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Biophilic design and office planting: a case study of effects on perceived health, well-being and performance metrics in the workplace

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Abstract

The philosophy of building 'lean' workplaces, to maximise occupant performance, has seen a stripping away of nature within built environments. However, the biophilia hypothesis indicates that a severance in human connection with nature can lead to significant reductions in health, well-being and performance. The aim of this study was to determine whether introducing and removing living plants within an office environment can affect occupants' perceived health, well-being and performance metrics. 40 occupants took part within a modern office building with 2 potted plants per person introduced into individual offices, and 8 in break-out spaces. Changes in occupants' perception were tested using questionnaires. Whether the location of planting impacted measured parameters and occupants' workplace satisfaction was also investigated. Introducing plants into offices had significantly positive effects on occupants' perceived attention, creativity and productivity; plants' removal elicited significantly negative effects in perceived attention, productivity, stress and efficiency. Planting had no significant effect on perceived health, tiredness, motivation or well-being. Furthermore, interactions with plants during break times had no significant effect on perceived performance metrics. This study showed occupants to have improved satisfaction with their overall workplace environment when they have physical and visual access to plants within their offices and break-out spaces.

Keywords: *Office buildings; environment and behaviour; indoor environmental quality; plants; office evaluation*

1.0 Introduction

1.1 The case for deciphering workplace performance metrics

As a result of a rapidly growing urban population and declining natural areas within the built environment, accompanied by lean philosophies of workplace design, there has been a severance in the connection between humans and nature (Nieuwenhuis, et al., 2014). This connection is thought to be vital in fostering healthy, highly performing people. As people often spend up to 90% of their time indoors, evidence shows investment into sustainable, healthy and attractive workplaces can encourage enhancements in human health, well-being and performance (Haghlesan, 2013; WGBC, 2014). This investment not only increases financial gain but reduces costs significantly, by recovering profits lost through absenteeism and staff turnover (Clements-Croome, 2018). A mere 15% increase in the productivity of employees has the potential to cover a property's entire cost (Oseland, 1999). Thus, the existing built environment agenda must clearly shift for companies to attain or maintain sustainable financial growth.

Buildings are dynamic assets which can add value to society if built sustainably and with people's needs in mind, with as much as 90% of a building's business lifecycle costs being attributed to its occupants (WGBC, 2014). Thus, implementing changes which lower these staff costs by improving occupants' perceptions of their health, well-being or performance by even a fraction has the potential to translate into notable savings for a business.Research shows that simply building 'green', by reducing energy consumption whilst using responsibly sourced and environmentally friendly resources, does not guarantee an enhancement in performance metrics (Deuble and de Dear, 2012). As such, further research into the factors which affect workplace performance metrics (and strategies which influence these factors) is warranted.

1.2 Factors influencing workplace performance metrics

Workplace performance metrics are multidimensional, consisting of both objective and subjective elements. These can be influenced both directly and indirectly by the quality of a person's surroundings (Alatartseva and Barysheva, 2015). As humans often spend most of their time indoors, design parameters should consider the factors comprising Indoor Environmental Quality (IEQ). This is known as the "perceived indoor environment experience that includes aspects of design, analysis, and operation of energy efficient, healthy, and comfortable buildings" (ASHRAE, 2018). Numerous studies have focused on the effects of IEQ on occupant performance and found significant correlations between poor IEQ and declines in workplace performance (Kim and de Dear, 2012; Al Horr, et al., 2016a). IEQ impacts are often realised during the occupational phase rather than the design and construction phases. Thus, the means of cost effectively rectifying adverse factors diminish significantly. Such oversights can render prospective benefits to occupants of green buildings mute (Deuble and de Dear, 2012). Instead, implementing strategies to enhance IEQ from the outset can see built environments being optimised for productive and healthy occupants (Fisk, 2000).

Changes in IEQ and the effects on occupants are often readily quantifiable following significant advances in research. Different strategies including optimisation of Heating, Ventilation, and Air Conditioning (HVAC) systems and natural daylighting exist which have been shown to influence IEQ to various degrees. Each of these differ in cost, lifespan and efficacy (Al Horr, et al., 2016b). Incorporating nature into the built environment, known as biophilic design, can work as a low-cost, multi-platform strategy to enhance several IEQ factors (Wilson, 1985; Lerner and Stopka, 2016; Clements-Croome et al., 2019; Kellert, 2018). This, in turn, can have a positive influence on occupants' performance metrics, by fostering positive connections between nature and people (Kellert, et al., 2008). An example of biophilic design interventions is introducing living plants into an indoor environment. Whilst plants are one of many strategies which can enhance IEQ, research shows that plants can create several advantages.

These include improving relative humidity levels, moderating air temperature, subduing sound, providing restorative effects such as attention restoration, improved cognitive function and stress relief through visual comfort (Lohr and Pearson-Mims, 2000; Lerner and Stopka, 2016). What is less well known, however, are the effects of plant placement (in break-out or working spaces) on IEQ. This is an area that needs to be addressed further, given that an improvement in one or multiple IEQ factors has been shown to positively influence objective and subjective measures of health, well-being and performance metrics (van Kamp, et al., 2003). Finally, following construction of a building there are often constraints in methods to improve IEQ. However, biophilic design strategies, such as placement of indoor living plants, can overcome many of these restrictions given that they are relatively cheap, easily sourced and can be flexibly used and retrofitted (Human Spaces, 2015).

1.3 Using plants as a strategy to influence performance metrics

Evidence for the effect of biophilic design, specifically plants, on human health, well-being and performance stems from research into cognitive, psychological and physiological responses. These responses have been explored within lab- and field-based studies, including schools, hospitals and offices (Kaplan, 1993; Shibata and Suzuki, 2004; van den Berg, 2005, , Nieuwenhuis, et al., 2014). Ulrich (1991) and Kaplan (1995) developed the two main theories which seek to explain the effect of nature, including plants, on humans' mental states. Attention Restoration Theory (ART) by Kaplan (1995) suggests that mental fatigue and reduced concentration, due to prolonged direct attention, can be improved following time spent visually or physically connecting with nature. This improvement is generated through restoration processes using less energy-intensive involuntary attention. Stress Recovery Theory (SRT), proposed by Ulrich (1991), explains how views of nature, including views of plants, induces a shift to more restful brain activity, reducing stress levels and encouraging more positive states of emotion. These theories form part of the main justification for use of plants in buildings to improve occupants' health, well-being and performance.

Several studies have shown that introducing indoor plants into workplaces can improve productivity (Lohr, et al., 1996; Khan, et al., 2005). Nieuwenhuis, et al. (2014), for example, found improvements in perceived concentration and productivity as well as actual productivity (less time taken to complete a task and less 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 (Lohr, et al., 1996; Chang and Chen, 2005; Largo-Wight, et al., 2011). Experiments have also explored the possible effects of plants in small offices (8-16m^2) on task performance or perceived attention and found mixed results. Shibata and Suzuki (2004) using one plant per person as well as Raanaas, et al. (2011) using four plants per person found positive effects whilst Larsen, et al. (1998) using 10-22 plants found a negative effect when this many plants were present.

Findings within research studies also showed people reporting a decrease in reports of poor health, including tiredness, when plants were introduced into offices (Fjeld, et al., 1998; Bringslimark, et al., 2007; Gray and Birrell, 2014). Overall, studies found significant effects for some performance metrics and no effect for others, indicating that these metrics are interrelated but do not always overlap or correlate (Bringslimark, et al., 2009). No studies reviewed within this literature review found significant negative effects on health or well-being when plants were present. Thus, it appears the biophilia hypothesis does warrant some merit, regarding the positive impact of plants on human health and performance. Nonetheless, there is still ambiguity, given that numerous studies have failed to find a consistent effect (Velarde, et al., 2007; Evensen, et al., 2015; Korpela, et al., 2017).

Additionally, documented effects have been shown to vary depending on subjects' exposure time to plants or nature. Studies also differ in the number of plants, species, foliage, size, introduction or removal of plants they studied (Bringslimark, et al., 2009). However, a review of the literature shows a research gap in how placement and setting affects how plants influence perceived occupant health, well-being and performance metrics. Measuring the effect that independent variables (e.g. plants) may have on performance metrics is a

challenge, as metrics may be subjective, objective or both (Terrapin Bright Green, 2012). This has seen the potential benefits produced by biophilic design interventions, such as improvements in IEQ and subsequent performance, often being greatly overlooked.

Nonetheless, studies have been undertaken to determine the effect of living plants on occupants by assigning value to objective and subjective changes in perceived health, well-being and performance metrics. These include attention, stress, tiredness, productivity, motivation, efficiency and creativity, within lab- and field-based studies (Oseland, 1999; Kim and de Dear, 2012; Clements-Croome et al., 2019). The latest model in this line of research, the 'Flourish' model as published by Clements-Croome (2018), captures requirement levels suggested by Kim and de Dear (2012). The model groups these requirement levels into environmental, perceptual and economic categories. According to the Flourish model, high quality physical environments will promote positive health and well-being which is conducive to higher performance (Clements-Croome, 2018).

1.4 Research Aims

Our study addresses several physical and perceptual aspects of the Flourish framework. It establishes impacts which a qualitative environmental factor (placement of indoor living plants) could have on objective and/or subjective environmental, economic or perceptual factors including health, well-being and performance metrics. Given its holistic nature and wide support within the industry, the Flourish model formed the basis of this study's theoretical framework.

The aims of this study were therefore to:

1. Investigate the impact of plant introduction in offices vs break-out spaces on perceived health, well-being and performance metrics such as attention, creativity, productivity, efficiency, motivation, stress and tiredness

2. Investigate the impact of plants' removal on perceived health, well-being and performance metrics

3. Understand occupants' preferences for visual and physical access to plants and satisfaction with overall office design

2.0 Methodology

2.1 Study site

The focus building for this study is located within Reading, UK, which is a regional centre with over 229,000 inhabitants. The study was carried out in a 3,844 m^2 four storey office building which underwent refurbishment in 2014 and achieved a Building Research Establishment Environmental Assessment Method (BREEAM) rating of 'Outstanding' in 2016. The building is south facing with a curtain walling system with solar control glazing and modesty fitted glass panels. To the front elevation there are brise soleil anodised fins. The building does not have openable windows on any facades. Individual offices vary in size and style with a mixture of small (<10m^2), medium (<20m^2), large offices (<40m^2) on floors 1 through 3 as well as an open-plan co-working area on the ground floor (see Appendix). The building has an office floor to suspended ceiling height of 2.7m. There are small break-out areas on all floors.

The building has been designed according to the following relevant parameters: heating and cooling to offices in summer maintains the indoor temperatures at 22˚C ± 1.0˚C without humidity control, and illumination levels at 450 lux. All offices included in this study had direct or indirect access to natural daylight. The building has an accessible terrace on the third floor with patches of landscaped greenery (which no offices look out onto) as well as potted green plants in reception. However, the first, second and third floors did not have green living plants within individual offices or break-out spaces. No participating individuals had a window with a view of outdoor green plants or green spaces, given the urban location of this office building.

2.2 Participant selection

Once approval for the study was granted by the Building Facilities Manager, a participant information sheet was designed to determine the willingness of occupants to participate. All participants who registered an interest within the 4-week inquiry period before the start of the

experiment were included in the study, totalling a sample size of 40 participants across 19 offices. Participants consisted of 27 males and 13 females aged 21 - 60 years, (μ = 31-40 years), who spent between 1-10 hours within their offices (μ = 7-10 hours) and had all occupied the building for between 1-6 months. As the building was let to an office rental agency, participants worked for various companies with different workplace cultures. Repeated measures methods were used for the collection of data to determine significant differences between conditions whilst controlling for demographic factors.

2.3 Plant selection

Green indoor plants of various sizes and species were sourced as spares from other green infrastructure projects at the University of Reading, based on what was available at the time, totalling a mixture of 72 plants. Plant taxonomy included *Spathiphyllum wallisii* cv. 'Verdi' (peace lily), *Dracaena fragrans* cv. 'Lemon Lime' and 'Golden Coast' (Madagascar dragon tree), *Ficus benjamina (*weeping fig trees), *Zamioculcas zamiifolia*, *Guzmania* and *Sedum sp.* mix (stonecrop), see Table 1. The effects of different plant taxa on measures in this study were not investigated, instead the plant placement and number of plants needed to elicit an effect was tested.

Table 1. Plant taxa used in this study, main characteristics and number of each used.

NAME OF PLANT SPECIES	DESCRIPTION/ CHARACTERISTICS	HEIGHT (CM)	NUMBER USED
Spathiphyllum wallisii cv. 'VERDI'	Light Green Foliage, Large White Flowers	55	4
Dracaena fragrans cv. 'LEMON LIME'	Light and Dark Green Foliage	70	9
Dracaena fragrans cv. 'GOLDEN COAST'	Light and Dark Green Foliage	70	8
Ficus benjamina	Dark Green Foliage	60	8
Guzmania	Dark Green Foliage	30	2

Zamioculcas zamiifolia	Dark Green Foliage	60	1
Sedum sp. mix	Light Green Foliage	5	40

Plants were maintained in Sylvamix growing medium (6:2:2 sylvafibre: growbark pine: coir; Melcourt, Tetbury, Gloucestershire, UK) in 3 L containers (other than Sedum which was in a 0.5 L container), with a slow release fertiliser feed (Osmocote, Marysville, OH, USA) Plants were watered by hand to maintain the substrate moisture in the 'well-watered' range (20-30% vol/vol), as determined by previous studies (Vaz Monteiro, et al., 2016) and prior experiments on the same species (Gubb, et al, 2018).

2.4 Questionnaire

2.4.1 Questionnaire design

Two paper-based questionnaires were designed, the first to be slightly longer to capture demographic factors during control conditions and the second excluding such demographic factors. The second questionnaire was used during the treatment conditions (see Appendix). The questionnaires were based on industry-known occupant satisfaction surveys including the Building Use Studies (BUS) Occupant and Office Productivity Network (OPN) Survey, as well as those used in similar studies (Deuble and de Dear, 2012; Gray and Birrell, 2014). Many of the participants who answered the questionnaires worked in creative industries e.g. typography, marketing and design. Thus, although creativity may not be conventionally measured as a key performance factor using a questionnaire, it is thought that participants would have had a good idea of how creative they were feeling at the time of answering. The questionnaires incorporated a three-point Likert scale for most questions. The first questionnaire was designed to take no more than than 10 minutes to answer and the second no more than 5 minutes, with timing and understanding tested during piloting with university staff members. Questionnaires addressed demographic factors, office hours and break lengths, physical or visual access to living plants, perceived health, well-being, performance

metrics and overall satisfaction with office design. Given the ordinal nature of the data, a priori power analysis was conducted in G*Power v. 3.1.9.2 (Heinrich-Heine-University Düsseldorf, Düsseldorf, Germany) to calculate a required sample size of 40 participants, which our study had.

2.4.2 Questionnaire distribution

Once occupants had returned their participant information sheets it was possible to see which offices respective participants were in and how participants were distributed across floors. Participants were then split equally into two groups: Group A and Group B. The intention was not for direct comparison of the occupants within the two groups. Rather, occupants were split into groups for rotation purposes to provide living plants within offices sequentially, and break-out spaces continuously. Plants were brought into an empty room in the office building, which was out of sight of occupants, for one week prior to the first questionnaire being distributed. This allowed the plants to acclimatise and enabled us to determine appropriate watering regimes.

The first questionnaire assessing perceived health, well-being and performance metrics acted as a baseline measurement before any living plants were introduced into the office building. Following baselines measurements, two living plants per person were introduced into the offices of Group A for two weeks, the maximum time agreed with the building facilities manager. This included one small *Sedum* for their desk and one of the other larger species to be placed elsewhere as seen in Figures 1 and 2. The number of plants used were based on studies which suggest that 1-3 plants per person can elicit significant changes in perceived and actual performance metrics (Burchett, et al., 2010; Raanaas, et al., 2011; Nieuwenhuis, et al., 2014).

During the two weeks in which Group A had living plants within their offices, Group B had none, and vice versa for the two weeks following. The first questionnaire was distributed to all 40 participants on the morning before the plants were introduced. After this questionnaire had

been collected from all participants, plants were introduced into break-out spaces for the next four weeks and into participants from Group A's offices for two weeks. After the two-week period the second questionnaire was distributed to both groups, totalling 40 participants. This questionnaire aimed to determine whether there was any change in occupants' perception regarding health, well-being and performance metrics, due to plants within offices and break-out spaces for Group A and plants within break-out areas for Group B. After completion of the second questionnaire by both groups, plants were removed from Group A's offices and distributed to Group B's offices for the final two weeks. Following the final two-week period, the second questionnaire was again distributed to all participants to determine the effects of the plant rotation.

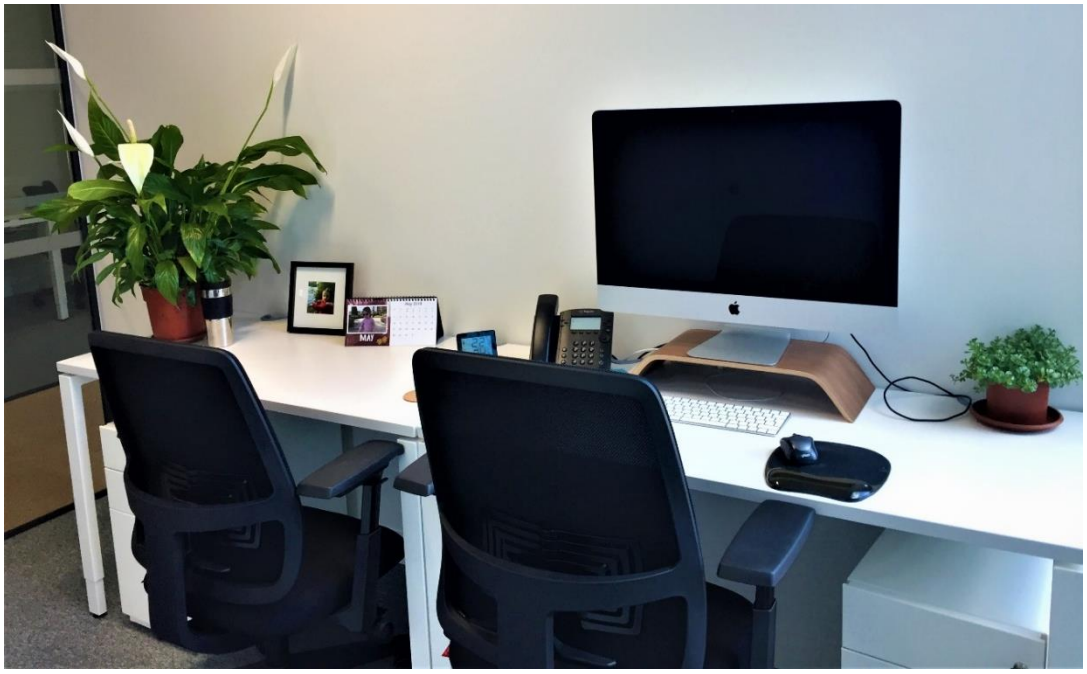

Figure 1. Example of 2 plants per person placement within a single occupancy office – one small Sedum on a working desk and a larger plant elsewhere.

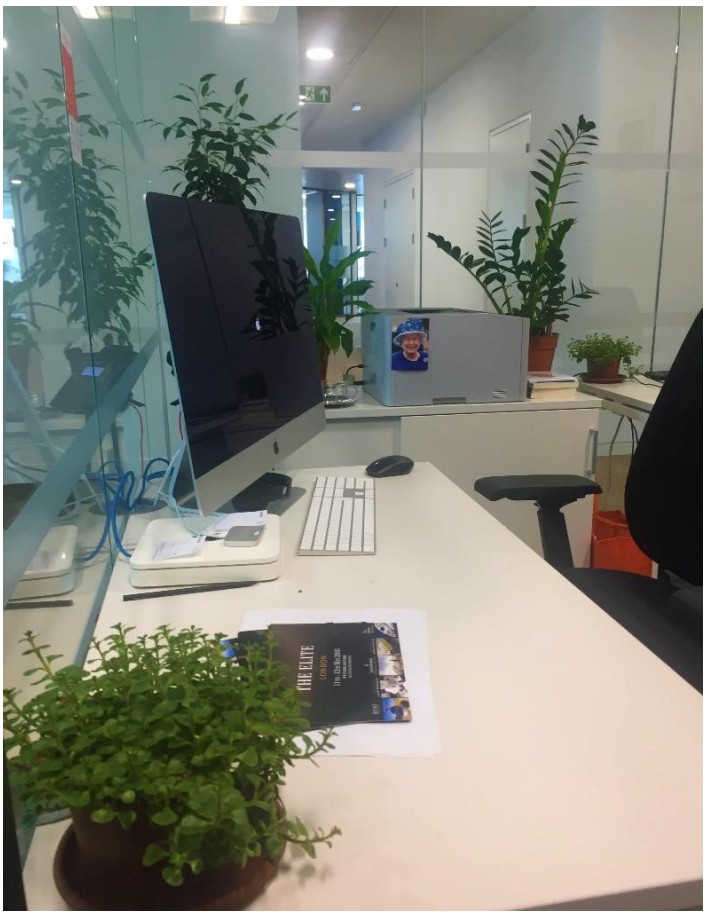

Figure 2. Example of 2 plants per person placement within a multi-occupancy office – one small Sedum on a working desk and a larger plant elsewhere.

The remaining 32 plants were then divided between each of the three break-out spaces, where they would stay for the length of the experiment (see Figure 3). This is because micro-restorative experiences, such as short breaks involving interactions with plants, can improve overall performance (Lee, et al., 2015).

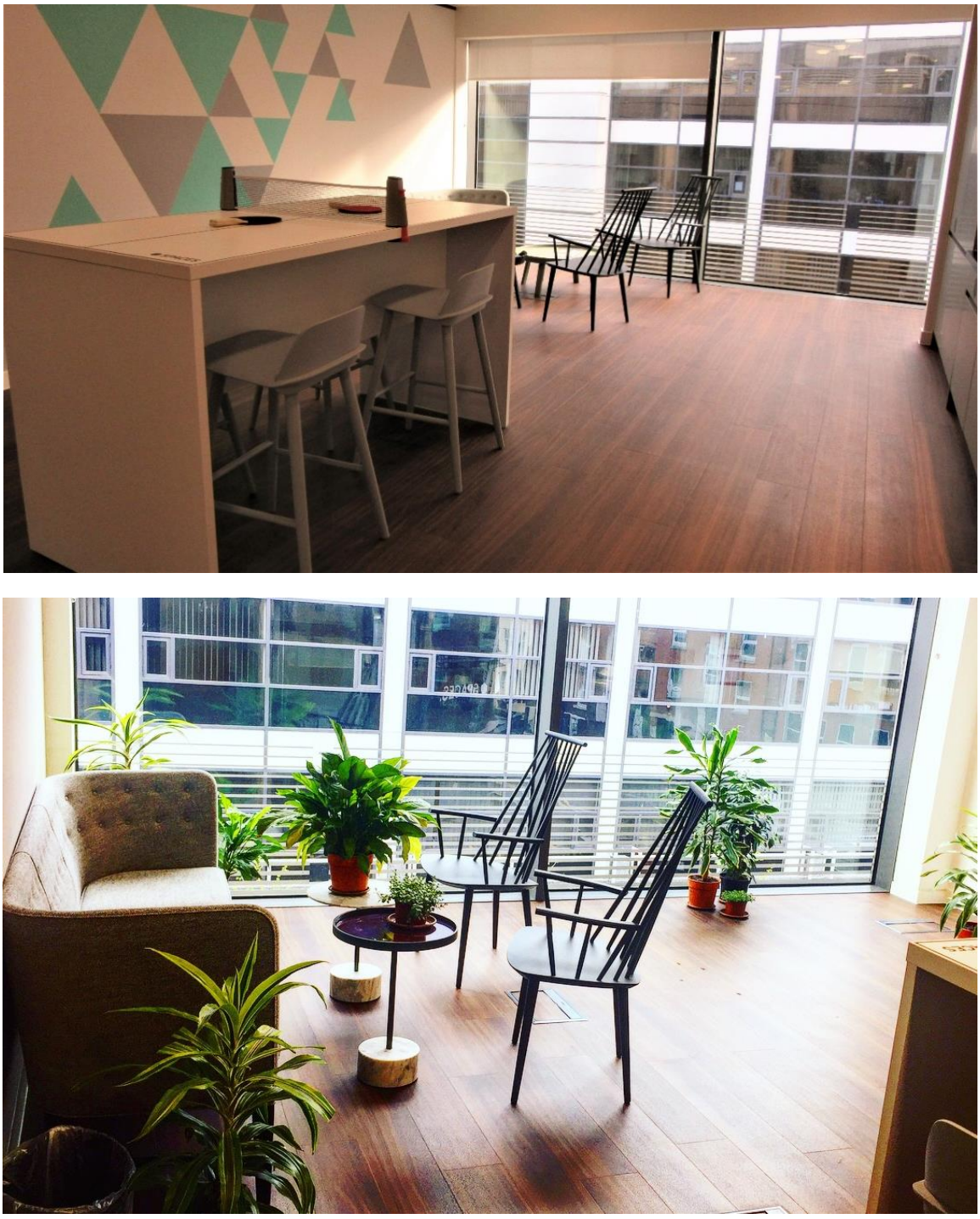

Figure 3. Top: control conditions before plants were introduced. Bottom: plant placement within a break-out space during treatment conditions.

2.5 Data Analysis

2.5.1 Statistical approaches

For the sample size in our experiment, the most robust approach was to calculate exact significance, using true distribution. This is because for a hypothesis test, it guarantees protection from Type I error at the nominal significance level (Hinton, 2014). As the sample size is >30, multiple comparison test statistics follow the Z distribution. Z statistics calculated represent the number of standard deviations that data points are above or below the population mean (Hinton, 2014). In this study a 90% confidence level was used based on statistician's advice and thus the critical Z scores were -1.645 and +1.645 standard deviations. If calculated Z scores were between -1.645 and +1.645, the exact calculated p value would be >0.1 and the null hypothesis was accepted. However, Bonferroni correction was then calculated, as when making multiple comparisons, it becomes more likely that a Type I error will be made (Hinton, 2014).

The original significance level (α) chosen must thus be divided by the number of tests run to calculate the altered α: $\alpha^{altered} = \frac{\alpha^{original}}{k}$ where k = no. of independent significance tests. In this study α original = 0.1 and k = 3. If p < altered α, the null hypothesis was rejected. If p>α altered, the null hypothesis was accepted. An original alpha level of 0.10 was used for all statistical tests, as upon statistical advice this is suggestive of a significant effect that warrants further study.

2.5.2 Research Question Analyses

2.5.2.1 Impact of living plants on perceived health, well-being and performance metrics

As the sample group was randomly sampled from the population and measured on three different occasions, assumptions for the Friedman test with exact significance as a non-parametric alternative to one-way ANOVA with repeated measures were met (Hinton, 2014). This test was conducted using Statistica 13.0 (Statsoft Inc, 2019) to detect differences in

perceived health, well-being and performance metrics between the various conditions. The three conditions included: control conditions without indoor living plants, living plants in individual offices and break-out spaces and living plants only in break-out spaces.

If results from the Friedman test were significant, a post-hoc Wilcoxon Signed Rank test (as a nonparametric equivalent to the paired or dependent sample t-test) was conducted using Statistica 13.0. This compared which matched pairs were statistically significantly different. Assumptions for this test, including random sampling from a population, having two points of sampling on the same subject which are independent from other samples and subjects, and data being measured at an ordinal scale, were met (Hinton, 2014).

2.5.2.2 Impact of break interactions with plants on perceived performance metrics

To test whether differences in statistically significant performance metrics between the three conditions were due to interactions with plants during break times, a Chi-square test was conducted using Statistica 13.0. Assumptions for this test, including having two or more categorical, independent groups and two variables measured at an ordinal or nominal level were met (Hinton, 2014). However due to having >20% of cells with an expected count of less than five, Fisher's exact test statistic was reported.

2.5.2.3 Changes in occupant preferences for access to living plants and office design

Given the ordinal nature of the data and that assumptions for the Friedman test with exact significance were met, this test was conducted. This was followed by a post-hoc Wilcoxon Signed Rank test, if results from the Friedman test were significant.

2.5.2.4 Graphical summary statistics

A graphical summary of statistically significant results was produced in Excel 2016, to show the percentage of questionnaire participants who had positive, neutral or negative perceptions, in a given condition. Bonferroni adjusted α and levels of significance: * $p < 0.033$; ** $p < 0.01$; ***$p < 0.001$ calculated in Statistica (Statsoft Inc, 2019) were included.

3.0 Results

3.1 Impact of living plants on perceived health, well-being and performance metrics

Within this study it was hypothesised that introducing indoor living plants into individual offices and/or break-out spaces can improve perceived health, well-being or performance metrics of occupants. Results from the relevant statistics applied are presented in Table 2 and Table 3.

*Table 2. Summary of results of non-parametric Friedman's tests of differences among perceived metrics for repeated measures under 3 conditions, N = 40, df = 2, α = 0.10. Levels of significance: † p <0.10; * p <0.05; ** p <0.01; ***p <0 .001.*

PERCEIVED METRICS	***CHI SQUARE*** ***Z***	***EXACT SIGNIFICANCE*** ***P***
TIREDNESS	*2.175*	*0.337*
HEALTH	*6.907*	*0.031**
STRESS	*8.296*	*0.015**
WELL-BEING	*2.062*	*0.358*
ATTENTION	*13.213*	*0.001****
EFFICIENCY	*5.711*	*0.060†*
CREATIVITY	*6.889*	*0.034**
MOTIVATION	*3.500*	*0.184*
PRODUCTIVITY	*10.483*	*0.005***

The results of the Friedman test displayed in Table 2 show that introducing plants into individual offices and/or break-out spaces elicited a statistically significant change in perceived health and several performance metrics. Statistically significant perceived metrics were then tested using the Wilcoxon Signed Ranks test, summarized in Table 3, to compare which matched pairs were statistically significantly different.

*Table 3. Summary of exact significance (2 tailed) of non-parametric Wilcoxon Signed Ranks tests of differences among perceived metrics for repeated measures under 3 conditions, N = 40, df = 2. Bonferroni adjusted α: 0.033. Letters denote direction of change between first and second condition presented where a = positive direction and b = negative direction. Levels of significance: * p <0.033; ** p <0.01; ***p <0.001.*

	CONDITIONS					
	Control vs Offices and Break-out spaces		***Offices and Break-out spaces vs Break-out spaces***		***Control vs Break-out spaces***	
PERCEIVED METRICS	*Z*	*p*	*Z*	*p*	*Z*	*p*
HEALTH	*-0.619*	*0.661*	*-1.886*	*0.096*	*-2.153*	*0.042*
STRESS	*-2.132*	*0.052*	*-2.696 [b]*	*0.008***	*-1.213*	*0.332*
ATTENTION	*-2.524 [a]*	*0.018**	*-3.157 [b]*	*0.002***	*-1.414*	*0.238*
EFFICIENCY	*-1.000*	*0.454*	*-2.358 [b]*	*0.023**	*-1.706*	*0.134*
CREATIVITY	*-2.524 [a]*	*0.019**	*-1.886*	*0.096*	*-0.626*	*0.680*
PRODUCTIVITY	*-2.399 [a]*	*0.023**	*-2.828 [b]*	*0.007***	*-0.250*	*0.973*

After Bonferroni correction was applied, the Wilcoxon signed-rank test showed that introducing plants into individual offices and break-out spaces elicited a statistically significant increase in perceived occupant attention (p = 0.018), creativity (p = 0.019) and productivity (p = 0.023), compared to control conditions. However, the test indicated that removing plants from individual offices and only placing plants in break-out spaces saw a statistically significantly increase in perceived stress levels (p = 0.008). Furthermore, it also saw a decrease in perceived attention (p = 0.002), efficiency (p = 0.023) and productivity (p = 0.007). Finally, the test showed that only having plants in break-out spaces had no statistically significant impact on any perceived metrics compared to control conditions.

A graphical summary of statistically significant perceived metrics for repeated measures under the three experimental conditions (control, plants in offices and break-out spaces and only in break-out spaces) is shown in Figure 4 below.

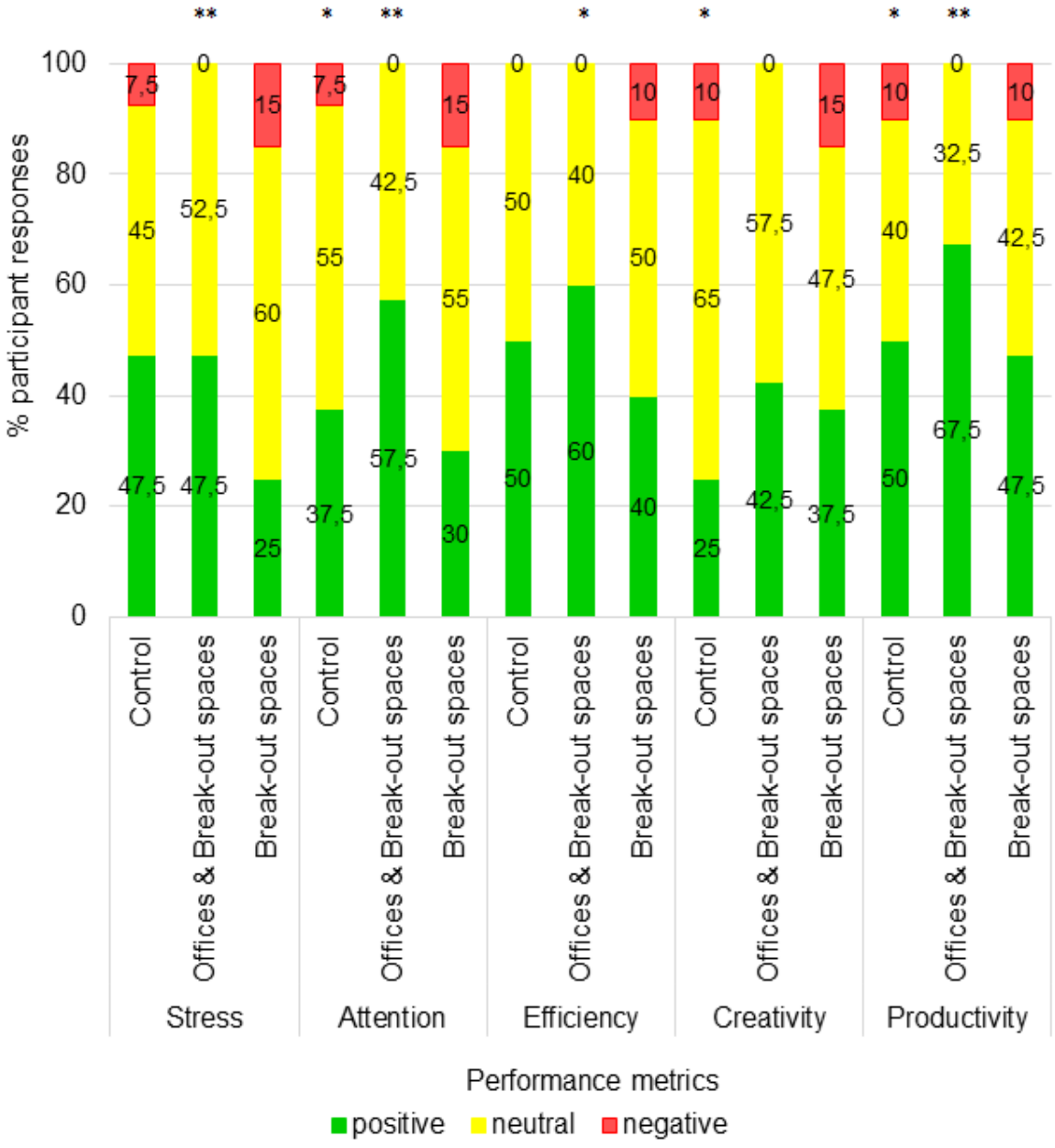

*Figure 4. Summary of statistically significant perceived metrics for repeated measures under 3 conditions: control, plants in offices and break-out spaces and only in break-out spaces. The graph shows the % of participants (N = 40) who had a positive (green), neutral (yellow) or negative (red) perception of a performance metric in a given condition. Bonferroni adjusted α: 0.033. Levels of significance: * p <0.033; ** p <0.01; ***p <0.001.*

3.2 Impact of break interactions with plants on perceived performance metrics

Participants noted themselves to have more physical and visual interactions with plants when introduced into offices and/or break-out spaces than control conditions (p=<0.001). Within this study it was hypothesised that occupants who have interactions with indoor or outdoor living plants during office breaks will see improved perceived health, well-being and performance metrics. Relevant statistics are presented in Table 4.

*Table 4. Summary of exact significance (2 sided) of a Fisher's Exact test for repeated measures under 3 conditions, N = 40, df = 1. Bonferroni adjusted α: 0.033. Levels of significance: * p <0.033; ** p <0.01; ***p <0.001.*

	CONDITIONS		
	Control	***Offices and Break-out spaces***	***Break-out spaces***
PERCEIVED METRICS	*p*	*p*	*p*
STRESS	*0.081*	*0.331*	*1.000*
ATTENTION	*0.224*	*1.000*	*1.000*
EFFICIENCY	*0.091*	*1.000*	*0.711*
CREATIVITY	*0.656*	*0.294*	*1.000*
PRODUCTIVITY	*0.407*	*1.000*	*0.281*

A Fisher's Exact test (displayed in Table 4) indicated that interactions with plants during break times under the three experimental conditions did not elicit a statistically significant change in any perceived metrics.

3.3 Changes in occupant preferences for access to living plants and office design

The results of the Friedman test indicated that introducing plants into individual offices and/or break-out spaces elicited a statistically significant change in occupants' satisfaction with overall office design, with X2(2) = 14.381, *p* = 0.001 (data not shown). A Wilcoxon Signed Ranks test was run as a post hoc test to isolate significance, summarised in Table 5 below.

*Table 5. Summary of exact significance (2 tailed) of non-parametric Wilcoxon Signed Ranks tests of differences among satisfaction with overall office design for repeated measures under 3 conditions, N = 40, df = 2. Bonferroni adjusted α: 0.033. Letters denote direction of change between first and second condition presented where a = positive direction and b = negative direction. Levels of significance: * p <0.033; ** p <0.01; *** p <0.001.*

SATISFACTION WITH OVERALL OFFICE DESIGN

	Conditions		
	Control vs Offices and Break-out spaces	***Offices and Break-out spaces vs Break-out spaces***	***Control vs Break-out spaces***
Z	-2.898 [a]	-2.577 [b]	-0.894
EXACT SIG. P VALUE	0.004**	0.010**	0.371

The results of the Wilcoxon signed-ranks test showed that when plants were introduced into individual offices, participants felt significantly increased satisfaction with overall office design, compared to control conditions (p = 0.004). Furthermore, the test also indicated that when plants were removed from individual offices and only placed plants in break-out spaces, this had a significant negative impact on participants' satisfaction with overall office design (*p* = 0.010). Nonetheless, the test showed that satisfaction with overall office design under control conditions did not change significantly when plants were introduced only in the break-out spaces (*p* = 0.371).

A graphical summary of differences among participants' satisfaction with overall office design for repeated measures under the three experimental conditions is shown in Figure 5 below.

*Figure 5. Summary of differences among satisfaction with overall office design for repeated measures under 3 conditions: control, plants in offices and break-out spaces and only in break-out spaces. The graph shows the % of participants (N = 40) who had a positive (green), neutral (yellow) or negative (red) perception of their satisfaction with overall office design in a given condition. Bonferroni adjusted α: 0.033. Levels of significance: * p <0.033; ** p <0.01; ***p <0.001.*

4.0 Discussion

4.1 Impact of living plants on perceived health, well-being and performance metrics

The introduction of plants into indoor built environments enables humans to connect with nature, providing numerous social and economic benefits, including improved performance, satisfaction as well as physical and mental health (Kellert, et al., 2008; Tyrväinen, et al., 2014; Human Spaces, 2015). This is achieved through direct and indirect interactions with potted plants, as a pattern of biophilic design known as 'nature in space' (Browning, et al., 2014; Brown, 2019). A review of the literature indicates that improvements in attention, creativity, productivity, efficiency, health, well-being and motivation, as well as reductions in stress and tiredness can be expected when humans interact with nature (Söderlund and Newman, 2015). There was variation in the effects which studies found, ranging from beneficial to negligible, associated with introducing living plants into buildings including offices and schools (Bringslimark, et al., 2009; Al Horr, et al., 2016b). In fact, critical review shows indoor environments which are devoid of nature, specifically indoor plants, have a strong detrimental outcome on human performance metrics, as well as health and well-being (Grinde and Patil, 2009; Human Spaces, 2015).

4.1.1 Impact of living plants on perceived attention, creativity and productivity

The results of our study revealed that introducing plants into offices and break-out spaces elicited a significant increase in perceived attention, creativity and productivity. This result is consistent with similar studies in the field and support the above findings. In such studies, including those of Lohr, et al. (1996), Raanaas, et al. (2011) and Nieuwenhuis, et al. (2014), the ability of plants to restore attention and improve performance of participants within an office setting was shown to be significant; workers reported a 15% increase in creativity and productivity when plants were introduced into work environments.

The findings of our study thus support the two leading theories, Attention Restoration Theory (ART) and Stress Recovery Theory (SRT), which explain the multifaceted process of restoration leading to increased performance, health and well-being (Ulrich, et al., 1991;

Kaplan, 1995). ART explains how active attention, demanded by focused office work, provokes mental fatigue which can be overcome through processes of restoration and recovery, provided by views of nature (Kaplan, 1995). Nature presented as indoor plants within offices is thought to restore direct attention, by engaging a different part of the brain than that which is used for detailed focused thinking. Indoor plants are thereby by their presence relaxing subjects and improving their cognitive functioning (Kaplan, 2001; Grinde and Patil, 2009; Brown, 2019).

The majority of research related to biophilic design (Kellert, et al., 2008; Browning, et al., 2014; Human Spaces, 2015; Söderlund and Newman, 2015) has had a strong focus on investigating the effects induced in performance metrics following the introduction, rather than the removal, of plants as covered in Grinde and Patil (2009). Our results showed that the removal of plants from individual offices but not from break-out spaces elicited a decrease in perceived attention spans and productivity. This aligns with ART, which postulates that the absence of plants within an indoor environment would have a negative effect on performance metrics involving cognitive functioning. Interestingly, however, perceived creativity did not decrease significantly when plants were *removed* from participants' offices and was not significantly different to when no plants were present in the study site.

4.1.2 Impact of living plants on perceived stress and efficiency

SRT places more emphasis on emotional and physiological processes than ART, suggesting that views or interactions with nature following a period of stressful conditions rapidly stimulates increases in humans' parasympathetic brain activity (Ulrich, et al., 1991). This type of brain activity induces physiological recovery and relaxation. It is also thought that the presence of nature improves the efficiency of human minds (Terrapin Bright Green, 2012). The results of our study, which showed that introducing living plants into offices and/or break-out spaces did not affect perceived stress or working efficiency compared to control conditions, are not consistent with findings from previous studies. Such studies, including Ulrich, et al. (1991), Bringslimark, et al. (2007) and Largo-Wight, et al. (2011) demonstrated stress

reduction effects when humans were in the presence of nature indoors, which in turn were thought to improve performance metrics, including efficiency. This was well summarised by Bringslimark, et al (2009).

However, when plants were removed from individual offices and placed only in break-out spaces in our study, this saw an increase in perceived stress and a decrease in perceived efficiency. This significant effect may be explained by considering how a transformation from an environment rich in vegetation to one characterised by an absence of nature (unnatural) can induce stress (Grinde and Patil, 2009). This is because opportunities for restoration in which psychological and physiological recovery is activated may have diminished when participants' ability to directly access views of plants within their immediate surroundings was disabled (Joye and van den Berg, 2013). Bringslimark, et al. (2009) support this view by explaining that should a study seek to assess restorative benefits provided by interventions such as living plants, the subjects of such studies must have a need or potential for restoration. Thus, using a stress-inducing mechanism such as the removal of living plants creates an opportunity to test the potential of such a tool, said to provide a restorative environment. Overall, our results are encouraging and merit further investigation into SRT whilst sustaining the case for biophilic design (incorporating living plants within the workplace).

4.1.3 Impact of living plants on health, well-being, motivation and tiredness

Biophilic design is thought to be vital in creating environments which foster enhanced health, well-being and performance of building occupants, by reconnecting humans with nature in the built environment (Browning, et al., 2014; Kellert, 2018; Brown, 2019). As a benchmark, when 80% of an office building's occupants are satisfied with their surrounding environment it can be deemed as providing high IEQ which promotes good health (ASHRAE, 2004). A review of the literature indicates that workplaces which incorporate elements of biophilic design, particularly living plants, promote higher perceived IEQ. This in turn sees occupants reporting higher perceived levels of well-being (up to 15%) than workplaces lacking such design (Human Spaces, 2015). Moreover, these occupants also report feeling happier, rejuvenated and more

motivated when entering a workplace which has elements of nature, specifically healthy green vegetation. The reasoning behind such findings is that directed attention within an office environment is energy intensive, eventually resulting in fatigue and employees feeling unmotivated, with a constant need for restoration as proposed by ART and SRT above (Ulrich, et al., 1991; Kaplan, 2001).

By providing occupants with direct access to office planting, their interest has been shown to remain 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). Moreover, given living plants' physical ability to improve air quality, enriching workplaces with nature may simulate healthy outdoor environments within a building which induce positive effects in the way that occupants perceive indoor air quality (IAQ) and subsequently health (Nieuwenhuis, et al., 2014). The same setting incorporating nature may also appear more tranquil and balanced, which is known to positively influence an individual's perception of well-being (Lohr, et al., 1996).

Our results, however, showed that the introduction into and removal of living plants from offices and/or break-out spaces did not elicit any changes in participants' perceived tiredness, health, well-being or motivation. This is in line with findings of several studies which investigated the link between several indoor living potted plants and effects on these metrics (Shibata and Suzuki (2001; 2002; 2004), Velarde, et al. (2007), Korpela, et al. (2017)). The lack of influence on these metrics may perhaps be explained by participants' preferences for more visual and physical access to living plants, as stated in the questionnaires and narratives. This may mean over time occupants failed to recognise the few potted plants within their field of vision which could have been exerting an influence, due to habituation or adaptation (Wohlwill, 1974). Factors such as health, tiredness, well-being and motivation may thus not be easily detected using self-report questionnaires as used in this study (Bringslimark, et al., 2009).

4.2 Impact of break interactions with plants on perceived performance metrics

Research shows humans experience the most significant effects of nature within the first five minutes of their visual or physical interaction, and that such interactions prior to stressful situations can help relax the human body and mind (Barton and Pretty, 2010). A number of studies show that immersion in nature for short periods of time ranging from seconds to several hours, also known as 'mini breaks', promote increased health, well-being and performance (Bratman, et al., 2012; Tyrväinen, et al., 2014; Lee, et al., 2015). This is because of the hypothesis that during breaks from work, plants can restore attention and promote recovery from stress and fatigue more effectively than when performing tasks. This is due to employees being able to allow their conscious mind to focus on nature rather than work or tasks present within their environment (Bringslimark, et al., 2009).

In our study, whether or not occupants had interactions with plants during break times did not have a significant effect on any perceived metrics, including health, well-being and performance. This may be due to the distribution of plants within the break-out spaces which appeared more disconnected than nature outdoors such as forests or parks (Grinde and Patil, 2009) or took up space on tables which otherwise could have been used for refreshments. Therefore, these living plants collectively may not have provided a strong enough effect to capture, hold and restore the attention of occupants (ART), nor promote effective recovery from stress (SRT) during breaks. As such, they did not affect perceived health, well-being or performance metrics significantly. Clearly, this area of study warrants further research into the effects of nature on occupant performance during office or 'mini' breaks, given the mixed results, as similarly concluded by Bringslimark, et al. (2009).

4.3 Occupant preferences for access to living plants and office design

Research shows that occupant comfort within their working environment has a direct relation to their overall satisfaction with IEQ (Frontczak, et al., 2012). As the presence of plants has been shown to increase occupant comfort as well as attractiveness of the workplace environment, it was expected that their introduction would have a positive effect on satisfaction

with the overall office design (Schoemaker, et al., 1992; Gray and Birrell, 2014). In terms of physical and visual access, participants generally expressed that they wanted more when plants were absent from their individual offices and break-out spaces, as well as when plants were introduced into either of these spaces.

This correlates well with the participants' responses to satisfaction with overall office design, with satisfaction increasing significantly when plants were introduced into offices and break-out spaces and decreasing when plants were removed from individual offices. Findings also showed that there was no change in satisfaction when plants were absent or only present in break-out spaces. This may be attributed to the fact that placement of plants on tables may actually have in part negated their potential restorative effects by obstructing their use for food or drink placement]. Occupants thus have greatest satisfaction with their overall workplace environment when they have physical and visual access to plants within their individual offices and break-out spaces. The findings support results from similar studies which found that enriching an office space with indoor greenery has a positive effect on occupant satisfaction and engagement with their work (Bringslimark, et al., 2007; Nieuwenhuis, et al., 2014). The reasoning behind the effect which plants have on overall occupant satisfaction is thought to be twofold. The first is the perceived effect of plants on occupants' health and IAQ and the second involves occupants' perception regarding managerial care and attention within the building (Nieuwenhuis, et al., 2014).

When buildings are perceived to have poor IAQ this correlates to low occupant satisfaction scores (Kim and de Dear, 2012). A further explanation considers what is known as 'The Hawthorne effect', which accounts for the managerial consequences which follow environmental influences on the workplace (Sedgwick and Greenwood, 2015). Put simply, enrichment of occupants' surroundings through indoor plants or other means demonstrates that management is taking an interest in their people's health, well-being and performance and are looking for ways to enhance these qualities (Nieuwenhuis, et al., 2014). The result, in

theory and in practice, is an increase in occupants' overall satisfaction with office design, given signals of managerial care and engagement (Haslam, 2004).

5.0 Conclusions

This study only used qualitative subjective measures to determine whether introducing living plants into offices and break rooms had a significant effect on health, well-being and performance. Our study revealed significant positive effects of plants in offices and break-out spaces on perceived attention, efficiency, creativity, productivity and stress reduction. Introduction of plants, however, did not influence perceived health, well-being, tiredness or motivation. Interactions with plants during break times also did not elicit a significant change in perceived health, well-being or performance metrics. Satisfaction of the occupants with overall office design increased significantly with the introduction of plants into the offices, but not the break-out spaces, possibly due to the choice of plant placement on coffee tables. To gain a better understanding of the multidimensional, complex relationships between IEQ and occupants' health, well-being, performance and satisfaction, cognitive performance tests or physiological measures could be taken in conjunction with surveys, such as those used in this study. Our future work will include investigation into the impact of other factors including positioning, types, sizes and volumes of plants, to provide further understanding of the mechanisms whereby plants can and do have a positive impact on office occupants. Clearly, biophilic design is not a 'one size fits all' performance enhancing approach. However, given the large returns from small increases in performance, it appears the relatively low cost of installing living plants is a sound financial investment. For maximum effect on health, well-being and performance, it seems that a full landscaping approach that does not hamper functionality should be taken to provide constant opportunities for restoration.

6.0 Appendix

Questionnaire.

* indicates questions omitted from the second questionnaire. ***Question***	***Answers***					
Full name and office number						
*Age**	<20	21-30	31-40	41-50	51-60	>60
*Gender**	Male	Female				
*How many hours per day do you spend in your office or workspace on a normal working day? **	1-3 hours	4-6 hours	7-10 hours	>10 hours		
*Considering your office environment, do you have a window with a view of green plants or green spaces?**	Yes	No				
Considering your office breaks, do you have any interactions (views or physical contact) with green plants during this time?	Yes	No				
If yes, for how long? (minutes)	1-5	6-10	11-15	>15		
Would you prefer to have more, less or no change in the level of physical or visual access to green plants or green spaces in/from your office? You may tick more than one.	More physical	More visual	No change	Less visual	Less physical	
In your current office environment and at the time of this questionnaire, how do you perceive your tiredness level?	Tired	Neutal	Awake			
In your current office environment and at the time of this questionnaire, how do you perceive your general health level?	Sick	Neutral	Healthy			
In your current office environment and at the time of this questionnaire, how do you perceive your stress level?	Stressed	Neutral	Relaxed			
In your current office environment and at the time of this questionnaire, how do you perceive your overall wellbeing?	Poor	Neutral	Good			
In your current office environment and at the time of this questionnaire, how do you perceive your concentration level/attention span?	Low	Neutral	High			
In your current office environment and at the time of this questionnaire, how do you perceive your work rate/efficiency?	Low	Neutral	High			
In your current office environment and at the time of this questionnaire, how do you perceive your creativity level?	Low	Neutral	High			
In your current office environment and at the time of this questionnaire, how do you perceive your motivation/work engagement level?	Low	Neutral	High			
In your current office environment and at the time of this questionnaire, how do you perceive your productivity level?	Poor	Neutral	Good			

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