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# The appearance of indoor plants and their effect on people's perceptions of indoor air quality and subjective well-being

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## 1. Introduction

Built environments affect our health, behaviour and mental well-being [1,2]. The adverse impacts of indoor air pollution and poor thermal comfort on the health, well-being and productivity of building occupants are well documented, and as people spend more time indoors in tightly sealed buildings these concerns are rising [3–5]. People's mental well-being is also a major health concern; in the UK mental ill health is the single largest cause of disability burden and stress [6]. Furthermore, depression or anxiety accounted for 55% of all working days lost due to work-related ill health in 2019/20 [7]. The psychological well-being of a person depends on many factors but the indoor environment, including the indoor air quality (IAQ) and the physical design of the space, is an important influence which can be manipulated in various ways [8]. The inclusion of indoor plants has been shown to benefit both the physical and psychological well-being of building occupants, leading to reduced health complaints and sick leave [9,10].

Common IAQ problems of increased concentration of carbon dioxide ($CO_2$) and low relative humidity (RH) can be controlled by mechanical ventilation systems, but these are expensive and energy intensive [11,12]. Plants can reduce ambient $CO_2$ concentration and add moisture, through $CO_2$ assimilation (photosynthesis) and evapo-transpiration [13–15] but their effectiveness within indoor environments with low light levels is still under debate [14,16]. Studies in office environments have shown that irrespective of actual changes in IAQ conditions, occupants perceived that the IAQ of the room [17], and their thermal comfort [18,19] improved when plants were present.

In built environments where people lack contact with nature, indoor plants have also been shown to reduce stress and improve people's subjective well-being (SWB) [10,20]. Laboratory studies suggest that viewing plants can reduce stress indicators such as heart rate variability and blood pressure [21,22]. Studies in healthcare [23], retail [24] and learning environments [25] have also shown stress-reducing effects of plants, which have been partially explained by the increased attractiveness of the rooms. The visual aesthetic experience of the environment is believed to affect people's perceptions, mood state, and stress levels [26,27]. Office environments with plants are typically perceived as more attractive [17,28] and have been associated with higher job satisfaction [29]. However, other studies have not found any effect of plants on mood [30] and results on cognitive performance are varied and difficult to compare due to the wide range of tasks, tests and subjects used [31].

The benefits of plants within indoor environments are generally associated with occupants' viewing the plants and it is therefore important to understand how the appearance of the plant affects people's responses. The physical appearance of the plant is primarily determined by its shape, colour, texture and size. Research involving trees and flowers has shown that shape and colour significantly affect people's emotional and physiological responses [32–35]. In an assessment of flower beauty by Hůla & Flegr [32], shape was found to be more important than colour. Healthiness, bushiness and shape have been identified as key factors affecting purchasing decisions for outdoor ornamental plants [36]. Despite this importance of plant shape for people's preferences and responses to outdoor plants and its dominance in characterizing the physical appearance of the plant, it has rarely been investigated for indoor plants. Plant shape was therefore a focus of this study.

The inclusion of plants within indoor environments can benefit the health and well-being of building occupants [9,10]. If designers, building managers and householders are to invest in plants and achieve maximum benefits for the building occupants, it is important to know how the appearance of the plant affects people's perceptions and responses. While the current evidence from our own work (Berger et al. manuscript (MS) in preparation) and other research [13–15] suggest that the impact of individual potted plants on IAQ parameters at a room scale, is relatively small, we hypothesise that people's perception of a

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positive change might lead to indirect augmented benefits of plants for SWB. We hypothesise that the appearance of the plant and attributes such as shape, leaf density and plant vigour will influence people's perceptions of its benefit for IAQ and SWB.

Therefore, the objectives of this study were:

i) To measure people's preference and response to the appearance of indoor plants displaying different physical characteristics
ii) To determine if the plant appearance and shape affects people's perception of its impact on IAQ, RH or SWB.

## 2. Methods

### 2.1. The survey

A web-based photo-questionnaire, created using Qualtrics XM software, was conducted to investigate people's preferences and responses to a range of indoor plants. People were invited to participate voluntarily through email, LinkedIn and Facebook. Respondents were told the survey was about the use of plants in building design, advised it would take around 10 min to complete and gave their informed consent by proceeding with the questionnaire which was approved by the University of Reading Ethics Committee, in accordance with the Helsinki Declaration of 1975, as revised in 2000.

The survey method has been successfully used by previous researchers [37] and people's response to viewing pictures of plants has been shown to be a reliable representation of people's response to live plants [38]. After providing information about their demographics and attitudes to indoor plants, participants were asked to view photographs of 12 individual plants and to answer the questions based on their opinion of the plant's appearance. The order of presentation of the plants was varied to minimize any ordering effects. Space was provided at the end of the survey for participants to provide any extra information or comments of their choice. The comments were collated, organised and analysed by thematic analysis.

Participants assessed the appearance of each plant in terms of its aesthetics or restorative effect, using a seven-point bipolar scale comprising of six pairs of contrasting adjectives. Participants also assessed the perceived benefit of each plant for IAQ, RH and SWB on a seven-point scale from low-high, based on its appearance. The descriptors were generated from a pilot study involving 14 participants who also identified that the meaning of the terms "air quality" and "humidity" were equivalent to indoor air quality (IAQ) and relative humidity (RH) and well-being meant subjective well-being (SWB). Previous studies have shown that questionnaires of people's self-reported SWB have good correlation with measurements of their physiological stress indicators such as heart rate and blood pressure [39,40] therefore the results of this study will not only directly indicate how a sense of well-being is influenced by the appearance of the plants but also, indirectly, how the appearance of the plants might moderate physical responses. After viewing all 12 plants, participants were asked to identify their most preferred and least preferred plants. Finally, participants ranked the physical characteristics (Colour, Leaf shape, Plant shape, Leaf pattern, Texture) in order of importance, from high to low, when considering the attractiveness of indoor plants. These characteristics were identified from previous research as important in affecting people's preference for trees and flowers [32,35,41,42]. The order of presentation of the terms was randomised to avoid ordering effects.

### 2.2. The plants

The final choice of plants included in the survey (Fig. 1) was limited to 12 to avoid participant fatigue and was based on a number of considerations summarised in Table 1.

All plants were readily available indoor plants commonly used in commercial UK offices or domestic homes, based on data from Ambius, a leading, commercial interior landscaping company and the Royal Horticultural Society (RHS) retail sales (personal communication). The plants represented examples of a range of physical characteristics and metabolic pathways (Table 1); they were evergreen, with no flowers, no excessively large specimen plants, and were of a comparable green colour. As the focus of the research was on understanding the influence of plant shape, strong variegation and markings were avoided except for *Sansevieria* and *Calathea* which had patterns on the leaves, but the contrast of these was reduced using Adobe Photoshop CS [43]. Different plant shapes were included that are typically used in plant landscaping and were representative of different theories about the impact of plants on SWB [34,44,45]. To enable direct comparison of the effect of plant


**Fig. 1.** Selection of plants used in the survey. Refer to Table 1 below for key and explanation.

**Table 1**
Characteristics of the plants included in the survey.

| Image No. | Plant | Shape | Leaf and canopy properties |
|---|---|---|---|
| 1 | *Ficus benjamina* 'Danielle' | Column soft | Small, slender, glossy, green, soft pointed leaves. Graceful medium dense canopy. Woody plant. C3 metabolism |
| 2 | *Sansevieria trifasciata laurentii* | Column sharp | Long, upright, thick, broad sword shaped leaves. Crassulacean Acid metabolism (CAM) |
| 3 | *Echinocactus grusonii* (Cactus[a]) | Sphere small spikey | Succulent. Glossy green ribs with radial yellow spines, not leaves. CAM |
| 4 | *Ficus benjamina* 'Danielle' | Sphere – Large soft | See plant 1. Thick, lush, dense glossy canopy |
| 5 | *Ficus benjamina* 'Danielle' | Pyramid -neat | See plant 4 |
| 6 | *Dypsis lutescens* (neglected palm[b]) | Spreading | Unhealthy plant. Tropical. Long arching, linear, narrow pointed leaves. Graceful shape. C3 metabolism |
| 7 | *Dypsis lutescens* (Palm[a]) | Spreading | Healthy version of plant 6 |
| 8 | *Ficus benjamina* 'Danielle' | Spreading -Savannah like | See plant 4 but less dense canopy |
| 9 | *Calathea* 'White star' | Spreading | Green and white striped effect, individual broad leaves on arching stems. Statement plant. C3 metabolism |
| 10 | *Asplenium nidus* | Spreading | Broad, large lance shaped fronds with wavy edges. Fern. C3 metabolism |
| 11 | *Epipremnum aureum* | Pyramid -natural | Large, glossy, rich green and yellow, heart-shaped leaves. C3 metabolism |
| 12 | *Dracaena marginata* | Sphere -large spikey | Slender, narrow pointed leaves. Which form at the top of upright stems. Sparse canopy. C3 metabolism |

[a] For simplicity, the common names of palm and cactus are used in this study.
[b] Hereafter referred to as neglected palm.

shape, and control other variables of plant appearance, *Ficus benjamina* plants of the same size and from the same batch were pruned into the shapes Sphere, Column, Pyramid and Spreading. The plants were photographed in the same type of pot, against the same background and adjusted using photo-editor to make the images comparable size, colour and brightness.

The plants represented a range of impacts on IAQ and RH determined from experimental data (Berger et al. MS in preparation [14,15]). The plants were all healthy except for one plant (Fig. 1 plant 6), which was included to determine if unhealthy plants affected participant's responses, in particular the impact on perceived SWB.

### 2.3. Statistical analysis

A sensitivity test was conducted using G*Power 3.1 software [46], this revealed that a repeated measures, within subjects MANOVA, with 520 participants, across 12 conditions, would be sensitive to effects of Cohens f = 0.05 ($\eta_p^2 = 0.002$), with 80% power (alpha = 0.05). This means the study should be able to detect small effects according to Cohens criteria [47], and compared to examples in the literature [48]. All other statistical analyses were carried out using SPSS version 25 (IBM).The frequency of participants' (N = 520) first and last choice preference votes was determined for each plant and tested to determine whether there were differences in plant preference by means of a chi-squared test.

Differences between participants' ratings of the descriptors were tested using a mixed design ANOVA. Mauchly's test was conducted to test the assumption of sphericity and adjusted data are reported. Post hoc, Scheffé multiple pairwise comparison tests were used to further test for significant differences between plants for each descriptor [33,49]. Bonferroni adjustment was included to account for inflated Type 1 error due to multiple comparisons.

The correlation between the mean scores for the predictors (Beauty, Interesting, Soft, Relaxing and Depressing), and participants perception of the impact of the plant on SWB, IAQ and RH were assessed using Pearson correlation coefficients, and multiple linear regression analysis was conducted to determine if the perceived benefit of the plant for SWB, IAQ or RH (outcome variable) could be predicted from the mean scores for the descriptions of the appearance (the predictors).

Data was verified to ensure that it met the assumptions of linearity, homoscedasticity independence of error term normality of the error distribution and multicollinearity. Initially the individual predictor variables (Beautiful, Interesting, Soft, Healthy, Relaxing and Depressing) were entered into the regression analysis all at once and the outcome variable was set as SWB, the analysis was repeated for the outcome variable as IAQ and RH. The importance of each variable was then assessed through a hierarchical multiple regression where the variables were entered in the order of importance identified from the correlation analysis.

The rank totals for the plant characteristics (colour, shape, leaf shape, leaf pattern, texture) were assessed using the Friedman statistical test, and Wilcoxon signed-rank tests were conducted on each pair of plant characteristics to determine the order of importance (all significance levels minimum of 0.05).

## 3. Results

### 3.1. Participants

Responses were received over a four-week period during May–June 2021, and 520 participants who successfully completed all sections of the questionnaire were included in the analysis. The majority (69%) of participants were female, 29% were male and 2% did not specify. The participants included a balance of age groups although the majority, 63%, were under 50 years old and further 35% were 50–65 (Table 2).

The majority (67%) of the participants were employed; 29% worked in professional roles, 17% in teaching roles, 17% were students, 11% were in administrative roles, 15% were in other roles and 6% were retired. Due to the pandemic lockdown restrictions at the time of surveying, 74% of participants spent the majority of their day at home, 10% spent their working day in an office building and 10% worked indoors but not in an office. Participants were asked if they had a background in: Environment (29%), Construction (16%), Art (8%), or None of these (48%) (data not shown).

The survey was voluntary with no incentives. The majority (96%) of participants stated that they liked indoor plants and enjoyed them both at home and work (84%). 79% of participants enjoyed looking after indoor plants either at home or at work, but 25% did not like looking after plants at work. 8% of participants had become interested in indoor plants during lockdown. The majority of participants had views of nature/plants during the day: 58% responded "A lot", 33% said "A little" and 9% responded "None" (data not shown).

### 3.2. Plant preference

The results of the Chi-squared test showed significant differences between the rated preferences of the plants, $\chi^2(df = 11) = 277.62$, $p < 0.001$. *Epipremnum, Ficus* sphere, Palm *and Ficus* column were significantly preferred to all other plants, receiving 113, 90, 71 and 63, first choice votes respectively from a possible total of 520.

The neglected palm was the least preferred plant with 60% (N = 313) of the participants voting it last (Fig. 2).

There was a significant effect of participants background on plant

**Table 2**
Numbers of participants in various age and gender groups, with % of the total provided in brackets.

| Summary of participants' gender and age | Under 25 | 25–34 | 35–49 | 50–64 | 65+ | Not specified | Total |
|---|---|---|---|---|---|---|---|
| **Female** | 16 | 103 | 114 | 116 | 9 | 2 | 360 |
| **Male** | 5 | 36 | 48 | 53 | 3 | 3 | 148 |
| **Not specified** | | | 3 | 1 | | 8 | 12 |
| **Total** | 21 (4%) | 139 (27%) | 165 (32%) | 170 (33%) | 12 (2%) | 13(3%) | 520 |

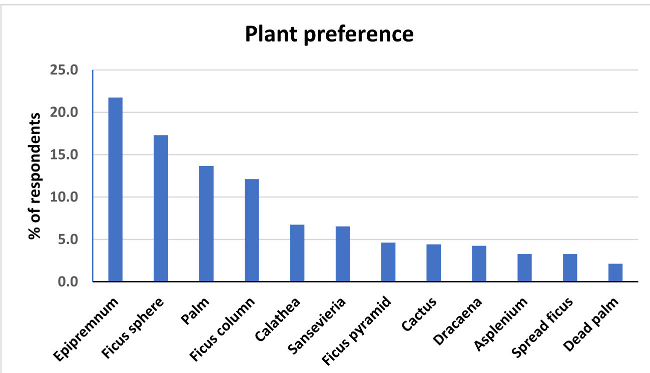


**Fig. 2.** The plant preference based on the percentage of participants (N = 520) stating their first choice of plant.

preference, $X^2$ (df = 44) = 66.27, p < 0.05. More participants with a background in Construction (30%) and Art (33%) preferred the *Epipremnum* plant, compared to people without these backgrounds (19%) who preferred both *Ficus* Sphere and *Epipremnum* (Fig. 3).

There was a significant effect of respondents' age on plant preference, $X^2$ (df = 5) = 371.54, p < 0.001 (Fig. 4) but further inspection, revealed this difference was only between the 25–34 year olds (N = 139), who preferred *Epipremnum* and the 50–65 year olds (N = 170), who preferred the *Ficus* sphere plant, F(5, 509) = 2.66, p < 0.05. (Fig. 3).

"None" refers to participants with no background in environment, construction or art.

There were no significant effects of gender $X^2$ (df = 33) = 41.99, p = 0.14, occupation, $X^2$ (df = 88) = 92.21, p = 0.36 or views of nature from their buildings, $X^2$ (df = 22) = 18.80, p = 0.66, on the participants plant preference.

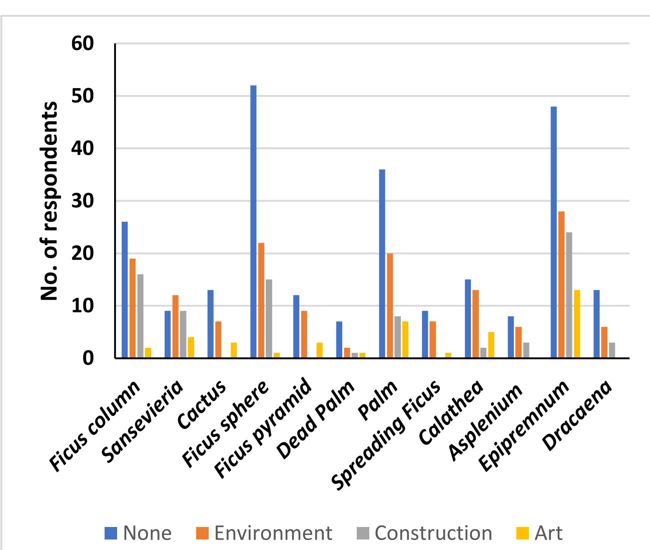


**Fig. 3.** Effect of participants' background on their preferred plant choices.

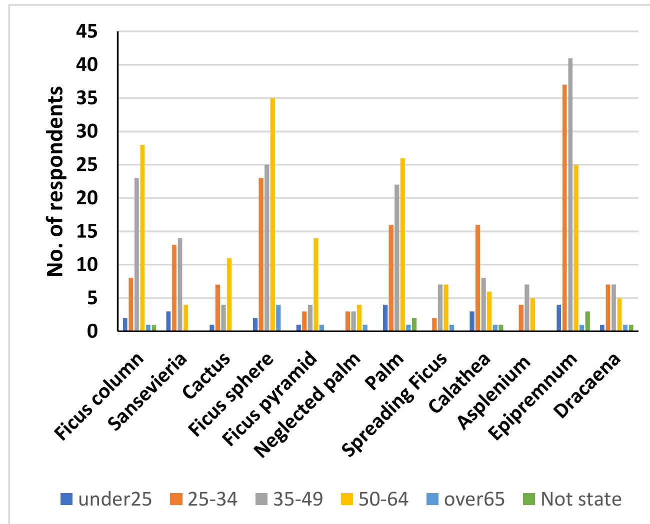


**Fig. 4.** Preferred plant choices for different participant age groups.

#### 3.2.1. *Plant shape and preference*

Within the *Ficus* plants, the most preferred shapes based on total of first choice votes, were the sphere (46%), column (33%), pyramid (12%) and spreading (9%). However, as the plants were ranked within a larger group of plants and not solely against each other this result cannot be statistically validated.

### 3.3. *Descriptive scores*

Results of the mixed method multivariate analysis of variance (MANOVA) showed the plant type had a significant effect on the mean scores for the descriptive terms F(11, 254) = 14.1, p < 0.001. The mean scores for each plant and descriptive term are provided in Fig. 5.

Further detailed analysis, using separate repeated measure ANOVAs, revealed there were significant differences between the plants for each of the individual descriptive scores (F-statistics shown in Table 3), (all p's < 0.001). As all tests violated Maulchy's sphericity test, the Huynh-Feldt procedure was used to correct for possible inflations of the type 1 error rate by modifying the degrees of freedom [50](See: Table 4).

There was no significant effect of the participants' demographics on the descriptive scores; gender, F(2,399) = 0.182, p > 0.5 $\eta^2$ = 0.001, age, F(5,399) = 1.83 p > 0.1, $\eta^2$ = 0.022, occupation F(8,399) = 1.356, p > 0.1, $\eta^2$ = 0.026, The effect of participants' background and other minor effects are discussed below.

The data for all descriptive scores discussed below are provided in Fig. 5.

#### 3.3.1. *Ugly-beautiful scores*

All plants except the neglected palm, were considered beautiful to some extent although the perception of beauty varied between participants. *Ficus* sphere, palm, *Ficus* column and *Epipremnum* achieved the highest mean scores for beauty (Fig. 5) but there was no significant difference between these top four plants. The opinions about the beauty

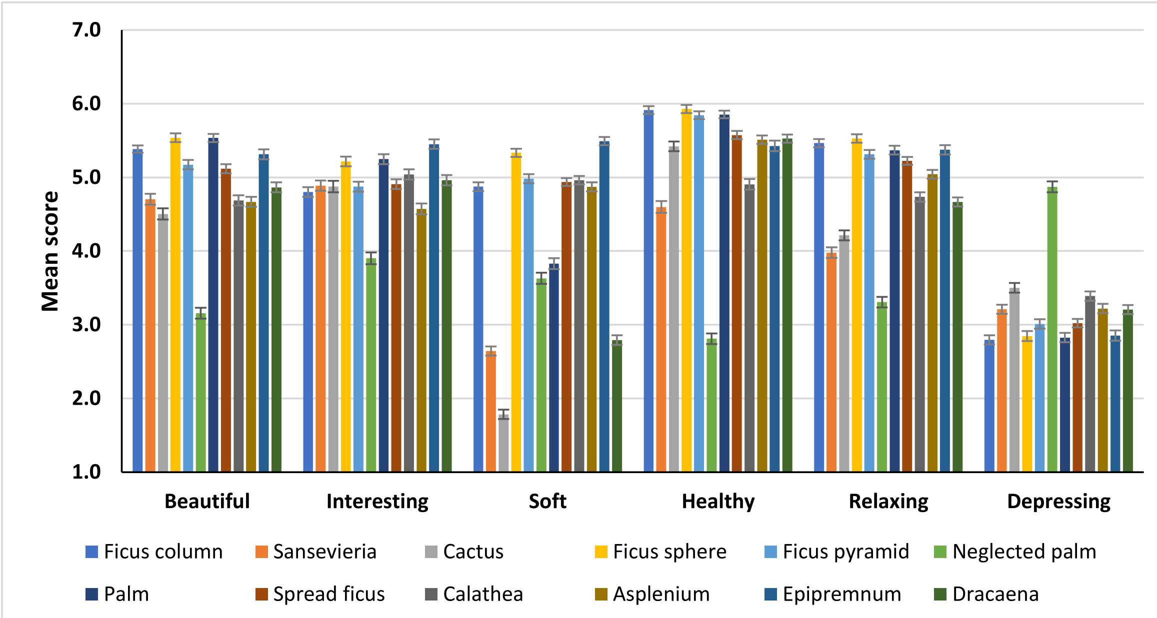


**Fig. 5.** Effect of the plant type on the descriptive scores; bars represent the mean scores (N = 520) ± standard error (SE), on a 1–7 scale.

**Table 3**
Results of the repeated-measures ANOVA for the mean scores for each descriptor and outcome variable assessed on the bipolar scales. All $p < 0.001$.

| | F statistic | Effect size (partial $\eta^2$) |
|---|---|---|
| Beautiful | (8.83, 4275.45) = 132.97 | .22 |
| Interesting | (8.94, 4335.92) = 41.98 | .08 |
| Soft | (7.79, 3779.49) = 436.42 | .47 |
| Healthy | (7.82, 3800.87) = 234.29 | .33 |
| Relaxing | (8.89, 4186.05) = 152.60 | .25 |
| Depressing | (9.04, 4336.92) = 107.26 | .18 |
| IAQ | (6.2, 23094.7) = 285.80 | .36 |
| RH | (6.5, 3264.4) = 191.29 | .28 |
| SWB | (7.6, 3838.3) = 203.77 | .29 |

**Table 4**
Results of the plant characteristic ranking test, showing the frequency of response and the rank position for the five physical characteristics in order of importance for the attractiveness of indoor plants. Data are the results from 520 participants.

| | No. of respondents ranking | | | | |
|---|---|---|---|---|---|
| | Plant shape | Colour | Leaf shape | Leaf pattern | Texture |
| 1st | 276 | 163 | 46 | 19 | 17 |
| 2nd | 120 | 159 | 127 | 66 | 48 |
| 3rd | 70 | 95 | 184 | 111 | 59 |
| 4th | 33 | 57 | 114 | 164 | 152 |
| 5th | 21 | 46 | 49 | 160 | 244 |

of the Cactus plant were most divided and the neglected palm scored significantly lower, ($p < 0.05$) than all other plants, thus the healthiness of the plant appears to increase the perception of its beauty. Between the four *Ficus* shapes, the sphere and column shapes were rated significantly more attractive than the pyramid and spreading shapes, ($p < 0.05$). Common physical characteristics associated with the more beautiful plants were rounded leaves and softer canopy edges. Comments from participants suggest that the sharp spikes on the cactus, snake like appearance of *Sansevieria* and the leaf pattern and colour of *Calathea* affected the beauty of these plants.

### 3.3.2. *Boring–interesting scores*

*Epipremnum* plant which had leaves on trailing vines, was reported as significantly more interesting than all other plants except palm ($p < 0.05$). There was no significant difference between the mean scores for Palm, *Ficus* sphere, *Calathea* and *Dracaena* but these four were significantly more interesting than the remaining seven plants ($p < 0.05$). The neglected palm was rated as the most boring plant ($p < 0.05$). Between the four *Ficus* plant shapes, the Sphere was significantly more Interesting than all other shapes ($p < 0.05$) but when comparing the different shapes across all species, no single canopy shape determines how interesting a plant will appear.

### 3.3.3. *Sharp-soft scores*

*Ficus* sphere and *Epipremnum* had the softest appearance ($p < 0.05$). Whilst cactus, *Sansevieria* and *Dracaena* were considered significantly sharper than all other plants ($p < 0.05$). The mean scores for the different *Ficus* shapes showed the sphere had a significantly softer appearance, but there was no difference between the remaining three shapes ($p > 0.05$). Plants with a sharp appearance typically had narrow pointed leaves on a sparse canopy or prickly spikes, suggesting that participants associated the contours of the canopy with the sharpness or softness of the plant rather than the geometrical canopy shape.

### 3.3.4. *Unhealthy–healthy scores*

All plants except for the neglected palm were considered to have a healthy appearance but the palm, *Ficus* column, *Ficus* sphere and *Ficus* pyramid achieved significantly higher scores compared to all other plants ($p < 0.05$). The neglected palm achieved the lowest score for healthiness ($p < 0.05$) followed by *Sansevieria* and *Calathea.* Between the four differently-shaped *Ficus* plants, the spreading *Ficus*, was reported as significantly least healthy, ($p < 0.05$) but there were no other significant impacts of canopy shape on Healthy scores. Overall, participants viewed the healthiness of the plant separately to canopy shape or softness and typical characteristics of healthy plants were bright green colour and a dense canopy.

### 3.3.5. *Stressful-relaxing scores*

*Ficus* sphere, *Ficus* column, palm, *Epipremnum* and *Ficus* pyramid, had the most relaxing appearance and highest mean scores but there was no significant difference ($p > 0.05$) between these five plants. The neglected palm was significantly more stressful than all other plants. *Sansevieria* and *Calathea* both had markings on their leaves which some participants found stressful as they associated them with snakes and dangerous insects or animals.

Comparison of the four *Ficus* shapes showed, sphere and column were significantly more relaxing than pyramid and spreading shapes. When the same shapes in different species were compared, such as the soft *Ficus* column and the sharp *Sansevieria* column or the soft *Ficus* sphere against the spikey sphere of cactus and Dracaena, it is apparent that sharp edged leaves and spikes reduce the relaxing appearance of the plant.

#### 3.3.6. Uplifting-Depressing scores

This question was reverse scored, so the lower the score the more uplifting the plant appearance. All plants, except the neglected palm, had an uplifting appearance. The four most preferred plants; *Ficus* column, *Ficus* sphere, palm and *Epipremnum* achieved the highest mean scores ($p < 0.05$) for Uplifting, although there was no significant difference between these four ($p > 0.05$). The neglected palm had significantly the most depressing appearance ($p < 0.05$).

Between the *Ficus* plants of different shapes, there was no significant difference between column or sphere, but the column was more uplifting than pyramid and spreading. Plants with prickles, sharp edged leaves and striped patterns were associated with a less uplifting appearance.

#### 3.3.7. Perceived benefit for SWB

Most participants perceived that all plants tested, except the neglected palm, would benefit their SWB as the mean scores were all higher than the mid-point of the scale. *Ficus* sphere, *Ficus* column, palm, *Epipremnum*, and *Ficus* pyramid achieved significantly higher scores than all other plants ($p < 0.05$) but there was no significant difference between them. The neglected palm scored significantly lower than all other plants. Comparing the scores for the healthy and neglected palms revealed that unhealthy plants have a low or negative impact on participants' perceived SWB. Within the differently shaped *Ficus* plants, participants perceived that the sphere, column and pyramid shapes would have a higher benefit for their SWB than the spreading *Ficus* shape.

#### 3.3.8. Perceived benefit for IAQ

The mean IAQ scores for all plants except for the neglected palm and cactus, were above the mid-point of the bipolar scale, showing that participants perceived the majority of the plants in this survey would have a positive impact on IAQ. *Ficus* sphere, *Epipremnum, Ficus* pyramid and *Ficus* column had the highest mean scores and perceived benefit for IAQ (scores approximately one standard deviation (SD), higher than the group mean).

The plants with a perceived mid-range benefit (scores less than half (SD) higher than the group mean) for IAQ, were Spreading *Ficus*, *Palm*, *Asplenium*, and *Sansevieria*. The *Palm* plant, which was one of the most preferred plants in the preference test and attained high scores for most other attributes is perceived as having only a medium benefit for air quality. *Calathea* and *Dracaena* with scores up to half a SD lower than the group mean, were perceived as having a positive, but lower benefit for IAQ compared to the other plants.

The neglected palm was perceived to have the lowest benefit for air quality, followed by the cactus. Comparison of the four differently shaped *Ficus* plants, showed the sphere and pyramid had significantly higher scores than the column and spreading shapes. The column was significantly higher than the spreading shape ($p < 0.05$).

#### 3.3.9. Perceived benefit for RH

All plants were perceived as having a lower benefit for RH compared to IAQ although the participants scored the impact of individual plants differently than for IAQ. *Epipremnum* and *Ficus* sphere, were perceived to have the greatest benefit for RH. Their mean scores were over one SD higher than the group mean and were significantly higher than all other plants tested ($p < 0.05$). *Ficus* pyramid achieved the next highest mean score which was significantly higher than the remaining plants ($p < 0.05$). Plants with a perceived mid-range benefit for RH, with means up to half a SD above the group mean, were *Ficus* column, spreading *Ficus*, *Asplenium*, palm and *Calathea*. The mean score for *Sansevieria* was 10% lower than the group mean and therefore perceived to have a lower benefit for RH. *Dracaena*, cactus and the neglected palm had significantly the lowest perceived benefit for RH ($p < 0.05$).

### 3.4. Correlation between plant appearance, SWB, IAQ and RH

Scatter plots and Pearson correlation tests revealed a significant positive correlation between the perceived benefit for SWB, IAQ, RH, and all descriptors of the plant appearance, except for a significant negative correlation with Depressing (Figs. 6 and 7) (data for RH not shown).

The order of strength of correlations for the descriptors for SWB was Depressing, Interesting Relaxing, Beautiful, Healthy and Soft and for IAQ; Healthy, Depressing, Interesting, Relaxing, Soft and Beautiful. For RH the correlations were in the same order of strength as for IAQ, but the associations were weaker. For RH the highest correlations were for Healthy ($r = 0.21$), Depressing ($r = -0.18$) and Interesting ($r = 0.15$). The order of strength of the correlations were used as the order of importance in the hierarchical method of entry of regression (section 3.5).

### 3.5. Predicting the benefits for SWB and IAQ from the plant appearance

Multiple linear regressions were conducted using the scores for the descriptive terms as predictor variables and setting the outcome variable separately as either SWB, IAQ or RH.

#### 3.5.1. Multiple linear regressions of SWB and predictor variables

A significant relationship between the descriptive terms and the score for SWB was revealed when all the predictor scores were into the regression model at once. The predictors accounted for a significant proportion of the variation in SWB scores with the model summary $R^2 = 0.52$, $F(6,511) = 92.187$, $p < 0.001$. The standardized regression coefficients (b), showed that when all the predictors are entered into the model, only Depressing ($b = -0.422$, $t = -8.785$, $p < 0.001$), Interesting ($b = 0.160$, $t = -2.606$, $p < 0.01$) and Relaxing ($b = 0\ 0.137$, $t = 2.468$, $p < 0.05$) were significant predictors of SWB scores. The further addition of predictors Beautiful, Healthy and Soft were not significant. The values for Depressing have a negative value, showing that as the score for Depressing appearance increases, the score for SWB decreases.

Running the model with the hierarchical entry method revealed that Uplifting-Depressing mean scores alone accounted for a significant proportion (47.1%) of the variation in SWB scores with a model summary of $R^2 = 0.471$, $F(1,516) = 460.061$, $p < 0.001$. The addition of the Interesting mean scores, accounted for a further 3.6% of the variation in SWB scores ($R^2$change $= 0.036$, F change$(1,515) = 37.103$, $p < 0.001$) and the addition of Relaxing accounted for a further 1% of variation in the SWB score. ($R^2$ change $= 0.01$, F change $(1,514) = 10.122$, $p = 0.002$). The further addition of other predictors was not significant ($p > 0.05$).

Each of the predictors can predict some of the variance of the SWB score, but their contribution reduces as the stronger predictors are added to the model.

#### 3.5.2. Multiple linear regressions of IAQ and predictor variables

Regression analysis revealed a significant association between the descriptive terms and the outcome variable IAQ. The predictors accounted for approximately 12% of the variation in IAQ, with the model summary of: $R^2 = 0.119$, $F(6,510) = 11.51$, $p < 0.001$. The standardized regression coefficients showed that only Healthy (b =

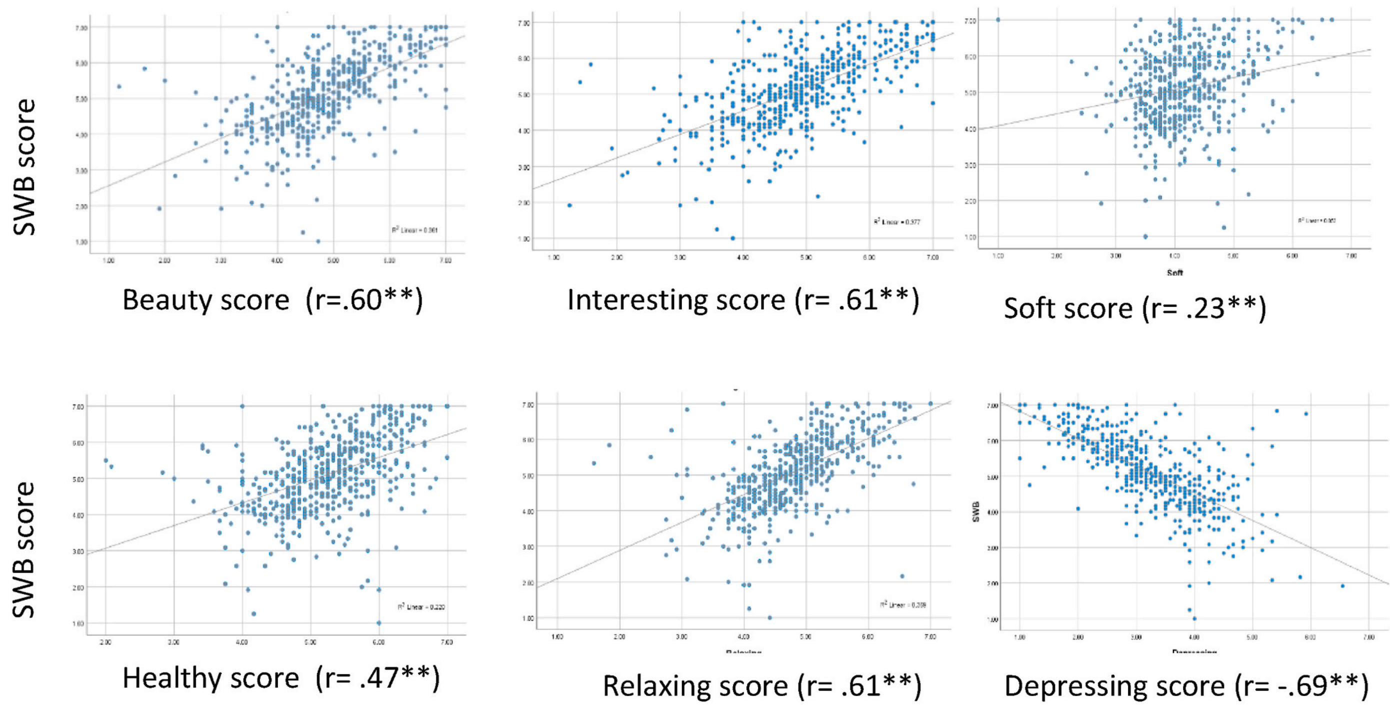


**Fig. 6.** Correlations between mean scores for descriptors and perceived SWB benefit (N = 520). Showing Pearson's r coefficient (** significant $p < 0.01$) and lines of best fit.

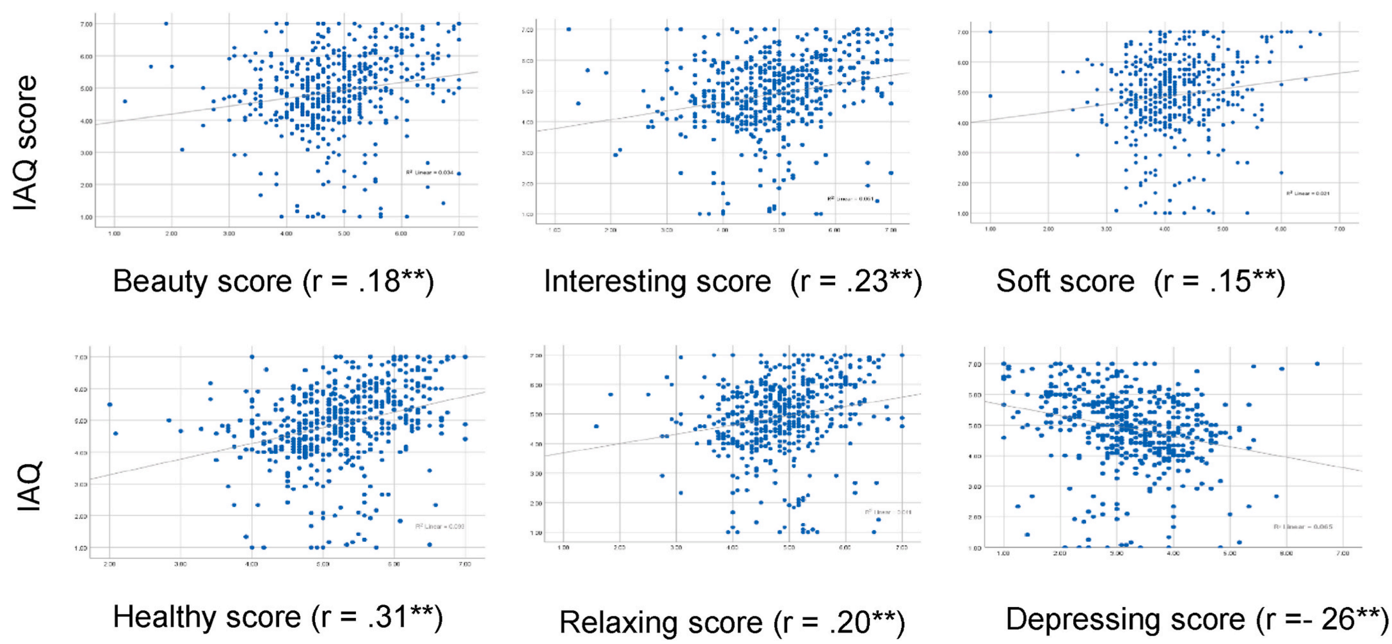


**Fig. 7.** Correlations between means scores for descriptors and perceived IAQ benefit (N = 520). Showing Pearson's r coefficient (** significant $p < 0.01$) and lines of best fit.

0.286, $t = -5.041$, $p < 0.001$) and Depressing ($b = -0.173$, $t = -2.658$, $p < 0.01$), were significant predictors of IAQ scores.

Results of the hierarchical regression analysis revealed that Healthy mean scores alone accounted for 9.8% of the variation in IAQ scores with $R^2 = 0.098$, $F(1,515) = 55.64$, $p < 0.001$. The addition of the Depressing mean scores, accounted for a further 0.9% of the variation with an $R^2$ change = 0.009, F change(1,514) = 5.163, $p < 0.001$. The addition of further predictors accounted for less than 1% each.

*3.5.3. Multiple linear regression of RH and predictor variables*

Entering all predictors into the regression model at once with RH as the outcome variable, revealed a significant association. The predictors accounted for approximately 6% of the variation in RH score, with the model summary of: $R^2 = 0.062$, $F(6,509) = 5.573$, $p < 0.001$.The standardized regression coefficients, showed that only Healthy ($b = 0.209$, $t = 3.548$, $p < 0.001$) and Depressing ($b = -0.133$, $t = -1.982$, $p < 0.05$), were significant predictors of RH score. The results are comparable with those for IAQ but the strength of associations between the predictors and the outcome variable of RH is weaker.

### 3.6. Analysis of ranked data for plant characteristics

The participants identified a significant difference in the importance of the plant characteristics on the attractiveness of indoor plants, as the Friedman $\chi^2$ statistic was significant, $\chi^2(df = 4) = 712.25$, $p < 0.001$ and Wilcoxon signed-rank tests (all p's $< 0.05$), confirmed that the order of importance, first to last, for the five characteristics was: Plant shape, Colour, Leaf shape, Leaf pattern and Texture.

There was no effect of participants' demographics on the order of importance.

### 3.7. Thematic analysis of participants' comments

Participants showed good engagement with the survey and 39% provided additional comments (203 participants recorded 262 comments). The frequency of comments recorded for each theme is outlined in Table 5.

The number in brackets (N) is the frequency with which the comment was recorded.

The appearance of the plant and the aesthetic contribution received the most comments (85). Respondents revealed that plants are decorative, but they are more than just objects of beauty; they also add interest and colour. Statements also suggested that grouping of different shapes and colours of plants in arrangements are important to add more interest and the planters or pots can add to the decoration. Plants were also identified as being useful screens in the office and on desks to provide sound barriers and privacy.

The benefit of plants for well-being or happiness was the next most frequent theme (71 comments). Participants used words such as welcoming, joyful, happy, relaxing and calming. These uplifting effects were mainly due to the plant appearance and the act of viewing it, but plants are also living things and some participants found it rewarding to nurture, care for and watch them grow. Three people commented that plants make the environment feel healthier which makes people feel well. One respondent commented that growing a shared chilli plant in the office had been great for team bonding and bringing people together.

The maintenance of plants was important and is a significant factor affecting plant purchases, with most people wanting easy to maintain plants. Only one person specifically referred to the plant light requirement affecting their choice. There were also 32 comments about the stress of caring for plants such as the hassle of watering plants, or feeling stressed if the plants became sick, were covered in pests, or died.

Plant health was important: healthy plants were described as appearing lush, bushy, with lots of bright green, luscious leaves. Unhealthy plants were regarded as spindly, depressing, and worse than having no plants at all. One respondent commented that variegated plants look less healthy. There were also four comments about liking plants to appear natural as a reminder of nature and therefore not wanting the plant to be too manicured. Under the theme of Adverse Effects, concerns about pests, toxins, pollen, allergies, danger to pets and dust collection were cited. Cost was not mentioned in the survey and there were only two comments about the cost affecting choice although other surveys have identified this as a key factor affecting people's purchases [51].

### 3.8. Discussion

The results of the bipolar scores and preference test showed the physical appearance of the plant had a significant impact on participant's emotional response and aesthetic preference. All healthy plants tested were considered beautiful to some extent and there was a significant relationship between the physical appearance of the plant and its perceived impact on SWB, IAQ and RH.

There were individual differences in plant preference and opinions of

**Table 5**
Summary of the thematic comments recorded in the survey, open text,section.

| Theme | Sub theme | Examples of comments |
|---|---|---|
| **Aesthetic appearance** (85) | Interest (25)<br>Colour (19)<br>Size (9)<br>Arrangements (13)<br>Flowering (14)<br>Interior decoration (5) | Decoration and interest<br>Add interest to room/office. Easy to change.<br>Needs to be interesting to look at - not necessarily beautiful. Size and shape most important.<br>I like trees - plants remind me of them<br>Flowering plants add more interest.<br>Trailing plants more interesting.<br>Rounded leaves better.<br>I like statement plants or rare ones as talking point<br>Leaf movement, catching insects, smell; all interesting<br>Add colour. Green colour is pleasing. I would like more colour. Like bright luscious fresh colours<br>Like some contrast in colour not just solid green.<br>I like: big and bold/vibrant and interesting/colour and variety.<br>Plant size important - both big and small. Has to fit space. Often bigger preferred at work- smaller at home.<br>Choice depends on space available.<br>Variety and shapes in planting arrangements important. Look better in groups.<br>Like flowering plants - add interest and colour<br>The planters or pots can add interest.<br>Soften & calms the space. Can act as screen in office. Provide privacy on desk.<br>LED lights look good on them. |
| **Well-being** (71) | Happiness (50)<br>Calming (8)<br>Health (7)<br>Nurturing (3)<br>Nature indoors (2)<br>Social benefit (1) | Plants bring happiness and joy. "I love them. I have 160 at home". Plants are uplifting. Welcoming.<br>Relaxing/calming. Mindfulness.<br>Bring a healthy feel to the environment. Benefit health.<br>The effects mainly due to the appearance but can be act of nurturing them.<br>I like having living things in my home.<br>Brings outdoor inside.<br>Can help team building – e.g. chilli growing in office. |
| **Plant maintenance** (51) | Maintenance (43)<br>Stressful (9) | Low maintenance is requirement.<br>Ease of maintenance important - often dictates plant choice - need to be easy to look after.<br>Watering them can be a chore.<br>Light requirement affects choice e.g. in office.<br>Cactus - liked because low maintenance<br>Looking after them & risk of them getting sick - fear of killing them is stressful (especially presents).<br>Sad when they die. *Calathea* and *Palm* are stressful and they die.<br>Not knowing how often to water is a worry.<br>Shedding leaves or making mess is undesirable. |
| **Plant health** (22) | Healthy plants -positive (8)<br>Unhealthy plants -negative (14) | Healthiness of the plant is important.<br>Healthy plants have lots of lush, bright green leaves<br>Bushy plants are better than spindly ones.<br>Dead, sick looking ones are depressing and worse than none at all. Variegated plants look unhealthy. |

(*continued on next page*)

**Table 5** (*continued*)

| Theme | Sub theme | Examples of comments |
|---|---|---|
| **Adverse effects** (11) | Bugs & pests (2)<br>Toxins (2)<br>Pets (5)<br>Dust (2) | Bugs, toxicity, allergy, pollen, risk to pets all causes of concern and affect choice.<br>Risk or danger to pets<br>Plants attract unwanted dust. |
| **Memories** (4) | Happy (3)<br>Negative (1) | Memories attached to plant can affect like/dislike– "My first plant", "My Mum had one of those", "Palm reminds me of tropical holidays", "Bad experience with cactus prickles" |
| **Air quality** (6) | Benefit IAQ | AQ impact – e.g. "they remove toxins" "remove $CO_2$" "they improve the air", "improve office climate" |
| **Danger** (6) | Spikes (4)<br>Leaf markings (2) | Sharp points/spiked leaves can be dangerous.<br>Cactus spikes dangerous. *Dracaena* – points could catch your eyes.<br>Stripey markings on leaves can evoke fear or dislike - *Sansevieria* associated with snakes -not nice.<br>*Calathea* stripes evoke both like and dislike. |
| **Natural** (4) | Natural | Naturalness of plant appearance important –e.g. should not look manicured. Adds natural feel. |
| **Cost** (2) | Cost | Cost is important and affects my choice. |

beauty between participants but overall, participants perceived that the most preferred plants, *Epipremnum, Ficus* sphere, palm *and Ficus* column, would have the highest benefit for their SWB and this would increase with increasing plant attractiveness. Previous research has also shown that exposure to more beautiful plants increased prosocial behaviour [52]. The least preferred, neglected palm plant, was perceived to have the lowest benefit for SWB.

Although there is little data on responses to the appearance of indoor plants, our findings paralleled results from studies of outdoor plants and trees, where a high correlation was found between participants' emotional responses, preferences and well-being [45,53]. For example, Lohr and Pearson-Mimms [45], measured the aesthetic preferences, affective responses, skin temperature and blood pressure of participants whilst they viewed photographs of individual trees of different shapes. Participants reported feeling happier and their diastolic blood pressure was lower when they viewed images of their most preferred tree shape and they appeared to respond more positively to trees with denser canopies. People also responded very positively to other tree shapes, and the authors concluded that human well-being can be improved by planting trees of any form. In addition a survey of office workers preferences for images of living roofs [48], showed that the plant characteristics influenced their preferences, the most preferred vegetation had the greatest restorative effect and there was a high value for healthy landscapes and green foliage [48]. In our study participants perceived that viewing most indoor plants would benefit their well-being.

Regression analysis revealed the terms, Uplifting, Interesting, Relaxing and Beautiful were the most significant predictors of the perceived benefit of the plant for SWB. The benefit for SWB was not just related to the beauty of the plant but also the interest that the plant appearance holds for the participant.

Numerous studies reporting the restorative effect of indoor plants have attributed their findings to the Attention Restoration Theory (ART) [54,55]. One of the key elements of ART is *fascination* whereby the stimulus has to be sufficiently interesting to attract people but not overly complex such that too much directed attention would be required [56,57]. The impact on mental fatigue was not measured in this study so there is no clear evidence that the perceived benefit for SWB is due to ART, but the results do provide some evidence that the interest or fascination of the plant influences the perceived benefit for SWB. By contrast, studies by Evensen et al. [58] found that interiors where indoor plants were present were rated as more fascinating than those without plants or with inanimate objects, but this did not lead to greater restorative effects.

A study by Haga et al. [59], showed that the restoration from nature experiences was not due entirely to responses shaped by evolution but also depended on the meanings associated with the stimulus. The qualitative feedback in this study provides evidence to support this, for example participants stated that memories attached to certain plants affected their responses (e.g. the palm was associated with holidays and happy memories).

The neglected palm plant was perceived to have a very low impact on participants' SWB. It was the least attractive, least preferred plant and participants thought the appearance was unhealthy and depressing. This important finding shows that to benefit occupants' well-being, sick or dead plants should be removed from the indoor environment. However, we investigated the responses to one unhealthy plant, but a broad spectrum of plant healthiness exists which could affect the plant appearance and people's responses. Furthermore, plant maintenance was identified as a main concern in participants' comments. This might affect plant health and hence people's subsequent responses to the plant in real settings. Guidance on plant choice and care at the point of sale or the use of professional maintenance companies could help alleviate some of these concerns.

The response of participants to plant colour was not tested here but several studies have reported that the green colour in plants is preferred as it has a calming, relaxing, uplifting effect [35,41,60] whereas brown is strongly disliked and has been associated with declining trees [34,35]. The brown colour could therefore help to explain participants dislike for the neglected palm and its perceived negative effect on their SWB.

The appearance of the plant had a significant effect on the perceived benefit of the plant for IAQ and RH although the perceived benefits for IAQ were lower than for SWB and the plants which participants perceived would have the greatest impact on IAQ, were different to those for SWB. *Ficus* sphere, *Epipremnum*, *Ficus* pyramid and then *Ficus* column were perceived to have the highest impact on IAQ. Participants associated plants with dense canopies and a healthy, lush green appearance as having the most impact on air quality. The canopy density rather than shape appeared to influence the perceived benefit for IAQ. This supports the findings from studies on outdoor plants where bushiness or leaf density has been associated with healthiness [36]. Dense canopies were also preferred in tree studies and the authors concluded this was because dense canopies indicated a productive environment which was better for survival [45].

Plants with narrow, sharp leaves were perceived as having less impact on IAQ and RH than broad leaved plants, which suggests participants associated the impact on IAQ with leaves and that a higher benefit would be achieved from plants with a greater leaf area. Previous studies have shown that people prefer leafy trees with dense canopies to sparse canopies [61,62] and leaves of moderate length and broader width to narrow ones [63]. The most frequently identified benefit, in a study of urban trees, was the improvement in air quality through the addition of oxygen [62].

The scores for perceived benefits for RH were lower than for SWB, and comparable but lower than for IAQ. Participants perceived that the *Epipremnum* and *Ficus* sphere plants would have the greatest benefit for RH, and the neglected palm the least benefit. The characteristics of the plants which would have the greatest benefit for RH were similar to those for IAQ. The lower scores and weaker perceived benefits for RH are possibly due to less familiarity or understanding of the term humidity compared to air quality as there has been considerably less media reporting about the benefits of plants for RH.

Regression analysis revealed that the strongest predictor of IAQ and RH scores was the healthiness of the plant appearance and participants correctly identified that the neglected palm would have significantly the least benefit for IAQ. As the appearance of the plant became more uplifting, interesting, relaxing and beautiful, the respondents perceived there would be a greater improvement in air quality and humidity. Taking into consideration the results of the scoring tests and comments provided, participants have intuitively identified some of the physical characteristics of the physical appearance which will impact IAQ such as leaf area, healthiness and bright green colour. $CO_2$ is the most common indoor air pollutant and is typically used as an indicator of the overall IAQ [64]. Previous work (e.g. Refs. [13,15]) linked the larger plant size/leaf area, healthiness and vigour to better removal of indoor $CO_2$, which is readily taken up by plants via stomatal pathway, and used in the process of photosynthesis. Our own work (Berger et al., manuscript in preparation) also showed that more vigorous plants, with greater leaf areas, through just size effect had a more pronounced impact on ambient RH, another component of IAQ (through greater overall evapo-transpiration), in measurement chambers.

The demographics of the participants had very little effect on the preferences or scores for plant appearance or the perceived impact on SWB, IAQ, or RH. Although many plant studies do not report the influence of demographics on results, previous research has shown an effect of gender on preference for plant colours but no effect of demographics on the attitudes and opinions of office workers towards plants in the workplace [34,41,54].

This study supports previous research which showed that indoor plants positively affected people's perceptions of IAQ and environmental quality [17,25], but it also advances this area of knowledge by showing that these perceptions and the extent of the perceived benefits are affected by the appearance of the plant.

### 3.9. The effect of plant and leaf shape on preference

Participants ranked shape as significantly the most important characteristic affecting the attractiveness of a plant's appearance but there was no clear preference for a single canopy shape. In a consumer survey, shape influenced people's opinions about plant attractiveness and their purchasing decisions and the authors related this to the symmetry and bushiness of the plant [36], Participants preferred plants which had canopies with softer, rounded contours whereas plants with spikes, narrow pointed leaves in a sparse canopy, or straight-edged leaves were rated as less beautiful and less relaxing. This may be partially because of the association of sharp edges with danger, in particular concerns about the risk of physical harm from the cactus spikes and sharp pointed leaves of *Dracaena* were highlighted. These results support previous studies of leaf shape where participants preferred rounded natural shapes and considered sharp leaves stressful [65], less friendly, uglier, less comforting, colder, harder and more dangerous compared to round leaves [42]. The palm plant is somewhat of an exception as it has narrow pointed leaves but is also considered beautiful and relaxing, this could be due to the sharp points falling downwards in a gently arching shape, or its association with tropical settings and holidays eliciting a relaxing uplifting response. It is also a very familiar plant and previous studies have shown that frequent exposure can influence preferences, although the effects are complex [66–68]. A previous study of the effect of leaf shape on perceptions of house prices and safety, revealed that palm-like vegetation generated a unique response compared to other sharp leaved vegetation [42].

Previous studies have typically reported an aesthetic preference for the spreading tree shape [33,45,69], which is contrary to the result from this study where the spreading shape was significantly the least preferred. The researchers posited that spreading trees are indicative of rich natural settings which offer survival benefits [45,69,70]. Our results offer little support for this preference of the spreading canopy shape and are more aligned with studies by Bar and Neta [71], who found a preference for curved visual objects and proposed that the type of contours influenced people's response to objects.

### 3.10. Limitations of the research method

Understanding and predicting IAQ and SWB is a complex task and is affected by a multitude of factors. In this study people viewed photographs, whereas their responses may be different when viewing real plants. However, a previous study found oxy-haemoglobin concentrations in the prefrontal cortex increased when subjects viewed real plants, but their emotional responses were similar for both stimuli [72], suggesting that although physiological responses may be sensitive to the difference in the way the stimuli are presented, subjective and emotional reactions to the plants are adequately and appropriately captured by pictorial stimuli.

Within real indoor spaces, the plant appearance and people's responses may be influenced by the individual aesthetics of particular spaces such as the light levels, colours and spaciousness. Note that our participants provided their responses in multiple different environments over which we had no control, therefore we are confident that our data reflect the average effect over these testing environments, but they do not address how the plants might interact with specific office aesthetics. Indoor plants have been shown to affect other human senses such as through noise reduction [73] and scent [19] which could further affect people's responses and these are not captured here. An interesting area for future study is the reaction not just to plants or pictures of plants in isolation, but to plants embedded within particular settings. Plants in this study were viewed as a singular plant whereas plants in different arrangements may affect people's perceptions; this can be explored in future studies. The majority of participants in the survey reported that they liked indoor plants; this may have influenced their views, although previous surveys have generally reported people are positive about plants in the workplace [17,65].

## 4. Conclusions

This study investigated the psychological responses of 520 participants to the appearance of twelve images of indoor plants. The findings show that the physical appearance of the plant had a significant impact on participants' responses, their aesthetic preference and the perceived benefit of the plant for subjective well-being, indoor air quality and humidity.

Descriptors of the plant's physical appearance can be used to predict perceptions of its impact on IAQ and SWB. The terms Uplifting, Interesting, Relaxing and Beautiful were the strongest predictors of benefits for SWB. All healthy plants tested were considered beautiful to some extent and to have a positive impact on SWB. The most preferred plants in this study; *Epipremnum, Ficus* sphere, palm *and Ficus* column, were perceived to have the highest SWB benefit. To maximize the well-being benefit for building occupants, designers and installers should choose healthy indoor plants which people find beautiful and interesting.

The perceived benefits for IAQ and RH were most strongly associated with the healthiness, and canopy density of the plant rather than the shape, beauty, or softness of its appearance. Unhealthy plants should be removed from indoor environments as they may negatively impact people's perceptions of IAQ and SWB. The findings of this study show people's perceptions of the indoor environmental quality will be maximized by plants with lush, bright green leaves and high canopy density. These characteristics may also enhance the thermal comfort benefits derived from the presence of indoor plants identified in previous studies [18].

Participants identified plant shape as a key characteristic affecting the attractiveness of the plant. There was a preference for plants with rounded contours but there was no clear evidence that participants' preferences or responses were determined by a single canopy shape.

The demographics of the participants had very little effect on the preferences or scores for plant appearance or the perceived impact on SWB, IAQ, or RH. Plant selection for maximum benefit, can therefore remain consistent for environments with different anticipated occupancies.

Depending on the test used and task being undertaken, plant density and location have been shown to affect cognitive performance and productivity of building occupants [28,30,31]. Our results suggest that the appearance of the plants could further influence performance. This study provides new evidence that the appearance of indoor plants can significantly influence people's perceptions of the benefit of plants for indoor air quality, humidity and well-being. The findings can assist designers, architects, building managers and homeowners in choosing plants which have maximum benefit for the well-being of building occupants and to create different aesthetic environments.

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## CRediT authorship contribution statement

**Jenny Berger:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Emmanuel Essah:** Writing – review & editing, Supervision. **Tijana Blanusa:** Writing – review & editing, Supervision. **C. Philip Beaman:** Writing – review & editing, Supervision.

## Declaration of competing interest

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

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