ENHANCE VISUAL COMFORT AND AESTHETICS OF URBAN GREEN STORMWATER INFRASTRUCTURE THROUGH LANDSCAPE DESIGN

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ABSTRACT
This research investigates enhancing the visual comfort and aesthetics of traditional urban Green Stormwater Infrastructure (GSI) through landscape design. It takes three commonly used GSI strategies—rain gardens, permeable parking lots, and bioswales as case studies. For each GSI strategy, three of the most fundamental factors (rain garden: depth, scale, and planting design; permeable parking lots: scale, pavements, and surrounding contexts; bioswale: width, depth, and planting design) related to landscape design are chosen as studied variables. Virtual Reality (VR) visualization is adopted to simulate various landscape design options that combine different design variables for these GSI strategies. Participants are recruited to assess these GSI landscape design scenarios through VR simulations, providing ratings for visual comfort and aesthetics via surveys. The VR simulations include modifications to key landscape design variables. For the visual comfort and aesthetics study, 40 participants are recruited via snowball sampling, and a Likert scale ranging from 1 to 5 points is utilized to evaluate various GSI design scenarios. Participants' responses are statistically analyzed to determine the impacts of different landscape design factors on the visual comfort and beauty of the GSI strategies studied. The research suggests that while increasing the scale of a GSI design can improve its visual quality, incorporating diverse plant species and complex structures has a more significant impact on public perception. Prioritizing landscape features like pavement and planting design over the physical size of the GSI may better enhance visual comfort and aesthetics. Overall, this study fills a research gap by exploring the visual value of GSI from a landscape architecture perspective, providing guidance on effectively integrating landscape design to balance the functions and visual appeal of urban GSI strategies.

Keywords
Green Stormwater Infrastructure (GSI), Virtual Reality (VR), landscape spatial perception, visual comfort, visual aesthetics

1 INTRODUCTION

Green Stormwater Infrastructure (GSI), a low-impact solution, contributes to sustainable urban development and plays a significant role in the urban green system (Liptan, 2017). Common GSI strategies are developed collaboratively across disciplines like civil engineering, hydraulic engineering, and planning, which traditionally prioritizes function over visual value. However, in the context of landscape architecture, GSI emerges as a crucial element in the urban green system, which reveals the significance of exploring the impacts of landscape design on enhancing traditional GSI, especially concerning visual comfort and beauty (Ge et al., 2023). Many existing GSI designs prioritize functionality, sometimes even overlooking the visual impacts of the design (Meenar et al., 2020). The stormwater management functions of a GSI landscape can be achieved through proper measurements and calculations, but the solutions of creating better visual impacts of a GSI design can be complicated and require consistent exploration. Therefore, a significant challenge faced by traditional GSI landscape design, as a vital component of the urban landscape system, is the lack of consideration for visual experience. This research explores how to enhance the visual comfort and aesthetics of traditional urban GSI through landscape design. This research focuses on three widely used GSI strategies—rain gardens, permeable parking, and bioswales—as case studies. Virtual Reality (VR) visualization is employed to simulate various landscape design options for these selected GSI strategies. Participants are recruited to evaluate various GSI design options by viewing these VR simulations and providing ratings for visual comfort and aesthetics through surveys.

1.1 Landscape design solutions and GSI

Landscape design is crucial in developing urban GSI systems (Suppakittpaisarn et al., 2017). Instead of merely constructing standard urban drainage and sewer networks, employing landscape and environmental design strategies can enhance stormwater management in various ways. Many cities recognize the significance of sustainable stormwater management (SSWM) practices, which greatly benefit from GSI associated with landscape design (Goulden et al., 2018). SSWM has the capability to enhance hydrological, ecological, social, and economic functions, while also improving the conventional urban drainage infrastructure comprehensively (Barbosa et al., 2012). GSI, as an essential aspect of SSWM, can support urban development by aiding in regional ecological restoration, regulating microclimates, enhancing the urban scenery's visual quality, and facilitating recreational activities in cities (Bourassa, 1990; Feng & Nassauer, 2022).

Common strategies for landscape design in GSI include the use of green roofs, retention ponds, rain gardens, vegetative bioswales, constructed wetlands, drainage channels, and pervious green pavement (Liptan, 2017). In addition to the stormwater management function of landscape design for typical GSI solutions, the importance of enhancing GSI landscape design lies in the aspects of environmental resilience, aesthetic appeal, and social recreation and well-being (Alcazar et al., 2016; Balany et al., 2022; Tóth et al., 2015, 2015). Today, GSI and associated landscape designs are recognized as crucial elements in the landscape industry (Apfelbaum, 1995; Atwa et al., 2019). Exploring ways to improve urban GSI from the perspective of landscape architecture is one of the most critical topics in contemporary landscape practice.

1.2 Visual comfort and aesthetics of GSI as urban landscapes

Visual comfort (eliciting feelings of relaxation, safety, and harmony) and visual aesthetics (feelings of interest, fascination, and vividness) are two critical dimensions associated with individuals' spatial perception of spaces. Visual comfort is the psychological condition where the entire visual system operates at its best. It describes a subjective state of visual well-being created by the visual environments (Dolnikova & Katunsky, 2019). The importance of visual aesthetics and beauty for human well-being in urban landscape space has gained considerable attention in public perception studies (Frank et al., 2013). Visual aesthetics indicates whether an object or a scene is pleasing to the eye. Landscape visual aesthetics quality emerges from the interaction between the visible features of landscape space and the psychological processes of people who experience it (Daniel, 2001; Kalivoda et al., 2014; M. Tveit et al., 2006). Many widely implemented GSI strategies are formulated through a collaborative effort spanning several disciplines and often emphasizing functionality over aesthetic considerations (Meenar et al., 2020). Landscape architecture, as one of the important industries involved in urban GSI development, always regards creating physical spaces with enjoyable visual value and visual experience as its fundamental profession (Bell, 2019; Ha & Yang, 2019; Krause, 2001). Therefore, exploring the impacts of landscape design skills on common GSI solutions is helpful in improving the visual experience of urban GSI, particularly in terms of visual comfort and aesthetics.

Different factors can affect the GSI landscape's aesthetic value and the users' visual perception of it. Existing studies raise the idea that context can influence visual experience of landscapes (Nassauer, 1988). The feature of planting such as wild, urban, or agricultura can affect the visual aesthetic of landscapes. Well-designed landscape can be more scenically and visual attractive compared with lanscape with simply wide planting (Adelvand & Ghashghaei, 2011). Existing studies also indicate that landscape designs with GSI functions are preferred over barren urban landscapes, especially those that incorporate trees and flowers (Suppakittpaisarn et al., 2017). Regarding the compostion of plants in GSI landscape, planting design with diverse vegetation is preferred from the perspective of visual aesthetics compared with a uniform composition. Trees in the background and shrubs or ground cover in the foreground bring people better visual comfort (Fathi & Masnavi, 2014).The openness of the view and the area of green spaces also influence people's visual experience of the urban landscape. Larger green spaces enhance people's sense of comfort and make the landscape more scenic and aesthetically pleasing (Bourassa, 1990; M. S. Tveit, 2009). Recent studies also highlight the impacts of GSI landscape's recreational value on its visual quality. GSI landscapes that located in designed open spaces with recreational facilities around are more likely to be appreciated by people (Meenar et al., 2020). Regarding the materials and distribution of elements in urban GSI landscapes, studies suggest that the messiness of GSI spaces can negatively impact people's visual experience. Both professional designers and laypersons prefer neat, well-organized GSI landscapes that incorporate innovative design elements (Suppakittpaisarn et al., 2019).

GSI landscapes with poor visual quality can have negative impacts from both public and urban perspectives. As a crucial component of the urban landscape system, GSI landscapes that lack visual comfort and aesthetics may reduce public engagement and usage (Conway et al., 2023; Meenar et al., 2022), leading to adverse psychological effects such as lowered mood and increased stress among users (Leonard, 2018; Suppakittpaisarn, 2017). From a city's perspective, unattractive GSI designs can contribute to a general decline in the city's visual appeal (Bates, 2019) and may also lead to a decrease in property values in nearby areas (R. Wang et al., 2022). Additionally, GSI landscapes with poor visual quality are at a higher risk of vandalism, which can increase maintenance costs and require additional attention (Apt et al., 2019).

1.3 Knowledge gaps and research goal

The literature review reveals that, as an important part of the urban green system, the design of GSI strategies should be enhanced not only from the perspective of engineering but also through the lens of landscape design. On the basis of achieving the required functions of stormwater management, the visual appeal of GSI strategies can be improved through landscape design skills, which can potentially enhance the visual comfort and aesthetics they provide to the public. Although numerous studies have investigated the visual value and related spatial perceptions of landscape spaces, more detailed research on visual comfort, visual beauty, and public perception of specific GSI landscape designs is necessary. Building on this, we can discuss how to enhance the visual value of typical GSI strategies through fundamental landscape design skills. Meanwhile, existing studies have discussed how various design factors affect the visual quality of urban GSI landscape, including planting composition, scale, environmental contexts, and materials. However, research that comprehensively explores the impact of these factors on users' visual experience for specific types of GSI landscapes is still lacking.

Therefore, this research uses three GSI approaches—rain gardens, permeable parking lots, and bioswales—as case studies to explore the impacts of various landscape design variables (for example, scale, depth, and planting design) on selected GSI strategies. The research findings are expected to serve as a pilot guideline for future GSI landscape designs from the perspective of visual comfort and aesthetics.

2 METHODS

2.1 GSI strategies and landscape design variable

This study investigates three widely used GSI strategies: rain gardens, permeable parking lots, and bioswales. These strategies are important elements in urban green systems and are consistently emphasized in the field of landscape architecture. For each GSI strategy, three of the most fundamental factors related to landscape design are chosen as studied variables to explore how different types of landscape design can affect the visual comfort and aesthetics of GSI strategies. For rain garden, the studied variables are scale of the rain garden, depth of the rain garden, and the planting design. For the permeable parking lot, the selected studied variables include the scale of the parking lot, the pavement designed for the parking lot, and the surrounding contexts of the parking lot. Similar to rain garden, for vegetated bioswale, the variables of width, depth, and planting design are selected. Based on the typical design and construction standards for GSI solutions (*Bioswales*, 2013; *Design Criteria for Permeable Pavement - Minnesota Stormwater Manual*, n.d.; *Rain Gardens*, n.d.; Strom et al., 2013), this study identified several different levels for each variable. Given the time and resource constraints of the study, the researchers did not include all possible variables and levels in the experimental design, but selected a few of the most typical variables and levels instead. The GSI strategies, landscape design variables, the levels included for different variables, and their labels are all displayed in Table 1.

Table 1. GSI strategies and related landscape design variables studied in the research.

GSI strategies	Studied variables		
Rain garden	Scale L (large): 6m*6m S (small): 4m*4m	Depth S (shallow): 0.15m D (deep): 0.30m	Planting design P1: only groundcover P2: groundcover + shrub P3: groundcover + shrub + tree
Permeable parking lot	Scale L (large): 30m*60m S (small): 18m*40m	Pavement P1: permeable brick P2: permeable paving with vegetation P3: asphalt paving	Surrounding contexts LA: natural environments U: urban environments without landscape
Bioswale	Width W (wide): 3.6m N (narrow): 2.4m	Depth S (shallow): 0.15m D (deep): 0.30m	Planting design P1: only groundcover P2: groundcover + shrub P3: groundcover + shrub + tree

2.2 Study Site

Although this study is based on the conceptual landscape design of selected GSI strategies, a specific study site where all the GSI design scenarios examined in this research can be implemented has been chosen. This is to ensure that the scale and form of all design options are realistic in real-world settings. Therefore, an area on the campus of Virginia Tech have been selected as the study site. Within this study site, the permeable parking lot, rain garden, and bioswale with different scales (studied in this research) can be located. Moreover, the computational simulations of various GSI design scenarios used in the subsequent perception study are based on the study site, serving as the fundamental environmental context.

2.3 Research Design

GSI design scenarios: The rain garden, bioswale, and permeable parking lot are selected as the GSI strategies studied in this research. The basic landscape design variables of these three GSI strategies are summarized in section 2.1. In this way, multiple GSI landscape design options can be developed by integrating different variables. Using Rhino and Twinmotion, the researchers generate the digital model and rendered perspectives of various design options for each studied GSI strategies. To ensure that people can correctly and comprehensively perceive the designed space, for different GSI strategies, one or more rendered views are generated. For the rain garden, 12 design options with one view for each of them are created. For bioswale, researchers make 12 design options from one perspective. Figure 1 shows the computational simulations of all landscape design scenarios for the rain garden and vegetated bioswale.

Figure 1. Computational simulations of landscape design scenarios for the rain garden and vegetated bioswale

For the permeable parking lot, which is on a larger scale compared with the other two GSI strategies, 12 design options with three different perspectives are generated for study. Figure 2 illustrates all landscape design scenarios for the permeable parking lot. The labels of different GSI design options are based on the information in Table 1. Since this study aims to preliminarily explore how different design variables affect the visual comfort and aesthetics of common GSI strategies conceptually, the simplest and most basic landscape design are applied to different design options. In real-world scenarios, there could be countless landscape design options for one combination of variables. However, in this study, researchers created only one landscape design for each combination of variables. This approach helps to eliminate confounding factors, thereby enhancing the validity of the analysis results.

Figure 2. Computational simulations of landscape design scenarios for the permeable parking lot

Immersive VR visualization and perception study: After generating various landscape design options for all three studied GSI strategies, the perception study is conducted by involving participants and employing VR visualization. 40 participants who are capable of operating VR devices and with no professional background in landscape architecture, were recruited for the survey through snowball sampling from Virginia Tech's students. This is to ensure that all participants can use computer and VR devices, and they will not rate the visual comfort and aesthetics of a GSI design option based on their design profession. Among the 40 participants, there are 25 females and 15 males. Their ages range from a minimum of 21 to a maximum of 37, with an average age of 27.To achieve a more immersive and realistic spatial experience for study participants, VR technologies are adopted to enhance the rendered perspectives created by common modeling and rendering approaches. One VR headset is connected to the working station for participants to view different GSI design options with immersive experiences. In this perception study, each participant is asked to evaluate all design scenarios for the three studied GSI strategies. Each participant has up to 10 seconds to view one landscape design scenario for each studied GSI strategy and spends up to 6 minutes to complete the study. If they believe that the time is insufficient, an additional 3 minutes can be provided to allow them to complete the entire evaluation process.

Visual comfort (eliciting feelings of relaxation, safety, and harmony) and visual aesthetics (feelings of interest, fascination, and vividness) are two critical dimensions associated with individuals' spatial perception of spaces. While viewing each GSI design option, participants are asked to rate their feelings about the visual comfort and visual aesthetics of the design. Before the perception test, the researchers explain how participants should define visual comfort and visual aesthetics. Visual comfort refers to whether they feel relaxed, safe, and harmonious when viewing a GSI design option, while visual aesthetics should reflect whether they perceive the GSI landscape as visually beautiful, interesting, and attractive. A Likert scale ranging from 1 to 5 points (from poor to excellent) based on the Richter scale (Z. Wang et al., 2023) is used for participants to evaluate different design scenarios. After completing the perception study and collecting all the survey data, the researchers used statistical analysis methods, including ANOVA and descriptive statistics, to process all the research data through SPSS. The ANOVA analysis assesses the impact of one or more independent variables on a dependent variable by comparing the variance within groups to the variance between groups. In this study, it is applied to examine whether different levels of design variables have significant impacts on the visual comfort and aesthetics of studied GSI strategies.

3 RESULTS

Table 2 presents the overall descriptive statistics of the collected data. The ANOVA analysis (Table 3) of visual comforts and visual aesthetics for rain gardens shows that the scale and planting design have a more significant effect on people’s perception of visual comforts and aesthetics. According to the descriptive statistics (Figure 3), it can be found that rain gardens with larger scale and more complex planting designs can bring people more visual comfort and improve their beauty as urban landscapes. Unlike the factors of scale and planting design, depth is not an important factor affecting either the visual comforts or visual aesthetics. It's worth mentioning that for the rain garden, under the influence of different landscape design variables, the changing trends of visual comfort and visual beauty are basically consistent. It is evident that although the definitions and emphases of visual comfort and visual aesthetics differ, for participants without a background in landscape design, their perception of the two is similar. In other words, without a foundation in design form and aesthetic education, people might tend to believe that the visual comfort and aesthetic quality of a landscape space are unified.

Table 2. Overall descriptive statistics for the mean of the collected data.

Rain Garden		**Visual Comfort**	**Visual Aesthetics**
Scale	L	3.02	3.71
	S	2.50	2.74
Depth	D	2.71	3.17
	S	2.81	3.28
Planting Design	P1	2.16	2.56
	P2	2.42	2.76
	P3	3.70	4.34
Permeable parking lot		Visual Comfort	Visual Aesthetics
Scale	L	3.43	2.86
	S	2.73	2.57
Pavement	P1	2.91	2.53
	P2	2.83	3.50
	P3	2.82	2.79
Surrounding contexts	LA	3.88	3.47
	U	2.28	1.96
Bioswale		Visual Comfort	Visual Aesthetics
Width	N	2.48	2.36
	W	2.98	2.94
Depth	D	2.80	2.72
	S	2.66	2.58
Planting Design	P1	1.41	1.76
	P2	2.56	1.79
	P3	4.22	4.41

Table 3. ANOVA analysis of visual comfort and aesthetics for rain garden.

Source/ Visual Comfort	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	27.063a	11	2.460	7.873	0.000
Intercept	346.688	1	346.688	1109.400	0.000
Scale	4.688	1	4.688	15.000	0.000
Depth	0.021	1	0.021	0.067	0.798
Planting	21.875	2	10.938	35.000	0.000
Scale * Depth	0.188	1	0.188	0.600	0.444
Scale * Planting	0.125	2	0.063	0.200	0.820
Depth * Planting	0.042	2	0.021	0.067	0.936
Scale * Depth * Planting	0.125	2	0.063	0.200	0.820
a. R Squared = .706 (Adjusted R Squared = .617)					
Source/ Visual Aesthetics	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	41.667a	11	3.788	27.273	0.000
Intercept	481.333	1	481.333	3465.600	0.000
Scale	12.000	1	12.000	86.400	0.000
Depth	.333	1	0.333	2.400	0.130
Planting	28.292	2	14.146	101.850	0.000
Scale * Depth	0.333	1	0.333	2.400	0.130
Scale * Planting	0.125	2	0.063	0.450	0.641
Depth * Planting	0.542	2	0.271	1.950	0.157
Scale * Depth * Planting	0.042	2	0.021	0.150	0.861
a. R Squared = .893 (Adjusted R Squared = .860)					

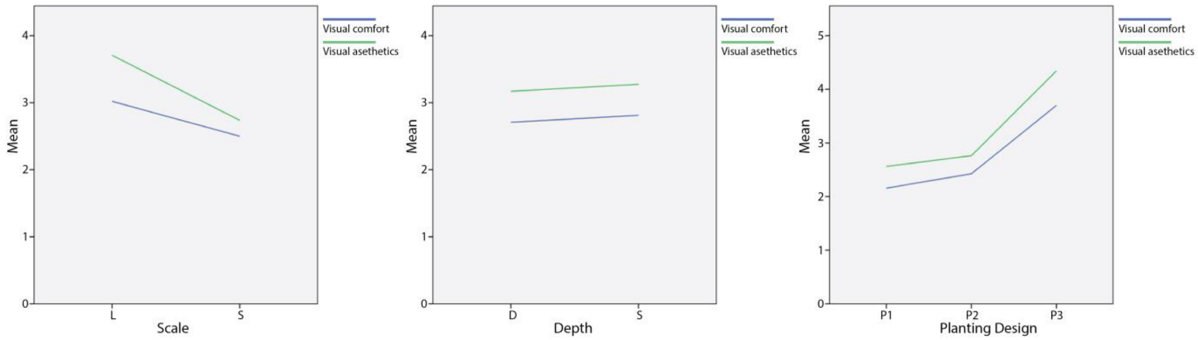

Figure 3. Descriptive statistics of rain garden

For the permeable parking lot, the results of ANOVA analysis (Table 4) show that the factors of scale and surrounding context can significantly affect people's perceptions of visual comfort and aesthetics. Meanwhile, The ANOVA analysis does not indicate a significant influence of pavement on visual comfort. Descriptive statistics are conducted to understand the impacts of scale and contexts on both visual comfort and visual aesthetics (Figure 4). The results suggest that the context of a permeable parking lot can markedly influence people's feelings about the space. Participants' ratings of both visual comfort and beauty obviously increase when the surrounding environments of a parking lot change from urban contexts to landscape contexts with vegetation. Therefore, it can be concluded that having landscape contexts, as opposed to buildings and hardscapes, enhances the visual comfort and beauty of the parking lot. Moreover, unlike visual comfort, the factor of pavement has a significant influence on visual aesthetics. The descriptive statistics indicate that pavement 2 (permeable paving with vegetation) is considered to have more aesthetic quality by participants, while the ratings for permeable brick and asphalt paving are relatively the same.

Table 4. ANOVA analysis of visual comfort and aesthetics for permeable parking.

Source/ Visual Comfort	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	31.333[a]	11	2.848	5.697	0.003
Intercept	170.667	1	170.667	341.333	0.000
Scale	2.667	1	2.667	5.333	0.040
Contexts	24.000	1	24.000	48.000	0.000
Pavement	1.333	2	0.667	1.333	0.300
Scale * Contexts	0.667	1	0.667	1.333	0.271
Scale * Pavement	2.333	2	1.167	2.333	0.139
Contexts * Pavement	0.000	2	0.000	0.000	1.000
Scale * Contexts * Pavement	0.333	2	0.167	0.333	0.723
a. R Squared = .839 (Adjusted R Squared = .692)					
Source/ Visual Aesthetics	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	32.125[a]	11	2.920	14.018	0.000
Intercept	198.375	1	198.375	952.200	0.000
Scale	3.375	1	3.375	16.200	0.002
Contexts	26.042	1	26.042	125.000	0.000
Pavement	1.750	2	0.875	4.200	0.041
Scale * Contexts	0.042	1	0.042	0.200	0.663
Scale * Pavement	0.750	2	0.375	1.800	0.207
Contexts * Pavement	0.083	2	0.042	0.200	0.821
Scale * Contexts * Pavement	0.083	2	0.042	0.200	0.821
a. R Squared = .928 (Adjusted R Squared = .862)					

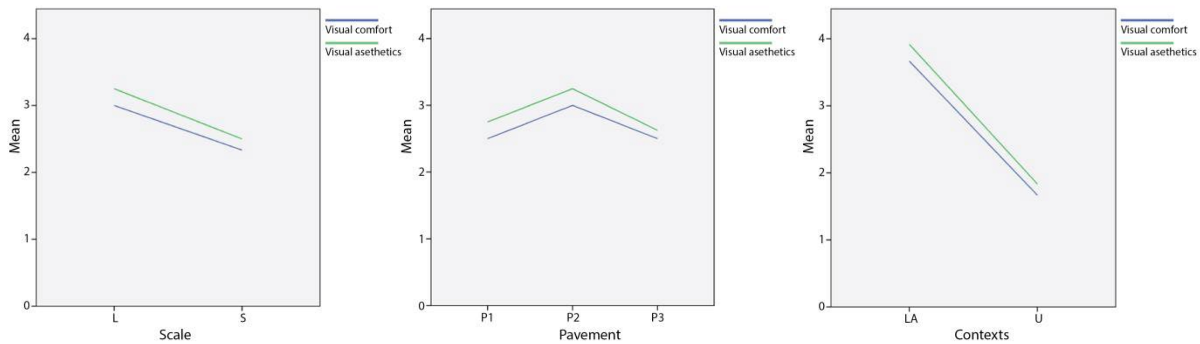

Figure 4. Descriptive statistics of the permeable parking lot

The results of the ANOVA analysis (Table 5) show that bot width and planting design are important factors that affect people's perception of visual comfort and visual aesthetics for bioswale. However, the factor of depth fails to have a significant impact on both visual comfort and visual beauty. Many participants indicated that they could not clearly perceive the differences in the depth of bioswales or rain garden among the various landscape design scenarios, and thus, their evaluations of visual comfort and visual beauty did not intentionally consider the factor of depth. Since the depths of the GSI strategies selected in this study (including the rain garden and bioswale) mainly followed professional design and construction standards, the changes in depth are not significant. This can be one of the major reasons why the depth variable did not show significant impacts in this study. According to the descriptive statistics (Figure 5), the bioswale with more width is rated to have better visual comfort and aesthetics. For planting design, the results show that adding shrubs is not an effective way to enhance visual aesthetics but is useful to improve visual comfort, since abundant vegetation might create a sense of inclusion (L. Wang et al., 2022). On the other hand, involving trees can significantly improve people’s ratings of visual comfort and aesthetics of a bioswale.

Table 5. ANOVA analysis of visual comfort and aesthetics for bioswale.

Source/ Visual Comfort	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	73.417[a]	11	6.674	53.394	0.000
Intercept	374.083	1	374.083	2992.667	0.000
Width	4.083	1	4.083	32.667	0.000
Depth	0.083	1	0.083	0.667	0.420
Planting	66.792	2	33.396	267.167	0.000
Width * Depth	0.750	1	0.750	6.000	0.019
Width * Planting	0.292	2	0.146	1.167	0.323
Depth * Planting	0.292	2	0.146	1.167	0.323
Width * Depth * Planting	1.125	2	0.563	4.500	0.018
a. R Squared = .942 (Adjusted R Squared = .925)					
Source/ Visual Aesthetics	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	84.167a	11	7.652	42.378	0.000
Intercept	341.333	1	341.333	1890.462	0.000
Width	3.000	1	3.000	16.615	0.000
Depth	0.083	1	0.083	0.462	0.501
Planting	80.667	2	40.333	223.385	0.000
Width * Depth	0.083	1	0.083	0.462	0.501
Width * Planting	0.000	2	0.000	0.000	1.000
Depth * Planting	0.167	2	0.083	0.462	0.634
Width * Depth * Planting	0.167	2	0.083	0.462	0.634
a. R Squared = .928 (Adjusted R Squared = .906)					

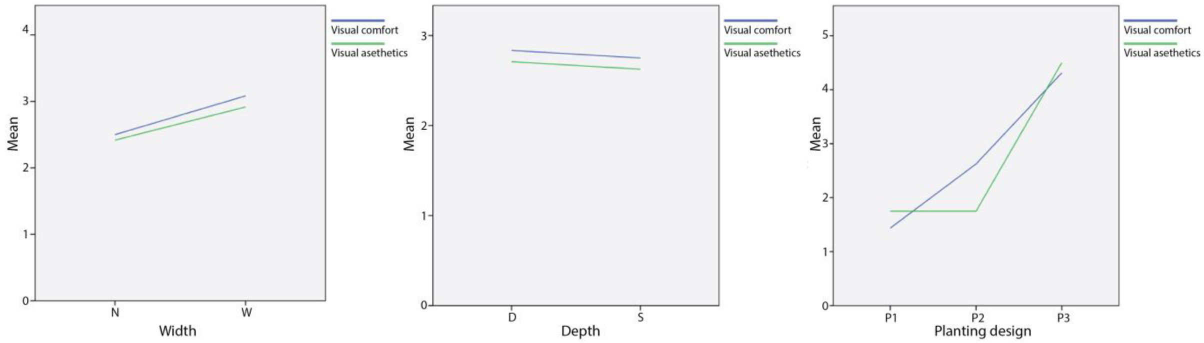

Figure 5. Descriptive statistics of bioswale

4 DISCUSSION

Based on the results of perception study and related statistical analysis, three points are valuable for further discussion, including the scale of GSI landscape design, the planting design of GSI landscapes, and the impacts between physical dimensions and landscape features of GSI design.

The Scale of GSI Landscape Design: Wide, open spaces with expansive views can be inherently impressive and create a sense of immersion, contributing to visual comfort and aesthetic value. Existing research indicates that GSI landscape with good visual quality can create emotional value (Leonard, 2018; Suppakittpaisarn, 2017). The broad view offered by larger green spaces allow for a visual experience that makes people feel uncluttered and expansive, which can psychologically encourage relaxation (Bourassa, 1990; Thompson, 2002; M. S. Tveit, 2009). According to the study results, a larger scale of GSI landscape design (including the width of bioswales) can bring more visual comfort and improve visual beauty. Compared to previous research, this finding confirms that scale and the openness of the view are equally important for both general recreational landscape and GSI landscapes.

The finding that the scale of GSI landscapes affects users' visual experience also has certain implications for urban GSI design. Since most GSI solutions are regarded as important parts of the urban green system, green coverage is their essential characteristic. Studies have discussed the green coverage of landscape spaces and found that the visual comfort and beauty of a green space, as perceived by people, increase with a high green-view ratio (Ma et al., 2021; Qin et al., 2023). Therefore, if possible, it's better to design GSI landscapes that are larger and have various functions. In some situations, a large-scale GSI landscape can even become a unique urban green space or part of a park, which increases the area's green coverage and improves the local green infrastructure system. Meanwhile, existing studies indicate that GSI in designed open spaces with recreational facilities are preferred by users (Meenar et al., 2020). Therefore, integrating GSI design with urban landscapes on a larger scale will have a positive impact on enhancing the visual appeal and public engagement of the green space. However, the scale of a GSI can be determined by the volume of stormwater that needs to be managed (Strom et al., 2013). A larger area of GSI landscapes also requires more land and incurs higher costs. Although a larger scale can improve the visual quality of GSI landscapes to some extent, it is not reasonable to rely solely on expanding the area to enhance GSI landscape design. Instead, integrating GSI designs into the broader and well-designed urban landscape is a more feasible approach.

The Planting Design of GSI Landscapes: According to the study results, including trees and shrubs can significantly improve the public perception of a GSI landscape from the perspectives of visual comfort and aesthetics. These findings are consistent to many existing studies. Research has proposed that planting design with limited species and structural diversity is easy to comprehend spatially, but often lacks visual appeal in urban GSI landscape design (Buyadi et al., 2015; Huan, 2012). The visual comfort and beauty of the landscape improve with a greater variety of plant species, relatively complex composition, and higher color contrast (Du et al., 2016). Considering this, the color contrast in planting design is a factor that was overlooked in this research but should be investigated in future studies. Conducting a targeted perception test and designing relevant questionnaires are feasible approaches to explore this issue further.

Furthermore, trees are crucial elements GSI planting design. For all three studied GSI strategies, the results of the perception study show no significant difference between planting designs that include only groundcover and those that include both groundcover and shrubs. However, when trees are incorporated into the planting design, participants' ratings for visual comfort and aesthetics clearly increase. Existing studies have also found that the visual beauty of urban green spaces is enhanced by the presence of trees, particularly when the trees are healthy (Ma et al., 2021; Ulrich, 1986). Therefore, based on the research findings, landscape designers and civil engineers should be suggested to pay more attention to planting design when designing and constructing a GSI landscape. The use of more diverse plant species and multilayers of vegetation should be the first choice, especially trees. Based on the overall design concept and environmental context, proposing suitable, healthy, and aesthetically pleasing trees in the planting design can to some extent enhance people's perception of urban GSI design (Zhao et al., 2017).

Physical Dimensions or Landscape Features: All landscape design variables examined in this research can be categorized into two types: physical dimensions and landscape features. Physical dimensions refer to the essential measurements or attributes of a GSI landscape design, while landscape features represent factors associated with landscape design elements that specific numbers cannot measure. The variables related to physical dimensions primarily include scale, depth, and width. In contrast, the variables related to landscape features mainly cover planting design, pavement, and surrounding contexts. By summarizing all the data analysis results, the study finds that compared to factors in the physical dimensions affecting the visual comfort and aesthetics of GSI landscapes, factors related to landscape features have a more pronounced impact. Among these factors, those related to plants (for example, planting design and the surrounding context) show the most significant influence. The reasons for these findings can be various. One possible reason might be the subtle physical measurement changes of various GSI design options. Essentially, the GSI landscape is a relatively micro aspect of the urban green system (Bosco et al., 2022), so the variables typically used to define general green spaces may not be clearly manifested in the space of the GSI landscape. Compared to depth and width, scale is the factor most easily perceived by people (Ge et al., 2023), and accordingly, it has shown a more significant impact on visual comfort and aesthetics in the study results. Therefore, when proposing a GSI landscape design, designers should pay more attention to and be confident in their professional skills. Developing good landscape form, color, material, and planting design is important while meeting functional requirements and construction standards. This also aligns with the findings of existing studies, which suggest that well-organized, neat, and scenic GSI landscapes with innovative design elements result in better visual quality and are more preferred by users (Adelvand & Ghashghaei, 2011; Suppakittpaisarn et al., 2019).

5 CONCLUSION AND FUTURE SCOPE

This study investigates ways to improve the visual comfort and aesthetics of traditional GSI strategies using landscape design. Common GSI solutions such as rain gardens, permeable parking lots, and bioswales are selected. Various landscape design variables associated with these solutions are examined through a perception study that employs computational simulation and VR visualization. Overall, this study bridges a research gap by exploring the visual value of GSI from a landscape architecture lens. The findings offer guidance on effectively integrating landscape design to achieve a harmonious balance between the functional and visual aspects of urban GSI strategies.

Key findings show that, among all the studied factors, the scale and planting design can significantly affect the visual comforts and aesthetics of rain gardens. For permeable parking, the factors of scale and surrounding context have significant impacts. For bioswale, the width and planting design can obviously influence people's evaluations of visual comforts and aesthetics. By discussing the key findings, this study proposes potential GSI landscape design guidelines for future practice. First, implementing GSI landscape designs on a broader scale, such as increasing the width of bioswales or the area of rain gardens, can enhance visual comfort and aesthetic appeal. Thus, when feasible, opting for expansive GSI landscapes with diverse functionalities is a preferable approach. Second, incorporating a variety of trees and shrubs can markedly enhance the public's visual experience of a GSI landscape, both in terms of comfort and aesthetic value. Opting for a broader range of plant species and establishing multiple layers of vegetation should be a priority in GSI landscape design. Third, compared to factors in the physical dimension affecting the visual comfort and aesthetics of GSI landscapes, factors related to landscape features have a more pronounced impact, especially those related to plants. Therefore, landscape designers should focus on developing good landscape form, color, material, and planting design while meeting the functional requirements and construction standards of GSI design.

As a pilot study of future GSI landscape perception research, this study has some limitations requiring improvement. First, the sample size of this research is still relatively small. In future studies, more participants should be recruited to lead to more valid and meaningful findings. In addition, limiting participants to those with undergraduate study experience and recruiting them exclusively from a campus setting cannot guarantee the validity of this study. Future research should involve participants with more diverse backgrounds, ages, and occupations. For participants who are not familiar with VR devices, basic tutorials should be provided prior to the perception test. Second, more types of GSI landscape design, including but not limited to rain gardens, permeable parking, and bioswale, should be involved in future research. Meanwhile, more studied variables such as the shape of the area, vegetation colors, or soil types can be considered in future studies. On the other hand, in future studies, instead of relying on computer-simulated model, using real photographs to construct the VR model could be considered to achieve more realistic visual experience during the perception test. Third, this research employed traditional surveys assisted by VR technologies as evaluation methods. In future research, interviews or other forms of perception tests can be considered as additional options. At the same time, in addition to using a Likert scale to assess people's evaluation of visual comfort and aesthetics, additional specific survey questions targeting various GSI design variables across different scenarios should be developed to gather participants' feedback more effectively.

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