students

also believe that the studies techniques also influence the ability to remember concepts and improve their academic performance. Some of the students believe that their study techniques also influence the ability to remember concepts and improve their academic performance.

4.2.3.4 Physiological and psychological aspects. Students feel physiologically and psychologically healthy when studying in this area. They do not feel overwhelmed or pressured by the design and structure of the environment. This therefore indicates that the implementation of biophilic elements in study areas can enhance the productivity of students studying in the area.

4.2.4 William Cullen study area. 4.2.4.1 Perception. According to the study conducted in the William Cullen Library, students perceive the study area as a tense study area that makes them feel anxious and fail to be productive as a result. It is also seen a dull study area that requires move natural element to help them improve their level of productivity.

4.2.4.2 Preference. Most elements that are preferred by students are not present in the William Cullen Library. Therefore, this indicates that the students may prefer studying in the area due to reasons that it is the only nearest study area open at that time and not because of the availability of natural elements. The students further indicated that they prefer natural elements because of the comfort they bring, and the calmness which influences their productivity.

4.2.4.3 Study practices and productivity. According to the analysis, majority of the students do not believe that the study techniques influence their level of productivity when studying. They also believe that the specific study area (William Cullen study area) does not influence the level of productivity. From the productivity graph above, student indicate that they are more productive when they study in minimal natural areas to be more productive.

4.2.4.4 Physiological and psychological aspects. Students feel a psychological discomfort when studying in this area. This, therefore, negatively affects their level of productivity and adds more stress to their academic profile. To sum it up, students in the William Cullen study area do not productively perform with this study areas due to the intense environment but would prefer more natural element to improve their level of productivity. This means, biophilic designs in study areas can improve their productivity.

4.2.5 Wartenweiler library study area. 4.2.5.1 Perception. The students who study in Wartenweiler library perceive the space as an environment that can help them, focus mainly due to less distractions and quietness. They also state that the library makes them feel great, energized and able to concentrate on their tasks hence improving their productivity.

4.2.5.2 Preference. The students' preferred study area differs greatly from what they perceive Wartenweiler library to be. Most students prefer a study area which elicits positive emotions, which can also contribute positively to their mental and physical health. They do not prefer a space void of greenery, a space with more artificial light than natural (similar to a basement in characteristics). They also prefer a space that can positively impact on their productivity, a space with controlled temperatures, open flexible plan, with plant life, direct sunlight, easily accessible, peaceful and comfortable. Their preferred study area Wartenweiler supports their studying practices with the main quality of peaceful and quiet; which the students value more for their productivity.

4.2.5.3 Study practices and productivity. All the students who use Wartenweiler library have adopted ways to ensure that their study sessions are productive, some of which include: organizing work, getting a space dedicated to studying, taking detailed notes, avoiding distractions and taking adequate breaks in between study session. The most important factors for them to have a productive study session are a very quiet and peaceful area which has an open flexible plan with controlled temperatures.

4.2.5.4 Physiological and psychological aspects. Most students feel calmer and at ease in the Wartenweiler library, even though they experience more positive emotions in a natural

environment. They are comfortable with the humidity and ventilation within the library, although they sometimes need to step outside to the natural environment to breath fresh air.

5. Conclusion

This study used a mixed method approach consisting of two sections. The one section being the evaluation of the presence of biophilic elements within five study areas at the University of the Witwatersrand. The second section was data collected via questionnaires from nine students studying in each of the study areas. This was to achieve the main aim of this study, which was to determine how biophilic design in study areas affects the perceptions, preferences and study productivity of students.

The University of the Witwatersrand does in fact have biophilic study areas although there are only a few of them. From the sample size of five study areas, only two study areas have the qualities of a biophilic study area: Old JMF and chamber of mines. The other study areas scored under 50%, and therefore do not qualify as biophilic. It was also noted that, while the study areas did not all demonstrate high percentages and frequencies of biophilic design (see Table 2), they all did show some presence of biophilic design, albeit not sufficient to qualify as biophilic in accordance with the deductive approach used in this study. However, this is not insignificant (the lesser presence of biophilic design) and would benefit from further analysis. In general, these findings indicate a somewhat positive outcome of the study's initial objective of evaluating the study areas for biophilic design.

In summary, the students prefer to study in biophilic study areas. Most students across all the study areas have stated that biophilic or natural environments elicit positive emotions and make them feel rejuvenated and energized. The main issue they face with some of the biophilic study areas is that they are not usually quiet and do not have proper monitoring to ensure quietness to improve productivity. Furthermore, in the non-biophilic study areas, the students may prefer biophilic spaces, but find that they do not largely contribute. The students that preferred either one of the two biophilic study areas (Old JMF and Chamber of Mines), reported an improvement in study productivity. This translates back to the main aim of this study. The students perceive the biophilic areas to have a positive effect on them, especially productive studying. This causes them to prefer the biophilic study areas.

It seems that the biophilic study areas draw many students. However, this has a negative effect on the quietness that is required. This then keeps other students away that are in greater need of a quiet study area. Perhaps if all study areas are biophilic and monitored to remain a quiet zone, it could have a greater impact on study productivity on campus.

Table 2. Frequency and percentage of biophilic elements per study area

Biophilic elements	JMF	JMC	WWL	COM	WCL
Actual nature features	7 = 87.50%	4 = 50.00%	2 = 25.00%	5 = 62.50%	2 = 25.00%
Natural shapes and forms	6 = 85.71%	0 = 0.00%	2 = 28.57%	5 = 71.43%	2 = 28.57%
Natural patterns and processes	8 = 80.00%	4 = 40.00%	5 = 50.00%	10 = 100.00%	5 = 50%
Colour and light	14 = 93.33%	6 = 40.00%	4 = 26.66%	13 = 86.67%	6 = 40.00%
Place-based relationships	4 = 66.67%	3 = 50.00%	1 = 16.67%	4 = 66.67%	3 = 50.00%
Human-nature relationships	8 = 100%	2 = 25.00%	2 = 25.00%	7 = 87.50%	2 = 25.00%
Total	*47 = 85.45%*	*19 = 34.55%*	*16 = 29.09%*	*44 = 80.80%*	*20 = 36.36%*

Source(s): Table created by author

This study made use of a small sample size of nine students per study area, which equates to 18% of the population of roughly 50 users at a time. This sample poses a limitation in terms of the generalizability of the findings. A greater sample size would make the findings more robust. Future studies can focus on evaluating study productivity and wellbeing in biophilic vs non-biophilic residences for students. Studies could also focus on biophilic vs non-biophilic lecture halls in South Africa. Greater focus can be given to the various elements of biophilic design. For example, which elements carry more weight than others and why?

There is a relationship between monitoring required and biophilic areas. What this means is that there are areas that are not well monitored and therefore allow too much noise permeation, which then turns to interference with the positive outcomes of being in a biophilic area. This relationship has not been studied by the researcher. Subsequently, there is a question of whether the observed biophilic study areas were designed with monitoring practices in mind, and if so, how it is that these are found lacking in these observed study areas. Additionally, one could then ask whether all biophilic buildings (those found in institutions of higher learning or other educational facilities) require that monitoring practices be included in their design. This discussion turns on the role of monitoring practices in biophilic design in general on two fronts, (i) it is a question of monitoring the natural elements and ensuring their continued survival, and (2) it is a question of monitoring the human element to prevent the destruction of the natural elements, as well as ensuring the sanctity of the biophilic area such that the benefits of the area can be best observed and enjoyed by users.

In conclusion, biophilic study areas can improve study productivity within students and thereby improve their academic performance, mental health and physical health. The biophilic study areas, however, need to be closely monitored to fit all the characteristics of a study area, including quietness and peacefulness. Universities should make it a priority to provide enough biophilic study areas with monitoring in place, so all students could have access to it.

References

Alabi, A.A. (2022), "Suicide attempts among students of higher education, Nelson Mandela Bay Municipality, South Africa", *South Africa Family Practice*, Vol. 64 No. 1, pp. 64-e7, 2022 Nov 8, doi: 10.4102/safp.v64i1.5609.

Ali, S., Haider, Z., Munir, F., Khan, H. and Ahmed, A. (2013), "Factors contributing to the students' academic performance: a case study of Islamia University Sub-Campus", *American Journal of Educational Research*, Vol. 1 No. 8, pp. 283-289, doi: 10.12691/education-1-8-3.

Aristizabal, S., Byun, K., Porter, P., Clements, N., Campanella, C., Li, L., Mullan, A., Ly, S., Senerat, A., Nenadic, I.Z., Browning, W.D., Loftness, V. and Bauer, B. (2021), "Biophilic office design: exploring the impact of a multisensory approach on human well-being", *Journal of Environmental Psychology*, Vol. 77, 101682, doi: 10.1016/j.jenvp.2021.101682.

Barbiero, G. and Berto, R. (2021), "Biophilia as evolutionary adaptation: an onto-and phylogenetic framework for biophilic design", *Frontiers in Psychology*, Vol. 12, 700709, doi: 10.3389/fpsyg.2021.700709.

Bernard, H.W. (1957), "Studying effectively", in Bernard, H.W. (Ed.), *Toward Better Personal Adjustment*, McGraw-Hill Book Company, pp. 115-139.

Bogerd, V.D.N., Dijkstra, S.C., Koole, S.L., Seidell, J.C., de Vries, R. and Maas, J. (2020), *Nature in the Indoor and Outdoor Study Environment and Secondary and Tertiary Education Students' Well-Being, Academic Outcomes, and Possible Mediating Pathways: A Systematic Review with Recommendations for Science and Practice*, Vol. 66, 102403, Health & Place.

Burton, D. (2022), "Biophilic design in higher education: exploring nature-based design inclusion in classrooms", Thesis. Georgia Southern University.

Campbell, F., Blank, L., Cantrell, A., Baxter, S., Blackmore, C., Dixon, J. and Goyder, E. (2022), "Factors that influence mental health of university and college students in the UK: a systematic review", *BMC Public Health*, Vol. 22 No. 1, pp. 1-22, doi: 10.1186/s12889-022-13943-x.

Determan, J., Akers, M.A., Albright, T., Browning, B., Martin-Dunlop, C., Archibald, P. and Caruolo, V. (2019), *The Impact of Biophilic Learning Spaces on Student Success*, available at: https://cgdarch.com/wp-content/uploads/2019/12/The-Impact-of-Biophilic-Learning-Spaceson-Student-Success.pdf

Dewi, O.C., Ismoyo, A.D., Felly, R. and Yohardi, L. (2020), "Energy-efficient lighting and biophilic design concept to boost reading interest in social facilities' library", *IOP Conference Series: Earth and Environmental Science*, Vol. 505 No. 1, 012008, IOP Publishing.

Dillon, R.F. and Osborne, S.S. (2006), "Intelligence and behavior among individuals identified with attention deficit disorders", *Exceptionality*, Vol. 14 No. 1, pp. 3-18, doi: 10.1207/s15327035ex1401_2.

Elmashharawi, A. (2019), "Biophilic design for bringing educational spaces to life", *Journal of Design Studio*, Vol. 1 No. 1, pp. 16-21.

Houri, A. and Kincade, L. (2022), *The Connection between Mental Health and Academic Success*, GLO-Groves Learning Organization, p. 2023, accessed February, 12.

Hung, S.H. and Chang, C.Y. (2021), "Health benefits of evidence-based biophilic-designed environments: a review", *Journal of People, Plants, and Environment*, Vol. 24 No. 1, pp. 1-16, doi: 10.11628/ksppe.2021.24.1.1.

Islam, A. and Tasnim, S. (2021), "An analysis of factors influencing academic performance of undergraduate students: a case study of rabindra university, Bangladesh (rub)", *Shanlax International Journal of Education*, Vol. 9 No. 3, pp. 127-135, doi: 10.34293/education.v9i3.3732.

Jimenez, M.P., DeVille, N.V., Elliott, E.G., Schiff, J.E., Wilt, G.E., Hart, J.E. and James, P. (2021), "Associations between nature exposure and health: a review of the evidence", *International Journal of Environmental Research and Public Health*, Vol. 18 No. 9, p. 4790, doi: 10.3390/ijerph18094790.

Kayihan, S., Guney, O. and Ünal, F.C. (2018), "Biophilia as the main design question in the architectural design studio teaching", *Megaron*, Vol. 13 No. 1, pp. 1-12, doi: 10.5505/megaron.2017.59265.

Kellert, S. (2016), "Biophilia and biomimicry: evolutionary adaptation of human versus non-human nature", *Intelligent Buildings International*, Vol. 8 No. 2, pp. 51-56, doi: 10.1080/17508975.2014.902802.

Kellert, S. and Calabrese, E. (2015), *The Practice of Biophilic Design*, Terrapin Bright LLC, London, Vol. 3, pp. 21-46.

Leech, N.L. and Onwuegbuzie, A.J. (2009), "A typology of mixed methods research designs", *Quality and Quantity*, Vol. 43 No. 2, pp. 265-275, doi: 10.1007/s11135-007-9105-3.

Makhubela, M. (2021), "Suicide and depression in university students: a possible epidemic", *South African Journal of Psychology*, Vol. 51 No. 1, pp. 3-5, doi: 10.1177/0081246321992179.

Mallen, E., Bakin, J., Stone, B., Sivakumar, R. and Lanza, K. (2020), "Thermal impacts of built and vegetated environments on local microclimates in an Urban University campus", *Urban Climate*, Vol. 32, 100640, doi: 10.1016/j.uclim.2020.100640.

Mofatteh, M. (2021), "Risk factors associated with stress, anxiety, and depression among university undergraduate students", *AIMS Public Health*, Vol. 8 No. 1, pp. 36-65, doi: 10.3934/publichealth.2021004.

Natalia, D. and Roman, S. (2022), "Life hacks for studying well", in *The 12th International scientific and practical conference "Modern directions of scientific research development"*, (May 18-20, 2022), BoScience, Chicago, USA, Vol. 2022 No. 930, pp. 693.

Peters, T. and D'Penna, K. (2020), "Biophilic design for restorative university learning environments: a critical review of literature and design recommendations", *Sustainability*, Vol. 12 No. 17, p. 7064, doi: 10.3390/su12177064.

Ryan, C. (2012), "Cross-case analysis", in *Field Guide to Case Study Research in Tourism, Hospitality and Leisure*, Emerald Group Publishing, pp. 543-558.

Ryan, C.O., Browning, W.D., Clancy, J.O., Andrews, S.L. and Kallianpurkar, N.B. (2014), "Biophilic design patterns: emerging nature-based parameters for health and well-being in the built environment", *ArchNet-IJAR: International Journal of Architectural Research*, Vol. 8 No. 2, p. 62, doi: 10.26687/archnet-ijar.v8i2.436.

Saunders, M., Lewis, P. and Thornhill, A. (2016), *Research Methods for Business Students*, 7th ed., Pearson, England.

Sayed, A. and Nagy, G. (2020), "Design strategies for integrating biophilic design to enhance the students' performance in existing primary schools in Egypt", *Fayoum University Journal of Engineering*, Vol. 3 No. 2, pp. 27-39, doi: 10.21608/fuje.2020.204935.

Simarmata, A. (2023), "The creativity in the design of hospital inpatient rooms with biophilic criteria", *E3S Web of Conferences*, Vol. 426, 01087, EDP Sciences.

Stake, R.E. (2000), "Case studies", in Denzin, N.K. and Lincoln, Y.S. (Eds), *Handbook of Qualitative Research*, pp. 435-454.

Szulewski, A., van Gog, T., Paas, F. and Sweller, J. (2022), *Cognitive Load Theory: Researching and Planning Teaching to Maximise Learning*, Researching Medical Education, pp. 303-314.

Tahoun, Z.N.A. (2019), "Awareness assessment of biophilic design principles application", *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, Vol. 329 No. 1, 012044, doi: 10.1088/1755-1315/329/1/012044.

Thermory (2022), "Implementing biophilic design in public spaces", available at: https://thermory.com/blog/implementing-biophilic-design-in-public-spaces/(accessed 1 June 2022).

Wijesooriya, N. and Brambilla, A. (2021), "Bridging biophilic design and environmentally sustainable design: a critical review", *Journal of Cleaner Production*, Vol. 283, 124591, doi: 10.1016/j.jclepro.2020.124591.

Wilson, E.O. (1984), "The relation between caste ratios and division of labor in the ant genus Pheidole (Hymenoptera: formicidae)", *Behavioral Ecology and Sociobiology*, Vol. 16 No. 1, pp. 89-98, doi: 10.1007/bf00293108.

Xue, J., Wu, T., Dai, Y. and Xia, Y. (2019), "Electrospinning and electrospun nanofibers: methods, materials, and applications", *Chemical Reviews*, Vol. 119 No. 8, pp. 5298-5415, doi: 10.1021/acs.chemrev.8b00593.

Yin, J., Zhu, S., MacNaughton, P., Allen, J.G. and Spengler, J.D. (2018), "Physiological and cognitive performance of exposure to biophilic indoor environment", *Building and Environment*, Vol. 132 No. 132, pp. 255-326, doi: 10.1016/j.buildenv.2018.01.006.

Corresponding author
Rolien Terblanche can be contacted at: rolien.terblanche@wits.ac.za