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Research Paper

'Blossom Buddies' – How do flower colour combinations affect emotional response and influence therapeutic landscape design?

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HIGHLIGHTS

- Flower colours affect emotional responses.
- Limited information exists for the effects of flower colour combinations.
- A strong warm colour – orange inhibited the relaxing effect of cool colours.
- Cool colours though did not reduce the positive emotional uplift of a warm colour.
- A respondent's preferred colour/combination promoted restorative effects for that individual.

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ABSTRACT

Natural landscapes are linked to health and well-being outcomes. This research investigated emotional responses to colour in the landscape. An online questionnaire (with 715 respondents) was employed to capture participants' preferences and positive psychological reactions to key flower colours and combinations. Images were created using combinations of pansy flowers in various colours. Flower combinations explored the effects of complementary, analogous and warm/cool colour harmonies. Orange flowers (a warm colour) provided a strong uplifting emotion in participants: an emotional response that was maintained even when up to 50 % of the orange flowers were replaced by the complementary (and cool) colour of blue. In contrast, the relaxing effect of 100 % blue flowers was lost when 25 % or more of the flowers were replaced by orange. Using analogous cool colours, it was evident blue provided more feelings of relaxation than purple, and adding purple to a blue combination (50:50) reduced the capacity of the floral composition to promote relaxation. The colour found to be most relaxing, however, was white; but again mixing this colour with either blue or purple tended to reduce its capacity to relax. Thus, the study suggests that certain patterns of colours and combinations provide a generic response in enhancing emotional well-being of individuals; a point that can be exploited in designed therapeutic landscapes. The data also indicated, however, that cool colours scored quite highly for positive uplifting emotion (mean score > 6.5) and people's favourite cool colour/combination was often described as uplifting (7.4), indicating the subjective nature of colour preference and emotional response. Thus, whilst understanding key principles about colour and therapeutic responses, designers also need to take account of personal preference and should provide some variety of colours/colour combinations in different parts of a garden/park. These findings provide valuable insights for horticultural design practices, emphasizing the importance of colour selection and user preferences in creating supportive environments for mental well-being.

1. Introduction

Poor mental well-being has a profound impact on individuals and society at large (Freeman, 2022; OECD & Union, 2022). As the prevalence of mental health issues continues to rise, there is a growing need for effective preventive and therapeutic interventions (Scott et al., 2019). In this pursuit, the healing potential of nature has emerged as a promising avenue for promoting mental well-being and improving

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overall quality of life (Greenleaf et al., 2013; Hartig & Kahn, 2016; Collins et al., 2020; Joschko et al., 2023).

Nature has long been revered for its ability to soothe and restore the human mind. From the serene beauty of natural landscapes to the vibrant colours of blooming flowers, nature's transformative effects have captivated poets, artists, and philosophers throughout history. More recently, scientific investigations have sought to unravel the underlying mechanisms through which nature positively influences mental health outcomes.

Fundamental theories such as attention restoration theory (Kaplan & Kaplan, 1989), stress reduction theory (Ulrich, 1983; Ulrich et al., 1991), and positive affect theory (Bratman et al., 2015; Cameron et al., 2020; Richardson et al., 2016) have laid the groundwork for understanding the psychological benefits of nature exposure. These theories propose that engaging with natural environments promotes cognitive restoration, reduces stress, and elicits positive emotions. Importantly, nature (and garden elements including plants e.g. Cameron and Hitchmough, 2016; Cameron, 2023) can stimulate different emotions. These include uplift (or 'joy'- a form of positive affect) (Richardson et al., 2016) and relaxation (i.e. stress reduction (Ulrich, 1983, Kaplan & Kaplan, 1989). Both these emotions are linked to longer-term health benefits, but may do so via different modes of action (e.g. uplift – Steptoe, 2019 and relaxation – Yao et al., 2021; O'Connor et al., 2021).

While these theories have provided valuable insights into nature's impact on mental well-being, in recent years, there has been a shift in focus towards investigating how specific elements of design and quality of green spaces can be optimized to maximize their therapeutic potential (Stigsdotter & Grahn, 2002; Keniger et al., 2013; Collins et al., 2020; Olszewska-Guizzo et al., 2022; Harries et al., 2023;. Numerous studies have examined the impact of various design elements, including water features, non-threatening fauna, natural sounds, and, notably, colourful flowers (White et al., 2010; Peschardt & Stigsdotter, 2013; Hoyle et al., 2017; Deng, et al., 2020).

Building upon these findings, further investigation is warranted to delve into the nuanced aspects of small-scale design decisions, as it is often said that "the devil is in the detail." For instance, in a healing garden featuring colourful flowers, it becomes crucial to examine the specific colours of flowers that should be included. Previous research has indicated that certain flower colours elicit distinct responses (Gu et al., 2012; Jang et al., 2014; Xie et al., 2021). Nevertheless, it's worth noting that most of these studies had limited participant numbers ($\leq$30) or focused on specific sample populations (e.g., students). Most importantly, they often evaluated only a restricted range of colours.

Recent systematic studies have examined the impact of flower colour on emotions and affect. A study by Zhang et al. (2023) with a large sample of 670 participants evaluating eight different flower colours, found that cool flower colours like blue and purple effectively promoted relaxation and reduced stress. In contrast, warm colours like orange, yellow, and red evoked more uplifted and positive emotions. These findings were supported by a cross-cultural study conducted in both the UK and USA by Neale et al. (2021). These studies broadly support concepts around colour theory in general (i.e. not just in the context of flowers). The extent to which a colour can excite or arouse an individual has been linked to the wavelength of its light signal; long-wavelength colours, like red, orange, and yellow, being arousing and short-wavelength colours at the other end of the colour wheel spectrum notably blue, indigo, and violet, being relaxing (Walters et al., 1982). Green has been described as neutral in its emotional response – at least as far as its wavelength is concerned (Walters et al., 1982), although subjectively it is often linked with promoting relaxation (Kaya and Epps, 2004). White is considered relaxing, being associated with terms like calm and serene (Schaie, 1961). Zhang et al. (2023) though, suggested that white flowers had the capacity to induce both relaxation and uplift. Short-term, emotional responses to natural features, such as those evoked by flowers (Zhang et al., 2023) can be linked to potential resilience against more significant, long-term mental health problems (Berto, 2014; Barnes et al., 2018; Teismann et al., 2019; Chalmin-Pui, et al., 2021; Keenan et al., 2021).

Another significant limitation of previous studies is that they have primarily focused on individuals' responses to single colours (Li et al., 2012; Jang et al., 2014; Xie et al., 2021; Zhang et al., 2023), whereas therapeutic landscapes like gardens typically consist of mosaics of different flower colours. Therefore, it becomes imperative for future research to explore how combinations of colours influence psychological responses.

In the realm of planting design, a number of common principles around colour are employed. These include the use of analogous (sometimes termed 'adjacent') and complementary (sometimes termed 'opposite') colour harmonies. Analogous colour harmonies involve using colours that are adjacent or near each other on the colour wheel (red and orange for example), while complementary (i.e. opposite) colour harmonies combine the most contrasting colours (red and green for example) (White et al., 2021). Landscape designers also often refer too to 'warm' flower combinations that exploit bright hues of red, orange and yellow, and 'cool' combinations composed of blue, purple, green and white colours. Drawing inspiration from these principles and the existing knowledge regarding restorative flower colours, this paper investigates two groups of colour combinations. The first are analogous colour harmonies comprising pastel shades of blue and purple, and the addition of another 'cool' colour − white. Although white is not analogous to blue or purple on the colour wheel, it is often considered a cool colour in garden design (Neale et al., 2021) and was considered a 'relaxing' colour in a previous study (Zhang et al., 2023). Additionally, the flower colours selected for the experiment have a base colour (undertone) of green, which is adjacent to blue. The second combination was a complementary colour harmony, consisting of blue, (the most relaxing colour from Zhang et al., 2023) and the colour opposite on the colour wheel − orange (the most uplifting from Zhang et al., 2023).

The implementation of complementary colour harmonies in planting design aims to create visually striking compositions that captivate observers and evoke a profound sensory experience (Wilson, 2011). As noted by Georges Truffaut, an esteemed horticulturist, the harmony resulting from combining the most opposite colours on the colour wheel produces a captivating spectacle that can 'lift the spirit'. However, such observations have predominantly been rooted in anecdotal evidence and expert experience, lacking robust scientific validation. Thus the current study aims to verify if these complementary colour combinations can indeed induce emotional uplift. Moreover, if they do, is it due to the *contrast* between the two colours or simply the addition of a warm (i.e. an uplifting') colour to the composition? If it is the latter, does the relative contribution of the warm colour affect the extent of uplift induced; i.e. the more flowers with the warm colour the stronger the response? Conversely, it is also important to establish how complementary colours affect the relaxation potential of the flower composition. If blue, a cool colour associated with relaxation, is the dominant colour, does adding a splash of orange make the combination more uplifting while still maintaining its relaxing properties? To address these inquiries, this study examines five groups of opposite colour harmonies, using a single flower form, i.e. *Viola* × *wittrockiana* (pansy). By varying the proportions of orange and blue in pansy flower arrangements, including: 100 % orange; 75 % orange and 25 % blue; 50 % orange and 50 % blue; 25 % orange and 75 % blue; and 100 % blue —we hope to gain insight into the intricate dynamics of colour perception and its impact on mental well-being. *Viola* × *wittrockiana* (pansy) was chosen as a model subject due to its popularity and familiarity as a garden plant, being the most widely sold annual bedding plant in the UK and in the top three in USA (Cameron and Hitchmough, 2016). Moreover, this genus has numerous cultivars covering a very extensive range of flower colours. The range includes white, red, purple, blue, pink, orange, yellow, black and even brown flowering types. Clear flower colours are available as are blotched varieties (dark centre) and those with multiple colours on the petals. One major producer of pansy offers 77 distinct varieties –

which includes e.g. 7 variations on orange flower cultivars alone (Anon, 2024). So pansy was an ideal subject providing a wide range of flower hues to choose from.

The use of analogous colour harmonies poses its own set of challenges in planting design. The delicate balance between uniformity and complexity becomes a crucial consideration. Research has shown that landscapes with higher complexity tend to captivate viewers for longer durations and attract visual attention due to the difficulty of extracting information (Jacob & Karn, 2003). While landscapes featuring single blue flowers have shown promise in creating relaxing healing gardens, questions arise regarding the potential benefits of introducing other colours, even if they are also cool and calming. Will the introduction of an extra colour disrupt the overall sense of uniformity, or could it introduce a surprising positive effect? To address these questions, this study compares colour harmonies based on an analogous cool grouping (50 % blue and 50 % purple) with single cool hues (100 % blue vs 100 % purple vs 100 % white) as well as other combinations of these cool colours − 50 % blue and 50 % white; and 50 % purple and 50 % white.

Research found that in addition to the generic responses associated with key flower colours, other phenomena have been identified to contribute to the psychological benefits experienced. It has been suggested that an individual's preference for a specific colour can independently elicit positive psychological effects, regardless of the inherent properties of that particular colour (Kuper, 2020; Zhang et al., 2023). Similar phenomena have also been observed in the study of general colour theory (Brengman & Geuens, 2004; Manav, 2007). For example, if an individual's favourite colour is red, then red flowers may promote a relaxation response in that individual (despite red being generically associated with emotional uplift). Consequently, in this study, participants' preferences for the colour harmonies presented were collected and compared with the therapeutic responses they elicited. By considering individual colour preferences, we aim to further explore the complex relationship between flower colour perception and psychological well-being.

In summary, this research was implemented to help address the gaps in our knowledge of how flower colour *combinations* affect human emotions and link to well-being. Using complementary colours (blue and orange) we aimed to determine how the proportions of 'warm' orange and 'cool' blue in floral montages affected two key emotions – 'uplift' and 'relaxation'. We wished to test if the presumed uplifting emotion of orange (from previous studies, Jang et al., 2014; Zhang et al., 2023) was weakened by the addition of blue; and conversely, whether the addition of orange reduced the relaxing effect of blue. We were also interested in adjacent colours (blue and purple) and how flower mixes of these colours affected emotions – for example reducing or further emphasising the relaxing effect of blue? In this second experiment within our study we also included white flowers in some montages, as this colour, somewhat paradoxically, was often associated with both emotional uplift and relaxation in our previous study (Zhang et al., 2023). Links were made between emotional responses reported and the flower colours the participants stated they preferred. Previous studies have investigated multi-colour plant communities *in vivo* (e.g. Hoyle et al., 2017), but we believe this study is novel in that it systematically adds in new flower colours to a composition in a controlled and proportional manner.

Through this research, we hope to contribute to the development of evidence-based landscape practices for promoting mental well-being. Landscape architects are now frequently called on to design 'restorative' landscapes, including those within the care sector such as hospitals and hospice gardens, and more detailed, specific information is required to optimise the benefits of such landscapes. We feel more information is warranted on how different types of plants, their forms and colours can contribute to the well-being potential of designed landscapes. This study aims to determine principles based on complementary and adjacent colour combinations and their effect on human emotions, within this context.

2. Methods

2.1. Online questionnaire design and procedure

A questionnaire was designed to capture participants' preferences for, and positive psychological responses to, flower colour combinations. *Viola × wittrockiana* (pansy) was chosen as a flower subject as the plant and flower shapes are uniform, but the taxa provide a wide range of flower hues. Four *Viola × wittrockiana* (pansy) cultivars were purchased from a single nursery on 27 August 2022, and potted into 10*L* pots with a John Innes potting compost. Cultivars were chosen based on their contrasting flower colours: − *Viola × wittrockiana* F1 Matrix cultivars 'Deep Orange' 'True Blue', 'Purple' and 'White' referred to subsequently as 'Orange', 'Blue', 'Purple' and 'White' pansies, respectively. Each pot contained a single plant specimen, i.e. only one colour of flower. Plants were grown on outdoors and provided with additional water as required.

On October 19, 2022, various colour combinations of pansies were captured in photographs, by systematic arrangements of the pots. Images were taken with a Nikon Z50 camera. To achieve the desired proportions of colours with similar-sized flowers, photomontage techniques (Wang et al., 2017, 2019; Navarrete-Hernandez & Laffan, 2019; Deng et al., 2020) were utilised. Images were adjusted using Adobe Photoshop CC 2017 (Adobe Inc., San Jose, CA, USA) and included removing the backgrounds from original photographs, fine adjustments to the colour balance and ensuring flowers were to scale, and arranged spatially to represent plants with a number of flowers per plant. Any instances of flowers showing signs of deterioration or inconsistencies were identified and replaced in Photoshop. To refine the composite image's colour proportions, we utilised the "Image Color Summarizer" website (http://mkweb.bcgsc.ca/color-summarizer/) and fully aligned and layered flowers and leaves to create the desired colour proportions. To provide consistency and mimic a real scenario, an open green park space was used as background. Additionally, artificial blurring was applied at the edges to simulate an 'out-of-focus' periphery, similar to that observed in authentic photographs. The flowers were intentionally positioned to dominate the front third of each image, enhancing their prominence.

Despite these measures, there remained a possibility of variation in clarity, brightness, or saturation of the images due to differences in participants' devices (e.g., screen size, colour settings, etc.). Prior pilot studies conducted *in vivo* at the University, however, suggested the majority of participants can differentiate colours effectively across a range of devices and common settings.

During the experiment, participants were initially provided with an information sheet and a consent sheet. To avoid potential language bias, a glossary page explaining key terms used in the questionnaire ("uplifting" and "relaxing") was provided. Subsequently, participants were presented with one of two montages of images within the questionnaire (complementary colours – the first five images in Fig. 1; or analogous and cool colours – the six images in Fig. 2) and asked to rate individual images based on the degree of uplift (positive affect) and relaxation they associated with them, using a ten-point scale ranging from "not at all" (0) to "a great deal" (10). To maintain focus and consistency, only one image was displayed on the screen at a time. After rating each image, participants progressed to the subsequent image by selecting the 'forward' button. Participants had the flexibility to revisit and modify their rates for previously viewed images using the 'backward' button. To prevent participant fatigue and potential inauthentic responses, as well as to avoid bias caused by the order of image display, a double randomization process was employed. Firstly, participants were randomly assigned to either the complementary or cool colour harmonies group. Secondly, the program randomly allocated the order in which the images in each were presented to each participant. After rating the assigned set of five (or six) individual images, all the images in each group were displayed together, and the participants asked to

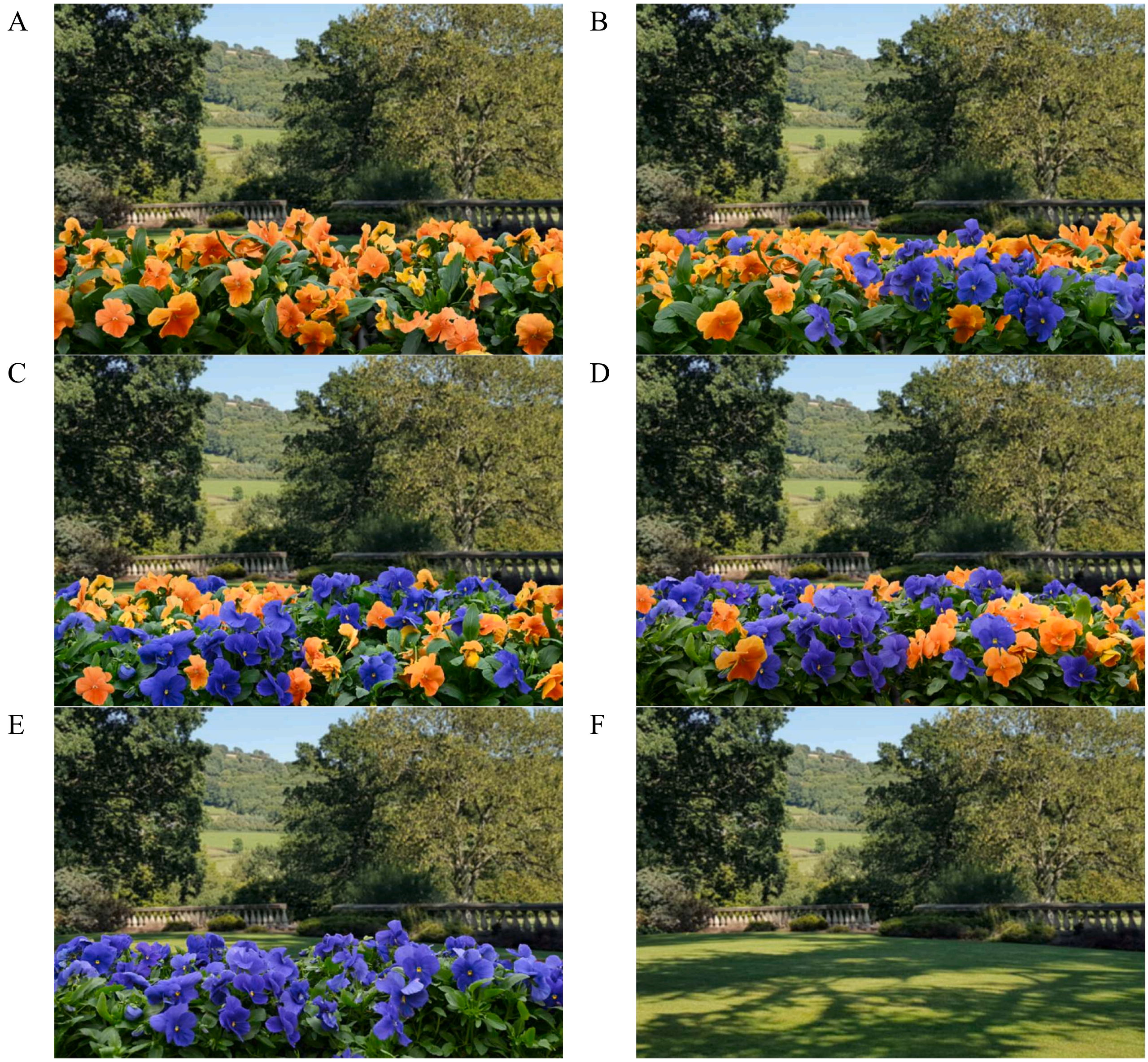

Fig. 1. Flower images of complementary colour harmonies/blue and orange flower combinations. A – 100% Orange, B – 75% Orange and 25% Blue, C – 50% Orange and 50% Blue, D – 25% Orange and 75% Blue, E – 100% Blue, F – Without Flower.

choose the image they preferred the most, and why. To give some indication of how the flowers themselves (irrespective of colour) were appreciated, a photo of the park background without flowers present (i.e. the last image in Fig. 1) was included in the preference question, but only for the complementary colour harmonies group.

The questionnaire ended with questions on demographic characteristics, particularly factors that may influence a participant's perception of designed landscapes or plants (Ode Sang et al., 2016). This included information on their place of residence and frequency of gardening. Furthermore, participants were asked whether they experienced any difficulty in perceiving colours, e.g. colour blindness or colour vision deficiency. Overall each participant was asked 16 questions, including six with respect to the Nature Relatedness Scale (Nisbet & Zelenski, 2013).

The online questionnaire survey was conducted using the dedicated web-platform Qualtrics (https://www.qualtrics.com/uk/). The survey was available for participants from December 5, 2022, to March 5, 2023, following ethical clearance (University Ethical Ref. 039702) and a pilot study conducted at the University of Sheffield (data not included). No incentives or rewards were offered for participating. After being informed about the study procedure, participants provided anonymous written consent via a consent form. Data was coded and authors had no access to information that could identify individual participants during or after data collection. Participants were English-speaking adults aged 18 years or older, and they had the option to terminate the questionnaire at any point. The questionnaire was promoted through emails, websites, social media platforms, and other online discussion forums. Careful consideration was given to ensure the inclusion of diverse platforms to reach participants across a broad age range. Additionally, preference was given to platforms predominantly using English to minimise language-related confusion during the completion of the questionnaire. By the end of the experiment, 354 people had been directed and responded to the first set of images (complementary harmonies), and 361 to the second set (analogous and white harmonies), giving a total of 715 respondents.

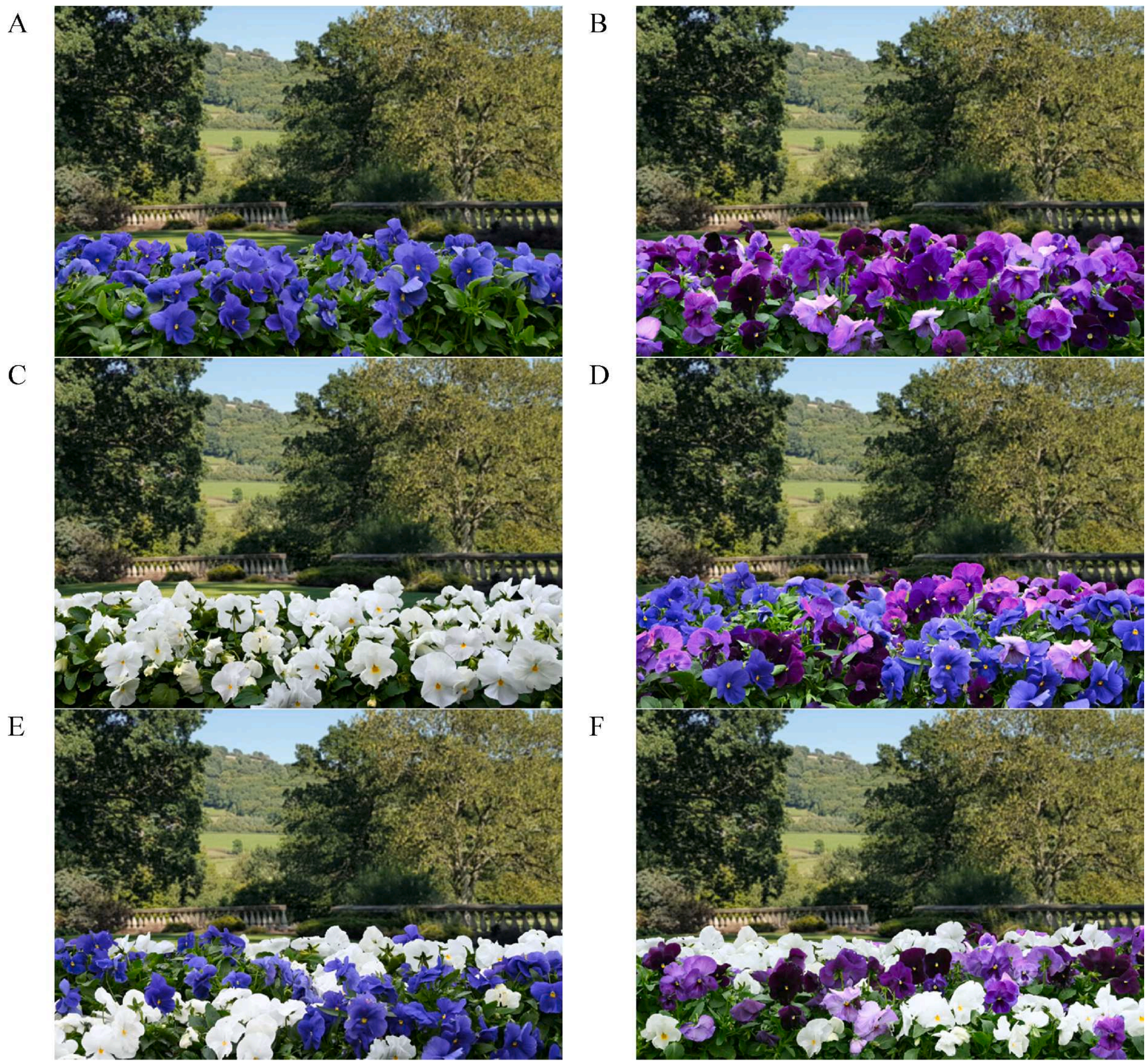

Fig. 2. Flower images of cool colour harmonies/blue, white and purple flower combinations. A – 100% Blue, B – 100% Purple, C – 100% White, D – 50% Blue and 50% Purple (analogous harmony), E – 50% White and 50% Blue, F – 50% Purple and 50% White.

2.2. *Online questionnaire data analysis*

Statistical analysis was performed using IBM SPSS Statistics for Windows 26.0 (IBM Corp, Armonk, NY, USA). Continuous variables were represented as means accompanied by standard errors (SE). The statistical analysis employed for these variables involved conducting a One-way repeated measures ANOVA followed by post-hoc pairwise comparisons with Bonferroni correction. Letters (a, b, bc, etc.) were used to indicate significant differences between mean values in corresponding figures. Categorical variables were presented as frequencies with corresponding percentages. To explore the associations between individuals' preferences for flower colour combinations and demographic variables, chi-square tests incorporating Fisher's exact tests and Pearson's chi-square tests were employed. The significance level was set at $p = 0.05$.

To gain insights into the reasons behind people's preferences for specific flower colour combinations, participants were asked an open-ended question: "Can you explain why?" The responses provided by the participants were systematically organised, coded and analysed using NVivo 2020 (QSR International Pty Ltd., Doncaster, Australia). A thematic analysis approach was adopted to identify recurring themes within the participants' responses (Braun & Clarke, 2006; Bryman, 2016). The data were thoroughly read and re-read to ensure familiarity, and codes assigned to capture the key ideas conveyed by the participants. These codes represented the primary concepts and patterns emerging from participants' explanations for their preferences. The coding process involved labelling specific segments of text with codes to categorise them according to their content and meaning. Following the coding process, the codes were compiled and categorised into broader themes based on their similarities and patterns. This allowed for a more comprehensive understanding of the reasons underlying participants' preferences for specific flower colour combinations.

3. Results

3.1. *Demographic characteristics of the sample*

Of the 715 participants who completed the survey and reported no difficulty in colour distinguishability, the majority, 79 %, were from the UK (Table 1). The distribution of ethnicities included 77 % White, 17 % Asian, and 6 % from Mixed/Multiple ethnic groups, Black/African/Caribbean, or other ethnic backgrounds. The participant pool spanned a wide range of ages, with a slight predominance of younger individuals. Approximately 67 % of participants held at least a bachelor's degree,

Table 1
Demographic profile of participants' (n = 715) (percentage of total in parenthesis) and attitudes to plant and health related factors.

Gender		Landscape Professional	
Male	183 (26 %)	No	620 (87 %)
Female	515 (72 %)	Yes	95 (13 %)
Non-binary/third gender	9 (1 %)		
Prefer not to say	8 (1 %)	**Gardening Frequency**	
		Rarely/never	378 (53 %)
Ethnic Group		2–3 times a month	169 (24 %)
White	553 (77 %)	Once a week	76 (11 %)
Mixed/Multiple ethic groups	18 (3 %)	2–3 times a week	65 (9 %)
Asian	118 (17 %)	Daily	27 (4 %)
Black/African/Caribbean	8 (1 %)		
Other ethnic group	18 (3 %)	**Living Environment**	
		Urban	284 (40 %)
Age		Suburban	323 (45 %)
18–24	206 (29 %)	Rural	108 (15 %)
25–34	187 (26 %)		
35–44	115 (16 %)	**Time Spent Outdoor as a Child**	
45–54	103 (14 %)	None	4 (1 %)
55–64	59 (8 %)	A little	70 (10 %)
65+	45 (6 %)	A moderate amount	276 (39 %)
		A lot	365 (51 %)
Education			
High school, GCSE or equivalent	141 (20 %)	**Nature Relatedness**	
Bachelor or equivalent	244 (34 %)	Very low	28 (4 %)
Master's or equivalent	236 (33 %)	Low	89 (12 %)
Doctoral or equivalent	90 (13 %)	Moderate	96 (13 %)
Other	4 (1 %)	High	218 (31 %)
		Very high	284 (40 %)
Living in			
United Kingdom	563 (79 %)		
United States	38 (5 %)		
China	25 (3 %)		
Other	89 (12 %)		

reflecting a relatively highly educated study population. In terms of gender, 72 % were female, and 26 % were male. Living environments were primarily suburban (45 %) or urban (40 %), with 15 % residing in rural areas (Table 1).

Regarding professional background, 87 % did not have expertise in landscape design or management, while 13 % were professionals in the field. However, the study attracted a substantial number of individuals with a passion for nature, as evidenced by 71 % of participants displaying a moderate to very high level of nature relatedness (nature connectedness). Moreover, 40 % of participants fell into the "very high" category, indicating a strong affinity towards the natural world. Additionally, the study revealed that 13 % of participants were frequent gardeners who gardened 2–3 times a week or more, while 51 % spent a lot of time outdoors during their childhood (Table 1).

3.2. Emotional responses

3.2.1. Complementary colour harmonies/blue and orange flower combinations

There were significant effects due to flower combinations for both uplifted emotions ($p < 0.001$, df. 227, Table S1) and relaxation ($p < 0.001$, df. 227, Table S2). Flower combinations consisting solely of orange pansies was found to elicit significantly higher levels of uplift ($p < 0.001$, Table 2, Fig. 3) and lower levels of relaxation ($p < 0.001$, Table 2, Fig. 4) compared to combinations comprising only blue pansies. Introducing blue pansies to an orange theme to create complementary colour harmonies, regardless of the proportion, did not yield statistically significant changes in the experienced feelings of uplift ($p = 1$, Table 2, Fig. 3) or relaxation ($p = 1$, Table 2, Fig. 4).

However, when orange pansies were added to a blue theme, even in a proportion as low as 25 % orange and 75 % blue, the complementary colour harmonies were observed to be significantly more uplifting ($p < 0.001$, Table 2, Fig. 3) and less relaxing ($p < 0.001$, Table 2, Fig. 4). In addition, the flower combination featuring an equal ratio of blue and orange pansies (mean 6.95 ± 0.100) was found to be significantly more uplifting than the combination dominated by blue flowers, i.e. with 75 % blue and 25 % orange pansies present (mean 6.73 ± 0.098) ($p = 0.002$, Table 2, Fig. 3).

Notably, compared with all other combinations, the flower combinations that received the highest preference ratings from participants had statistically the highest uplifted (mean 7.39 ± 0.118) ($p < 0.001$, Table 2, Fig. 3) and relaxed (mean 7.76 ± 0.106) emotion scores ($p < 0.001$, Table 2, Fig. 4). It is important to note that all images irrespective of flower colours/combinations had mean scores > 6, i.e. many respondents found the images overall uplifting and/or relaxing.

3.2.2. Cool colour harmonies/blue, white and purple flower combinations

Flower colour combinations affected uplifted emotions ($p < 0.001$, df. 360, Table S3). The data suggests, however, that individually the three cool colours, when used alone, did not differ in their capacity to uplift mood ($p = 1$, Table 2, Fig. 5). Augmenting one cool colour with another gave mixed responses. Mixing blue and purple flowers (the adjacent combination) increased positive uplift (mean 7.01 ± 0.110) compared to purple alone ($p < 0.001$, Table 2, Fig. 5), but not blue alone ($p = 0.418$, Table 2, Fig. 5). A combination of blue and purple was deemed more uplifting that a combination of white and purple ($p = 0.003$, Table 2), but not white and blue ($p = 1$, Table 2). Also, blue and white gave greater uplift than white and purple ($p = 0.004$, Table 2, Fig. 5).

Overall, there was a significant effect due to the flower colour combinations on relaxation ($p < 0.001$, df. 360, Table S4). Pansies with white flowers alone (mean 7.60 ± 0.102) were significantly more relaxing than those with blue alone (mean 7.33 ± 0.101, $p = 0.042$, Table 2) or combinations of blue and white (mean 7.18 ± 0.104, $p < 0.001$, Table 2). Additionally, combinations featuring all-purple pansies, including purple alone, purple and white, and purple and blue, were found to be the least relaxing. In other words, introducing another cool colour (blue or purple) into a white combination significantly decreased relaxation ($p < 0.001$, Table 2). Similarly, adding the analogous colour of purple to blue exhibited a decrease in relaxation compared to blue alone ($p < 0.001$, Table 2, Fig. 6). Conversely, incorporating another cool colour into a purple combination (blue or white) did not result in a significant change in relaxation ($p = 1$, Table 2, Fig. 6).

As with the first set of images – it is notable that all mean values in Figs. 5 and 6 have an absolute value > 6, again indicating that many people found uplifting elements and relaxing aspects of the images, irrespective of the flower colour combinations present.

Consistently, the flower combinations that garnered the highest preference ratings among participants were statistically proven to be both more uplifting (mean 7.46 ± 0.104, Fig. 5) and more relaxing (mean 7.89 ± 0.099, Fig. 6) to those viewing them than any set cool

Table 2
Analysis of Variance (ANOVA) pairwise comparisons of 'uplifted' and 'relaxed' emotion scores for flower images with complementary colour harmonies (i.e. orange [O] v blue [B]) and cool colour harmonies (i.e. blue [B] v purple [P] v white [W]): Number denote ratio of colour composition, e.g. 100O = 100 % orange flowers; Prefer = Preferred colour combination. Analysis based on estimated marginal means. * p < .05, ** p < .01, *** p < .001. a = adjustment for multiple comparisons: Bonferroni. Term 'n.s.' indicates a non-significant difference.

Colour Harmony (I)	Colour Harmony (J)	Uplifted Emotion			Relaxed Emotion		
		Mean Diff. (I-J)	Std. Error	Sig.[a]	Mean Diff. (I-J)	Std. Error	Sig.[a]
Complement.							
100O	75O - 25B	0.056	0.073	n.s.	0.000	0.077	n.s.
	50O - 50B	−0.105	0.079	n.s.	0.031	0.086	n.s.
	25O - 75B	0.113	0.082	n.s.	−0.082	0.092	n.s.
	100B	0.517***	0.089	<0.001	−0.616***	0.101	<0.001
	Preferred	−0.550***	0.095	<0.001	−1.160***	0.095	<0.001
75O - 25B	50O - 50B	−0.161*	0.052	0.020	0.031	0.060	n.s.
	25O - 75B	0.056	0.059	n.s.	−0.082	0.062	n.s.
	100B	0.460***	0.089	<0.001	−0.616***	0.097	<0.001
	Preferred	−0.607***	0.079	<0.001	−1.160***	0.086	<0.001
50O - 50B	25O - 75B	0.218**	0.058	0.002	−0.113	0.064	0.794
	100B	0.621***	0.092	<0.001	−0.647***	0.099	<0.001
	Prefer	−0.446***	0.080	<0.001	−1.191***	0.094	<0.001
25O - 75B	100B	0.404***	0.085	<0.001	−0.534***	0.090	<0.001
	Prefer	−0.663***	0.078	<0.001	−1.078***	0.087	<0.001
100B	Prefer	−1.067***	0.090	<0.001	−0.544***	0.092	<0.001
Cool							
100B	100P	0.116	0.082	n.s.	0.452***	0.088	<0.001
	100 W	−0.091	0.088	n.s.	−0.266*	0.085	0.042
	50B - 50P	−0.186	0.079	0.418	0.488***	0.085	<0.001
	50 W - 50B	−0.130	0.071	n.s.	0.150	0.070	0.691
	50P − 50 W	0.144	0.085	n.s.	0.421***	0.090	<0.001
	Prefer	−0.637***	0.070	<0.001	−0.560***	0.068	<0.001
100P	100 W	−0.208	0.096	0.635	−0.717***	0.097	<0.001
	50B - 50P	−0.302***	0.075	<0.001	0.036	0.081	n.s.
	50 W - 50B	−0.247	0.084	0.077	−0.302*	0.095	0.036
	50P − 50 W	0.028	0.075	n.s.	−0.030	0.077	n.s.
	Prefer	−0.753***	0.082	<0.001	−1.011***	0.089	<0.001
100 W	50B - 50P	−0.094	0.107	n.s.	0.753***	0.108	<0.001
	50 W - 50B	−0.039	0.080	n.s.	0.416***	0.083	<0.001
	50P − 50 W	0.235	0.086	0.133	0.687***	0.083	<0.001
	Prefer	−0.546***	0.076	<0.001	−0.294**	0.079	0.004
50B - 50P	50 W - 50B	0.055	0.079	n.s.	−0.338**	0.093	0.007
	50P − 50 W	0.330**	0.086	0.003	−0.066	0.087	n.s.
	Prefer	−0.452***	0.082	<0.001	−1.047***	0.086	<0.001
50 W- 50B	50P − 50 W	0.274**	0.073	0.004	0.271*	0.084	0.027
	Prefer	−0.507***	0.069	<0.001	−0.709***	0.075	<0.001
50P − 50 W	Prefer	−0.781***	0.079	<0.001	−0.981***	0.089	<0.001

colour or combinations of colour ($p < 0.001$, Table 2). As preference plays a key role in the emotional responses to colour combinations, the next section will further investigate participants' preferences for different flower colour combinations, along with the factors that may influence them.

3.3. *Preference*

3.3.1. *Complementary colour harmonies − blue and orange flower combinations*

Among 354 participants who were presented with the complementary colour harmonies (Fig. 1), large proportions of respondents preferred the image without flowers at all (36 % of total), this proportion

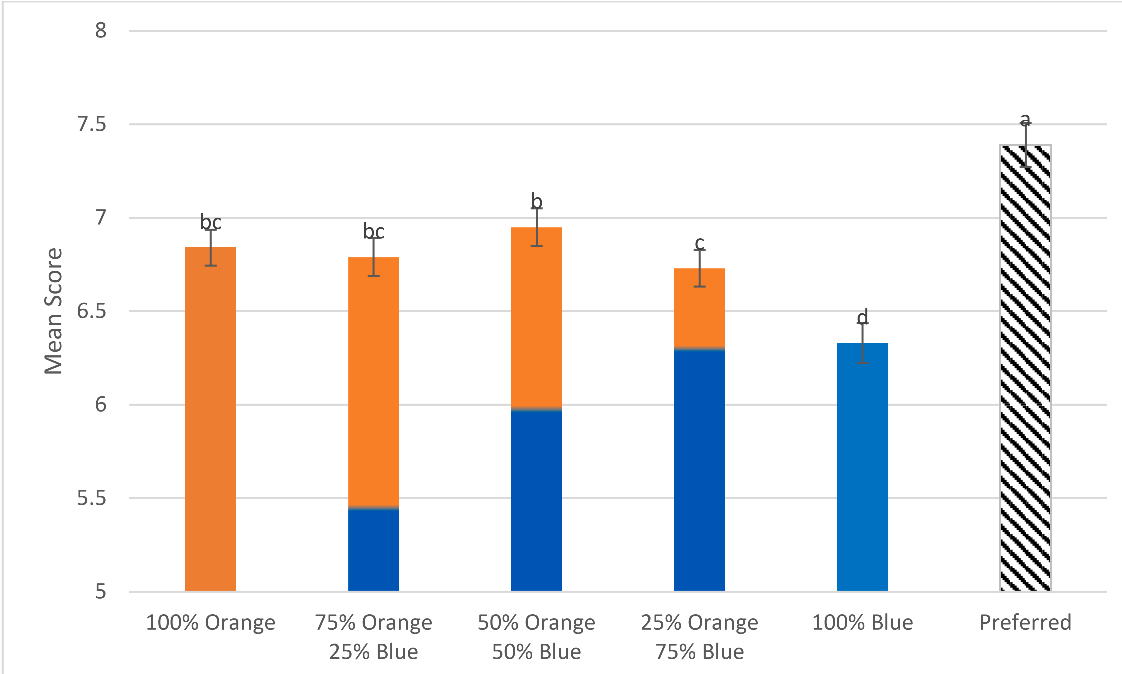

Fig. 3. Mean uplifted emotion scores for flower images of complementary colour harmonies/blue and orange flower combinations are presented. Error bars represent the standard error (SE) of the mean. Letters denote significant differences between means based on post-hoc tests. For example, within the group, 50% Orange and 50% Blue (b has significantly greater score than e.g. 25% Orange and 75% Blue (c), but is not significantly greater than 100% Orange (bc). The 'preferred' column relates to the uplift score based on an individual's preferred image, irrespective of what that colour/combination was.

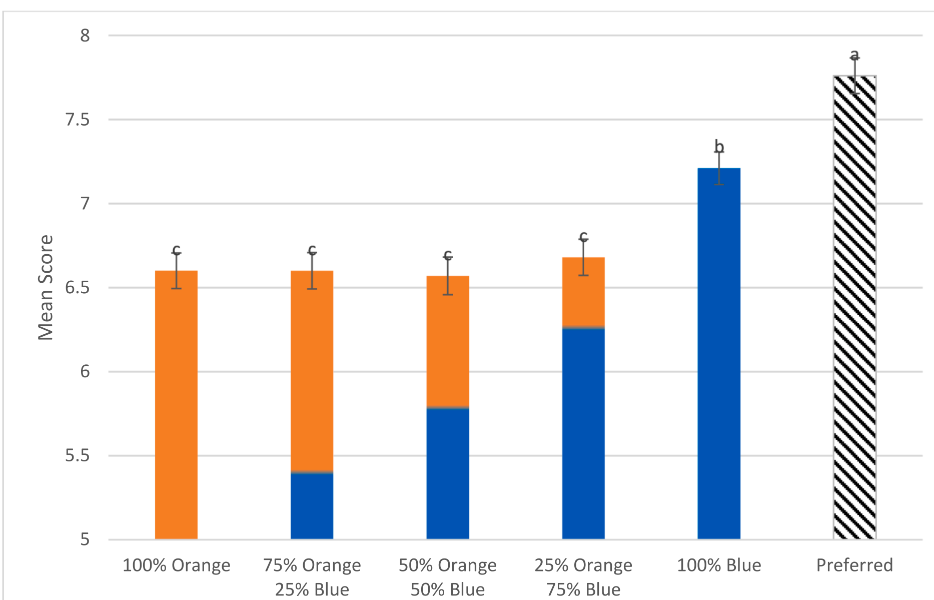

Fig. 4. Mean relaxed emotion scores for flower images of complementary colour harmonies/blue and orange flower combinations are presented. Error bars represent the standard error (SE) of the mean. Letters denote significant differences between means based on post-hoc tests. For example, within the group, Preferred (a) has significantly greater score than e.g. 100% Blue (b), and 25% Orange and 75% Blue (c). The 'preferred' column relates to the relaxation score based on an individual's preferred image, irrespective of what that colour/combination was.

increasing as age of the group increased (Table 3). A Fisher's exact test revealed a statistically significant association between respondents' age and their preference for flowers in the image, and indeed, different blue and orange flower combinations ($p < 0.001$). Participants in the 18–24 age group exhibited a relatively even preference for the various flower combinations, except for the combination with 100 % orange and 25 % blue, which was chosen by only 8 % of participants. In the 25–34 age category, 100 % blue flowers were the most popular (21 %), and in 35–44 year olds a 50:50 orange/blue ratio (24 %) was most popular, in those images with flowers present.

Nature relatedness level demonstrated a significant correlation ($p = 0.041$, CI [0.037, 0.045]) with flower preference. Participants with a "Very high," "High," and "Moderate" level of nature relatedness exhibited the highest preference for the image without flowers, while

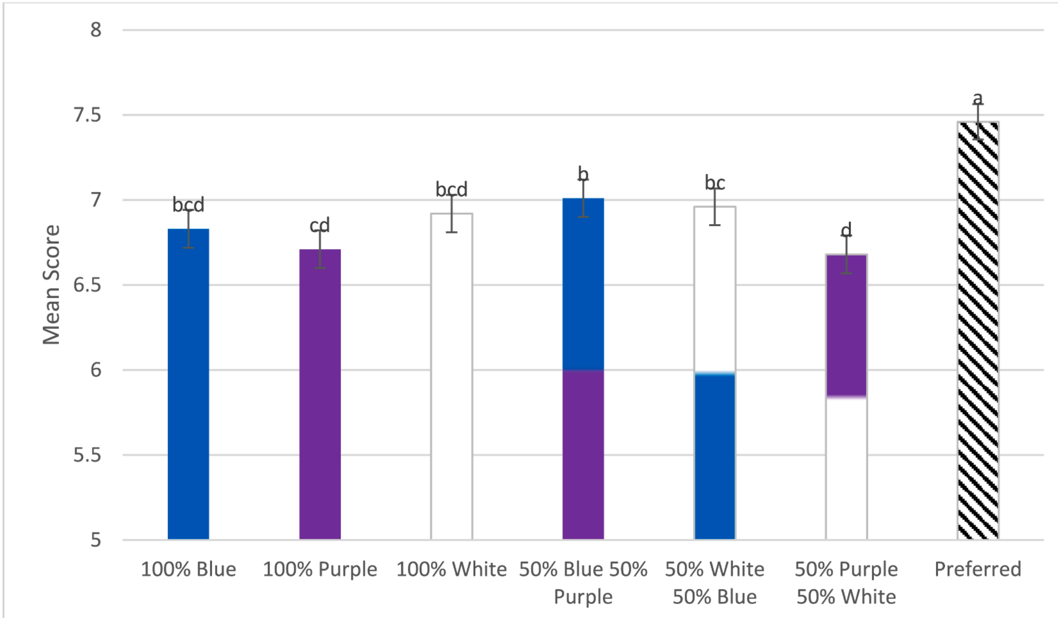

Fig. 5. Mean uplifted emotion scores for flower images of cool colour harmonies/blue, white and purple flower combinations are presented. Error bars represent the standard error (SE) of the mean. Letters denote significant differences between means based on post-hoc tests. For example, within the group, 50% Blue and 50% Purple (b) has significantly greater score than e.g. 100% Purple (cd), but is not significantly greater than 50% White and 50% Blue (bc). The 'preferred' column relates to the uplift score based on an individual's preferred image, irrespective of what that colour/combination was.

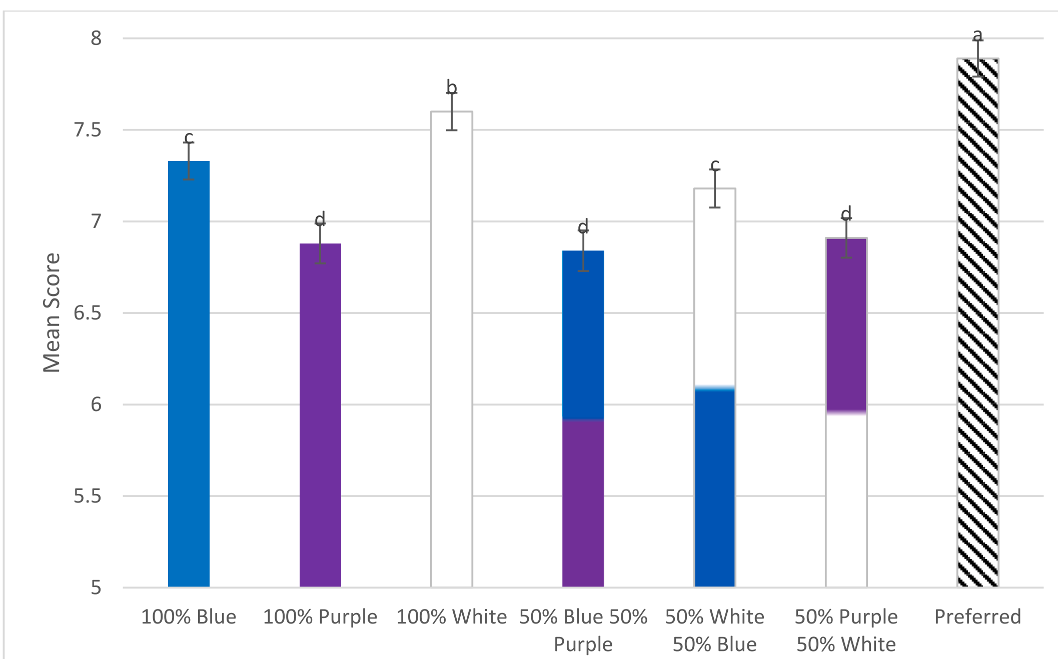

Fig. 6. Mean relaxed emotion scores for flower images of cool colour harmonies/blue, white and purple flower combinations are presented. Error bars represent the standard error (SE) of the mean. Letters denote significant differences between means based on post-hoc tests. For example, within the group, 100% White (b) has significantly greater score than e.g. 100% Blue (c), and 100% Purple (d). The 'preferred' column relates to the relaxation score based on an individual's preferred image, irrespective of what that colour/combination was.

displaying relatively even preferences for the other combinations (Table 4). In contrast, participants with "Low" or "Very Low" levels of nature relatedness appreciated the flower images better, with 100 % blue (25 %) and 50 % orange/50 % blue (21 %) being popular with the "Low" group; and the "Very Low" group favouring 100 % orange (36 %) and 25 % orange/75 % blue (27 %) (Table 4).

To investigate factors influencing participants' preference choices beyond demographic differences, an open-ended question was posed: 'Can you explain why you prefer this image?' A majority, 89 % of participants, answered the questions. Almost 40 % of participants who preferred the image without flowers mentioned words 'open/spacious', or 'less chaotic/busy", associating them with a sense of relaxation. Many participants also cited the dominant green colour from the grass, which evoked feelings of both relaxation and uplift. Those who chose a

Table 3
Preferred flower colour of complementary colour harmonies/blue and orange flower combinations. Percentage of participants (n = 354) by age.

	n	Percent					
		100 % Orange	75 % Orange & 25 % Blue	50 % Orange & 50 % Blue	25 % Orange & 75 % Blue	100 % Blue	Without Flower
Age							
18–24	107	8	18	19	15	21	21
25–34	99	16	12	17	6	21	27
35–44	54	7	11	24	6	15	37
45–54	52	8	4	4	15	17	52
55–64	25	4	8	4	4	8	72
65+	17	6	6	0	12	6	71
Total	354	10	12	15	10	18	36

Table 4
Preferred flower colour of complementary colour harmonies/blue and orange flower combinations. Percentage of participants (n = 354) by nature relatedness level.

	n	**Percent**					
		100 % Orange	75 % Orange 25 % Blue	50 % Orange 50 % Blue	25 % Orange 75 % Blue	100 % Blue	Without Flower
Nature Relatedness Level							
Very low	11	36	9	9	27	9	9
Low	44	9	16	21	11	25	18
Moderate	46	11	13	9	13	13	41
High	112	12	13	19	9	16	32
Very high	141	6	10	13	9	19	44
Total	354	10	12	15	10	18	36

combination with orange and blue flowers expressed a preference for the contrast between the two colours. Notably, 10 out of 55 participants who favoured the combination featuring an equal proportion of blue and orange pansies mentioned words like 'balance'.

Interestingly, participants who selected the uneven combination of 75 % orange and 25 % blue provided similar responses to those who preferred 100 % orange. They often mentioned their appreciation for the bright or warm feeling that orange evokes, with minimal mention of the blue in the combination. Conversely, the uneven mixture of 25 % orange and 75 % blue, instilled feelings of calm and relaxation.

3.3.2. *Cool colour harmonies/blue, white and purple flower combinations*

Among the 361 participants presented with images of cool (including the analogous purple/blue) colour harmonies, the combination featuring all-white pansies received the highest preference, with 26 % choosing it as their favourite (Tables 4 and 5). The percentages of participants choosing images with other colour combinations were relatively similar (around 15 %). However, the combination with half purple and half white pansies received the least favour: only 11 % of participants selected it as their preferred choice (Tables 4 and 5).

Fisher's exact tests revealed a statistically significant association between respondents' preference for cool colour flower combinations and two variables: ethnic group ($p = 0.027$, CI [0.024, 0.030]) and education ($p = 0.014$, CI [0.011, 0.016]). Specifically, the preference choices of white participants aligned closely with the overall sample preferences mentioned above, likely due to the fact that nearly 80 % of the participants were white (Table 1). Among the second-largest ethnic group, Asian participants, the highest favourability was observed for both the 100 % white combinations and the half blue and half white combinations (33 %) (Table 5). Participants with a doctoral or equivalent education degree demonstrated a preference for purple flower combinations, while the majority of others predominantly favoured all-white flowers (Table 6).

People who preferred cool combinations provided similar reasons, expressing their appreciation for the colour, and describing it as relaxing, calming, or peaceful. An exception was observed among participants who chose full white pansies, as 13 % of them also mentioned the word "bright" in their comments. Participants who preferred mixed colour combinations often mentioned liking the combination of the two colours, perceiving them as well-matched, and finding them more interesting. In comparison to participants in the group of complementary colour harmonies, only 4 % individuals mentioned feeling "uplifted" in their responses, with many more discussions focusing on the sense of relaxation (33 % of participants). This suggests that while the images may have been rated on their uplifting qualities, participants' overall perception leaned more towards a relaxing experience. This

Table 5
Preferred flower colour of cool colour harmonies/blue, white and purple flower combinations. Percentage of participants (n = 361) by ethic group.

	n	Percent					
		100 % Blue	100 % Purple	100 % White	50 % Blue 50 % Purple	50 % Blue 50 % White	50 % Purple 50 % White
Ethic Group							
White	286	15	16	25	17	15	12
Mixed/Multiple ethnic	11	18	27	18	18	0	18
Asian	54	11	4	33	13	33	6
Black/African/Caribbean	3	0	67	33	0	0	0
Other	7	14	14	29	14	29	0
Total	361	14	15	26	16	17	11

Table 6
Preferred flower colour of cool colour harmonies/blue, white and purple flower combinations. Percentage of participants (n = 361) by education.

	n	Percent					
		100 % Blue	100 % Purple	100 % White	50 % Blue 50 % Purple	50 % White 50 % Blue	50 % Purple 50 % White
Education							
High school, GCSE/ equiv.	72	21	13	31	8	24	4
Bachelor/ equiv.	127	16	15	28	17	18	7
Master's /equiv.	113	13	14	27	18	13	14
Doctoral /equiv.	46	4	22	15	24	13	22
Other	3	0	0	0	33	33	33
Total	361	14	15	26	16	17	11

finding underscores the subjective nature of emotional responses to colour combinations and highlights the dominant theme of relaxation observed among the participants who viewed cool colour comparisons.

4. Discussion

The present study aimed to explore the influence of specific colours and colour combinations on psychological responses in therapeutic landscapes, specifically focusing on complementary and cool (including analogous) colour harmonies.

4.1. Complementary colours

The findings regarding complementary colours revealed that a group consisting solely of orange pansies was perceived as more uplifting, but less relaxing, than a uniform group of blue pansies. This aligns with previous research and the foundation of this study, suggesting that warm colours (like orange) evoke uplifted emotions and deliver better positive affect, while cool colours (like blue) play an effective role in relaxation and stress reduction (Neale et al., 2021; Zhang et al., 2023).

Surprisingly, the addition of blue pansies to an orange harmony did not significantly alter the experienced feelings of uplift – the uplifting effect of orange still dominated (Fig. 3). However, when orange pansies were introduced to a blue harmony, even in a proportion as low as 25 % orange and 75 % blue, the combinations became significantly less relaxing (Fig. 4) and more uplifting (Fig. 3). We believe these results on the systematic inclusion of cool colour to a warm flower composition (and vice versa) on people's emotional responses are novel.

To optimise emotional uplift, the ratio of colours seems important. The combination featuring an equal ratio of blue and orange pansies was found to be significantly more uplifting than the combination dominated by blue flowers with a smaller proportion of orange (Fig. 3). This suggests that a balanced mixture of blue and orange can heighten the uplifting effect while maintaining some cool colours in the composition. Thus, to create an uplifting garden, it is possible to have both warm and cool colour flowers, but the warm colours should represent at least half of the planting design (based on this study on blue and orange, at least). Another implication from this data is that in a complementary colour harmony, the uplifting colour itself likely plays a more important role (more orange = more uplift) than the contrast *per se* (the contrast between blue and orange is still present in a low blue ratio, but less positive uplift is recorded).

4.2. Analogous and cool colours

With cool colours, increasing colour diversity through the addition of another cool colour did not significantly increase emotional uplift, except in the case of the combination of purple and blue (Fig. 5). This combination exhibited a statistically significant enhancement in uplift compared to combinations featuring solely purple pansies. This is an intriguing result, as blue and purple are considered very similar to each other and superficially seem to have very little contrast.

Regarding the relaxation effect, white pansies alone were significantly more relaxing than all other cool colour combinations, including the pure blue group (Fig. 6). This finding differs from our previous study (Zhang et al., 2023). It is possible that the blue colour of the flowers used in the two experiments varied in tone, which could account for the difference in results. Nonetheless, the pure blue composition here, along with the blue and white combination, still ranked second equal in terms of relaxation in this study. Therefore, these three combinations – 'white', 'blue' and 'white combined with blue' should be considered by landscape architects when designing relaxing therapeutic landscapes.

All purple combinations, including purple alone, purple and white, and purple and blue, were found to be less relaxing compared to those with blue or/and white flowers. These results suggest that, in the context of relaxing colours, the specific colours employed have a more significant impact on emotional responses than colour diversity itself. In addition, it is worth considering the nuanced attributes associated with different shades of purple within the context of this investigation. Some participants noted a perceived presence of red/warm undertones in the purple hue employed in this study. Hence, the choice of specific hues, along with their inherent colour attributes, may be influencing the intended emotional states within the domain of relaxing colour palettes.

4.3. Preference

Despite the clear advantages of warm colours for uplift and cool colours for relaxation discussed above, it is noteworthy that the strongest responses were associated with colours or colour combinations that participant's actually *preferred*. This implies that an individual's inclination towards a particular flower colour combination can elicit positive psychological benefits, irrespective of the specific colours involved. These findings underscore the subjective nature of colour preferences and their potential impact on emotional experiences, aligning closely with previous literature (Kuper, 2020; Zhang et al., 2023). The results also reveal, paradoxically, relatively high scores for uplift in cool colour harmonies (mean values > 6, Fig. 3) and relatively high scores for relaxation with the orange combinations (mean values > 6.5, Fig. 4). This reinforces the point that individual preference is diluting our primary, simplistic assumptions that warm colours are exclusively uplifting, and cool colours are merely relaxing. Thus, when designing environments with flowers, incorporating *preferred* colour combinations may serve as a catalyst for enhancing the emotional well-being of individuals. This study contributes valuable insights in this regard.

Notably, within the cool colour harmonies in this study, the fully white combination received preferences from 95 participants, which is twice as many as the preferences for the blue-only combination. It is worth highlighting that among participants who opted for the full white pansies, many not only chose this colour scheme but also explicitly mentioned the word "bright" in their comments. This finding aligns with prior research in the field (Granger, 1955; Hemphill, 1996; Zhang et al., 2023), reinforcing the significance of the "bright" aspect in the allure of white flowers.

Furthermore, white flowers have been consistently identified as the most preferred flower colours in our previous literature (Zhang et al., 2023) and elsewhere (Pavlova, 2015), indicating that white is a colour capable of inducing both relaxation and uplifting emotions. Our study found that the fully white flower combination was the most relaxing, while also being one of the most uplifting colour combinations within the cool colour harmonies. These findings strongly suggest that a garden predominantly featuring white flowers, holds significant promise as a healing garden.

Looking into participants' reasons for preferring a mixed colour combination, words like "interesting" were commonly mentioned. Additionally, the word "balancing" was most frequently used by people when discussing their preferences for equal-ratio colour combinations, indicating harmonious blends are visually appealing.

The preference for flower colour combinations was also influenced by participants' demographic variables such as age, ethnicity, nature relatedness, and educational background, which aligns with findings in studies of general colour preference (Choungourian, 1968; Dalke et al., 2006; O'Connor, 2011; Ghamari & Amor, 2016) and flower colour preference (Saito, 1996; Neale et al., 2021; Zhang et al., 2023).

Despite the literature that state flowers are one of the key elements that evoke emotions in a designed landscape (Haviland-Jones et al., 2005) and are linked with restorative health responses (Hoyle et al., 2017; Nordh et al., 2011), it is noteworthy here that many participants expressed a preference for an open space without flowers rather than with them. Based on participants' feedback, the therapeutic influence of green spaces continues to be attributed to the presence of "green" elements, such as grass and trees, as indicated in prior research that contrasts flowers with green components (Nordh et al., 2011). Broadly, the relative preference for the non-flower (green) image increased with age (although there were much fewer people over 55 who took the survey) and higher reported nature engagement levels.

4.4. *Complexity of image and numbers of colours present*

The relative popularity for non-flowering images suggest that over-complexity of the image and the fractals employed in each could have been an additional factor affecting preference (Huang and Lin, 2019; Lavdas & Schirpke, 2020; Muth et al., 2021). There was some limited evidence too, that certain flower images and combinations were mentally over-loading some participants (see Limitations below). In the context of colour alone, our data suggests simpler colour compositions were preferred. The colour themes favoured by the majority of participants were monochromatic: 100 % blue in the first set of images and 100 % white amongst the second set of images. Sometimes, simplicity proves to be more favourable, although the literature comes to no overall consensus on this. Whilst Zhao et al. (2022) support the notion that less complex features in the landscape (lawn grass) are more restorative than more complex geometrical ones (bamboo), others report more complex vegetation structures are actually preferred (Harris et al., 2018). Similarly, Shi et al., (2022) suggest that increasing plant diversity (and heterogeneity) in the landscape increases aesthetic preference, but did not make comment about the potential of such landscapes to be restorative *per se*. Additionally, a previous study found that flowers with lower complexity received the highest beauty ratings, further reinforcing this notion of preference (Hůla & Flegr, 2016). Further research is warranted in this area, especially in investigating systematically the relationships between visual composition complexity, preference and well-being.

4.5. *Implications for landscape architects*

The results have important implications for landscape design. To promote the maximum feelings of relaxation cool flower colours should be used predominately in a garden setting; as even the limited inclusion of bright, warm colours to an otherwise cool coloured landscape, may undermined the desired, optimum relaxation response (Fig. 4). Although warm colours may induce relaxation in some people – orange pansies scored 6.6 out of 10 (Fig. 4) for relaxation, the values for white (6.9) and blue (6.8) were higher (Fig. 5; although care should be taken when comparing absolute scores across two different sample populations). Nevertheless, both the data here and from our previous research (Zhang et al., 2023), where white and blue significantly increased relaxation over orange and other warm colours (within the same sample population) suggests that cool colours should be favoured when aiming for a relaxation response. We did not evaluate all the cool colours in the colour spectrum in this study, but of those we did, we conclude that three compositions – 'white', 'blue' and 'white combined with blue' should be considered when designing specifically relaxing landscapes. Anecdotally, these colours are often quoted as calming, but so is purple, yet our results did not fully substantiate this.

The long-term health benefits of uplift (moments of joy) (Richardson et al., 2016; Cameron et al., 2020) are relatively under-reported compared to that of relaxation and stress relief (Kaplan & Kaplan, 1989; Ulrich et al., 1991), yet therapeutic gardens should not be viewed solely in terms of relaxation and inducing calm. The use of warm flower colours and complementary combinations have a role to play in evoking strong positive emotions – with their own separate implications for health. Certain locations in gardens can be devoted to warm colours as a distinct therapeutic intervention. Moreover, our data suggests that these areas can also include cool colours, so long as the warm colours continue to dominate the composition (e.g. consist of more than 50 % of the flowers in the one area). It is worth noting that we have not conducted an examination of analogous warm hues here; therefore, it is imperative to acknowledge that further study is required to ascertain whether colours such as red and yellow may exhibit an excessive dominance, when combined with orange.

In addition, our data suggested strong salutogenic responses associated with an individual's preferred colour/colour combination. Again landscape architects should accommodate opportunities for colour mixes to be presented that can link to people's individual preferences (including perhaps areas without flowers – see below). Taken in the round, these points suggest many gardens should provide distinct areas or 'rooms' that align with people's emotional desires at any one time or cater for different individuals and their preferences. Marcus and Barnes (1999) have proposed that while a particular garden may meet the needs of one group, they also speculated that gardens could be as varied as the patient groups they are meant to serve. This proposition was supported by a more recent study conducted by Goto et al. (2013). Meanwhile, for those with stress-related mental disorders, reducing stress and gaining positive joviality from the natural environment are beneficial at *different* stages of the recovery process (Palsdottir et al., 2014). A study by Corazon et al. (2010) showed how different areas of the healing forest garden at Nacadia created peaceful, or conversely, stimulating natural environments, which aided in stress and trauma recovery. Therefore, planting designs with the "right" flower colour combinations in the "right" areas can be beneficial for people's recovery at various stages.

The link between people with high nature relatedness scores and preference for the (green) image without flowers perhaps alludes to situations where foliage or specific plant types (e.g. native species) becomes more important. For example, it may be that landscape architects can rely less on strong flower colours to gain appreciation for the landscape where communities value local nature highly or hold stronger pro-environmental attitudes (hybrid, large-flowered 'bedding-plant' pansies used here for example, might not align with ideas of nature/naturalness).

4.6. *Limitations to the study*

There are some limitations of the study. Firstly, the use of online questionnaires may introduce variability in colour perception due to differences in participants' devices. However, significant differentiation in colour between the options should still have been discernible. In other studies, involving this team (e.g. Liwen et al; Farris et al. – unpublished), we have compared responses from on-line questionnaires directly to that of computer lab studies – where in the latter we control colour intensity and brightness, and found little variation in experimental results. Secondly, although efforts were made to minimize the display of similar images to participants (we showed a maximum of seven images in total), it is possible that fatigue and a sense of repetition may have occurred, potentially causing some inaccuracies at the end of the questionnaires. Some participants commented on feeling 'over-loaded' by the repetition of images of a similar theme. Future verification of results in real-world or virtual settings is warranted. Our protocols now involve larger sample groups in pilot studies to test that the questionnaire duration/number of images is not excessive to cause fatigue.

It should also be noted that throughout all the data, the mean values presented always exceed a value of 6 (in a range of scoring options that ranged from 0 to 10). This could be interpreted as misunderstandings around the terms 'uplift' and 'relaxation' (despite us defining these). However, it may also be true that the images presented were both providing elements that some saw as uplifting, and some saw as relaxing. So for example, the image with only orange flowers could receive quite a high score for relaxation – possible due to the green background, or the rural aspect of the scene in general. The nature of the topic (flowers in the landscape) and the terms presented 'uplifting' and 'relaxing' may have elicited relatively subjective responses; for example, many participants may describe the presence of flowers in general (irrespective of colour), as being relaxing or uplifting. This is especially so as we did not design the questionnaire to make comparison across images (i.e. we did not ask if 'A' is more uplifting than 'B'), but rather asked participants to evaluate each image separately, on its own merit.

Furthermore, the sample primarily consisted of English-speaking adults from the UK, with a skewed representation towards female participants and those under the age of 34. It is important to further investigate how gender or ethnic background may influence some of the reported results. Lastly, the study focused specifically on pansy flower combinations, and the results may not fully capture the broader range of flower species and their respective colour effects. Further research is needed to explore the impact of different flower species and their colour combinations on psychological responses.

5. Conclusions

Data presented here indicates flower colour influence emotional responses, and thus may affect well-being and restorative processes. Gardens/landscapes designed to be relaxing and promote tranquillity can utilise white and blue flowers and avoid the inclusion of cultivars with warm coloured flowers such as orange, red or strong yellow (Zhang et al., 2023). In contrast, the inclusion of cool colours does not necessarily diminish a landscapes capacity to induce uplift, although perhaps more than 50 % of the composition should involve the stronger, warmer colours. Despite these generic 'rules' it is important to note individual preferences for specific colour combinations can evoke positive psychological benefits, irrespective of the specific colours chosen. This may be one aspect at play in private gardens – where individuals choose their own (presumably preferred) colours and combinations and often quote restorative responses (Chalmin-Pui et al., 2021). This research utilised a limited range of hues in the colour wheel, but confirms previous anecdotal information that white, blue and green can be used to help induce feelings of calm and relaxation. Future research, however, needs to examine a wider range of colours and specifically their combinations. Nevertheless, this study raises some important principles for landscape architects as they move towards designing effective, evidence-based 'restorative' landscapes and strengthens our understanding of the 'cause and effect' between aspects of design and citizen well-being.

CRediT authorship contribution statement

Liwen Zhang: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nicola Dempsey:** Writing – original draft, Supervision, Resources, Methodology. **Ross Cameron:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization.

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.

Data availability

Data will be made available on request.

Acknowledgement

For the purpose of open access, the authors have applied a Creative Commons Attribution (CC BY) licence to any Author Accepted Manuscript version arising. We extend our gratitude to Yuzhou Du for his assistance with plant procurement and photography, to Bartolomeo Sasso for his contributions in plant acquisition and planting, to Zhouhui Lu for his diligent plant care, and to Simone Farris and Pablo Javier Navarrete Hernandez for their suggestions in designing and developing the online questionnaire on Qualtrics. Their support was vital to the success of this research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2024.105099.

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