Flourishing the Indoor Environment Quality of Workplaces using the Biophilic Architectural Design

A Thesis Submitted for the Degree of Doctor of Philosophy

by

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ABSTRACT

The central argument in this thesis is that workplace users' health, well-being and productivity are affected by indoor environmental quality (IEQ) and that their overall satisfaction is related to the IEQ factors within the workplace. In addition, it is proposed that enhancing the indoor environment using Biophilic Design can positively influence occupants' health, well-being and productivity in co-working offices and university research rooms.

To test this argument, a methodology based on the Flourish Model was developed to collect interview data, discrete IEQ measurements and post-occupancy evaluation (POE) responses. This thesis is made up of three empirical parts.

The first part evaluates occupants' health, well-being and productivity in the Second Home co-working offices, which contain 30 multidiscipline companies. Data were collected through on-site observation and interviewing 10 HR members; these data were then analysed to determine how the implication of Biophilic Design patterns can help solve several IEQ issues and establish how these patterns are related to overall satisfaction and productivity. The results of this empirical part show two main points: first, the addition of plants as part of the Biophilic Architecture positively affected occupants' health and well-being positively, and some of these plants controlled the thermal comfort, which includes the temperature and humidity as well as the air quality of the office environment; second, other Biophilic features were added to control noise levels in the space, while some of them were for aesthetic value. However, using some green features for atheistic value is not enough to reach the best environment quality and meet occupant expectations in the office environment. Finally, the implication of the Biophilic patterns is connected to the cost used in a project, starting from adding plants to significant changes in the whole building construction.

The second empirical part of this study was conducted in five research rooms at Brunel University London in 2 old and 3 recently developed buildings by surveying the researchers twice and conducting a measurement test using Arduino sensors in five zones for 14 days. The most obvious finding to emerge from this study is that the

qualities of the five key aspects of IEQ, namely thermal comfort, indoor air quality, lighting environment, acoustic environment and office space layout, have significantly positive correlations with occupants' productivity. Moreover, the participants assured that Biophilic Design offers many ways to improve their offices. Several suggestions have been presented for Biophilic solutions depending on the building age and issues raised. Finally, although some of the measured IEQ conditions were relatively good, with no significant fluctuation across the research rooms, it was noted that there is a difference between objective IEQ data and subjective occupant evaluations. The recently developed buildings which designed with fully double-glazed façades showed the highest overall health, well-being and productivity levels, whereas the old buildings constructed with small windows or with no access to the daylight had the lowest; they had lower window-to-wall ratios. The results support that the measurements do not express the absolute satisfaction of the occupants. Nevertheless, the findings were useful to be considered in the third imperial part.

As the main research output, this project created a co-design toolkit that offers an opportunity for designers and architects to indicate their perspectives on improving open-plan workplaces. At the same time, this toolkit helps enhance the office environment by means of Biophilic Design and by bringing the natural environment indoors. This project is the first of its kind to develop a co-design toolkit for workplace design that can be used by designers, architects, students and even stakeholders to improve the design of workplaces in a way that positively affects their occupants.

The toolkit was created in a co-design study in which the participants interactively discussed and shared their ideas as to the functionality and design of the toolkit. Then, using tow testing rounds with 6 and 15 designers and architects respectively. The researcher collated and modelled the results in the direction that they wished by using four types of cards: the activity guide, which is designed to explain the aim and the process of the toolkit to the user; the flourish cards, which created to evaluate the existing workplace situation and determine the main IEQ issues; the Biophilic cards, which present different solutions with different user budgets; and finally, the plant cards, which deliver a number of floor and desk plants with some tips that help the user to find the right location for using them.

DEDICATED TO …

This trip assured me that one's only army is his family. Whatever the circumstances and whatever the difficulties, the family will always be the purest bond and the first priority. There are no people more important than my family to dedicate my thesis to.

***My Father**, the man who was absent from my eyes and was never absent from my heart. I know that you see me from a better place now and you would be proud of me if you witnessed this moment.*

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"Allah will exalt those who believe among you, and those who have the knowledge, to high ranks" Sorah Al-Mujaadila, verse 11.

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DECLARATION OF AUTHORSHIP

I, YOUMNA AL-DMOUR, "hereby declare that the thesis is based on my original work, except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Brunel University or other institutions". I confirm that:

1. Al-Dmour, Y., Garaj, V. and Clements-Croome, D., 2021. The flourishing of Biophilic workplaces:'Second Home'offices as a case study. *Intelligent Buildings International*, 13(4), pp.261-274.

2. Clements-Croome, D., Bowman, C., Al-Dmour, Y. (2021). Using the Flourish Model for Environmental Design. *In: Kohlert, C. (eds) Das menschliche Büro - The human(e) office. Springer Vieweg, Wiesbaden*. https://doi.org/10.1007/978-3-658-33519-9_20

3. A paper (*In the Eye of the Flourish Wheel: An Assessment of Users' Health, Well-Being and Productivity in University Research Rooms*) was drawn from the first survey presented in Chapter 5, written with Dr Vanja Garaj and accepted in March 2022 in *Intelligent Building International Journal*

4. Al-Dmour, Y. and Garaj, V. (2022) '*Flourishing the Biophilic Workplaces: A Co-Design Toolkit*', Proceedings of the 3rd Transdisciplinary Workplace Research Conference, Milan, Italy, 7-10 September, pp. 327 – 339.

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1. CHAPTER ONE: INTRODUCTION

1.1 Background

1.1.1 Indoor Environments of Workplaces

In today's rapidly expanding world, people spend about 70–90% of their time indoors, and a large number of them work in offices (Oseland, 1999; ASHRAE, 2004, 2010; Clements-Croome, 2020). This is dependent on the area they live in, the responsibilities of their job, gender, seasons and age (Heinrich, 2011, ASHRAE, 1993). The time spent indoors is higher for employed adults. The daily time spent at the workplace and the effect of the indoor environment quality of an office building on occupants led the researcher to focus on and investigate office buildings.

It was not until the mid-20th century that researchers considered the effect of some physical parameters of indoor environments. An early example in this vein is Maslow's (1943) hierarchy of needs, as well as Vernon and Bedford's (1930) work on air quality. Later, the influence of the indoor environment on workplace productivity was discussed by Herzberg (1966) and Heschong (1979). Therefore, the need to address the impacts of these spaces on the health, well-being and productivity of occupants has grown (Gray and Birrell, 2014).

Building on the principles of Maslow and Herzberg, extant literature suggests that the indoor environment in an office building directly affects the comfort of occupants and, in turn, impacts their health and well-being (Bordass, Bromley and Leaman, 1993; Leaman and Bordass, 1999; Bordass et al., 2001; Mackerron and Mourato, 2013; Collinge et al., 2014; Tsushima, Tanabe and Utsumi, 2015; McCunn, Kim and Feracor, 2018). Furthermore, these works highlighted that healthy buildings produce more flourishing and happy inhabitants (Clements-Croome, 2013; Mendell et al., 2002). Also, workplaces with effective and favourable atmospheres help decrease employee absenteeism, reduce staff turnover and increase occupant productivity and satisfaction (Construction, 2014; Council, 2004).

It is becoming essential to not only understand the indoor workplace environment and its effect on occupant perceptions and economics but also to consider the basic human aspects within the design of buildings to create sustainable workspaces (Frontczak et al., 2012; Van Der Voordt, 2004).

Quality and productive work require good levels of concentration; therefore, it is essential to understand how human systems deal with workflow. In addition, various stressors can arise from the physical environment (Clements-Croome, 2016), and these can exist across the indoor environmental quality (IEQ) factors, a worker's personal life and actual work tasks.

1.1.2 Post-Occupancy Evaluation (POE)

Post-Occupancy Evaluation (POE) is a general approach to obtaining feedback about a building's performance in use, including energy performance, IEQ and occupants' satisfaction and productivity, among others (Li, Froese and Brager, 2018).

Evaluating building performance is encouraged mainly to, first, learn from current buildings and their occupants how buildings are made and used to provide the knowledge necessary to design buildings according to user requirements, such as the design briefs and programs; second, evaluate the possible consequences of design alternatives to enable the selection of the most appropriate materials, systems or structures; and third, allow the possibility of reviewing whether and to what extent the conditions predicted for the design action did occur in the completed building (Manning, 1967).

Accordingly, it would be useful for architects and environmental designers to use POE to determine how environments are being used by their occupants and assess the degree to which these users have satisfied specific design objectives (Friedmann et al., 1978; Malkoc and Ozkan, 2010).

The methods of POE can broadly take account of energy; IEQ physical measurements; occupant survey questionnaires; focus group meetings; structured interviews; visual records; walkthroughs; and technical measures of a building's structure, services and systems (Sanni-Anibire, Hassanain and Al-Hammad, 2016; Leaman, Stevenson and Bordass, 2010).

For example, in the seminal work by Clements-Croome (2016), a theoretical framework for a POE model, called the Flourish Model, was established. It can be used to evaluate a building's environmental factors and the occupants' perceptions of their work environment. The framework also measures how the occupants' bodies respond to the work environment, thereby identifying the actual state of an individual at a particular time and place (see, e.g. Wilson, 2017). The Flourish Model was developed to help create environments in which people thrive. The reasoning behind the model is based on various previous studies on comfort and well-being (Clements-Croome, Turner and Pallaris, 2019). This model is considered a recent POE model and can holistically evaluate the environmental effect of space on users, as shown in the British Council for Offices Wellness Matters Report (BCO, 2018).

1.1.3 IEQ Factors

The effect of IEQ on the well-being and comfort of occupants is an important area of study. The complex nature of IEQ impacts and their subsequent interpreted results are unique, primarily because every individual has different needs and perceptions. A review of a previous IEQ factor analysis (Frontcza and Wargocki, 2011) demonstrated the diverse results across the indoor air quality (IAQ), acoustic, thermal and visual conditions.

Building and occupant performance assessment is a complex subject influenced by external effects, internal criteria and subjective stimuli (Hopfe et al., 2013).

Subjective surveys and physical measurements are the most widely adopted approaches in POEs of IEQ. Subjective surveys ask about occupant perceptions, satisfaction and complaints related to individual environmental factors. Subjective surveys reflect how occupants perceive the IEQ and help identify the degree to which the IEQ satisfies their expectations. Physical measurement of a broad suite of IEQ parameters is expensive and has not been included as frequently as surveys in prior studies.

1.1.4 Biophilic Design Approach

The development of human society and technologies has revolutionised daily life and work. People have gradually moved away from the natural environment to build the environment (Klaniecki et al., 2018; Conn, 1998). This shift has reduced contact with nature and, thus, causes adverse effects on people's health and well-being (Grinde and Patil, 2009; Maller et al., 2006; Wadsworth et al., 2010; Abdelaal, 2019).

Previous studies have explored the concept of Biophilic Design (BD), which presents a method of design that satisfies people's deep and fundamental need to connect with nature (Cooper and Browning, 2015; Xue et al., 2019).

Biophilia is defined as people's innate affinity to the natural world; since the 1980s, it has been explored in the fields of sociology and psychology (Wilson, 1984, 2017). In architecture and design, there has been a recent and rising interest in the impacts of nature on people in buildings (Salingaros, 2015; Kellert et al., 2011), and in the past decade, there has been a significant increase in published peer-reviewed design research relevant to BD (Joye, 2007; Coburn et al., 2019; Abboushi et al., 2019). As a result, BD has emerged in recent years as an architectural design approach that aims to reconnect building occupants to their environment by integrating various natural elements or evocations of nature into the built environment (Gillis and Gatersleben, 2015; Gillis, 2020).

The vast majority of BD studies have focused on designing traditional types of workplaces, elementary schools and healthcare environments such as nursing homes or hospitals. More specific studies have examined the benefits of BD for extreme climates (Parsaee et al. 2019) on the scale of urban design (Beatley and Newman, 2013). Nevertheless, there is a lack of research on the benefits of BD in co-working spaces and university research room settings.

The main reason BD is chosen is that the craving for 'nature' is widely recognised in the contemporary built environment; thus, it is essential to explore Biophilia as a design approach for conceptualising 'nature' in architecture and to discuss how it contributes to enhancing the health and well-being of workplace occupants.

1.2 Research Aim

The primary aim of this research is to assess the impact of IEQ factors on the health and well-being of the occupants of co-working offices (subjectively) and university research rooms (subjectively and objectively).

In addition, this research also evaluates the IEQ of two naturally ventilated types of buildings: one with BD implementation and the other with typical conditions.

This research helps with enhancing office environments using the BD approach and contributes to the development of a co-design toolkit for designers and architects to improve workplaces.

1.3 Research Questions

This research seeks to expand on the existing knowledge by understanding IEQ factors and the relationship between the health and well-being of occupants and the workplace environment.

This research critically considers workplace issues and occupants to present Biophilic solutions and enhance the IEQ of workplaces.

The research contributes to the literature by answering the following questions in sequence:

1. What IEQ factors impact the health, well-being and productivity of workplace occupants?
2. Does BD implementation in the co-working office environment improve the productivity of occupants?

3. If it does, how can the effects of IEQ factors on the occupants of university research rooms be measured and interpreted?
4. How can a tool be designed through BD to help designers and architects improve IEQ issues in the workplace?

Answering these questions contributes to the literature in different ways. First, IEQ is essential to a building's performance because it impacts the health, well-being and productivity of the occupants. Second, it is essential to assess how implementing Biophilic features in an office building can help create a healthy and productive workplace. This is why the effect of IEQ on health and well-being was evaluated at the Second Home company, which was built according to the concept of BD. Third, this study uses Clements-Croome's (2016) POE model, the Flourish Model, which contributes significantly to investigating the university research rooms' actual environment along with the health, well-being and productivity of their occupants as influenced by the IEQ.

Finally, this thesis develops a toolkit that helps designers and architects improve the IEQ in existing workplaces using different Biophilic patterns and budgets.

1.4 Research Objectives

There are three main objectives of this research, as follows:

1. To review the existing theories about POE models and the IEQ factors that affect the health, well-being and productivity of occupants and to describe BD approach applications in open-plan office buildings.
2. To investigate and evaluate the IEQ of university research rooms, both subjectively and objectively, and find out how it affects the health, well-being and productivity of the occupants as well as study the potential for improving these workplaces using BD. Fulfilling this objective identifies the key challenges, opportunities and barriers to improving university research rooms.

3. To create and assess recommendations by designing a co-design toolkit to help designers and architects improve existing workplaces using BD based on the Flourish Model.

1.5 Benefits of the Thesis

This research study benefits people working in the built environment and architecture design sectors of research and academia. The study offers the following contributions:

1. It contributes to the knowledge of the health, well-being and productivity of workplace occupants and IEQ.
2. It contributes to understanding the IEQ factors that are important to the occupants, besides understanding how to measure and enhance them.
3. It presents the IEQ factors that mainly affect the health, well-being and productivity of the occupants. Therefore, this framework can assist designers in creating office buildings that garner higher levels of productivity and performance from the occupants.
4. For researchers, a toolkit to help architects and designers design workplaces using the BD approach was developed as part of this study
5. The study outcomes will benefit professionals in architecture and the built environment who want to design buildings for healthy and productive users as it recommends ways of creating better office spaces.

1.6 Thesis Structure

This section provides an overview of the methodologies used in this research and outlines the thesis. The chapters are structured to represent the sequence of the research study. A summary of the chapters and methods covered in this research is given below (Table 1):

Table 1: Thesis Structure

Chapter	Description	Methods
Chapter 1: Introduction	Provides background on the research and introduces the research study. Contains the research overview, aims, objectives and questions. It also lists the benefits of the research.	–
Chapter 2: Literature Review	Presents a comprehensive literature review of the study. Reviews known IEQ and workplace factors and describe the physical environment of thermal comfort, IAQ, acoustics, lighting and layout and existing health and well-being research. Provides a foundation for developing the field research methodology, presents monitoring and measurement techniques and, finally, reviews the current knowledge on BD.	**Archival**
Chapter 3: Research Methodology	Describes the research methodology, tools and techniques selected from Chapter 2. Also describes each Biophilic specific aspect and how they link to support the study's key objectives and research questions. Presents the data collection methods, divided into qualitative and quantitative research methods.	–
Chapter 4: Qualitative research	Presents a case study of the Second Home company by evaluating how BD affects the health, well-being and productivity of the occupants.	**Case study:** 1. non-participatory observational method. 2. Semi-structured interviews.
Chapter 5: Quantitative research	Describes two- surveys conducted by the researcher in five different research rooms at Brunel University London to evaluate the effect of	**1. Survey**: Two-round questionnaire.

	the surrounding environment on the health, well-being and productivity of the occupants. Reviews the environmental measurements obtained along with the second survey and assess issues noted during the research periods. Finally, a statistical assessment is presented.	**2. IEQ Measurements Test.**
Chapter 6: **Toolkit design**	Presents the design of the toolkit for helping designers and architects improve open-plan workplaces using BD.	**Toolkit design**: Online interviews and focus groups.
Chapter 7: Conclusion	Provides a conclusive review of the holistic research. Reviews the study's success in meeting the research objectives and answering the research questions, and further recommendations are proposed to enhance the research based on the conclusions reached. Describes the originality of the work and its contribution to the existing knowledge.	-

1.7 Chapter Summary

This chapter outlined the current gaps in the research and focused on the health, well-being and productivity of workplace occupants. It also presented the potential benefits of focusing on the IEQ issues in co-working workplaces and university research rooms and how to improve them using BD. Finally, the study's aim, objectives, research questions and benefits were presented.

In support of the hypothesis, a research structure was designed (Figure 1).

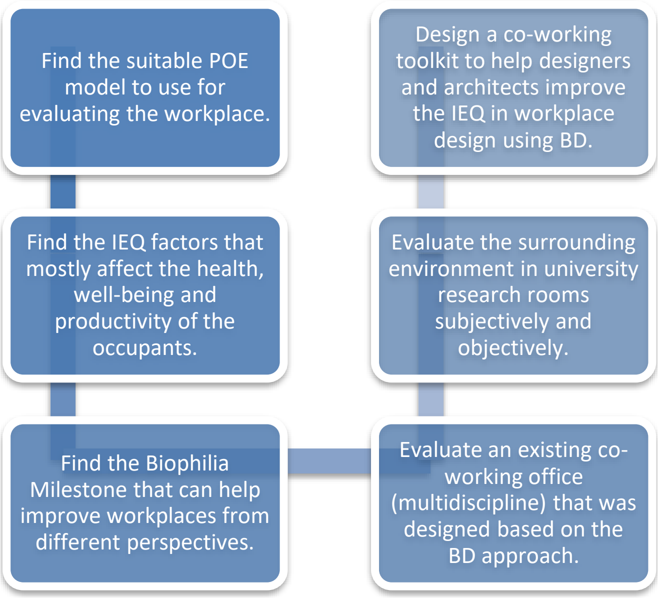


Figure 1: Research Process

The next chapter covers the literature review. It surveys the current literature and research available on IEQ and the health, well-being and productivity of occupants, together with implementing the BD approach in the workplace.

2. CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents background information relative to this study, covering four main areas: the definition, types, and POE methods of workplaces. Then, the IEQ factors that affect the health, well-being and productivity of occupants most and the BD approach are introduced. Finally, a brief background of co-design and co-design toolkits is presented. Figure 2 illustrates the literature review flow.

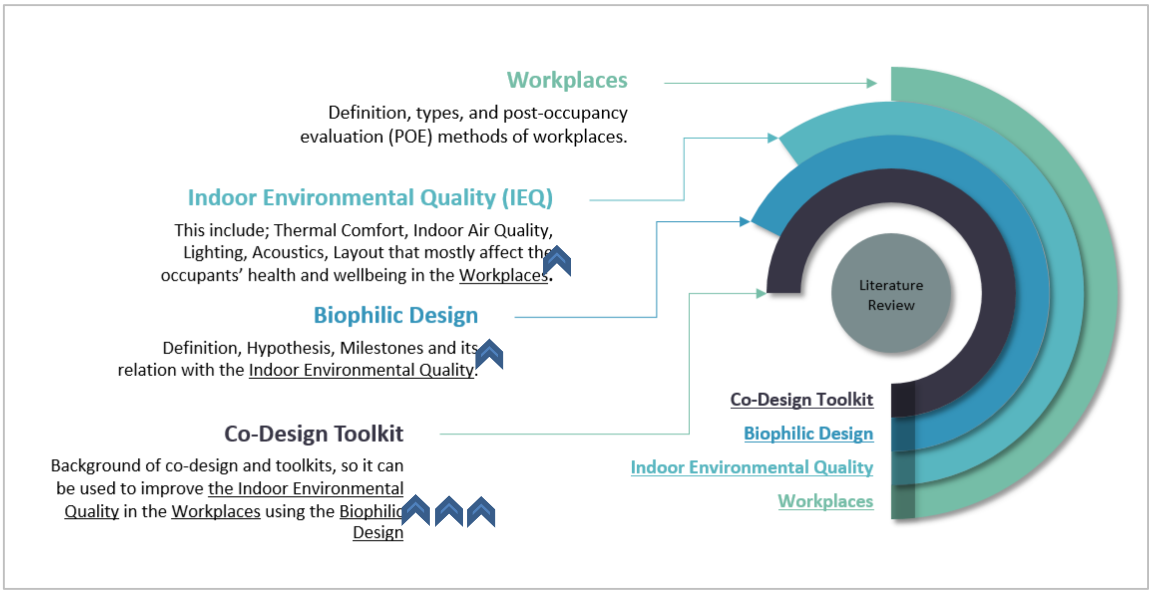


Figure 2: Literature Review Flow

2.2 Workplaces

Giuliano (1982) described an office as a place where people read, think, write and communicate; where ideas are discussed, and plans are made; where money is collected and spent; where a company and other organisations are managed. Offices need to alter their design and structure when technology affects how office work is done. Marmot and Eley (2000) referred to the variety of meanings that can be given to the term 'office'; it may mean the organisation to which an individual belongs, the building itself or just a small space in which one does one’s job (e.g. a cubicle). The office may also relate to individuals within an organisation.

Five office types were named by Duffy (1999), defined according to a particular combination of architectural (spatial organisation) and functional (the type of work) features (Bodin and Bodin, 2008). These types are the cell office (single room office), shared office (up to three people share a single room), flex office (no individual workstation, both furniture and employees are flexible), open-plan office (where the layout is flexible to organisational change and handles changes without reconstruction) and combi office (where the employees spend > 20% of their time at workstations other than their own). The office type in which this research will study IEQ is the open-plan office.

Table 2 summarises the specific architectural and functional features of open-plan offices.

Table 2: Open-Plan Office Features (Bodin and Bodin, 2008)

Open-plan Office	Architectural Features	Functional Features
This layout is flexible to organisational change and handles changes without reconstruction.	Shared space with workstations in groups that are mostly freely organised. Screens between workstations minimise noise at individual workstations and provide some privacy.	Sometimes, amenities can be found at individual workstations. Occupants mainly work individually on routine-based work with low levels of interaction.

Open-plan offices became popular because of their lower building expenses due to the reduced amount of partitions required, lower rental costs due to increased worker density, better adjustability and daylight access (Brennan, Chugh and Kline, 2002). Danielsson and Bodin (2008) concluded that the office type correlates with staff well-being, health and work satisfaction. Their study based on Swedish offices produced the following results: open-plan offices were found inferior to other kinds of offices in terms of general health, and small and large open-plan offices were inferior in terms of psychological and physical issues (Danielsson and Bodin, 2008). Furthermore, unsatisfactory results were identified for all open-plan and combi offices, although the latter showed high satisfaction with cooperation (Quiros, 2009).

Danielsson and Bodin's (2008) literature review identified that high levels of stress, conflict and high blood pressure and a high turnover of workers were triggered by open-plan offices. In addition, the high noise levels cause workers to lose focus, which results in low productivity. Furthermore, privacy is problematic because people can see what others are doing on their computers or hear what they say on the phone, which gives rise to a sense of vulnerability (Oommen, Knowles and Zhao, 2008). However, the trend of designing and constructing open-plan offices is growing globally. In the meantime, several studies have been carried out on this type of office, and they have shown the significant effects of IEQ on the health, well-being and work efficiency of open-plan office occupants (Shafaghat et al. 2014, 2015). In this study, two forms of open-plan workplaces will be investigated: co-working offices and university research rooms.

Several market changes have led to the growth of new types of multi-tenant offices (Van Meel and Vos, 2001): the sharing economy (Bouncken and Reuschl, 2018), the increasing need for flexibility (Gibson and Lizieri, 1999), the growing number of self-employed workers, the growth in the use of technologies and the decreasing and changing need for office space.

Co-working spaces are classified as a significant subgroup of multi-tenant offices (Calder and Courtney, 1992; Parrino, 2015; Weijs-Perrée et al., 2016). They offer workspaces with a high service level and focus on creating a community. The popularity of co-working spaces has increased over the past years (e.g. Huwart, Dichter and Vanrie, 2012; Moriset, 2013; Parrino, 2015). Co-working spaces are dynamic, inspiring and low-cost workplaces where people (from different business backgrounds) can interact, share knowledge and co-create (Spinuzzi, 2012; Fuzi, 2015).

Kojo and Nenonen (2017) suggested that the main drivers for the evolution of co-working spaces were new ways of working, attractiveness, work/life balance, economic efficiency and sustainability.

University research rooms are another form of open-plan office considered in this study. Lately, a great many research rooms (or so-called 'study rooms') in colleges and universities have been designed and constructed for groups of individuals (especially young researchers, such as full-time postgraduate students and post-doctoral researchers) to carry out their daily research work have fallen into this category and can be classified as open-plan offices (Kang and Mak, 2017; Peters and D'Penna, 2020). These young researchers, who spend much time in such research rooms, are an essential and respected part of universities and make a significant contribution to university research work (e.g. Kang and Mak, 2017).

The factors influencing the health, well-being and competitiveness of the occupants of these open-plan office users and the ways to evaluate and improve them must be discussed in depth.

2.3 POE

POE is a process of evaluating the performance of a building after it has been occupied for at least several years (Li, Froese and Brager, 2018). It is a general approach to obtaining feedback about a building's usage performance, including energy performance, IEQ, occupants' satisfaction and productivity, among others.

Organisations gain significant advantages from ensuring that the workplace atmosphere of their offices benefits its occupants and, consequently, their work. Understanding how a workplace affects its occupants can give insights into the interaction between people and their environment, and the data can be fed back into the design process. Furthermore, people benefit from a better awareness of the workplace environment and its effect on their well-being through improved workplace comfort and possible increases in productivity (Duffy, 1999). Nevertheless, despite the importance of the workplace environment and the need to learn its advantages, limited research has been found on the overall effect of the workplace environment on occupants. This is a view endorsed by some researchers (e.g. Preiser, Rabinowitz and White, 1988; Preiser and Wolfgang, 2001; Oseland, 2004).

An extensive literature review by Preiser (2005) found that the history of modern-day POE methods dates back to the 1960s, although not all the studies conducted at that time were called POEs. Preiser (2005) proposed that people started to suspect the difficulties experienced in prisons and hospitals around the time they were partly affected by the design of these environments.

Subsequently, a methodology was developed to establish empirical proof to help understand that the environment had an impact on its occupants. The methodology aimed to test the effect of the built environment on the occupants and determine how they perceived the environment. This methodological framework became known as POE. This terminology became more mainstream when, in 1988, Preiser, Rabinowitz and White wrote a POE textbook, in which POE was defined as ‘the process of evaluating buildings systematically and rigorously after they have been built and occupied for some time’.

Li, Froese and Brager (2018) categorised the purposes of POE in relation to a large number of projects. The purposes of POE that are relevant to this research are the following:

1. **1.** To evaluate the comfort, satisfaction, well-being or health of occupants (Hwang and Kim, 2011; Mlecnik et al., 2012; Ali, Chua and Lim, 2015; Dorsey and Hedge, 2017);
2. **2.** To investigate the factors that affect the satisfaction of occupants (Deuble and De Dear, 2012; Khair et al., 2015; Leder et al., 2016; Martellotta et al., 2016);

3. To understand occupants' opinions or experiences of space (Silva et al., 2017; Brown, 2016; Ferri et al., 2015; Mundo-Hernández, Valerdi-Nochebuena and Sosa-Oliver, 2015);
4. To assess the productivity of occupants (Agha-Hossein et al., 2013; Collinge et al., 2014;)
5. To measure one or more physical characteristics of IEQ: thermal condition (Lakeridou et al., 2012; Jones, Goodhew and de Wilde, 2016), lighting (Alzoubi and Bataineh, 2010; Mathiasen and Frandsen, 2016), IAQ (Wang et al., 2015) and acoustics (Hill and LaVela, 2015).

Traditionally and historically, POE assessments or reviews of the effect of the built environment have been considered the architect's duty. The work plan developed by the Royal Institute of British Architects (RIBA) lays out the phases of an architect's job, from customer briefing and design to completion (RIBA, 1962). However, by the 1990s, researchers of building services engineering had established an interest in the impact of the workplace environment (Cohen et al., 2001). The Building Services Journal recorded the results of several POEs; for example, the studies by Leaman and Bordass (2001) and Cooper (2001) indicated the understanding that developed within the profession of the benefits which might be derived from considering the impact of the workplace environment upon its occupants. Consequently, post-occupancy reviews have concentrated on building facilities, energy use and building operations (Preiser, 2001).

POE has continued to attract research attention over the past decade. The analysis of 146 POE projects since 2010 indicated that housing projects are the most popular research targets, and occupant performance and satisfaction are the most common focus. The most frequently used data collection method is occupant surveys. Many POE protocols have been proposed in the UK, the US, Canada and other countries, but no singular POE protocol has gained worldwide or nationwide dominance. Some emerging research topics related to POE include the visualization of POE results, analyses of occupant survey databases and measurement of occupancy patterns (Li et al., 2018).

2.3.1 POE Methods

POE methods can generally include energy and water assessment; IEQ physical measurements; occupant survey questionnaires; focus group meetings; structured interviews; visual records; walkthroughs; and technical measures of the building structure, services and systems (Leaman et al. 2010; Sanni-Anibire et al., 2016).

Together, Li, Froese and Brager's (2018) work provided important insights into POE methods and classified them into two main groups subjective and objective methods. The subjective methods included occupant surveys, interviews and walkthrough tours, while the objective methods mainly concerned on-site IEQ measurements, energy and water.

Overall, subjective methods like walkthroughs, interviews and surveys (which might include qualitative, open-ended questions) are more commonly used because they are inexpensive (equipment associated with physical measurements is not required) and can help identify problems quickly. Moreover, the occupant survey is gradually becoming a must for POE projects, confirming that increasing attention is being paid in the building industry to issues of occupant health and well-being. As also concluded by Li, Froese and Brager (2018; Figure 3), physical measurements are not commonly used; however, few projects focused on the thermal conditions, lighting, IAQ and acoustics of indoor environments.

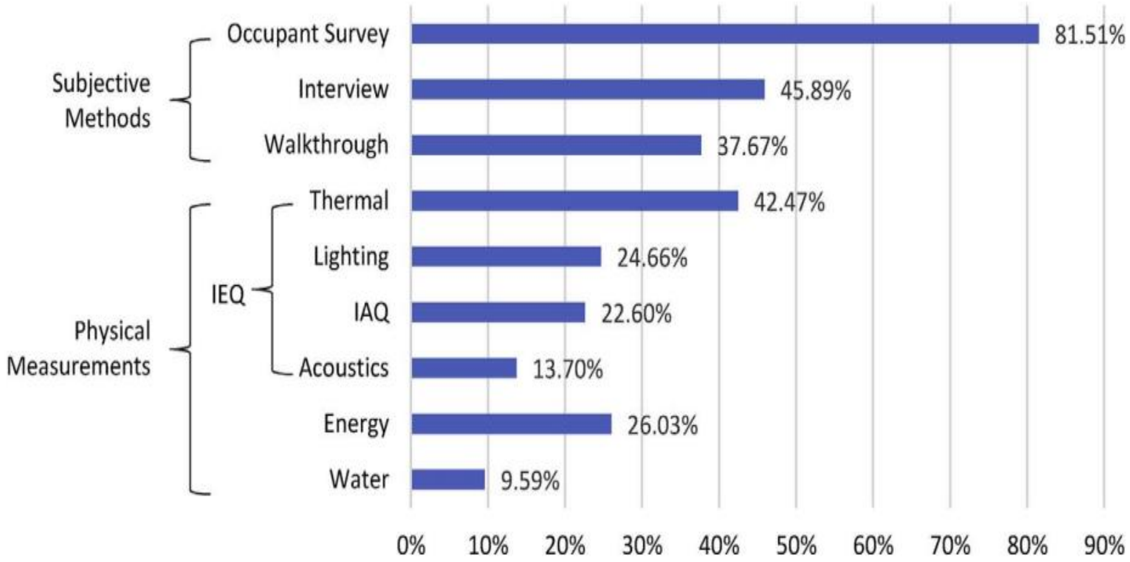


Figure 3: Percentage of Projects That Used Specific Methods (Li, Froese and Brager, 2018).

2.3.2 POE Perspectives

The approach of post-occupancy (PO) assessment has grown with input from the architectural perspective, building services engineers and social scientists who are interested in the effects of the workplace environment (Cooper, 2001). Significant studies from these disciplines have contributed to the development of PO assessment and the current state of knowledge in each field.

From an architectural perspective, Preiser, Rabinowitz and White (1988) indicated that 'PO assessment offers insight into the effects of past design decisions and the subsequent performance of construction'. These writers proposed three components of building performance that can be evaluated. The first is technical, concerning health and safety, for instance, illuminance standards and acoustics. The second is functional, referring to the ability of users to work efficiently in a given setting, for example, ergonomics, storage capacity, etc. The third and final component is behavioural, relating to such psychological dimensions of the workplace environment as the satisfaction and well-being of its occupants.

While Preiser et al.'s (1988) methodology demonstrates positives in advocating the measurement of some objective factors (both quantitative and qualitative) and the collection of both objective and perceptual data, there are some limitations to their evaluations. For example, the questionnaire incorporates aesthetic appeal as a qualitative measure of the environment but does not explore this concept in detail, such as colour scheme, plants, etc. In addition, there are no measures of other qualitative aspects of the environment, such as the furniture. The aspects of the environment which are easier to measure objectively, i.e. space, light, temperature and acoustics, constitute a more significant proportion of the evaluation. Preiser et al. (1988) designed their methodology to be suitable for measuring the impact of any built environment, not specifically workplace environments. Thus, a methodology suitable for evaluating any built environment may not investigate details fine enough to establish the true, holistic impact of the workplace environment.

From a building services perspective, the Usable Building Trust has significantly contributed to POE research. Members of the Usable Buildings Trust and periodicals such as the Building Services Journal and Building Research and Information have promoted POE and a methodology called Post-Occupancy Review of Buildings and their Engineering (PROBE). Aspects evaluated by PROBE are mainly energy audits by Office Assessment Method (OAM), Building Use Studies (BUS), occupant survey (used in PROBE studies and to assess over 700 buildings worldwide to date), Design and Construction and Maintainability and Control Issues.

The PROBE team's research revealed that users still perceive their workplace environment, or aspects of their environment, negatively, and this is linked with lower levels of occupant satisfaction and comfort ratings (Leaman et al., 2010; Leaman and Bordass, 1999; 2001).

The results of their research specifically highlighted that noise and thermal comfort harmed building occupants and that these problems are persistent. In addition, a lack of personal control over the environment was also cited as a significant issue for building occupants (Bordass, Bromley and Leaman, 1993).

The aspects of the environment that rated negatively were cited most frequently and by the highest number of participants were open-plan work areas, large workgroups within organisations, varied activities being carried out in the space, higher densities of occupancy, long working hours, people remaining in the exact same location for the whole working day, long hours spent working at computers, the presence of complex technology which users found difficult to use, irrelevant noise and an inadequate facilities management team with slow response rates (Leaman and Bordass, 2001).

The aim of highlighting these findings was to encourage designers to learn from previous projects and implement this knowledge to develop future designs. This is intended to be part of a continuous feedback loop.

Leaman and Bordass (2001) argued that the complexity of the built environment requires that some limitations be placed upon evaluations to ensure that they are manageable. However, they recognised the importance of other aspects of the environment outside the focus of the PROBE studies. These more qualitative aspects have been considered by social scientists in the POE methodologies they have developed.

One of the first PO assessments reported from a social science perspective that assessed multiple workplaces was by Brill, Margulis and Konar (1984). Using a structured approach based on a questionnaire, with supporting data from quantitative observations of the internal climate and environment, the researchers measured around 70 workplaces. In addition to the quantifiable aspects assessed by construction services engineers, the social science approach included qualitative environmental aspects. The most important aspects of job satisfaction were enclosure, layout, decor, noise, flexibility, engagement, comfort, connectivity, light, temperature, air quality and occupancy. These findings illustrate the value of considering all aspects of the workplace, including some that are not easily quantifiable. The closest association with job satisfaction was found to be the spatial layout, followed by a variety of other qualitative variables, including furniture and personal control or the exercise of preference.

An analysis of the different methods of POE by Oseland and Burton (2012) indicated that whilst internal climate conditions and spatial layout were the aspects of the workplace included most frequently in POEs, the majority of researchers also investigated less easily quantifiable characteristics such as furniture provision, storage and personal control, which were included in over half of the POE methodologies. In addition, other qualitative factors were included in over a quarter of the POEs, such as aesthetics, decoration, breakout space and equipment.

The nature of PO assessment practices has changed over the decades. In the 1960s, architects were encouraged to feed the knowledge of the building they were working on into the design process, which influenced the methodology and heavily influenced the design of the building itself (Preiser, Rabinowitz and White, 1988). Thus, as engineers in building services started to take greater responsibility for PO assessment in the 1980s and 1990s, the internal environment and energy efficiency became the focus of PO assessments.

More in-depth and detailed workplace assessments followed the transition to a narrower focus than the assessments of architects. Researchers such as the PROBE team took environmental and physical measurements and used questionnaires to explore how people viewed their surroundings and the impact that the environment had on their levels of comfort and job satisfaction (Thomas, 2011).

The social scientists' approach was much more holistic in terms of the variety of environmental aspects examined. In their PO assessment models, more qualitative aspects of the environment were investigated, addressing such features as lighting, window provision, etc. and other indirect environmental characteristics, including the sense of personal control and privacy concerning the environment. Thus, the aspects incorporated in the analyses allowed for more holistic evaluations of the workplace (Thomas, 2011).

2.3.3 Flourish Model

Many studies in the current literature focus on just one or two perspectives of the workplace environment; this does not allow for a comprehensive understanding of the experience of occupants in the office environment as a whole, as it is affected simultaneously by so many different aspects (Thomas, 2011).

All the features that establish the workplace environment can have an individual influence on the occupants; however, interaction effects appear when these features are experienced together, as they are in practice. In any case, all aspects may have a different impact when experienced together from their effect when analysed separately (Thomas, 2011). For example, a workplace's colour scheme and spatial layout may affect illuminance levels. This may also influence the occupants' performance and satisfaction with the workplace. Therefore, analysing each aspect of the workplace individually and assuming that the occupants' experience of the environment is simply the result of the sum of isolated experiences may be inaccurate. Thus, the workplace in a real-world setting should be analysed to better understand the workplace environment.

Instead of evaluating the workplace as a whole, Design Quality Matrices (DQM) (Cook, 2008) and PROBE studies (Leaman and Bordass, 1999) considered nothing beyond satisfaction with particular aspects of the environment, such as air temperature. Factors such as perceived productivity, motivation and stimulation, and how they relate to the environment, were not involved in the studies.

Nowadays, organisations recognise that the well-being and productivity of employees play a highly significant role in what is considered economic value. Therefore, indoor environments that support the health, well-being and productivity of occupants are now in growing demand. Figure 4 shows the studies from the past decade, preceding the Flourish Model, in which academic researchers developed an understanding of the health and well-being of workplace occupants and used these aspects to assess factors in workplaces.

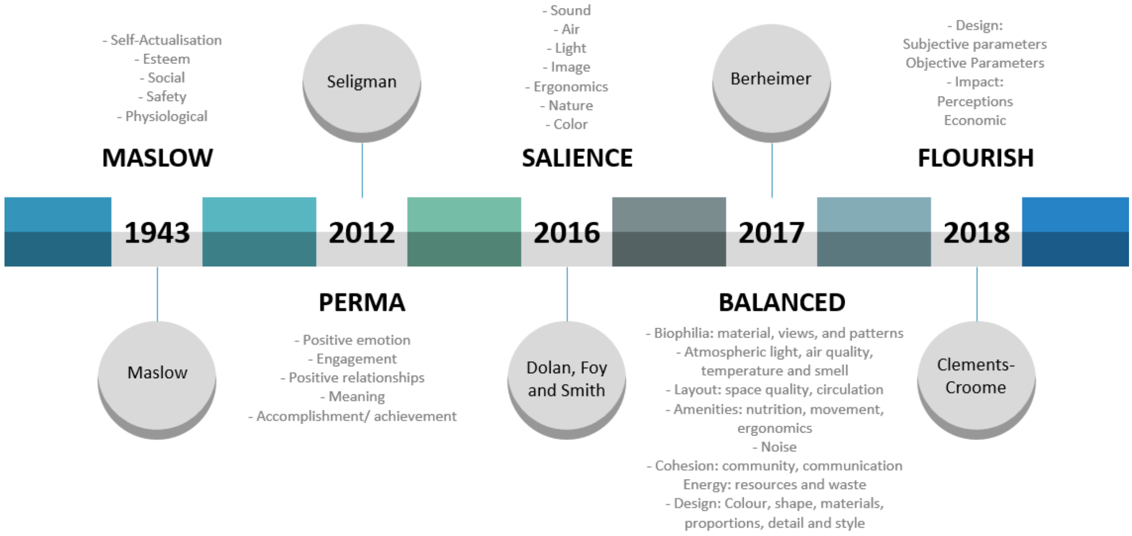


Figure 4: The Academic Research That Preceded the Flourish Model

Figure 4 shows the evaluation models from several researchers' points of view, where they tried to evaluate new aspects. For example, Maslow (1943) was one of the first to describe 'well-being' with his characteristics of a self-actualised person. In 1998, Dr Seligman worked on his questionnaire to define, quantify and create well-being (Rusk and Waters, 2015).

In developing a theory to address this, Seligman (2011) selected five components people pursue because they intrinsically motivate well-being and contribute to it. These elements are pursued their own sake and are defined and measured independently of each other.

The SALIENCE checklist identifies seven essential elements that can be used to explore the design of built environments with well-being in mind: sound, air, light, image, ergonomics, nature and tint. The SALIENCE checklist was designed to bring together behavioural science evidence on how built environments affect what people do and how they feel (Dolan, Foy and Smith, 2016).

Bernheimer (2017) also developed a checklist called the BALANCED Space checklist. This checklist provides a framework to balance the needs of people and purpose with the constraints of space and budget.

With regard to the Flourish Model, flourishing refers to the 'experience of life going well. It is a combination of feeling good and functioning effectively. Flourishing is synonymous with a high level of mental well-being, and it epitomises mental health' (Huppert and So, 2013). The human performance underlying productivity depends on ability or competence, motivation and amenities and opportunity from support systems. As a result, the link between people's feelings and their performance can be seen clearly, together with the effects of their current environment on them (Clements-Croome, Turner and Pallaris, 2019).

This research will adopt the Clements-Croome evaluation model. Clements-Croome (2016) created and developed the Flourish Wheel to help create environments where people thrive. It was developed to establish environments that allow people to flourish in both their daily lives and work, and it is also used as a POE to evaluate the actual situation from three viewpoints: the physical factors, perceptions and feelings and economic consequences of the environment, as shown in Figure 5.

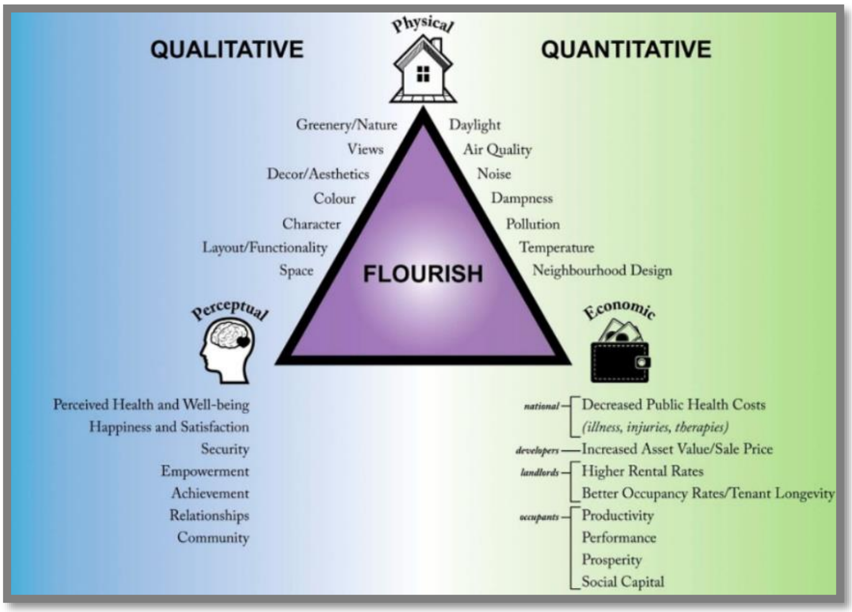


Figure 5: The Flourish Model

The interrelationship between how occupants feel in their environment influences their motivational energy to work and make decisions. This explains the advantages of using the Flourish Model for various stakeholders (Clements-Croome, 2018).

The Flourish Model promotes creating a calm, natural and harmonious environment that will stimulate alpha brain waves (high relaxation) and lower high beta brain waves (high stress). In this manner, it aims to calm the mind of the occupants to improve their attention and create space for their imagination to thrive (Clements-Croome, 2018).

The Flourish Model echoes the checklists proposed by Dolan (2014) in his book ‘Happiness by Design’ and Bernheimer (2017) in her book ‘The Shaping of Us’.

The Flourish Model is also rooted in the research of Maslow (1943), Seligman (2011), Diener and Biswas-Diener (2009) and Barrett and Barrett (2010), together with evidence from Clements-Croome (2000, 2006, 2018). Besides the previous models, Clements-Croome continued to develop the model based on the WELL version 2 rating system, which has 10 factors to consider for health and well-being; air, water, light, nourishment, movement, thermal comfort, sound, materials, mind and community (Clements-Croome, Turner and Pallaris, 2019).

Using the Flourish Model involves several steps:

1. Working with client mapping needs.
2. Using a sample survey of occupants that uses questions based on the Flourish Wheel (Figure 6).
3. Working with Human Resources (HR) on user perceptions and economic factors.
4. Using a multi-factor decision-making approach to analyse results and derive a predesign map using the Flourish Wheel.
5. At the POE stage, collecting data from the physical environment, HR and people’s psychological and physiological responses via questionnaires or wearables.
6. Recommending improvements.

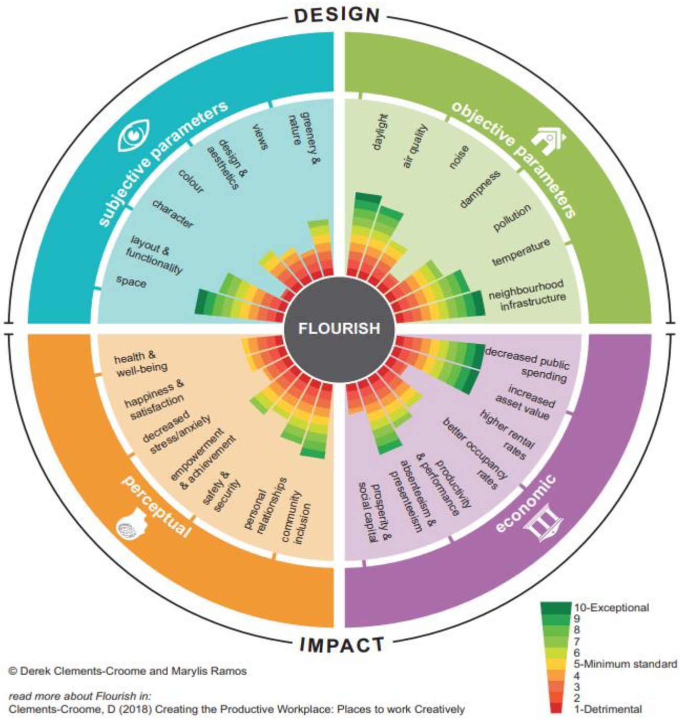


Figure 6: The Flourish Wheel

The Flourish Wheel (Figure 6) shows how objective and subjective factors can affect people's feelings and, consequently, the economics of the workplace. Besides aiding POEs, the Flourish Model can be used to set and evaluate project success criteria. It relies on collecting data by measuring factors like air quality and temperature using traditional instrumentation. Assessing subjective environmental data involves interviewing and administering questionnaires (Clements-Croome, 2021).

This research incorporated the Flourish Model with IEQ factors (to be discussed in-depth in the next section) that affect the health, well-being, and productivity of the occupants of open-plan workplaces the most.

2.4 IEQ and the Health, Well-Being and Productivity of Occupants

One of the most significant challenges in designing and building workplaces is achieving a healthy and productive environment for the occupants. It has been well established that poor IEQ can impair people's health, well-being and productivity.

Extensive research has shown that the actual influences of individual IEQ parameters (e.g. air quality, thermal comfort, lighting quality and acoustics) differ according to occupant demographics (Smith-Jackson and Klein, 2009) and office type (Bodin and Bodin, 2009; Kim and De Dear, 2011).

Therefore, it is of great importance to fully understand the factors influencing IEQ and their interdependent, complex and dynamic nature, as well as their impact on the health and productivity of people.

Generally, all environmental aspects significantly impact the quality of people's lives and their productivity (Woo et al., 2011). For example, in the UK and the US, it is estimated that roughly 15 billion pounds and 38 billion dollars, respectively, are lost due to the reduced productivity of workers and illnesses caused by an inadequate supply of fresh air alone (Fisk, Black and Brunner, 2012).

The quality of people's living and working environments profoundly impacts their health. Organisations must be morally responsible for providing healthful facilities conducive to prosperity, where people and workers feel satisfied.

Recent times have seen a tendency in building design to emphasise low energy consumption and reduce the environmental impact of buildings (Ingrao et al., 2018; Naidoo and Gasparatos, 2018; Baleta et al., 2019).

The literature considered five physical factors that influence the productivity of workplace occupants: thermal comfort (Fanger, 1970; De Dear and Schiller Brager, 2001; Nishihara, Tanabe and Haneda, 2007; Djongyang, Tchinda and Njomo, 2010; Lan, Wargocki and Lian, 2011), IAQ (Vernon and Bedford, 1930; Wargocki, 2000; Wargocki, 2016; Fisk, Black and Brunner, 2012), lighting comfort (Hopkinson and Harris, 1966; Alrubaih et al., 2013; Edwards and Bagozzi, 2000; Poria et al., 2013), acoustic comfort (Sundstrom et al., 1994; Banbury and Berry; 2005; Wong, Mui and Mui, 2006) and office layout (Laing et al., 1998; Haynes et al., 2009).

Given all the evidence, these five factors substantially affect the comfort and productivity of occupants. However, the literature also suggests that there are interdependencies and interactions between the factors as well as with the health, well-being and productivity of the occupants.

Although these studies show the impact of IEQ factors on the health, well-being and productivity of occupants, little discussion has so far concerned the interaction between the different IEQ factors. However, any variation of one IEQ parameter not only affects the occupants' perception of it but also indirectly influences their perception of other IEQ factors.

Next, the study discusses the effect of the IEQ on the health, well-being and productivity of occupants.

2.4.1 Thermal Environment

Thermal comfort produces a state of mind that positively reflects the thermal environment (ASHRAE, 2004). It is indeed a subjective condition that differs from individual to individual. It is possible to date references to this environmental aspect as far back as the early 20th century (Dufton, 1930). Prior studies highlight the early stages in identifying the implications of temperature on human comfort and function in an indoor environment.

The judgment of comfort is a cognitive process containing inputs that are affected by physiological, psychological and physical variables (Lin and Deng, 2008) because it relies on relatively independent and varied categorical factors. These variables range from attire, seating and physical activity to location, attitude and mood (ASHRAE, 2005). Age, metabolism, gender, geography and local climate are the human factors influencing thermal comfort (Quang et al., 2014). Thus, thermal comfort seems to be the collective reaction of occupants to the thermal state provided by various physical variables. Achieving thermal comfort for all the occupants in a building has become a widespread effort in the building services industry.

It is a complicated process to achieve general thermal comfort in a building since thermal comfort is the result of various physical parameters producing a thermal state and recognising a set of subjective human responses to a particular thermal state (Al

Horr et al., 2016). Using three principles, human reactions to thermal comfort are, broadly speaking, thermal sensation, thermal desire and thermal acceptability (Langevin, Gurian and Wen, 2015; Roumi, 2023).

When an atmosphere transitions from an acceptable thermal state to the preferred one, occupant health, productivity and well-being increase, and the preferred thermal state of an area differs from individual to individual, according to personal preference.

The ventilation and heating systems of an indoor environment consume energy to achieve thermal comfort for the occupants (Kwok and Rajkovich, 2010). As a result, many researchers have been inspired to constructively design buildings more conveniently for their occupants and, thus, contribute to greater productivity.

An office setting is used for many activities, including learning, reading and typing. Thermal comfort plays an essential role in the productivity of workplace occupants, with low productivity recorded by occupants who complain of thermal discomfort (Fisk, 2000; Akimoto et al., 2010; Lan, Wargocki and Lian, 2011). In addition, studies suggest that temperature significantly affects the health and well-being of occupants.

In determining the thermal comfort of occupants, ambient temperature plays a crucial role, while task ventilation frequently affects their comfort levels. Task conditioning systems are designed to maintain thermal conditions in a localised zone and are either operated by a group of occupants or individually (Bauman and Arens, 1996; Zheng et al., 2009). Creative activities, for example, may be performed best in comfortable temperatures; however, the strength and pace needed for an office job may require moderately cold temperatures for maximum efficiency (Fisk, 2000).

The wide variety of indoor criteria for occupant health in current practice highlights the gaps between different design standards. Although a thermal comfort level for occupants is maintained, occupants aren't necessarily efficient within the temperature range (Roumi et al., 2023).

The literature suggests that a task-based, local thermal environment attempts to enhance efficiency (Zheng et al., 2009). The basic category of a task might not always align with optimal thermal comfort and efficiency. For instance, imaginative mental work may correlate with optimal thermal temperature and efficiency. In contrast, a more labour-intensive type of mental work may need a relatively cold temperature for optimum/increased efficiency (Fisk, 2000). Providing a local air conditioning unit, table fans and smart furniture that regulates its temperature will enhance the local thermal climate and improve the productivity and well-being of occupants (Shahzad et al., 2018). When considering the thermal architecture of an office, these results illustrate the value of concentrating on office duties. Using a local control system in an office's various task zones would help preserve the overall comfort and efficiency of the occupants. Therefore, some essential factors influence thermal comfort and the effect of thermal comfort on the productivity of workplace occupants.

In this respect, two factors in thermal comfort can be distinguished. The first consists of obvious elements that characterise the environment's thermal condition, which include variables such as air temperature, relative humidity, etc. The second concerns the implicit aspects of human beings, such as human perception, desire and thermal state acceptance; these are a reaction to the thermal state.

2.4.2 IAQ

The IAQ of a building significantly affects the comfort of occupants in workplaces. Higher IAQ contributes to greater productivity and comfort (Fanger, 2000; Ng et al., 2012; Langer et al., 2016; Wolkoff, 2018). Workplaces with better air quality have greater work productivity and performance in office tasks such as mathematical calculation, proof-reading and text typing (Fanger, 2000).

Low air quality has been recorded in existing buildings, creating higher rates of dissatisfaction from occupants and a range of health problems for them (Fisk, Black and Brunner, 2012; Bluyssen, 2019). Allergy symptoms, asthma and sick building syndrome (SBS) are among the more critical health problems recorded (Silva et al., 2017).

SBS is a construction-related sickness and a major issue of inadequate air quality in existing buildings. Along with irritated noses and sinusitis symptoms, dry, itchy, sore and burning eyes seem to be the most severe SBS symptoms. Other symptoms include headaches, respiratory discomfort, mental exhaustion and lethargy (World Health Organization (WHO), 1982; Hodgson, 2000).

Global awareness of such signs and diseases has contributed to scientific attempts to understand IAQ and its elements. However, the consistency of indoor air depends on independent physical factors such as relative humidity, air contaminants and temperature. These factors are influenced by weather conditions (climate), building conditions (structure, materials and construction), ventilation of heat, pollutants in buildings by machines or human action, internal layout design (furniture and smart equipment) and productivity, well-being and health patterns of the occupants. The multiple correlations and deviations in such interdependent variables increase their complexity (Szczurek et al., 2015).

Since the 19th Century, the indoor carbon dioxide (CO2) concentration has been used as an indicator of air quality in buildings and of the effective outdoor air supply rate in occupied rooms. Many studies are focused on the measurement of CO2 concentrations in educational buildings. In Europe, carbon dioxide (CO2) is categorized as a substance hazardous to health. At room temperature and atmospheric pressure, it is a colourless, non-flammable, and odourless gas. Nevertheless, CO2 is considered toxic in high concentrations. Increased concentration levels can lead to irritation of the eyes, nose, and throat.

The quality of indoor air can be controlled by either increasing the amount of ventilation or reducing the air pollutant load, leading to an improvement in the overall comfort of the occupants. One of the key factors affecting IAQ, comfort and productivity seems to be the ventilation rate. Ventilation is often used to replace indoor air and remove carbon dioxide and other airborne contaminants (Seppanen, Fisk and Mendell, 1999; Kosonen and Tan, 2004). A higher ventilation rate leads to higher indoor air comfort and productivity, while a lower rate leads to SBS symptoms and reduces productivity (Wargocki, 2000; Frontczak and Wargocki, 2011; Frontczak et al., 2012; Ezzeldin and Rees, 2013).

Research suggests that the financial gains from increasing occupant comfort and productivity are several times more than the yearly expenditure on heating, ventilation, and air-conditioning (HVAC) at a higher ventilation rate. In the US, if the ventilation rate in offices increases from 8 to 10l/s per person, 13 billion dollars would be gained per annum from higher levels of productivity and less health problems (Fisk et al., 2012). It is also recommended to use efficient HVAC systems to reduce the environmental impact of higher ventilation rates.

Three different types of ventilation systems can be used for buildings: natural, hybrid/mixed and mechanical (Kim and De Dear, 2012). The hybrid/mixed ventilation system uses both natural and mechanical ventilation processes depending on various local climate variables, building types and occupant behaviour patterns and expectations (Kim and De Dear, 2012).

2.4.3 Visual Comfort (Lighting and Daylight)

There are several subjective parameters that contribute to visual comfort; however, light intensity is the primary objective measurement (Roumi et al.,2023). Visual comfort often affects the satisfaction and comfort of occupants in an indoor environment (Lan, Wargocki and Lian, 2011). Visual convenience – both daylight and artificial lighting – depends on the type and level of lighting.

Humans have depended on the cycle of day and night to manage their lives for millions of years. Daylight and the changes it undergoes throughout the year affect the everyday activities of people’s biological clocks. Therefore, people need light to regulate their physiology and efficiency (Aries, 2005).

Office workers spend almost all of their time indoors, so their office activities rely on indoor lighting or such daylight as they can access. Daylight is the optimal light source for visual comfort and human health, providing excellent colour. In addition, it has a positive effect on people and transmits a sense of cheerfulness and brightness, which influences people’s fitness, mood, efficiency and mental attitude (Li and Lam, 2001; Li, 2010; Beute and de Kort, 2018).

Globally, buildings account for about 40% of the world’s annual energy use (Omer, 2008). However, in estimates of the average energy use in UK office buildings, lighting accounted for the greatest percentage (33%; Al Horr et al., 2016).

Efficient steps to maximise daylight and intelligent lighting systems may help lower a building’s artificial energy load and carbon footprint. Organisations that consider the value of daylighting in their workplaces achieve greater occupant efficiency (Yang and Nam, 2010; Yang et al., 2019). Research indicates that businesses achieve a long-term advantage by investing in daylight inclusivity in their workplace design through higher occupant productivity and lower energy costs (Lim et al., 2017). Building occupants prefer natural light to artificial light (Kong et al., 2018). This preference is three-fold: physiological, psychological and physical.

There are several ways to integrate daylighting into the design of workplaces; the incorporation of windows to optimise daylight in the office space is one of the most frequently used. Office workers enjoy having windows in their workplace and remark that they help boost their well-being and performance of office activities (Haans, 2014; Lottrup et al., 2015).

When designing workplace windows, several variables must be accounted for. First, the literature confirms that workplace occupants like windows. Nevertheless, the acceptable window size varies depending on several variables, including the sum of indoor and outdoor light levels, sky luminance and sun location (Mansfield, 2018).

Window size and glazing studies demonstrate a wide range of window size preferences among occupants, and it is not generally the case that all occupants favour large windows. Excessive direct sunlight may result in a glare that produces visual irritation. Consequently, visual distress leads to decreased productivity and well-being (Kong et al., 2018). However, using blinds results in artificial lighting, a lack of available sunshine and increased CO_2 emissions. However, external façade design features can be used to prevent glare problems even in hot regions and places with high solar radiation (Lim et al., 2012).

In brief, occupants seek daylight in the workplace; however, a building's daylight design should be based on the local climate, the orientation of the building, solar altitude and the immediate surroundings, the essence of the space and the building's layout together with the availability of daylight.

Daylighting design is a technique for incorporating daylight into the lighting design of a space. It looks at the availability of daylight and the light levels necessary for the space and uses elements such as windows, reflector glasses and skylights (Wong, 2017). Daylight contributes to the secretion of the hormone melatonin, which influences alertness, output and visual comfort.

Reviewing the above literature, both natural and artificial lighting should be used in the lighting design of a workplace to create favourable lighting conditions for the occupants. Contextual factors should be examined, including the light requirements for tasks and working hours, venue, workplace orientation and height, occupants' requirements and preferences and daylight availability. Designers should seek to optimise the use of daylight together with the above factors; the energy use of a building could be reduced by using operational façade elements to effectively distribute daylight in a building.

2.4.4 Noise and Acoustics (Acoustic Comfort)

The ability to hear is an intrinsic human sensation, a part of the human survival kit. Varieties of sounds enter the ears daily and are transferred to the brain. WHO classified any unwanted sound as noise. Psychological reactions such as annoyance, rage or judgements arising in response to noise and loudness illustrate the effects of noise in terms of auditory response (Ayr et al., 2003).

In office design, the acoustic efficiency of a building is becoming more critical, and most office duties involve a degree of noise control to allow the occupants to operate properly. Sleep disruptions, cardiovascular disturbances, mental illnesses, impaired job performance and negative social activity, are the adverse effects of noise (Fuks et al., 2017). In conjunction with the environmental requirements of the workplace, these issues require the acoustic design of the workplace to be highly relevant. Inefficiency in controlling disruptive acoustics and noise can contribute to frustration within the workplace environment and can negatively influence the performance of employees (Balazova et al., 2008; Toftum et al., 2012).

To function effectively, workers need a comfortable acoustic environment. In an office, acoustic distress contributes to lower productivity and greater chances of adverse effects on occupant physiology and psychology (Neitzel et al., 2018).

The noise in a building can cause distractions, stress, and annoyance, which could result in fatigue or hearing damage to occupants (Roumi et al.,2023). Noise in workplaces can be internal or external. Road traffic, the public, air traffic and machinery are considered to be external noise. Internal noises include conversations with colleagues, one-minute demands and electronic sounds from telephones and other office equipment (Fuks et al., 2017; Bielefeld, 2018). Both internal and external sounds have a negative impact on the productivity of occupants.

Studies indicate that frequent external noises from construction and transport cause stress and health issues relating to high blood pressure (Bluyssen, Aries and van Dommelen, 2011). Comparably, internal noises from air conditioners, fax machines, printers and telephones contribute to discomfort and frustration; a persistent state of annoyance leads to tension and issues with high blood pressure (Ayr et al., 2003).

The output of an office occupant is reduced by both internal and external noise, which contributes to stress and anxiety and can cause long-term health problems. External building elements and design can shield the office interior from external noise. The internal structure and office layout affect the internal noise in the office environment; material for building envelopes may be used to regulate noise. Therefore, it is possible to use the internal structure, office layout and wall materials to tackle internal noise in the workplace.

Open-plan office noise may negatively impact the fatigue, performance and motivation levels of occupants (Jahncke and Halin, 2012). Tasks associated with word processing and the measurement of numbers are influenced by internal noise in the workplace. Since open-plan offices have no partitions between meeting/conversation areas and work areas, workers have remarked on the distraction of and need for privacy from such office noises as conversations, telephones and printers (Toftum et al., 2012).

The reduction of low-level background noise in an office may minimise acoustic discomfort. This would help to reduce the distraction produced by unwanted loud noises from acoustic spikes.

The above literature review identified the significance of sound levels with regard to the productivity and comfort of workplace occupants. A building's acoustic strategy considers two factors: internal and external noise levels. Buildings should have a structure and envelope that mitigates disturbances from external noise.

The acoustic design must take into consideration activities in the office that raise the internal noise and separate areas according to their predicted noise level. Noise-absorbing materials in noisy areas and soundproofing for low-noise areas may enhance acoustic conditions in the workplace.

2.4.5 Office Layout

One of the indoor characteristics that affect efficiency and productivity in the workplace is office layout design. Not only does it play a critical role in the workplace's acoustic architecture, but it also affects the overall comfort of occupants and, in many ways, their efficiency. The office layout deals with creating the seating arrangement that determines the occupants' working pattern, closeness to each other, opportunities for interaction areas and privacy (Haynes, 2008; Lee, 2010). An organisation's physical atmosphere (layout and appearance) affects its recruiting, retention and efficiency, thus affecting its business capacity to achieve success (Wheeler and Almeida, 2006). An organisation's office layout should be well planned to ensure an effective work process that produces organisational success.

The reviewed literature indicates the value of an office layout in achieving productivity. It stresses that the chosen layout type may affect the productivity of occupants and the efficiency of offices. It also emphasises that open-plan offices have a negative effect on the well-being and productivity of their occupants.

2.4.6 IEQ Monitoring Methods

One of the biggest obstacles to accurately evaluating IEQ performance is the lack of reliable, affordable, and user-friendly measuring tools. The procedure of measuring different construction metrics becomes substantially less labour-intensive. Measurement is still a laborious procedure due to a variety of operational challenges, though. While sensor and logging device manufacturers have made products that are increasingly accurate and easy-to-use, the work of creating devices with multiple sensors is still largely in the hands of the users.

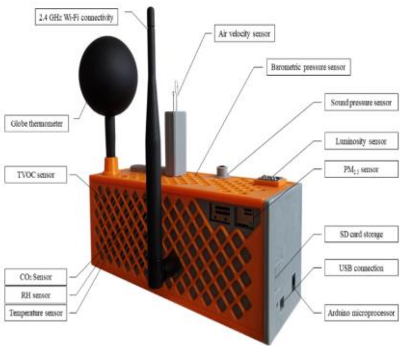
IEQ measurement requires a combination of devices and individual sensors to capture the state of IEQ in a space. (Mujan et al.,2019; 2021; Wei et al.,2020).

The current procedures for IEQ assessment are often sporadic, expensive, intrusive and often limited to a few parameters and expert use only. However, recent years have witnessed the introduction of low-cost IEQ monitors to the market, thus opening up an opportunity for building managers and occupants to receive ubiquitous information about their environment and act upon it.

Table 3 summarises the recent literature on monitoring the IEQ factors both subjectively and objectively:

Table 3: A Summarised Review of the Literature on Measuring IEQ

Paper 1: An indoor environmental quality assessment of office spaces at an urban Australian university (2021)		
Method	**Sample**	**Parameters**
Objective and subjective assessment (Questionnaire was	Seven office buildings were predominantly used to accommodate	Air temperature (°C) Relative humidity (%)

<table>
<tr><td>developed to collect attitudes, perceptions and beliefs)</td><td>professional (non-academic) staff, a total of 519.</td><td>CO2 concentration (ppm)
Globe temperature (°C)
Lux meter
Sound level meter</td></tr>
<tr><td colspan="3">Paper 2: Building and indoor environmental quality assessment of Nigerian primary schools: A pilot study (2018)</td></tr>
<tr><td>Objective assessment</td><td>Five Nigerian schools from two states in south western Nigeria were randomly selected for the study.</td><td>Indoor and outdoor temperature (T) and relative humidity (RH).
Carbon dioxide (CO_2) and carbon monoxide (CO).</td></tr>
<tr><td colspan="3">Paper 3: Development of indoor environmental quality index using a low-cost monitoring platform (2021)</td></tr>
<tr><td>Objective and subjective assessment
(The occupant's subjective perception of IEQ was evaluated by the use of a paper-based survey).</td><td>A total of 12 occupants participated in the field studies, 69 in two open offices and 56 in the educational building.</td><td>A low-cost IEQ device:

</td></tr>
<tr><td colspan="3">Paper 4: Continuous monitoring of indoor environmental quality using an Arduino-based data acquisition system (2018)</td></tr>
<tr><td>Objective assessment</td><td>An open computer laboratory was chosen for the installation for 10 days.</td><td>Temperature and relative humidity levels.
Air velocity measurement.
Light level or illuminance.
The proximity of occupants.</td></tr>
<tr><td colspan="3">Paper 5: Associations of perceived indoor environmental quality with stress in the workplace (2020)</td></tr>
</table>

Subjective assessment (using the validated OFFICAIR questionnaire.)	464 full-time workers from four companies in Singapore. Data on socio-demographic characteristics, lifestyle/health-related factors, and workplace factors were collected through self-administered questionnaires.	None

2.4.7 The IEQ Standards

Several interrelated standards focus on various aspects of the workplace environment, particularly IEQ aspects. However, these standards tend to be concentrated in specific workplace comfort areas (e.g. thermal comfort, lighting and IAQ) and are primarily biased towards matching comfort with energy efficiency.

These interrelated supplementary type standards are predominantly based upon IEQ monitoring and the subjective psychological response of building occupants through survey responses. Consequently, they neglect the physiological reactions that result from the relationship between the building and the occupant.

In the US, the joint-developed ASHRAE/CIBSE Performance Measurement Protocol's (PMP) best practice guide supports the EU Standard EN15251 (2007) 'Indoor environmental input parameters for design assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Temperature, humidity, CO2, noise and illuminance levels are shown in Table 4.

Table 4: Comparison of IEQ Factors BS EN 15251; US and UK Standards for Open-Plan Offices

IEQ Input parameter	ASHRAE Typical Design Value	CIBSE Typical Design Value
Temperature	22–26 oC Summer 20–24 oC Winter	22–24 oC Summer 21–23 oC Winter
Humidity	30–70%	40–70%
Lighting	<500 lux open-plan offices <300 lux small offices	350–500 lux
Noise	dBA < 44 Healthy 44 < dBA < 46 Uncertain dBA > 46 Unhealthy	
CO_2 Levels	CO2 < 550 ppm	

2.5 Biophilia

Having defined the main IEQ factors that affect the health, well-being and productivity of occupants in the workplace, the next step is to discuss the best way to determine how to resolve the IEQ issues and improve the office environment using the BD approach.

Over the last 10 years, ‘nature’ and BD have received extensive architectural attention, especially in response to growing environmental challenges. Architects and planners look forward to solutions for the built environment that comprehend society’s architectural design aspirations while integrating important natural attributes such as fresh air, daylight, vegetation and views of nature, which can enhance human health and well-being. Hence, BD focuses on enriching the built environment’s vital relationship between people and nature.

This section aims to identify the Biophilia hypothesis and BD, as well as explore the significance of BD for human health, well-being and productivity. Accordingly, this section defines the Biophilia hypothesis; BD patterns; and, finally, the relationship between Biophilia and the IEQ factors that mainly affect the health, well-being, and productivity of occupants in the workplace.

2.5.1 The Biophilia Hypothesis

Humans are part of nature and, as such, need to be associated with the natural environment. Biophilia may be a relatively new term, but indeed, the definition is not. When the term is broken down, ‘bio’ means ‘of or relating to life’ and ‘philia’ ‘denotes affection, particularly an unusual passion for a specific thing’ (Stevenson and Lindberg, 2013).

Biophilia is identified as the love of life in its most apparent sense. Since the dawn of human history, people have been instinctively conscious of it; natural objects, forms and patterns have also served as sources of inspiration for artists and architects throughout history. Three prominent scientists have established concepts of Biophilia, as shown in Table 5.

Table 5: Biophilia Concepts

Reference	Definition
Fromm, 1964	True love for life and for everything that is living. This explained two fundamental tendencies of living organisms: sustaining life from death threats and positive integration with each other.
Wilson, 1984	The inherent human propensity to reflect on life and life-like forms and to interact with them emotionally in certain instances.
Wilson, 1993	‘The Biophilia Hypothesis’ was put forward to postulate that the emotional connection with ‘life’ was preserved after humankind migrated from the primitive natural environment into the artificial new environment.
Kahn, 1997	A simple, biologically dependent human need and inclination to be associated with life and lifelike systems.

Prior studies show that Fromm (1973) emphasised the improvement of human beings and, consequently, not deliberately tampering with other aspects of nature. For their part, Wilson (1984; 1917) and Kellert (1997) emphasised improving nature but also actively improving civilisation due to the interconnection of the two.

2.5.2 Defining BD

The concept of BD is built upon but not limited to the hypothesis of Biophilia. Many theories from environmental psychology demonstrate that humans' need for 'nature' is due to an instinctive attraction towards natural elements. Such theories explain how physical and mental functions are generated from contact with 'nature' (Joye, 2007; Ryan et al., 2014; Söderlund and Newman, 2015; Peters and D'Penna, 2020).

Since the 1990s, the concerns of the Biophilia hypothesis have shifted from its initial focus on life or living organisms to exploring the relationship between humans and the natural environment.

At the beginning of the 21st century, the notion of Biophilia was developed and adapted within the architectural domain, drawing attention to the emotional aspect of humans' need for interaction with the natural environment in the built environment.

The BD approach was proposed to provide some design guidance to satisfy this longing for 'nature' in architecture (Joye, 2007; Cramer and Browning, 2008; Kellert, Heerwagen, and Mador, 2008; Wilson, 2006; Almusaed, 2010; Ryan et al., 2014).

Furthermore, BD refers broadly to incorporating natural elements into various contexts as necessary support for the human connection to nature. BD aims to build environments that allow for positive interactions between people and nature that could encourage human health and well-being (Kellert, Heerwagen and Mador, 2008; Heerwagen, 2011).

Heerwagen (2009) concluded that survival instincts in the human brain continually return to look for items and places that support survival, such as food (animals, flowers and plants), shelter, water, fire and light. Therefore, it is crucial to understand what draws individuals to such features so they can be integrated into the built environment. Thus, BD is characterised as the expression of the inherent human need to design the built environment in connection with nature (Kellert, Heerwagen and Mador, 2008). Furthermore, Biophilic architecture can be applied in several ways within the built environment; a building may directly, indirectly or symbolically link its users with nature through its exterior features, decoration, interior spaces and exterior landscapes.

When comparing BD with sustainable design, the desire for human interaction with nature may not be seen as an obstacle to the realisation of sustainability but as an effort to introduce contexts that meet environmental needs as human needs for interaction with nature (van den Berg, Hartig and Staats, 2007). In addition, while sustainable construction is leading the way to developments in construction and the link to natural processes and systems, it is becoming essential for Biophilic dimensions to be fully integrated into leading green building designs and offer several strategies for supporting sustainability in architecture (Almusaed and Almssad, 2006; Almusaed, 2010; Jones, 2013; Browning and Ryan, 2018; Xue et al., 2020; Wijesooriya and Brambilla, 2021).

2.5.3 BD and Work Productivity

According to Wilson (1984), the relationship between people and nature is defined by Biophilia. Humans experience an unconscious inclination towards every living form; people are extremely sensitive to nature's shapes, systems and patterns (Paul and Sara, 1993; Paul and Taylor, 2008). Our psychological processes stem from the prehistoric period when human relationships with other living species (plants and organisms) were more overt, active and regular than in the present world of urban living (Heerwagen, 2009; Krčmářová, 2009).

Numerous studies have shown that people closer to the natural world have higher levels of satisfaction and well-being (Mackerron and Mourato, 2013; Sanchez, Ikaga and Sanchez, 2018; Hähn, Essah and Blanusa, 2021).

From ancient times to the modern day, humans have drastically changed their lifestyles, habits and surroundings. For example, the choice to live in cities allows for fewer encounters with animals. This has contributed to a decline in human well-being and satisfaction. In contrast, incorporating the natural environment or vegetation into an office positively influences workers' performance (Heerwagen and Hase, 2001; Kellert, Heerwagen and Mador, 2008; Gray and Birrell, 2014).

Vegetation in workplaces is positively related to efficiency and negatively related to occupant tension. Indoor plants help improve IAQ (Lohr, Pearson-Mims and Goodwin, 1996); they assist in reducing indoor air pollution by decreasing the volatile organic compounds produced by indoor furniture and synthetic materials (Grinde and Patil, 2009). Passive viewing of natural stimuli from openings can lower tension and increase workplace occupants' positive attitudes (Heerwagen et al., 2004).

Even when beyond the window, nature and plants help relieve anxiety and stress. Views of nature and plants from windows have been shown to mitigate occupant anxiety and stress and help improve well-being and productivity (Chang and Chen, 2005). In addition, American psychologists have shown that windows with an outdoor view are a crucial criterion for the happiness of office occupants (Kellert, Heerwagen and Mador, 2008). For instance, studies show that workers with windows overlooking nearby nature (e.g. trees) report greater job satisfaction and better physical health and mental well-being than workers without these views (e.g. Gilchrist et al., 2015).

Research by Bjørnstad, Patil and Raanaas (2016) found that workers with more significant amounts of indoor contact with nature at work tend to report lower levels of job-related stress, fewer subjective health complaints and fewer days off of work due to illness than those who have less indoor contact with nature at work.

2.5.4 Effects of BD on Human Health and Well-being

People across the world set the personal goal of achieving a state of well-being since individuals and communities as a whole cannot grow without individual well-being. The Oxford Dictionary describes well-being, in its simplest form, as a state of ease, health or satisfaction. According to the Center for Disease Control and Prevention (McGuire, 2013), 'well-being' covers several attributes of public health, such as physical, mental, economic, psychological and social well-being; growth and activity; life satisfaction and jobs and activities that are involved in fostering well-being.

Biophilia caters for well-being: it supports a range of consumers in various contexts, irrespective of age, skills and financial standing (Heerwagen, 2009). Innovative human-made environment structures may positively or negatively impede continued interaction with natural systems and processes through Biophilia. Besides the importance of having a relationship with nature for human health and well-being, BD is supported as a growing knowledge base. This rationale was explored by Kellert (2012) and summarised in the following results:

1. Natural touch has also been developed to enhance healing and rehabilitation from disease and major surgical operations, including direct communication (e.g. increased by the presence of plants and natural lighting) and interpretive and symbolic representations of nature.
2. Fewer social and health concerns are reported by people living near open areas, irrespective of rural or urban residence, income level and education. The presence of even small quantities of vegetation, such as grass and a few trees, has also been linked to fewer management and behaviour problems.
3. Natural ventilation, natural lighting and other natural conditions in offices result in increased worker efficiency, lowered stress and increased motivation.
4. Natural communication has also been correlated with cognitive ability in tasks that involve memory and attention.
5. Communication with natural features and the environment has been associated with healthy development and progress in childhood.
6. The human brain dynamically reacts to sensory patterns and signals from the physical world.
7. More favourable assessments of nature, greater quality of life, enhanced neighbourliness and a deeper sense of place are revealed by communities with higher-quality ecosystems than communities with poorer environmental sustainability. Such contrasts often occur between poor and wealthy suburban and urban areas.

A review of the relevant literature indicated that workplaces incorporating BD elements, mainly living plants, promote higher perceived IEQ. This, in turn, sees occupants reporting higher perceived levels of well-being (up to 15%) than workplaces lacking BD elements (Spaces, 2015).

By providing occupants with direct access to office plants, their interest remained relatively constant when viewing scenes of greenery repeatedly over time compared to scenes absent in nature, thus providing an efficient source of restoration (Biederman and Vessel, 2006).

2.5.5 The Economy of BD

To successfully incorporate BD into workplaces, it is essential to recognise and identify the weaknesses that must be addressed to create a valuable design framework. Wijesooriya and Brambilla (2021) identified possible weaknesses that could appear when designing with BD. On the one hand, the adoption of BD as a main design approach is challenged by the increased costs associated with construction, maintenance and higher requirements of land, which hinder the diffusion of BD on a larger scale (Mandasari and Gamal, 2017; Riley et al., 2019; Xue et al., 2019). Furthermore, the use of natural elements in building designs could lead to a shorter life span of building components and, consequently, to increases in maintenance costs (Riley et al., 2019). The concern over land requirements is explained by Soga et al. (2015), who highlighted the existing misconception that BD's success depends on the design interventions' size and the number of natural elements incorporated in the projects.

On the other hand, Biophilic features providing nature in the workplace increased productivity among staff, with economic benefits ranging from $1,000 per employee to $3.6 million company-wide (Makes and Sense, 2012).

Even low-cost BD implementation can benefit and generate higher returns from occupants. The consequent health benefits and greater psychological support affect workers' perceptions of the workplace. For example, research shows a 10% decrease in employee absenteeism after implementing Biophilia in the office space (Elzeyadi, 2011).

Moreover, plants can and do positively impact office occupants. Although BD is not a ‘one size fits all’ performance-enhancing approach, the relatively low cost of installing living plants is a sound financial investment. An entire landscaping approach that does not hamper functionality should be taken to provide constant opportunities for restoration for maximum effects on the health, well-being and productivity of office occupants (Hähn et al., 2020).

BD shouldn’t be seen as an expensive option but rather as a creative exercise to improve well-being. The key is recognising the opportunities and creating strategies that make them accessible at various scales. With that in mind, this research will inspire designers and architects with examples of implementing BD on different scales according to economic considerations as late-stage design options, as shown in Figure 7.

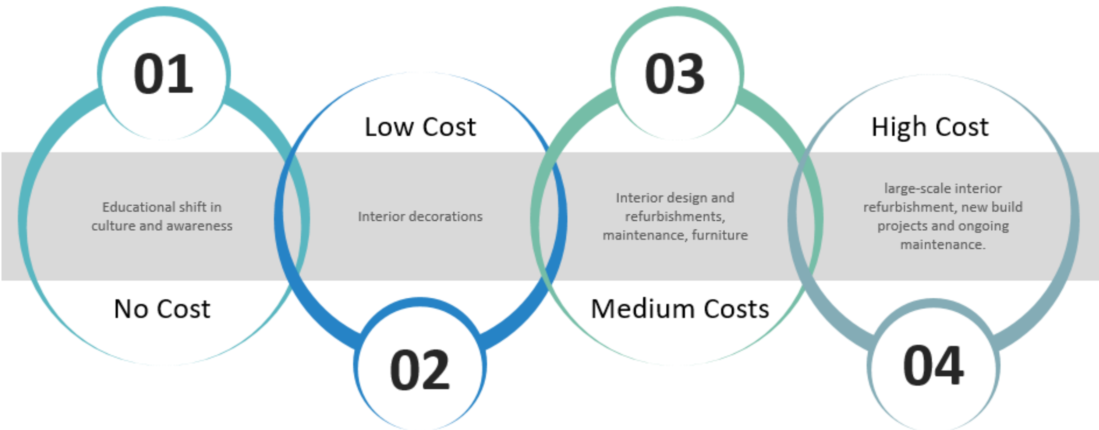


Figure 7: BD Implementations and Costs

2.5.6 BD Milestones

Over the years, numerous articles have been written by designers and practitioners that include new technologies and methods for transforming Biophilia from a hypothesis to an implementation through BD in the built environment. Currently, around five major groupings seem to be the most comprehensive and essential for applying architectural BD applications, according to Zhong, Schröder and Bekkering (2022), as in Table 6.

Table 6: Groupings to Implement Biophilia in the Built Environment

Author	Milestone	Year
Heerwagen and Hase	Characteristics of Biophilic Design	2001
Kellert	Dimensions, Elements, and Attributes of Biophilic Design	2008
Heerwagen and Gregory	Sensory Aesthetic in Biophilic Architecture	
Hildebrand	Survival Advantageous Characteristics of Biophilic Architectural Spaces	
Cramer and Browning	Categories of Biophilic Buildings	
Browning et al.	Categories and 14 Patterns of Biophilic Design	2014, updated in 2020
Kellert and Calabrese	Experiences and Attributes of Biophilic Design	2015, updated in 2018
Xue et al.	Categories in Biophilic Framework	2019

In some of the groupings, the writers have built more than one technique, created one over time or published new approaches. Likewise, studies have sometimes proposed or been part of developing more than one tool or have published new methods over time.

Heerwagen and Hase (2001) were the first to describe various features in Biophilic architecture. They attributed various natural qualities to eight characteristics based on habitability, natural elements, process and geometry in design, as well as joyfulness and enticement. Their framework illustrated that ‘nature’ could be conceptualised differently in architecture, although it was a tentative work.

‘Biophilic Architecture: The Theory, Science and Practice of Building Buildings to Life’ as part of the BD masterwork by Kellert, Heerwagen and Mador (2008) contains a framework of the ‘Dimensions, Elements and Attributes of Biophilic Design’. This framework addresses the need for a detailed understanding of BD to assist the practical application of BD to the built environment (Kellert et al., 2008).

Heerwagen and Gregory (2008) and Hildebrand (2008) proposed some perceivable and cognisable attributes/characteristics of ‘natural’ spaces that can be used in spatial layouts to create Biophilic buildings.

Moreover, in 2014, the environmental consulting and strategic planning firm Terrapin Bright Green published a newly defined organisation of 14 patterns that inform design in the built environment based on research focused on cognitive, psychological and physiological responses to different environments. These 14 patterns were then developed and re-released in a new report, ‘14 Patterns of Biophilic Design: Improving Health and Well-Being in the Built Environment’ (Browning, Ryan and Clancy, 2014).

Similarly, Kellert and Calabrese (2015) streamlined Kellert et al.’s (2008) first framework and proposed a new one that includes 24 attributes within three categories. Later, their proponents further revised and updated these two similar frameworks (Kellert, 2018; Ryan and Browning, 2020). Finally, Xue et al. (2019) recently suggested the connections with ‘nature’ from the individual (building user health and well-being) to social (public health) perspectives.

Among the numerous BD interpretations, Terrapin Bright Green’s 14 Patterns of BD conceptual framework was chosen for this study as it aims to create inspirational, restorative, healthy and integrative spaces with the functionality of the place and the (urban) ecosystem to which it is applied. It also helps in understanding how to implement BD in three pillars: nature in the space, which is about the incorporation of plants, water and animals into the built environment; the natural analogues, which include the materials and patterns that evoke nature; and finally, the nature of the space, which explains the psychological and physiological responses to spatial configurations.

2.5.7 The 14 Patterns of BD (Terrapin Bright Green)

Terrapin Bright Green's 14 Patterns of BD offers a background of Biophilia and BD along with '14 patterns', or a 'series of tools, to incorporate BD, together with the concept and analysis underlying it. In addition, it contains various design features to address the variables that designers should consider for the efficient implementation of the BD patterns. The significance of this work is that, in an accessible manner, it provides a way to translate research to design application, balancing research, benefits, evidence and ways to apply the patterns successfully in an appropriate design approach.

The 14 patterns seem to place a strong emphasis on health benefits; all the 14 patterns are described in relation to evidence of stress reduction, cognitive efficiency, emotion, performance and mood (Browning, Ryan and Clancy, 2014).

BREEAM Standard (2020) considered the 14 patterns in measuring the Biophilic health aspects in the buildings and rated them into three categories: the direct experience of nature, the indirect experience of nature and the experience of space and place (Zhong, Schröder and Bekkering, 2022). The criteria for measuring the biophilia in the buildings (three categories and 14 patterns of biophilic design (Browning et al., 2014)) were as follows:

1. At least one of the three categories is included.
2. At least seven of the 14 patterns are included.
3. In 80 % of the living spaces, at least two patterns can be directly experienced, while the other five can be experienced on the same floors.
4. No significant negative effect on the main health aspects.
5. At least three measures (patterns) are not typical for the building and user function in which they are applied.

The following are descriptions of each pattern and how they can be implemented to consider a building Biophilic:

Pattern 1: Visual Connection with Nature

The development of environmental creativity for designing is carried out in connection with natural spaces, which in turn activate the intuitive sense of the designer. For architects, nature serves as a symbol of the decline of time and space, and their intuitive perception of nature differs completely from their perception of indoor spaces. Furthermore, the variation in the appearance of natural components (light, water, plants, etc.) raises concern in designers' questioning minds and makes them wonder, which is one of the phases of the creative design process (Browning, Ryan and Clancy, 2014). Thus, the complexity of natural elements or the visual link with nature significantly influences workplace design.

Pattern 2: Non-Visual Connection with Nature

By listening, touching, tasting or smelling, which generates positive feelings for nature in design, a non-visual relation with nature can be created. It may also be concluded that nature's small or instant interactions with non-visual sensory stimuli may benefit the architecture of the natural space (Sullivan, Kuo and Depooter, 2004). This positive perception of space is connected to a sense of peace that gives creativity and revelation (Kellert, Heerwagen and Mador, 2008). A realistic approach to the development of the designer's idea is the use of ambient noise moderately focused on the sounds of nature, which, of course, can also be sensed and touched by optimizing the capacity of this form of positive space interaction, by simultaneous non-visual contact with nature and with a preference for the sounds of nature to urban sounds in the environment.

Pattern 3: Non-Rhythmic Sensory Stimuli

Curiosity, imagination, visualisation and ingenuity accompany the natural world. Often, the interesting atmosphere and unequal stimulation of the environment affect curiosity; an attractive space can provoke curiosity. Mobility, in contrast, is affected by relaxation and freedom because free activities often raise the degree of risk (Kellert, Heerwagen and Mador, 2008). Mobility in the natural world is recognised as one of the pillars of the designer's physical and mental growth and even mind. UNESCO declarations stress that mobility in all physical, cognitive, social and emotional areas will address the need for artistic development. Discovering an environment is a powerful motivation: the designer enters a new space and moves to find other spaces; their creativity in the settings can also explore them, and their sensory input will somehow become inconsistent (Browning, Ryan and Clancy, 2014).

Pattern 4: Thermal & Airflow Variability

This variability can be defined as the subtle changes in air temperature, relative humidity, airflow across the skin and surface temperatures that mimic natural environments (Ojamaa, 2015). Natural ventilation, thermal diversity and airflow impact a building's thermal balance. Nowadays, the role of natural ventilation in buildings is very significant in terms of the building's environmental compatibility, given the significance of renewable energy, particularly fossil fuels, and growing environmental pollution (Cele, 2004). Therefore, among the significant objectives in designing a building is considering the circumstances of thermal diversity and integrating air conditioning in the design; this is consistent with the formal approaches in Biophilic architecture of using the power of nature (Kellert, Heerwagen and Mador, 2008).

Pattern 5: Presence of Water

Contact with water by seeing, hearing and touching it enhances the perception of space. The presence of water patterns in Biophilic architecture is understood to express the desire to make a visual connection to nature with a water component which improves emotional reactions to it (Xue et al., 2019). Increased relaxation; lowered stress; reduced blood pressure and heart rate; enhanced attention and memory through natural fluctuations of water-induced visual stimulation in a natural environment; and improved, proper physiological and cognitive responses are widely present where multiple senses are stimulated at once (Browning, Ryan and Clancy, 2014). In turn, each of these variables plays an important role in enhancing the growth of innovation in a designer. In this state, water is the stimulation; it is a common factor, and this function is called the stimulation of natural materials.

Pattern 6: Dynamic & Diffused Light

Designers present interactive comfort in space with a distinct psychological impact on the occupants by using light as an architectural element. Studies have shown that clear, natural light positively influences the designer's perceptions and contributes to their vitality. If the natural light originates from the glittering sun, the potency of the positive emotions from nature is enhanced in their mind and inspires them (Al-musaed, 2004). Since light is synonymous with clarity, the most significant work in architecture in a complex setting should be required to be done by light since sunlight is never unintended by the architect; it is connected with reality and essence. Appropriate and adequate daylight in a setting (where it does not conflict with artificial light) enhances the pattern and, therefore, the reliability and concentration of the senses and the eye health and vision capacity of occupants in the environment (Browning, Ryan and Clancy, 2014). In addition, the various colours of the light spectrum and their natural elements may be a driving force in developing a unique design.

Pattern 7: Connection with Natural Systems

Multiple locations may be included in the areas related to natural systems belonging to other locations. The goal is to plan, adapt and align such areas through an architectural understanding of all the areas with the concept of Biophilia, which can be considered a helpful instrument. By combining with other forms, stabiliser forms can be recognized and linked to natural systems resulting from an accumulation of separate elements (Cele, 2004). To avoid uniformity, topographic maps, from a designer's perspective, that connect a natural area to other areas must be generated based on nature, the interactions between elements, forms and even peer configurations (Sharifi and Sabernejad, 2016). Integrating a sense of belonging with diversity is optimal in the BD architecture approach. It enables the diverse types and spaces of an architectural vision to exist conceptually and perceptually in a pre-set, integrated and organised whole (Fisher and Pedersen, 1996).

Pattern 8: Biomorphic Forms & Patterns

Biophilic architecture represents a creative vision in which the use of natural patterns and biomorphic forms can generate a sense of vitality and new assumptions in the mind of a designer so that the building they design is connected with vitality, in addition to being habitable and can respond positively to limitations and the mutual respect between the environment and man (Browning, Ryan and Clancy, 2014).

Pattern 9: Material Connection with Nature

Any natural environment can be used in the design and development of work by isolating and reducing a volume from the original volume in nature or by connecting one or more forms to the natural raw volume. The designer can, however, use a framework to organise the definitions and provide distinct perceptions of Biophilic architecture in its construction (Kellert, Heerwagen and Mador, 2008).

Pattern 10: Complexity & Order

In space, a balanced degree of complexity, creativity, variety, freshness and excitement is important for the designer in adjusting to environmental events. This will positively affect the existence of any uncertainty or difficulty and the desire to scan and discover (Sharifi and Sabernejad, 2016). The ambiguity of these environmental variables generates a fascinating space and simultaneously contributes to environmental stimulation; a space's impact is often enhanced by the existence of some uncertainty, difficulty and the opportunity to scan and discover. Through fractal geometric designs and geometric complexities in natural patterns, the pattern of complexity and order is widely recognized (Browning, Ryan and Clancy, 2014). Fractal geometric patterns are formed by repetition, which indicates that the repeated occurrence of deformation relies on the starting place of the template and contributes to greater induction of the sensation. The application of the concepts of fractal geometry in space is a mathematical representation of natural architecture. Geometric fractal structures with cubic consistency significantly affect the soul and body of the environment (Kellert, Heerwagen and Mador, 2008).

Pattern 11: Prospect

The visual communication of space and human psychological features in architectural research could be used to accomplish such a pattern (Browning, Ryan and Clancy, 2014). The involvement of the natural landscape in an area can contribute directly to a reduction in environmental stress, boredom and tiresome thoughts while simultaneously increasing comfort.

Pattern 12: Refuge

Everyone is vulnerable to environmental conditions that are sometimes dangerous. However, this aspect is correlated with fear and anxiety, at first sight of which designers find strategies for developing their talent very quickly (Browning, Ryan and Clancy, 2014). The shortage of a favourable physical and mental climate and a sense of congestion prevent the individual and the environment from communicating properly. Therefore, for the growth of imagination, the sense that the designer still has a refuge and territory for their environmental practices is a way of engaging with the environment.

Pattern 13: Mystery

Mystery is a spatial disorder characterised by data collected in the presence of reasonably substantial sights or other sensory stimuli. In a natural environment, humans are stimulated and motivated to go and explore this sensation in person (Kellert, Heerwagen and Mador, 2008). The mystery pattern of an environment points to the belief that people require two variables in an environment: exploration and comprehension (Browning, Ryan and Clancy, 2014). The features of this prototype are derived from a visual link with nature and a sense of fear and danger in the world and are generated through research on acceptable reactions to the situations predicted. The enigmatic existence of the environment's atmosphere triggers a positive reaction from the brain's faculties, which can simultaneously anticipate and guess (Romm and Browning, 1994; Browning and Romm, 1995). Thus, the existence of quality parameters and the mysterious nature of the environmental space do not induce a reaction of fear. These authors specified criteria for such a pattern in environmental space: create landscapes of medium to high depth, and create two-dimensional lines of courtyards and spaces.

Pattern 14: Risk/Peril

Generally, the architectural opportunity should be to design a room. However, revelation through the environment is probable in situations where various activities are carried out by establishing separate and identifiable fields and boundaries (Browning, Ryan and Clancy, 2014). Therefore, the existence of an atmosphere with signs of dread and fear will be such that the designer's imagination is stimulated, and its limitations or the environmental signs are modified to implement the imagined necessary improvements to the plan in the process of environmental impulsivity.

2.5.8 BD and IEQ

Bringing elements of the natural environment or greenery into the workplace positively impacts the productivity of occupants; it relates negatively to stress in occupants (Kellert, Heerwagen and Mador, 2008; Gray and Birrell, 2014). Furthermore, indoor plants help to improve IAQ (Lohr, Pearson-Mims and Goodwin, 1996). Plants greatly help to reduce pollution in the office by reducing the volatile organic compounds that can be produced by various indoor furniture or synthetic materials (Grinde and Patil, 2009). In addition, the passive viewing of natural stimuli through windows can minimise discomfort and improve the positive mood of the occupants (Heerwagen and Heerwagen, 2003).

A field study showed that occupants with a window view of nature were more satisfied than occupants with a view only of the built environment (Kaplan and Kaplan, 1989). Generally, nature helps to minimise stress levels and anxiety even when only seen from a window. Windows with views of nature and plants have been noted as helpful in reducing the tension and anxiety of occupants and increasing their productivity and well-being (Chang and Chen, 2005). An American psychological study claimed that BD also helps to balance the temperature and humidity levels in offices by using plants and radiant surface materials (Kellert, Heerwagen and Mador, 2008).

Based on the previous literature, Table 7 was created to show the link between the 14 patterns of biophilia and the IEQ factors and sub-factors that mainly affect the health, well-being and productivity of workplace occupants.

Table 7: The Link Between the 14 Patterns of Biophilia and the IEQ Factors and Sub-Factors

IEQ Factors and Sub-Factors	Design Strategies Examples	Biophilia Patterns	Reference
Thermal comfort: - Temperature - Humidity	Adopt natural materials like wood, bamboo, rock, stone, clay, etc. Enhance exposure to weather through operable windows, porches, balconies, terraces, courtyards, etc. Incorporate plants into buildings using green roofs, walls and facades, large atria with park-like settings, green pockets, etc.	- Non-Visual Connection with Nature (Pattern 2) - Thermal & Airflow Variability (Pattern 4) - Connection with Natural Systems (Pattern 7)	Berman et al. (2008), Windhorst and Williams (2015), Stigsdotter et al. (2017), Shi et al. (2017).

IAQ: - Fresh and polluted air quality	Increase natural ventilation using operable windows, vents, narrower structures, etc. Simulate natural air and ventilation through operable windows, vents, airshafts, porches, clerestories, HVAC systems, etc.	- Visual Connection with Nature (Pattern 1) - Non-Visual Connection with Nature (Pattern 2) - Non-Rhythmic Sensory Stimuli (Pattern 3) - Connection with Natural Systems (Pattern 7)	Windhorst and Williams (2015), Peters and D'Penna (2020), Browning et al. (2014), Gou et al. (2014), Kellert (2018).
Acoustics - Noise	Consider textures beyond materials, such as light, colour and sound. Achieve inside and outside experiences through window views, balconies, courtyards, arcades, etc.	- Non-Rhythmic Sensory Stimuli (Pattern 3) - Non-Visual Connection with Nature (Pattern 2) - Visual Connection with Nature (Pattern 1)	Jahncke et al. (2011).
Lighting comfort: - Daylight	Bring in natural light via glass walls, clerestories, skylights, atria, reflective colours/materials, etc. Mimic natural light's spectral and ambient qualities; include arranging multiple low-glare electric light sources, ambient diffused lighting on	- Dynamic & Diffused Light (Pattern 6) - Biomorphic Forms & Patterns (Pattern 8)	Karlen (2017), Browning et al. (2014), Kellert (2018).

	walls/ceiling and daylight-preserving window treatments.		
Layout - Layout and functionality - Spaces	Conceive interior-exterior connections in transitional spaces, such as porches, patios, balconies, courtyards, pavilions, gardens, entry areas, foyers, atria, etc. Consider mobility in spaces like entrances, exits, corridors, stairs, high-glass lifts, etc.	- Dynamic & Diffused Light (Pattern 6) - Non-Visual Connection with Nature (Pattern 2) - Biomorphic Forms & Patterns (Pattern 8) - Material Connection with Nature (Pattern 9) - Complexity and Order (Pattern 10) - Prospect (Pattern 11)	Bellia (2013), Felsten (2009), Kellert (2008).

Based on the previous literature about the IEQ factors that mostly affect the wellness of occupants, a need appeared for a tool that can deliver many solutions using BD and help designers and architects achieve the best design solutions in open-plan workplaces.

In their work about card-based design tools, Roy and Warren (2019) concluded that despite a large number of toolkits, there are some gaps in their coverage. For example, domains with few existing tools include architecture/built environment, sustainable design and graphic and transport design. Developing more tools for these domains could be a fruitful area for design research. The following section justifies the researcher’s choice to design a co-design toolkit as one of the contributions of this study.

2.6 Co-design Toolkit

Co-design brings together a group of consumers, users, families or workers to improve service. It creates an equal and reciprocal relationship between all stakeholders, enabling them to design and deliver services in partnership. Planning, designing and producing services with people with experience in the problem or service means the final solution is more likely to meet their needs (Roper et al. 2018).

Steen (2013) highlighted that co-design could be understood as a process of collaborative design thinking, joint inquiry and imagination in which jointly diverse people explore and define issues and then develop and evaluate solutions. Participants can share their experiences, discuss and negotiate their roles and interests and jointly bring about positive change. Co-design participants combine inquiry and movement from the outside world to others and the inside world so that they can be curious and jointly learn and imagination and action from the inside world to the outside world and others so that they can be creative and bring about change together.

This way of working demonstrates a shift from seeking involvement or participation after a plan has already been set to seeking consumer leadership from the outset so that consumers are involved in defining the problem and designing the solution (see, e.g. Happell and Scholz, 2008).

Co-design typically uses a staged process that adopts participatory and narrative methods to understand the experiences of receiving and delivering services, followed by collaborative consumers and health professionals co-designing improvements (as shown in Figure 8).

Co-design is often considered more a way of thinking than a process. It requires that organisations and individuals shift their mindset to embrace and embed the principles and values it embodies.

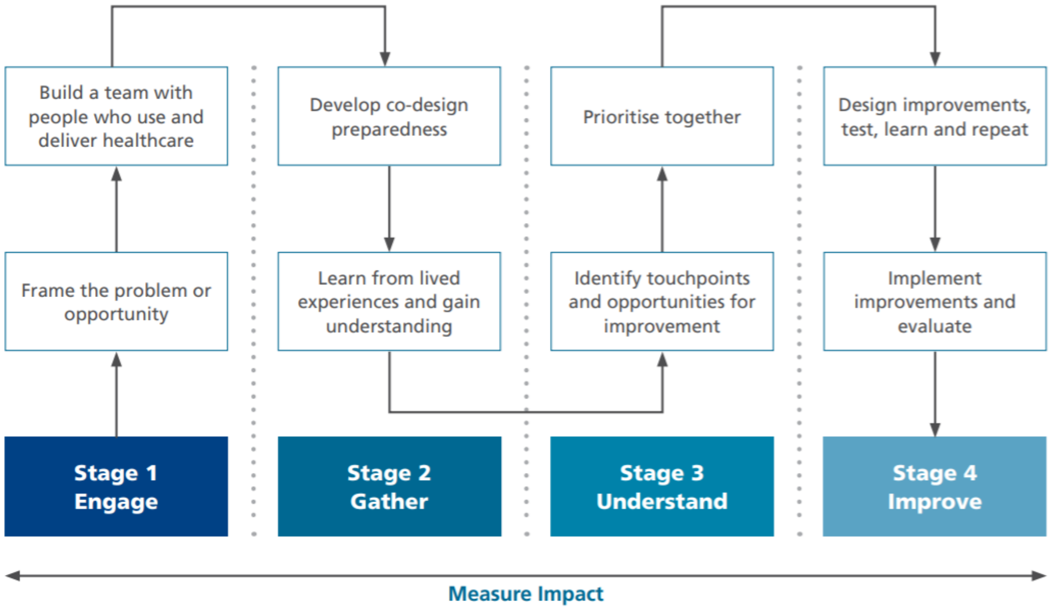


Figure 8: The Co-design Process

The move to co-designing tools affects the participants' role in the design process. In the classical design process, a user is a passive object of study, and the researcher brings knowledge from theories and develops more understanding through observation and interviews. The designer then passively receives this knowledge as a report and adds a sense of technology and the creative thinking needed to generate ideas, concepts, etc.

On the other hand, in co-design, the roles get mixed up: the person who will eventually be served through the design process is given the position of 'expert of their experience' and plays a prominent role in idea generation and concept development. In generating insights, the researcher supports the 'expert of their experience' by providing tools for ideation and expression. The designer and the researcher collaborate on the tools for creativity because design skills are critical for developing the tools. The designer and the researcher may be the same person, but they still play a crucial role in giving form to the ideas (e.g. Sleeswijk et al., 2005; Sanders and Stappers, 2008).

2.6.1 Toolkit Design Method

The term 'toolkit' can be applied to many forms of content and information: it refers to a set of tools arranged together in one place. The concept of the toolkit is not new in the design field. Still, it is a consolidated practice often used to overcome the lack of knowledge, methodology or practical tools for various activities (Lockton, 2013).

Wölfel and Merritt (2013) sketched a panorama of card-based design toolkits and defined '5 design dimensions' to classify them. Toolkits can be distinguished by their intended use; the scope, duration and placement of the design process; their system and methodology; their customisation; and their formal qualities.

Physical cards are popular design tools, perhaps because they are simple, tangible and easy to manipulate. Recent studies of card-based tools have generated guidelines for their practical development, although the structure and shape of design toolkits may vary. For example, there are card-based toolkits, such as IDEO's Method Cards, and toolkits that combine an online platform with a printable guidebook, such as the 'Design Kit' (Designkit.org) and 'The Field Guide for Human-centred Design' (Van der Bijl-Brouwer, 2017). Other common toolkit forms are canvases, like the Service Design Toolkit (2014), and even games and hybrid solutions have been put forward (for example, the 'IoT Service Kit', 2016).

Lockton (2013) argued that:

> *'The toolkit metaphor may have reached design practice through the use of the term in computer science, particularly in HCI and interaction design where toolkits such as GTK+, Qt and jQuery UI comprise collections of a graphical user interface 'widgets', with the associated code, which can be used to build a variety of applications by the developers, often cross-platform. A toolkit, in this sense, is directly deployable, providing an API (application programming interface) which can be called by applications, compared with interface design pattern libraries [...] which are more akin to collections of 'ways to solve' particular common problems' (p. 61).*

Card-based design tools have been used as a standard method of disseminating design analysis insights and making them available in the design process. Characteristically, card-based design tool research projects have found card-based tools very effective in facilitating the generation of ideas in design workshops (Vaajakallio and Mattelmäki, 2014). Cards help present theoretical constructs and allow the design practice to become more engaging and playful, thus enlarging the group of people that participate in designing new systems. They can be an effective vehicle for transferring knowledge from theory to practice, such as converting theoretical frameworks to guidelines that designers can manipulate (Deng, Antle and Neustaedter, 2014). Card-based tools help to keep people at the centre of the design process (IDEO, 2003); they allow for shared understanding and facilitate creative dialogue. Cards can stimulate a discussion that has grown unproductive; it is also possible to use cards to measure, rank or bookmark ideas generated during design sessions (Hornecker, 2010).

Card-based tools are argued to have more benefits in helping design than other media (e.g. Roy and Warren, 2019). Evidence from different studies and applications of the tools suggests that their advantages derive from the specific characteristics of cards.

Cards engage many objects that summarise information, methods or practice realistically so designers will be able to absorb and act on them. Furthermore, they can be shuffled and merged in several ways; they can serve as a shared reference for teams of designers, occupants and others to encourage discussions between the members; and they provide words and photos to widen the search space and overcome design blocks (Roy and Warren, 2019).

Additionally, a significant strength of cards is that they are a physical artefact with which individuals and teams can interact. Deng et al. (2014) described the benefits of cards as a design tool.

> *'In studies of design cards, design researchers have found cards can help structure design discussions, ensuring a design space is viewed from different perspectives. Cards can help speed up the refinement and iteration of ideas... The information on the cards provides designers with a common vocabulary…*

> *The small physical form of cards affords physical manipulation. Cards can serve as a physical reference during design discussion, facilitating communication and shared understanding' (p. 696).*

Roy and Warren (2019) concluded that the use of a physical tool could be seen as 'moving against the grain' of all digital tools, while a large proportion of card decks (33 out of 155 or 21.3%) are targeted at helping design digital products, applications and systems, including websites, interactive devices, etc. Hence, some tools are now available as software or online applications.

Not many toolkits take the design thinking approach to improving the built environment; therefore, card-based design tools have also been applied to architectural and urban planning design. For instance, the 'Designing Streets Toolkit' (2016) was used to aid the design and development of a proposal/masterplan in Scotland. Another example is the 'Thoughtful Design Toolkit' (2020) by the HLM (David Hutchison, Graham Locke and Tony Monk) Architects company, which includes a suite of digital resources that allows designers and commissioning clients to identify, create and review their building projects based on evidence. This tool introduces itself as an online survey that engages users in building themes of well-being and activity.

Furthermore, the 'Healthy Built Environment Linkages Toolkit' was designed by the CDC and the British Columbia (BC) Healthy Built Environment Alliance (HBEA) Steering Committee (Canada) in 2018 to make relations between design, planning and health (CDC, 2018). This toolkit aims to generate conversation and adaptation by outlining a rationale for why the built environment is essential for health.

Together, this evidence suggests that cards act as physical props to externalise thought and help suggest common structure concepts to which everybody can relate (Brandt and Messeter, 2004) by taking risks within the framework of a game.

2.7 Conclusion

This chapter has reviewed the current literature to understand both the workplace as an environment and the range of POEs and to justify using the Flourish Model in this research to evaluate the health, well-being and productivity of workplace occupants. Moreover, this chapter described the main IEQ factors and their parameters, their theoretical backgrounds and their effect on the health, well-being and productivity of workplace occupants. Finally, BD and its applications in the workplace were discussed, and the 14 patterns of BD used in the present research to improve the IEQ of the office environment were outlined.

A summary of the literature review is presented below (Table 8).

Table 8: Literature Review Summary

1.	**Workplace type: Open-plan workplaces in:** - Co-working open-plan offices - Research rooms in universities These workplaces combine users from multi-disciplinary backgrounds working in the same environment. Why: Previous literature shows that there is a lack of research on the impact of IEQ factors on the health, well-being and productivity of the occupants of such workplaces.
2.	**POE Model:** Flourish Model It has four main quarters: the objective and subjective design parameters and the perceptual and economic impacts. **Why:** Based on the previous literature, the Flourish Model was designed based on other POE models, and it combines them to evaluate buildings from the architectural perspective, the engineering services perspective and the social science perspective. It can be used to evaluate the workplace (objectively) and the occupants' responses (subjectively).
3.	**IEQ factors**: - Thermal environment - IAQ

	- Acoustic environment - Lighting environment - Layout **Why:** Previous literature indicated that these factors affect the wellness of occupants the most. As the Flourish Model was chosen to evaluate the buildings in this study, there was a need to combine the model's parameters with the IEQ factors to find a way to evaluate the impact of building design on the health, well-being and productivity of occupants in the workplaces both subjectively and objectively, as detailed in this chapter.
4.	**Biophilic design:** 14 patterns of Biophilia milestone In this chapter, BD was justified as one of the most suitable approaches used nowadays in the workplace to improve the health and well-being of occupants. Therefore, this approach was used in this research by applying the 14 patterns of Biophilia. **Why:** It helps in understanding how to implement BD in three pillars: nature in the space, which is about the incorporation of plants, water and animals into the built environment; the natural analogues, which include the materials and patterns that evoke nature; and the nature of the space, which explains the psychological and physiological responses to spatial configurations.
5.	**Co-design approach:** Toolkit Developing toolkits for domains such as architecture and the built environment is a fruitful area for design research. **Why:** Based on previous literature and the research hypothesis, the researcher chose to develop the toolkit as a contribution of the research.

3. CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter illustrates the methods, concepts, tools and measuring equipment selected to conduct the research. It also covers the main research steps taken to meet the objectives of this study. To do so, this chapter starts by determining the research subject and then focuses on the research questions and objectives.

A comprehensive research plan and a robust data collection and analysis framework were put together to achieve the research aim (Bryman, 2006; 2012). Both qualitative and quantitative research methods were adopted to support the research objectives (Chapter 1) and the literature context (Chapter 2). Furthermore, although seen as two different research methods, both methods have been mutually inter-connected (via triangulation) to create an objective view of the collected and analysed data (Creswell, 2009). A typical view of research strategies (Figure 9) allowed the researcher to structure the research methods into a discrete project delivery strategy.

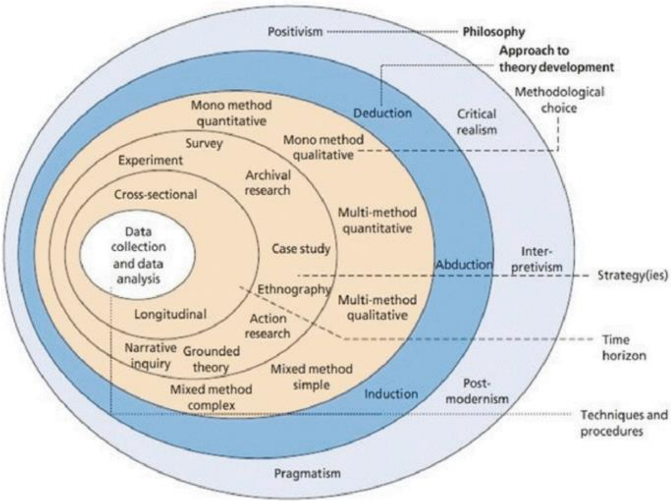


Figure 9: Strategies and Methods of Research – The Research Onion (Saunders et al., 2009)

The benefit of the research onion with its layered steps is that it creates a series of stages under which the different data collection methods can be understood and managed. It also illustrates the steps by which an analytical study can be performed.

The first step is defining the research project or philosophy. This creates the starting point for the appropriate research approach, which becomes the second step. In the third step, the research strategy is adopted, and in the fourth step, the time horizon (sectional or longitudinal) of the study is identified. Finally, the fifth step is the stage at which the data collection methods are identified.

3.2 Research Philosophy

Research philosophy points to the nature of knowledge and its development. It helps to create a more comprehensive perspective informing a study's general methodology and research process (Creswell, 2014). Research philosophy usually has three significant aspects: epistemology, ontology and axiology (Igwenagu, 2016).

The first aspect, epistemology, deals with general expectations about the ways of gaining and absorbing knowledge about the world. Its forms include positivism, critical realism, interpretivism, postmodernism and pragmatism (Saunders, Lewis and Thornhill, 2009; Saunders et al., 2019).

This research study aimed to evaluate the effect of BD in the Second Home company on the health, well-being and productivity of occupants. It also analysed the impact of various indoor environmental conditions on occupants of open-plan research rooms. The study required data from Second Home's co-working office, which hosts multidiscipline companies in the same indoor and outdoor environments. Other data were collected from university research rooms located in the same and different indoor environments. These data were then statistically analysed. The analysis investigated the cause-and-effect relationship between IEQ and Biophilia on the one hand and the health, well-being and productivity of the occupants on the other.

In doing so, it can be said that this study adopted both interpretivism and positivism since different groups were targeted and various indoor and outdoor environments were studied. Interpretivism is the search for explanations of human actions (Igwenagu, 2016) and focuses on researching individuals rather than objects. It adopts an empathic stance to understand the social world and gives meaning to people's views. The data collection and analysis of interpretivism involve qualitative data and in-depth investigations with small samples. As for positivism, it is a rational approach to searching for cause-and-effect relationships. It involves neutral and objective observation and uses large samples of quantitative data, and tests them statistically.

Ontology, the second aspect of research philosophy, aims to outline the perceptions people create about the nature of reality. It takes one of two main stances: objectivism and subjectivism. This research study dealt with the perceptions of occupants, and it can be stated that this research adopted the subjective stance (subjectivism states that the perceptions and actions of social actors create social phenomena; Saunders, Lewis and Thornhill, 2009).

Finally, axiology, the science of inquiry into human values, studies the researcher's judgements about value. It relates to the researcher's axiological skill in determining 'value-free' and 'value-laden' attitudes to the research. Value-free research aims to be value-free and objective, while value-laden research is value-biased and subjective (Igwenagu, 2016). In this research, the researcher considered herself 'value-laden'.

3.3 Research Approach

The research approach of a study encompasses the plans and procedures adopted to conduct the research, from general opinions to specific methods of data collection, analysis and interpretation.

Selecting the appropriate approach is based on the nature of the research gap or the problems being addressed, the researcher's personal experience and the study audience(s). The present study adopted a convergent parallel mixed method to aid the data collection. The purpose was to learn more about the problem by obtaining different but complementary data.

Two types of approaches exist the deductive approach and the inductive approach. The deductive approach develops the hypothesis or hypotheses upon a pre-existing theory and then formulates the research approach to test it/them (Silverman, 2021). This approach is best suited to contexts where the research project examines whether the observed phenomenon/phenomena will fit expectations and is generally based on previous research output (Wiles et al., 2011; Chapter 4). The inductive approach is characterised as a move from the specific to the general (Bryman and Bell, 2011) and uses observations as the starting point for the research. The researcher looks for patterns within the collected data (Beiske, 2007). However, within this approach, no framework initially informs the data collection; therefore, the research focus can be formed after the data has been collected (Flick, 2011; Chapter 5).

3.3.1 Mixed Methods Approach

A mixed methods approach to inquiry involves collecting both quantitative and qualitative data, integrating these forms of data and adopting distinct designs that may include philosophical assumptions and theoretical frameworks.

The premise of this method is that the combination of quantitative and qualitative approaches will provide a complete understanding of a research problem than either approach alone (Creswell, 2013).

In a mixed methods study, the combination of quantitative and qualitative data can be useful at several stages of the study, as either method can complement the other. Quantitative and qualitative methodologies are equally valuable instruments by which researchers can examine and analyse aspects of a common phenomenon. Mixed methods research allows researchers to use the strengths of both the quantitative and qualitative methods and then select which is more helpful for addressing their research questions.

This research aimed to use the mixed methods approach to first examine whether the adapted Biophilic features in the Second Home's co-working office environment (where almost 30 multi-disciplinary companies work in the same building environment that was designed based on Biophilia principles) can improve the health, well-being and productivity of the occupants using the qualitative method; and second, examine five different research rooms at Brunel University London using the quantitative method. This was to check if the IEQ factors and sub-factors affected the health and well-being of the occupants and evaluate the potential of adding the Biophilic approach to their environment to improve their productivity. A measurement test was also conducted, using different types of sensors, to physically monitor the IEQ factors in the research rooms.

Finally, the research used the qualitative method to create a co-design toolkit that can help designers and architects improve several IEQ issues in the workplace. This toolkit was designed based on the results of the previous chapters.

3.3.2 Quantitative and Qualitative Methods

Quantitative and qualitative procedures cannot be viewed as static and separate categories, nor are they opposites or dichotomies. Instead, they signify different ends of a continuum (Newman and Benz, 1998) in which mixed methods research integrates elements of both quantitative and qualitative approaches.

Normally, the distinction between qualitative and quantitative research is framed in terms of words that are classed as qualitative instead of numbers as quantitative indicators; or using closed-ended questions (quantitative hypotheses) instead of open-ended questions (under qualitative interview conditions).

In quantitative studies, most data are collected quantitatively by specific methods, whereas qualitative data are collected by observing the users or their environment. From the late 19th century to the mid-20th century, quantitative approaches were more dominant in research. Nevertheless, historical evolution resulted in a growing interest in qualitative research and the development of mixed methods research. As a standalone tool, quantification has attracted high counter-pressures among researchers.

This research used a quantitative survey technique, two qualitative semi-structured interviews and focus group techniques applied within a descriptive research framework. In addition, empirical IEQ factor measurement tests were collected at five research sites.

3.4 Research Strategies

The research strategy of a study sets out a vision of how the researcher intends to carry out the work (Saunders et al., 2007). Research strategies include conducting experiments, pilot surveys, action research and grounded theory; archival research (literature reviews); and case studies (Saunders et al., 2019). The choice of research strategy depends, first, on the research questions and objectives; second, on the existing knowledge, time and resources; and finally, on the research area.

Since the aim of this research was to assess the difficulties of field research within real workplace environments, a cross-sectional approach was the preferred option selected. Furthermore, considering the requirements for surveys and field measurements, a mixed methods approach was chosen, thus allowing the researcher to cross-connect various collected data sources and providing flexibility in selecting the relevant research techniques:

1. Measurement tests: This refers to creating a research process that evaluates the actual environment (Saunders et al., 2007). It can be used in most research areas and involves considering a relatively limited number of factors (Saunders et al., 2007).
2. Case study research method: This method seeks to establish where key features may exist and further aims to draw generalisations (Bryman, 2016) from within the wider study area.
3. Survey method: Surveys tend to be used within quantitative research projects and involve sampling a representative proportion of a population (Bryman and Bell, 2011). The surveys produce quantitative data that can be analysed empirically and are most commonly used to connect variables between different data types.
4. Archival research method: Conducted from existing materials, this form of research involves a systematic literature review to examine patterns and establish the sum of knowledge available within a particular area of study. It can also be

used to explore the application of existing research to a specific problem (Flick, 2011).

5. Toolkit method: a collection of authoritative and adaptable resources that enables users to learn about an issue and identify approaches for addressing them. It often focuses on a single major topic and can assist in putting theory into practice (Aswad et al.,2022).

3.5 Research Design

Research design is the procedural plan adopted in a study to answer the research questions and address the research objectives (Igwenagu, 2016). It is the framework in which the research intent, theory, investigative strategies, analytical techniques and specific methods to be used in a research project intersect (Johnson, Onwuegbuzie and Turner, 2007). Based on the literature review in Chapter 2, this research was conducted in three phases (presented in Chapter 4, Chapter 5 and Chapter 6, respectively).

Regarding the first research question, this study explored the relationship between the Biophilic patterns implemented in a building and the occupants' responses within the Flourish Model parameters. On the one hand, the research generated a matrix that clarified, first, the factors of IEQ in the office environment that mainly affect the occupants, and second, the sub-factors that were delivered. Tables 9 and 10 show these relationships.

Based on the literature review in Chapter 2, which discussed the IEQ factors that affected the health, well-being and productivity of workplace occupants the most, Table 9 shows the objective Flourish Model parameters as IEQ sub-factors in a matrix; this indicates a contradiction between the main factors and the Flourish Model sub-factors.

The table shows that for IAQ, the Flourish Model focuses on how fresh or polluted the air in the office environment is. At the same time, the thermal environment is mainly concerned with the level of both temperature and humidity. For the lighting environment, the Flourish Model focuses on the daylight factor. The acoustic environment is concerned with noise.

Table 9: Environmental Matrix

IEQ Factors	Objective Parameters (Design sub-factors)					
	Daylight	IAQ	Noise	Dampness	Air Pollution	Temperature
IAQ						
Thermal environment						
Lighting environment						
Acoustic environment						

Table 10 shows the Flourish Model's subjective parameters as sub-factors for the IEQ in office buildings. Clearly, this quarter of the wheel mainly focuses on the layout of the offices, which relates to space and layout functionality. The rest of the parameters are concerned with aesthetic values; these features are mainly non-quantifiable but essential, as they indirectly affect the occupants.

Table 10: Visible Environmental Factors

IEQ Factors	Subjective Parameters (Design sub-factors)						
	a. space	b. Layout and functionality	c. character	d. colour	e. Design and aesthetics	f. views	g. Greenery and nature
Office Layout							
Aesthetic Values							

The procedure of selecting the variables taken in this study is further explained in the next paragraphs.

By using the literature and available resources besides the Flourish Model design factors, this study examined how both temperature and relative humidity (dampness) influenced the health, well-being and efficiency of a group of occupants (Figure 10).

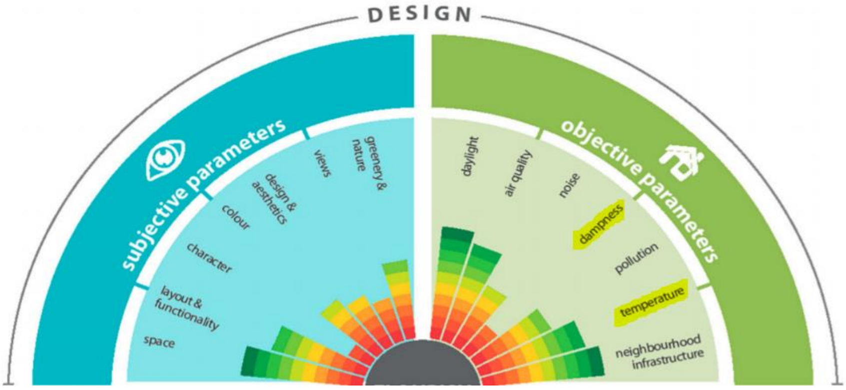


Figure 10: Temperature and Relative Humidity

Then, this research study used the occupant survey to collect occupant responses and sensors for the physical measurement of temperature and relative humidity (Table 11).

Table 11: Thermal Comfort Parameters

Measurable Parameters	Instrument	Occupant Survey
Ambient Temperature	Arduino Sensors	How satisfied are you with the temperature and humidity levels in your workplace?
Relative Humidity	Arduino Sensors	

This study collected occupant responses by evaluating the IAQ in open-plan office rooms and the ratio of fresh air to polluted air (Figure 11).

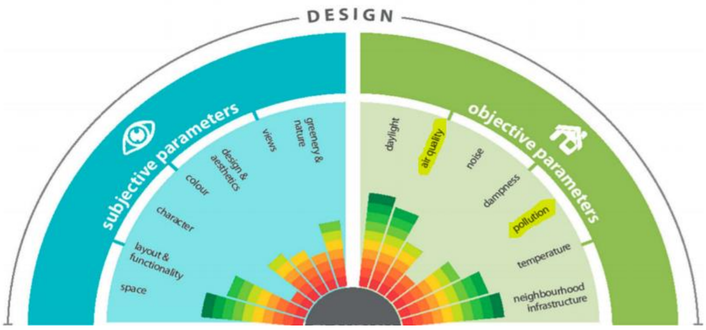


Figure 11: Air Quality and Pollution

This research focused on measuring carbon dioxide and collecting the occupant responses (Table 12).

Table 12: IAQ Parameters

Measurable Parameters	Instrument	Occupant Survey
Carbon Dioxide	Arduino Sensors	How satisfied are you with the air quality in your workplace?
CO_2, TVOC, HCHO	Portable Digital Sensor	

The relevant literature set out the fundamentals and strategies of daylighting and lighting that affect the health, well-being and productivity of workplace occupants. Figure 12 shows the daylight sub-factor as part of the Flourish Wheel.

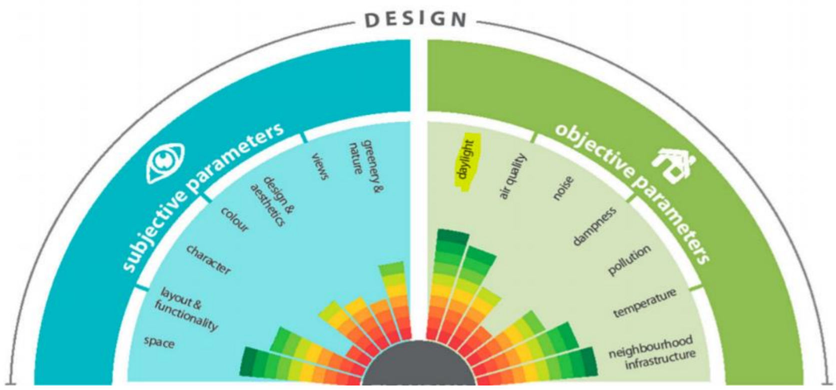


Figure 12: Daylighting

This research focused on measuring illuminance levels (lux) and how these affect the occupants' visual health, well-being and productivity, shown in Table 13.

Table 13: Visual Comfort Parameters

Measurable Parameters	Instrument	Occupant Survey
Illuminance Level	Arduino Sensors	How satisfied are you with the lighting and daylight levels in your workplace?

In the present work, an occupant survey was used to elicit comprehensive comments from workplace occupants on the sound levels they experience so that ways to use BD to enhance the workplace environment could be determined, as suggested by the Flourish Wheel (Figure 13).

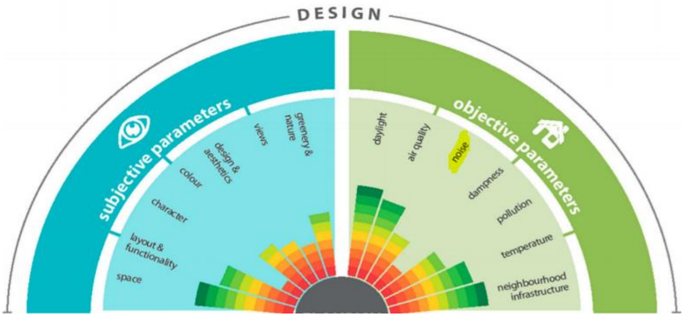


Figure 13: Noise parameter in the Flourish Wheel

This research measured sound levels and occupant responses to determine the effect of sound levels on occupant comfort and productivity (Table 14).

Table 14: Acoustics parameters

Measurable Parameters	Instrument	Occupant Survey
Indoor sound level	Arduino Sound Sensor	How satisfied are you with the acoustics levels in your workplace?

Many factors should be considered when designing the layout of an office (Figure 14). These include office work procedures, assignments, specifications for sound levels and occupants' privacy and contact requirements. The influence of the office layout (physical space design) on the health, well-being and productivity of occupants will be evaluated in the following chapters.

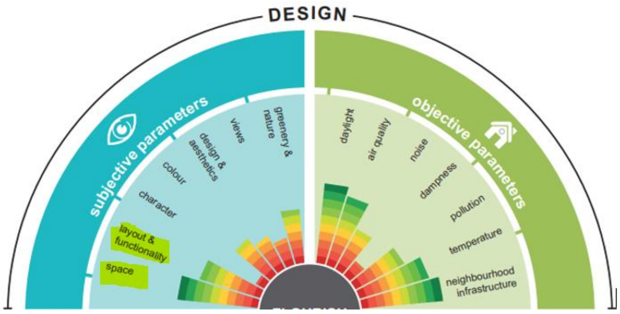


Figure 14: Layout parameters in Flourish Wheel

This research investigated the effect of an open-plan office layout on the health, well-being and productivity and office efficiency of occupants (Table 15).

Table 15: Layout parameters

Measurable parameters	Instrument	Occupant Survey
Office Layout and Functionality	–	How satisfied are you with your office layout?
Spaces between Desks	–	

Finally, in this study, the researcher used the Flourish Model to identify the way the design portion of the wheel affects both the health and well-being of occupants from the perceptual quarter and productivity from the economic quarter (Figure 15) of the occupants.

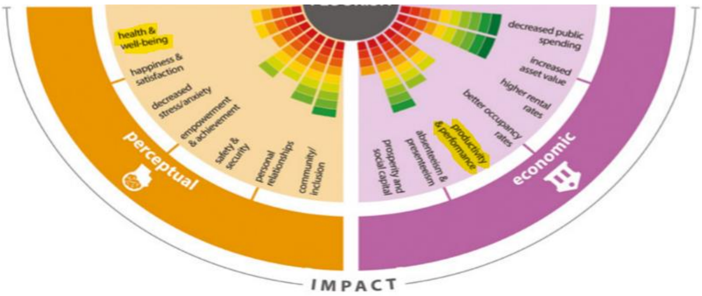


Figure 15: The Perceptual and Economic Quarters of the Flourish Wheel.

The second research question of this study was to check if the BD implementation in a co-working open-plan office environment improves the health, well-being and productivity of the occupants. Therefore, the study employed a qualitative research methodology centred on observation and interviews. The main reason for using this methodology was the need to figure out how BD can be implemented in an office environment and observe its relation with the indoor environment. At the same time, as recommended by the Flourish Model, there was a need to interview the HR managers of 10 companies and evaluate the effect of Biophilia on the health, well-being and productivity of the offices' occupants.

The third research question was how the effects of IEQ factors on the workplace occupants in university research rooms could be measured and interpreted and how they could be enhanced using Biophilia. The methodology to answer this question consisted of a survey and indoor measurements using several types of sensors.

It is worth noting that the occupant survey was given priority, and the indoor environmental conditions were monitored to complement and enhance the interpretation of the survey results in the present study.

To answer the fourth research question, a toolkit was developed to help designers and architects improve IEQ issues in the workplace. To do so, a qualitative method was adopted: online focus groups were conducted to validate the tool. The focus group method was the best way for the researcher to interact with the designers and architects and receive recommendations for improving the toolkit.

3.6 Research Stages

To allow data validation and continuous analysis to be undertaken and to manage the amount of data to be collected, five research stages (Figure 16) were subsequently developed and then linked together to provide a triangulated view across both the quantitative and qualitative collected data.

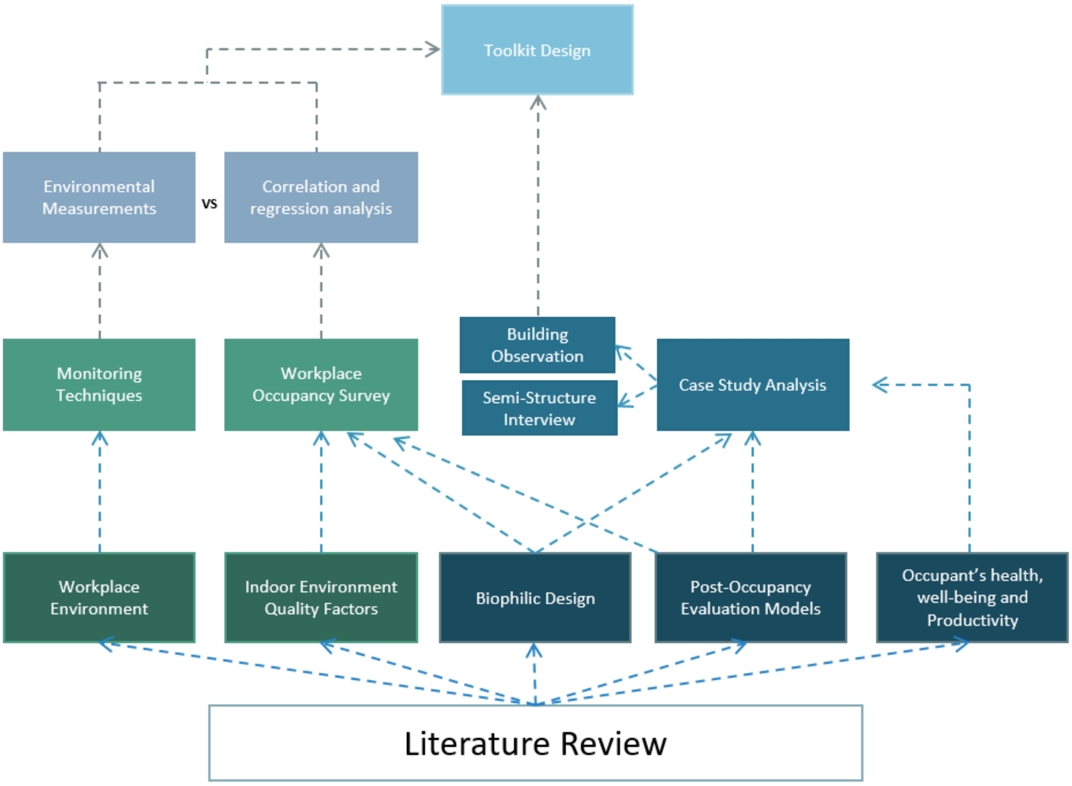


Figure 16: Research Stages

3.6.1 Stage 1 - Literature Review

A detailed IEQ and BD literature review was undertaken to understand the research problem and assess the extent of data required to support the research hypothesis and aim. The appropriate research methods and POE models were also assessed in the literature review, along with the data to be collected, how to measure and capture the relevant parameters empirically and how to conduct the project in a live workplace environment. As a result of the literature review, and based on the needs of the project, four data collection methods used within the research field were selected:

1. Semi-structured interviews within an observation
2. Occupant POE surveys
3. Workplace environmental monitoring
4. Toolkit focus groups

3.6.2 Stage 2 - Case Study Method

A case study is an experiential analysis that explores a contemporary phenomenon within its real-life setting, mainly when the borders between the phenomenon and the context are not clearly evident and thus, the analysis relies on multiple sources of evidence (Yin, 2014; 2017). Yin (2018) listed six considerable sources of evidence: interviews, observation, archival records, documents, participant observation and physical artefacts.

In this study, to answer the first research question (whether the Biophilic features in an office environment with the same outdoor and indoor environment improve the health, well-being and productivity of occupants), on-site observation was meant to quantify how BD affected the performance of occupants; the field study included a combination of the spatial configuration described by non-participatory observation and in semi-structured interviews.

The research methods adopted a qualitative approach that consisted of a descriptive-analytical method, case study and logical reasoning. First, the case was observed on-site without participation. Second, semi-structured interviews were conducted in the field with several occupants of the workspaces to provide a holistic view of their perception of using BD as a design approach intended to improve the health, well-being and productivity of occupants in the office. In these interviews, the majority of the question was open-ended.

As this research adopted the Flourish Model way of evaluation, there was a need to work with client mapping needs and HR (Clements-Croome, Turner and Pallaris, 2019, Clements-Croome, 2020).

The results were analysed to determine how Biophilic office buildings had been designed and how they affected the occupants' perceptions. Finally, the study explored the relationship between the BD patterns adopted in the building and the occupants' responses; this also showed the strengths and weaknesses of the design.

Furthermore, to better understand the Biophilic patterns in workplaces, an on-site observation was set up to quantify how BD affects workers' performance.

Site Description

The Second Home company is located near Spitalfields in the East End of London. Its concept is that of the shared workspace (co-working space), and it hosts around 30 small-scale companies that are as alternative as the neighbourhood. The studios vary from a single place in a large common area with room for up to 75 people to studios that can accommodate 5, 7, 10 and 20 people (the largest maximum capacity).

The building appropriates the space between the slabs and grid of concrete pillars, transforming it into a fluid atmosphere. After the brick façade of the first level was eliminated to introduce an orange structure containing the café, all barriers were dematerialised, vertical and horizontal. Parts of the slabs were removed so that the entire extent of the space could be taken in visually. In the rest of the area, 31 private cells (Figure 17) were distributed, divided by resin panels providing acoustic insulation.

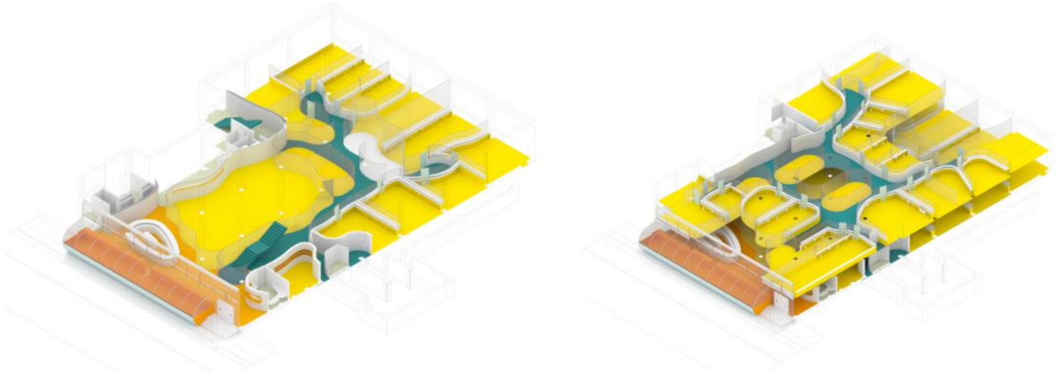


Figure 17: Interior Division

The studio floors are painted yellow with epoxy paint. There are 1,000 plants inside, wholly integrated into the shelving. The concept of Second Home involved the unavoidable need to occupy small workspaces, as every area was bathed in daylight, as shown in Figure 18.

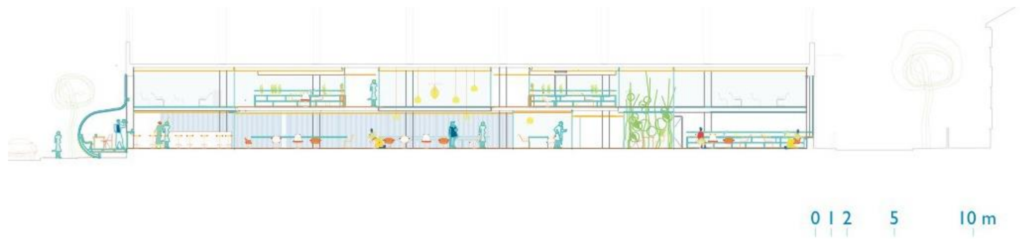


Figure 18: Section of the building

Semi-structured Interview

Semi-structured interviews were seen as an ideal solution to assess subject matter experts' appreciation of the importance of BD. In addition, using a semi-structured interview facilitated the ability to use open-ended questions to stimulate expert responses.

The development of the interview required the number of questions to be minimal; therefore, all the questions were open-ended.

Ten HR members of the Second Home offices were asked to provide a holistic view of their perception of the BD approach in office buildings. In this case, the qualitative method was designed based on the parameters of the Flourish Wheel, and thus, the interviews were divided into questions on design and impact. The semi-structured interview design targeted the IEQ factors and their influence on the productivity areas to understand how important the BD experience is to the performance of the occupants. The results were analysed to determine how Biophilic office buildings are designed and how they affect human perceptions.

As a result, this research presents a holistic view of the building, both physically and psychologically, because the designed matrix assessed the impact of the IEQ on the productivity of the occupants and conveyed the importance of understanding the BD application and its effects on the occupants. It was also used to analyse the on-site observations as well as the semi-structured interviews. A total of seven questions formed the interview and are detailed below (Table 16).

Table 16: Interview Questions

Construct	**Open-ended questions**
About the Second Home	1. What motivated you to choose the Second Home as a place to start your enterprise?
	2. How is the Second Home different from the other companies in the same type of co-working form?
Health and well-being of occupants	3. How do you describe the impact of the Biophilic features on the health and well-being of the occupants?
	4. Was the change in the well-being and satisfaction of the occupants noticeable?
Productivity of occupants	5. How do you describe the productivity and performance levels of the occupants compared to those in traditional office buildings?

The IEQ in the building	6. How do you expect Biophilia to affect the IEQ of the office building?
	7. Does Biophilia solve some IEQ issues in the office building, or do you think that it was based on offering aesthetic values for the interior of the office?

Each HR member that participated in the semi-structured interview requested that the interview not exceed 30 minutes. The questions were not presented to the interviewees in advance of the interview; however, an explanatory note concerning the research and details of the interview structure was provided. The interview was conducted by the researcher asking each question in sequence and coaching the interviewees to respond in a managed time of 3–4 minutes. Interview times ranged from 15–25 minutes.

Chapter 4 will discuss the results of the case study method and describe the observations made in the Second Home company and how the BD affected the IEQ in the building.

Semi-structured Interview Sampling Size

In qualitative research, samples tend to be small so as to support the depth of case-oriented analysis, which is fundamental to the inquiry mode (Sandelowski, 1996). Additionally, qualitative samples are purposive, selected by their capacity to provide richly-textured information relevant to the phenomenon under investigation.

Sandelowski (1995) recommended that qualitative sample sizes be large enough to allow the unfolding of a ‘new and richly textured understanding’ of the phenomenon under study but small enough that a ‘deep, case-oriented analysis’ (p. 183) of qualitative data is not precluded.

The interviewees were selected by approaching various HR members and briefing them regarding the research project, the expected outcomes and the specific need to interview building subject matter experts. The criteria for the interviewees' selection are presented below (Table 17).

Table 17: Interviewees' Selection Criteria

Criteria	Requirements
Age	25 years
Gender	Female or male
Experience	Worked within the built environment in the last three years
Position within Organisation	HR member

No statistical calculation method existed to determine the actual sample size for the interviews; therefore, out of the 30 companies that occupy the Second Home offices, 10 interviews were conducted in October 2019 to determine an answer to the second research question.

3.6.3 Stage 3 - Survey

POE differs from conventional surveys and market research. It uses the direct, unmediated experiences of building users to evaluate how a building serves its intended use. It also indicates the building's performance and effect on the users.

POEs assess how buildings meet the users' needs, identify ways to improve building design and operation, determine performance levels and assess the buildings' general fitness for purpose. POE can be classified as an assessment method, an analysis tool or an investigative framework to evaluate a building's performance.

As part of the POE methods, survey research is a social research methodology that focuses on structured or systematic sets of data collected about the same variable; survey findings are provided through a data matrix that allows the data to be analysed (De Vaus, 1995). By asking questions during the data collection process, a numeric description of a fraction of the population, known as a sample, can be provided in a way that allows the researcher to generalise the results to the population as a whole (Fowler, 2009; Creswell, 2014).

Survey Technique

A POE survey was developed within this research as a consequence of the in-field nature of the evaluation, directed at the researchers in five research rooms at Brunel University London, and a cross-sectional survey method was adopted.

Cross-sectional surveys use a selected sample drawn from a section or segment of the area to be studied. The benefits of this approach are that it is simple, reasonable and easily managed with the participants.

The first round of the survey questionnaire was administered between January 2020 and February 2020. The second survey questionnaire was administered in February 2022, along with a measurement test in the same research rooms. The questionnaire was directed at the doctoral and post-doctoral researchers at Brunel University London. This questionnaire aimed to answer the third research question of how the effects of IEQ factors on the occupants in university research rooms that have the same outdoor environment but different indoor environments can be measured and interpreted. Hence, the questionnaire was designed to first evaluate the IEQ factors and sub-factors in the university's open-plan research workplaces; and second study the potential for adapting BD patterns in a technological context from the point of view of the occupants.

Site Description Overview of IEQ in Brunel University's Research Rooms

This part of the data collection was conducted at Brunel University London, which is located in the Uxbridge area of London, England. It evaluated the IEQ factors of the research rooms in five buildings, each of which has a number of multi-disciplinary occupants and varies in size, methods of ventilation (including different types of windows), mode of thermostatic control and level of use of electrical equipment.

Figure 19 shows a map of Brunel University London, with the location and direction of each of the rooms highlighted in yellow and printed in red, respectively, and the sun path and wind direction at the time of the survey shown to the right.

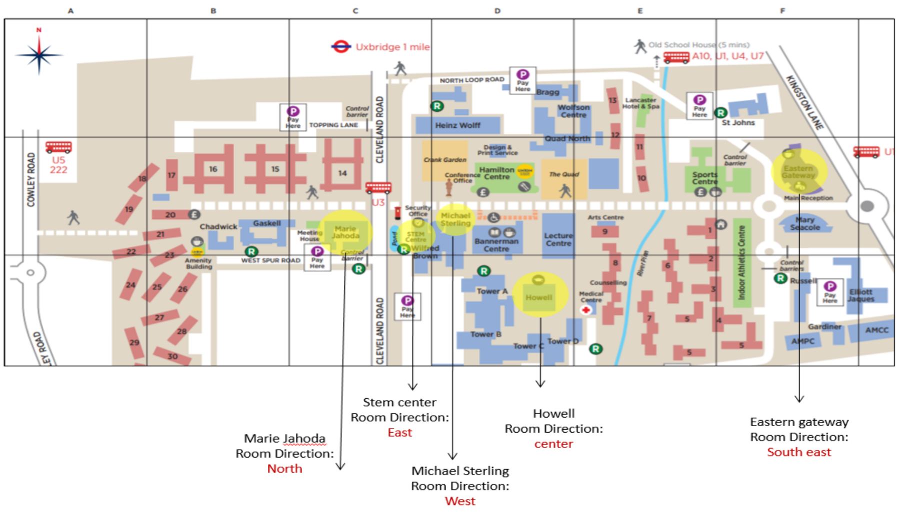


Figure 19: Brunel University London Map

The physical conditions of the five research rooms, including the building in which each is located, the year it was built, the level of the selected office, the workspace area, the occupant density, the ceiling height and the function of the office, are shown in Table 18.

Table 18: Physical Conditions of the Considered Research Rooms

Name	**Michael Sterling**	**Howell Building**	**Marie Jahoda**	**Wilfred Brown**	**Eastern Gateway**
Year	2010	1990	Around 1980	Redeveloped in 2018	2012
Total Floors	4	3	2	4	4
Office Level	Second Floor	First Floor	First Floor	Third Floor	First Floor

Research room Area (m^2)	66.36	124.74	82.77	122.22	119.04
Number of Workstations	15	20	11	15	20
Ceiling Height (m)	3.20m	2.80m	2.80m	3.20m	3.20m
Room Function	(Design students)	(Engineering students)	(Economic students)	(Computer Science students)	(Accounting students)
Max Occupancy	15	20	11	15	20
HVAC System	Centralised CAV	Centralised CAV	Centralised CAV	Centralised CAV with temperature regulation systems	A biomass boiler is the primary source of heating. A gas-fired boiler plant provides additional heat when needed.
Glazing Type	Double-glazing	Single	Single	Double-glazing	Double-glazing
Window-to-Wall Ratio	62%	32%	10%	77%	73%

Buildings Characteristics

The first research room was in the Michael Sterling building (shown in Figure 20). It is an open-plan office consisting of 15 occupied desks. It has two doors (the main entrance and an emergency exit) and an elevation with large windows giving direct access to the outside environment.

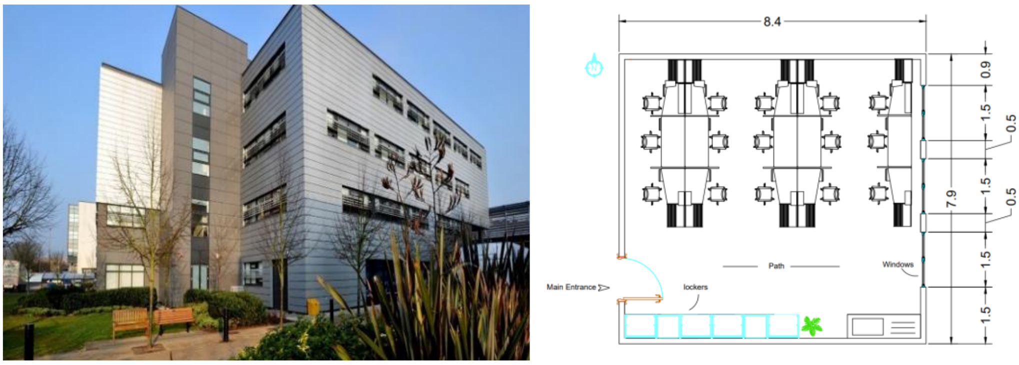


Figure 20: Michael Sterling Research Room Plan

The Howell Building (completed in 1990) houses the second research room selected. This open-plan office can accommodate 20 people. As shown in Figure 21, it has two doors but no windows; in particular, it has no access to fresh air.

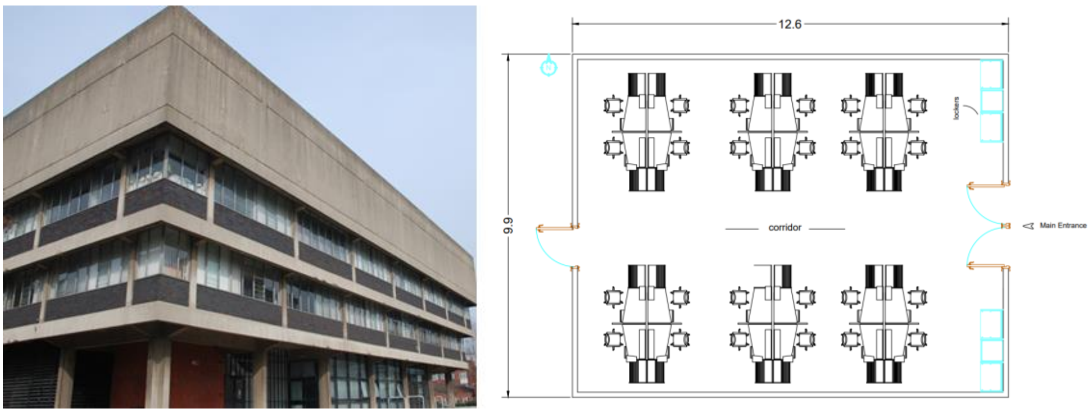


Figure 21: Howell Building

The third research room is located in the Marie Jahoda building. As can be seen from Figure 22, it is one of the university's oldest buildings. Its small, open-plan research room has two small windows and one main door.

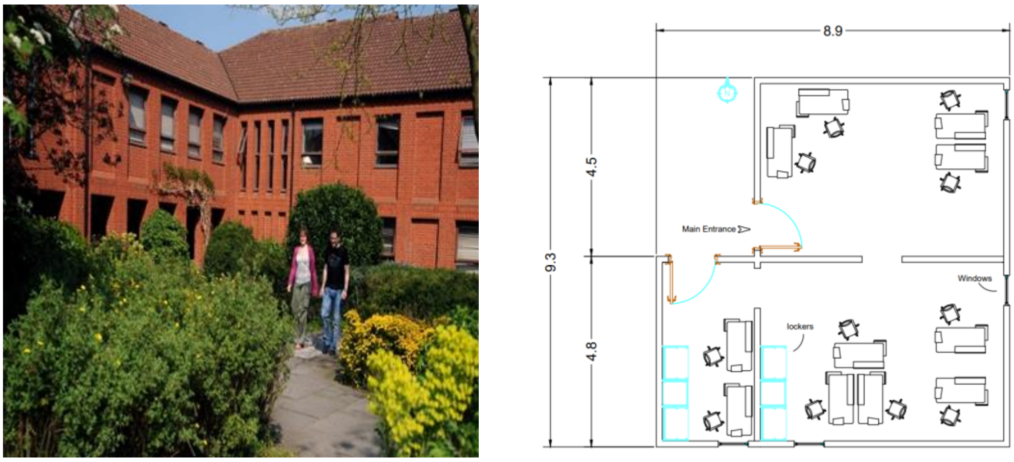


Figure 22: Marie Jahoda Building

The Wilfred Brown building (Figure 23), where the Computer Science department is located, was the fourth building considered in the study. It is one of the newest buildings on campus. Many forms of technology seen in other areas of the campus have been incorporated into this building, including photovoltaic panels, temperature regulation systems and rainwater harvesting. The Computer Science department research room accommodates 15 people and is open-plan. It has two doors and large windows along the elevation constructed of glass.

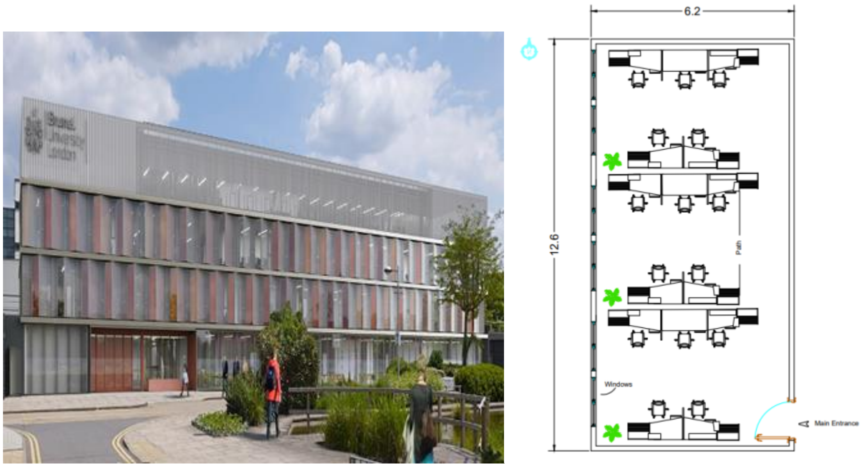


Figure 23: Wilfred Brown building

The last research room considered in this study was in the Eastern Gateway building (shown in Figure 24), which was completed in May 2012, and rated BREEAM 'Excellent'. Brunel University London aims to build environmentally sustainable buildings and embed sustainability into its estate management; this building was planned, built and occupied to ensure the most significant energy and water use efficiency and the lowest carbon emissions possible.

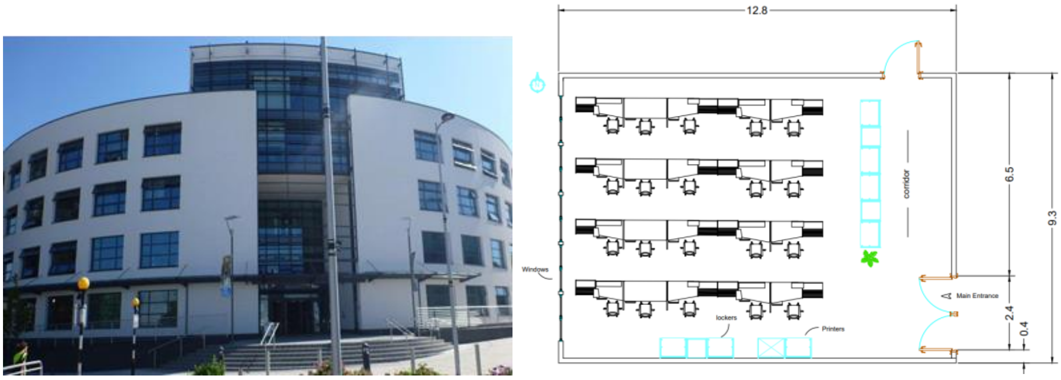


Figure 24: The Eastern Gateway Building

The Estates department aims to promote a sustainable future by investing in cost-effective efficiency measures that reduce energy use and carbon emissions. Accordingly, the department has ensured that operational staff are suitably trained and updated to secure the best possible return on investment in energy efficiency measures and is discovering opportunities for exploiting alternative fuels and new technologies and seeking to achieve BREEAM ratings of ‘excellent’ or ‘very good’ for new university buildings.

The main features that distinguish this building from the others are its low embodied energy materials and glazing with low-E coatings, selected for their low maintenance and high durability; prefabricated elements were chosen to reduce waste. The building also uses natural ventilation for cooling and has reduced glazed areas and orientated structures to minimise solar gain. The building was designed with ultra-efficient heating and lighting systems to meet and transcend the new Part L regulations (conservation of fuel and power) for enhanced energy efficiency. Building Regulations Part L is a building regulation in England that concerns construction projects that are new or result in the change of use of a dwelling or all other types of buildings. It sets the standards for the energy performance and carbon emissions of new and existing buildings. Finally, the Eastern Gateway building uses some renewable energy technologies.

Survey Sampling

Sampling is an essential part of the survey method; a population segment is used to make estimated assertions regarding the nature of the overall population from which the sample has been chosen (Babbie, 1990).

When designing or considering a POE survey sample size, the researcher needs an understanding of the statistics that drive the choice of sample size.

In this study, a 'purposive' theoretical sampling approach (Dawson 2009) was utilised. It was relevant for the study to understand how the IEQ factors and sub-factors affected the occupants of five research rooms at Brunel University. The research rooms chosen are used by the Design, Accounting, Computer Science, Economics and Civil Engineering departments. Similarly, knowing how each aspect of the IEQ affected the health, well-being, and productivity of the occupants was essential.

Sample Size

The size of the sample is defined by De Vaus (1995) as the result of the degree of accuracy required for the sample and the extent to which the population varies concerning the key characteristics of the research.

In order to answer the third research question, a two-stage sampling strategy was adopted; in the first stage, five buildings, accounting for 50% of Brunel University's buildings with research rooms, were chosen. Each structure has two research rooms. The next stage involved surveying the occupants in these rooms. Due to the small number of occupants, the survey was conducted in two rounds: 81 students participated in the first and in second surveys.

It is worth mentioning that the selection of the buildings was based on the buildings' various ages and the number of research rooms, what discipline they cater for and how busy these rooms are.

In cluster sampling, all the occupants in the selected clusters are surveyed. Moreover, the efficiency of cluster sampling depends on the size of the cluster. As the size increases, efficiency decreases. This suggests that higher precision can be attained by distributing a given number of elements over a large number of clusters, then taking a small number of clusters and enumerating all the elements within them.

In subsampling, there is a need to divide the population into clusters. In the first stage, a sample of clusters is selected. Then, in the second stage, a sample of the specified number of elements is selected from each of the previously selected clusters.

Two-stage sampling also means that the construction of sampling frames is much simpler. This is shown in Figure (25).

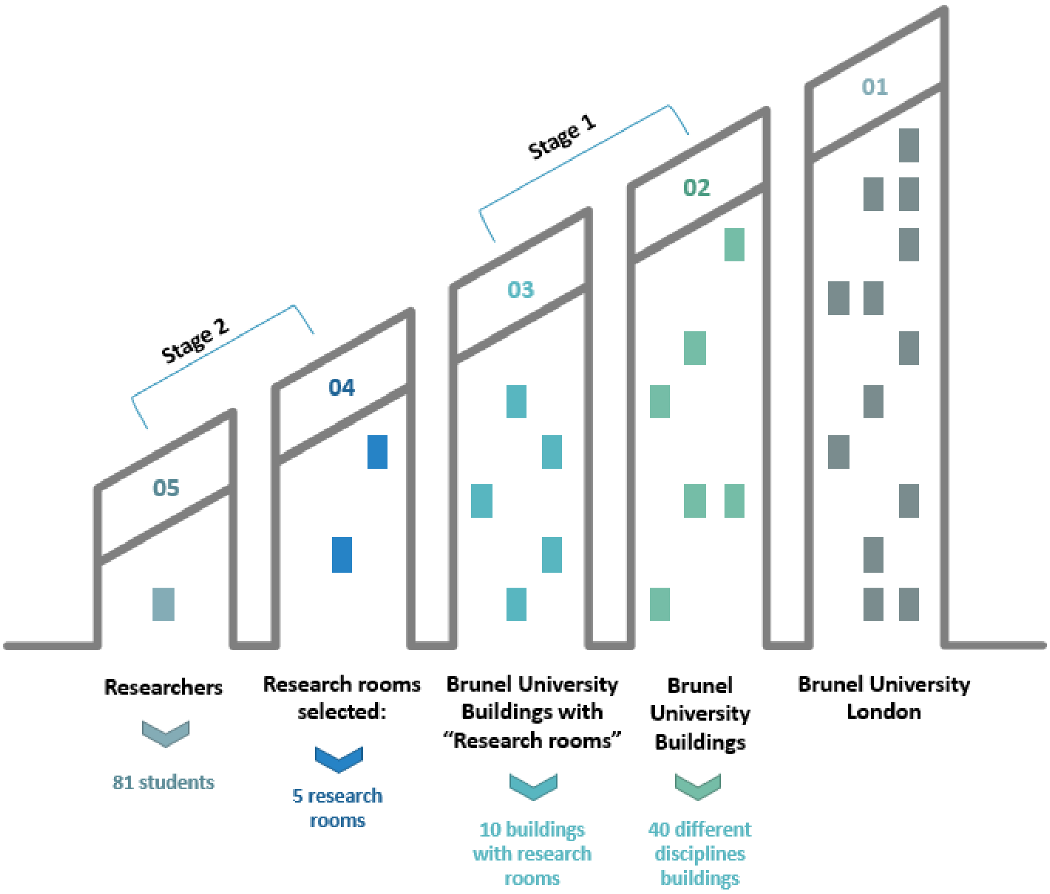


Figure 25: Two-stage Sampling

The total number of respondents for each room in each survey is shown in Table 19.

Table 19: Total Number of the Sample size

Main Group	Sub-group	Number of occupants in each room	Respondents (First Survey)	Respondents (Second Survey)*
Doctoral and Post-Doctoral Researchers' workplaces	Michael Sterling	15	15	124
	Howell	20	20	142
	Marie Jahoda	11	11	82
	Eastern Gateway	20	20	149
	Stem Centre	15	15	133
Total:			81	630

* The number here represented the accumulative response of 65 researcher for 14 days.

Survey Design and Structure

The IEQ issues can be characterised by imbalances in temperature and humidity in the office environment, which affects the efficiency of occupants, as suggested by the literature (Zheng et al., 2009). Also, it could be the absence of fresh air in a highly polluted environment, which creates higher rates of dissatisfaction among occupants and a range of health problems for them (Fisk, Black and Brunner, 2012; Bluyssen, 2019). Allergy symptoms, asthma and SBS, are among the more critical health problems recorded (Silva et al., 2017).

The absence of daylight also affects the health and well-being of occupants; daylights are recommended as the optimal light source for visual comfort and human health, providing excellent colour. It has a positive effect and transmits a sense of cheerfulness and brightness within a space, influencing the fitness, mood, efficiency and mental attitude of occupants (Li and Lam, 2001; Li, 2010; Beute and de Kort, 2018). Moreover, open-plan office noise negatively impacts the fatigue, performance and motivation of occupants (Jahncke and Halin, 2012).

The survey instrument addressed the five facets of the IEQ aspects that affect the health, well-being and productivity of occupants the most, with a broad selection of questions constructed based on the IEQ within their workplaces, as shown in Figure (26).

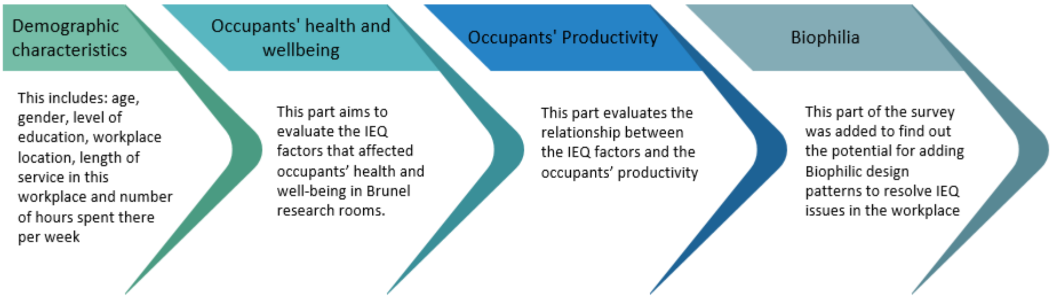


Figure 26: Questionnaire Structure

The study's second survey can be considered a "Right Now" survey, which is short – never more than half a page. It's designed to be distributed in person at an existing meeting or in parallel with a test (Cao et al., 2012; Chiang et al., 2001; Li et al., 2018; Mui et al., 2005).

The questionnaire was developed based on the Building Use Studies (BUS) occupant survey and the Flourish Wheel to collect the perceptions and beliefs of the occupants and their subjective responses to IEQ performance and check the correlation between them. The questionnaire took less than five minutes to complete, and the Design and Physical Sciences Research Ethics Committee of Brunel University London reviewed and approved the research questionnaire. The questionnaire was distributed in hard copy format to the occupants in the research rooms while the IEQ measurements were being taken.

The questionnaire required the respondents to rate the indoor environment conditions of their workplace, including thermal comfort, IAQ and noise and lighting levels, on a scale of 1 to 7[1].

[1] The Layout factor was not included because, first, it is not changeable and can't be monitored as it is a stable variable, and second, it had been evaluated in the first survey.

The questionnaire was designed to evaluate the size and direction of the relationships between the subjective and objective assessments of the indoor conditions shown in Table 20.

Table 20: Satisfaction Survey

Question	Subjective Criteria (On a scale of 1 to 7)	Objective Criteria
Describe your level of perceived temperature; where on the following scale would you position the indicator?	Thermal sensation (Too cold–Too hot)	Air Temperature
How would you rate the indoor humidity?	Humidity (Dry–Humid)	Humidity
How would you rate the overall Indoor Air Quality (Ventilation) within your workplace?	Air Freshness (Fresh–Stale)	Air Quality (CO_2 concentration)
What do you feel about the acoustics environment?	Overall noise (Very quiet–Very noisy)	Sound Level
What is your opinion of the light entering the space?	Overall lighting (Very dark (No access to daylight)–Very bright (Too much daylight))	Lighting Level

3.6.4 Stage 4 – Environmental Measuring Devices:

Indoor environmental quality is the result of the combination of indoor environment components that interact with users of the environment. It is largely characterized by four environmental categories: thermal comfort, IAQ, lighting and acoustics (Larsen et al., 2020). More recently, specific IEQ factors and their association with overall comfort or satisfaction have been explored so as to determine more influential factors in the built environment.

Heinzerling et al. (2013) reviewed the IEQ performance assessment comprehensively, including both subjective and objective measurement methods and tools. However, continuous IEQ measurement devices, integrating various sensors and/or meters, have been created for different studies because no integrated, continuous IEQ measurement toolkit is commercially available (Karami et al., 2018). A low-cost device for data collection and analysis is essential to make IEQ assessment affordable and to use a comprehensive evaluation of IEQ for better control of the built environment. For instance, Ali et al. (2016) created a low-cost Arduino-based IEQ sensing system, including an Arduino Uno board, an SD memory card for data storage and a series of low-cost sensors for temperature, relative humidity, occupancy, lighting intensity and eqCO2 concentration.

This part of the research contributed to identifying which IEQ factors positively or negatively influence overall satisfaction, presenting the degrees of their association. During the second survey, measurements of the indoor environmental conditions, including air temperature, relative humidity, eqCO2 concentration levels, sound levels and lighting levels, were taken using Arduino sensors along with three hand-held monitors, as shown in Figure 27. The measurements included spot measurements as well as continuous measurements.

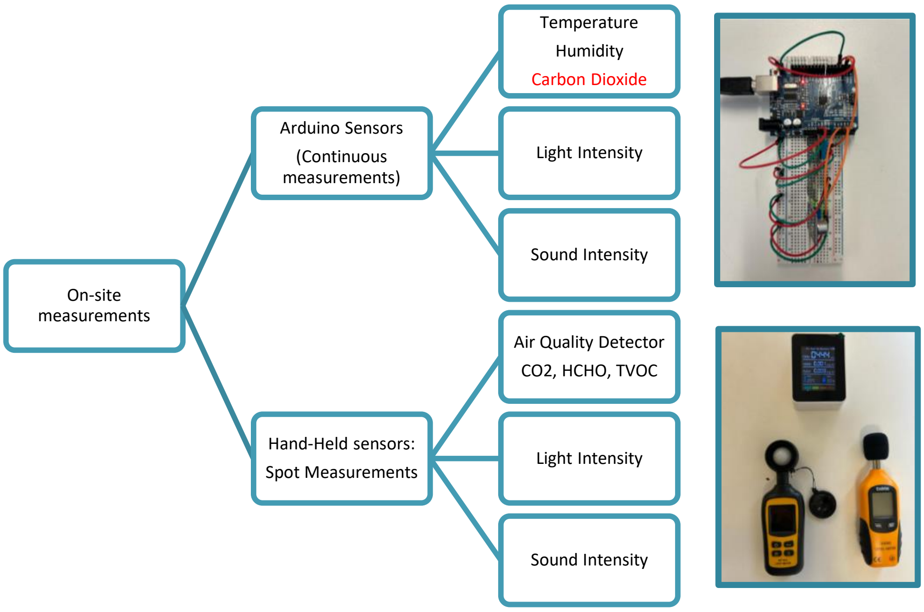


Figure 27: Arduino Sensors and Hand-held Monitors

3.6.4.1 Arduino Sensors

The Arduino platform provides various circuit boards, some of which utilise Atmel's low-power CMOS 8-bit microcontrollers based on AVR-enhanced RISC architecture. The microcontrollers compute around 300,000 lines of program code per second, which is more than sufficient for most of the input and output applications required for typical building data collection timescales (for example, seconds or minutes; Ali et al., 2016).

Arduino provides an integrated development environment (IDE) that can run on all major operating systems and supports a simplified C/C++ programming language. Arduino also has a large online community that stimulates engagement in the development and enables rapid prototyping and debugging.

Furthermore, many high-grade sensors and devices have custom Arduino libraries and active support from manufacturers for the platform (Barroca et al., 2013; Lian et al., 2013; Nagy et al., 2014). This has demonstrated the reliability and ease of use of the Arduino platform for data collection, making it a viable choice for developing the measurements in this study. Table 21 describes the IEQ sensors used in the measurement test.

Table 21: Arduino Sensors

Sensor name	Parameter	Measuring Range and Accuracy
Grove – Temperature, Humidity and CO_2 Sensor	Temperature Humidity CO_2	Temp range: -40–80 °C Humidity range: 5–99% rH Temp accuracy: ±0.5 Humidity accuracy: ±2% eqCO_2 range: 400ppm–8000ppm
Grove – Sound Sensor that can detect the sound intensity of the environment.	Sound Intensity	3.2V to 5.2V
Grove - Light sensor that integrates a photoresistor (light-dependent resistor) to detect the intensity of light.	Light Intensity	UVA, UVB and UVBI measurement 0 to 650 Lux
Other Components:		
Arduino Uno: A microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which six can be used as PWM outputs), six analogue inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header and a reset button.		
Breadboard: It is self-adhesive and compatible with Arduino sensors and shields.		

The layout of the sensors set up in the office spaces is shown in Figure 28. The data were recorded simultaneously in each office space using five packages for two weeks (14 days).

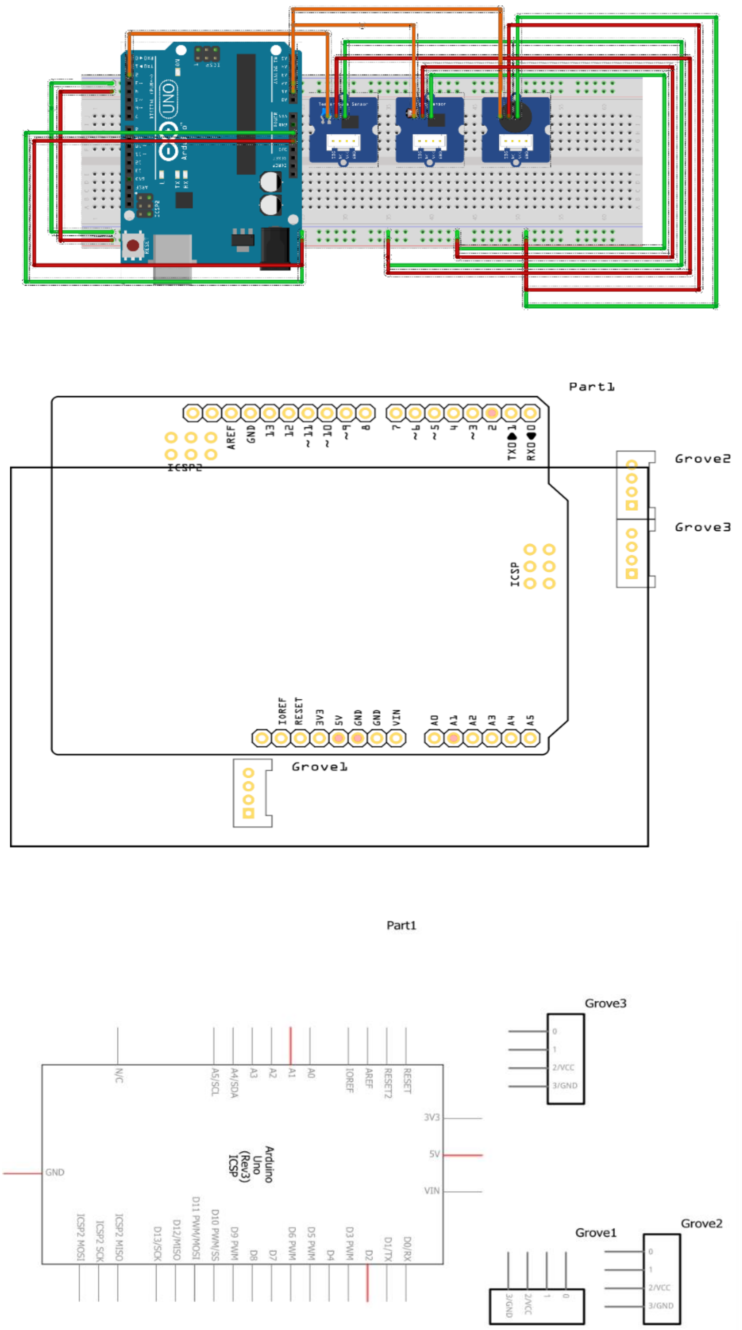


Figure 28: Schematic Diagram

The official Arduino IDE is used for microcontroller software programming. It offers both an online and an offline version, which is free for use by anyone. The online version of the Arduino IDE that was used in this study can be seen in Figure 29.

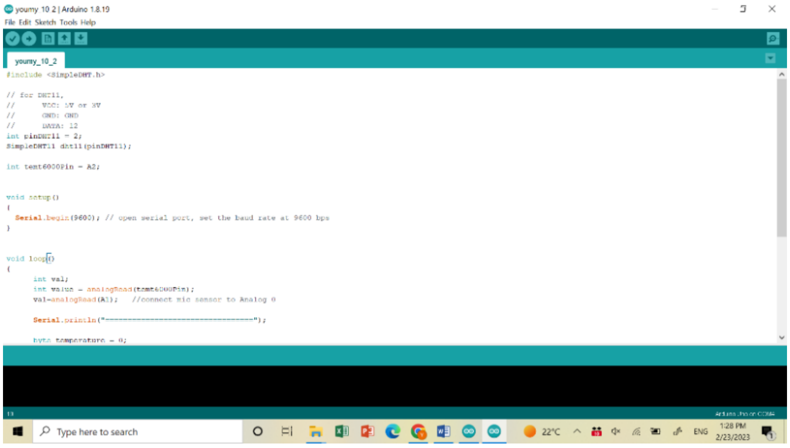


Figure 29: Arduino IDE

After downloading the Arduino IDE, the next step was generating the code and connecting the base shield to the Arduino board and connecting the board to the computer, as shown in Figure 30.

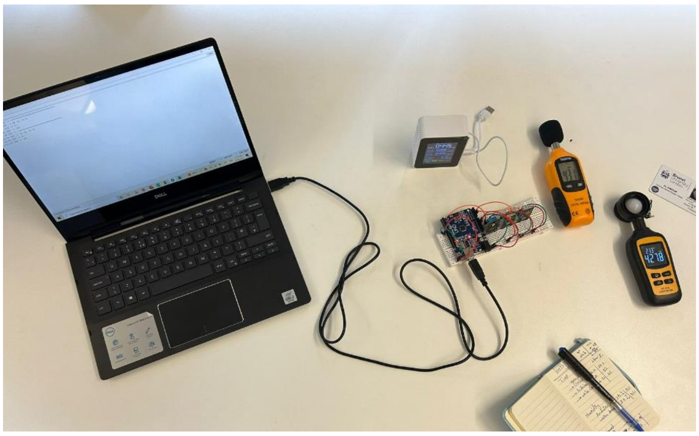


Figure 30: Data Collection Process

The continuous data from the sensors were downloaded from each individual sensor-set from each research room every day using the Arduino IDE software, which was connected to the Excel Data Streamer; a sample is provided in Figure 31. Once downloaded into the software, the data were transferred to the Excel software and cleaned.

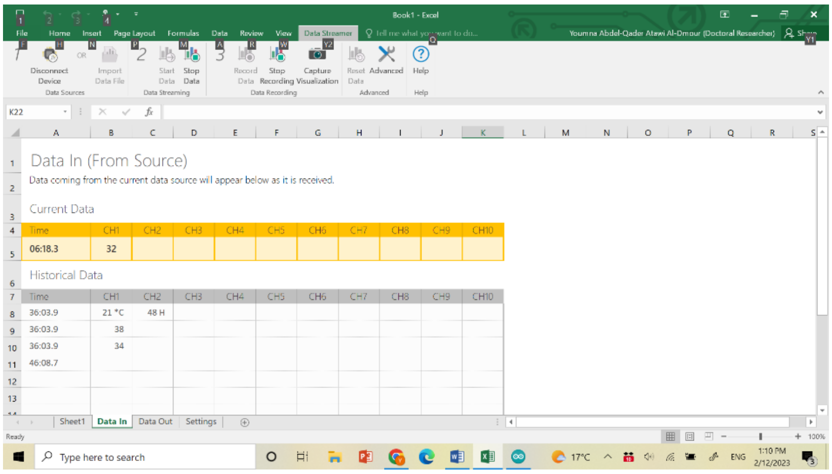


Figure 31: Excel Data Streamer Screenshot

The data cleaning was a manual process conducted on each line of data to remove any corrupted data, incorrect timestamps and/or data errors.

3.6.4.2 Hand-held Environmental Monitoring Equipment

A range of calibrated hand-held monitoring devices was utilised to make reference readings for comparison and to ensure the reliability of the data. These hand- held monitoring devices were utilised to provide a spot value assessment of the general research area during the 14-day research period. The following environmental equipment was deployed at the research locations:

1. Air Quality Detector: This device can monitor and display the CO2 concentration/m3 in real-time, clearly displaying HCHO, ambient temperature and humidity.
2. Sound Meter: This device was selected to measure the overall sound level and is factory calibrated. Frequency weighting “A” was selected because the study reflects more closely on the ears’ interpretation of noise, and therefore, it could align the measurements with the occupants’ survey responses. An “A” weighting and “Fast” response noise setting is commonly used when assessing environmental noise levels, particularly when instantaneous peaks may occur within a workplace environment.

Table 22: Noise Meter Specification Details

Specifications:	
Sound Level	30~130 dB
Resolution	0.1 dB
Accuracy	±1.5 Db
Frequency Range	31.5 Hz~4 kHz
Frequency Weighting	A
Time Weighting	FAST (125mS)
Microphone	1/2-inch electret condenser microphone
Index	1–15 dB Silence 15–20 dB Quiet 20–40 dB Whispering 40–60 dB Normal 60–70 dB Noisy 70–90 dB Very noisy Above 100 dB Hearing impairment

3. Light Meter: The light meter was selected to provide a general horizontal illuminance. It was factory calibrated and located within the centre of the research area with close proximity to the environmental poles. The unit of measurement selected was “lux”, which reflects the current industry standards referenced in Chapter 2. Table 22 indicates the meter’s specification. It covers a measuring range of up to 200,000 lux, with highly accurate results.

Table 23: Light Meter Specification Details

Specifications:	
Measuring Range	0 ~ 200,000 lux, 0 ~ 20,000 Fc
Resolution	< 1000: 0.1; > 1000: 1
Accuracy	±3% rdg ± 8 dgts (< 10,000 lux), ±4% rdg ±10 dgts (> 10,000 lux)

3.6.4.3 Calibration Methods

Various interpretations of the term 'calibration' can be found in the literature. In some cases, it is used purely for the procedure of establishing the measuring error of an instrument, while in other cases, it also includes adjustment of the instrument (Pertijs, Huijsing, 2006; Sydenham and Thorn, 2005). Error in Sensor Measurement is the difference between the indication and the actual value of the measured variable. Errors in sensor measurement can be caused by many factors.

In order to reduce the time that it takes to complete a sensor calibration, an "as found" check on the instrument should take place. This is simply performing a calibration prior to making any adjustments. If the instrument/sensor calibration is found to be within the stated tolerance for the device, then re-calibration is not required. Another way is by using a calibrated sensor or instrument known to be accurate. It can be used to make reference readings for comparison.

Table (24) shows the factors and calibration levels and whether it is acceptable or not.

Table 24: Factors and Calibration Levels

Factor	Procedure	Calibration level	Acceptance level
Temperature and Humidity	closely controlled and monitored environmental room with known values of uncertainty.	10^{o}C/80%RH 20^{o}C/50%RH 30^{o}C/30%RH using tolerance values of 0.8^{o}C/4%RH	A % out of specification <90% is considered acceptable
CO2	known volume and quantity of both nitrogen and CO2 into a sealed bag.	0; 500; 1000; 2500 ppm using tolerance values of 0/40; 500/40; 1000/50; 2500/125 ppm	A % out of specification <90% is considered acceptable

Lighting	Digital lux meter, portable photometer, calibrated at the factory Recommended by Arduino's official website. Reading was taken from the sensors and compared with the light meter reference instruments.
Noise	Sound dB meter calibrated at the factory. Readings were taken from the sensors and compared with the sound meter reference instruments.

3.6.5 Stage 5 - Toolkit Design Method

The first step towards constructing a viable toolkit was to identify a design-oriented conceptual framework containing the particulars of BD applications. The framework covered some essential aspects that had to be considered to build a complete set of guidelines on designing using the Flourish Wheel and improving workplaces with BD.

Designing for the workplace involves considering different levels of complexity, in which design elements relate to the occupants, each other and a broader range of conditions. Given this complexity, the present study identified the need for guidance in designing Biophilic workplaces using the Flourish Wheel. This need presented the opportunity to construct a toolkit adapted to the recognised framework.

The steps of designing the Biophilic Workplaces Flourish Toolkit were as follows:

1. The research was conducted on the existing design toolkits and other resources associated with the relationship between the design discipline and the workplace;
2. The vision and mission of the toolkit were defined, and the requirements and positioning of the resource in the Flourish Wheel representation were outlined;
3. The toolkit elements were designed;
4. The toolkit was tested and validated by experts;

In this research, it was observed that the design process needed the support of a specific design toolkit that defined a broad and ambitious theoretical framework by analysing the state-of-the-art potential of existing solutions. In the end, the goal was to perceive this toolkit as a resource. To position the toolkit, the research analysed the main factors and sub-factors that should be available throughout the design process.

The toolkit's design was based on the Flourish Wheel; it describes in detail each of the subjective parameters (IEQ aspects) and objective parameters (the layout and the aesthetic values of the space) considered. It is worth noting that this wheel is based on three main environmental factors: the subjects; the design, perceptions, and feelings people have in different environmental settings; and the economic consequences created by the environment (World Green Building Council, 2014).

The researcher developed and tested the toolkit through online focus groups through five levels between November 2020 and June 2021 (Table 25).

Table 25: Toolkit Design Testing

Focus Group/Interview	Members	Time
Interview (during the design process)	3 architects	September 2020
Focus group	3 designers 3 architects	October 2020
Interview	1 expert in design 1 expert in the built environment	April 2021
Focus group	7 designers	July 2021
Focus group	6 Architects	July 2021

Focus Groups

Focus groups offer a well-established method of collecting data in the research field of the social sciences, bringing together participants with mutual characteristics or preferences to record their individual and collective observations under relevant topics (Morgan, 1996).

Focus groups share common epistemological issues with other observational approaches since they relate to the depth and meaning of the participants' experiences; however, they are differentiated based on certain characteristics. Researchers argue that focus groups are reflexive and empowering experiences for participants, given that some advocates encourage participants – through group conversations – to discuss their opinions and experiences (Goss and Leinbach, 1996).

These 'collaborative study performances' (Bosco and Herman, 2010) are purported to illustrate the nature of socially constructed knowledge better since participants are motivated to query, question and justify their views through group interaction (Goss and Leinbach, 1996; Kamberelis and Dimitriadis, 2013).

The potential of focus groups, however, depends on overcoming a number of methodological limitations associated with their use, including the size and structure of groups, the practical constraints of location and timing and the positionalities of the researcher and participants (including class, gender, ethnicity and lived experiences; Hopkins, 2007).

Online Focus Groups

Online focus groups capitalise on the growing use of the Internet as a communication tool. They currently take two forms: synchronous, involving real-time live conversations similar to the conversational interactions of face-to-face focus groups (Fox, Morris and Rumsey, 2007), and asynchronous, using 'static' text-based communication, such as forums and email lists (Gaiser, 1997; Kenny, 2005).

This research conducted an online focus group with three designers and three architects to test the toolkit called 'Flourishing in the Biophilic Workplaces' to check whether the toolkit properly showed information and whether the users knew what they could do with it and how to do it. Knowing whether the toolkit provided an effective way of collecting data and helped users to identify issues and get solutions (Grinyer, 2016).

3.6.6 Validity, Reliability, and Analysis

Reliability determines how far a test, process or tool, such as a questionnaire, can produce similar or related outcomes in various situations, assuming no other changes have occurred.

Validity refers to the proximity between what was intended to be measured and what is assumed to have been measured; in other words, as Punch (1998) explained, validity is the extent to which a measure reflects the concept it seeks to measure.

In quantitative tests, reliability is the proportion of variability in a measured score that is due to variability in the true score (Roberts, Hann and Slaughter, 2006). This means that a reliability of 0.75, equal to 75% of the variability in the true score, is true; the remaining 25% is the result of an error.

In quantitative studies, validity can be either internal or external. External validity is related to applying the research analysis results to other individuals and situations (Black, 1999). Internal validity outlines the reasons for a specific study's results, then helps reduce the effect of other unexpected grounds for these outcomes.

Before analysing all the data, the researcher conducted exploratory factor analysis followed by a reliability test of the research room in the Michael Sterling building of Brunel University, which accommodates 15 researchers. The results indicated that all the constructs were reliable and achieved the minimum cut-off value of 0.7 in Cronbach's alpha.

The POE surveys had not previously been undertaken in any of the research rooms; therefore, this new data collection was the first such feedback associated with workplaces. The collected surveys were prepared discretely for analysis, tabulated using Microsoft Excel and filed under each respective survey method. No analysis was undertaken until all the collected data had been cleaned and scheduled.

Moreover, no previous monitoring had been conducted in any of the research rooms; therefore, no previous measurements existed to benchmark the measured values. Finally, using the monitoring equipment required the best available coincident time stamping to be achieved. Moreover, two calibration methods are used to make the sensor function as accurately, or error-free, as possible.

3.6.7 Testing

Pretesting is necessary for the successful communication and delivery of intended messages to the target respondents; its purpose is to improve the quality of the data and the responses (Summers, 2001).

For this reason, five individuals who had, at some point, been involved in the design of the first survey were invited to take part in the pre-testing survey. They were all doctoral researchers. Some constructs were modified after the pre-tests to help the survey questions flow more logically. The questionnaire items for this study were derived from existing studies and, therefore, had already been subject to validation; nonetheless, they had to be adapted to suit the present research objectives.

Both quantitative and qualitative methods accordingly drove the analysis of the data collected. IBM SPSS version 20 was used to carry out the quantitative analysis.

Finally, for the toolkit stage, there was a need for a number of designers and architects to test the tool and validate it; this was done in five stages during the process of the toolkit design.

3.6.8 Ethical Issues for the study

Due to the nature of the research needing human involvement and personal data recording and storage, the research was conducted in adherence to the strict rules governing ethical research set by the ethics department of Brunel University London. An ethics form was downloaded for this purpose. Several measures had to be taken to ensure the confidentiality and privacy of all the respondents and that the participants were aware of the nature of this research and their rights as participants.

The doctoral and post-doctoral researchers were given complete information about the purpose of the study, the methods and their rights to privacy, confidentiality and withdrawal from the study. This was provided to them in the form of a participant information sheet and a model consent form.

The researcher's contact details were also made available in case anyone wished to express concerns and queries regarding the research. No names or personal information were asked for or indicated in any part of the study. The participants were also informed that participation was entirely voluntary and that they had the option of skipping some questions if they did not feel inclined to answer or were uncomfortable answering. Password-protected access to the raw data was withheld throughout the study period by the researcher. Finally, after the data were written up, measures were taken to protect the privacy and confidentiality of the participants.

3.7 The Timing Decision

When researchers select a mixed methods approach, they must be able to determine the timing for using both quantitative and qualitative methods. In the research field, timing denotes the temporal relationship between the quantitative and qualitative components of the study (Greene, Caracelli and Graham, 1989). The concept of timing is discussed in terms of the time when the data sets are collected; Bryman and Bell (2015) referred to this concept as the sequence decision regarding which method precedes the other.

In this study, the researcher first collected the qualitative data of the case study to identify the various IEQ factors that had an effect on the health, well-being and productivity of occupants and then defined BD approach applications in the co-working open-plan office buildings. This was done in October 2019.

The researcher first visited the four branches of the Second Home company in London to observe how Biophilia is implemented and how it has been merged with the environment. After that, the researcher selected the Spitalfields branch for interviewing the occupants as it was the only branch that gave permission to do so.

The researcher then collected the quantitative data from the questionnaire to evaluate the IEQ and the degree to which it affected the health, well-being and productivity of occupants in the five research rooms of Brunel University London and to study the potential for improving these workplaces using BD. This part of the research was done between January and February 2020. Then, due to covid-19 pandemic restrictions, in February 2023, a robust check of the second questionnaire was conducted, with a number of IEQ measurement tests.

Finally, the researcher designed the co-design toolkit in November 2020 to help designers and architects improve an existing workplace using BD based on the Flourish Model. The researcher developed and tested the toolkit through online focus groups through five levels between November 2020 and June 2021. The focus group was supposed to be held face-to-face with physical cards; however, due to the pandemic restrictions, the plan had been changed.

3.8 The Weighting Decisions

Furthermore, the researcher had to assess the relative weighting of the quantitative and qualitative methods in the study. To answer the research questions that the study posed, the relative priority and importance of the approaches had to be considered (Creswell et al., 2006). This consideration is also referred to as the priority decision (Bryman and Bell, 2015): whether the qualitative or quantitative method is more important for the data collection or whether they carry the same weight. The present study assumed that the two methods were of equal weight. This was because, on the one hand, the qualitative research clarified how BD was applied at the Second Home company and found the strengths and weaknesses in the office building; therefore, it was essential to study these applications and how they affected their users. On the other hand, using the quantitative study also helped to understand the IEQ factors and sub-factors that mostly affected the health, well-being and productivity of the workplace occupants.

3.9 Summary

This chapter describes the methodology and research philosophy of the study as well as its approach and strategies. The study adopted triangulation methodologies using quantitative research (from survey and IEQ measurements test) and qualitative research (from on-site observation, semi-structured interviews and focus groups) to test the findings. These research methods were designed to answer the research questions. The following chapters discuss the results from the study's phases and link them with the existing literature.

4. CHAPTER FOUR: THE SECOND HOME OFFICES AS A CASE STUDY

4.1 Introduction

Recent trends of urbanisation and today's revolution in society have led to the majority of people spending most of each day indoors, either at home or in their workplaces, resulting in reduced exposure to nature and measurable physiological and psychological impacts. Therefore, it has become necessary to design buildings in such a way that helps to mitigate SBS and reduce the adverse effects of the built environment on its occupants. However, many researchers have shown that the connection between indoor building design and the well-being of occupants is complex (Bluyssen et al., 1995; El-Salamouny et al., 2019; Esfandiari et al., 2017).

When evaluating IEQ, indoor stressors present in many forms, for example, unacceptable thermal levels, poor lighting and access to daylight, dampness, noise sources and vibrations, chemical compounds and fluctuations in particulate matter, which may have cumulative effects or complicated interactions. In the workplace, various impacts have been associated with these factors, such as reduced productivity. Evidence that the office environment has a significant effect on people in ways that may either impair or improve their health, well-being and productivity is well documented (Aboulnaga, 2006; Clements-Croome, 2006; Newsham et al., 2009; Oseland and Bartlett, 1999; Veitch et al., 2008).

A study on workplace design indicated that 58% of 7600 office workers in 16 countries reported no plants in their office, and 47% reported no natural light (Browning and Cooper, 2015). Work-related health problems, such as stress-related diseases, have caused 4–6% of GDP losses in most countries (Ko et al., 2022; World Health Organization, 2017). On the other hand, a good working environment with natural elements can efficiently avoid physical and mental impacts of a negative nature (Fritz et al., 2013; Mendell et al., 2011), improve social relationships and employee self-esteem, and eventually maximise organisational profits (Clements-Croome, 2018; Houtman et al., 2008; Moksnes et al., 2013).

With the growing emphasis on the importance of natural elements in workplaces, BD has been developed rapidly (Kellert et al., 2011; Kellert and Calabrese, 2015). Systematic design strategies on both BD attributes (for example, greenery, natural light and window views) and spatial combinations have been put forward (Jiang et al., 2022; Kellert and Calabrese, 2015; Xue et al., 2019).

Nowadays, society is more aware of ecology than ever; therefore, effort should be put towards understanding in some depth how implementing Biophilic features in office workspaces can affect the quality of this indoor environment and, in turn, affect the social environment.

In their recent work, Yin et al. (2020) conducted an experiment with 100 participants by combining virtual reality and wearable biomonitoring sensors to test the restorative effect of Biophilic elements on stress and anxiety through methods such as adding green plants and wooden materials in the indoor environment, besides having windows that let in daylight and had outdoor views of a natural environment. It was found that Biophilic environments had larger restorative impacts than non-Biophilic environments in terms of reducing physiological stress and psychological anxiety levels.

Sanchez et al. (2018) conducted a 5-day pilot study to evaluate a Biophilic office environment and concluded that the participants in the Biophilic space had higher creativity, better environmental perceptions and fewer negative symptoms than those in the control space. The quantifiable benefits of the Biophilic workplace go beyond measurable physiological indicators. The inclusion of daylight and implementation of green features in the workplace play a significant role in the health and cognitive functions of the occupants, and both can be assessed through the measurement of subjective and objective parameters (see also Hähn et al., 2021; Lerner and Stopka, 2016; Yin et al., 2018).

Based on the literature review, this study aims to first assess the effect of different BD elements, such as indoor greenery in the workplace, on the health, well-being and productivity of occupants. The inclusion of vegetation was selected in this study as one of the most common strategies of BD (Kellert and Calabrese, 2015); one of the essential applications of the BD approach is to understand the possible role of plants and green features, besides the effect of architectural planning, on social interaction in the workplace. Second, this study aims to verify how the IEQ affects the perceptions of occupants and how it could benefit their health and well-being if designed using the BD. Finally, the question of how far such Biophilic features solve a range of issues in the built environment, both indoors and outdoors, is asked.

A research study in the UK compared the productivity levels of two groups of office employees exposed to different levels of contact with nature. The results showed that the actual productivity of those who worked in offices with natural greenery rose by 15% in three months compared to those with no natural elements or greenery in their environment (Browning and Cooper, 2011). Another recent study in Singapore (Lei, Yuan and Lau, 2021) concluded that workplace environment greenery improves working performance. Also, the green coverage ratios of 0%, 0.2%, 5%, 12% and 20% were tested, and the results suggested that 12% is the appropriate ratio of Biophilic elements to include in the workplace to improve the psychological and physiological and productivity performances of all the occupants (Lei, Yuan and Lau, 2021). This understanding could serve as a guide towards the most convenient approaches to the indoor and outdoor design of a balanced workspace through the inclusion of vegetation. It is essential to understand the needs and expectations of the occupants.

In the present chapter, interviews with 10 HR members of the companies occupying the Second Home are presented. The interviews were based on the Flourish Model, which was designed to survey people's feelings about their working conditions, besides identifying the actual state of being of the individuals at a particular time and place (Clements-Croome et al., 2019).

As mentioned in Chapter 2, the Flourish Model takes into account three leading environmental factors: design, the perceptions and feelings that people have in different environmental settings and the economic consequences of different environments (World Green Building Council, 2014). Using the Flourish Model as a POE model involves several steps, including collecting data from HR members or people's psychological and physiological responses as part of a social science survey.

4.2 The Second Home Company

The Human Space report (2015) mentioned that the country with the most significant percentage of workers reporting that their office does not provide natural light was the UK (66%). Interestingly, natural light was the most requested element in the workplace in both US and UK, much more than any other design element. Similarly, 58% of workers reported having no greenery, in the form of plants, within their work environment.

Studies on BD present substantial evidence of how IEQ affects the health, well-being and productivity of occupants. Over the last 10 years, BD has become an approach used widely in designing workplaces; previously, its applications were limited to small projects.

The researcher first observed several office buildings designed based on the BD principles in London. These office buildings implement elements of BD, from air-purifying plants to living walls, flooring, wall decor, acoustic panels, artwork, sounds, scents and fabrics. As a result, the IAQ is improved, boosting the satisfaction and productivity of the occupants while reducing their stress levels.

The four main Second Home branches in London, located in Spitalfields, London Fields, Holland Park and Clerkenwell Green, were visited. All four branches were designed based on the concept of BD; they have curved and transparent walls, considerable attention is given to the plants and green walls inside the spaces and natural materials and other BD elements are included, as can be seen in Figure 32.

Second Home, Spitalfields

Architects: Selgascano Area: 2,400 m² Year: 2014


Second Home, London Fields

Architects: Estudio Cano Lasso Area: 1813 m² Year: 2019


Second Home, Holland Park

Architects: Selgascano Area: 1048 m² Year: 2017


Second Home, Clerkenwell

Architects: Estudio Cano Lasso Area: 1500 m² Year: 2017

Figure 32: The Four Main Second Home Branches in London

The researcher chose to observe the Second Home branch in Spitalfields. It was completed in 20142 and merited special attention because, first, it was founded on the concept of the shared workspace (co-working space) and catered to nearly 30 companies in the same indoor environment, all of which are small-scale alternatives in the neighbourhood. Second, according to the Office for National Statistics, the number of self-employed workers has doubled in the last two decades (Baitenizov et al., 2019). This has made it necessary to improve the provision of an environment that offers futuristic workspaces. Third, it was the largest office space in the area and had more BD elements and plants than the other Second Home branches. Finally, permission for the researcher to observe and take photos was given only at the Spitalfields branch in October 2019.

4.2.1 On-site Observation

Interestingly, the Spitalfields branch of this company was the launchpad and first UK project by the architects José Selgas and Lucia Cano. It provides an affordable and accessible working environment for every type of business by offering flexible

[2] It is worth noting that besides the other Second Home branches, there are other new co-working office buildings (for example, the One Heddon Street workplace in Westminster, established in 2019, and Uncommon co-working offices in Liverpool Street, established at the end of 2018). However, these buildings were nor chosen for the observation because they were not occupied at the time of the data collection.

"roaming" or "studio" memberships to more established firms. Its exceptional dynamic approach has changed the traditional division of businesses to share and integrate ideas and work on projects that businesses would never have engaged in individually.

The architects are intensely interested in evolutionary psychology and BD. They treat spaces quite differently from the typical, identical office environments where people are used to spending most of their time every day. Furthermore, they like designs in which thousands of plants, even trees, grow directly out of the floor because they are enthusiastic about promoting Biophilia, which, essentially, is the concept of humanity's inherent love of nature.

Figure 33 shows the ground-floor and first-floor plans of the building. The working areas are shaped like bubbles, and the studio floors are painted yellow. It is clear that all the interior walls are curvilinear.

Figure 33: The Ground Floor and First Floor Plans of the Spitalfields Branch Building

The Second Home company describes the building as "a new creative hub workspace". The researcher conducted the observation and 10 interviews with HR members from different companies occupying the building during the second week of October 2019.

The questions asked during the interviews concentrated on the three main issues pertaining to the Flourish Wheel: design, perception and economic issues. Table 26 below summarises a description of the IEQ in the building based on the Flourish Wheel design factors.

Table 26: On-Site Observation

IEQ	Observation Description
1. Office Layout	Different offices are spread across the floors, all behind plastic partitions, similar to the bubbles. These partitions offer views through the building, from the front to the end. The reason for having such partitions is to provide extra glazing to the outer walls, thus reinforcing the visual connection. To guarantee flexibility, some of the open-plan rooms feature a large U-shaped meeting table that can be winched up to the ceiling when the occupants are not going to use it or if they need the space for other activities, such as yoga, morning pilates, evening concerts, parties, dinners, conferences and film screenings.  **Essential materials:** Polycarbonate acrylic, wood, felt. **BD patterns:** Bellia (2013), Felsten (2009) and Kellert (2008b, 2018). 1. Non-Visual Connection with Nature: - Highly textured fabrics/textiles that mimic natural material textures 2. Dynamic and Diffused Light: - Desks are positioned close to windows/skylights - Glass doors/walls 3. Biomorphic Forms and Patterns: - Organically shaped furniture

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- The layout of interior/exterior spaces, such as curved paths and zones
4. Material Connection with Nature:
- Materials: natural colours, textures and patterns
- Wood: handles/handrails, timber wall panels
5. Complexity and Order:
- Partitions (glass textures, etched film on glass)
6. Prospect:
- Transparent materials: glass/polycarbonate walls/doors/partitions
7. Refuge:
- Quiet corners are set up (seat, lamp, carpet)
8. Mystery:
- Winding paths through spaces, gently curving (slightly disorientating)
</td></tr>
<tr><td>2. IAQ</td><td>
The air quality in the building was controlled using some sensors based on the needs of the plants.

The air in the building does not come from the windows; an automated cross-ventilation system is used.
BD Patterns: Windhorst and Williams (2015), Peters and D’Penna (2020), Browning et al. (2014), Gou et al. (2014) and Kellert (2018).
1. Visual Connection with Nature:
- Window planters
2. Non-Visual Connection with Nature:
- Natural ventilation (operable windows, breezeways)
- Green walls that release the scent and are resilient to touch
3. Non-Rhythmic Sensory Stimuli:
</td></tr>
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	- Opening windows allows breezes to create gentle movement in plant leaves, blinds or curtains 4. Thermal and Airflow Variability: - The opening and closing of windows throughout the day according to comfort levels is possible 5. Prospect: - Balconies – the sense of space, mezzanine, elevated platforms (interior and exterior)
3. Thermal Environment	The building is highly exposed to direct sunlight, with no shading elements. Thus, the temperature becomes very high in the summer, resulting in the areas with no shading being unoccupied during that time of the year.  BD **Patterns:** Berman et al. (2008), Windhorst and Williams (2015), Stigsdotter et al. (2017) and Shi et al. (2017). 1. Non-Visual Connection with Nature: - Green walls – absorb heat, humidity and moisture imbalances. 2. Thermal and Airflow Variability - Radiant surface materials
4. Lighting Environment	The building consists of a collection of lighting fixtures with different colours and shades based on the plants' needs.  The building is exposed to daylight and has low energy consumption, LED light bulbs and 100% green electricity. **BD Patterns:** Karlen (2017), Browning et al. (2014) and Kellert (2018). 1. Dynamic and Diffused Light

<table>
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- Materials: light-reflecting floors, tables, walls and surfaces; mirrors; light-reflective paint; tile glazes; white surfaces; and sequin/mirrored surfaces.
- Glass doors/walls
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<tr><td>5. Acoustic Environment</td><td>
Many curvy plastic enclosures are small workspaces for four to five people, whereas other spaces can accommodate up to 20 occupants, including several double-height spaces. Each one of the offices is transparent as well as soundproofed due to the insulation property of the acrylic material, which works perfectly for acoustics as it is not glass. Still, it is plastic, and it absorbs different sounds, which affects the acoustic comfort of the occupants.

BD Patterns: Jahncke et al. (2011).
1. Non-Visual Connection with Nature
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The current study bridges the gap in understanding the importance of applying the BD patterns to workplaces, as the results indicate a significant link between the physical body of the building and the wellness of its occupants. The latter is in line with the Clements-Croom hypothesis, which points to the usefulness of holistically evaluating all the indoor environment design layers simultaneously with the perceptual and economic impacts of the design on the occupants and the company itself.

4.2.1.1 Plants and Trees

The introduction of plants into indoor built environments enables humans to connect with nature, thus providing numerous social and economic benefits, including improved performance, satisfaction and physical and mental health of the occupants (Kellert et al., 2008; Spaces, 2015; Tyrväinen et al., 2014). These are achieved through direct and indirect interactions with plants, the “Nature in Space” pattern of BD (Brown, 2019; Browning et al., 2014).

The role of nature in the workplace has been researched in a limited context in the past; however, the few studies that have been conducted in the context of hospitals, prisons and residential settings (Moore, 1981; Ulrich, 1984; Ulrich, 1993; Verderber, 1986) found that indoor plants play an essential role in the well-being of humans (Kaplan, 1993).

Several studies have shown that introducing indoor plants into workplaces can improve productivity (Raanaas et al., 2011; Lohr, Pearson-Mims and Goodwin, 1996). For example, Nieuwenhuis et al. (2014) found improvements in perceived concentration and productivity as well as actual productivity (less time taken to complete a task and fewer errors made) of approximately 15% when plants were introduced into an office. Other studies also found participants to have reduced stress levels when plants were added to offices with and without windows (Chang and Chen, 2005; Largo-Wight et al., 2011; Lohr, Pearson-Mims and Goodwin, 1996).

Generally, the CO2 levels within a work environment are higher because the occupants naturally exhale (Torpy et al., 2013). Research conducted in Norway suggested that plants within the office environment reduced approximately 12 symptoms of illness – such as headaches, fatigue, coughs, dry skin and sore throats, among others – that are linked to SBS by an average of 23% (Fjeld et al., 1998).

Zhong, Schröder and Bekkering (2022), among others (Aydogan and Cerone, 2021; Barton and Pretty, 2010; Grinde and Patil, 2009; Hoelscher et al., 2016; Korpela et al., 2017; Söderlund and Söderlund, 2019), argued the strengths and opportunities of bringing vegetation indoors, besides incorporating plants into buildings by using green roofs, green walls and facades, and concluded that plants achieve the following:

1. Increase green space coverage, native plants ratio and biodiversity;
2. Improve shading/sheltering ability and reduce building energy consumption;
3. Edible plants promote food production for urban farming;
4. Provide accessible green spaces and support physical exercise;

5. Provide visual connections with green spaces for restoration, stress reduction, productivity and positive moods; and
6. Reduce air pollution and optimise air quality.

However, extra care should be taken while implementing the inclusion of plants inside workplaces, as they could sometimes cause structural problems, excessive humidity, insect trouble, odour issues, etc. Also, adding single plants and isolated gardens has limited impacts, while highly artificial designs require intensive energy and maintenance (Barton and Pretty, 2010; Kellert, 2018; Oldfield et al., 2015; Revell and Anda, 2014).

In 1985, the fundamental research that revealed the capacity of indoor plants and their root microorganisms to clean chemical pollutants from indoor air developed further. Seventy-two subsequent large-scale experiments determined that various interior plants could remove volatile organic compounds (VOCs) from sealed chambers (Wolverton, McDonald and Watkins, 1984; Wolverton, 1993).

Plants can remove indoor pollutants, including CO, CO2, ketones, pesticides and asbestos; emissions associated with cleaning products, tobacco smoke, insulation and furnishings; and fungi and bacteria (Wolverton, 1990).

A pervasive constituent of indoor air is CO2, and studies have confirmed that plants can effectively reduce CO2 concentrations during the day or night, depending on the plant type (Lohr and Pearson-Mims, 1996; Raza, Shylaja and Gopal, 1995).

Traditional HVAC systems are effective for removing heat and moisture but cannot add moisture when heating systems are in use. However, it is essential to ensure that HVAC systems limit humidity and prevent the accumulation of standing water. In poorly designed systems, excessive moisture can lead to fungal growth, which can cause significant health problems (Adan and Samson, 2011; Torpy et al., 2013).

With this in mind, trees and potted plants were included in the design of the Second Home spaces, with some growing directly out of the floor. Selgascano has also utilised new roof surfaces to welcome additional natural light. There are hundreds of plants inside, and they are completely integrated into the shelving. All the plants are alive, so there is a need to take care of them. Many of the potted plants are growing in soilless hydroponic conditions and are kept alive with the help of a “plant hospital” and four days of specialist care per week.

Before selecting the appropriate plants for the Second Home, specific environmental characteristics were considered, such as their suitability for the work environment, the light levels, people’s movement, air-conditioning and aesthetics. The following plants are an example of those that were utilised: *Chamaedorea seifrizii*, more commonly known as the reed palm (Figure 34), was selected for its excellent ability to filter VOCs from the air; *Aglaeonema* BJ Freeman (Figure 35) was chosen for its ability to handle low light conditions, filter VOCs and provide great aesthetics; *Phlebodium aureum* (Figure 36) was selected for its aesthetic, hardiness and suitability to the environment; *Dypsis lutescens*, the Areca Palm (Figure 37), is believed to conduct a significant amount of air cleansing during the day; *Sansevieria trifasciata*, also known as Mother-in-Law’s Tongue (Figure 38), converts CO_2 to oxygen, specifically at night; and *Epipremnum aureum*, the Money Plant (Figure 39), filters out and removes formaldehyde and other VOCs from the air (Bhavan and Nagar, 2008).

Figure 34: Chamaedorea seifritzii

Figure 35: Aglaonema

Figure 36: Phlebodium aureum

Figure 37: Dypsis lutescens

Figure 38: Sansevieria trifasciata

Figure 39: Epipremnum aureum

4.2.2 Interviews

In the field study, face-to-face interviews were conducted with 10 HR members from different companies within the co-working space during the observation period (8–11 October 2019). Each interview took almost 20 minutes. The occupants answered the questions voluntarily and provided a holistic view of their perception of BD as an approach to designing office buildings.

At the time of the research, the number of occupants in the Spitalfields branch of the Second Home ranged from 100 to 150. Overall, the company can accommodate about 30 companies of different sizes, where the number of workers in each company ranges from six to 20.

The companies occupying the Spitalfields branch fall into the following business specialisations: Creative Agencies, Architecture, Art, Culture and Music, Consultancy, Design, Education, Technology and Travel and Tourism, among others.

Among the interviewees, six were female, three were male, and one preferred not to say. Their ages ranged from 25 to 44 years old. Three of them had worked in the Second Home co-working space for five years, four for approximately three years and the remaining three for less than one year. Three interviewees specialised in Technology, three in Design and four in Travel and Tourism.

The design of the qualitative interviews was based on the parameters of the Flourish Wheel. As shown in the on-site description, this working environment is untypical and non-traditional and was designed with a BD approach; the architects sought to include as much nature inside the building as the environment could accommodate.

Overall, the HR members confirmed that working in such a workspace positively affected the health and well-being and productivity of their respective companies' employees. Because the building's design was unique and flexible, it also met the needs that they would have had in any workplace. When asked, "What motivated you to choose the Second Home company as a place to start your enterprise?" nine out of the 10 participants agreed that they chose the Second Home because it is different and uniquely designed to follow the green buildings concept and BD. They added that such buildings help improve the health, well-being and productivity of the occupants. Specifically, one of the interviewees said, "*I think it is important to provide nature and a place that offers an energetic environment for the occupants, which mainly increases their productivity. I have previously worked in a traditional design building and noticed a distinct difference between both environments.*"

Another interviewee said, "*The health and well-being of building occupants are affected by the quality of the environment delivered into the space. So, I suppose it relies on any company's awareness to specify any enhancements to the base build design to provide a better environment in the first place. It was a new way to work in an environment that made the occupants feel directly connected with nature.*"

The interviewees agreed that the inclusion of a large number of plants and greenery features was one of the most significant aspects of the space that made them feel in touch with nature and helped to refresh the air inside the building, which in turn helped to maintain the health of the occupants and reduce SBS symptoms. So, when they were asked if the change in the well-being and satisfaction of the occupants was noticeable, most of the interviewees affirmed that such an environment increases the productivity of the occupants and the outcome of the company. One interviewee said, "*Yes, I believe that the occupants in our company now have a unique look and feel to where they work as we particularly want an identical office for both occupants and clients.*"

When the interviewees were asked to describe the productivity and performance levels of the Second Home occupants compared to those in traditional office buildings, one interviewee said, "*I used to work in a traditional type of office building, and I would notice that the greenery at the 'Second Home' provide much more fresh air within the building which by default affects the occupants' comfort while working the whole day.*"

Moreover, another interviewee remarked, "*There is a seasonal difference in the 'Second Home' environment due to the external conditions and particularly in the winter when we have all the windows closed."* Finally, another interviewee shared some differences, *"For example, natural daylight is undoubtedly better than artificial lighting, in my opinion, as well as the natural air in the layout."*

Some interviewees pointed out that the open-plan design of the workspaces and the transparent walls encouraged communication and increased employee interaction. Others felt that this violated their privacy at work; two interviewees who worked in the Technology sector were slightly unhappy because their tasks, such as making calculations, needed more uninterrupted concentration than such offices could give. For this reason, the design needed to be flexible enough to meet the needs of companies with different multidisciplinary work teams. An interviewee said, "*I find office noise a significant distraction. When other people are talking, I find it very difficult to concentrate and tend to listen rather than focus, so it's a big issue for me.*" He added, "*We could probably do something about this by doing some acoustic analysis and treatment, but it's not considered a significant issue.*"

Some interviewees were concerned about the absence of curtains or shading on the building's elevations to keep the thermal comfort balanced. In the summertime, especially in June and July, the offices oriented towards the sun become very hot. As a result, the users of those offices have to find another space in the building, which negatively affects their yearly satisfaction.

When asked how they perceived the effect of BD on the IEQ within the office building, nine participants agreed that they were satisfied with the acoustic comfort because of the insulating capacity of the acrylic material, which, unlike glass, provides perfect acoustic performance. Furthermore, the material can absorb a range of sounds, and this maintains the acoustic comfort of the occupants. In their accounts of their surroundings, all the interviewees confirmed that working in an environment that brings them high levels of comfort positively affected their productivity and performance. In addition, this healthy environment reduced issues of absenteeism.

When the interviewees were asked whether the BD solves some IEQ issues in the office building or whether they think that the approach was based on offering aesthetic values for the interior of the office, the interviewees agreed that both are important: the first in a direct way, as it helps to improve the air quality, acoustics and lighting; and the second in an indirect way, as it affected the occupants' indirectly by making them feel in touch with nature. An interviewee answered, "*The general ergonomics of the space and its functionality for providing the user with a comfortable environment is vital in keeping the staff satisfied. I think this has been achieved by implementing sustainable features that help solve the occupants' thermal comfort and ventilation in the first place*." Another interviewee added, "*Having a healthy and productive space is essential to keep a team spirit. In addition, the Biophilic design gives flexibility to the workspace, which positively affects the company's benefits.*"

From an economic point of view, most of the interviewees agreed that using the Second Home co-working space had decreased absenteeism. It also helped improve the employees' actual performance, which improved their productivity. An interviewee said, "*we don't seem to have sick building syndrome issues. Second Home has been designed better, lighting and ventilation are totally better.*"

4.3 Results and Discussion

The main goal of this work was to, first, observe the implication of some of the BD elements inside a co-working space and, second, evaluate to what extent BD affects IEQ, which in turn affects the health, well-being and productivity of the occupants.

From the observation conducted, it was clear that the Second Home building has implemented the "Nature in the Space" aspect of BD perfectly because it included most of the natural elements, such as a large number of plants and the presence of water, as well as the concept of courtyards inside the structure so that the occupants could feel the presence of nature in their surroundings (Browning et al., 2014).

At the same time, however, the building design does not achieve the best possible airflow and thermal comfort for the occupants because the architects concentrated more on an environment that suited many plants. Furthermore, the view indoors was full of life, but on the outside of the building, there was no evidence of care for the terraces and outdoor landscape. Therefore, the most achieved patterns in the building are Visual and Non-Visual Connection with Nature, Non-Rhythmic Sensory Stimuli, Thermal and Airflow Variability and Dynamic and Diffused Light (Abboushi et al., 2019; Dematte et al., 2018; Jahncke et al., 2011).

The on-site observation also showed that the building mimics some of the flexibility of nature through the use of natural, recycled and organic materials, in addition to the curvilinear shape of the walls, which the interviewees agreed had a positive effect on their visual comfort because curvilinear forms provide a sense of openness and satisfaction, which in turn indirectly affects the productivity and performance of people. The Biomorphic Forms and Patterns and Material Connection with Nature are the patterns implemented the most to help solve some of the company's IEQ problems (Kellert et al., 2008; Mayer et al., 2009).

The interviews with the HR members confirmed that creating a Biophilic environment can reduce the mismatch between evolutionary needs and contemporary settings and thereby increase job satisfaction and performance. This result is in line with that of Fitzgerald and Danner (2012).

It was also found that BD improved the social climate within the workplace, as well as the occupants' mood, concentration, physical well-being and even their sense of the workplace's competitiveness (Thomsen, Sønderstrup-Andersen and Müller, 2011).

BD offers excellent potential to add natural beauty to a building (Bartczak et al., 2013; Capaldi et al., 2017), arouse visual interest (Abboushi et al., 2019; Dematte et al., 2018) and improve the overall aesthetics and quality of the building itself (Lee, 2019).

The interviewees agreed that the presence of many plants and greenery features was one of the most significant things that made them feel in touch with nature. Various studies have confirmed that the presence of indoor plants can increase health, well-being (Abdelaal and Soebarto, 2019), and productivity (Thompson Coon et al., 2011); however, the effect may vary depending on a range of factors. For instance, the density of the vegetation and its placement with regard to workstations change the degree of influence. In addition, the type of work being done in the space appears to be a significant factor (Shibata and Suzuki, 2002; 2004).

One study conducted by Africa et al. (2019) mentioned that with an appropriate façade and floor plan design, daylight could meet daytime lighting needs for visual comfort while reducing buildings' electrical and cooling costs. For example, external living walls can be used to cool a building's exterior façade, which reduces overheating, both on the surface and in indoor spaces, through shading and evapotranspiration. However, in the case of the Second Home, the interviewees mentioned that the amount of daylight and natural ventilation was significant in the wintertime, but in the summertime, the offices oriented towards the sun became too hot to work in, so they were avoided and became unoccupied.

Almusaed (2011) reported on the successful use of plants for acoustic and thermal insulation, which has been confirmed through observation and interviews.

Through the observation and interviews conducted, it was found that BD can positively influence IEQ and increase the sustainability performance of design interventions.

4.4 Conclusion

The Second Home company was an appropriate case in which to study the influence of BD features in workplaces. Two main points in this research emerged from the interview responses. First, using BD features as an aesthetic value is not enough to attain the highest IEQ or satisfy the expectations of the occupants for their office, as it affects their satisfaction indirectly. Second, the Biophilia pattern in the Second Home building provides a great example of how to design a workplace using BD in a way that helps to solve different IEQ issues and increases productivity. Furthermore, when designing an office environment using BD, it is essential to use suitable types of plants that help balance the temperature and humidity in the space; this also freshens the air if appropriately implemented.

The analysis of BD in the Second Home was performed within the SWOT analysis framework, a tool developed in the 1960s that identifies a situation's strengths, weaknesses, opportunities and threats (Learned et al., 1969). While it is primarily applied to strategic management (Phadermrod et al., 2019), SWOT analysis has also been used across disciplines to understand the impacts of internal and external factors on a particular situation.

Each interview transcript was carefully analysed using the SWOT analysis framework to identify and categorise concepts, findings and conclusions into the four SWOT dimensions. Generally, strengths and weaknesses are internal factors that can be controlled from within and can either support or hinder the achievement of targets. In contrast, opportunities and threats are usually identified as external factors (Wenping and Xuelan, 2012).

In this study, the following classification has been adopted for the SWOT dimensions:

1. **Strengths:** Potential benefits to the building's performance, controllable through design

2. **Opportunities:** Potential benefits to the building occupants (real or perceived)
3. **Weaknesses:** Negative impacts on the building's performance can be controlled through design
4. **Threats:** Potential negative impacts on the building occupants that are external to the building and may occur during the building's operation

Table 27: SWOT analysis of the case study building indicating its strengths, weaknesses, opportunities and threats

STRENGTHS:
The observation and interviews with the HR members of the companies in the Second Home co-working office made it clear how the building's unique design positively affects the health and well-being of the occupants. They affirmed that it noticeably affects the productivity and outcome of their companies. The designers used almost 10 out of the 14 BD patterns, which helped avoid IEQ issues, as previously discussed in the chapter. It was important to choose the right kinds of plants and locations for them to help to improve the IAQ and thermal environment in the space. As a result, using BD in the Second Home does the following: - Adds natural beauty - Improves IAQ by increasing natural ventilation using operable windows - Improves thermal comfort and reduces internal heat - Improves visual comfort - Improves acoustic performance - Increases productivity - Brings in natural light via glass walls, skylights, reflective colours/materials, etc. - Provides various sensory experiences
WEAKNESSES:

- First and foremost, construction costs for the BD approach are generally higher than for standard design approaches, and implementing BD in the construction of the Second Home increased its costs.
- Some of the green features used in the building only provide aesthetic value and do not help with the IEQ issues. For example, some rooms directly exposed to the sun are not occupied in the summertime because no shading elements have been incorporated into the building. The occupants also mentioned that there is no privacy between the offices because the walls are transparent.
- Natural ventilation may increase the circulation of pollutants. When there is high outdoor humidity, ventilation brings in excess moisture, increasing the risk of mould contamination.
- Glares and spilling light interfere with visual performance, and intense dynamics might be distracting and lead to overheating and decreased building performance.
- A large amount of vegetation in the building could cause excessive humidity, insect trouble, odour issues, etc.
- Highly artificial designs require intensive energy use and maintenance.

OPPORTUNITIES:

- Second Home is one of the few companies in London that implemented the concept of bringing nature to the inside of buildings on an internal landscaping scale.
- This building serves as an example to designers and architects of how to design using nature and how to use the BD patterns properly, which helps improve IEQ directly and indirectly.
- Second Home can be taken as evidence suggesting that BD significantly impacts the health and well-being of building occupants and enhances their social interactions and satisfaction.

THREATS:

- The following threats were identified through the analysis:
- Functional difficulties (for example, the method of implementing Biophilic elements, the costs of plants and their upkeep, and maintenance costs)

- Design restrictions (including threats to design involving incorrect needs assessment, potential structural failures and requirements for individual testing)

It is clear from the SWOT analysis that, in this case, the Strengths and Opportunities of BD are more significant than the Weaknesses and Threats. However, some points, such as the plant types, costs and essential IEQ factors, should be considered when improving workplaces using BD.

5. CHAPTER FIVE: IN THE EYE OF THE FLOURISH WHEEL: AN ASSESSMENT OF USERS' HEALTH, WELL-BEING AND PRODUCTIVITY IN UNIVERSITY RESEARCH ROOMS

5.1 Introduction

There is an increase in open-plan workplace design and construction worldwide. Several investigations have been carried out on this type of office and have demonstrated the essential effects of IEQ on the comfort and productivity of office occupants. Furthermore, these investigations have shown that the precise influence of IEQ factors differs according to the demographics of the occupants (Smith-Jackson and Klein, 2009), the type of office (Bodin and Bodin, 2009; Kim and De Dear, 2013), and several other factors.

This chapter presents and discusses the results of two surveys; as the first survey conducted to evaluate the occupants' health, well-being and productivity while the second survey conducted along with the IEQ measurement test which carried out at Brunel University London to learn about the indoor environmental conditions of the open-plan research rooms in five different buildings. A description of the five workplaces is provided in Chapter 3. The following sections will describe the first and second surveys and the implementation of the Arduino sensors to measure the IEQ in the rooms, along with the second survey. This chapter also aims to develop a framework for improving the IEQ factors using the BD patterns.

5.2 Survey Methodology

Conducting surveys is often the most straightforward and least expensive method for evaluating IEQ concerns in a building (ASHRAE, 2010). Moreover, occupant satisfaction is ultimately the primary interest of the building user survey of physical IEQ conditions.

In this chapter, two surveys are described and discussed. They were conducted at two different times but at the exact same location. Table 28 shows the main differences between the two surveys.

Table 28: Differences Between the Conducted Surveys

Category	Survey 1	Survey 2
Time	Between 15 February and 29 February 2020	Between 6 February and 19 February 2023*
Invitation	The invitation link was sent to doctoral and post-doctoral researchers in five different research rooms at Brunel University London.	The researcher visited the research rooms daily to do the measurement test and, at the same time, personally asked the respondents to fill in the questionnaire.
Respondents	A total of 81 users.	A total of 65 users answered the questionnaire for 14 days in five research rooms (results in 630 questionnaires were answered).
Purpose	To evaluate how the IEQ in the research rooms affected the health, well-being and productivity of the occupants. Also, to evaluate the potential to add Biophilic features within the research rooms to help enhance the environment.	To check the correlation between the occupants' responses and the environmental measurements.
Analysis	Descriptive Analysis	Descriptive Analysis
	Regression Analysis	Mean Difference Analysis

	Correlation Analysis	Correlation Analysis
***This gap in time was due to the Covid-19 pandemic and its related restrictions.**		

5.2.1 Survey 1: Health, Well-being and Productivity Survey

5.2.1.1 Participant Demographics

There were six demographic questions in the first survey. The responses to these questions were analysed to generate the participants' profiles. Table 29 presents the demographic questions asked at the beginning of the questionnaire.

Table 29: The First Part of the Questionnaire

Questions	Type of analysis
Demographic questions: 1. **Gender** 2. **Age** 3. **Level of education** 4. **Location** 5. **Work duration per year** 6. **Work duration (hour/week)**	Descriptive analysis

It was clear that the researchers' genders were almost equally distributed: 49.4% were males, and 48.1% were females (Figure 40).

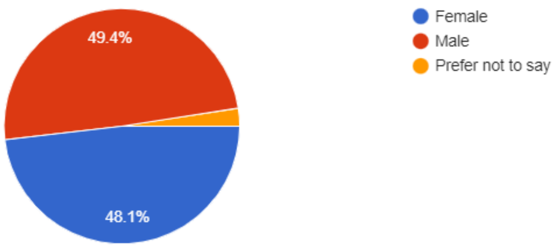

Figure 40: Pie Chart of the Gender Distribution of the Sample

The researchers' ages (Figure 41) ranged from 18 to 65. The age group of 31–50-year-olds was the largest age group and consisted of 45 researchers. The age group of 51–65-year-olds was the smallest and consisted of three researchers. The age group of 18–30-year-olds was the second-largest and consisted of 33 researchers. The 65+ age group was not represented in the sample. Of the entire population of 81 respondents, 12 were post-doctoral researchers, 12 were studying for a master's degree, and the rest (57) were doctoral researchers.

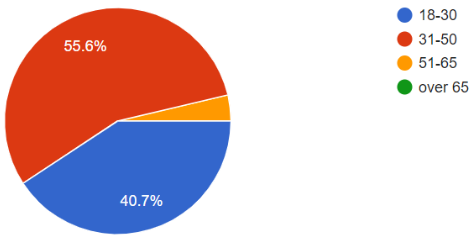

Figure 41: Pie Chart of the Age Distribution of the Sample

The researchers in the five rooms were mainly post-graduate students at Brunel University London; almost three-quarters of them are doctoral researchers, as shown in Figure 42.

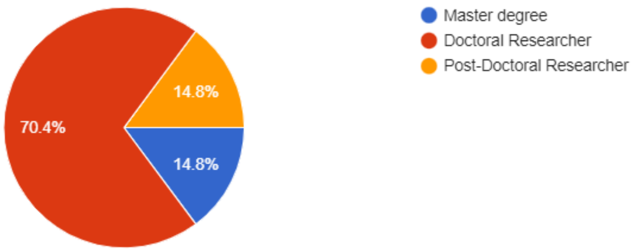

Figure 42: Pie Chart of the Respondents' Level of Education

This study targeted five different locations; therefore, the participants were asked about the location of their workplace. The distribution of the participants is shown in Figure 43.

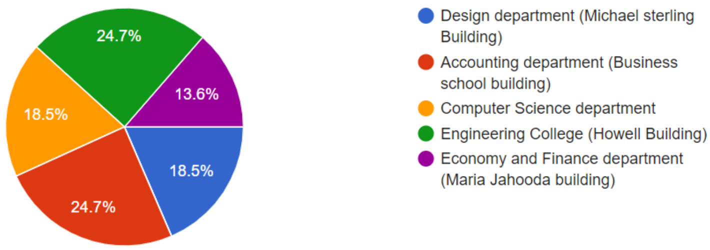

Figure 43: Distribution of the Participants

The researchers were asked how long they had occupied their respective offices and how many hours they spent there each week. It was helpful to note that the longer the time they had spent there, the more accurate the answers they could provide about their experience using them. As shown in Figure 44, a total of 19 researchers had used their respective offices for less than a year, while 30 researchers had spent from one to two years in their current office. The remaining 32 researchers had been in the same office for the past three years or more.

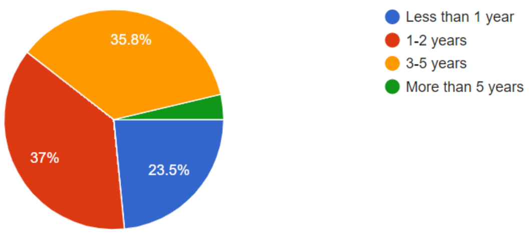

Figure 44: Distribution of the Number of Years the Participants had Spent at their Respective Offices.

Figure 45 shows that more than half of the researchers (56.8%) spent between 30 and 40 hours per week at their office desks, and 13.6% spent more than 40 hours per week. However, 29.6% of the researchers spent less than 30 hours a week in the office; this was due to several reasons. One reason was the IEQ, as discussed in the analysis of the next part of the questionnaire.

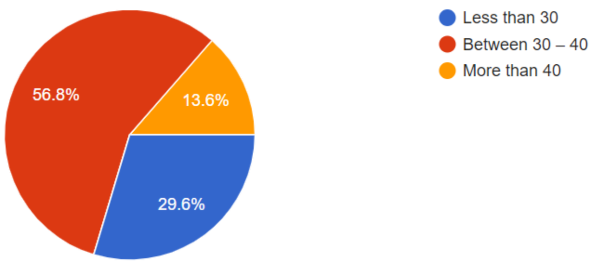

Figure 45: Distribution of the Number of Hours Spent in the Office.

5.2.1.2 IEQ Factors and Sub-Factors with the Health and Well-being of Occupants (Descriptive Analysis)

The sub-factors for the IEQ in the office building were chosen, following the literature review (Chapter 2), as the five IEQ aspects that most affected the health and well-being of the occupants. Table 30 below presents the questions in the survey on health and well-being regarding the IEQ factors and sub-factors.

Table 30: Health and Well-Being Questions Regarding the IEQ Factors and Sub-factors

IEQ Factor	IEQ Sub-Factor	Health and Well-being Questions	
Thermal Comfort	Temperature Humidity	Health	You feel that your office's temperature and humidity affect your health.
		Well-being	You feel that your office temperature suits your preference.
			You are comfortable with the level of humidity in your office
IAQ	Air Quality and Freshness Pollution	Health	You experience symptoms of irritants in the air environment, such as headaches, dry eyes, cough, sputum, nose itchiness, and dry skin.
			The previous symptoms persist after leaving your office.
		Well-being	You feel that the air in your office is fresh.
			You feel that the air conditions are comfortable in your office and affect your performance positively.
			You feel the air in your office is polluted occasionally.
Acoustics	Noise	Health	The noise in your work affects the health of your hearing sense.

		Well-being	You are comfortable with the acoustics in your office.
			You feel that your sound privacy is violated in the office.
Lighting	Daylight	Health	The light in your office negatively affects your eye health
		Well-being	Your office has access to daylight through the windows.
			You are visually comfortable in your office.
Layout	Layout and Functionality	Health	The layout of your office help in making your body active and energetic.
		Well-being	You feel that the spatial layout of your office is successful.
			The spaces between the workspaces, windows, desks and other kinds of stuff are comfortable.
			You feel comfortable with the orientation of your desk

The first set of analyses examined the researchers' satisfaction with each IEQ sub-factor. In the first set of questions, the respondents were asked about the two main sub-factors of the thermal environment: temperature and humidity. The results are presented in Table 31. As can be seen, the respondents in the Michael Sterling building (Panel A of Table 31) and the Eastern Gateway building (Panel B of Table 31) partially agreed that they are satisfied with the temperature and humidity levels in the offices;

the mean in both cases is around 5. A possible explanation for this result is the use of natural ventilation to cool the buildings, minimal glazed areas and the orientation of the buildings to minimise solar gain.

However, the responses to these questions differed for all the other buildings considered. For the Marie Jahoda building and the Howell building, it can be seen from the data in Panels C and D of Table 31 that the respondents disagreed that their office temperature (M = 2.27 and M = 2.52) and humidity (M = 2.45 and M = 1.60) levels suited their preferences. There are several possible explanations for this result. One is that these two buildings are among the university's oldest buildings. For instance, the Marie Jahoda building is constructed of red brick, the windows are very small, and the offices have an open-plan layout but still feel crowded. The respondents agreed that such an environment had a slightly negative effect on their health. Similarly, although the Wilfred Brown building is considered to be one of the recently developed buildings at Brunel University, the participants were not satisfied with the temperature or the humidity in the building because the glass used to construct the front elevation of the building allowed too much sunshine to access the room; it unbalanced the indoor temperature and gave no shade.

Table 31: Analysis of the Thermal Environment

	Temperature	Humidity	Health and Well-being
Panel A: Michael Sterling			
Mean	5.93	4.73	4.97
Std. Deviation	1.75	1.62	1.87
Variance	3.07	2.64	3.5
Panel B: Eastern Gateway			
Mean	5.3	5.8	1.7
Std. Deviation	1.42	1.79	1.22
Variance	2.01	3.22	1.48

Panel C: Marie Jahoda			
Mean	2.27	2.45	3.64
Std. Deviation	1.49	0.93	1.43
Variance	2.22	0.87	2.06
Panel D: Howell			
Mean	2.52	1.6	3.2
Std. Deviation	1.61	1.35	1.44
Variance	2.58	1.83	2.06
Panel E: Wilfred Brown			
Mean	2	2.87	2.13
Std. Deviation	1.73	1.51	1.68
Variance	3	2.27	2.84

The second set of questions pertained to IAQ. The researchers were asked about the freshness of the air in their research rooms and how polluted it was. The respondents from the Michael Sterling building (Panel A of Table 32), the Eastern Gateway Building (Panel B of Table 32) and the Wilfred Brown building (Panel E of Table 32) all agreed that their offices admit fresh air through the windows. On the other hand, they disagreed on whether it was occasionally polluted. Some researchers also agreed that they experienced some annoying symptoms from the air conditions, such as headaches, dry eyes, coughing, sputum, nose itchiness and dry skin. Others, however, responded that the air quality in the office did not positively or negatively affect their health.

The researchers who worked in the older buildings, the Marie Jahoda building and the Howell building (Panels C and D of Table 32), agreed that their access to fresh air was deficient and the environment was sometimes polluted. With regard to this, they did not agree that there were enough windows to control the variable airflow in the space and no plants or green features in the office but small ducts in the roof, which slightly affected their health and well-being (M = 3.18).

Table 32: The IAQ

	Fresh	Polluted	Health and Well-being
Panel A: Michael Sterling			
Mean	5.53	2.53	4.4
Std. Deviation	1.77	1.6	1.59
Variance	3.12	2.55	2.54
Panel B: Eastern Gateway			
Mean	5.15	1.8	2.3
Std. Deviation	1.79	1.4	1.98
Variance	3.19	1.96	3.91
Panel C: Marie Jahoda			
Mean	2.27	3.82	3.18
Std. Deviation	1.35	1.25	1.17
Variance	1.82	1.56	1.36
Panel D: Howell			
Mean	2.25	4.78	4.95
Std. Deviation	1.68	1.69	1.61
Variance	2.83	2.87	2.58
Panel E: Wilfred Brown			
Mean	5.73	5.4	2.13
Std. Deviation	1.71	1.55	1.19
Variance	2.92	2.4	1.41

The third set of questions aimed to examine the respondents' satisfaction with the noise level in their offices and the acoustic environment. Out of the five buildings considered, only the respondents in the Michael Sterling building (Panel A of Table 33) and the Wilfred Brown building (Panel E of Table 33) agreed that they were satisfied with the acoustic levels in their office; the only source of noise for them came from outdoor noises. As a result, they agreed that their hearing, health and well-being were unaffected. According to the respondents in the other buildings, the main type of noise in their offices was that of the conversations around them, a result of the open-plan layout of the offices as well as the existence of a corridor passing through for others to reach their rooms.

As for the rest of the sample, the researchers slightly disagreed on their satisfaction with the noise levels in their offices. They reported that they were always aware of both telephone and other conversations and noise from the HVAC and machines. The results also show that this noise level adversely affects the quality of their hearing and increases stress, which negatively affects their productivity.

Table 33: Acoustic Comfort

	Noise	**Health and Well-being**
Panel A: Michael Sterling		
Mean	5.27	2.67
Std. Deviation	1.18	1.76
Variance	1.39	3.1
Panel B: Eastern Gateway		
Mean	2.58	4.15
Std. Deviation	0.9	1.39
Variance	0.82	1.92
Panel C: Marie Jahoda		

Mean	2.36	5.73
Std. Deviation	0.92	1.62
Variance	0.85	2.62
Panel D: Howell		
Mean	3.07	4.55
Std. Deviation	0.94	1.82
Variance	0.88	3.31
Panel E: Wilfred Brown		
Mean	5.67	1.87
Std. Deviation	0.58	1.46
Variance	0.33	2.12

The fourth set of questions asked about the lighting environment and whether the offices had enough access to daylight. The results in Table 34 show that the respondents agreed that the recently developed buildings, namely, the Michael Sterling building (Panel A of Table 34), the Eastern Gateway building (Panel B of Table 34) and the Wilfred Brown building (Panel E of Table 34), have good access to daylight through windows. However, they disagreed that the light in their offices negatively affects their eye health. A possible reason is the use of smart fluorescent and LED lighting in many of the buildings' areas. High-efficiency light fittings and LED lighting have movement sensors to detect when people are present and switch off lighting at other times.

Table 34: Lighting Environment

	Daylight	Health and Wellbeing
Panel A: Michael Sterling		
Mean	5.87	1.33

Std. Deviation	1.51	1.91
Variance	2.27	3.67
Panel B: Eastern Gateway		
Mean	5.4	4.7
Std. Deviation	1.57	1.72
Variance	2.46	2.95
Panel C: Marie Jahoda		
Mean	2.36	5
Std. Deviation	1.03	1.41
Variance	1.06	2
Panel D: Howell		
Mean	1.8	3.15
Std. Deviation	1.91	1.98
Variance	3.64	3.92
Panel E: Wilfred Brown		
Mean	6.4	2.93
Std. Deviation	0.74	1.87
Variance	0.54	3.5

Finally, the fifth set of questions asked the researchers about their satisfaction with the general layout of their offices and the space between the desks. The results show that the respondents in the Michael Sterling building (Panel A of Table 35), as well as those in the Wilfred Brown building, were satisfied with the space between all the desks but had slight reservations about the functionality; their office had some views of greenery but not enough to make them feel comfortable.

Again, the remaining researchers in Marie Jahoda, Howell and Eastern Gateway sample did not agree that the space between the workstations, windows, desks and other elements was comfortable, and the orientation of the offices did not follow the direction of the sun. Only sometimes did the respondents agree that there were some views of green outdoor spaces. In addition, the layout slightly affected their health, as their offices did not feel active, and the furniture was uncomfortable.

Table 35: Layout

	Layout and functionality	Spaces	Health and Wellbeing
Panel A: Michal Sterling			
Mean	5.27	5.2	4.07
Std. Deviation	1.98	1.74	1.39
Variance	3.92	3.03	1.92
Panel B: Eastern Gateway			
Mean	3.8	4.1	3.75
Std. Deviation	1.79	1.97	1.92
Variance	3.22	3.88	3.67
Panel C: Marie Jahoda			
Mean	2.18	2.36	2.45
Std. Deviation	0.87	0.92	0.93
Variance	0.76	0.86	0.87
Panel D: Howell			
Mean	3.2	3.65	3.35
Std. Deviation	1.67	1.42	1.69
Variance	2.8	2.03	2.87
Panel E: Wilfred Brown			

Mean	4.93	4.2	4
Std. Deviation	2.15	2.14	2
Variance	4.64	4.6	4

5.2.1.3 The Direct Impact of the IEQ Factors on Productivity

In this stage of the research, it was essential to evaluate the perceived productivity in each office so that the regression analysis would link the respondents' satisfaction with each IEQ factor with the researcher's perceived productivity factors as dependent variables. It is worth noting that, among others, Leaman and Bordass (1999), who are members of the UK's Usable Buildings Trust, listed what variables best contribute to human productivity. These variables were personal control, responsiveness, building depth and workgroups. Personal control refers to the level of comfort experienced by individuals in their workplaces and pertains to "heating, cooling, lighting, ventilation and noise". Responsiveness refers to the ability of a workplace environment to adapt to changes in employee needs. Building depth is the workplace's capacity to provide appropriate levels of natural ventilation, air conditioning and window arrangements. Finally, workgroups refer to the sheer size of groups working together in the workplace. Research suggests that a fine balance must be achieved between solitary individuals and large groups working together in an open environment (Leaman and Bordass, 1999). Table 36 shows the questions used to conduct the regression analysis.

Table 36: Regression Analysis Questions

Variables that Best Contribute to Human Productivity (Dependent Variables)	IEQ Factors (Independent Variables)
Your office environment adapts to changes in your needs.	**1.** Thermal Environment **2.** IAQ **3.** Lighting Environment
Your office provides the appropriate levels of natural ventilation, air conditioning, and window arrangement.	

You are satisfied with the sheer size of groups working together within the workplace environment.	**4.** Acoustics Environment **5.** Layout
IEQ issues in your office affect the time you spend working in the environment.	

The regression analysis models that were used to investigate how the listed variables contribute to human productivity are presented below.

Starting with the impact of the IEQ factors on the offices' ability to adapt to changes, the equation can be written as follows:

$$\text{Personal Control} = \alpha_1 \text{Thermal} + \alpha_2 \text{ Air Quality} + \alpha_3 \text{ Acoustic} + \alpha_4 \text{ Lighting} + \alpha_5 \text{ Layout} \quad (1)$$

Next, the impact of the considered factors on responsiveness can be expressed as follows:

$$\text{Personal Control} = \beta_1 \text{Thermal} + \beta_2 \text{ Air Quality} + \beta_3 \text{ Acoustic} + \beta_4 \text{ Lighting} + \beta_5 \text{ Layout} \quad (2)$$

As for the impact of the IEQ on the building depth, the regression line can be estimated using the equation below:

$$\text{Building depth} = \gamma_1 \text{Thermal} + \gamma_2 \text{ Air Quality} + \gamma_3 \text{ Acoustic} + \gamma_4 \text{ Lighting} + \gamma_5 \text{ Layout} \quad (3)$$

Lastly, the impact of the IEQ on workgroups can be expressed as follows:

$$\text{Workgroups} = \delta_1 \text{Thermal} + \delta_2 \text{ Air Quality} + \delta_3 \text{ Acoustic} + \delta_4 \text{ Lighting} + \delta_5 \text{ Layout} \quad (4)$$

It is worth mentioning that the vectors of the parameter α_i, β_i, γ_i, δ_i had to be estimated.

The results of the multiple analyses for the five buildings are summarised below. With the level of comfort as the dependent variable, the overall model was statistically significant at $\rho < 0.05$, as suggested through the F-value. The proportion of variance explained by these regressors in the model is reasonably informative (see Panel B of Table 37 for the values of R^2). Furthermore, no evidence of serial correlation was found since the Durbin Watson (DW) statistics were close to 2.

Moreover, the models indicate that the results varied from one building to another. In particular, the results of the regression analysis show that almost all the IEQ factors in both the Eastern Gateway building and the Wilfred Brown building have a significant positive impact on the rooms' ability to adapt to changes. The same can be seen in the Michael Sterling building, where a significant positive effect of the regressors was found, except in the case of thermal comfort, which has a significant negative impact. The latter indicates that the unstable thermal environment affects the productivity of the office occupants.

It is also apparent from Table 37 that air quality, thermal comfort and lighting negatively affect the productivity of the Howell Building occupants. However, both the acoustics and layout have an insignificant effect. This also applies to the Marie Jahoda building occupants, where most of the variables have no impact, except for the IAQ and layout, which have a significant negative effect.

Table 37: The Influence of the IEQ on Personal Control

Panel A: Estimation Results "Personal Control"						
		MS	**EGW**	**MJ**	**H**	**WB**
Thermal	Coefficient	-0.258*	0.239***	0.473	-0.097**	0.493***
	SE	-0.063	-0.125	-0.394	-0.044	-0.279
	t-value	4.095	-1.912	-1.201	2.205	-1.767
	***P*-value**	**0.000**	**0.059**	**0.233**	**0.030**	**0.081**
Air Quality	Coefficient	0.238**	0.197*	-0.818***	-0.395*	0.356*
	SE	-0.108	-0.043	-0.474	-0.123	-0.112
	t-value	-2.204	-4.581	1.726	3.211	-3.179
	***P*-value**	**0.031**	**0.000**	**0.088**	**0.002**	**0.002**
Acoustic	Coefficient	0.109*	0.018**	1.428	-0.248	0.54***
	SE	-0.036	-0.009	-1.019	-0.265	-0.283
	t-value	-3.028	-2.000	-1.401	0.936	-1.908
	***P*-value**	**0.003**	**0.049**	**0.165**	**0.352**	**0.060**
Lighting	Coefficient	0.394*	0.229**	0.467	-0.189*	0.174*
	SE	-0.103	-0.112	-0.398	-0.042	-0.027
	t-value	-3.825	-2.045	-1.173	4.500	-6.444

	***P*-value**	**0.000**	**0.044**	**0.244**	**0.000**	**0.000**
Layout	Coefficient	0.621	0.453*	-0.457*	0.373	0.065***
	SE	-0.379	-0.129	-0.167	-0.248	-0.002
	t-value	-1.639	-3.512	2.737	-1.504	-32.500
	***P*-value**	**0.105**	**0.001**	**0.008**	**0.137**	**0.000**
Panel B: Goodness of Fit						
R^2		0.325	0.445	0.529	0.475	0.682
***F*-test**		4.867	2.243	1.124	1.678	3.852
DW		1.614	1.961	2.061	1.734	1.778
***, **, *** indicate that *F*-test is significant at 1%, 5%, and 10%, respectively.**						
SE: refer to Standard Error, which is in parentheses.						

Next came the question of responsiveness to the IEQ factors. Table 38 highlights that the overall model was statistically significant at $\rho < 0.05$ since the F-value was greater than 1. Further, the proportion of variance explained by these regressors in the model is relatively high, as suggested by the R^2. Again, no evidence of serial correlation was found since the DW statistics were close to 2.

A close inspection of Table 38 also shows that in the Michael Sterling building, with the dependent variable of responsiveness, all the variables that were considered positively affect the productivity of the occupants. The results in the case of the Eastern Gateway building and the Wilfred Brown building show a significant positive impact from all the variables except acoustic comfort, which has a significant negative effect. A possible reason for this is that the buildings are new and hence, could be improved in the future to increase the productivity of the occupants. In fact, acoustic comfort is the factor that has the most negative effect on their productivity.

By contrast, all the variables negatively impacted the productivity of the Howell and Marie Jahoda building occupants. Specifically, the researchers emphasised that all the IEQ factors negatively affect their comfort level, thus directly affecting their health, well-being and productivity.

Table 38: The Influence of the IEQ on Responsiveness

Panel A: Estimation Results "Responsiveness"						
		MS	**EGW**	**MJ**	**H**	**WB**
Thermal	Coefficient	0.431***	0.221	-0.358***	-0.848*	-0.237***
	SE	-0.226	-0.135	-0.207	-0.311	-0.121
	t-value	-1.907	-1.637	1.729	2.727	1.959
	***P*-value**	**0.060**	**0.106**	**0.088**	**0.008**	**0.054**
Air Quality	Coefficient	0.358***	0.293**	-0.134***	-0.372	0.362**
	SE	-0.181	-0.134	-0.073	-0.227	-0.169
	t-value	-1.978	-2.187	1.836	1.639	-2.142
	***P*-value**	**0.052**	**0.032**	**0.070**	**0.105**	**0.035**
Acoustics	Coefficient	0.413***	-0.417*	-0.615**	-0.651***	0.289***
	SE	-0.209	-0.155	-0.286	-0.338	-0.153
	t-value	-1.976	2.690	2.150	1.926	-1.889
	***P*-value**	**0.052**	**0.009**	**0.035**	**0.058**	**0.063**
Lighting	Coefficient	0.265*	0.373**	-0.224**	-0.165*	0.672*
	SE	-0.084	-0.181	-0.105	-0.068	-0.123
	t-value	-3.155	-2.061	2.133	2.426	-5.463
	***P*-value**	**0.002**	**0.043**	**0.036**	**0.018**	**0.000**
Layout	Coefficient	0.842**	0.431*	-0.171*	-0.096*	0.474*
	SE	-0.325	-0.137	-0.046	-0.016	-0.121
	t-value	-2.591	-3.146	3.717	6.000	-3.917
	***P*-value**	**0.011**	**0.002**	**0.000**	**0.000**	**0.000**
Panel B: Goodness of Fit						
R^2		0.638	0.807	0.565	0.405	0.896
***F*-test**		3.173	11.714	2.301	1.905	15.447
DW		2.185	2.447	1.485	1.511	2.267
***, **, *** indicate that the test is significant at 1%, 5%, and 10%, respectively.**						

The third analysis examined the impact of IEQ factors on the researchers' productivity when the building depth was the dependent variable. As presented in Table 39, the estimated model was statistically significant for each building. Moreover, the proportion of variance explained by these regressors in the model is quite acceptable, as suggested by the R^2. Furthermore, the model is well specified since no evidence of serial correlation was found (DW statistics were close to 2).

With regard to the estimated coefficient, the air quality and thermal comfort have a significant positive impact on the productivity of the users of two of the recently developed buildings, the Eastern Gateway building and the Wilfred Brown building, but the other factors have no effect. However, the case of the Michael Sterling building indicates a significant positive impact on the air quality variable and an insignificant one for the other variables. The reason behind this is that this office's potential to affect the level of natural ventilation, air conditioning and window arrangements negatively affects the health, well-being and productivity of the occupants.

For both the Howell and Marie Jahoda buildings, the researchers were sure that the office's capacity to affect the level of natural ventilation, the air conditioning and the window arrangements are affected negatively by both the air quality and thermal comfort factors.

Table 39: The Influence of IEQ on the Building Depth

Panel A: Estimation Results "Building Depth"						
		MS	**EGW**	**MJ**	**H**	**WB**
Thermal	Coefficient	0.278	0.405	-0.294	-0.142*	-0.304**
	SE	0.271	0.317	0.345	0.023	0.143
	t-value	1.026	1.278	-0.852	-6.174	-2.126
	***P*-value**	**0.308**	**0.205**	**0.397**	**0.000**	**0.037**
Air Quality	Coefficient	0.592**	0.171***	-0.494**	-0.361**	-0.273**
	SE	0.237	0.089	0.215	0.179	0.129
	t-value	2.498	1.921	-2.298	-2.017	-2.116
	***P*-value**	**0.015**	**0.058**	**0.024**	**0.047**	**0.038**
Acoustics	Coefficient	-0.418	-0.007	0.734	0.054	0.303
	SE	0.372	0.221	0.892	0.319	0.298
	t-value	-1.124	-0.032	0.823	0.169	1.017
	***P*-value**	**0.265**	**0.975**	**0.413**	**0.866**	**0.312**

Lighting	Coefficient	-0.846	0.119**	0.516	0.153	0.193
	SE	0.641	0.057	0.411	0.205	0.239
	t-value	-1.320	2.088	1.255	0.746	0.808
	***P*-value**	**0.191**	**0.040**	**0.213**	**0.458**	**0.422**
Layout	Coefficient	0.463	0.246	-0.673	0.356	0.214
	SE	0.390	0.195	0.632	0.297	0.236
	t-value	1.187	1.262	-1.065	1.199	0.907
	***P*-value**	**0.239**	**0.211**	**0.290**	**0.234**	**0.367**
Panel B: Goodness of Fit						
R^2		0.581	0.617	0.519	0.319	0.42
***F*-test**		2.532	4.502	1.079	1.311	1.302
DW		1.913	2.376	1.358	1.429	1.576
***, **, *** indicate that *F*-test is significant at 1%, 5%, and 10%, respectively.**						

The subsequent regression analysis involved the impact of IEQ on productivity using workgroups as the dependent variable. As can be seen from Table 40, the variables in question were jointly significant at $\rho < 0.05$. In addition, these regressors explain a reasonable amount of the variation in the dependent variable, as indicated by the R^2 (Table 40). Furthermore, no evidence of serial correlation was found since the DW statistics were close to 2.

The model indicates the significant positive impact of almost all the variables on productivity in the case of the Michael Sterling, Wilfred Brown and Eastern Gateway buildings (except for thermal comfort in the Wilfred Brown building, which has an insignificant impact). That is to say; the respondents agreed that their overall satisfaction positively affects their productivity in their office environment. But, in line with the descriptive analysis, it was clear that all the researchers in the Howell and Marie Jahoda buildings were dissatisfied with their office environment.

Table 40: The Influence of IEQ on the Workgroups

Panel A: Estimation Results "Workgroups"						
		MS	**EGW**	**MJ**	**H**	**WB**
Thermal	Coefficient	0.506***	0.328***	0.033	-0.295*	-0.173
	SE	0.279	0.171	0.213	0.085	0.272
	t-value	1.814	1.918	0.155	-3.471	-0.636
	***P*-value**	**0.074**	**0.059**	**0.877**	**0.001**	**0.527**
Air Quality	Coefficient	0.271*	0.342**	-0.183	-0.382***	0.441**
	SE	0.046	0.161	0.256	0.222	0.204
	t-value	5.891	2.124	-0.715	-1.721	2.162
	***P*-value**	**0.000**	**0.037**	**0.477**	**0.089**	**0.034**
Acoustics	Coefficient	0.185*	0.418***	-0.513	-0.445*	0.167**
	SE	0.038	0.234	0.551	0.121	0.076
	t-value	4.868	1.786	-0.931	-3.678	2.197
	***P*-value**	**0.000**	**0.078**	**0.355**	**0.000**	**0.031**
Lighting	Coefficient	0.535**	0.247**	-0.245	-0.184*	0.634*
	SE	-0.235	-0.103	0.253	0.059	0.221
	t-value	-2.277	-2.398	-0.968	-3.119	2.869
	***P*-value**	**0.026**	**0.019**	**0.336**	**0.003**	**0.005**
Layout	Coefficient	0.804**	0.643*	-0.101	-0.427***	0.268**
	SE	0.351	0.207	0.391	0.229	0.119
	t-value	2.291	3.106	-0.258	-1.865	2.252
	***P*-value**	**0.025**	**0.003**	**0.797**	**0.066**	**0.027**
Panel B: Goodness of Fit						
R^2		0. 747	0.673	0.193	0.646	0.778
***F*-test**		1.64	5.755	1.972	2.911	6.301
DW		1.829	2.406	2.263	2.804	2.695

***, **, *** indicate that *F*-test is significant at 1%, 5%, and 10%, respectively.**

5.2.1.4 The Role of Biophilia Patterns in Improving Conditions in the Indoor Workplace

Correlation analysis was used to explore the possibility of improving the indoor workplace environment by using the patterns of Biophilia. With this target in mind, the correlation analysis involved measuring the relationship or correlation between two sets of variables, the IEQ factors and the Biophilia applications in the workplace, to ascertain whether they were positively or negatively associated in any way whatsoever. Put differently; the researchers were asked seven categories of questions regarding the potential of applying Biophilia to improve their workplace and the possibility of using Biophilic applications to solve the problems in their research rooms with the five main IEQ factors, as well as three additional categories. These categories were the aesthetic values that Biophilia adds to a building, the potential to integrate Biophilia with technological sensors to balance the adverse IEQ factors in the office environment and the effect of adding Biophilic applications on the health, well-being and productivity of the occupants.

The following formula was used to obtain this correlation:

$$r = \frac{Cov(x,y)}{SDev.(x) * SDev.(y)} \quad (5)$$

where $Cov(x, y)$ is the covariance between the two variables, and SDev is the standard deviation.

Table 41 shows the correlation analysis, which expresses the degree of the association or the relationship between variables. For the Michael Sterling and Wilfred Brown buildings, there is clear evidence that the respondents highlighted the need to improve aesthetic values and thermal comfort – two of the variables that are positively correlated with the wellness of occupants. Moreover, the researchers were sure that their office needed some technological additions to balance temperature and humidity. For the Eastern Gateway building, it was clear that the highest correlation was the need for other technologies to balance the IEQ levels. Next came the aesthetic additions of Biophilia that were mainly connected with the researchers' wellness. Moreover, the researchers were sure that the acoustic environment of their office needed improvement.

The case with the older buildings (Marie Jahoda and Howell) was found to be somewhat different. The researchers in the Marie Jahoda building paid more attention to the IAQ, followed by the Biophilic applications of the lighting environment that were mainly connected with their wellness. Moreover, the layout was one of the essential variables that would enhance their wellness if the use of Biophilia patterns improved it. Similarly, the correlation between IAQ and wellness was the highest for the Howell building, followed by Biophilic patterns applied to the lighting environment. Finally, the need to add technological sensors was another variable that was positively correlated with the researchers' wellness.

Table 41: Correlations Analysis

	Michael Sterling	Eastern Gateway	Marie Jahoda	Howell	Wilfred Brown
Thermal Comfort	0.225*	-0.260	0.244	-0.185	0.431*
IAQ	-0.038	0.523	0.352**	0.602*	-0.384
Acoustic Environment	0.101	0.394**	0.172	0.193	0.194
Lighting Environment	0.335	-0.478	0.214*	0.516**	0.577
Layout	0.227	-0.372	0.207*	0.556	0.398
Aesthetics	0.213*	0.207*	0.165	0.197	0.189*
Sensors	0.363*	0.453*	0.246	0.492*	0.393**
*** and ** Correlation is significant at the 0.05 and 0.01 levels (2-tailed), respectively.**					

5.2.2 Survey 2: Satisfaction Survey Results and Discussion

5.2.2.1 Descriptive Analysis

In February 2023 a total of 630 questionnaires were returned over the course of 14 days, as can be seen in Figure 46.[3]

The combined data from the five research rooms were analysed to outline the occupant perceptions of indoor condition parameters and satisfaction within the office environments.

As part of the description analysis for the second questionnaire's data, the graphical information on the location, the dispersion and the skewness of a dataset was used to summarise the respondents' subjective feelings towards the IEQ for 14 days.[4]

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[3] Its worth noting that the actuall number of researchers in the selected rooms are about 65 and the number of returned series (630) denotes the accumulation number of questionnaires collected from those 65 researchers over the 14 days period. Moreover, the participants' profiles are eschewed here but avlaiable upon request.

[4] In these figures, the x-axis illustrates the research rooms under consideration, while the y-axis is the quantitative survey scale ranging from strongly disagree (1) to strongly agree (7). The whiskers represent the ranges for the bottom 25% and the top 25% of the data values, excluding outliers. The black dot denotes the mean, and the dash represents the median of the sample.

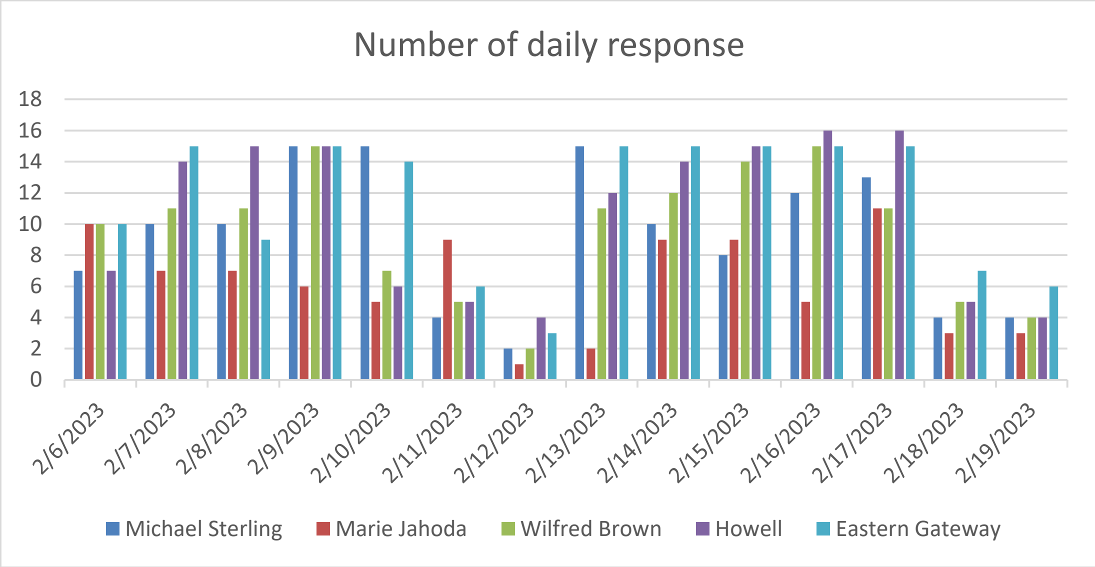
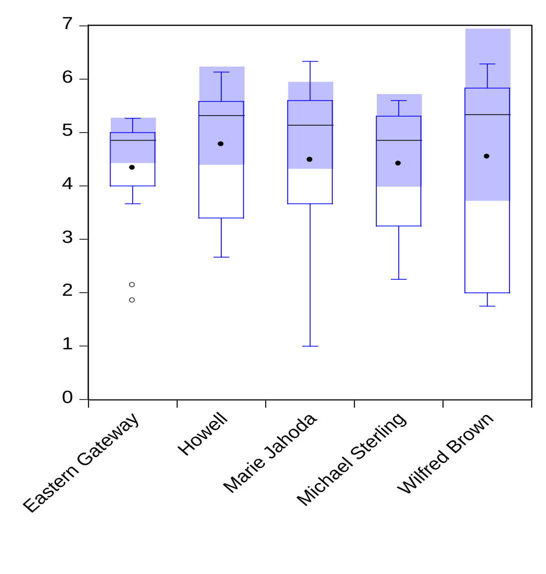
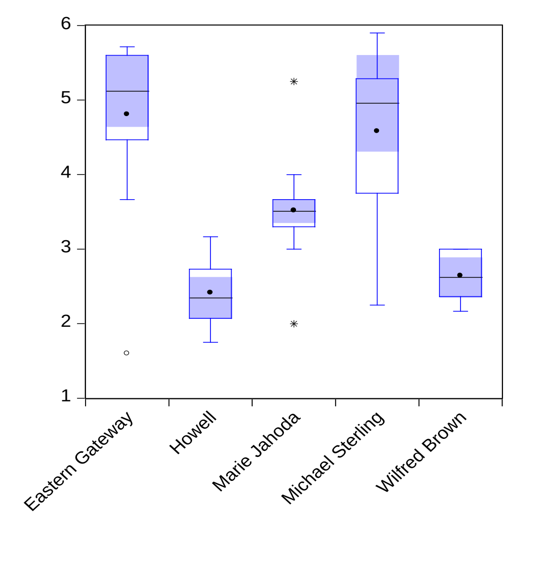


Figure 46: Number of Daily Responses

The researchers were asked to describe their perceptions of the level of temperature and humidity. It is apparent in Figure 47 that the median of the perceived temperature and humidity of the respondents from the Michael Sterling and Eastern Gateway buildings is around the neutral level when compared with the other research rooms, as they generally felt comfortable, followed by the respondents from the Howell building. However, the respondents from the Wilfred Brown building felt that it was too hot and that the air was dry in their office environment due to its orientation towards the sun as well as the large windows, as seen in Figure 48.



a) Temperature



b) Humidity

Figure 47: Comparative Boxplots - Temperature and Humidity

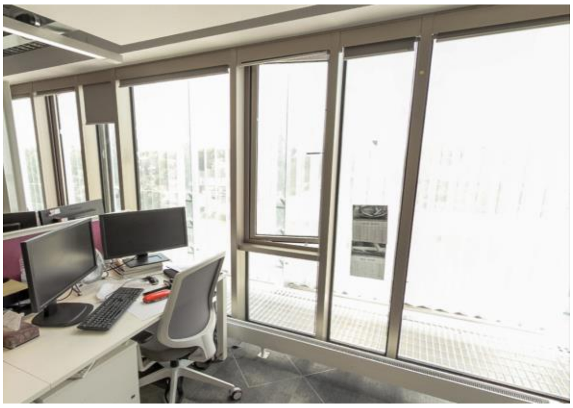


Figure 48: Wilfred Brown Research Room

The perception of IAQ was assessed across air freshness (fresh to stale). Figure 49 shows that the respondents in the Michael Sterling, Wilfred Brown and Eastern Gateway buildings felt that there was fresh air in their office environment. However, the respondents in both the Marie Jahoda and Howell buildings found the air in their office environment relatively stale (5–7 on the scale).

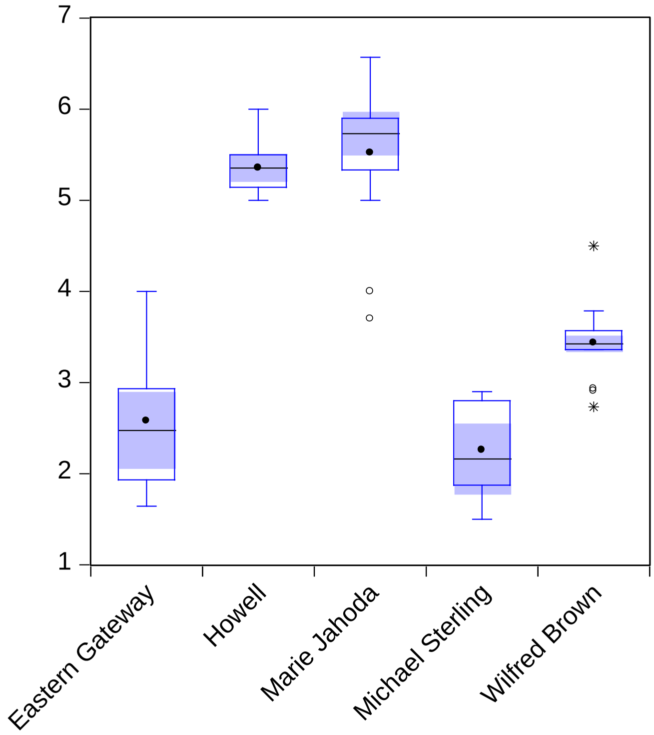


Figure 49: Comparative Boxplots: IAQ

In regard to the overall quality of lighting (Figure 50), the respondents in the Michael Sterling building answered neutrally (4 on the scale), reporting that it was neither very dark nor very bright. Whereas, in the Marie Jahoda and Howell buildings, it is worth noting that the respondents received more illuminance through artificial light than natural light; they reported that they had less natural light (1–3 on the scale) due to the small size of windows in the Marie Jahoda building (as seen in Figure 51) and the lack of windows in the Howell building.

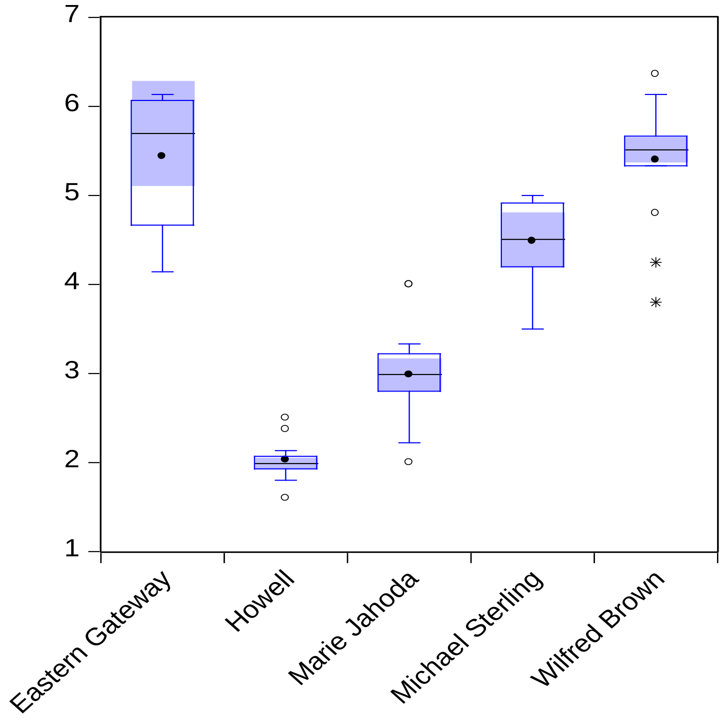


Figure 50: Comparative Boxplots: Overall Quality of Lighting

Figure 51: Marie Jahoda Research Room

Noise is one of the most commonly reported issues in an office environment, particularly in open-plan offices (Abbaszadeh et al., 2006; Kang et al., 2017). The results of this study confirm the reported results of previous studies. Figure 52 presents the respondents' perceptions of the acoustic environment (Very quiet–Very noisy). Overall, the noise was reported to be an issue in the Eastern Gateway and Howell buildings (5–7 on the scale).

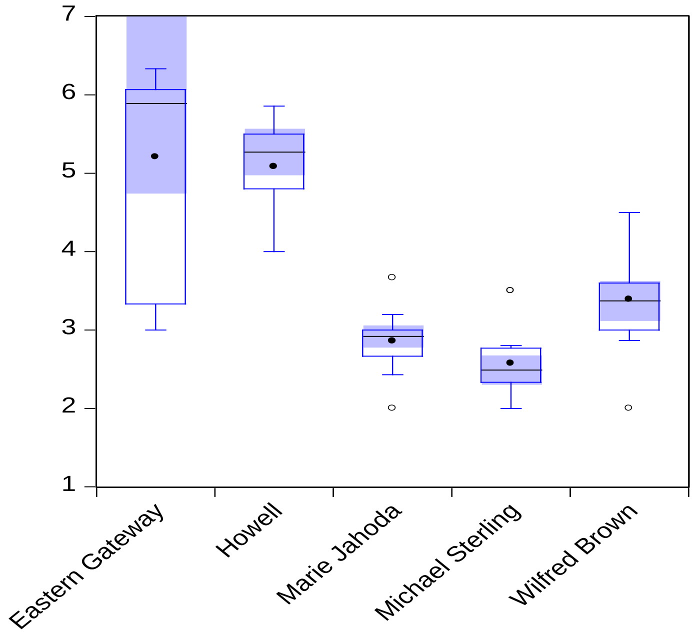


Figure 52: Comparative Boxplots - Noise

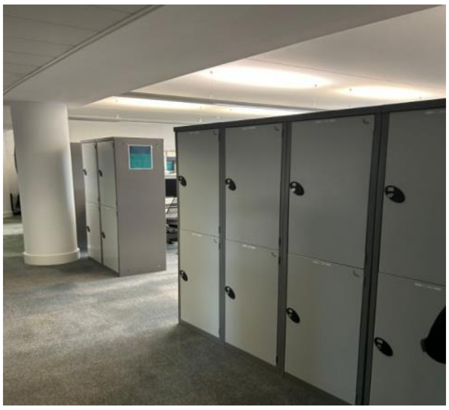


Figure 53: Eastern Gateway Research Room

5.2.2.2 Mean Differences in The Respondents' Satisfaction

To ascertain whether there are differences in the respondents' satisfaction with the considered rooms, the Games-Howell nonparametric post hoc analysis approach was adopted. The advantage of this approach is that it takes into account the violations of homogeneity of variance; that is, it does not require each group to have equal variance (Dunnet, 1980).

The results of mean differences in the respondents' satisfaction with each building are presented in Table 42. A statistically significant difference is apparent for almost all five IEQ factors.

Specifically, the respondents in the Marie Jahoda, Howell and Wilfred Brown buildings felt slightly warmer than those in the Michael Sterling and Eastern Gateway buildings. However, there were no mean differences between the older buildings (Marie Jahoda and Howell) and the recently developed buildings (Michael Sterling and Eastern Gateway).

With regard to humidity and IAQ, the respondents in the recently developed buildings felt the environment was slightly humid and were more comfortable with the CO2 levels than the respondents in the older buildings. The main reasons behind these results are the size of the windows in the research rooms and the amount of fresh air that comes into them, as well as the construction materials used in the buildings.

Considering both light and noise satisfaction, there is no evidence of any mean difference among the recently developed buildings, suggesting that the occupants in those research rooms have approximately the same perceptions towards the light and noise levels. However, statically significant evidence was found when those recently developed buildings were compared with the older ones.

Table 42: Mean Differences for Responses Survey

			T-test Value for Mean Differences				
IEQ Factors	**Building Name**	**Mean**	**MS**	**MJ**	**EG**	**H**	**WB**
Temperature	**MS**	4.45	-	-	-	-	-
	MJ	2.58	-6.29*	-	-	-	-
	EG	4.34	-0.56	5.59*	-	-	-
	H	2.51	-5.78*	-0.32	5.17*	-	-
	WB	2.03	-8.19*	-3.48*	7.50*	-2.09**	-
Humidity	**MS**	4.58	-	-	-	-	-
	MJ	2.09	-7.40*	-	-	-	-
	EG	4.59	0.01	7.35*	-	-	-
	H	2.42	-6.35*	2.14**	6.31*	-7.40*	-
	WB	2.65	-5.82*	4.23*	5.79*	1.62	-
IAQ	**MS**	5.31	-	-	-	-	-
	MJ	2.36	-15.83*	-	-	-	-
	EG	5.42	0.45	13.73*	-	-	-
	H	2.79	-6.24*	1.12	6.23*	-	-
	WB	5.38	0.29	13.53*	0.14	6.14*	-
Noise	**MS**	5.17	-	-	-	-	-
	MJ	2.86	-5.78*	-	-	-	-
	EG	5.21	0.06	6.33*	-	-	-
	H	3.49	-4.24*	4.55*	4.67*	-	-
	WB	5.32	0.29	7.28*	-0.24	5.47*	-
Light	**MS**	5.41	-	-	-	-	-
	MJ	2.98	-8.71*	-	-	-	-

	EG	5.44	0.10	9.73*	-	-	-
	H	2.03	-14.16*	-5.78*	16.41*	-	-
	WB	5.40	-0.03	9.98*	0.15	17.27*	-
***, **, *** represent 1%, 5% and 10%, respectively.**							

5.2.3 IEQ Monitoring Results and Discussion

The literature recommended monitoring IEQ during working hours for two weeks, where possible (Demanega et al., 2021; Liu, 2012). Therefore, the measurements were conducted during the winter period (6–19 February 2023).

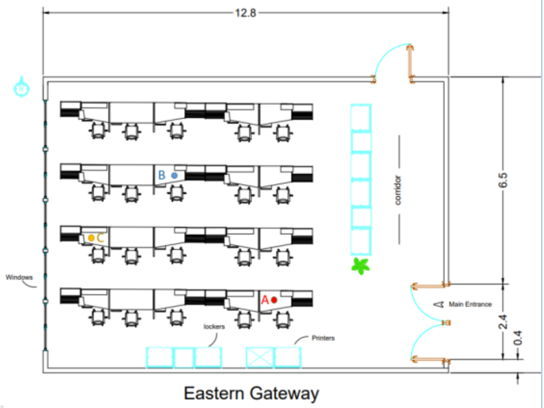
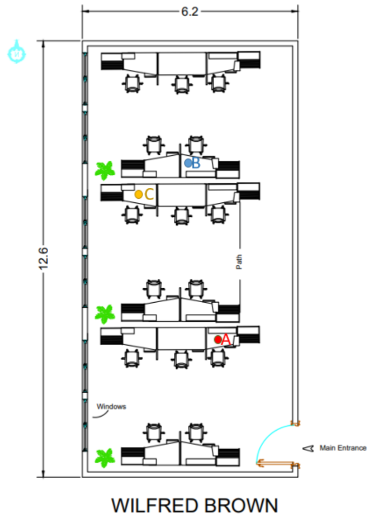
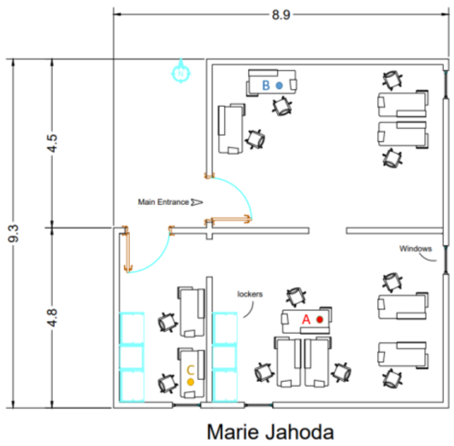
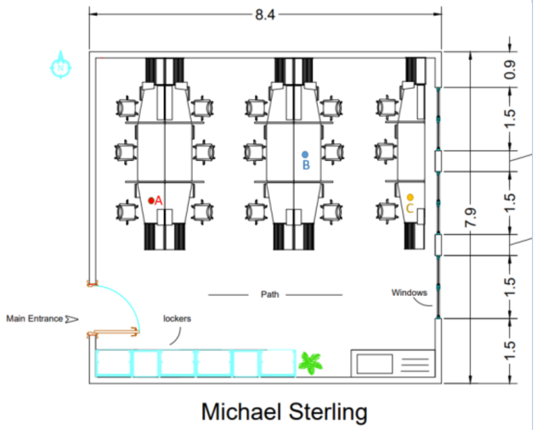
The sensors were programmed to record data at 5-minute sampling intervals (ASHRAE, 2017). Also, they were installed at the height of 1.1 m to be within the breathing zone of the occupants when in a seated position, as recommended by ASHRAE-129 (1992). In addition, one set of sensors was placed at selected locations in each office, and the researcher collected the data for two days from three locations in each room before starting the measurement test. However, the sensors had to be located away from doors and windows, avoiding being directly underneath air supply diffusers (Woo et al., 2021). Table 43 shows the initial locations and their justifications.

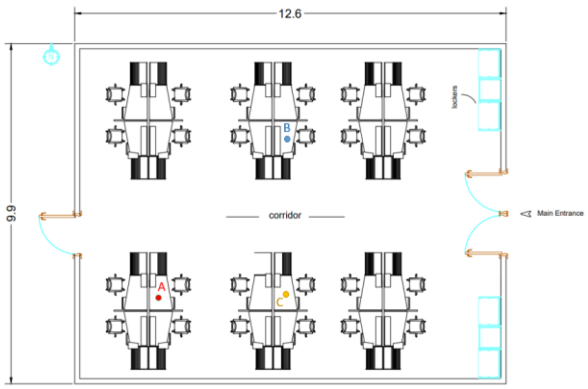
Table 43: Plans with Plots

<table>
<tr><th colspan="2">Locations and Plans with Plots</th></tr>
<tr><td colspan="2">Location A (shown in red): Near to the corridor, so it is extra noisy

Location B (shown in blue): Acceptable

Location C (shown in yellow): Near to windows and directly underneath the sunshine

In the Howell building, Location C is directly underneath a small ventilation duct.</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>



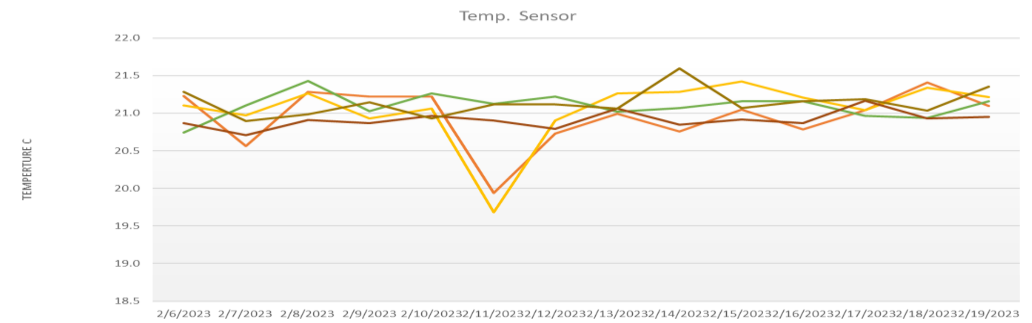
Howell research room

5.2.3.1 Descriptive Analysis for Measurements Data

The data were measured during daily working hours (9 am to 5 pm) to assess the differences in building performance while the occupants were present.

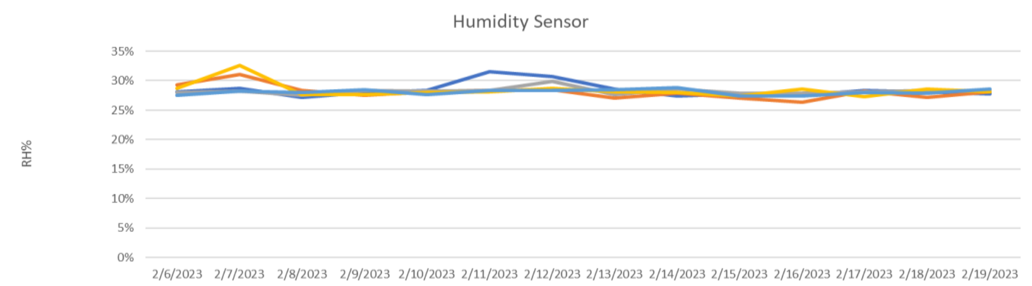
The five office spaces were allowed to run freely so as to measure the working spaces while occupied and functioning as usual; therefore, the data may or may not have been affected by extraneous influences. The five spaces have the same external data but different internal data, and this was determined around the number of daily occupants and the age and type of the respective building.

Starting with the temperature and humidity data in the considered rooms (shown in Figures 54 and 55), the temperature ranged between 19.7°C and 21.6°C. The minimum and maximum relative humidity ranged between 26% and 33%. Together, these values suggest that the temperatures and humidity were mostly compliant with the thermal comfort standards (ASHRAE Standard 55) for winter, and some occasional peaks in temperature were observed during the day. However, relative humidity (RH) in both old buildings was slightly lower than that recommended in ASHRAE Standard 55 (30–60%). The minimum value of RH in the Marie Jahoda building was 26%, and in the Howell building, 27%. These results are in line with the literature in Chapter 2, e.g. (Langevin, Gurian and Wen, 2015; Roumi, 2023; (Al Horr et al., 2016; Shahzad et al., 2018).



	2/6/2023	2/7/2023	2/8/2023	2/9/2023	2/10/2023	2/11/2023	2/12/2023	2/13/2023	2/14/2023	2/15/2023	2/16/2023	2/17/2023	2/18/2023	2/19/2023
Michael Sterling	21.2	20.6	21.3	21.2	21.2	19.9	20.7	21.0	20.8	21.1	20.8	21.0	21.4	21.1
Marie Jahoda	21.1	21.0	21.3	20.9	21.1	19.7	20.9	21.3	21.3	21.4	21.2	21.0	21.3	21.2
Wilfred Brown	20.7	21.1	21.4	21.0	21.3	21.1	21.2	21.0	21.1	21.2	21.2	21.0	20.9	21.2
Howell	20.9	20.7	20.9	20.9	21.0	20.9	20.8	21.1	20.8	20.9	20.9	21.2	20.9	21.0
Eastern Gateway	21.3	20.9	21.0	21.1	20.9	21.1	21.1	21.1	21.6	21.1	21.2	21.2	21.0	21.4

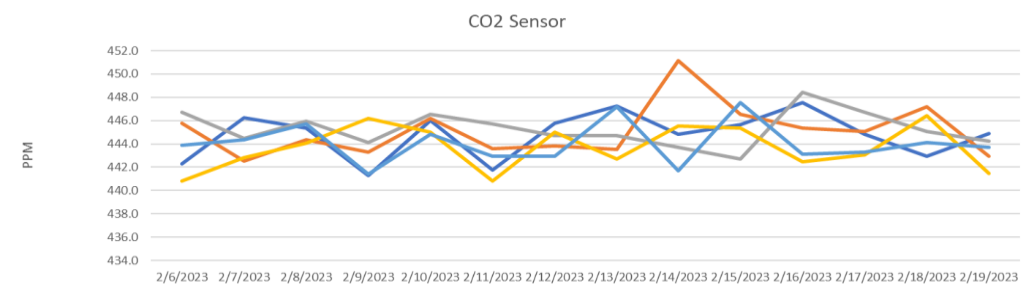
Figure 54: Temperature Data



	2/6/2023	2/7/2023	2/8/2023	2/9/2023	2/10/2023	2/11/2023	2/12/2023	2/13/2023	2/14/2023	2/15/2023	2/16/2023	2/17/2023	2/18/2023	2/19/2023
Michael Sterling	28%	29%	27%	28%	28%	32%	31%	29%	27%	28%	28%	28%	28%	28%
Marie Jahoda	29%	31%	28%	28%	28%	28%	28%	27%	28%	27%	26%	28%	27%	28%
Wilfred Brown	28%	28%	28%	28%	28%	28%	30%	28%	29%	28%	28%	28%	28%	28%
Howell	29%	33%	28%	28%	28%	28%	29%	28%	28%	27%	29%	27%	29%	28%
Eastern Gateway	27%	28%	28%	28%	28%	28%	28%	28%	29%	27%	27%	28%	28%	29%

Figure 55: Humidity

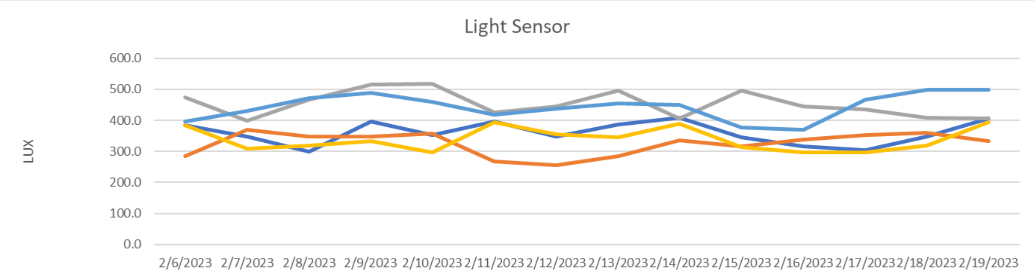
Carbon dioxide concentration levels ranged between 440.8 and 451.2 ppm, as shown in Figure 56. When CO2 concentration levels exceed 1000 ppm, it indicates insufficient ventilation and unacceptable conditions in relation to odour removal (ASTM, 2018).



	2/6/2023	2/7/2023	2/8/2023	2/9/2023	2/10/2023	2/11/2023	2/12/2023	2/13/2023	2/14/2023	2/15/2023	2/16/2023	2/17/2023	2/18/2023	2/19/2023
Michael Sterling	442.3	446.2	445.3	441.3	446.0	441.8	445.8	447.3	444.9	445.7	447.6	444.9	442.9	444.9
Marie Jahoda	445.8	442.5	444.4	443.3	446.2	443.6	443.8	443.5	451.2	446.6	445.4	445.0	447.2	442.9
Wilfred Brown	446.7	444.5	446.0	444.1	446.5	445.7	444.7	444.7	443.7	442.7	448.4	446.7	445.1	444.2
Howell	440.8	442.8	444.1	446.2	445.0	440.8	445.0	442.7	445.5	445.3	442.4	443.1	446.4	441.5
Eastern Gateway	443.9	444.4	445.7	441.4	444.8	442.9	442.9	447.2	441.7	447.5	443.1	443.3	444.1	443.7

Figure 56: CO_2 Concentration Levels

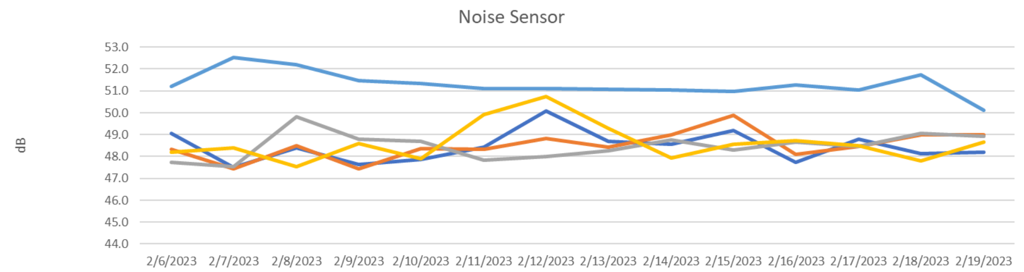
Lighting and sound levels were measured in the selected offices with respect to the workstation layout, proximity to windows and use of internal blinds (Figure 57). The illuminance levels demonstrated variations that ranged from 255 to 517 Lux. The maximum levels of illuminance in the open-plan offices were 500 Lux (ASHRAE, 2006). These results are supported by the literature in chapter 2, e.g. ((Li and Lam, 2001; Li, 2010; Beute and de Kort, 2018). Research indicates that businesses achieve a long-term advantage by investing in daylight inclusivity in their workplace design through higher occupant productivity and lower energy costs (Lim et al., 2017). However, Building occupants prefer natural light to artificial light (Kong et al., 2018).



	2/6/2023	2/7/2023	2/8/2023	2/9/2023	2/10/2023	2/11/2023	2/12/2023	2/13/2023	2/14/2023	2/15/2023	2/16/2023	2/17/2023	2/18/2023	2/19/2023
Michael Sterling	384.0	348.0	300.0	396.0	354.0	397.0	349.0	387.0	408.0	345.0	317.0	305.0	348.0	406.0
Marie Jahoda	285.0	370.0	349.0	348.0	357.0	267.0	255.0	286.0	336.0	316.0	339.0	353.0	360.0	333.0
Wilfred Brown	475.0	400.0	466.0	516.0	517.0	425.0	446.0	497.0	407.0	497.0	444.0	435.0	408.0	407.0
Howell	385.0	308.0	320.0	333.0	296.0	395.0	355.0	345.0	390.0	314.0	296.0	296.0	319.0	395.0
Eastern Gateway	397.0	430.0	472.0	489.0	460.0	419.0	437.0	454.0	451.0	378.0	371.0	466.0	498.0	498.0

Figure 57: Light

Sound levels varied from 47.5 to 52.5 dBA, depending on the type of work performed and workstation occupancy. The ASHRAE Standard recommends background noise levels for open-plan offices to be in the range of 40–45 dBA. Studies indicate that internal noises from air conditioners, fax machines, printers and telephones contribute to discomfort and frustration; a persistent state of annoyance leads to tension and issues with high blood pressure (Ayr et al., 2003).



	2/6/2023	2/7/2023	2/8/2023	2/9/2023	2/10/2023	2/11/2023	2/12/2023	2/13/2023	2/14/2023	2/15/2023	2/16/2023	2/17/2023	2/18/2023	2/19/2023
Michael Sterling	49.1	47.5	48.4	47.6	47.9	48.4	50.1	48.7	48.6	49.2	47.7	48.8	48.1	48.2
Marie Jahoda	48.3	47.4	48.5	47.4	48.3	48.3	48.8	48.4	49.0	49.9	48.1	48.5	49.0	49.0
Wilfred Brown	47.7	47.5	49.8	48.8	48.7	47.8	48.0	48.3	48.8	48.3	48.7	48.5	49.1	48.9
Howell	48.2	48.4	47.5	48.6	47.9	49.9	50.7	49.3	47.9	48.6	48.7	48.5	47.8	48.7
Eastern Gateway	51.2	52.5	52.2	51.5	51.3	51.1	51.1	51.1	51.1	51.0	51.3	51.0	51.7	50.1

Figure 58: Noise Levels

5.2.3.2 Mean Differences for Sensors Data

The next step in the study was to ascertain whether the occupants' responses reflected the data obtained from the sensors. The results of mean differences in the sensor data for each building are presented in Table 44.

No significant difference between the buildings was evident in terms of temperature, humidity and IAQ. One explanation for these results is that the centralised CAV system controls the temperature and ventilation in the buildings, and the data from the sensors were likely to fall within the recommended temperature ranges. However, the temperature, humidity, and even the IAQ sometimes fluctuated slightly depending on the number of occupants in the room, the windows situations (open, closed) and the external weather conditions.

What is interesting about the data in Table 44 is that there is a statistically significant difference in terms of noise levels and light intensity levels between (i) the Eastern

Gateway building and the Marie Jahoda building, (ii) the Eastern Gateway building and the Michael Sterling building, (iii) the Eastern Gateway building and the Howell building and (iv) the Eastern Gateway building and the Wilfred Brown building. The Eastern Gateway building showed the highest levels of noise as well as light intensity. The latter could be due to its location close to a shared corridor and a printing machine. It also has a large window which allows sunlight to penetrate into the room and make it bright.

Table 44: Mean Differences for Sensors Data

			***T*-test Value for Mean Differences**				
IEQ Factors	**Building Name**	**Mean**	**MS**	**MJ**	**BS**	**HB**	**WB**
Temperature	**MS**	20.95	-	-	-	-	-
	MJ	21.05	0.64	-	-	-	-
	BS	21.14	1.65	0.72	-	-	-
	HB	20.91	-0.39	-1.18	4.01*	-	-
	SC	21.10	1.33	0.41	0.61	3.58*	-
Humidity	**MS**	0.28	-	-	-	-	-
	MJ	0.28	-0.87	-	-	-	-
	BS	0.28	-1.03	0.09	-	-	-
	HB	0.28	-0.09	0.74	-2.86**	-	-
	SC	0.28	-0.53	0.58	-0.87	-2.39**	-
IAQ	**MS**	444.77	-	-	-	-	-
	MJ	445.09	0.40	-	-	-	-
	BS	444.04	-1.01	-1.35	-	-	-
	HB	443.70	-1.45	-1.75***	0.49	-	-
	SC	445.28	0.77	0.26	-1.37	2.42**	-
Noise	**MS**	48.44	-	-	-	-	-

	MJ	48.51	0.25	-	-	-	-
	BS	51.30	11.82*	12.19*	-	-	-
	HB	48.62	0.60	0.40	9.64*	-	-
	SC	48.49	0.18	-2.08*	12.53*	-0.47	-
Light	**MS**	122.10	-	-	-	-	-
	MJ	121.68	-1.98***	-	-	-	-
	BS	122.50	1.72***	3.78*	-	-	-
	HB	122.14	0.18	2.43**	1.72***	-	-
	SC	122.09	-0.09	1.99***	1.88***	-0.29	-
***, **, *** represent 1%, 5% and 10%, respectively.**							

5.2.3.3 Correlation between Subjective and Objective Data

To compare the differences between the subjective and objective assessments of the indoor conditions, Pearson's product-moment correlation coefficient (r) was calculated to estimate both the size and direction of the relationship.

It is worth mentioning that the value of correlation ranges from -1 (a perfect negative relationship) to +1 (a perfect positive relationship). Following the literature (see, for example, de Vaus, 2002; Field, 2018), the correlation is Trivial when $0.01 < r < 0.09$, Low to Moderate when $0.10 < r < 0.29$, Moderate to Substantial when $0.30 < r < 0.49$, Substantial to Very Strong when $0.50 < r < 0.69$, Very Strong when $0.70 < r < 0.89$ and Near Perfect when $0.90 < r < 0.49$. It is also worth noting that the correlation value is statistically meaningful and indicative of a genuine effect in the population when the probability falls below 0.05 $(p < 0.05)$.

Table 45 delivers the results of the differences between the subjective and objective assessments. Starting with the occupants' perceptions of temperature and the temperature measured using the sensors, the results indicate a negative correlation between the variables in the recently developed buildings (Eastern Gateway, Michael Sterling and Wilfred Brown) but a moderately positive correlation between the variables in the older buildings (Howell and Marie Jahoda). This picture changes when considering the occupants' perceptions of humidity. In this case, the results indicate that the occupants' perceptions of humidity in the recently developed buildings are positively correlated with the real humidity in the rooms. By contrast, the two variables are negatively correlated in the Howell and Marie Jahoda buildings.

Surprisingly, there is no evidence that IAQ has an influence on the occupants' perceptions in almost all the considered rooms, except for the Howell research room, where evidence of low to moderate correlation was found. One explanation behind this result is that it is the only room with no windows; it has small ducts in the roof.

The occupants' perceptions of light intensity also showed a negative low to moderate correlation with the light sensors data from the Eastern Gateway, Michael Sterling and Wilfred Brown buildings. There was, however, no evidence that the occupants in the Marie Jahoda and Howell research rooms were being affected by light intensity. Overall, the occupants rely on illuminance achieved with artificial light rather than natural light, which prevents them from noticing the difference in the lighting levels during the day.

Considering the noise level, the occupants' perceptions showed a positive low to moderate correlation with noise sensors data from the recently developed buildings, whereas a trivial correlation was found in the older ones.

As stated in the indoor environmental conditions mentioned above, although the measured air temperature was likely to fall within the recommended temperature ranges, the calculations indicated that some offices in the recently developed buildings did not meet the thermal compliance standards, which could explain this result.

Table 45: Correlation Between Subjective and Objective Assessment

Building	**Occupants' Responses to Questions Regarding:**				
	Temp.	**Hum**	**IAQ**	**Light**	**Noise**
BS	-0.15**	-0.38**	0.02**	-0.29***	0.35**
	[0.03]	[0.02]	[0.03]	[0.07]	[0.02]

CS	-0.11***	0.36***	-0.01***	-0.30**	0.21***
	[0.06]	[0.09]	[0.06]	[0.03]	[0.07]
HB	0.38**	-0.16**	0.23**	0.06	0.03**
	[0.04]	[0.04]	[0.04]	[0.13]	[0.02]
MJ	0.33*	-0.11**	0.22	-0.35	0.03***
	[0.01]	[0.04]	[0.34]	[0.10]	[0.09]
MS	-0.13**	0.36***	0.15	-0.45***	0.31**
	[0.04]	[0.06]	[0.61]	[0.07]	[0.03]
***, **, *** represent 1%, 5% and 10%, respectively. *P*-value is presented in [ ].**					

5.3 Conclusion

The work in this chapter was undertaken to, first, observe the relationship between IEQ factors and sub-factors, based on the Flourish Wheel, and the health, well-being and productivity of the occupants in five open-plan research offices at Brunel University London. Second, to evaluate the IEQ in the selected research rooms subjectively and objectively.

The most obvious finding to emerge from the first survey (Health, Well-being and Productivity Survey) is that the qualities of the five key IEQ aspects (thermal comfort, IAQ, lighting environment, acoustic environment and layout) are significantly and positively correlated with the wellness of the occupants.

The second significant finding was that of the five key aspects of IEQ, the quality of the thermal environment and the IAQ have the most significant influence on the productivity of the occupants in the older buildings due to the lack of fresh air as well as the instability of the temperature and humidity levels. However, the descriptive analysis showed that the occupants of the recently developed buildings were satisfied with the thermal comfort, IAQ and lighting environment of their offices, though they had some reservations regarding the office layout and acoustic comfort. Of course, such matters are always possible and even expected in open-plan offices.

Another significant finding to emerge from this study was from the regression analysis, which showed that the level of comfort that occupants experience within their workplace environments was satisfactory in the Eastern Gateway, Wilfred Brown and Michael Sterling buildings. Moreover, it has a direct positive effect on productivity in those buildings.

The participants in the first survey interacted significantly with the correlation analysis questions since they were sure that BD has many solutions that can improve their offices in different ways, such as adding plants, using radiant surface materials, installing an HVAC system, etc.

The next task of the chapter is to evaluate the temperature, humidity, indoor air quality (IAQ), lighting, and noise of workspace objectively and subjectively[5]. In the field of study, there has been a growing attempt to comprehend the difference between objective data about IEQ and the evaluations given by occupants. In this vein, previous literature has emphasized the differences between objective measurements and subjective evaluations, highlighting that occupant perceptions are influenced by not only the physical environment factors, but also social and cultural impacts, organizational aspects, and individual factors (de Dear, 2004; Gupta et al., 2020; Roskams and Haynes, 2020). To this end, researchers have proposed capturing "right-now" assessments of the workplace environment by conducting multiple occupant surveys with continuous IEQ measurements (Candido et al., 2016; Choi and Lee, 2018; Deuble and de Dear, 2012; Li et al., 2018; Roskams and Haynes, 2020). This second survey (satisfaction survey) was designed to evaluate the occupants' responses on how they feel towards the IEQ factors for 14 days in the wintertime. In parallel with a measurement test, results show a difference between the data collected from the old

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[5] Following the literature, IEQ is largely characterized by four environmental categories: thermal comfort, IAQ, lighting, and acoustics, without taking into account the spatial comfort of the occupants (Clements-Croome & Baizhan, 2000; Larsen et al., 2020). The four environmental categories are more fundamentally affected by building design and technical solutions such as building envelope and services. In contrast, spatial comfort can be achieved by making changes in the internal layout and workspace arrangements, taking into consideration different work types, occupant behavior, and personal preferences.

buildings (Howell and Marie Jahoda) and the recent developed buildings (Michael Sterling, Wilfred Brown and Eastern Gateway).

The current study found a sensible correlation between the measured indoor environmental quality (IEQ) and the occupant evaluations. While the subjective evaluations are likely to align with the objective measurements, it appears that the occupant responses to the indoor environment are not always correlated with the corresponding indoor environmental parameters of the buildings. For instance, the correlation analysis between the occupants' responses and the measurement data shows that the temperature in the Wilfred Brown building, which is considered one of the recently developed buildings, was within standards; however, the occupants' feelings show that they feel so hot when it's sunny, this was because of the building orientation and the large size of the windows.

Furthermore, it is worth noting that the measured indoor conditions across the selected buildings did not show significant fluctuations and fell within the acceptable ranges. This is likely due to the centralized mechanical systems that can maintain universally acceptable conditions. The uniformity of the physical conditions was observed in open-plan offices where occupants had limited control over their environment due to centrally controlled mechanical systems and standardized workstations.

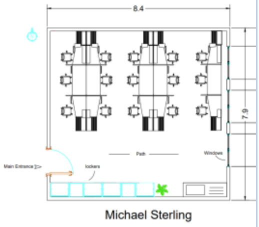
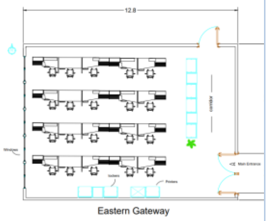
Although a uniform lighting scheme was implemented, the field study observed some variations in lighting and air quality levels. This was due to certain windows being opened and curtains being used during the day, which was observed in the Michael Sterling and Wilfred Brown buildings.

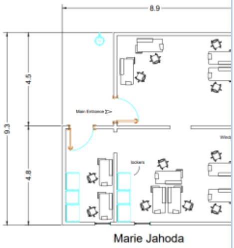
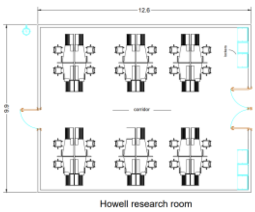
The comprehensive IEQ assessment conducted in this study provides a sound understanding of IEQ factors and their interaction with building users in the field of built environment research. Furthermore, it offers methodological guidance on IEQ assessment for facility managers who aim to bridge the gap between physical building conditions and occupant feedback, thereby enabling effective building management and space planning decisions.

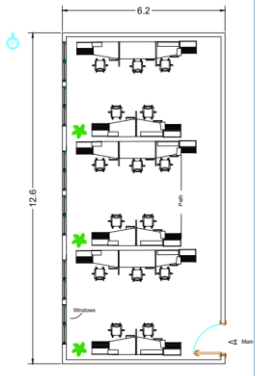
However, further work needs to be done to establish a co-design toolkit that helps designers, interior designers, and architects improve open-plan workspaces using the Biophilic Patterns by evaluating the main IEQ factors in the workspaces and making technological and aesthetic additions where possible.

Table 46 below summarises the analysis of the questionnaire results and some recommendations for improving the research rooms based on the Biophilic Patterns.

Table 46: Summary of Questionnaire Results

Building	Plan	IEQ Problems	Biophilia Improvements
Michael Sterling		Thermal comfort	**Visual Connection with Nature:** Include plants that are responsible for converting CO_2 to oxygen, especially at night. **Non-Visual Connection with Nature:** Include green walls that absorb heat, humidity and moisture imbalances.
Eastern Gateway		Noise Thermal comfort	**Non-Visual Connection with Nature:** Include green walls that absorb heat, humidity and moisture imbalances. **Non-Rhythmic Sensory Stimuli:** Use blinds that cut out light to project shadows and control the sunlight's penetration into the interior. **Connection with Natural Systems:** Inside and outside: temperature/humidity/air pressure measurements.

Marie Jahoda		Thermal comfort IAQ Lighting environment Layout	**Visual Connection with Nature:** Include window planters, and use plants that have an excellent ability to filter VOCs from the air. **Non-Visual Connection with Nature:** Include green walls that absorb heat, humidity and moisture imbalances. **Dynamic and Diffused Light:** Change materials: use light-reflecting floors, tables, walls and surfaces; mirrors; light-reflective paint; tile glazes; white surfaces; sequin/mirrored surfaces. Include glass doors/walls. **Complexity and Order:** Include partitions (glass textures, etched film on glass). **Refuge:** Move existing furniture and plants to create private spaces for retreating and restoring energy.
Howell		Thermal comfort IAQ Lighting environment Acoustic environment	**Visual Connection with Nature:** Include plants responsible for converting CO_2 to oxygen, specifically at night, as well as plants that tolerate low light and darkness. **Thermal and Airflow Variability:** Apply HVAC delivery combined with the natural plant strategy.

Wilfred Brown		Thermal comfort	**Visual Connection with Nature:** Include plants that are responsible for converting CO_2 to oxygen, specifically at night. **Non-Visual Connection with Nature:** Include green walls that absorb heat, humidity and moisture imbalances. **Non-Rhythmic Sensory Stimuli:** Use blinds that cut out light to project shadows and control the sunlight's penetration into the interior. **Connection with Natural Systems:** Inside and outside: temperature/humidity/air pressure measurements.

6. CHAPTER SIX: THE DESIGN OF THE TOOLKIT

6.1 Introduction

In order to answer how BD can be used as a guide for designers and architects to support health and well-being in the context of open-plan offices within workplaces, the findings and discussion in Chapters 4 and 5, as well as the literature reviewed in Chapter 2, suggest that a co-design toolkit can be developed to offer designers and architects the opportunity to indicate their perspectives on improving open-plan workplaces.

Despite the existence of a large number of card-based design tools, there are some gaps in their coverage, as the domains include architecture/built environment, sustainable design, graphics and transport design, with few existing tools (Roy and Warren, 2019). Therefore, developing more tools for these domains could be a fruitful area of pursuit in design research.

Such a toolkit and card-based design would help those who want to improve an office environment by using a modern approach, such as BD, and bringing the natural environment indoors. In this research, the users of BD fall into two groups: interior designers and architects. In addition to helping these designers and architects, the toolkit contributed by this study allowed the researcher to conduct a co-study with a number of participants. They identified the main issues and impacts of the IEQ in an office and showed how these things affect the health, well-being and productivity of the occupants. Then, they proposed recommendations for improving the IEQ of the office using BD. Finally, in the co-design study, the participants interactively discussed and shared their ideas, and the researcher collated and modelled the results in their desired direction.

6.2 Toolkit Design Diagram

This toolkit was designed based on the previous chapters of this research, as shown in Figure 59.

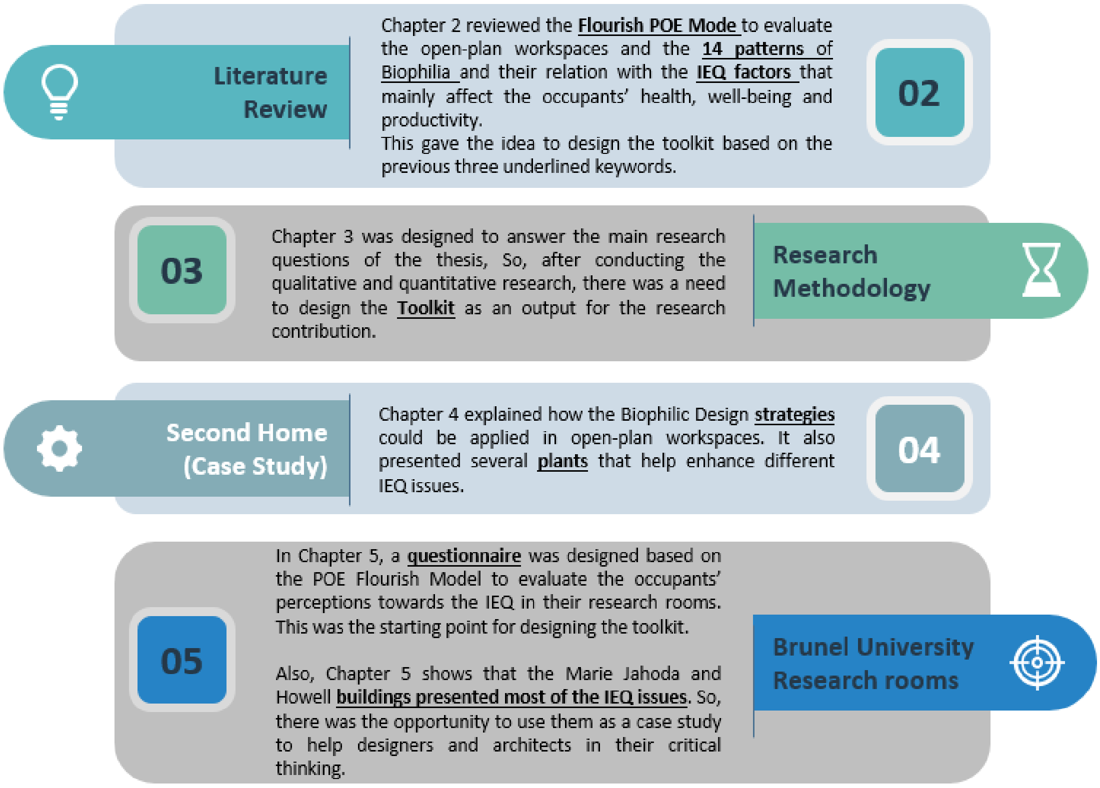


Figure 59: Toolkit Design

6.2.1 Overview of the 14 Patterns of Biophilia

Section (2.5.7) of the literature review systematically explored the concept of the "14 Patterns of Biophilic Design" by Browning et al. (2014) to give a clear image of what BD encompasses and what each pattern concerns. However, to understand the BD concerning strategies and application, this section explores how it can be added to a workspace and improve the health and well-being of the occupants.

Table 47 explores BD strategies and the language used to describe nature and its application in design, making it easier to transfer the information into a tool.

Table 47: Biophilic Design Strategies

NATURE IN THE SPACE: The most extensive and diverse category of Biophilic Patterns with much research behind it. All the patterns in this category aim to work with living or changing properties of the natural environments that we experience.
1: Visual Connection with Nature
Design Strategies: (Browning, Ryan and Clancy, 2014) Designing to support a visual connection that can be experienced daily. Adding small interventions of nature where space is limited.
2: Non-Visual Connection with Nature
Design Strategies: (Sullivan, Kuo and Depooter, 2004; Kellert, Heerwagen and Mador, 2008) Designing for visual and non-visual connections to be experienced simultaneously to maximise potential positive health responses.
3: Non-Rhythmic Sensory Stimuli
Design Strategies: (Kellert, Heerwagen and Mador, 2008; Browning, Ryan and Clancy, 2014) Provide natural stimuli as positive distractions that grab attention and help individuals to replenish their capacity to focus.
4: Thermal and Airflow Variability
Design Strategies: (Ojamaa, 2015; Cele, 2004; (Kellert, Heerwagen and Mador, 2008) Provide the users with the ability to control their environment or have access to different conditions within a space.
5: Presence of Water
Design Strategies: (Xue et al., 2019; Browning, Ryan and Clancy, 2014) Utilise water to enhance the experience of a space, promoting enhanced mood and restoration. Work with water to provide visibility over existing bodies of water or create smaller ponds or fountains.
6: Dynamic and Diffused Light

<u>Design Strategies: (Al-musaed, 2004; Browning, Ryan and Clancy, 2014)</u> Provide lightning options that provide comfort, support attention and help maintain the functioning of occupants' circadian system.
7: Connection with Natural Systems
<u>Design Strategies: (Cele, 2004; Sharifi and Sabernejad, 2016; Fisher and Pedersen, 1996)</u> Heighten the awareness of natural properties within an ecosystem and improve the environmental stewardship of that ecosystem.
NATURE ANALOGUES All the patterns in this approach aim to create exciting and coherent visually and tactically stimulating spaces.
8: Biomorphic Forms and Patterns
<u>Design Strategies: (Browning, Ryan and Clancy, 2014)</u> Provide representational design elements that allow the user to make connections to nature. The intent is to use the elements to create a more visually preferred environment.
9: Material Connection with Nature
<u>Design Strategies: (Kellert, Heerwagen and Mador, 2008)</u> Explore the characteristics and optimise the quantities of natural materials to promote cognitive or physiological responses. They can be used both decoratively and functionally.
10: Complexity and Order
<u>Design Strategies: (Sharifi and Sabernejad, 2016; Browning, Ryan and Clancy, 2014; Kellert, Heerwagen and Mador, 2008)</u> Provide symmetries and fractal geometries in a coherent structure to create a visually pleasing environment to promote cognitive or psychological responses. Fractal geometries can also be used on any scale.
NATURE OF THE SPACE This approach focuses on different spaces that can be found in nature that have benefited our survival as the human species. All the patterns in this approach focus on the atmosphere and the layout of a space.
11: Prospect
<u>Design Strategies: (Browning, Ryan and Clancy, 2014)</u>

This pattern focuses on providing views over a distance; the pattern is one with the most evidence behind it.
12: Refuge
Design Strategies: (Browning, Ryan and Clancy, 2014) This pattern focuses on providing spaces for withdrawal, shelter or protection within a more extensive area outside the main flow of activities.
13: Mystery
Design Strategies: (Kellert, Heerwagen and Mador, 2008; Browning, Ryan and Clancy, 2014; (Romm and Browning, 1994) This pattern focuses on curiosity and the basic spatial need to understand and explore.
14: Risk/Peril
Design Strategies: (Browning, Ryan and Clancy, 2014) This pattern combines perceived risk with trusted safeguards to trigger positive arousal and curiosity.

6.3 Toolkit Parts

To understand BD usage, it's beneficial to try and explore it in practice. In aiming to support designers and architects in improving the users' environment through BD, this analogue kit offers a framework of relevant topics and specific questions. Furthermore, it highlights the BD key features, putting the workplace design through three stages to reach the highest level of satisfaction.

The elements of the toolkit can be used in different phases of the design process, supporting activities such as research, user studies, benchmarking, brainstorming and interaction design.

The toolkit is divided into three elements that can be used freely or for structured activities, individually or with a team. The three elements of the toolkit are:

1. Activity Guide
2. Flourish Cards

3. Biophilic Cards

The toolkit was created to give ideas to designers and architects seeking solutions for various IEQ issues in different open-plan office environments. The present study aimed to investigate how the use of BD patterns can be facilitated within various budgetary limits. The three elements are related to each other but serve different functions. To reach the best design results, they should be used together. The toolkit envisions a design methodology in which conducting research is the first step, followed by an immersive focus on the design itself. Therefore, the Activity Guide and the Flourish Cards are used first, followed by the Biophilic Cards, shown in Figures 60 and 61.

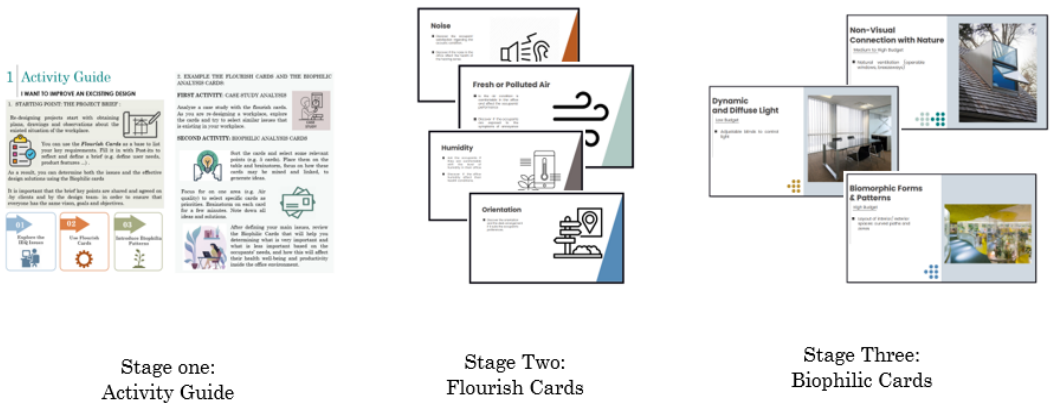


Figure 60: Overview of the Toolkit Elements

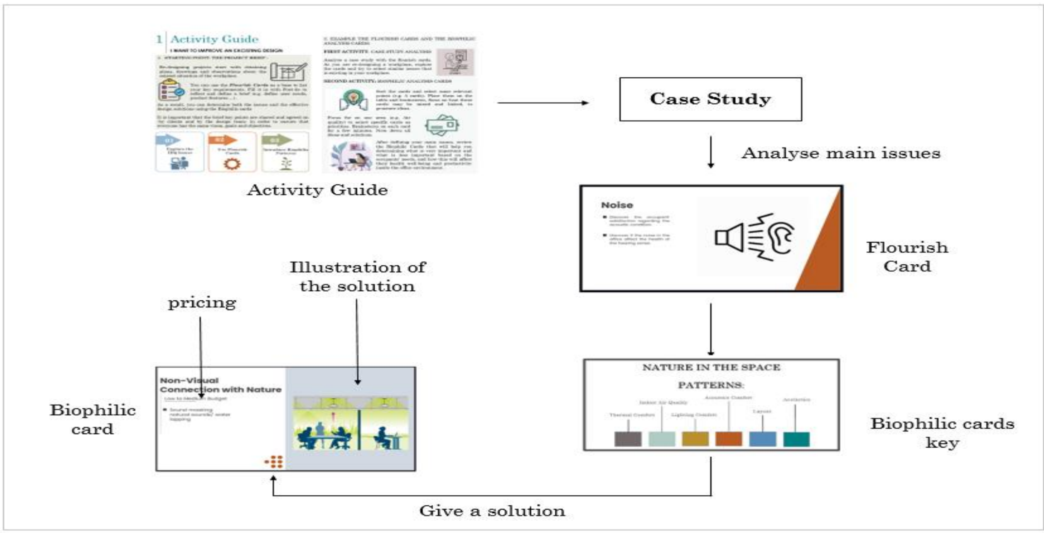


Figure 61: Relationship Between the Toolkit Elements and the Interactional Flow

6.3.1 Activity Guide

The first element of the toolkit is a guide that explains how to perform design activities with the support of all the toolkit components. Therefore, the Activity Guide is an instructional resource to assist the toolkit users in reaching their design goals, as shown in Figure 62.

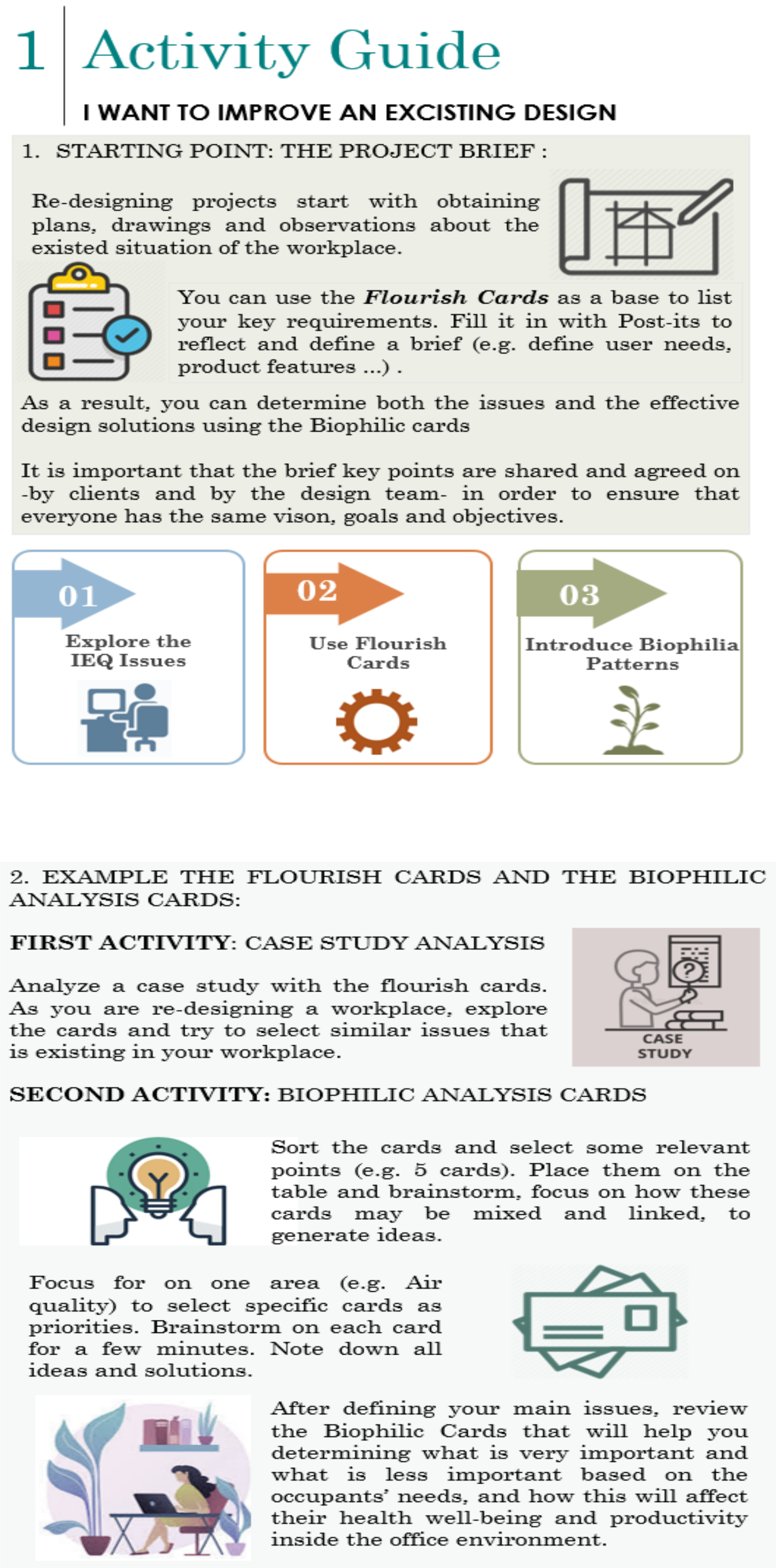


Figure 62: Activity Guide

The Activity Guide was developed from the results gathered in Chapter 5. The survey showed that it was essential to evaluate the health, well-being and productivity of occupants and ask about the main IEQ issues that could be improved in the office environment since "If you cannot measure it, you cannot improve it". Activity guides set out to overcome such lack of knowledge of design methodologies and are structured like a walkthrough; they present different steps for carrying out activities autonomously.

6.3.2 The Flourish Cards

The Flourish cards can be described as an expandable resource currently made up of 19 one-sided cards divided into six original categories, as shown in Figure 63. The card format was preferred for its flexibility, which made further updates of the tool possible; in the field of architecture today, green buildings are a hotly debated topic, continually evolving.

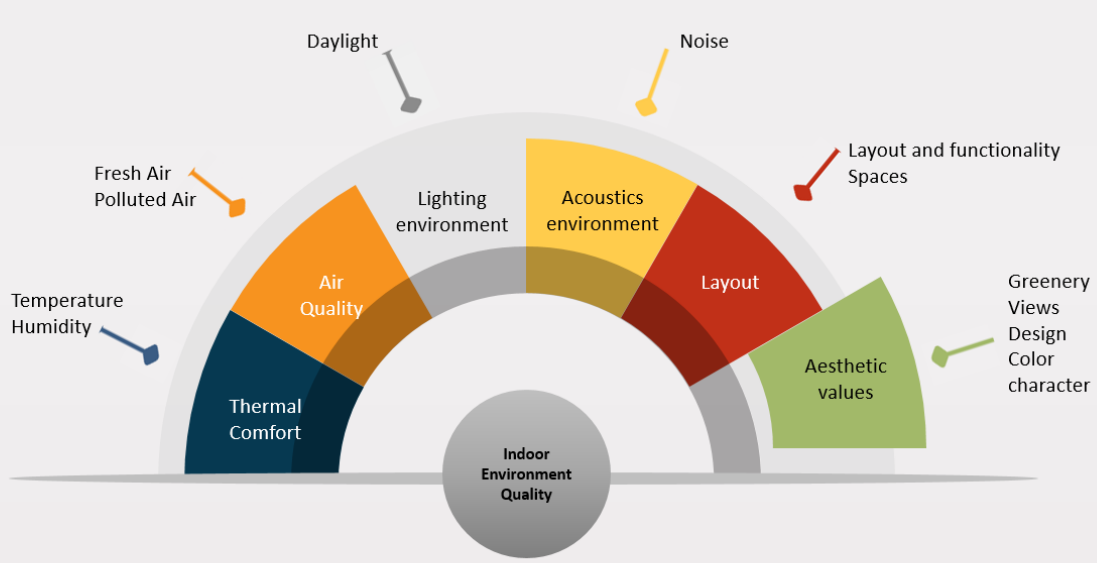


Figure 63: Categories of Flourish Cards

The front of each card is designed differently to show its distinct function. Each category introduces a related topic in its title and asks a critical question. The aim of this is to allow various workplace issues to be quickly explored. Each card is also recognisable by a colour/pattern code and identified by one in a sequence of numbers in the related category; this supports the structured use of the cards in combination with the other toolkit features.

The six categories are thermal comfort, IAQ, lighting environment, acoustic environment, layout and aesthetic values. Each category represents the key factors that need to be strategically enhanced and the point of view from which to analyse an office. Clients are asked to arrange the cards to show how important each of the categories is, as with the Six Thinking Hats system (De Bono, 1986); the division into categories lets the users see the question from several different perspectives. Moreover, the pricing section was essential for encouraging the designer or the architect to choose flexibly between no budget or low, medium or high budget after deciding the main issue in each one of the categories.

The Flourish Cards provide elements for reflection that determine the occupants' experience in an office environment and highlight their needs and expectations. It proposes a strategic vision of the process and questions the impact of the IEQ. All the categories and a general idea of the factors and sub-factors are presented below:

1. **Thermal comfort:** These cards let designers and architects focus on the effect of the temperature and humidity of the internal environment on the occupants and prompt them to ask themselves whether these affect the health of the occupants in the office.
2. **IAQ:** The role of these cards is to determine if the air in the office is fresh or polluted and evaluate the arrangement of the windows. They give designers and architects a chance to check whether the office has any green features that could affect the health and well-being of its occupants.
3. **Acoustic environment:** The purpose of these cards is to find any sources of noise in the office environment and check the type, that is, determine whether the noise is from telephone and other indoor conversations, traffic and other outdoor sources or even from a machine.

4. **Lighting environment:** These cards can be used to find out more about access to daylight in the office.
5. **Layout:** These cards pose questions about the orientation of the office in relation to the external environment, the spaces between the office functions and the design of the neighbourhood.
6. **Aesthetic values:** These cards reveal the factors that indirectly affect the productivity of occupants, such as the colour of the walls and other visual features, as well as the views and greenery seen in the office. As a result, the designers/architects can add aesthetic value to the office environment to improve its current state.

In general, the Flourish Cards (shown in Appendix 3) encourage confrontation and openness regarding expectations and new possibilities. Together, they stimulate a survey and a repository of questions and facilitate divergent production and team discussion. The categories serve as lenses through which to analyse existing solutions with more awareness.

6.3.3 The Biophilic Cards

Linked with the Flourish Cards, the Biophilic Cards are coloured and number 54 in total. They show a possible solution for many IEQ issues on the front, identified by a graphic image. An initial card also indicates the colour key.

The cards propose a research exercise. Once a relevant case study is selected, the idea is to analyse it using the Flourish Cards. The Biophilic Cards can answer design questions, taking into account the designers'/architects' needs and expectations. On the cards, there are also dedicated areas in which to write down positive and negative details about the case being studied. This makes it simpler to gather insights and comparable data on each case.

Once the users have collected the data, the Biophilic Cards offer another functionality: under the pattern name; specific suggestions include the cost of each of the Biophilic applications, which gives the designers/architects a choice to improve the office environment with either no budget or a low, medium or high budget; it acts as a hyperlink. For example, in Figure 64, the Flourish Card for "Green Feature" ask the designers/architects to find whether there are green features or plants to help the production of fresh air in the office. This question is directly linked to the Biophilic Card carrying the solution "Non-Visual Connection with Nature"; this card also shows a graphic image and the cost of this Biophilic application.

These connections provide an overview of key aspects regarding a given issue, establishing a process of guidance and value creation. In this way, the Biophilic Cards become more structured, offering general stimuli and targeted content.

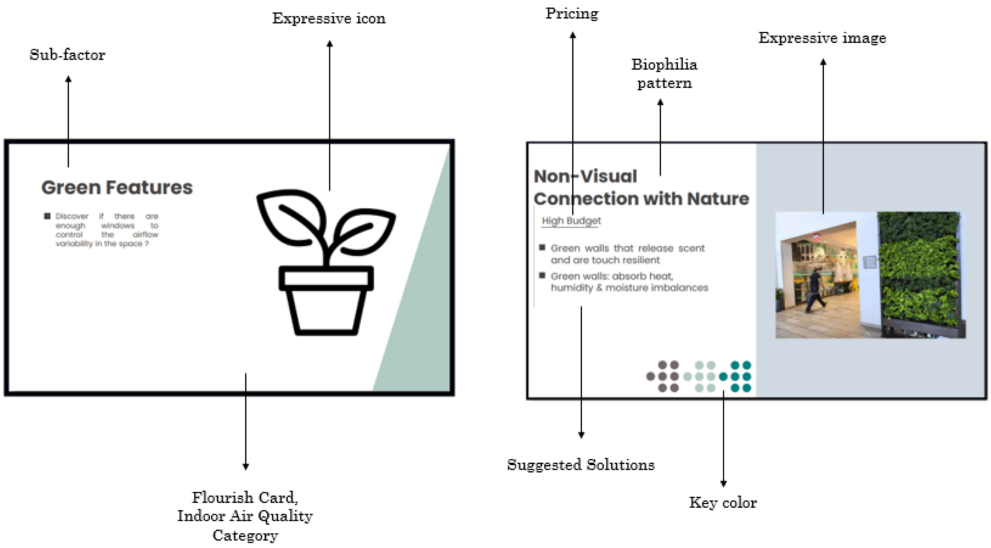


Figure 64: Example of the Link Between the Flourish and Biophilia Cards

The Biophilic Cards show the elements suitable for use in short sessions and workshops with small teams of architects and designers. In general, activities of this kind have flexible timetables, and using the cards makes it possible to visualise the features of case studies quickly.

6.4 Testing the Toolkit (First Round)

In testing the toolkit, the researcher wanted to discover if the toolkit properly showed the information, taught the users what they could do with it and how to do it, provided an efficient way to collect data, ensured that the users carried out the appropriate exercises, assisted the users in identifying problems and getting solutions and enabled the collected data to be easy to use or supported the researchers in their field of work and expanded their knowledge (Grinyer, 2016).

First, three architects tested the toolkit during the architectural design process. The plan for the co-design session was to discuss the theoretical framework behind the toolkit and to test the structured research exercise provided by the toolkit. The framework and structure of the toolkit were generally appreciated. The toolkit components were also tested when the architects used the toolkit to improve one of the research rooms that had been evaluated (see Chapter 5). The use of the toolkit demonstrated that a greater awareness led to the improvement of the workplaces using BD.

Initially, the toolkit was designed to be tested physically by way of printing out the cards into their main categories and conducting a physical focus group with a number of designers and architects so the researcher could monitor their actions and reactions while they were using the toolkit. However, due to the Covid-19 pandemic and the new instructions for social distancing, it was impossible to conduct the physical evaluation of the toolkit and print the cards out as initially planned. Therefore, the toolkit was instead reviewed by six designers and architects in an online focus group using the Zoom application, with the researcher sharing the cards with the participants on the Miro website and, at the same time, letting them interact. The group was asked to use the toolkit to assess and improve the Marie Jahoda building research room and the Howell building research room because they both have several IEQ problems that affected the health, well-being and productivity of the occupants, as indicated in Chapter 5 and shown in Figure 65.

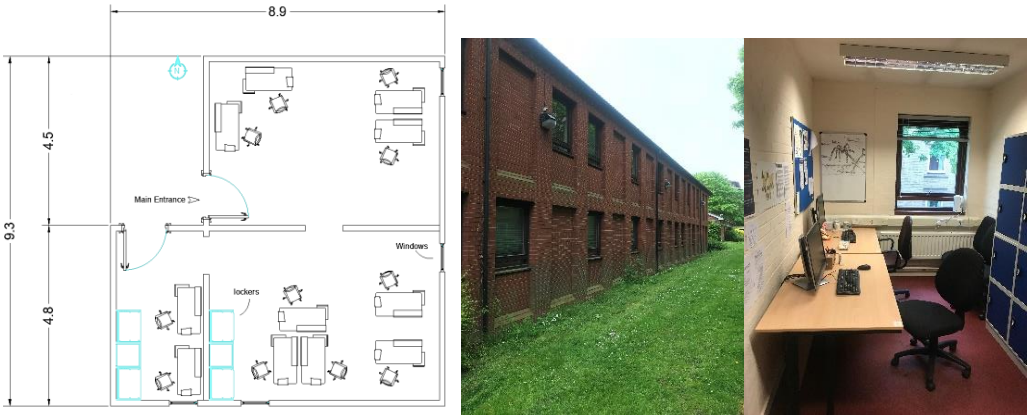


Figure 65: Marie Jahoda Research Room

The researcher provided each one of the three participants with a plan of the office, together with some pictures showing the main issues. Then, the participants started to use the toolkit; the components of the toolkit were available step by step on the Miro website, named “the Biophilic Workplaces Flourish Toolkit”, as shown in Figure 66.

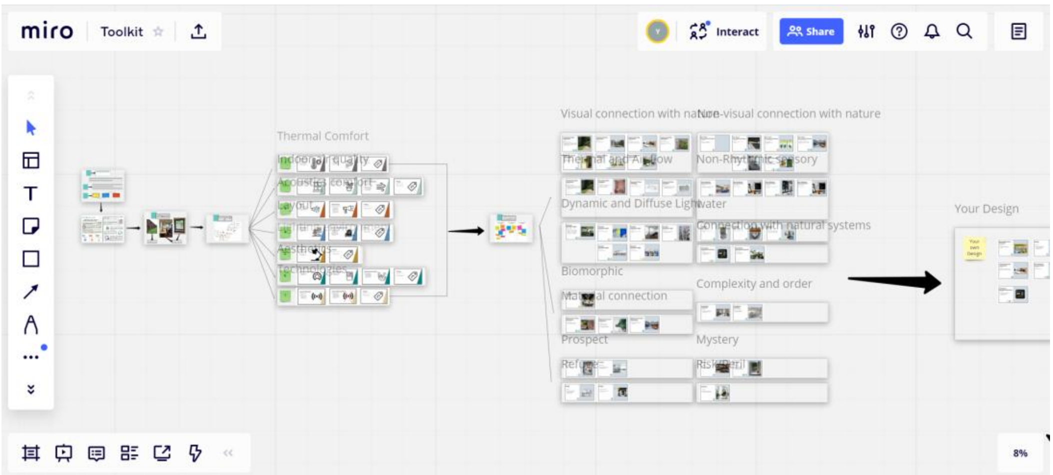


Figure 66: Toolkit on Miro Website

After reading the Activity Guide, the researcher presented the case study pictures of the current state of the Marie Jahoda research room so that the participants could answer the questions on the Flourish Cards and discuss how each of the six categories affected the health, well-being and productivity of the occupants as they spent time working there. Next, the researcher asked them to use the Biophilia Cards to find suitable solutions for the research room problems based on the 14 Patterns of Biophilia.

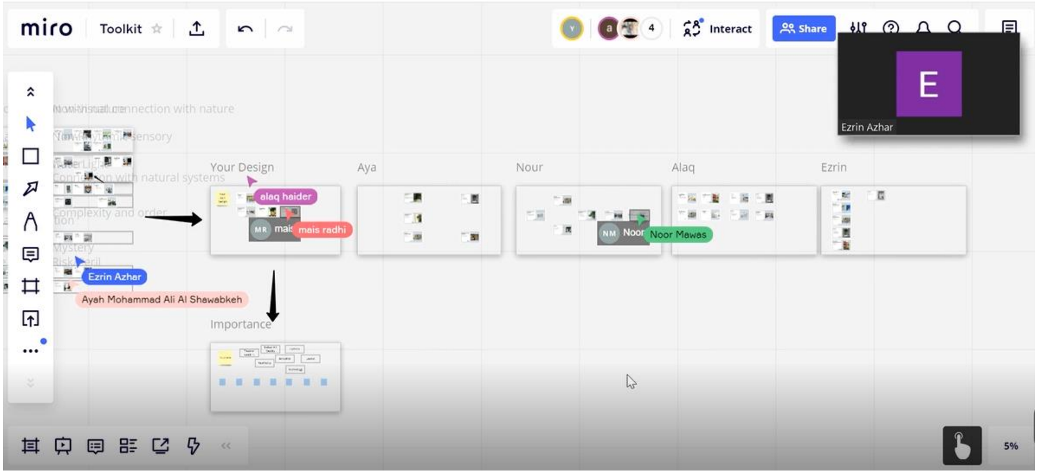


Figure 67: The Interaction Between the Participants

After the exercise, additional comments were collected in a survey questionnaire designed for the participants, which consisted of five questions: (1) Is the tool easy to use? (2) Is the toolkit efficiently designed? (3) Does the tool include the information that you expect? (4) Does the tool enable you to indicate your ideas? (5) Were the objectives of the co-design session achieved using this tool?

The participants emphasised that the Activity Guide helped them understand how to use the toolkit's cards properly, step by step. They also gave some comments regarding the efficiency of the toolkit's design, such as using the key colours to link both stages together and the budget needed for each one of their design concepts.

Two participants asked that more information about Biophilia be added to the digital version of the toolkit so that the users can learn more about the benefits of BD and how it differs from other design approaches. Finally, the toolkit helped the participants suggest several possible improvements for a single space, which means that it is flexible to use with different types of workplaces. As a result, most of the participants confirmed that the co-design objectives were achieved using this toolkit.

6.4.1 Results and Discussion

The online focus group took around 45 minutes, and everyone in the workshop observed all the toolkit elements. Additionally, the feedback from the occupants was analysed, and the advantages and disadvantages of the toolkit and its components were discussed under the headings of use, design and information delivery.

In terms of its design, most of the users agreed that the toolkit was very straightforward, simple, well laid out and well explained, and the colours were well coded. Moreover, the toolkit allowed the users to identify the quality issues in an indoor environment (here, an office) and link the problems with the health and well-being of the occupants. It also defined all the categories presented and asked the users to put every item on a scale according to its importance; consequently, they were sure that it provided or called for detailed and well-explained information.

The toolkit also allowed the users to make recommendations using BD patterns for a comprehensive solution. Even though one participant found that the link between the IEQ factors and BD patterns was slightly unclear, the other users indicated that the toolkit was able to demonstrate this relationship.

However, a few participants commented that the toolkit's Activity Guide was slightly confusing to use at first. Three participants also preferred a physical format to a digital format; they believed this would make it easier to compare the results.

Regarding the toolkit's output, the participants felt that it served its purpose and helped them expand their knowledge of the relationship between workplace design and BD. Furthermore, it gave them a good understanding of the need to improve the workplace since people spend most of their day in an office. Moreover, the participants suggested adding another part to the toolkit to give an idea of the types of plants that are suitable for use in a workplace, define their botanical features and show how each could help balance the IEQ levels and give the workplace aesthetic value.

In addition to their comments, the researcher observed that, even though the toolkit aimed to serve as a co-design study, some participants did not cooperate as well as expected in generating and discussing ideas. One possible reason is that the event was online. As a result, examining the cards or even chatting about anything related to the toolkit was challenging.

6.5 Development of the Co-Design Toolkit

Following the first round of testing, analysis and the users' suggestions, the researcher added a new part to the main design of the toolkit: the "Plants Cards". These cards suggest a number of plants that can be used inside the workplace to help balance the IEQ levels. As mentioned in Chapter 4, plants generally enable humans to connect with nature and provide numerous social and economic benefits, including improved performance, satisfaction and physical and mental health. *Chamaedorea seifrizii*, *Aglaeonema*, *Chrysalidocarpus*, *Sansevieria trifasciata* and *Epipremnum aureum* help in offering fresh air and converting CO_2 to oxygen, specifically at night, which in turn helps in improving the IEQ of the workplace.

Besides the previously mentioned plants, further examples of the plants that are going to be used in the "Plants Cards" part of the toolkit are shown in Table 48; designers and architects can use them to create different scenarios to improve existing workplaces using BD.

Table 48: Plants Cards Used In The Toolkit

Plant Type	Details	PIC
***Aglaonem*a - BJ Freeman**	One of the best indoor plants with plenty of interesting foliage.	

***Agathis robusta* - Queensland Kauri Pine**	For interior spaces where there is a lot of natural light.	
***Anthurium* - Lady Jane**	One of the few plants that will flower indoors. Depending on the light, the flowering period will last several months.	
***Aspidistra* - Elatior Cast Iron Plant**	A tough little plant that was popular back in the Victorian era. It tolerates low light and low water levels.	
***Chamaedorea seifritzii* - Bamboo Palm**	Traditionally one of the best indoor plants as this palm loves indoor environments. It has lovely light green, almost feathery foliage with beautiful bamboo-like stems.	
***Beaucarnea recurvata* - Pony Tail**	This plant does well on balconies.	

Cycas revoluta **- Cycad**	This is an extremely hardy plant, but it needs high light levels. So, in the long term, it is only suitable for balconies and exterior gardens.	
Dracaena fragrans **- Massangeana**	Commonly known as the happy plant, they are tolerant of low light and low water levels; they are probably the best indoor plant.	
Dypsis lutescens **- Areca Palm or Golden Cane Palm**	A beautiful upright palm with many leafy stems. It needs a bright sunny location and lots of water. It is best as a patio plant, as it works as one of the best plants for absorbing noises.	
Epipremnum aureum **- Pothos Golden or Devil's Ivy**	A natural climber, it is often grown on a totem pole, giving the plant about 1.5 metres in height. It is a floor plant and tolerates low light and medium water levels.	

***Ficus lyrata* - Fiddle Leaf Fig**	A great indoor plant if you want the plant to make a statement; it has a great silhouette when placed against a bright window.	
***Howea forsteriana* - Kentia Palm**	This palm has been used indoors all over the world as it is one of the best indoor plants. It tolerates low light levels.	
***Sansevieria trifasciata laurentii* - Mother-in-Law's Tongue**	It looks good when mass planted and is usually considered an "architectural" or minimalist plant. It is a desk or floor plant and tolerates low light and low water levels.	

Eco Walls	This highlights the wall and helps support the greenery. It also helps in balancing temperature and humidity in the office.	 
Schiavello Vertical Garden.	A clean solution for modern offices.	

During the improvement stage, designers and architects may recommend a mix of the plants or choose mass planting to create the desired special effect depending on several factors, as the open-plan office has many micro-environments: some areas get full sunlight, while some are in the shade or do not receive natural light (low light plants); some areas are near air-conditioning, and some are near external doors; another potential area is a balcony in the shade or exposed to the sun. Moreover, some office spaces can accommodate large, wide plants and some spaces, tall, narrow plants; some office staff have preferences about the type of plant, and others leave it up to the designer's expertise.

Each Plants Card mainly gives the name and description of a plant, as shown in Figure 68.

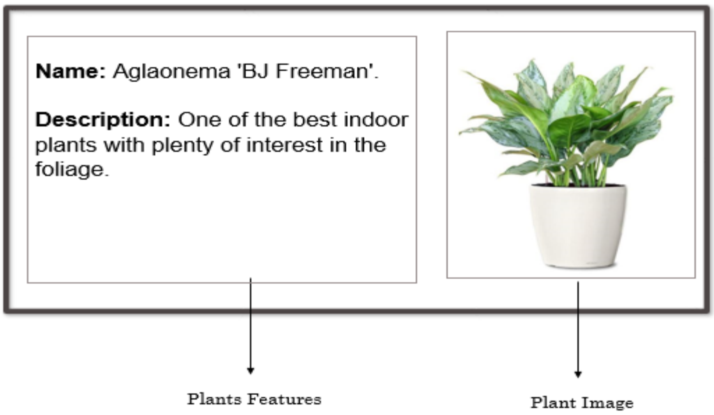


Figure 68: Plants Card

Designers and architects can use the physical and digital versions of these cards to suggest the most suitable plants for improving the workplace.

The physical version helps improve team interaction and collaboration; it is also different in its creative customisations and easy work breakdown. However, the online version is beneficial for asynchronous collaboration through comments, attachments and notes; remote collaboration and inclusion of remote team members; and home and on-the-go access for co-located teams.

6.6 Testing the Toolkit (Second Round)

6.6.1 Discussions with Experts

The toolkit was presented a second time to two experts: one in the design field and the other in the architecture and built environment field. The aim was to discuss the toolkit's development and the Plants Cards that were added after the first round of testing. The framework and structure of the toolkit were generally appreciated. The experts mentioned that validation of the tool is required. That is, more architects and designers should test the toolkit holistically. They also pointed out that the need to explain how the cards are integrated into the toolkit and whether there is a sequence of iterations to be developed must be mentioned while testing the toolkit. They also suggested including a web link to the platform designed for the tool so that it can be tested/verified/used by future toolkit users. Finally, they suggested adding tips on the cards on how to implement the different types of plants in an open-plan workplace in various types of areas, openings and layouts.

6.6.2 Two Online Evaluation Focus Groups

As a result of the interviews with the experts, the researcher decided to hold two more online focus groups using the Miro website platform used for the previous discussions with the two experts. The first focus group was held with seven designers from Brunel University London (Group A), and the second focus group was held with six architects who work in the "Dar Al-Handasah" company in Amman, Jordan, a leading international multidisciplinary consulting organisation in engineering, architecture, planning, environment, project management and economics (Group B).

The online focus groups aimed to identify opportunities for improvement and further co-design the toolkit using the Miro website platform to examine the connection between the toolkit elements from design and architectural perspectives. They also aimed to test the toolkit and check the range of its usefulness in the future. Therefore, the ideal focus group participants had pre-existing experience in the design and development of toolkits; the architects had good knowledge of the Biophilia patterns and an interest in its broader applications.

The focus group participants were requested to join the Miro website platform using the invitation link that was sent to them previously and to join Zoom at the same time to be able to discuss the process of the toolkit step by step. The aim of testing the toolkit with Group A was to examine the toolkit's design elements, the integration between them and the use of the colours and to check if it is understandable or requires more improvement. However, the aim of testing the toolkit with Group B was to discuss improving the IEQ in workplaces using the Biophilia Cards and the different tips for implementing the inclusion of plants, green walls and other Biophilic applications. In both focus groups, everyone was free to share and suggest any resources, studies and improvements connected to the topic.

The first focus group took place in the morning; Group A discussed the toolkit from their design point of view. The second focus group took place in the afternoon; Group B explored how the toolkit worked and used a case study to figure out how workplace IEQ issues can be solved using Biophilia. After an open discussion regarding their experiences, each group was asked to edit the toolkit freely. Then, the participants presented their changes and feedback.

6.6.2.1 Data collection and analysis

A video of each focus group session was recorded. Researchers also observed and took notes during the sessions. The videos were later replayed, and transcripts were produced from them. Data from the questionnaires were aggregated and analysed using spreadsheet software. Observations made by the researchers were also meant to spot and discover the process, intended as unexpected usage of the toolkit or pre-defined procedures supported by the focus group. Transcripts of the videos and free-entry comments from the questionnaires were coded using the focus criteria of the evaluation. The quotations reported in the following sections are from the unmodified transcripts of the participants' feedback, mainly collected through video recording.

The Activity Guide helped the participants improve a workplace through a six-step process; it helped keep the design process visible and minimised the need for supervision. The participants were asked to perform the following activities:

1. Select a case study and a context you agree to design for – This helped define the boundaries of the design space.
2. Browse the Flourish Cards and select the main IEQ issues in the office room by answering the questions on the cards – This enabled the participants to start generating ideas by leveraging their native knowledge of how thermal comfort or any of the IEQ parameters can affect the health and well-being of occupants. This step is shown in Figure 69.

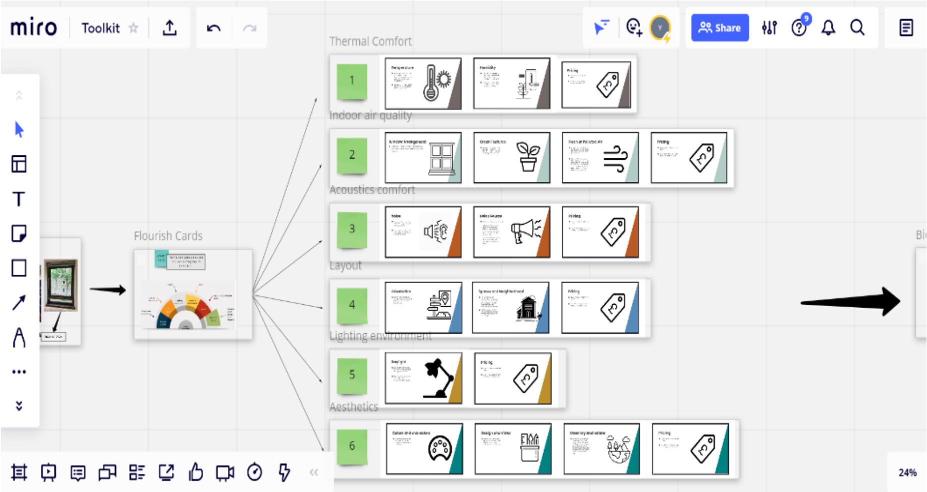


Figure 69: Browsing the Flourish Cards

3. After defining the main issues, improve them using the Biophilic Cards, which are divided into 14 patterns – This allowed the participants to define and link these cards with the Flourish Cards by colour and give different design tips and budgets.

4. Flesh out ideas on the Miro board section – This allowed participants to focus on one idea by presenting the Biophilic applications used and what values they bring to the users.

5. Use Plants Cards where needed to find ways to apply them in the space and make it Biophilic, depending on the plants' features and the space's needs.

6. Look through the design tips and discuss how well one's idea fits with any of them – At this stage, the design is ready to be presented.

The participants were given limited time to complete each step. This time constraint was added to the process to avoid participants getting stuck or converging too early on an idea before exploring different cards.

Collaboration within each group was left informal; the cards could be browsed through freely and chosen according to the persona and scenario for which the group was designing. However, some strategies were enforced when needed to guarantee that everyone participated in the discussion.

The participants presented the ideas generated during the focus groups to exemplify the type and complexity of ideas that can be achieved within each one of the sessions, and they followed all the steps in the activity guide.

The ideas put forward by Group A expressed their opinions about the toolkit components and how it was generated to help designers improve an office space completely to enhance the health and well-being of the occupants. The roles of the tool data from the questionnaires are shown in Figure 70.

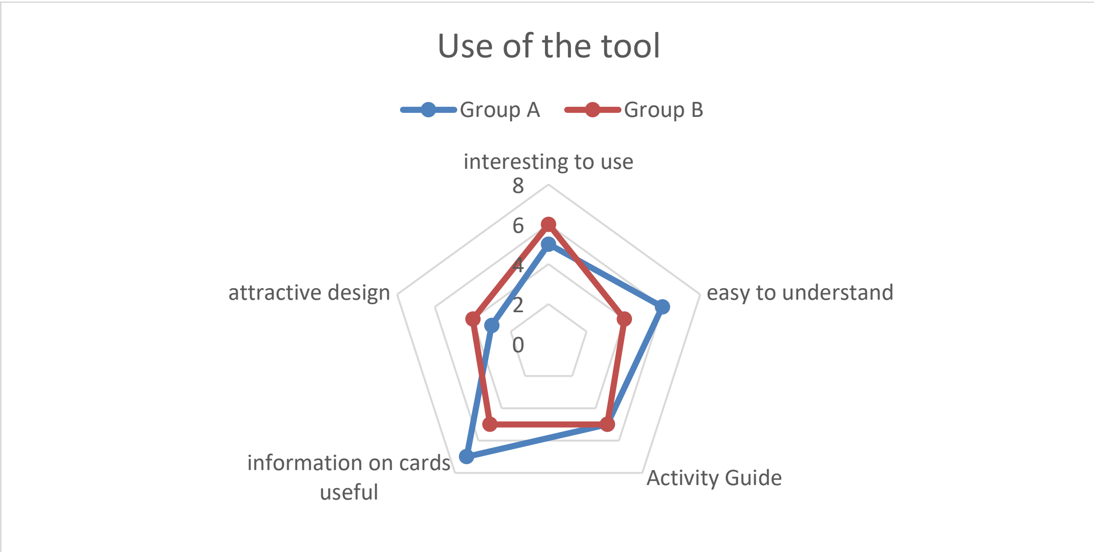


Figure 70: Questionnaires Results

Three designers and four architects agreed that the design of the cards was appealing. The majority felt that the cards were easy to understand and that the Activity Guide for the design process provided assistance for developing new ideas.

Observations made by the researchers and data collected from the questionnaires show that the toolkit was useful in helping users navigate through the workplace design. The participants remarked that "*This process shows you several possibilities for the Biophilia we haven't thought about*", "*the cards are structured and made it easier to* *remember and recall the concepts*", and "*The process was helpful to understand what the possibilities are*."

Other opinions were also collected about generating ideas: "*The cards show a massive array of possibilities, opens your mind a lot*." Moreover, the cards were a source of inspiration for many: "*Cards were useful at the beginning to trigger the initial idea, a lot of possible combinations*." Finally, some participants suggested improvements to the Plants Cards process.

Overall, the strengths and limitations of this toolkit can be summarised as follows. The design process was guided by the instructions presented in the Activity Guide. This was an element of novelty compared to other works that chose not to provide prescriptive guidelines about using cards (for example, Halskov and Dalsgård, 2006; Mueller et al., 2014).

During Steps 2 and 3 of the Activity Guide, the participants were pushed to think about connecting the issues in the Flourish Cards with the solutions in the Biophilic Cards. However, despite the Activity Guide's focus on outlining the process they should follow, the participants continued referring to their selected cards to get inspiration.

Using the case study forced the participants to discuss a detailed scenario. At the same time, cards were added and/or removed, and the idea was generally refined and improved, resulting in a more robust version. There was much more happening while choosing the plants than simply writing down a developed idea. The design tips also helped the participants to gain confidence in their ideas; they were relieved to find that their ideas fit one or more scenarios, depending on the design budgets.

However, one limitation was that at some points during the online focus group, certain participants assumed the role of the leader, "driving the show" without involving the other group members much. Moreover, several points of improvement to the Miro board design were suggested. Some users struggled to understand how the cards were intended to be placed on the Miro board or how it was meant to be used.

6.6.3 Results and Discussion

After some ideas were generated, the participants in the focus groups remarked that the Plants Cards and design tips helped them to reflect on and re-think their design outcomes by looking at their ideas through a set of connections between the Flourish and Biophilic Cards (Figure 71).

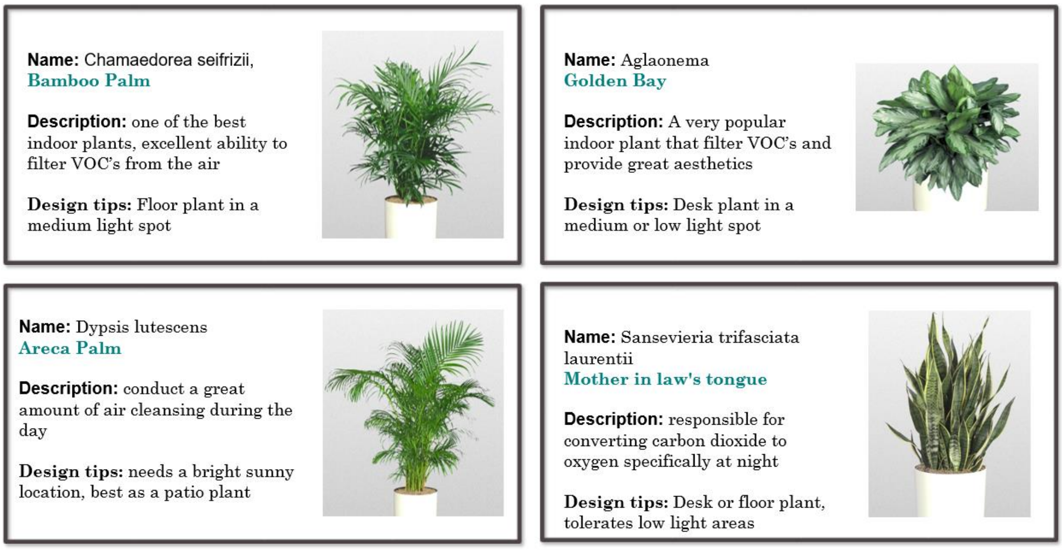


Figure 71: Plants Cards with Tips

While the Plants cards provide information on floor, desk and balcony plants that complete the design process, the design tips provide the designers/architects with the exact way and location in which to implement them.

Both focus groups began with a five-minute presentation about the BD approach, followed by a brief description of the toolkit elements, as shown in Figure 72. The participants were then asked to start an idea-generation session following the rules reported in the Activity Guide, which was provided as a reference during the focus group.

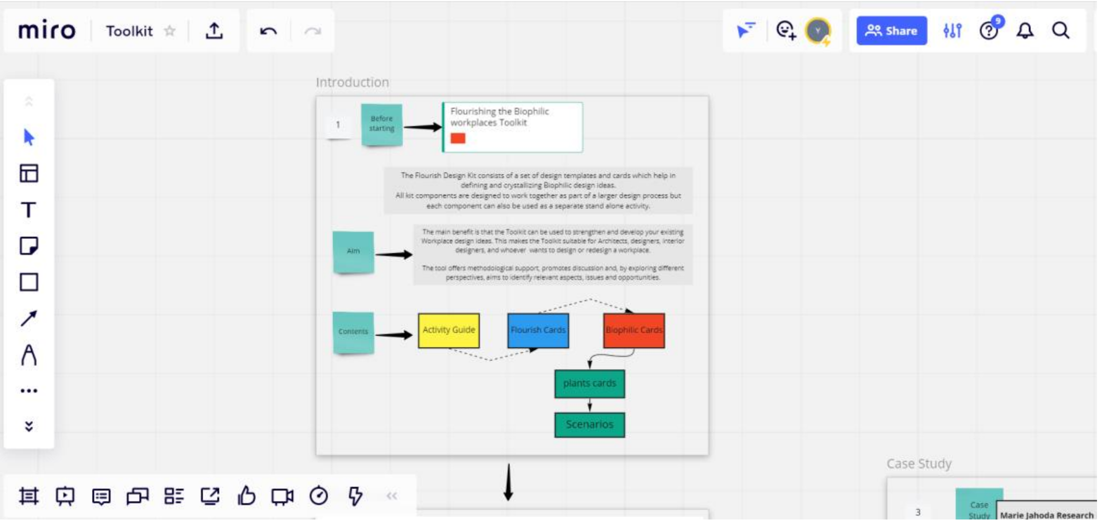


Figure 72: Brief Description of the Toolkit Elements

The participants were given about 15 minutes to complete each Activity Guide step. Each of the focus groups lasted for 55 minutes. After the ideas were finalised, each group member presented their outcomes in a short pitch. The participants were then asked to respond individually to a questionnaire about their experience in the focus group. A five-point scale was used to assess the results. Finally, each session ended with a 10- to 25-minute group interview. The participants were asked to provide feedback about the toolkit and the process and encouraged to comment on relevant details. The discussion was also meant to confirm the data collected by the questionnaires.

6.7 Conclusions

Besides outlining the process for developing a toolkit for designing workplaces using BD, this study also tried to reach out to the interior design community. Its goal was to open up discussion about the best ways to design a successful office environment and to engage architectural companies and stakeholders, especially in universities, in testing and expanding the toolkit. The toolkit developed offers a methodology based on constant research, which encourages being aware of and up-to-date on all the latest architectural and design developments. Its structure is also able to evolve and expand.

It aims to help spread the design approach to the built environment as far as dealing with office buildings. This idea of openness is also related to the possibility of personalising the toolkit's elements and receiving suggestions for new forms of integration. In this way, the toolkit can evolve, following future scenarios and covering updated issues and topics. The Biophilic Workplaces Flourish Toolkit aims to make its users, whether designers or architects, more aware of the office design possibilities of BD. The next step envisioned for developing the toolkit is creating a digital version alongside the current one. While tangibility is valuable for some activities, like workshop use and team discussion, a digital version of the toolkit or digital toolkit element may augment some specific functionalities. For example, an online tool could automatically suggest design feedback and insights, highlighting recurrent design patterns.

7. CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter readdresses the research objectives of the study and presents the most important findings and their conclusions. Then, the limitations of the research are discussed, and the study's contribution is presented. Finally, areas for further research are proposed.

This research study aimed to understand four main areas: POE models in workplaces; the effect of IEQ factors on the health, well-being and productivity of occupants in open-plan offices, both subjectively and objectively; the BD approach; and finally, co-design toolkits.

As mentioned in Chapters 1 and 2, currently, only a few holistic evaluation models can simultaneously measure workplaces from various perspectives as well as that of their occupants. The Flourish Model, developed by Clements-Croome (2016), is one of the recent evaluation models that present a way to evaluate workplaces from three different perspectives: design, perception and economic perspectives. Furthermore, there is very little research and understanding of the effect of IEQ on the health, well-being and productivity of occupants in co-working and open-plan university research offices. Finally, the BD approach has presented several ways to enhance the IEQ factors in workplaces using the 14 Patterns of Biophilia as a guide for applying BD in the workplace environment.

This research investigated this area of the design field by analysing a case study in a co-working office and conducting two rounds of a survey in university research rooms along with a measurement test of the IEQ factors. Finally, a toolkit was designed to help improve the IEQ in offices as an output of the research contribution.

This chapter, divided into four main sections, concludes the research study by presenting its main accomplishments and offering recommendations for practice and further research. The first section presents the achievement of the present research's objectives and the conclusions. The second section discusses the contribution of the study. The third section lists the study's limitations, and the final section offers recommendations for future research.

7.2 Research Objectives and Conclusion

This research aimed to evaluate the impact of IEQ factors within workplaces with and without the application of BD techniques using different methods and locations. This aim contributed to the design of a toolkit linking IEQ factors, occupant responses and subjective perceptions within the office workplace, thus enabling the designer, the occupant and the workplace to be connected.

In particular, this research first analysed and summarised recent literature on POE models and IEQ factors that affect the health and well-being of occupants. It also analysed the definitions, applications and milestones of BD that can be used to improve workplaces. Then, the co-design toolkit was developed to be a tool that helps designers and architects improve the IEQ in workplaces using BD.

Following that, the research identified and analysed how to implement BD and connectedness with nature, including the 14 patterns within a co-working office, and linked them with the IEQ factors. Based on that, the main IEQ issues in five Brunel University research rooms were studied in two rounds. The first round of study was conducted subjectively through a survey. However, the second round was done both subjectively and objectively through a survey conducted in parallel with a measurement test for the IEQ levels in the five research rooms. This part of the research focused on how to measure the IEQ and health, well-being and productivity of the occupants practically, taking into consideration the actual needs of the occupants and how best to consider connecting the occupants to the building.

Finally, co-design recommendations for incorporating BD with the IEQ factors to enhance the health, well-being and productivity of occupants were presented.

Thus, the research aim with its three objectives was achieved. The breadth of the achievement of these objectives is presented in the following sections.

7.2.1 First Objective and Conclusion

This research considered the wide subject area of IEQ factors and their impact on the relationship between building occupants and the space in which they work.

The first objective was to identify the POE models and the surrounding environment that affects the health, well-being and productivity of occupants. Next, BD approach applications in co-working office buildings and university research rooms were described in the literature review and partly by observing the Second Home co-working office as a case study.

This first objective was achieved by conducting the literature review of the POE; the IEQ factors and the health, well-being and productivity of occupants; and the 14 patterns of Biophilia. A range of literature, from journal articles, conference proceedings and references dated from 1920 to 2022, was reviewed. The literature led to the identification of five IEQ factors that influence the comfort and productivity of occupants. These are thermal comfort (temperature, relative humidity), IAQ (fresh and polluted air, window arrangements, the sight of natural features), acoustic comfort (noise), visual comfort (daylight) and office layout (physical space design, building orientation and neighbourhood design). The achievement of this objective can be found in detail in Chapter 2.

Chapter 2 can be summarised under the three main headings of the study, as shown in Table 49.

Table 49: Results of the First Objective

	1. **POE**	2. **IEQ**	3. **Biophilia**
Conclusion	The workplace as a whole should be evaluated to give an accurate understanding of the effects of the workplace environment. Few studies were identified that focused on quantitative data collected from the environment design and qualitative data about users' perceptions. (Sanni-Anibire, Hassanain and Al-Hammad, 2016; Wolfgang and Preiser, 2001)	This study contributed to investigations of the IEQ factors that most affect the health, well-being and productivity of occupants as a holistic evaluation using the Flourish Model (Bodin and Bodin, 2009; Kim and De Dear, 2012; Smith-Jackson and Klein, 2009)	Few studies exist on the effect of biophilia on the holistic health, well-being and productivity of occupants. Seven studies mark the milestones of BD. (Kellert, Heerwagen and Mador, 2008; Heerwagen, 2009; Ojamaa, 2015)
Chosen criteria	The Flourish Model can be considered a holistic model for evaluating the workplace as a physical design with perception and economic implications.	1. Thermal comfort 2. IAQ 3. Lighting environment 4. Acoustic environment 5. Spatial layout (De Dear, Brager and Cooper, 1997;	This research adapted "14 Patterns of Biophilic Design" by Terrapin Bright Green as the most appropriate study for improving workplaces.

	(Clements-Croome, 2016; Clements-Croome, Turner and Pallaris, 2019)	Djongyang, Tchinda and Njomo, 2010; Fanger, 1970; Lan, Wargocki and Lian, 2011a; Tanabe, Nishihara and Haneda, 2007;)	(Browning, Ryan and Clancy, 2014)

The second part of the first objective was achieved by analysing the Second Home company as a case study to see how Biophilia was applied in this kind of building (where the offices are of the co-working type and have the same indoor and outdoor environment) and affected the health, well-being and productivity of the occupants. To this end, on-site observation and semi-structured interviews were held with 10 HR members from 10 companies working in the Second Home. Details of this can be found in Chapter 4.

Two main points clearly emerged from the case study analysis. The first point was that using BD significantly affects the health, well-being and productivity of the occupants in the co-working environment. Unlike traditional workplaces, the Second Home company shows how BD increases the productivity of employees through their extraordinary contact with the natural environment. Furthermore, using particular kinds of plants helps with enhancing the thermal comfort as well as the air quality in the space's interior. However, using some natural features only for aesthetic purposes is not enough to attain the highest environmental quality or even the occupants' expectations of their offices. Moreover, it was obvious that BD also has to be integrated with some technological sensors to increase the satisfaction of the occupants in the office environment since they would want to control the IEQ in terms of thermal comfort, air quality, lighting, acoustic comfort and spatial layout.

The results showed general agreement in connecting the building and occupants for evaluating workplaces. Considering the IEQ factors, the following were found:

1. Noise remains a significant issue to solve through better architectural design.

2. Thermal comfort, although understood, is still a key issue to manage.
3. Indoor air quality needs to be defined, understandable and affordable.
4. Indoor environmental quality factors need to be mutually connected to create a better workplace.

7.2.2 Second Objective and Conclusion

The second objective of the research was to evaluate the health, well-being and productivity of occupants in five research rooms at Brunel University London and quantitatively study the potential for improving these workplaces using BD.

This objective was achieved by designing a survey to evaluate the occupants' perceptions towards the IEQ factors in the open-plan research rooms (which had the same outdoor environment and different individual indoor environments) to study the impact of these conditions on the health, well-being and productivity of the occupants.

Another survey followed this; however, it was combined with IEQ measurement tests conducted in the five research rooms to validate the results.

The research study used the Flourish Model to develop the questionnaires. The achievement of this objective is described in detail in Chapter 5.

The most prominent finding to emerge from this part of the study was that the qualities of the five key IEQ aspects (thermal comfort, IAQ, lighting environment, acoustic environment and layout) had significantly positive correlations with the health, well-being and productivity of the occupants.

The second significant finding was that of the five key aspects of IEQ, the quality of the thermal environment and the IAQ have the greatest influence on the productivity of the occupants in the older buildings due to the lack of fresh air and the unstable temperature and humidity levels. However, the descriptive analysis showed that the occupants in the recently developed buildings were satisfied with the thermal comfort, IAQ and lighting environment, though they had some reservations regarding the office layout and acoustic comfort. In open-plan offices, such verdicts are always possible and even common.

Another finding came from the regression analysis, which showed that the comfort level experienced in the workplace was satisfactory among occupants of the Eastern Gateway building, the Wilfred Brown and the Michael Sterling building. Moreover, the comfort level had a direct positive effect on the productivity of the occupants there. Finally, the occupants interacted well with the correlation analysis questions since they were sure that BD has many solutions that would improve their offices, such as adding plants, using radiant surface materials and installing an HVAC system, among others.

Interestingly the comfort range for any physical parameter ranges from person to person. The measurement test was lower in importance, consistent with the qualitative survey results. For instance, the results show that the temperature in the Wilfred Brown building, which is considered one of the recently developed buildings, was within standards; however, the occupants' feelings show that they feel so hot when it is sunny, this was because of the building orientation and the large size of the windows.

After finding out from the occupants the main IEQ issues in the research rooms, the conclusion of this chapter suggested various enhancements to them using the Biophilic patterns that help in solving other IEQ issues in these university research rooms. As a result, this study went on to design a co-design toolkit to help designers and architects improve different types of workplaces using Biophilic patterns.

Finally, it was clear that the guidelines recommend ranges for different physical parameters that are vague and had received a spectrum of responses when tested on different occupant profiles. It is necessary to improve the classification and focus of different building standards and guidelines based on climate and occupant profile.

7.2.3 Third Objective and Conclusion

The third objective of this research was to design a toolkit that would help designers and architects improve a workplace using Biophilia based on the Flourish Model.

This objective was achieved as described in Chapter 6. The design of the toolkit was based on the results of the earlier chapters. The toolkit has three main parts: the Activity Guide, which is used to direct its use; the Flourish Cards, which contain questions to evaluate the effect of the IEQ on the health, well-being and productivity of occupants (from Chapter 5); and finally, the Biophilic Cards, which were designed to present solutions for different IEQ problems (from Chapters 2 and 4).

The purpose of the toolkit was to open up the discussion about the best ways to design a successful office environment and to engage architectural companies and stakeholders, especially those in universities, in testing and expanding the toolkit. This toolkit offers a methodology based on constant research that encourages awareness and the updating of all architectural and design developments. Therefore, its structure can evolve and expand. The toolkit was tested five times, with a total of 23 participants, and several improvements were made to achieve the best toolkit design.

7.3 Contribution to the Knowledge

This research study makes the following contributions:

1. It provides a significant new contribution to the current knowledge of the Flourish Model, as it is one of the first studies to use it to evaluate workplaces. In addition, it has produced some helpful literature that adds to the knowledge of POE for assessing five physical factors of IEQ and improving them using BD.
2. It highlights various direct and indirect effects of IEQ on the health, well-being and productivity of occupants. These relationships are new to the literature and provide an excellent starting point for researchers in this area who want to improve the factors and sub-factors of IEQ.
3. It is the first to analyse Biophilia in a (co-working) space that hosts nearly 30 companies from different disciplines (the Second Home company).

4. It developed a co-design toolkit for architecture design that can be used by designers, architects, students and even stakeholders to improve the design of workplaces in a way that positively affects the occupants.
5. It supports existing IEQ assessments and POE models within a free-running, naturally ventilated environment.

7.4 Limitations of the Research

1. This research only focused on co-working office buildings and university research rooms in the UK's climatic conditions. Therefore, its results are only applicable to buildings in similar climatic conditions.
2. Due to the Covid-19 pandemic, lockdown and transportation issues obliged the researcher to postpone the measurement test, which was supposed to take place in 2020 rather than 2023. Moreover, testing the toolkit was supposed to be conducted through face-to-face focus groups with physical cards; however, these focus groups were conducted online using the Miro website platform instead.

7.5 Recommendations for Future Research

1. This research provides a starting point for researchers investigating IEQ and the health, well-being and productivity of occupants. In addition, it can be used as an example to examine similar relationships in different types of buildings in various climatic conditions. For example, a future study evaluating the satisfaction of occupants within the office environment can also measure the physical IEQ factors by using a monitor with sensors.

2. The suggested range of current results should be used to update post-occupancy guidelines in the Middle East region. Future research can be conducted using pilot studies in office buildings. This study's implications are to inform future design and the evaluation of workplace environments. The methodology developed in this research enabled data to be collected from a number of different workplaces and compared.
3. In terms of benefits to future research, the findings of this research provide the scope for further analysis. Further analysis of the Flourish Model needs to be conducted to test whether additional aspects of the workplace environment need to be incorporated and develop a more conclusive evidence base to understand the impact of the qualitative aspects of the workplace within a holistic evaluation process.
4. The Biophilic Workplaces Flourish Toolkit aims to make its users, whether designers or architects, more aware of the office design possibilities with Biophilia. A possible direction envisioned in the future development of the toolkit is the creation of a digital version alongside the current one. While tangibility is valuable for some activities, such as workshop use and team discussions, a digital version or a digital toolkit element may amplify some specific functionalities.
5. Involving designers in the research of BD strategies and their relationship to health and well-being benefits in order to provide a bridge to practice. It is crucial that designers participate in addressing questions of how to implement green features and plants to implement the optimum workplace design.

7.6 Summary

This chapter presented the conclusions of the present research. First, it outlined the research aim and objectives. Descriptions and the results of meeting all the objectives were given; thus, the research aim of the study was achieved. Next, the research contributions to the industry and current knowledge were presented, followed by an outline of the limitations of the research. Finally, recommendations for future research were suggested.

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9. Appendices

9.1 Appendix 1: First Survey Questionnaire Format

Survey format

Dear respondents,

This survey is part of a field study in a PhD thesis under the title of "**Flourishing the Indoor Environment Quality of Workplaces using the Biophilic Architecture Design** ".

This study aims to evaluate the indoor environment quality in workplaces and improve the occupants' wellness by using "Biophilic Architecture" patterns in the context of the smart application.

This survey was directed to the Doctoral and Post-Doctoral researchers in the postgraduates' rooms at Brunel University London.

I would appreciate your help in providing answers for this questionnaire, knowing that the information you provide will be purely for scientific purposes and within the process of screening and analysing information only. Participation in this survey is voluntary. All participants' identities will be kept confidential.

The questionnaire should take less than 15 minutes to complete.

Please do not hesitate to ask any questions, and feel free to add your comments.

Regards,

Researcher,

For correspondence:

Youmna Al-Dmour - Doctoral Researcher

Brunel University London
Email: 1744233@brunel.ac.uk
Phone: +44 7853948291

1. Demographic Questions:

1. What is your gender?				
a. Male	b. Female	c. Prefer not to say		
2. What is your age?				
a. 18-30	b. 31-50	c. 51-65	d. over 65	
3. What is your highest level of education?				
a. Master degree	b. Doctoral researcher	c. Post Doctorate		
4. where is your workplace located :				
a. Design department (Michael sterling Building)	b. Business school	c. Computer science department	d. English literature department	e. Finance department (Marie Jahoda building)
5. How many years have you worked in this workplace?				
a. Less than one-year	b. 1-3 years	c. 3-5 years	d. More than 5 years	
6. In a week, how many hours do you spend at your desk in the office (do not include fieldwork)?				
a. Less than 30	b. Between 30 – 40	c. More than 40		

2. Post Occupancy Evaluation:

Questions	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
A. Thermal Comfort :							
1. You feel that your office temperature suit your preference.							

2. You are comfortable with the level of humidity in your office.							
3. You feel that the temperature and humidity of your office affect your health conditions.							
4. You feel satisfied with the thermal condition in your office.							
Comments (please specify below):							
B. Indoor air quality (IAQ) :							
5. You feel that the air in your office is fresh.							
6. You feel that the air conditions are comfortable in your office and affect your performance positively.							
7. You feel the air in your office is polluted occasionally.							
8. You expose to the symptoms of annoyance in the air environment, such as (Headache, Dry eyes, Cough, Sputum, Nose, Itchiness, Dry skin).							
9. The previous symptoms persist after leaving your office.							
10. You think that there are enough windows which control the airflow variability in the space.							

11. Your office has Green features; such as plants, natural materials furniture, exist of water and access to green views only from your desk.							
Comments (please specify below):							
C. Acoustics Questions :							
12. You are comfortable with the acoustics in your office.							
13. You feel that your sound privacy is violated in the office.							
14. The noise source in your office is the Telephone or side conversations.							
15. The noise source in your office is Traffic and outdoor noise.							
16. The noise source in your office is the HVAC and machines' noise inside the office.							
17. The noise in your workplace affects the health of your hearing sense.							
18. You feel that you are satisfied with the acoustic condition.							
Comments (please specify below):							
D. Lighting Questions :							

19. Your office has access to daylight through the windows.							
20. Overall, the lighting condition of your office is bright.							
21. The light in your office affects the health of your eyes negatively.							
22. You are visually comfortable in your office.							
23. You are Satisfied with the lighting condition.							
Comments (please specify below):							
E. Layout Questions :							
24. You feel that the spatial layout of your office is successful.							
25. The spaces between the workspaces, windows, desks and other kinds of stuff are comfortable.							
26. You feel comfortable with the orientation of your desk							
27. There are some green areas in the neighbourhood areas of your office.							
28. You are Satisfied with your desk arrangement in the office.							

29. The layout of your office help in making your body active and energetic.							
Comments (please specify below):							
F. IEQ Questions							
30. You are satisfied with the level of comfort you experience within your workplace environments, which pertains to "heating, cooling, lighting, layout, ventilation and noise."							
31. Your office environment can adapt to changes in your needs.							
32. Your office has the potential to affect appropriate levels of natural ventilation and air conditioning, as well as window arrangement.							
33. You are satisfied with the sheer size of groups working together within workplace environments.							
34. having IEQ issues in your office affect the time that you spend working in such an environment.							
35. How would you weigh the impact factors for your work on a scale from the least important to the most important?							

- Thermal comfort	1	2	3	4	5	6	7	8	9	10
- IAQ	1	2	3	4	5	6	7	8	9	10
- Acoustics	1	2	3	4	5	6	7	8	9	10
- Lighting	1	2	3	4	5	6	7	8	9	10
- Layout	1	2	3	4	5	6	7	8	9	10
Comments (please specify below):										

3. Biophilic design Questions:

Biophilic design,

Defined as a response to the inherent need of human beings to be in contact with nature in the workplace, improves productivity and user health and well-being.

Questions	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
1. You feel that adding natural features (e.g. plants, water) to your office design will offer a healthy environment.							
2. You feel that the presence of green elements and plants will affect your comfort in the time that you spend in your office.							
3. you prefer daylight instead of artificial light in your office.							
4. the use of multiple low-glare electric light sources can promote visual comfort for you while working inside the office.							

5. controlling Indoor air quality and thermal comfort by using radiant surface materials will offer a pleasant environment and increase productivity.							
6. adding some natural materials in your workplace will make you feel in contact with nature.							
7. using natural features could decrease the noise in your office, you feel that such an application will affect your productivity in the office.							
8. you feel that the size and orientation of the windows in your office offer you suitable fresh air and natural lighting.							
9. the view of your office gives you a nature scene that affects your visual comfort positively.							
10. the layout of your office as an (open plan office) affects achieving your tasks every time you spend there.							
11. You feel that the presence of water inside the office reduces the stress.							

12. You feel that adding sensors to measure the indoor environment quality (IEQ) in your workplace will help in solving any environmental problems you may face.							

9.2 Appendix 2: Second Survey

Satisfaction Survey

This survey is part of a research study you have volunteered to participate in, and I thank you for your involvement.

1. It is voluntary to participate in this study.
2. You can stop at any time and are not required to complete all or any of the questions within any survey.
3. Survey Submission indicates that you have agreed to participate in this part of the research study.

This "Right Now" questionnaire will take less than 5 minutes to fill out your feelings towards the Indoor Environment factors in your research room. A list of questions will now be presented as follows:

What is your gender?				
a. Male	b. Female	c. Prefer not to say		
What is your age?				
a. 18-30	b. 31-50	c. 51-65	d. over 65	
What is your highest level of education?				
a. Master degree	b. Doctoral researcher	c. Post Doctorate		
Where is your workplace located :				
a. Design department (Michael sterling Building)	b. Business school	c. Computer science department	d. English literature department	e. Finance department (Marie Jahoda building)
How many years have you worked in this workplace?				
a. Less than one year	b. 1-3 years	c. 3-5 years	d. More than 5 years	
In a week, how many hours do you spend at your desk in the office (do not include fieldwork)?				
a. Less than 30	b. Between 30 – 40	c. More than 40		

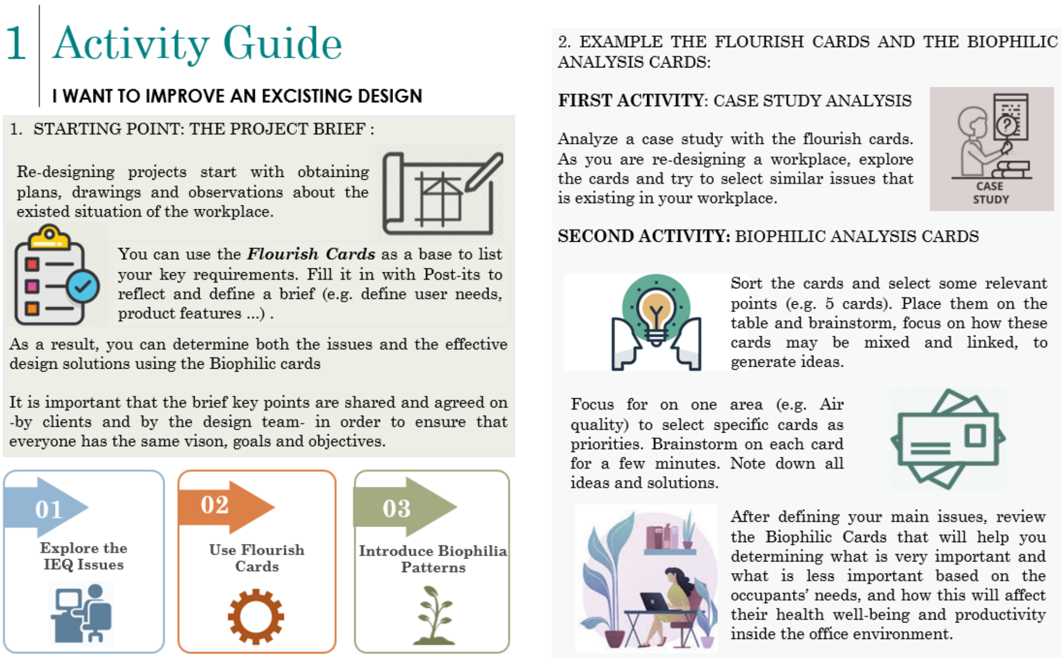
Q1: Describe your level of perceived temperature; where on the following scale would you position the indicator?

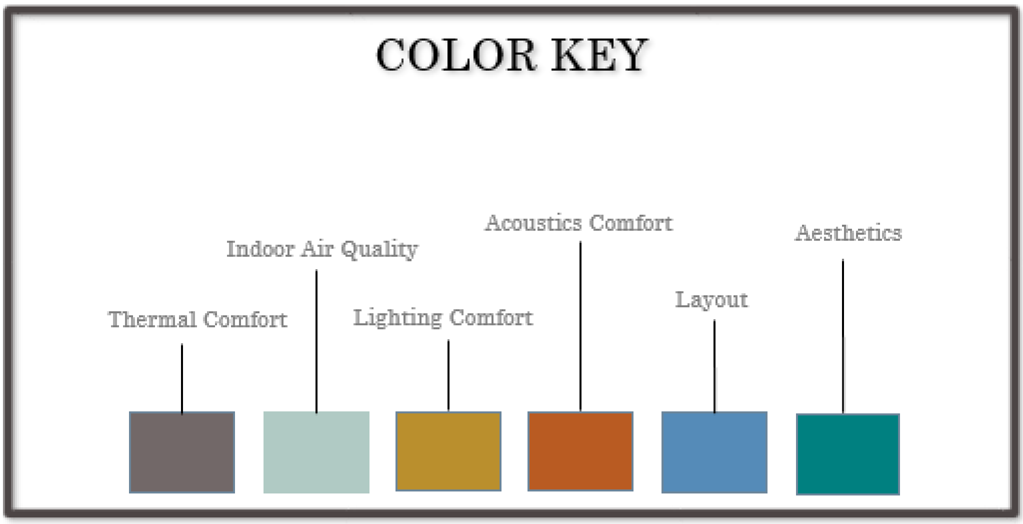
Too Cold	Cold	Mildly Cool	Neutral	Mildly Hot	Hot	Very Hot
Q2: How would you rate the indoor humidity?						
Very Dry	Dry	Slightly Dry	Neutral	Slightly Humid	Humid	Very Humid
Q3: How would you rate the overall Indoor Air Quality (Ventilation) within your workplace?						
Very Fresh	Fresh	Rarely fresh	Neutral	Rarely stale	Stale, dusty	Very stale, dusty
Q4: What do you feel about the acoustics environment?						
Very quiet	Quiet	Slightly Quiet	Neutral	Slightly Noisy	Noisy	Very noisy
Q5: What is your opinion of the light entering the space?						
Very dark (No access to daylight)	Very poor	Poor	Neutral	Good	Very Good	Very bright (Too much daylight)

Thank You

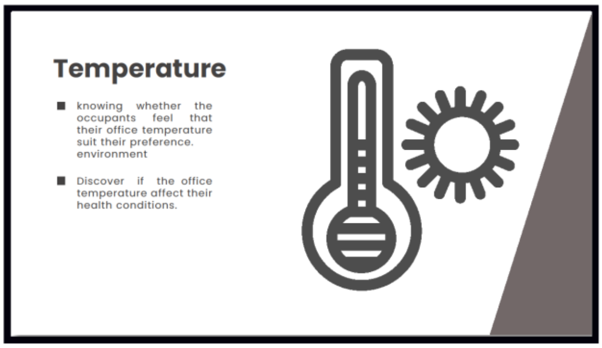
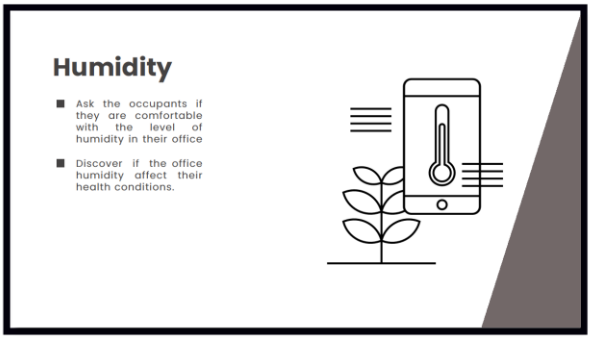
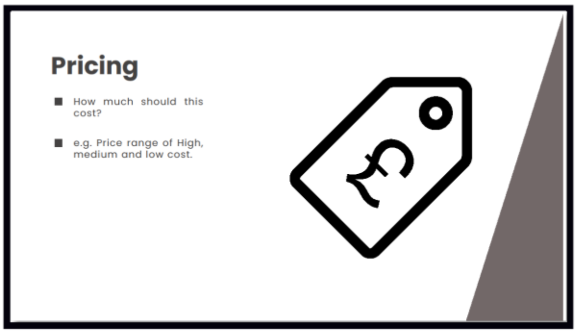
9.3 Appendix 3: Toolkit Cards

1. Activity Guide

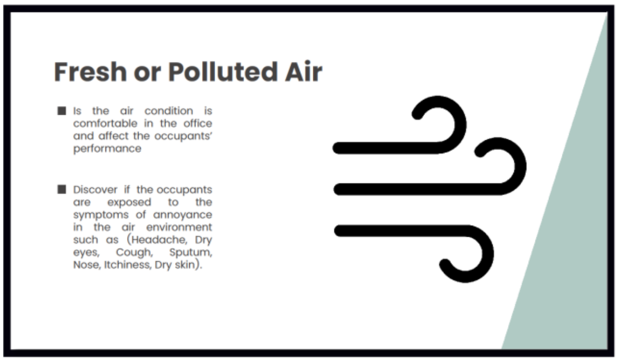


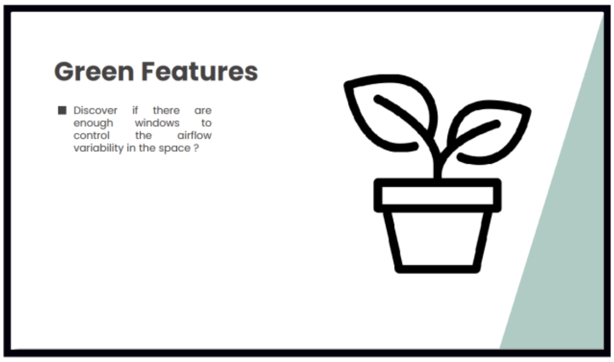


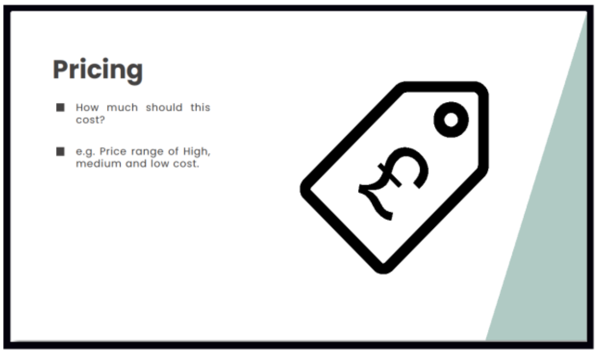
2. Flourish Cards

Thermal comfort cards
  

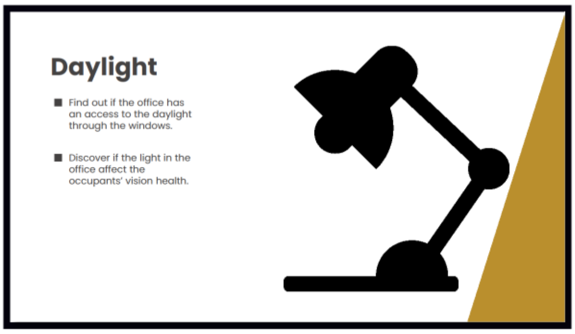
Indoor Air Quality Cards:

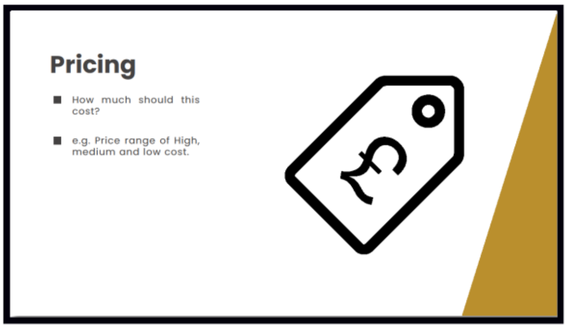




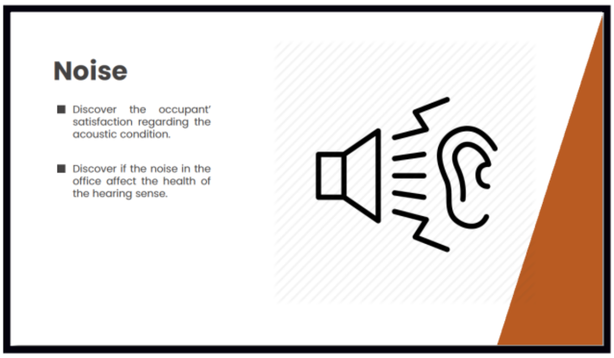


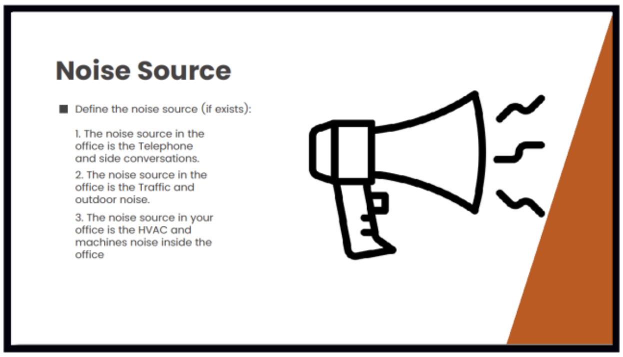
Lighting Environment Cards:

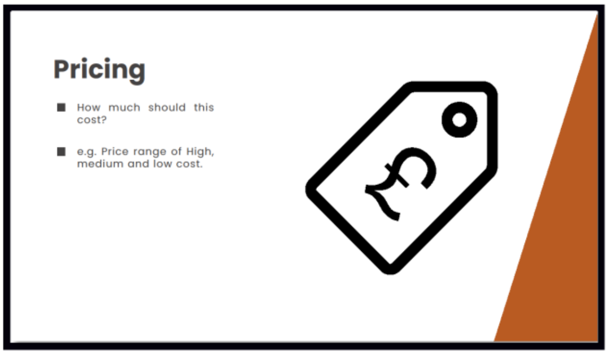




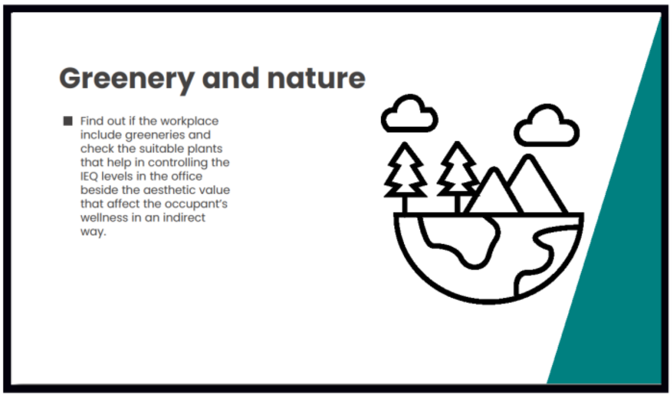
Acoustics environment cards:

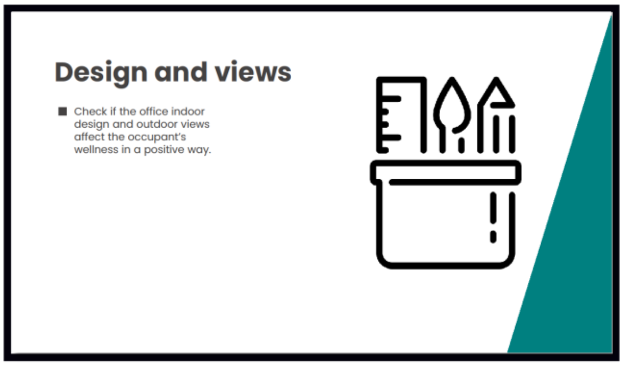


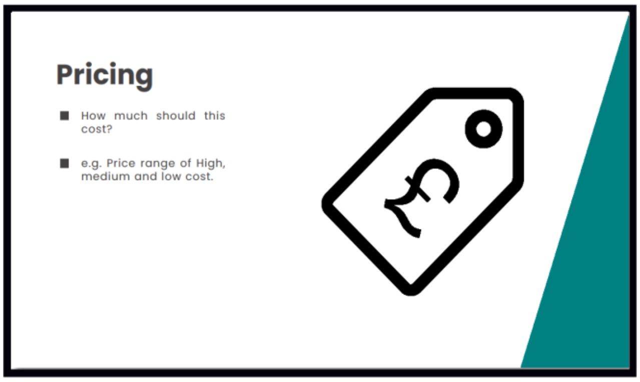




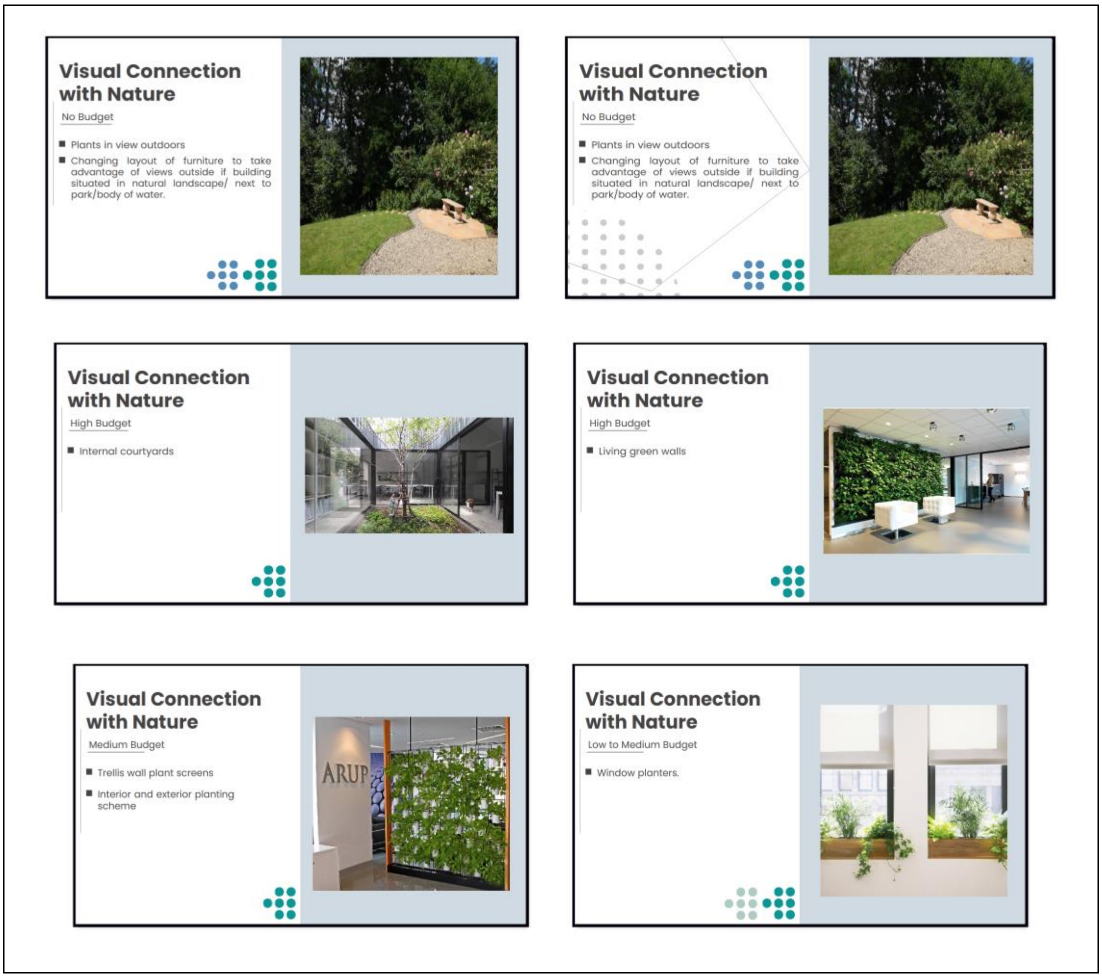
Layout Cards:

Aesthetics Cards:
 


Design and views
Check if the office indoor design and outdoor views affect the occupant's wellness in a positive way.

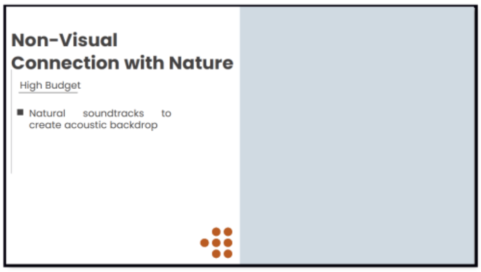

Pricing
How much should this cost?
e.g. Price range of High, medium and low cost.

3. Biophilic Cards



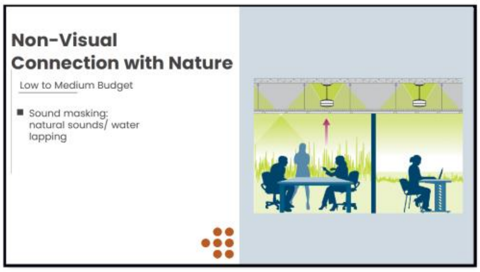

Visual Connection with Nature
Low to Medium Budget
Hanging plants: kokodema, macramé, baskets.


Visual Connection with Nature
Low Budget
Cut flowers on tables and desks
Potted plants on desks and shelves


Non-Visual Connection with Nature
High Budget
Natural soundtracks to create acoustic backdrop

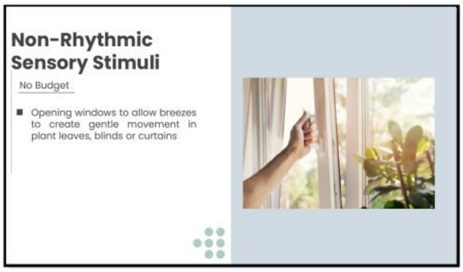

Non-Visual Connection with Nature
High Budget
Green walls that release scent and are touch resilient
Green walls: absorb heat, humidity & moisture imbalances


Non-Visual Connection with Nature
Low Budget
Scent atomizers and diffusers


Non-Visual Connection with Nature
Low to Medium Budget
Sound masking: natural sounds/ water lapping


Non-Visual Connection with Nature
Medium to High Budget
Highly textured fabrics/textiles that mimic natural material textures.


Non-Visual Connection with Nature
Medium to High Budget
Natural ventilation (operable windows, breezeways)

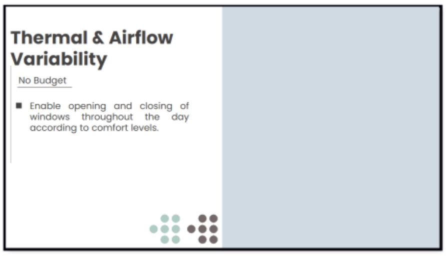

Non-Rhythmic
Sensory Stimuli
No Budget
Opening windows to allow breezes to create gentle movement in plant leaves, blinds or curtains


Non-Rhythmic
Sensory Stimuli
No Budget
Lighting that projects dappled light (gobo/ moving lights)

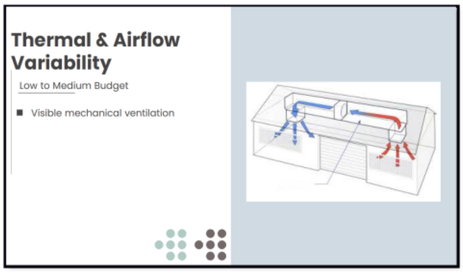

Non-Rhythmic
Sensory Stimuli
Low Budget
Blinds: cut outs to project shadows and light.

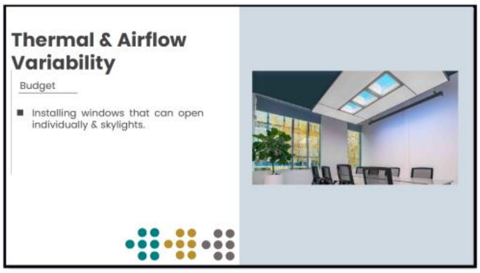

Non-Rhythmic
Sensory Stimuli
High Budget
Indoor willow tree


Non-Rhythmic
Sensory Stimuli
Medium Budget
Kinetic sculptures


Thermal & Airflow Variability
No Budget
Enable opening and closing of windows throughout the day according to comfort levels.

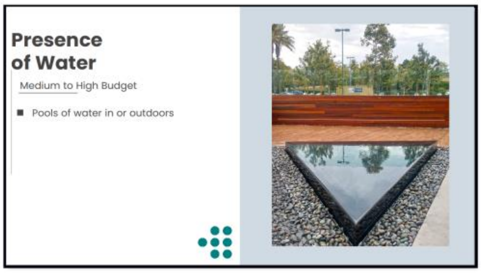

Thermal & Airflow Variability
Low Budget
Clay paints and surfaces: absorb heat/ moisture imbalances
Radiant surface materials


Thermal & Airflow Variability
Low to Medium Budget
Visible mechanical ventilation

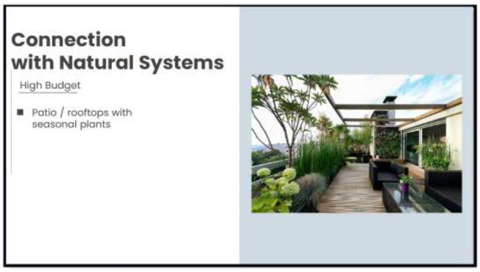

Thermal & Airflow Variability
Budget
Installing windows that can open individually & skylights.

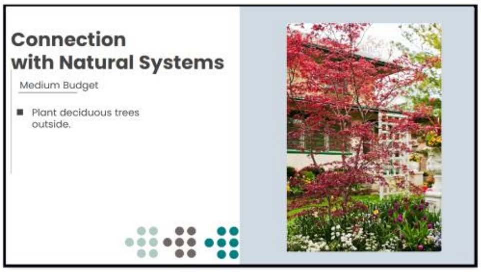

Thermal & Airflow Variability
High Budget
HVAC (heating, ventilation and air conditioning) delivery combined with natural plant strategy.


Presence of Water
Medium Budget
Seating by non-fixed water features

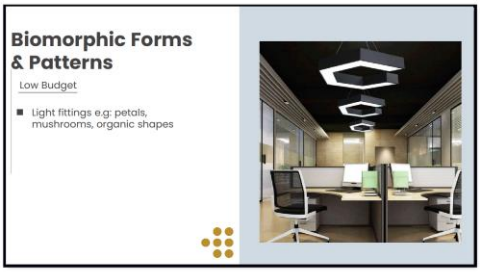

Presence of Water
Medium to High Budget
Pools of water in or outdoors

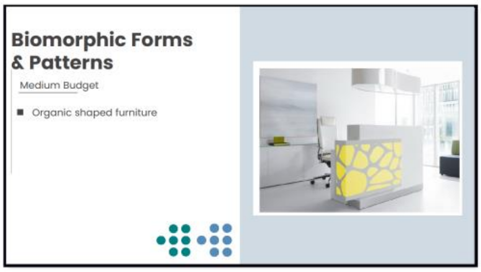

Presence of Water
High Budget
Full height glass walls/ windows to see water flow down – rain or water feature

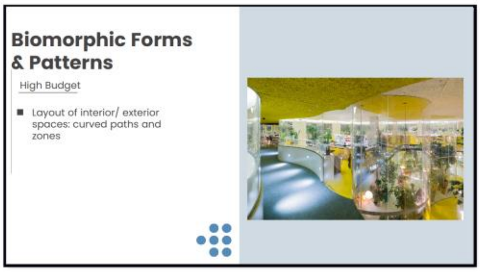

Connection
with Natural Systems
High Budget
Patio / rooftops with seasonal plants

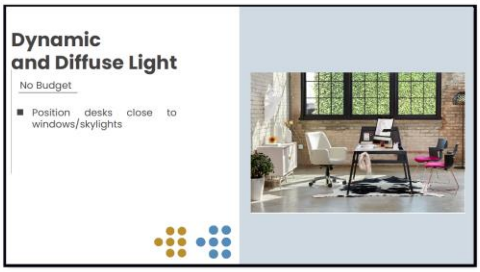

Connection
with Natural Systems
Medium Budget
Plant deciduous trees outside.

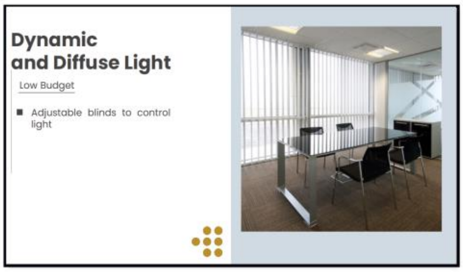

Connection
with Natural Systems
Low Budget
Inside/outside: temperature/ humidity/ air pressure measurements.


Biomorphic Forms
& Patterns
Low Budget
Light fittings e.g: petals, mushrooms, organic shapes


Biomorphic Forms
& Patterns
Medium Budget
Organic shaped furniture


Biomorphic Forms
& Patterns
High Budget
Layout of interior/ exterior spaces: curved paths and zones

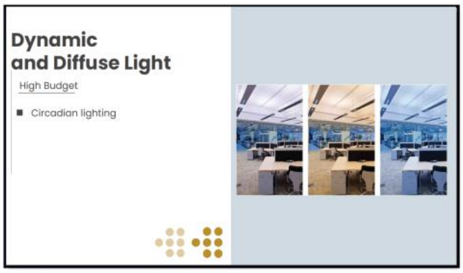

Dynamic
and Diffuse Light
No Budget
Position desks close to windows/skylights

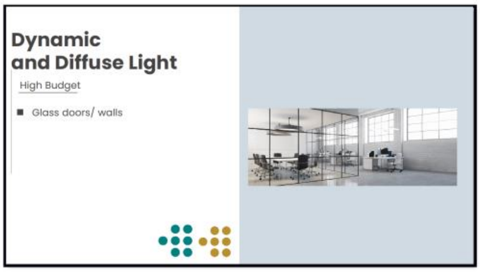

Dynamic
and Diffuse Light
Low Budget
Adjustable blinds to control light


Dynamic
and Diffuse Light
Low Budget
Color changing LED lights

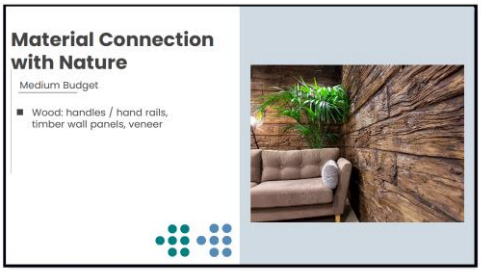

Dynamic
and Diffuse Light
Low Budget
Planting to create shadows (deciduous windows)


Dynamic
and Diffuse Light
Medium Budget
Materials: light reflecting floors, tables, walls and surfaces, mirrors, light reflective paint, tile glazes, white surfaces, sequin/mirrored surfaces


Dynamic
and Diffuse Light
High Budget
Circadian lighting

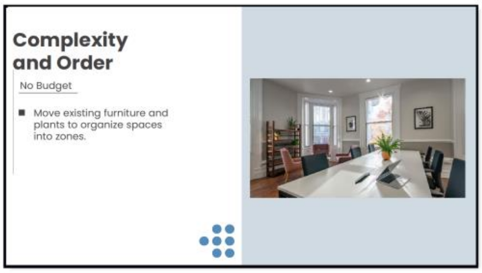

Dynamic
and Diffuse Light
High Budget
Glass doors/ walls


Material Connection with Nature
Low Budget
Materials: natural colors, textures and patterns
Use of nature inspired color – ecological valence theory


Material Connection with Nature
Medium Budget
Wood: handles / hand rails, timber wall panels, veneer

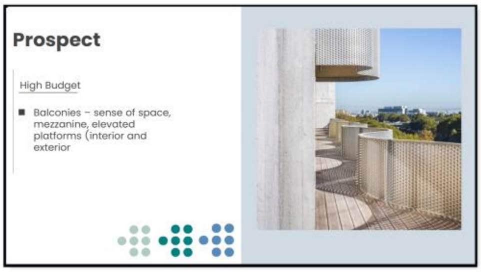

Material Connection with Nature
Medium to High Budget
Clay / ceramics furnishings and fittings.

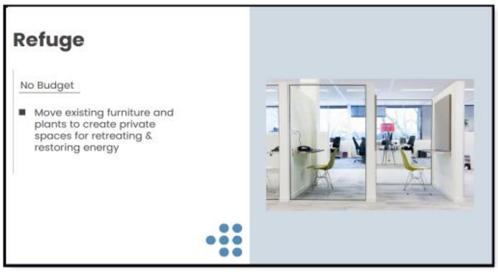

Complexity and Order
Medium to High Budget
Partitions (glass textures, etched film on glass)

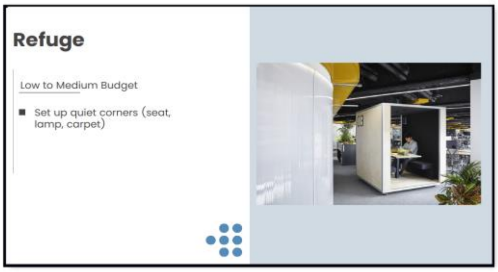

Complexity and Order
No Budget
Move existing furniture and plants to organize spaces into zones.


Prospect
Low Budget
Wayfinding through signpost


Prospect
Medium Budget
Transparent materials: glass/ polycarbonate walls/ doors/ partitions

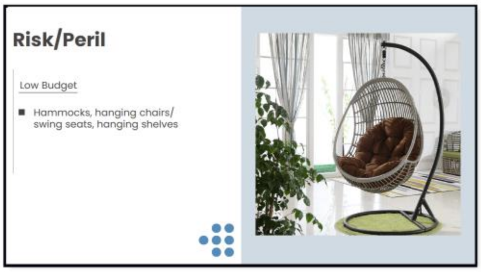

Prospect
High Budget
Balconies – sense of space, mezzanine, elevated platforms (interior and exterior


Refuge
No Budget
Move existing furniture and plants to create private spaces for retreating & restoring energy


Refuge
Low to Medium Budget
Set up quiet corners (seat, lamp, carpet)


Mystery
Medium Budget
Screen/ curtain/ frosted glass creates shadow movement and implied activity that you want to see.


Mystery
High Budget
Winding paths through spaces, gentle curving (slightly disorientating)


Risk/Peril
Low Budget
Hammocks, hanging chairs/ swing seats, hanging shelves

4. Plants Cards

Name: Chamaedorea seifrizii,
Bamboo Palm

Description: one of the best indoor plants, excellent ability to filter VOC's from the air

Design tips: Floor plant in a medium light spot

Name: Aglaonema
Golden Bay

Description: A very popular indoor plant that filter VOC's and provide great aesthetics

Design tips: Desk plant in a medium or low light spot

Name: Dypsis lutescens
Areca Palm

Description: conduct a great amount of air cleansing during the day

Design tips: needs a bright sunny location, best as a patio plant

Name: Sansevieria trifasciata laurentii
Mother in law's tongue

Description: responsible for converting carbon dioxide to oxygen specifically at night

Design tips: Desk or floor plant, tolerates low light areas

Name: Epipremnum aureum
Pothos Golden/ Money Plant

Description: responsible for filtering out and removing formaldehyde and other volatile organic compounds from air

Design tips:. Floor plant in a low light spot

Name: Agathis robusta
Queensland Kauri Pine

Description: Beautiful tree for indoors when there is a lot of natural light as it make some shades in the wanted spaces

Design tips: Floor plant in a medium to high light spots

Name: Anthurium
Lady Jane

Description: One of the few plants that will flower indoors giving fabulous aesthetic views

Design tips: Desk plant in a medium light spot

Name: Aspidistra Elatior
Cast Iron Plant

Description: It will tolerate low and dark light spaces (spaces with no windows for example)

Design tips: Desk plant, in low light areas.

Name: Chamaedorea seifritzii
Bamboo Palm

Description: one of the best indoor plants this palm loves the indoors.

Design tips:. Floor plant in a medium light spot

Name: Beaucarnea recurvata
Pony Tail

Description: used very much specially in balconies

Design tips:. Floor plant in a high light spot

Name: Cycas revoluta
Cycad

Description: extremely hardy plant but needs high light so, long-term, it is only suitable for balconies and exterior gardens.

Design tips:. Floor plant in a High light spot

Name: Dracaena fragrans
Massangeana

Description: tolerant of low light and low water, probably the best indoor plant.

Design tips:. Floor or desk plant in a low light spot

Name: Dypsis lutescens
Areca Palm or Golden Cane Palm

Description: Best as a patio plant, as it works as one of the best plants for absorbing noises

Design tips:. Floor plant and needs a bright sunny location

Name: Ficus lyrata
Fiddle Leaf Fig

Description: A great silhouette against a bright window.

Design tips:. Floor plant in a high light location

Name: Howea forsteriana
Kentia Palm

Description: used indoors all over the world. It is one of the best indoor plants.

Design tips:. Floor plant and will tolerate low light.

Name: Eco Walls

Description: This highlights the wall and helps support the greenery.

It also helps in balancing temperature and humidity in the office.

Name: Schiavello Vertical Garden

Description: A clean solution for modern offices.