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PERCEPTION OF GREEN INFRASTRUCTURE SYSTEMS: GREEN WALLS AND GREEN ROOFS

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ABSTRACT

Integrating green walls (GWs) and green roofs (GRs) into urban areas enables several sustainable development objectives to be met. However, there is little research on the aesthetic perception and environmental and psychological benefits that users assign to these greening systems. Therefore, this paper evaluated the perception towards these two green infrastructures, GWs and GRs. The research was conducted via the Internet through a semi-structured survey with Likert scale questions, with a total of 243 participants. The results revealed that approximately 90 % of the participants have a positive perception of GWs and GRs. The psychological and environmental benefits of greening in urban environments are recognized, such as creating habitats for small species, reducing stress, and improving mood, among others. Some significant differences were seen in some socioeconomic aspects, such as age, gender and educational level. Women showed a tendency to find calm when in contact with plants, while the tendency for men is more neutral. Participants with a lower educational level, secondary school and a technical career, do not fully agree that nature positively affects their mood. In general, green walls were found to be preferred to green roofs; however, it is suggested to consider incorporating more colors, flowers and a greater variety of plants to improve the aesthetics of these structures.

Keywords: Aesthetic perception, green walls, vertical gardens, green roofs, psychological and environmental benefits.

INTRODUCTION

Perception allows people to interpret, differentiate and analyze the environment around them according to their values. Landscape perception is influenced by an individual's memory and experiences, cultural background, beliefs and preferences (Rahman *et al.*, 2015). The study of landscape perception, also called environmental assessment, is a transdisciplinary methodological tool, necessary in the territorial planning process, in which users actively participate by responding to the perceived needs of the environment (Bruno-Rivera *et al.*, 2014).

In cities, vegetated areas have decreased and with it the quality of life of the inhabitants. Despite the changes and evolution of the human habitat, man still perceives the environment as a source of comfort and pleasure that plays a pivotal role in his emotional and psychological state (Rosley *et al.*, 2014). The World Health Organization (WHO) recommends 9 to 12 square meters of green area per inhabitant (Thaiutsa *et al*., 2008); however, there are few places in the world that comply with this recommendation. For example, in Mexico City the average is 12.75 square meters of green area per inhabitant, since in some areas such as in the south of the city the index is higher, but in the north and east it is much lower (Checa-Artasu, 2016).

In recent decades, greening elements have been incorporated into urban infrastructure as conservation tools (Manso *et al*., 2021). Greening systems in buildings are established both vertically and horizontally and are called green walls (vertical gardens, green facades, living walls) and green roofs (naturalized roofs), respectively. These two systems contain a set of layers that may vary with the complexity of the design, but the essential ones are vegetation, substrate, irrigation system (may not include it, especially on roofs), a waterproof membrane (green roofs and living walls), and a support system (Perini and Ottelé, 2012; Abass *et al*., 2020).

Green infrastructures, such as green walls and green roofs, are highly visual implementations that contribute to several sustainable development goals, such as 3 (health and well-being), 10 (reduced inequalities), 11 (sustainable cities and communities), 13 (climate action) and 15 (life on land) (Nguyen-Dang *et al*., 2023). Liberalesso *et al.* (2020) emphasize that these greening systems bring various economic, social and environmental benefits, such as supplying food and ornamentals through urban agriculture, improving aesthetics, regulating microclimates, and significantly improving air quality, among others. This is why researchers encourage stakeholders and the public to adopt greening infrastructures, such as green roofs and green walls, as a climate change mitigation strategy (Shafique *et al*., 2020).

Many cities promote the installation of green roofs and green walls, such as Mexico City, Tokyo, Chicago, Toronto, Copenhagen, and Lisbon, among others. However, globally, few studies have evaluated public perception regarding the benefits and potential problems of these greening systems, as well as the policies for promoting them (Loder, 2014; Ávila-Hernández *et al*., 2023). García-Albarado *et al.* (2021) show that infrastructure in good condition, cleanliness and evident maintenance (signs of care) are necessary to improve the visual attractiveness of green areas in cities, as could apply to greening systems.

There are several studies on the perception of urban greening, carried out mainly from the aesthetic, economic, social and environmental points of view. Aesthetically, differences in perception have been found. On the one hand, Butler *et al.* (2012) found that, among green roof experts, architects are the most likely to promote native species while engineers are on the opposite end of the spectrume, and landscape architects and biologists are in the middle. On the other hand, Nagase and Koyama (2020) found that Japanese people prefer green roofs with turf because they are "neat and

tidy" and they like biodiverse meadow roofs less, totally contrary to what was found by (Jungels *et al.* (2013) who indicate that Americans had more positive reactions to mixed perennial roofs than to grass ones. In Copenhagen, Denmark, Danuta-Lausen *et al.* (2022) found that 70 % of their interviewees have a positive opinion of the aesthetics of wild vegetation.

Zhang *et al.* (2020) found that residents of Guangzhou, China value environmental services related to their daily life such as air pollution, high temperatures and noise pollution, and care less about biodiversity protection services. Jim *et al*. (2022) note that Tokyo residents agree with the contribution of green roofs and green walls to improving air quality, thermal comfort and the aesthetics of the urban landscape, but they find the costs high and consider the presence of mosquitoes and the accumulation of plant waste a problem.

From an economic point of view, studies show that not all users of these greening systems are willing to pay for them. At a train station in Lisbon, Portugal, Benoliel *et al.* (2021) found that users attributed value to greening systems, but are willing to pay only a little and prefer more seats or better waiting areas. In Guangzhou, China, 80 % of 409 participants were willing to pay to use and maintain greening systems, especially young people (Zhang *et al.*, 2020). For their part, Tokyo residents, according to Jim *et al.* (2022), are mostly unwilling to pay to improve neighborhood vegetation (40.2 %), and of those who are willing to pay, 29.4 % would not pay more than $ 300 MXN (2000 JPY).

The objective of this study was to analyze the perception of green roofs and green walls from an aesthetic, psychological and environmental point of view in order to recommend design criteria to landscaping professionals.

MATERIALS AND METHODS

A semi-structured survey was conducted to ascertain people's perceptions. This was prepared in Google Forms and was executed via the Internet during the month of November 2022. The instrument consisted of three sections; in the first, the socioeconomic characteristics of the respondents were collected: age, sex, place where they lived, place where they currently live, monthly income (MXN), occupation and educational level. The importance of these characteristics lies in the fact that they usually constitute the independent variables used in experimental research. The second included two photographs, an extensive green roof and an outdoor green wall (Figure 1) that respondents evaluated aesthetically: liking, color, design, and plant selection, as well as their affinity to the existence of these greening systems. In the third section, participants chose their degree of agreement (strongly disagree (1), disagree (2), neutral (3), agree (4) and strongly agree (5)) with statements indicating the psychological and environmental benefits associated with nature and greening systems.

The survey consisted of 30 questions divided into 3 sections. Sections 2 and 3 used 4- and 5-level Likert scales, as shown in Table 1. The survey items are long sentences,

Figure 1. A: Extensive green roof; B: Outdoor green wall.

Table 1. Perception survey applied via the Internet.

Variable	Code	Values entered in R
Section 1. General data		
Age	Age	16 to 64 (years)
Gender	Gen	Female (F), Male (M)
Place where you grew up	Lived	Rural area (RA), Urban area (UA)
Place where you live	Live	Rural area (RA), Urban area (UA)
Educational level	Educa	Elementary, Secondary, High School, Technical career, University, Postgraduate
Occupation	Occup	Student, Employed, Unemployed, Retired, Other
¿What is your monthly income ($MXN)?	Income	< 5,000; 5,000 – 10,000 ; 10,000 – 15,000; 15,000 – 20,000; 20,000 – 30,000; > 30,000
Section 2. Design of greening systems (Photos of a green roof and a green wall are evaluated)		
How much do you like this green roof? ǂ	GRliking	Not at all (1), a little (2), somewhat (3) and a lot (4)
How attractive do you find the green roof design? ǂ	GRdesign	Not at all (1), a little (2), somewhat (3) and very attractive (4)
How attractive do you find the plant selection? ǂ	GRplants	
How attractive do you find the color selection? ǂ	GRcolors	
What would you like to add or remove to make the green roof to your total liking? ǂ	GRadd	NA (Keywords were identified in the respondents' comments in Excel®).
How much would you agree that there should be more green roof spaces in the city? ǂ	MoreGRs	Strongly disagree (1), disagree (2), agree (3) and strongly agree (4).
How much do you like this green wall? ǂ	GWliking	Not at all (1), a little (2), somewhat (3) and a lot (4)
How attractive do you find the design? ǂ	GWdesign	Not at all (1), a little (2), somewhat (3) and very attractive (4)
How attractive do you find the plant selection? ǂ	GWplants	
How attractive do you find the color selection? ǂ	GWcolors	

Table 1. Continue.

Variable	Code	Values entered in R
What would you like to add or remove to make the green wall to your total liking? †	GWadd	NA (Keywords were identified in the respondents' comments in Excel®).
How much would you agree that there should be more green wall spaces in the city?	MoreGWs	Strongly disagree (1), disagree (2), agree (3), and strongly agree (4)
Which do you prefer, a green roof or a green wall? †	GRvsGW	A green roof (1), a green wall (2), both (3) and neither (4)
Section 3. Benefits of greening systems		
Green roofs and walls provide a space for the development of small animal species (bees, butterflies, and other insects). ‡‡	SmallAni	Strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5).
I like the aesthetics of a building with greening (green walls and roofs) more than a concrete one. †	GreenBuild	
It is important to integrate nature into urban areas. ‡‡	NatUA	
Integrating vegetation into urban areas represents an opportunity to manifest Mexican culture. ‡‡‡	Culture	
I consider that the presence of nature positively affects my mood. ‡‡‡	PosMood	
I consider that being in contact with nature reduces my stress level. ‡‡‡	LessStr	
I associate nature with pleasant memories. ‡‡‡	PleasMem	
Being in contact with plants makes me calm. ‡‡‡	PlantCalm	
I seek more contact with plants after the COVID confinement. ‡‡‡	PlantCOV	
I would like to have a green wall or roof in my home †	HomeGWGR	

†Aesthetic, ‡‡environmental and ‡‡‡psychological criteria.

so they were coded for handling in the Rstudio software and for the creation of the graphs.

The statistical analysis was performed in the free software Rstudio and Excel®. Cronbach's alpha was applied to the items to evaluate the reliability of the questions. The Kolmogorov-Smirnov test was used to evaluate the normality (p-value > 0.05) of the variables. Graphs were made of the distribution of responses (percentage of agreement, disagreement, etc.) for sections 2 and 3. Because of the type of variables in the survey, the non-parametric Kruskal Wallis test was performed, with the dependent variable being one of the items and the independent variable being some socioeconomic data (age, gender, lived, live, education, occupation, income). The non-parametric Kruskal Wallis test was also included, in which the evaluation of the aesthetics of the green roof and the green wall was considered to depend on the design, colors and plant selection. In addition, manually, with the help of Excel®

filters, keywords were identified for open-ended questions 5 and 11, which sought the essential characteristics of green roofs and walls.

RESULTS AND DISCUSSION

Socioeconomic characteristics of respondents

A total of 243 participants were obtained, of which 125 were women and 118 were men, 51.4 % and 48.6 %, respectively. Of these, 53.1 % grew up in rural areas; however, 82.7 % currently live in urban areas, which is consistent with the phenomenon of rural-to-urban population change in Mexico. Ages ranged from 16 to 64 years, with most of the participants being between 16 and 40 years old (83.6 % of the sample). The educational level of the respondents is high: 49.8 % have a university degree, 40.3 % have a postgraduate degree, 7.4 % have a high school diploma, 1.2 % have a technical diploma and 1.2 % have a secondary school diploma, and more than half of them are students (51.9 %). It should be noted that, like age, educational level does not represent the reality of the Mexican population and this could impact the results since people with higher levels of education are more aware of current environmental damage and the need to make changes.

Statistical analysis of the survey

The tool used in this research was the survey, in which sections 2 and 3 contain closed questions using the Likert scale with 4 and 5 categories. Some researchers, who have also applied surveys using a Likert scale, have carried out parametric analyses such as ANOVA and Tukey's test, as in the case of Jungels *et al.* (2013) and Nagase and Koyama (2020). However, in the present research, the Kolmogorov-Smirnov normality test was performed on the survey variables (p-value > 0.05, normal), and the data did not present normality, so they were analyzed with non-parametric tests as was done by Lee *et al.* (2014) and Liberalesso *et al.* (2020) who also found their variables to be non-normal. Jamieson (2004) is of the opinion that Likert scale data are ordinal, that is, they can be ordered, so they should be treated as interval data since the intervals between Likert scales are not equal.

Reliability and distribution of perception responses

Cronbach's alpha internal consistency test was used to check the reliability of the survey. It was applied to the items with a Likert scale and an alpha of 0.891 was obtained, indicating that the internal consistency of the data is good (Taber, 2018). Subsequently, response distribution plots of all respondents were made with the "Likert" package in R.

Participants had a positive response towards green infrastructures, with green roofs receiving 94 % and green walls 96 % (Figure 2), which is consistent with the biophilia effect, which describes the human drive to connect with nature (García-Albarado *et al.*, 2021; Rosley *et al.*, 2014). It is noteworthy that green walls received more of the "I like it a lot" response than green roofs with 76.5 % and 55.1 %, respectively.

Figure 2. Distribution of preferences for green walls and green roofs (n=243). GW: green wall, GR: green roof. GWliking: How much do you like this green wall, GRliking: How much do you like this green roof?

Green walls obtained higher positive percentages and within positive appreciation they received more "very attractive" responses for design, plant selection and color selection than green roofs. In this study, participants tended to express greater liking for the outdoor green wall (Figure 3). Even with the differences in aesthetic perception between green roofs and green walls, the participants showed similar behavior in acceptance towards the establishment of these greening systems (94 % GR, 95 % GW). Respondents generally gave positive responses about the psychological and environmental benefits of green structures (Figure 4). Of the 10 items, 6 had more than a 90 % positive response ("agree" and "strongly agree"). Likewise, 3 other items exceeded 85 % positive response. The item "I seek more contact with plants after the

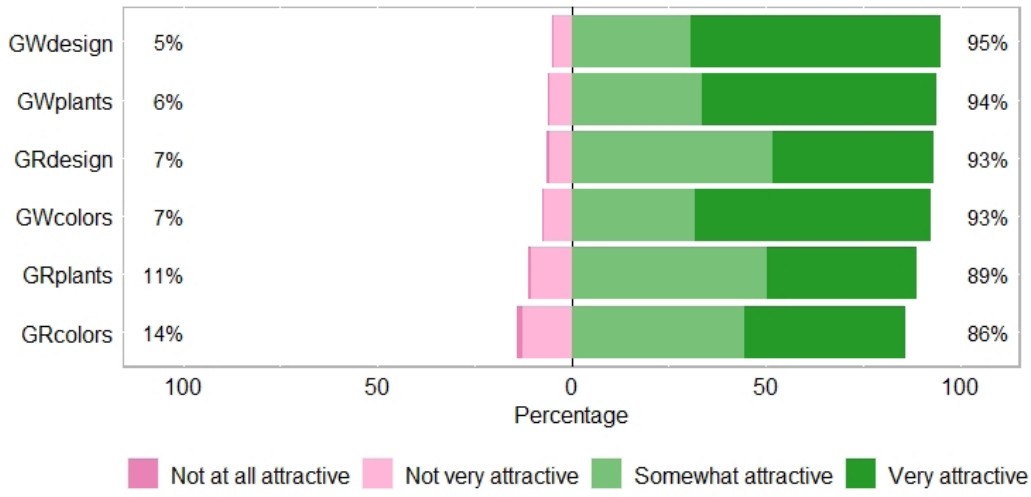

Figure 3. Perception of green roofs and green walls (n=243). GW: green wall, GR: green roof, Design: How attractive do you find the design?, Colors: How attractive do you find the color selection?, and Plants: How attractive do you find the plant selection?

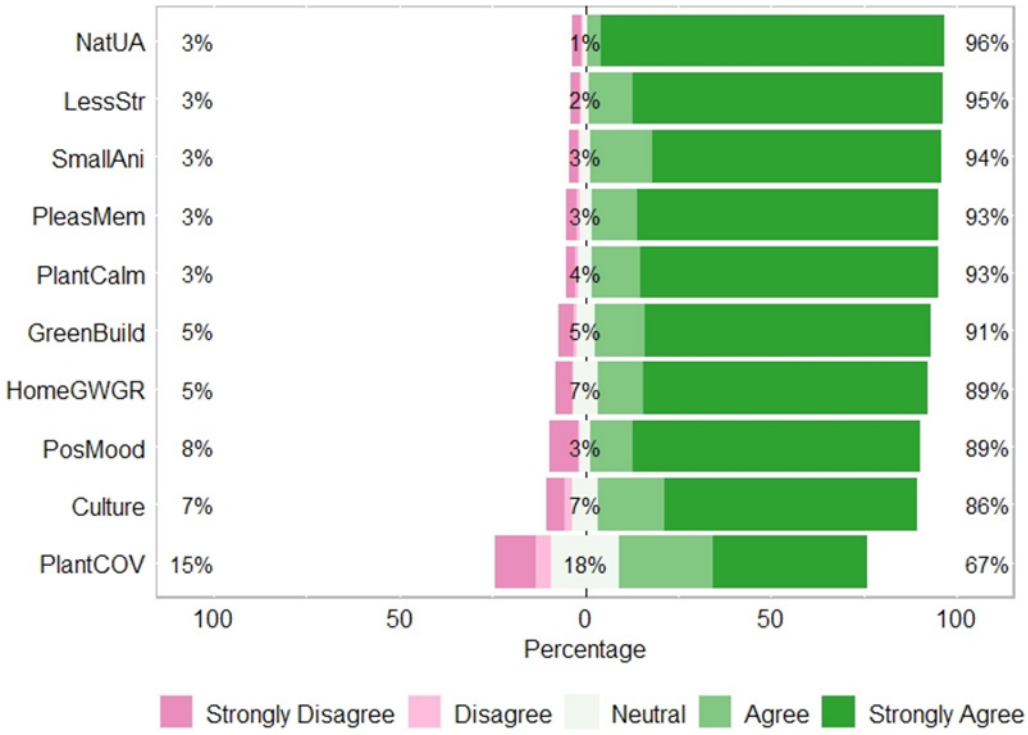

Figure 4. Benefits that respondents associate with greening systems (n=243). NatUA: it is important to integrate nature into urban areas, LessStr: I consider that being in contact with nature reduces my stress level, SmallAni: green roofs and walls provide a space for the development of small animal species (bees, butterflies and other insects), PleasMem: I associate nature with pleasant memories, PlantCalm: being in contact with plants makes me calm, GreenBuild: I like the aesthetics of a building with greening (green walls and roofs) more than a concrete one, HomeGWGR: I would like to have a green wall or roof in my home, PosMood: I consider that the presence of nature positively affects my mood, Culture: integrating vegetation into urban areas represents an opportunity to manifest Mexican culture, and PlantCOV: I seek more contact with plants after the COVID confinement.

COVID confinement" was the most varied, with 11.1 % answering "strongly disagree," 4.1 % "disagree," 18.1 % "neutral," 25.5 % "agree" and 41.2 % "strongly agree."

The results show a trend indicating that 9 out of 10 participants considered integrating nature into urban areas, due to the benefits of less stress, calm and pleasant moments in these spaces (Arvay, 2016). This also agrees with Benoliel *et al.* (2021), who suggest that integrating vegetation into the urban environment provides several environmental, economic and social benefits.

According to descriptive statistics, the results indicate that participants positively valued the psychological and environmental benefits attributed to the presence of

greening systems presented in the survey. A study that agrees with what was found here is that of Zhang *et al.* (2020), who stated that the inhabitants of Canton, China value the environmental services of greening systems that are related to their daily life, such as the reduction in noise and air pollution. Moreover, the findings of Williams *et al.* (2019) give evidence that green roofs can provide greater aesthetic enjoyment, attention control, and restorative experiences.

Respondents indicated that they really like green roofs and green walls, and they also agree on the benefits they bring. However, there was a lack of research on how much they are willing to pay for these greening systems, so it is suggested that future work should include this variable, as other authors have done (Benoliel *et al.*, 2021; Jim *et al.*, 2022).

Differences in aesthetic perception, and psychological and environmental benefits by socioeconomic variables

The non-parametric Kruskal Wallis test ($\alpha = 0.05$) was applied to determine whether there are significant differences in the aesthetic, psychological and environmental perceptions of the respondents. Most of the items showed no significant differences, with a few exceptions (Table 2). Similarly, Nguyen-Dang *et al.* (2023) found, at a Sydney university, that user perception did not differ by sociodemographic characteristics, although students perceived social benefits more than administrative staff. It should be noted that in this study 51.9 % of the participants were students; however, there were no differences by occupation.

The age group of 49-56 years old unanimously mentioned that they like the green wall "a lot" and the youngest group, 16-24 years, responded similarly. In their research, Liberalesso *et al*. (2020) found no significant differences (Kruskal Wallis test) between the age ranges and the dependent variable "green infrastructure as a decision point for choosing a hosting location." On the other hand, Zhang *et al.* (2020) found that age had

Table 2. Kruskal Wallis test for all items.

Independent variable	Dependent variable	Chi-square (X^2)	p-value	Significance level
Age (6 intervals)	GWliking	11.749	0.038	*
Gender	PlantCalm	4.139	0.041	*
Like	GRvsGW	4.051	0.044	*¿1
Education	NatUA	13.510	0.009	**
Education	PosMood	10.248	0.036	*

Significance levels: NS (Not significant), * ($P < 0.05$), ** ($P < 0.01$). GWliking: How much do you like this green wall?, PlantCalm: Being in contact with plants makes me calm, GRvs GW: Which do you prefer, a green roof or a green wall?, NatUA: It is important to integrate nature into urban areas and PosMood: I consider that the presence of nature positively affects my mood.

a significant effect on willingness to pay for the maintenance of green roofs and green walls, with young Cantonese people (18-35 years old) being the most willing to pay.
In terms of gender, the results also show that there is a greater tendency for women to "totally agree" with the statement "Being in contact with plants makes me calm," while the tendency for men is more "neutral." Given this, Liberalesso *et al.* (2020) indicated that women have a moderately stronger environmental concern and sensitivity than men since the "urban men" group frequently responded with lower ratings to questions about possible benefits, disadvantages and their perception of the installation of green roofs and green walls than the "urban women" group (significant differences). García and Dunnett (2009) suggest in their study that these differences between men and women, as well as by age, could be due to cultural factors or evolutionary theories of landscape perception. They also found a tendency for women to have a more favorable perception of naturalistic plantings compared to those with a more formal appearance.
Education also influenced the items "It is important to integrate nature into urban areas" and "Nature positively affects my mood," as respondents with a technical diploma, unlike the other levels of education, only "agreed" and not "strongly agreed". However, it is very likely that this difference occurred because this group did not have a representative number.
Allard-Poesi *et al.* (2022) proposed a model that measures how the individual's perception and the characteristics of nature influence the sense of well-being. In this study, the respondents, 2500 French citizens, indicated that small spaces with nature (a balcony, a patio, or a roof garden) contribute to well-being, but to a lesser extent than less domesticated natural areas (forests, fields, and scrubland).

Differences in aesthetic perception between green roofs and green walls

There was a difference between the aesthetic perception of green roofs and green walls (Table 3). The green wall shown in this survey was consistently rated more positively in terms of overall liking, design, plant selection, and color scheme compared to green roofs. This indicates a widespread preference for green walls over green roofs among

Table 3. Kruskal Wallis test for aesthetic perception of green roofs and walls.

Variable	Chi-square (X^2)	p-value	Significance level
Liking	23.076	1.557E-06	**
Design	22.779	1.82E-06	**
Plants	21.976	2.76E-06	**
Colors	18.918	1.37E-05	**
More	0.600	0.4385	NS

Significant levels: NS (Not significant), * (P <0.05), ** (P <0.01).

participants. The inclination towards green walls may be associated with properties that characterize the aesthetics of a landscape, such as colors, textures, and shapes, and how these relate to each other, as noted by López-Contreras *et al.* (2019) in their research.

Liberalesso *et al.* (2020) had similar results, where respondents, hostel users in Lisbon, Portugal, showed a preference for five types of greening structure in the following order: 1) Indoor living wall, 2) Accessible green roof, 3) Outdoor living wall, 4) Green façade and 5) Inaccessible green roof. Teotónio *et al*. (2020) found that users prefer and are willing to pay more for accessible greening systems. In their research, users valued the additional space of an accessible green roof for recreational activities more than the aesthetic improvement obtained through the greening of the building.

The work of Ávila-Hernández *et al.* (2023) shows that in Mexico there is more research on green roofs than on green walls; however, it is necessary to increase the research and legislation on green walls, since they are of interest to potential users.

Respondents' proposals for aesthetic improvement

From the main responses to the questions "What would you like to add or remove to make the green roof/green wall to your total liking," it is indicated that for both greening systems, more needs to be added in terms of colors, flowers and plant variety. Among others, it was mentioned to include plants for pollinators and plants with low water consumption (Table 4).

The design of greening systems and their attractiveness are correlated with the selection of plants and their colors. That is, they are more attractive if they integrate a diversity of colors, flowers and plant species. In addition to these characteristics, García-Albarado *et al.* (2021) state that infrastructure in good condition, cleanliness and evident maintenance (signs of care) are necessary to improve the visual appeal of green spaces where greening systems can be included.

Lee *et al.* (2014) found the following preferences of employees in Melbourne, Australia: herbaceous plants over succulents, green foliage over gray and red foliage, and taller vegetation over lower-growing vegetation on green roofs. They also found that flowers

Table 4. What respondents would add to the green roof and green wall to improve its aesthetics.

Green roof		Green wall	
Characteristic	**Frequency**	**Characteristic**	**Frequency**
More colors	44	More colors	38
More flowers	32	More flowers	19
Edible plants	20	Creeper plants	7
Design (improve)	16	Red color	6
Shade plants	13	Symmetrical shapes	5
Greater plant variety	10	Greater plant variety	4

make any arrangement of vegetation on a green roof more attractive. On the other hand, Nagase and Koyama (2020) found that Japanese people prefer green roofs with turf because they are "neat and tidy" and like biodiverse meadow roofs less, contrary to Jungels *et al.* (2013) who indicate that Americans prefer green roofs with mixed perennial or Sedum-dominated species over those with grasses. Likewise, Garcia and Dunnett (2009) found that women tend to prefer plantings with a greater diversity of colors and flowers. They attribute this in part to the fact that, evolutionarily speaking, women, in charge of the fruit-gathering process, have specialized their sense of selection, unlike men.

CONCLUSIONS

In Mexico, little has been studied about the perception of urban greening systems, green roofs and green walls, although it is important since this type of work provides a guide for the characteristics and types of greening systems that users are willing to adopt and therefore maintain in order to improve their quality of life.

In this study, in general, no significant differences were found in the perception of the participants based on the socioeconomic variables, although some differences were observed by age, gender and educational level. Within the scope of this research we found a positive tendency of the participants towards green walls and green roofs; in addition, they attribute psychological and environmental benefits to these greening systems such as the creation of habitats for small species, stress reduction, mood improvement and evocation of pleasant memories. This suggests that greening is perceived as beneficial to the quality of life. From the results of this research, it can be suggested that greening systems, green roofs and green walls, should include a greater diversity of plants, colors and flowers to make them more aesthetically appealing. This finding is consistent with previous studies and can help in the design and creation of these green infrastructures in cities.

Furthermore, and given that perception is affected by all the sensory senses, namely touch, smell, hearing, taste and not just vision, it is suggested that future research include *in situ* perception surveys applied in the greening systems.

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