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Shades of green for living walls – experiences of color contrast and its implication for aesthetic and psychological benefits

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ABSTRACT

Living (green) walls are nature-based solutions (NbS) that can be an important environmental and social contributor within urban environments, but there are important knowledge gaps remaining in understanding their psychological benefits. In planning processes, aesthetic thinking is incorporated to improve attractiveness, health, and well-being outcomes in urban greenery solutions. However, in contrast to the wealth of research on well-established green infrastructure like urban parks, there is a knowledge gap for recently created ecosystems such as living walls and green roofs with respect to the relationship between aesthetic value, species composition, and psychological benefits. In order to increase this knowledge base this study explores human experiences of color characteristics on living walls, and the implementation of living walls for improving human health and well-being. We used a color theory framework in the development of graphical color contrast combinations designed by various green shades, and tested each color concept combination on human judgement of affective qualities. The results showed that living walls, designed through color contrast principles, have the potential to be comprehensively designed from an aesthetic aspect and be highly valued by people. However, the results indicate that perceived color contrasts may also reduce levels of arousal and human experiences of pleasantness. While more work on this topic is needed, this study has shown the importance of emphasising awareness of the color aspect in the design of nature-based solutions, to improve delivery of positive human psychological benefits.

Introduction

In the dense city, living walls and green roofs have an important role as a nature-based solution (NbS), providing a range of ecosystem services where there is limited space for other types of vegetation. A substantial amount of research has shown the potential role of NbS in improving public health and, in particular, psychological well-being [1]. In an urban context, NbS are acknowledged as ecological assets that can provide ecosystem services [2], where studies of living walls have shown the potential to contribute toward both cultural- and regulatory ecosystem services [3]. Today, living walls are gradually being incorporated into urban environments because of the various benefits they can provide. These include improvements in thermal comfort, carbon sequestration and thermal performance [4,5], reductions in noise [6] and air pollution [7], and the potential to support urban biodiversity [8, 9]. Recent reviews of living walls showed their potential to provide health benefits through cultural ecosystem services, such as providing environmental appraisal, which in turn is linked to psychological well-being [10,11]. Furthermore, a study by Eliasson et al. [12] showed that an intensification of cultural ecosystem services in green installations could lead to an increase in sense of place and level of identity. The delivery of these services is affected by species composition and physical access [11], and design parameters affect the performance of living walls and roofs in relation to public health benefits, both through visual exposure as well as more physical interaction with nature [13].

Studies by Lee et al. [14] and Loder [15] show that green roofs with a lot of flower vegetation contribute more to restoration and human well-being than green roofs with a succulent plant composition. Design parameters such as species composition are linked to aesthetic and psychological benefits on green roofs [11], but there is a lack of research explicitly looking at green or living walls and their aesthetic value, as well as species composition, in relation to environmental appraisal [16]. A conscious use of an aesthetic approach in design of living walls could

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lead to positive aesthetic experiences, and thereby psychological well-being and health benefits [11].

A recent study by Thorpert et al. [17] examined explicit aesthetic benefits via theoretical color arrangements. Aesthetic values were set in relation to species composition and biological diversity values of living walls. The results indicated that it is possible to attain an appealing aesthetic expression using color theory and color contrast as interpretation models in the design of living walls. Living walls can be designed in a conscious and careful way using accurate species composition without compromising with biodiversity outcomes.

In today's landscape architecture, we find designers such as the botanist and artist Patrick Blanc that arrange the plant material on living walls through an awareness of the living conditions of the plants, as well as the structure of the plant species and aesthetic combinations. Patrick Blanc strives to design living walls that influence senses of human well-being through inspiration from art theory and natural habitats [18]. His-works are well in line with the aim of this study since color theory are one of the parameters he uses to enhance appealing and visual experiences. One example of Patrick Blanc's works is the living wall located on Musée du Quai Branly – Jacques Chirac in Paris, see Fig. 1. However, many living walls are lacking explicit design focus and uses standardised solutions with regards to plant materials.

Harmony and pleasurable experiences are important factors in our understanding of green infrastructure. Perceived pleasantness as a result of aesthetic values can be linked to intensities and levels of arousal, where both visible changes in light and hues affect the arousal level [19]. Previous studies have shown that fluctuations in arousal level might be interrelated with aesthetic values such as colors and a conscious use and awareness of the color aspects. In particular, color contrasts in design of urban green infrastructure have the ability to improve human experiences of pleasantness [20]. Studies from Polat and Akay [21], Eroğlu et al., [22] and Huang and Lin [23] indicate that the use of color contrast in the design of green infrastructure installations provides positive visual preferences and contributes to increased human experiences of harmony and beauty.

Multidisciplinary studies [24] with an experimental approach are needed, to improve understanding and explore the aesthetic and psychological benefits of living walls [17]. This would help illuminate the role that living walls play in people's everyday lives and the importance of this interaction in increasing public support and well-being [11]. The overall aim of this study is therefore to identify design parameters for living walls in order to optimise the support for aesthetic and psychological benefits. Delivery of environmental appraisal is influenced by such factors as the color composition of the plant species in a living wall. We specifically examine color contrast as a design parameter and set abstract color contrast concepts against human experiences of the affective major dimensions: pleasure and arousal. The affective qualities, pleasure and arousal, can be considered as elementary building blocks in experienced emotion [25].

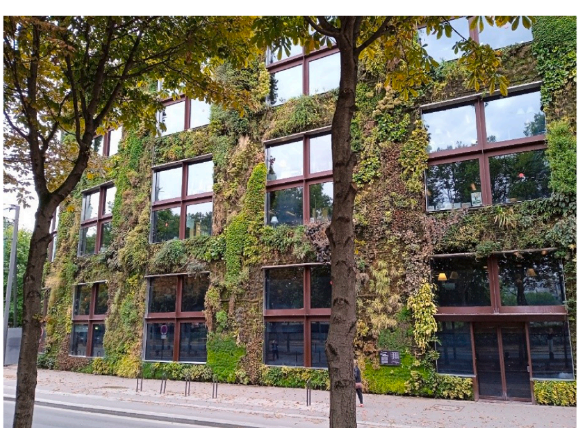

Fig. 1. Living wall designed by Patrick Blanc positioned on the Musée du Quai Branly – Jacques Chirac in Paris. Photo: Petra Thorpert.

The study also examines how plant species in living walls can be designed in relation to color contrast principles, and tests living wall plant species against the distribution and position in the CIE ($L^*a^*b^*$) color space. According to Berns [26] the CIE ($L^*a^*b^*$) color system is recommended for standardized perceptual color communication and quality affirmation and is directly modelled on human perception of color [27].

Materials and methods

This study examines the effects of abstract color contrast concepts designed with green shades on human judgments, and measures the color value dispersion in four conceptual color design proposals respectively, using the CIE ($L^*a^*b^*$) color space for calculating the plants' leaf color.

We collected data for interpretation of the abstract color concepts by making plant leaf color observations in-situ using Royal Horticultural Society (RHS) color chart. According to Voss and Hale [28] the RHS color chart system is devised for determining colors for horticultural and botanical purposes and descriptions. The RHS color registrations were converted to CIE ($L^*a^*b^*$) for further analysis.

The data on plant leaf color were sampled from a living wall experiment in southern Sweden. The living wall was facing east and installed on a building on a masonry wall in a closed area at the Swedish University of Agricultural Sciences in Alnarp. GPS Coordinates 55.660432, 13.083801.

The living wall system comprised 32 plant species with four to six replicates per plant species, as shown in Table 1. We created abstract modelling of color design concepts by using 15 plant species per m^2 of living wall area, and all four designs had the same level of diversity. The color concept material was created from a color theory perspective using Itten's color contrast concepts: *light-dark* and *cold-warm* and contrast as interpretation models [29]. Color theory is intimately linked to the physiology of the human visual system, and color theory design is equally intimately linked to human perception [30]. Finally, in a randomised study, we tested the color concept on human judgments of the major affective qualities pleasure-displeasure and arousal-sleepiness.

Color determination in-situ and analysis

Colors of the inherent dominant foliage were determined in-situ (Fig. 2), using color charts from the RHS Color Chart 5th edition. For each of the four to six replicates of the 32 plant species (Table 1) in the living wall, the characteristic foliage color was decoded with the RHS Color Chart, giving a total of 158 color registrations. The color determinations were performed in summer, in August 2019, between 10:00 and 14:00 in overcast weather to avoid reflective surfaces caused by direct sunlight and variations in color temperature. Before color determination, the plant species had been fertilised to remove any possible effect of nutrient deficiencies. The same person with experience in this field conducted the color measurements.

The 158 color registrations were converted into the CIE ($L^*a^*b^*$) space using a Konica Minolta Chroma Metre Cr-400. The colorimeter was calibrated with the values $Y = 92.4$, $x = 0.3137$, and $y = 0.3195$. The CIE ($L^*a^*b^*$) color space has linear measurements of lightness (L^*), where $L^* = 100$ represents the brightest white and $L^* = 0$ the darkest black. L^* measurements are combined with the two dimensions a^* and b^*, where dimension a^* represents a spectrum of green/magenta colors, from green at negative a^* values to magenta at positive a^* values. The spectrum of blue/yellow colors is represented in the b^* dimension, from blue at negative b^* values to yellow at positive b^* values. The CIE ($L^*a^*b^*$) is one of the most consistent color systems for quantifying perceived colors [32]. The CIE ($L^*a^*b^*$) mean values of each plant

Table 1
Selectable plant leaf colors for designing the abstract color concepts. The living wall and selectable plant species comprised 21 plant species native to Sweden (denoted 1 in Table 1) according to Mossberg [31]. As well as 11 plant species from the National Gene Bank for the preservation of older varieties of ornamental species (denoted 2 in Table 1) otherwise known as "The Swedish Program for Diversity of Cultivated Plants" or the acronym POM. The plant species are named in accordance with the Swedish nomenclature database SKUD (Swedish Cultural Plant Database).

Botanical name	n	Mean			St.dev.		
		*L**	*a**	*b**	*L**	*a**	*b**
1. *Alchemilla alpina* L.[1]	5	44.68	−15.68	15.34	3.6	1.1	2.0
2. *Allium schoenoprasum* L.[1]	5	49.69	−18.50	18.16	5.7	2.0	2.3
3. *Anaphalis margaritacea* L.559:46[2]	5	59.99	−16.82	18.33	5.8	3.9	4.1
4. *Antennaria diocia* (L.) Gaertn.[1]	5	47.79	−17.18	17.74	2.1	1.4	1.4
5. *Armeria maritima* (Mill.)Willd.[1]	5	47.55	−16.53	16.93	1.9	0.7	0.5
6. *Bergenia cordifolia*Möja'(Haw.)Sternb.[2]	5	51.77	−24.04	29.26	2.1	4.4	7.9
7. *Bergenia* sp. Moench. LON 2009051301–18[2]	5	50.25	−21.84	23.47	1.7	4.6	5.9
8. *Cerastium* sp. L KPN 2007061902–9[2]	5	71.86	−8.11	6.62	1.8	0.9	2.2
9. *Cerastium tomentosum* L.[1]	6	78.42	−5.99	5.43	5.7	1.8	2.2
10. *Dianthus arenarius* L.[1]	5	50.10	−16.69	16.80	13.4	2.3	3.8
11. *Dianthus deltoides* L.[1]	5	46.24	−16.43	16.54	3.4	1.5	2.2
12. *Dianthus plumarius* 'Marieberg' L.[2]	5	56.83	−12.99	10.87	1.1	2.9	5.2
13. *Euphorbia cyparissias* L. 239:9[2]	5	54.27	−19.81	19.15	2.7	0.4	1.0
14. *Geranium sanguineum* L.[1]	5	45.41	−18.58	20.01	6.6	7.9	9.2
15. *Geranium sylvaticum* L.[1]	5	50.29	−20.03	24.16	2.7	4.6	10.1
16. *Geum rivale* L.[1]	5	45.54	−16.01	15.58	3.9	1.2	2.2
17. *Helianthemum nummularium* (L.)Mill.[1]	5	41.82	−14.83	13.75	1.3	0.2	1.3
18. *Heuchera x brizoides* 'Rikard' Lemoine.[2]	5	49.50	−19.60	21.44	4.7	5.4	8.1
19. *Hylotelephium telephium* (L.)H.Ohba.[1]	5	47.60	−20.11	21.23	4.9	6.2	8.1
20. *Hylotelephinum spectabile* 'Granlunda' H.Ohba.[2]	5	64.64	−25.87	41.72	3.9	0.4	4.7
21. *Luzula pilosa* (L.)Willd.[1]	5	47.83	−17.37	21.14	4.1	3.1	10.2
22. *Nepeta racemosa* 'Linghem' Lam.[2]	4	54.34	−21.66	22.06	3.3	3.5	5.3
23. *Primula veris* L.[1]	4	54.09	−20.94	29.94	7.6	4.0	13.7
24. *Pulmonaria obscura* Domort.[1]	5	60.19	−25.09	41.11	7.5	2.6	4.4
25. *Pulsatilla vulgaris* Mill.[1]	5	47.67	−16.86	17.33	2.0	1.2	1.2
26. *Scorzonera humilis* L.[1]	5	51.15	−22.36	27.11	2.4	4.6	9.1
27. *Sempervivum* sp. L. 585:63[2]	5	56.52	−24.40	28.40	3.9	4.1	8.3
28. *Sempervivum tectorum* L. 180:1[2]	5	54.65	−22.38	28.73	10.3	5.6	11.2
29. *Silene uniflora* Roth.[1]	4	57.22	−17.47	19.46	12.0	0.8	2.9
30. *Veronica spicata* L.[1]	5	42.97	−15.02	14.86	1,6	0.3	1.5
31. *Viscaria alpina* (L.)G.Don.[1]	5	43.83	−15.35	15.10	2,9	0.9	1.8
32. *Viscaria vulgaris* Bemh.[1]	5	46.70	−15.54	16.34	2.6	3.2	2.6

species used in the study constitute the data material in the following process. The mean values together with the standard deviations and number of replicates are presented in Table 1.

Design of abstract color concept combinations

Four abstract modelling of color contrast concepts was created to produce material against which to test human judgement. This made it possible to test the effect of different color contrast concepts on aesthetic values. The conceptual design proposals were planned to create a spectrum of various color composition principles common in landscape architecture contexts. The design concepts, A, B, C and D were planned from a color theoretical perspective, and Itten's contrast concepts *light-dark* and *cold-warm* contrast [29], were used as interpretation models. From the CIE ($L^*a^*b^*$) mean values of the 32 plant species in Table 1, four design combinations of 15 species in each design concept were chosen from their combined aesthetic qualities in accordance with Itten's color contrast principles and information from the analyses of the plant species mean values, see Fig. 4.

Assessment of effect of abstract color concept combinations A, B, C and D on human judgements, with the major affective qualities pleasure and arousal

An Affect Grid [33] was used to assess the affective quality of human judgments of pleasure and arousal in relation to color concept combination A, B, C and D. The Affect Grid is designed to register human judgments of effects of a subjective kind, and assess dimensions of pleasure-displeasure on the horizontal dimension and arousal-sleepiness along the vertical dimension [25]. The affective quality of pleasure and arousal in the experience of color contrast was addressed by asking, "How do you feel about the image's color composition". We used a 5-point scale Affect Grid and, to verify the reliability of the Affect Grid, the respondents also responded on single questions about pleasure and arousal on a five-point Likert scale [34]. The values from the five-point Likert scale are not reported in detail in the article, but the analysis of

Fig. 2. The picture show a few examples of plant material growing in the capillary mat pocket living wall system. The green shades of the leaf colors were determined in-situ in southern Sweden, where the wall used for the project faced east in the northern hemisphere. Photo: Petra Thorpert.

Table 2
The relation between answers for five-point Likert scale (rows) and Affect Grid (columns) for pleasure-displeasure and all concept combinations. The number of observations for each combination out of the 268 answers.

Affect Grid → ↓ Five-point Likert scale	1	2	3	4	5
1	8	6	1	1	0
2	4	40	7	2	1
3	2	5	40	29	1
4	0	1	8	72	17
5	0	0	0	2	21

Table 3
The relation between answers for five-point Likert scale (rows) and Affect Grid (columns) for arousal-sleepiness and all concept combinations. The number of observations for each combination out of the 268 answers.

Affect Grid → ↓ Five-point Likert scale	1	2	3	4	5
1	15	11	1	0	1
2	8	57	5	2	0
3	0	8	33	14	2
4	0	1	11	71	3
5	0	1	0	5	19

variance and the Tukey post hoc test gave the same result as for pleasure and arousal measured in the grid. The relation between the answer from the grid and the five-point Likert scale is illustrated in Tables 2 and 3.

The question focused on perceived color aesthetic from a broad perspective, and assessed human aesthetic reaction and underlying experience of the feeling of the color contrast combination. Before the assessment, the respondents were asked to take several minutes to learn how to use the Affect Grid. Once the respondents were familiar with the instructions, the respondents were given the Affect Grid together with the abstract color concept combination. The respondents assessed each color concept separately, via printed color photographs on an A4 document, see Fig. 3. The color concepts A, B, C and D were evaluated in a randomised design.

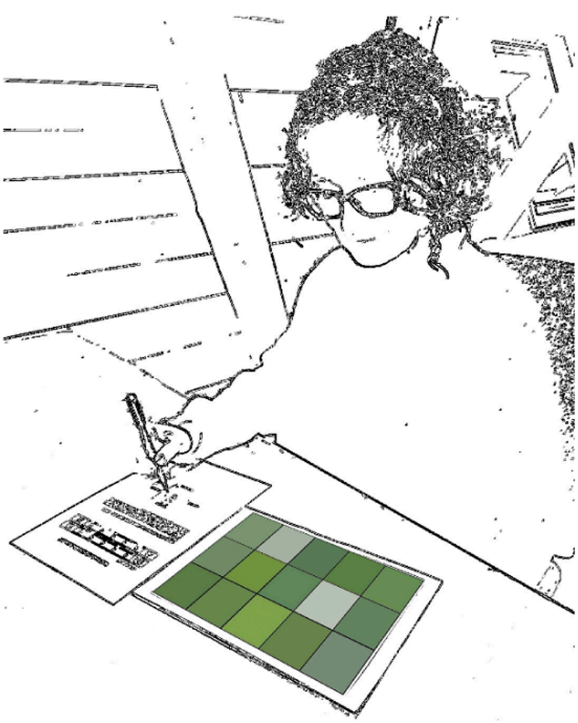

Fig. 3. The illustration show the assessment occasion of the effect of abstract color concept combination on human judgements.

The study on human judgments involved 67 participants. The participants consisted of first-year landscape design students at the Swedish University of Agricultural Sciences, Alnarp. All students were between the ages of 18 and 50, with a dominant age range of 18–30 (82%). Before the color contrast assessments, all students were asked about any vision problems or color blindness. No participant reported such a problem. The study comprised 87% women and 13% men.

Assessment of effect of abstract color concept combination A, B, C and D on human judgements, with the major affective qualities excitement and stress

To test for more dimensions by a rotation of pleasure and arousal axes, the dimensions excitement *versus* depression and stress *versus* relaxation [25], were calculated from the Affect Grid using the formulas:

$$\text{Excitement} = (\text{Pleasure} + \text{Arousal})/2 \quad (1)$$

$$\text{Stress} = 3 + (\text{Arousal} - \text{Pleasure})\ /2 \quad (2)$$

The formulas can produce nine different values, from 1 to 5 in steps of 0.5, and 3 could therefore be considered as the centre point also for these variables, see Tables 4 and 5.

Statistical analyses of human judgements

From the results of the Affect Grid, the differences between the color concept combinations A, B, C and D for the major affective qualities pleasure *versus* displeasure and arousal *versus* sleepiness, respectively, were analysed using analysis of variance with a block design, followed by Tukey's post-hoc test. The block factor was the identity of the participant and the treatment factor was the four combinations; the level of significance used for Tukey's test was 5%.

The differences between the color concept combinations A, B, C and D for excitement *versus* depression and stress *versus* relaxation, respectively, were analysed with the same model as above for pleasure and arousal.

For the analysis of variance and post-hoc tests, the packages multcomp and emmeans from R were used and for the figures, the package ggplot2 from R (version 4.1.2). The analysis of variance is justified due to the large number of observations and the lack of extreme outliers.

Results

For the type of plant species used in this study, the correlation between a^* and b^* is strong and negative, and the correlation with L^* is weaker. The correlations for the mean values of the 32 species in Table 1 is shown in Table 6.

The variation in L^* and b^* is greater than the variation in a^*, as can be seen in Table 7, with mean values and standard deviations for the mean values of the 32 plant species in Table 1.

Table 4
The values of excitement from arousal and pleasure.

5	3.0	3.5	4.0	4.5	5.0
4	2.5	3.0	3.5	4.0	4.5
3	2.0	2.5	3.0	3.5	4.0
2	1.5	2.0	2.5	3.0	3.5
1	1.0	1.5	2.0	2.5	3.0
↑ Arousal/Pleasure →	1	2	3	4	5

This can be illustrated further by using an analysis of the plant

Table 5
The values of stress from arousal and pleasure.

5	5.0	4.5	4.0	3.5	3.0
4	4.5	4.0	3.5	3.0	2.5
3	4.0	3.5	3.0	2.5	2.0
2	3.5	3.0	2.5	2.0	1.5
1	3.0	2.5	2.0	1.5	1.0
↑ Arousal/Pleasure →	1	2	3	4	5

Table 6
Correlations and p-values for the mean values in Table 1 of the variables L^*, a^* and b^* for the 32 plant species, with a significant correlation for a^* and b^*.

	correlation	p-value
L^* and a^*	0.19	0.29
L^* and b^*	0.04	0.83
a^* and b^*	−0.92	< 0.001

Table 7
Means and standard deviations of the mean values from Table 1.

	mean	standard deviation
L^*	52.2	8.1
a^*	−18.1	4.4
b^*	20.4	8.0

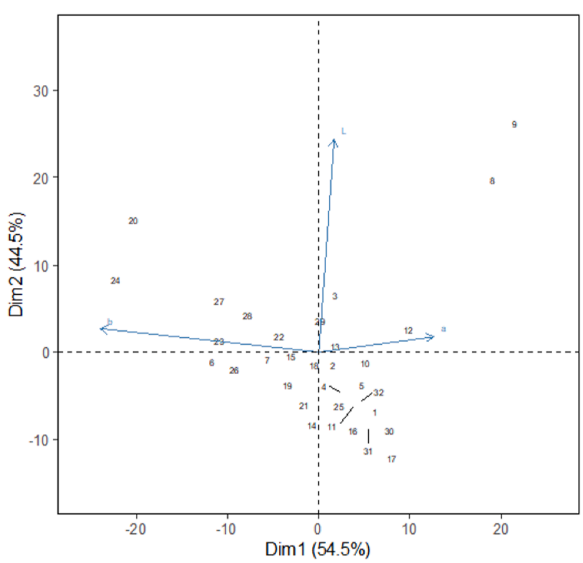

Fig. 4. Biplot of the variables L^*, a^* and b^* (arrows) and scores (numbers) for a principal component analysis based on the covariance matrix. The numbers refer to the species in Table 1; the lines in the score plot describe the exact position of the species, and are used to prevent the points from covering each other. The first two principal components explain 99.0% of the variation in the data. The original data is centred before the analysis, so the origin is the centre of the biplot.

species mean values in a principal component analysis based on the covariance matrix.[1] For the green plants in this study with a negative correlation for a^* and b^*, two dimensions can explain 99.0% of the variation in the $L^*a^*b^*$ for the 32 species and therefore contains a lot of the information about the colors. The biplot for the first two dimensions is shown in Fig. 4 together with the numbers of the species from Table 1. The opposite directions of the arrows for a^* and b^* indicate that these colors dimensions are negatively correlated.

Design description of abstract color concept combinations A, B, C and D

This study examines the abstract color contrast concept and its effect on human judgments, and measures the color value dispersion in four conceptual color design proposals. The material used for testing human judgement (abstract color combinations) is presented via color schemes (Fig. 5). Each of the four abstract color contrast models are designed according to Ittens color contrast principle: *light-dark* and *cold-warm* color contrast.

Two dimensions explained 99.0% of the variation for the 32 plant species in the principal component analysis based on the covariance matrix. The biplots in Fig. 6 therefore illustrate much of the difference between the color combinations.

Color concept combination A and D (Fig. 5) focus on light intensity and cold-warm contrast. In color concept combination A, the design is mainly orientated towards a large range of light gradation with values of L^* from 42 to 78 (Fig. 6), with green shades mainly orientated towards a cold light-dark contrast. The L^* value in color concept combination D ranges from 50 to 78 (Fig. 6), with green shades mainly orientated towards a warm light-dark contrast. Comparing the color schemes A and D, combination A has relatively high values of a^* and low values of b^*, and combination D has a large range for a^* and b^* with predominantly values against b^*.

Color concept combination B is mainly orientated towards warm green shades with values of L^* from 43 to 65 (Fig. 6). Comparing color contrast combination B with color contrast combinations A, C and D, combination B has relatively low values of a^* and high values of b^* (Fig. 5). In color concept combination C the design is mainly orientated towards a small range of light intensity, with values of L^* from 42 to 50 (Fig. 6). Relative to the other combinations, combination C has relatively small range for the variables a^* and b^*(Fig. 5).

Outcome of color concept combinations on human judgements of affective qualities

The sections below describe the outcome of human judgements on four color contrast concepts. The abstract color combinations, A, B, C, D (see Fig. 5) are tested against the affective major dimensions pleasure *versus* displeasure, arousal *versus* sleepiness, as well as the dimensions excitement *versus* depression and stress *versus* relaxation [25] defined by Eqs. (1) and (2). The general result of the Affect Grid is shown in Fig. 7. The mean values and standard deviations, together with the result from Tukey's post-hoc test, are shown in Tables 8-11. There was a clear difference between the tested color contrast combinations. The analysis of variance showed a significant difference for all four assessments with $P < 0.001$.

Results of pleasure vs. displeasure based on color concept combinations

The respondents rated the color combinations B (warm light-dark contrast) and D (color intensity contrast) as a pleasurable experience (Table 8).

The combinations B and D are significantly different from the color combinations C and A. The interpretation is that a design with green shades mainly orientated towards a warm light-dark contrast (combination B) and green shades with a relatively large range of color intensity contrast (combination D) is preferred and gives a dimension of reported experience of pleasure. Color combinations C and A refer to neutral reported subjective experience, with green shades orientated towards cold light-dark contrast (combination A) and a narrow range of color intensity (combination C).

[1] Using the function princomp for the PCA and fviz_pca_biplot in factoextra for the biplot (R version 4.1.2)

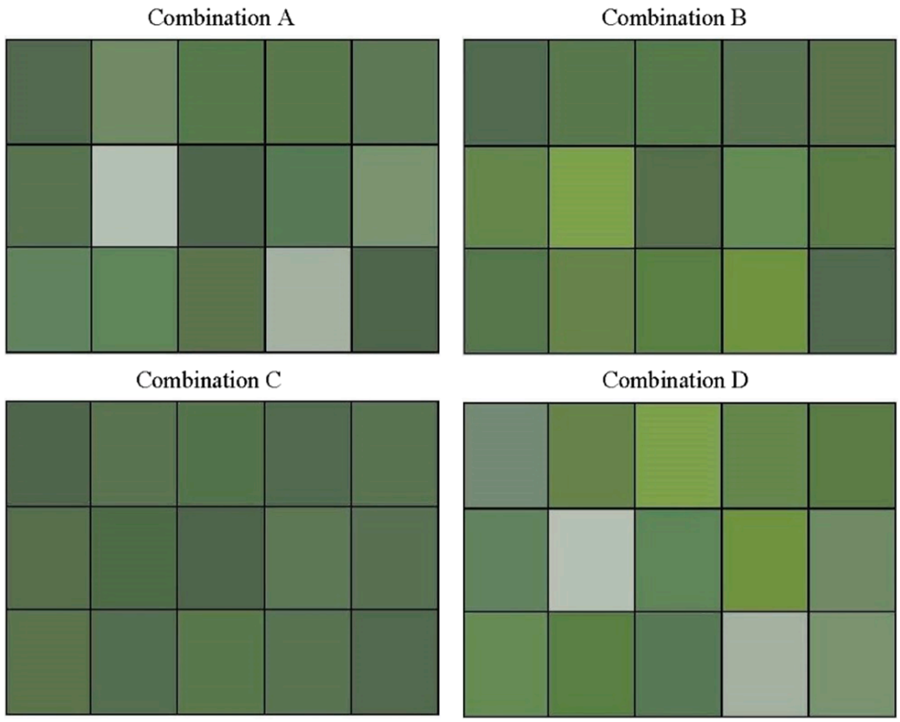

Fig. 5. Abstract color concept combinations. In all four combinations, the color mean values of the selected plant species are arranged by rows, from top left to bottom right as follows. Combination A 31; 29; 7; 15; 10; 25; 9; 30; 2; 3; 13; 22; 21; 8; 17. Combination B: 1; 15; 7; 5; 21; 28; 20; 11; 27; 26; 18; 23; 6; 24; 31. Combination C: 30; 4; 19; 1; 25; 11; 14; 17; 10; 32; 21; 16; 15; 5; 31. Combination D: 12; 23; 20; 28; 26; 13; 9; 22; 24; 29; 27; 6; 2; 8; 3.

Results of arousal vs. sleepiness based on color concept combinations

The respondents rated color combination D (color intensity contrast) as a high arousal experience (Table 9).

Combination D is significantly different from the color combinations B, A and C, with combination C having the lowest mean value. The interpretation is that a design with green shades mainly orientated towards a relatively large range of color intensity contrast (combination D) can give a subjective high arousal experience. Combination C has the lowest mean value and is significantly different from the other three tested color combinations. The interpretation is that green shades in a design combination mainly orientated towards a small range of color intensity can give a reported subjective experience of sleepiness.

Results of excitement vs. depression based on color concept combinations

The respondents rated the color combinations D (color intensity contrast) and B (warm light-dark contrast) as an experience of excitement (Table 10).

Color combinations D and B refer to high mean value of reported subjective experience of excitement. Combinations D and B are significantly different from the color combinations A and C, with combination C having the lowest mean values.

The interpretation is that green shades in a design combination mainly orientated towards a small range of color intensity are associated with the reported subjective experience of depression (combination C). Color contrast combinations with green shades mainly orientated towards a relatively large range of color intensity contrast (combination D) and a design with green shades mainly orientated towards a warm light-dark contrast (combination B) are preferred and give a reported subjective experience of excitement.

Results of stress vs. relaxation based on color concept combinations

The respondents rated the color combinations in a way that suggests that higher stress was experienced when viewing A (cold light-dark contrast) and D (color intensity contrast) (Table 11).

Color combinations A and D refer to high mean value of reported subjective experience of stress, where color combinations A and D are significantly different from the color combinations B and C.

The interpretation is that green shades in a design combination mainly orientated towards a small range of color intensity (combination C) and design with green shades mainly orientated towards a warm light-dark contrast and with green shades orientated towards a relatively small range of color intensity (combination B), are associated with reported subjective experience of relaxation. Color contrast combinations with green shades in a design mainly orientated towards a relatively large range of color intensity contrast (combination A and D) are associated with reported subjective experience of stress.

Discussion

This study is based on art theory and should be viewed as an exploratory study. The results were based on plant leaf color, using a multidisciplinary approach to, in the best way, answer the study's research question. The results show that a color contrast combination designed with green shades and a small range of light intensity (combination C) might be experienced as less stressful than the other tested combinations. However, such a color contrast combination might also cause experiences of displeasure and sleepiness. In color theory the artist strives for the polarity of light and dark [29], and previous studies indicate that color contrasts in the outdoor environment with a high gradation of light-dark values are preferred (*e.g.* [20,23]). To date, no study has investigated the perceived impact of color contrast compositions in outdoor environments in relation to human judgements and related experiences. In contrast to previous studies, this study indicates that not all outdoor compositions designed with green shades and with a high variation in lightness value will contribute equally much to human well-being

This study also shows that a color contrast composition designed

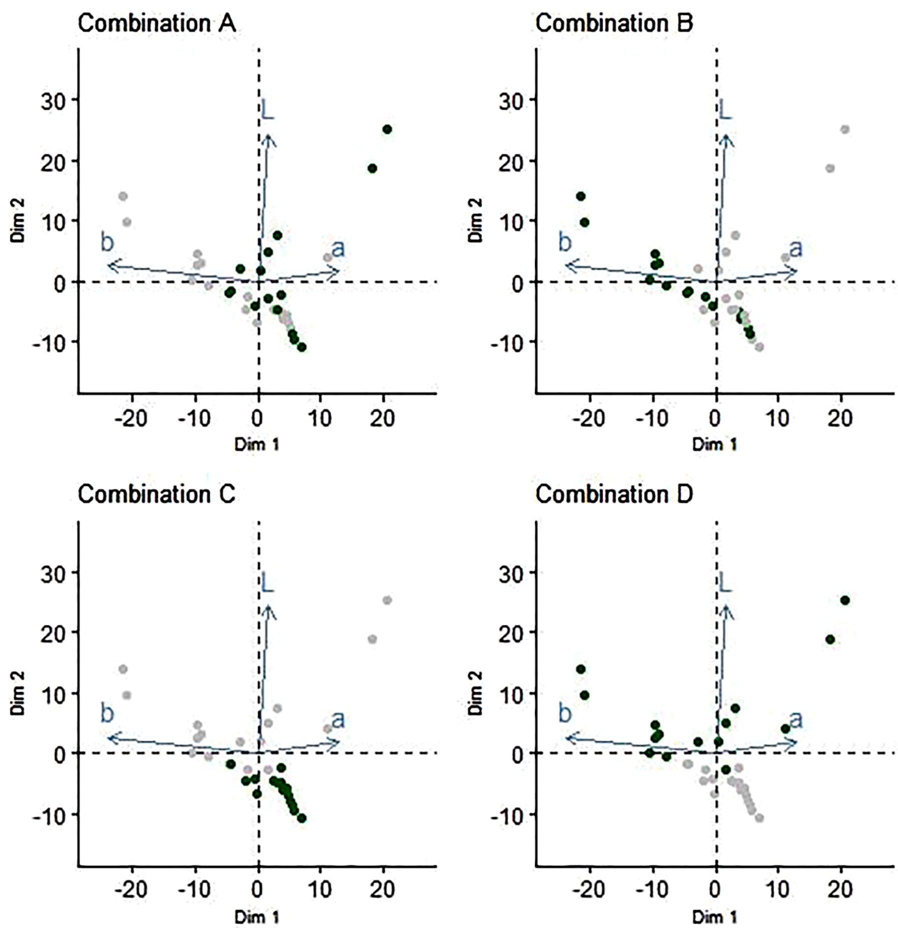

Fig. 6. Biplots where the green dots show plant species represented in the color concept combinations, respectively. The light grey dots represent plant species from the 32 plant species not selected in the color combination.

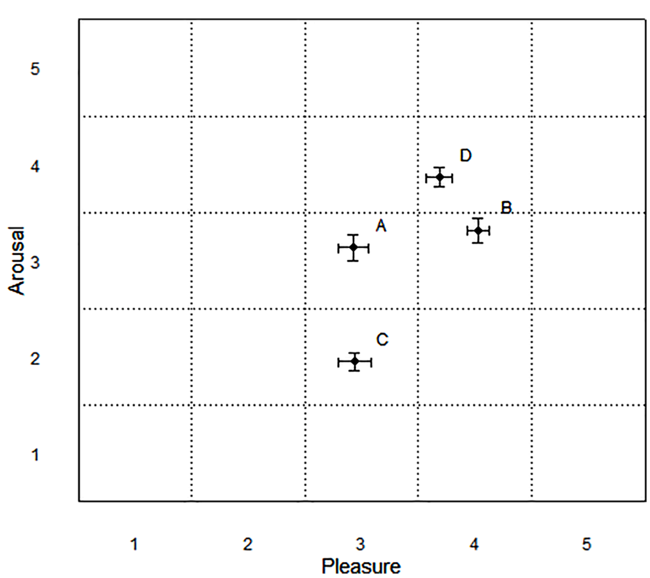

Fig. 7. A graphical illustration of the mean values and standard errors for the different combinations in the Affect Grid.

with a large range of light intensity gradation and with the green shades mainly orientated towards cold green shades (combination A) might generate less pleasant experiences. In contrast, a design composition designed mainly orientated towards warm green shades (combination

Table 8
Results of the affective major dimensions pleasure *versus* displeasure.

Pleasure Combination	n	Mean	StDev	Grouping
B	67	4.03	0.82	a
D	67	3.69	0.92	a
C	67	2.94	1.17	b
A	67	2.93	1.11	b

Table 9
Results of the affective major dimensions arousal *versus* sleepiness.

Arousal Combination	n	Mean	StDev	Grouping
D	67	3.87	0.81	a
B	67	3.31	1.05	b
A	67	3.13	1.07	b
C	67	1.96	0.77	c

Table 10
Results of the affective dimensions excitement *versus* depression.

Excitement Combination	n	Mean	StDev	Grouping
D	67	3.78	0.60	a
B	67	3.67	0.75	a
A	67	3.03	0.81	b
C	67	2.45	0.74	c

Table 11
Results of the affective dimensions stress *versus* relaxation.

Stress Combination	n	Mean	StDev	Grouping
A	67	3.10	0.73	a
D	67	3.09	0.63	a
B	67	2.64	0.56	b
C	67	2.51	0.65	b

D) and with a similar spread in light intensity as in color contrast combination A, might be perceived as a pleasurable experience with high experienced level of arousal and excitement. A recently published study on flower colors showed a link between warm flower colors, altered heart rate variation and restorative effects [35]. The multifaceted expressive powers of cold and warm colors might be explained by the fact that color temperature contains elements suggesting distance (cold) and nearness (warm) [29]. The above reasoning indicates that flower colors are important for how we visually and physiologically experience a plant composition. From that perspective, the inclusion of flower colors in Table 1, would visually have changed the abstract color contrast combinations and probably have affected the results.

The most preferred color contrast composition (combination B) in this study was designed with a narrow light-dark gradation and green shades mainly orientated towards warm green shades. A color contrast composition with these qualities might lead to perceived pleasurable experiences, give experiences of excitement, and be less stressful. The interpretation of the results is that developing a design composition with a focus on color contrast in an outdoor context should be considered as an act of well-balanced understanding of color theory and awareness of related human experiences. This is especially important, since colors have the power to affect the human mind and to alter human moods [36]. However, awareness of the living wall's location, surrounding surfaces and the overall context plays an important role in the visual color experience. A holistic approach in the design of living walls should therefore be a given part of the design process.

In this study we chose to work with abstraction of vegetation color based on actual species color, with a variation in the level of light and temperature between the four designs. However, all four designs show the same level of diversity, which is an important concept in relation to perception and preference [37]. Diversity in plant species has also shown to be positively linked to species richness regarding, for instance, spiders and beetles through the provision of a range of niche habitats [38]. Here, the results could provide an important tool for how to additionally enhance the experience based on the diversity of green shade for aesthetic benefits.

In the design of health promoting natural environments the results show that considering color contrast effects in the design of green elements could impact the restorative potential of the environment. This is particularly interesting for NbS such as green roofs and living walls which often are used in the dense city to respond to multiple challenges, including health benefits (*e.g.* [3]). We would argue that the finding from this study with regards to the design is particularly relevant for the construction of living walls and green roofs located at places where people would view them during longer time and hence have a longer exposure time, such as care homes and hospitals [11].

Based on the framework developed in van den Bosch and Ode Sang [1], this study can be seen as a contribution to the understanding of design parameters of NbS role for improving psychological aspects of public health. The result does further address the knowledge gap between perceived green landscape elements and experienced psychological health that has been identified [8]. This study are well in line with research showing the potential role of living walls in the context of NbS [3,11] and with the result contributing to enhance the delivery of cultural ecosystem services.

While this study specifically focused on the color contrast composition of living walls, the results with regard to the effects of different color contrast principles could also be expected to be applicable to other green elements, such as green roofs and perennial borders.

Methodological considerations

The main strength of this study is that the tested color contrast combinations were designed on the basis of living wall plant species assessed in-situ. This means that the color combinations designed in this study are created on the basis of real plant colors existing in the urban environment on living walls. From a color theory point of view, the results from this study give some indications that the method used could be a design factor and an aesthetic approach for living wall compositions and similar green infrastructure installations.

In the principal component analysis performed in this study, two dimensions described 99.0% of the variation in the data, and the analysis illustrated the difference between the color combinations. This is probably a general result for plant species with green shades used in landscape design. The large negative correlation between a^* and b^* makes it possible to describe most of the variation in two dimensions.

The loadings of L^*, a^* and b^* in the CIE ($L^*a^*b^*$) space were close to the axes, and therefore a factor analysis with rotation did not simplify interpretation for this data, but could perhaps be an alternative for another group of plant species. The use of biplots of the available plant species could be an indication of whether the color combination is attractive and, to achieve an aesthetic combination in accordance with color contrast implementation, the chosen plant species should not be one-dimensional in the space described by L^*, a^* and b^*.

The methodology used to design abstract color contrast combinations and to test these compositions on human judgement has some challenges. The characteristics of the individual plant species – form, texture, structure, and reflective surfaces – has not been included in the design compositions, and is therefore not a parameter in the human judgement phase. A more profound understanding about human judgements and plant species color contrast performance in-situ could help to ensure a well-balanced aesthetic outcome and increase the degree of human psychological benefits. A deeper understanding about seasonal changes in plant color performance could therefore help to ensure a more well-adjusted and holistic color contrast design approach.

In this study, the sample had a significant female bias. In accordance to former studies, these variables could have influenced the results, since women experience greater aesthetic value in urban green spaces [13]. However, a trained participant can professionally evaluate perceived colors, and studies using trained respondents show reliability in reporting of color results [39]. The use of competent students in this study can be seen as a positive factor and increase the validity of the study results. Nevertheless, it is desirable in future studies to use a wider population and even gender and age distribution to obtain more generalizable recommendations of color contrast compositions in urban green spaces. Finally, the study was performed in the northern hemisphere, within a specific geographical area using participants with shared cultural backgrounds, which can therefore be seen as a limitation, since it makes it difficult to generalise the results in other geographical contexts. However, studies have showed a reliable response in the cold-warm colors across different cultures [40], and the results from this study could be part of a more comprehensive widespread landscape context.

Conclusion

In planning and designing green infrastructure, aesthetic thinking is central and can be a way of improving human psychological benefits. Well-designed green infrastructure using an aesthetic approach, has the potential to be attractive and positively improve human health. As mentioned in the introduction, Patric Blanc's living wall design is partly built on art theories. In line with the results from this study, his work has the potential to bee visually appealing and contribute to human well-being.

The color contrast models developed in this study can be used to improve design concepts, focusing on aesthetic issues in landscape architecture contexts. The result of the study shows that through not only working with color effects of flowers but also working with different shades of green we can potentially provide and stimulate different type of responses and emotions in urban settings. An important aspect here is while the flowering season is rather short, the leaf color remain the same for a longer period of time. Therefore when designing and planning for NbS such as living walls and green roofs, using warm green shades as well as a narrow light-dark gradation we are likely to create environments that provide more pleasurable experiences.

The awareness of color could also be brought in as a design aspect in the maintenance of more dynamic vegetation system such as green roofs with meadow vegetation. Here the shade of green could provide a guide for management, favouring species towards the warmer spectrum while also keeping a narrow light-dark gradation while maintaining a heterogeneous and diverse vegetation community.

The method described here identified the factors in a planting design concept that are the driving force in developing aesthetic qualities (color contrast), and highlighted key factors in a color contrast composition that influence human experiences and well-being outcomes. Awareness of color contrast aspects and related human experiences deserve to be addressed in design processes. A top priority is that landscape architects and related professions consider the changing nature of color contrast effects in relation to both seasonal changes and succession over time. The results of this research have the potential to support an understanding of how public values within landscapes can be increased by aesthetic improvements. Integration of the results can support planning and design processes in ecosystems for green built environments and urban planning decisions.

However, more studies are needed for a comprehensive representation of the aesthetic quality color contrast and its potential as a design factor and positive parameter for human psychological benefits. To verify the outcome of this study, more of the same type of study could broaden understanding of aesthetic considerations on human perception and related experiences. A follow-up of this study could be preference studies in-situ, to assess planted color contrast compositions that can best support nature-based solutions and delivery of positive human psychological benefits.

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.

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