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Assessing the restorative effects of campus greeness on student depression: a comparative study across three distinct university campus type in Macau

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Abstract

This study addresses the growing mental health challenges among university students, with a particular focus on depression, by examining the role of campus greenness in mitigating its effects. In contrast to the majority of studies that concentrate on campus environments in Western countries, this research uniquely investigates how variations in campus density and form within the Chinese context influence the role of campus greenness in mitigating depression among university students. By analyzing three distinct types of university campuses in Macau, the study also reflects on the broader implications for campuses across China. A comprehensive model is then employed to assess the effects of perceived greenness, frequency of use, and ease of access on depression, identifying both mediation and moderation effects through the application of PLS-SEM. The results demonstrate that perceived greenness exerts the most significant influence in high-density campuses, while frequency of use and convenience of access play a greater role in larger, lower-density campuses. Mediation analysis shows that perceived greenness partially mediates the relationship between green space usage and depression, particularly in smaller, high-density campuses. Additionally, moderation analysis indicates that frequency of use amplifies the restorative effects of higher perceived greenness, especially in medium and large campuses. These findings advance current theories in environmental psychology and campus planning by underscoring the contextual intricacies of green space benefits. The outcomes are expected to inform future campus design and urban planning, emphasizing the importance of green spaces in fostering environments that support student well-being.

Keywords Perceived Greeness, Access Frequency, Convenience to Green Space, Depression, Restoration, Campus Green Space, University Student

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Introduction

In the wake of the global economic downturn, university students worldwide are experiencing unprecedented pressures due to intensifying market competition and rising youth unemployment rates. This issue is particularly acute in East Asian countries such as South Korea, Japan, Vietnam, and China. In China, the youth (16–29 years old) unemployment rate reached 23.6% in July 2024 [45], adding to the social and economic challenges faced by young adults. Among Chinese college students, the incidence of depression is notably high,recent studies report that approximately 34.1% of university students suffer from depressive symptoms [45]., underscoring the heightened mental health challenges faced by this demographic. This population is uniquely vulnerable due to academic pressures, career uncertainties, and rapid social transitions that intensify stress levels, exacerbating the risk of depression and associated health issues [29]. These factors not only impair academic performance but also disrupt social functioning and increase the risk of severe mental health consequences [14]. Given these conditions, investigating environmental interventions, such as campus green spaces, becomes increasingly relevant in providing preventive mental health support within educational settings.

Globally, depression is recognized by the World Health Organization (WHO) as a leading cause of disability, affecting over 264 million people [30], particularly, 99% colleges reported students experiencing anxiety and depression in the UK [7], and 26% graduate students even considering suicide [62]. In China, the prevalence of depression mirrors these global trends, exacerbated by the rapid pace of urbanization, modernization, and significant socioeconomic shifts. Recent data from the Chinese National Mental Health Survey indicate that approximately 4.2% of the adult population in China suffers from depression, with the highest rates observed among individuals aged 18 to 29 [11, 43], and from research of anxiety and depression of Chinese university students, 34.10% (total over 40 million university students in China in [45] were affected by depression [29]. This younger demographic is particularly vulnerable due to the intense pressures of academic achievement, career development, and social integration, underscoring the urgent need for effective mental health interventions and preventive strategies in educational settings.

In response to the growing mental health crisis, research on depression has increasingly focused on environmental factors that can either mitigate or exacerbate this condition. A substantial body of literature highlights the therapeutic benefits of natural environments, particularly green spaces, in promoting psychological well-being and facilitating emotional and cognitive restoration (Dzhambov et al., [18, 20, 21, 28, 33, 46, 52, 54]. These green environments are believed to reduce stress, alleviate depression, and enhance cognitive recovery through mechanisms such as attention restoration and stress reduction [31, 42, 53]. Moreover, the healing effects of these environments extend beyond immediate emotional relief, contributing to long-term mental health and well-being by promoting a sense of peace and recovery [35, 43, 55, 59]. Furthermore, from campus perspective, limited research has pay attension to affections of campus environment to students' mental health with impacts to their quality of life [21, 28, 41].

However, relavent studies were mostly focused on the campuses in western countries, which the style, form, urban density and building structures were largely different compare to global south, especially China. Within this context, the specific influence of green spaces within different university campuses types remains underexplored. Additionally, much of the existing research has focused primarily on children and adolescents [2, 57], with extremelly limited attention to university students. This demographic, however, faces unique challenges and environmental stressors, such as intense academic competition and limited access to natural environments in high-density urban campuses. These factors can exacerbate mental health issues, particularly depression, when opportunities for restorative interactions with nature are constrained.

This research aims to investigate the relationship between campus green spaces and the mental health of university students in China, focusing on depression and the restorative effects of these environments. The study specifically examines how perceived greenness, frequency of use, and convenience of access to green spaces influence students' restorative experiences across various university campus types. By exploring these factors, the research seeks to determine their contribution to alleviating depression and enhancing restoration among students. Additionally, the study will assess the mediating and moderating roles of usage frequency [41, 60] and convenience in the relationship between depression and perceived restorative effects [5, 8, 38, 51], providing deeper insights into the mechanisms.

By addressing these research questions, the study contributes to the broader fields of environmental psychology and mental health in urban setting, providing empirical evidence on the restorative effects of green spaces within educational contexts. The findings are anticipated to inform campus design and urban planning practices, emphasizing the critical role of green elements in creating environments that are supportive of student well-being.

Development of conceptual model

Indicators for analysis

Based on existing literature, this study employs several key indicators to explore the relationship between campus green spaces and the mental health of university students, particularly in relation to depression and restorative outcomes. The selection of these indicators is grounded in a comprehensive review of existing literature, focusing on the most relevant and validated measures in the field.

The Zung Self-Rating Depression Scale (ZSDS) and the Perceived Restorative Scale (PRS) are utilized as primary tools to measure self-rating depression (SD) and perceived restorative (PR) outcomes, respectively. The ZSDS is a well-established instrument designed to assess various dimensions of depression, including core depression, cognitive disturbances, anxiety, and somatic complaints [71]. The enduring use of ZSDS in psychological research is a testament to its robustness and validity, which has been consistently affirmed in numerous studies [47, 66–68]. This scale's comprehensive coverage of depression-related makes it particularly well-suited for this study, as it allows for a nuanced exploration of how environmental factors such as campus green spaces influence mental health. The decision to use ZSDS over other scales, such as the Beck Depression Inventory (BDI) or the Hamilton Depression Rating Scale (HDRS), stems from its self-report nature, which is less invasive and more suitable for a university setting where the focus is on subjective experiences of depression rather than clinical diagnosis.

Similarly, the PRS is a widely used scale that captures the restorative effects of natural environments, measuring dimensions such as psychological relaxation, emotional renewal, and cognitive recovery [4, 16, 26–28, 40, 51]. The PRS is particularly relevant for this study because of its focus on perceived restorative outcomes, aligning well with the study's objective to evaluate the impact of green spaces on students' mental health. The PRS has been widely validated in various contexts, ensuring its continued relevance and effectiveness in capturing the nuanced ways in which green spaces contribute to mental health restoration. Alternative scales, such as the Restorative Components Scale (RCS) [65], were considered, but the PRS was ultimately selected due to its broader applicability and established use in similar studies.

The perceived greeness of campus green spaces is shaped by the interplay of several key factors, each contributing to the environment's overall impact on mental health. Many scholars have directly [69, 70] and indirectly [3, 6] shown that vegetation density and plant diversity are central to creating immersive and restorative natural environments. Dense, diverse greenery can evoke a strong sense of connection to nature, enhancing cognitive recovery through what [31] describe as "soft fascination," where the environment gently captures attention, allowing mental fatigue to dissipate [20]. However, the benefits of dense vegetation are context-dependent,in some urban settings, excessive density can lead to feelings of enclosure or insecurity, particularly if it obstructs visibility and increases perceived risks [56]. On the other hands, complementing these structural elements, the variety of plant colors further enriches the sensory experience, adding depth and vibrancy to the visual field. The interplay of diverse hues, from the greens of foliage to the vibrant tones of flowers, has been linked to emotional recovery, as it engages viewers and enhances the aesthetic appeal of the space [23]. This visual complexity, however, must be balanced, becaude over-perceived variety without coherence can overwhelm rather than soothe, indicating that the restorative potential of plant color diversity is influenced by how well it integrates with the overall landscape design.

In addition, aesthetic preference emerges as a critical subjective element that ties together these physical characteristics. While dense, diverse, and colorful vegetation can theoretically enhance a space's restorative quality, it is the alignment with users' aesthetic preferences that determines whether these attributes are perceived as beneficial [32]. Cultural and individual differences play a significant role here, suggesting that what one group finds restorative might be less effective for another [36]. This variability points to the importance of designing campus green spaces that are adaptable to different aesthetic tastes, thereby maximizing their psychological benefits across a diverse student body. Another layer of complexity is added by the concepts of visual openness and maintenance. Open views within a green space can counterbalance the effects of dense vegetation, providing a sense of freedom and reducing feelings of confinement, especially in high-density urban environments [9, 17, 19]. However, excessive openness might reduce the perceived sense of security, which is crucial for restoration. Well-maintained spaces, on the other hand, are consistently associated with positive perceptions of safety and order, which enhance the likelihood of frequent use and contribute to the space's restorative potential [41]. The interaction between openness, maintenance, and vegetation structure thus plays a pivotal role in shaping the overall perceived greeness and its impact on mental health. Moreover, comfortable, well-designed pathways encourage exploration and deeper engagement with the environment, which in turn enhances the restorative experience [9, 19]. The effectiveness of green spaces as therapeutic environments depends not only on their

visual appeal but also on how easily and comfortably they can be navigated and enjoyed.

The frequency of access green space is another crucial indicator [41]. It reflects the extent to which students engage with these natural environments, which has been shown to have a direct impact on mental health. Existing studies consistently demonstrate that regular interaction with green spaces is associated with reduced levels of depression, anxiety, and stress, as these environments provide opportunities for relaxation, physical activity, and social interaction [1, 15]. The frequency of use is often influenced by individual preferences, the availability of time, and the perceived benefits of engaging with these spaces [15, 38].

Convenience, in terms of accessibility and ease of use, is the third major indicator analyzed in this study. The proximity of green spaces to students' daily routes, the availability of well-designed pathways, and the overall accessibility of these environments significantly affect their use. Research shows that when green spaces are convenient to access, students are more likely to use them regularly, thereby reaping the psychological benefits associated with nature exposure [22, 38]. The ease of access is particularly critical in high-density urban environments where students may have limited time and resources to seek out natural spaces, making convenience a key determinant of whether or not they engage with these restorative environments [9].

From the discussion above, the indicators identified in this study are conclude in Table 1.

The relationships between key variables

As measured by the Zung Self-Rating Depression Scale (ZSDS), and perceived restorative (PR) effects of green spaces on campus. Self-rating depression are known to significantly impair cognitive and emotional functioning, leading to a decreased ability to experience positive states such as relaxation and restoration. Environmental psychology suggests that natural environments, particularly those that are perceived as restorative, can help mitigate the effects of depression by providing a calming and rejuvenating experience [31, 53]. Therefore, the relationship between SD and PR is expected to be inversely proportional, where higher levels of depression are associated with lower restorative effects. This leads to the first hypothesis:

> H1: There is a negative relationship between depression (SD) and perceived restorative effects (PR).

Moving forward, the relationship between depression (SD) and perceived greeness (PG) of campus green spaces is examined. It is theorized that individuals with higher levels of depression may have a heightened sensitivity to their surroundings, particularly to environments that are aesthetically pleasing and well-maintained. Perceived greeness, including factors such as vegetation diversity and maintenance, can provide a sense of order and tranquility that counters the feelings of chaos often associated with depression [20]. This suggests that individuals with higher depression may place greater value on high-quality visual environments. In turn, these high-quality environments are more likely to be perceived as restorative, as they fulfill the psychological need for beauty and order [28, 56, 60, 61]. Therefore, the following hypotheses are proposed:

> H2: There is a positive relationship between depression (SD) and the perceived greeness (PG) of campus green spaces.

> H3: There is a positive relationship between the perceived perceived greeness (PG) of campus green spaces and perceived restorative effects (PR).

In addition, the study investigates the connection between depression (SD) and the frequency of green space use (FR). Previous research indicates that individuals experiencing depression might either increase their interaction with natural environments as a form of escapism or decrease their usage due to a lack of motivation [31]. The frequency of interaction with

Table 1 The information of three universities

	City University of Macau	Macau University of Science and Technology	University of Macau
Type number	Type I	Type II	Type III
Number in modeling	Model I	Model II	Model III
Compactness	High	Medium	Low
Total area	0.038 km^2	0.21 km^2	1.0926 km^2
Student amount	4260	21,000	13,800
m^2/person	8.9 m^2/person	10 m^2/person	791 m^2/person
Greeness conditions	Very limited greeness	Moderated greeness	Very large greeness

green spaces is crucial, as regular engagement has been shown to amplify the psychological benefits associated with these environments, such as stress reduction and mood improvement [1, 41]. Consequently, the frequency of use is also expected to be positively associated with restorative effects, as more frequent exposure to green spaces provide consistent opportunities for mental recovery. Based on this, the following hypotheses are developed:

> H4: There is a significant relationship between depression (SD) and the frequency of green space use (FR).
> H5: There is a positive relationship between the frequency of green space use (FR) and perceived restorative effects (PR).

The study considers the relationship between depression (SD) and the convenience of green space use (CO). Convenience, which encompasses factors such as proximity and ease of access, plays a vital role in determining whether individuals will engage with green spaces. Those with higher depression might prefer easily accessible environments that require minimal effort to reach, which in turn could influence their frequency of use and subsequent restorative experiences. The convenience of access is hypothesized to be positively linked to restorative effects, as it facilitates more frequent and potentially longer interactions with nature, which are critical for mental health recovery [22]. Therefore, the final hypotheses are:

> H6: There is a significant relationship between depression (SD) and the convenience of green space use (CO).
> H7: There is a positive relationship between the convenience of green space use (CO) and perceived restorative effects (PR).

The restorative potential of campus green spaces depends not only on their visual appeal but also on their capacity to promote regular engagement and easy accessibility. Research indicates that green spaces with high vegetation density and plant diversity create immersive natural environments conducive to cognitive recovery and stress reduction, which significantly contribute to mental health and well-being [63, 64]. Additionally, structured pathways and visual openness within these spaces enhance accessibility, encouraging students to interact more frequently with green environments and thereby reinforcing the cumulative psychological benefits through consistent exposure [10, 63]. Based on these considerations, the following hypotheses are developed:

> H8: There is a positive relationship between perceived greenness (PG) and frequency of green space use (FR).
> H9: There is a positive relationship between perceived greenness (PG) and convenience of access (CO).

Based on these hypotheses, the conceptual model can be developed in Fig. 1.

Moderation effects

The role of frequency of green space use (FR) as a moderator is considered (Fig. 1). The impact of perceived greeness on restorative effects is likely to be influenced by how often students engage with these spaces. Existing literature suggests that frequent exposure to green spaces enhances the psychological benefits derived from them, as repeated interaction can reinforce the restorative experience and allow individuals to build a deeper connection with the environment [1, 15]. Therefore, it is hypothesized that the relationship between perceived greeness and restorative effects will be stronger for students who use green spaces more frequently. This leads to the following hypothesis:

> H10: The frequency of green space use (FR) moderates the relationship between perceived greeness (PG) and perceived restorative effects (PR), such that the relationship is stronger for individuals who use green spaces more frequently.

We also consider the convenience of access to green spaces (CO) as another moderating factor. The ease with which students can access green spaces is likely to influence how they perceive the greeness of these environments and, consequently, their restorative effects. When green spaces are conveniently located and easy to access, students may be more inclined to visit them regularly and for longer periods, thereby maximizing the benefits of the high-quality visual environment [22]. Conversely, if access is inconvenient, even high-quality green spaces may be underutilized, reducing their potential restorative impact. Hence, the study hypothesizes that:

> H11: The convenience of access to green spaces (CO) moderates the relationship between perceived greeness (PG) and perceived restorative effects (PR), such that the relationship is stronger for individuals who find green spaces more convenient to access.

Mediation effects

Mediation analysis is crucial for understanding how these intermediary variables transmit the impact of depression on restorative outcomes, thereby providing deeper

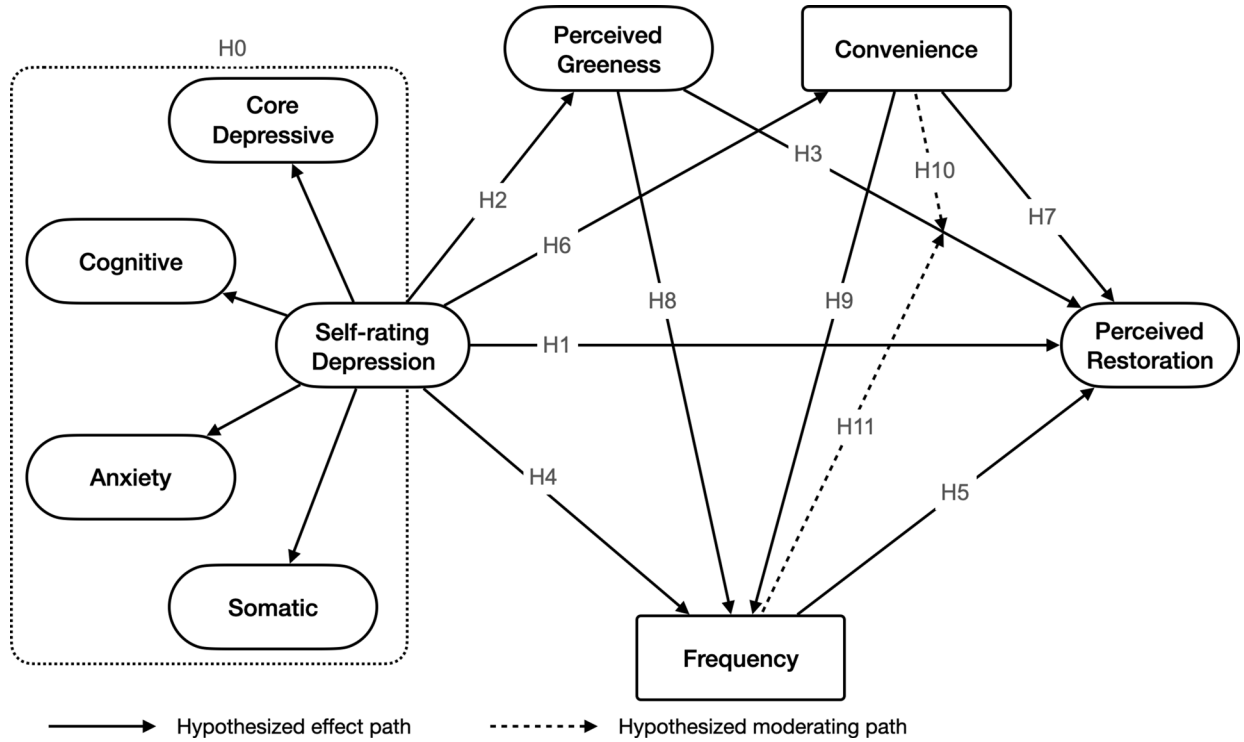

Fig. 1 Conceptual model

insights into the processes through which campus green spaces can affect student mental health.

The first mediation effect to consider involves perceived reeness (PG) as a mediator. Depression can alter an individual's perception of their environment, particularly in terms of how they value and respond to aesthetic qualities such as vegetation diversity, color, and overall landscape maintenance. It is posited that individuals with higher levels of depression may develop a heightened sensitivity to environmental aesthetics, leading them to place greater importance on high-quality visual environments [12, 13, 58]. These environments, in turn, are more likely to be perceived as restorative due to their ability to provide a sense of peace and order [20, 31]. This suggests that perceived greeness may mediate the relationship between depression and restorative effects:

> H12: Perceived greeness (PG) mediates the relationship between depression (SD) and perceived restorative effects (PR).

The study also examines the role of frequency of green space use (FR) as a mediator. Individuals experiencing higher levels of depression might engage with green spaces differently, either by seeking them out more frequently as a form of emotional relief or by avoiding them due to a lack of motivation. The frequency of interaction with green spaces is critical, as regular engagement is associated with enhanced psychological benefits, including stress reduction and mood improvement [1]. Consequently, frequency of use is hypothesized to mediate the relationship between depression and restorative effects:

> H13: The frequency of green space use (FR) mediates the relationship between depression (SD) and perceived restorative effects (PR).

Lastly, the study considers the convenience of access to green spaces (CO) as a mediator. The ease with which students can access green spaces plays a significant role in determining their usage patterns. Students experiencing depression might prefer environments that are easily accessible, as these require less effort to reach, thereby lowering the barriers to engagement. This convenience could lead to more frequent and meaningful interactions with green spaces, ultimately enhancing the restorative effects they experience [22]. Based on this understanding, the final mediation hypothesis is proposed:

> H14: The convenience of access to green spaces (CO) mediates the relationship between depression (SD) and perceived restorative effects (PR).

The mediating roles of perceived greenness (PG) and convenience of access (CO) in conjunction with frequency of green space use (FR) reveal how specific green space attributes contribute to enhanced psychological

outcomes through a chain of mediating factors. Green spaces with high perceived greenness tend to attract users through their aesthetic appeal, fostering frequent visits that support cognitive recovery and stress reduction [63, 64]. This sequence suggests that PG acts as an initial mediator, enhancing the likelihood of frequent use (FR), which, in turn, amplifies restorative effects through ongoing exposure to natural elements. Similarly, convenience of access (CO) functions as an initial mediator by reducing physical and perceived barriers to green space entry, further encouraging regular visitation. Accessible and well-maintained spaces create a pathway whereby increased access leads to more frequent interactions, reinforcing mental well-being through consistent engagement [50, 63]. Together, these pathways highlight the pivotal roles of both aesthetic appeal and accessibility in promoting sustained engagement, leading to cumulative psychological benefits. Based on this, the following hypotheses are proposed:

> H15: Perceived greenness (PG) and frequency of green space use (FR) act as chain mediators in the relationship between green space quality and psychological outcomes.
> H16: Convenience of access (CO) and frequency of green space use (FR) act as chain mediators in the relationship between green space accessibility and psychological outcomes.

Control variables

In this study, gender and education level are included as control variables to account for their potential influence on the relationships between depression (SD), perceived greeness (PG), frequency of green space use (FR), convenience of access (CO), and perceived restorative effects (PR).

Gender is known to affect both mental health outcomes and environmental perceptions. For instance, research suggests that men and women may experience and respond to depression differently, which could influence their interaction with and benefit from green spaces [25, 48]. Controlling for gender ensures that the relationships between the key variables are not confounded by these differences. Education level also plays a role in shaping health behaviors and environmental engagement. Individuals with higher education levels might have greater awareness and access to the benefits of green space use, leading to more frequent and effective engagement with these environments [44]. By controlling for education, the study ensures that the findings reflect the true associations between the variables, independent of educational background.

Including these control variables enhances the accuracy and validity of the study's results, providing a clearer understanding of how campus green spaces influence student mental health across different demographic groups.

Methods

Case study investigation

This study investigates the restorative effects of green spaces across three distinct university campuses in Macau, chosen for their varied spatial contexts (Fig. 2 and Table 1). The campuses represent different levels of density and spatial arrangement, allowing for a comparative analysis of how green space characteristics influence student interactions and mental health outcomes (Figs. 3 and 4). The selection of these campuses provides an ideal framework for understanding the role of campus design in promoting mental well-being through natural environments.

Type I: City University of Macau (CUM)

The City University of Macau represents a high-density, small-scale campus with very limited greenness, which the type of campus can be often found in such as Hong Kong and Macau. The university covering just 0.038 square kilometers, the campus features limited green spaces, such as rooftop gardens. The spaces are interspersed throughout the compact campus, creating a confined and highly structured environment. Due to the limited area and spatial constraints, the frequency of green space use may be lower compared to larger campuses, making the perceived greeness of these spaces—such as plant diversity, vegetation density, and maintenance—critical for any restorative effects. In this type of campus, students may rely heavily on the aesthetic appeal and maintenance of green spaces, as frequent, extended use may not be feasible due to the campus's compactness.

Type II: Macau University of Science and Technology (MUST)

The Macau University of Science and Technology represents a medium-density, moderately compact campus and greenness, which this type is rarely found in China. Spanning approximately 0.21 square kilometers, this campus offers a more balanced mix of green spaces, including sports facilities and shaded outdoor areas, as well as fragmented green belts. Its moderate size allows for more frequent use of green spaces, while maintaining some spatial constraints. The availability of shaded pathways and the presence of a Chinese medicinal herb garden may encourage more interaction with these natural areas, suggesting that both the perceived greeness and frequency of use could play significant roles in the

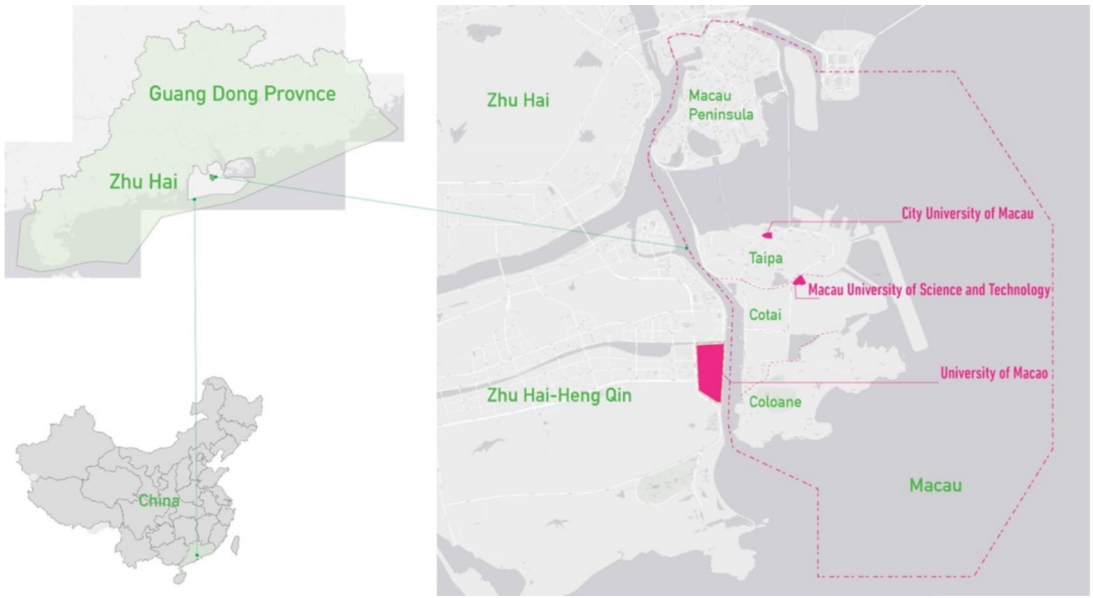

Fig. 2 The location of study area and selected cases

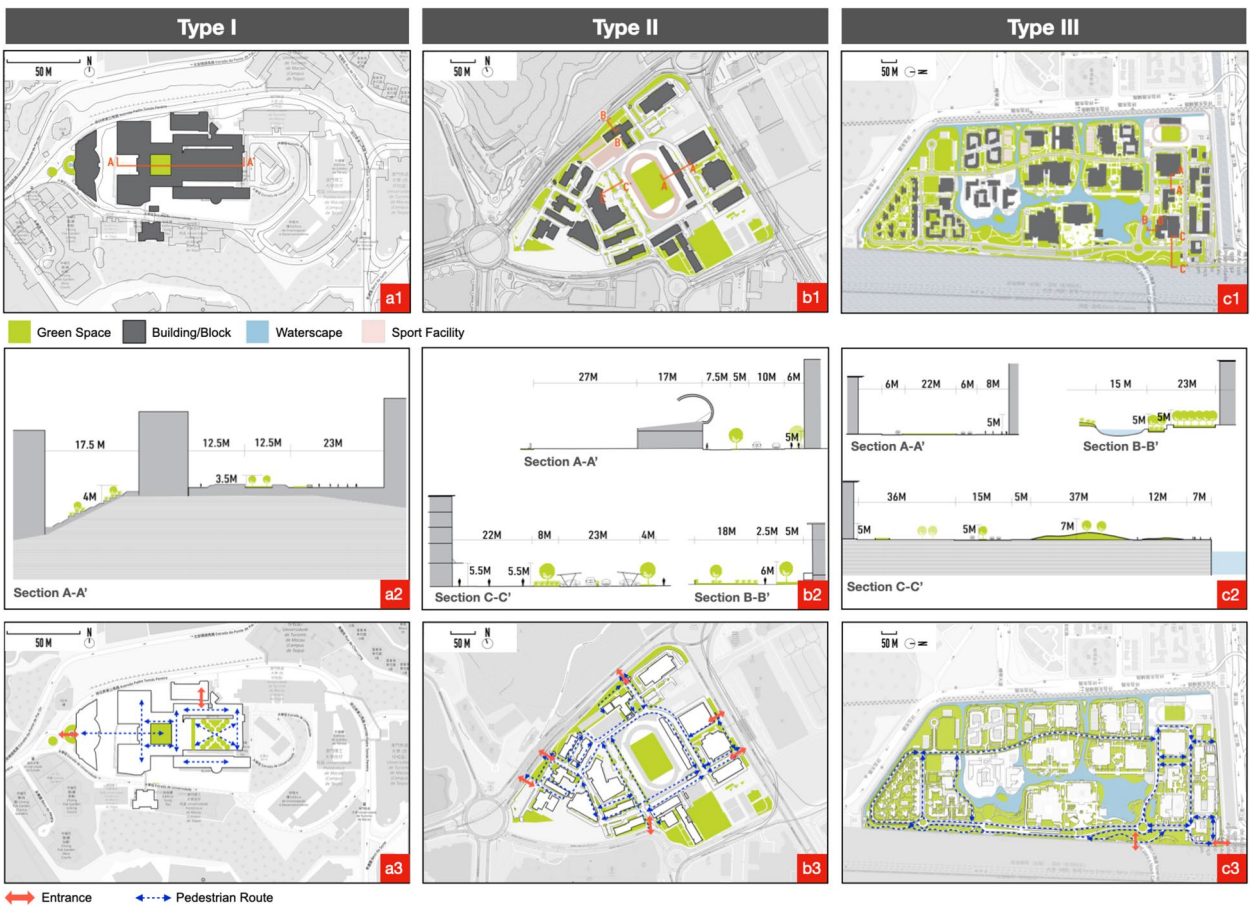

Fig. 3 The form and section of selected campuses

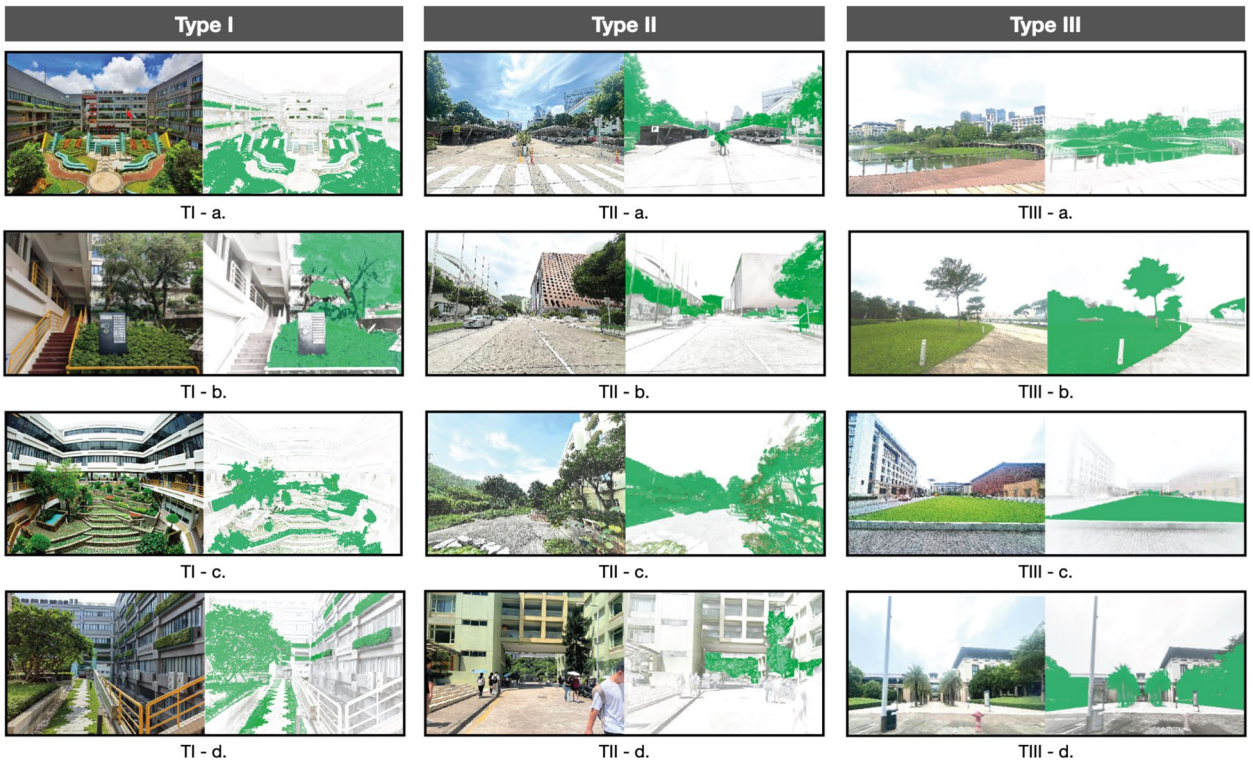

Fig. 4 The conditions and coverage of greeness in public spaces across vasiours campuses

restorative benefits experienced by students. This type of campus offers a balance between accessibility and the aesthetic appeal of green spaces, potentially enhancing both cognitive recovery and emotional well-being.

Type III: University of Macau (UM)

The University of Macau, the largest of the three campuses, which the campus type is the most common type and widely seen in China. The campus covers 1.09 square kilometers and is characterized by its low-density, expansive layout. The campus offers extensive green spaces, including large gardens, tree-lined pathways, and access to both mountain and marine environments. Due to its large area, students have ample opportunities for frequent interaction with green spaces, which could lead to greater restorative effects through prolonged engagement with nature. In this context, the frequency of green space use, as well as the convenience of access, may be more influential in promoting mental health, as the expansive layout facilitates more regular and immersive experiences with nature. The perceived greeness of the spaces, while still important, may have a more secondary role compared to the accessibility and frequency of use in this low-density environment.

These three campuses were selected due to their contrasting green space configurations and accessibility, which are essential for examining how spatial factors influence mental health outcomes among students. By analyzing the differences in green space availability, frequency of use, and perceived greeness, this study aims to understand how specific campus designs can either enhance or limit the restorative effects of natural environments. The diversity of green space characteristics across the campuses provides a comprehensive basis for exploring their respective impacts on depression and emotional recovery.

Demographic characteristics of the participants

The study sample consisted of 818 participants distributed across three campus types (Table 2): 275 from the small campus, 286 from the medium campus, and 257 from the large campus. Gender distribution was relatively balanced, with a slight male majority: 57.8% male and 42.2% female on the small campus, 58.7% male and 41.3% female on the medium campus, and 56.0% male and 44.0% female on the large campus. Participants' study status varied, with the small campus comprising 25.1% in Matriculation Courses, 32.4% Undergraduates, 36.0% Post-Graduates, and 6.5% Doctoral students. On the medium campus, 20.3% were in Matriculation Courses, 25.9% Undergraduates, 48.3% Post-Graduates, and 5.6% Doctoral students. The large campus had 17.1%

Table 2 Demographics statistics of the sample data from three universities

		CUM		MUST		UM	
		N	%	N	%	N	%
Gender	Male	159	57.8	168	58.7	144	56.0
	Female	116	42.2	118	41.3	113	44.0
Study Status	Matriculation Course	69	25.1	58	20.3	44	17.1
	Undergraduate	89	32.4	74	25.9	80	31.1
	Post-Graduate	99	36.0	138	48.3	116	45.1
	Doctor	18	6.5	16	5.6	17	6.6
Participants number		275	100	286	100	257	100

Total participants $n = 818$

in Matriculation Courses, 31.1% Undergraduates, 45.1% Post-Graduates, and 6.6% Doctoral students. This demographic diversity allows for a robust analysis across different educational levels and campus environments.

Data collection sampling

To ensure the validity of the data sample, the survey targeted students from the three types of universities representing the most common campus types in China. The questionnaire, written in Traditional Chinese, was collected in person by using a snowball sampling method. Additionally, some studies suggest that seasonal factors can affect plant growth, thereby influencing participants' perceptions of green space vegetation [21, 34]. However, this study was conducted in Macau, where the subtropical climate ensures consistent vegetation year-round. As Macau does not experience significant seasonal changes that affect plant life, the timing of data collection is unlikely to bias participants' perceptions of green space quality.

Before the formal distribution of the questionnaire, a pilot test was conducted with 10 participants who met the criteria to identify and revise questions that could cause ambiguity. The revised questionnaire was distributed in April 2024, with data collection completed by early June. Total 970 completed sample were received, but since the actual time required to complete the questionnaire was approximately 2 min, 152 invalid questionnaires were removed due to excessively short response times, resulting in 818 valid questionnaires being collected.

Measures

This study employs a combination of validated instruments and indicators to measure the constructs central to understanding the impact of campus green spaces on students' mental health (Table 3). The Zung Self-Rating Depression Scale (SD) was utilized to assess depression,

Table 3 The key variables, items and references

Variable	Items	References
Self-rating Depression (SD)	Core Depression (Cd) – 8 items	[47, 66, 68, 71]
	Cognitive (Co) – 4 items	
	Anxiety (An) – 3 items	
	Somatic (So) – 3 items	
Perceived Restoration (PR)	18 items	[4, 16, 26, 27]
Frequency (FR)	Frequency access	[9, 15, 17, 32, 38, 41]
Perceived Greeness (PG)	Plant coverage	[20, 56]
	Richness of plant color	[23]
	Plant diversity	[20, 32, 56, 60]
	Landscape aesthetic preferrences	[32, 36]
	Visual comfortable with green	[9, 17, 19]
	Visual openness of green space	[9]
	Maintenance of green space	[9]
	Engagement opportunities with greenery	[9]
Convenience (CO)	Convenience for using the green space	[22, 38]

encompassing core depression, cognitive disturbances, anxiety, and somatic complaints. This scale is well-established in psychological research, offering robust insights into the mental health status of participants and frequently used in studies related to depression. Therefore, the questionnaire of ZSDS was adopted in this study [71]. The Perceived Restorative Scale (PRS), with 18 items, was used to evaluate the restorative effects of natural environments, specifically focusing on psychological relaxation, emotional renewal, and cognitive recovery (Hartig et al., [27]. The PRS scale was slightly modified in order to fit the investigation setting, and modified measurements were presented in Supplementary File.

The study also considered three key environmental variables: Frequency of green space usage (FR), Perceived Greeness (PG) and Convenience (CO). Perceived greeness was assessed through multiple facets including plant density, color richness, diversity, aesthetic preferences, visual comfort, openness, maintenance, and pathway quality. These indicators were selected based on their demonstrated impact on the psychological benefits of green spaces, as supported by existing literature (Table 3). Convenience was evaluated in terms of the ease of accessing and using green spaces, which is crucial in determining the frequency and quality of engagement with these environments. All these indicators were developed based on existing studies for the investigation, the details of measurements can be found in Supplementary File.

Data analysis

In this study, Partial Least Squares Structural Equation Modeling (PLS-SEM) was selected due to its distinct advantages in handling complex relationships between latent variables such as depression, perceived greeness, frequency of green space use, and perceived restorative effects. PLS-SEM is particularly suitable for this research because it does not require the stringent normality assumptions of covariance-based SEM and performs well with smaller sample sizes, such as the 818 cases analyzed here [24]. Additionally, PLS-SEM allows for the simultaneous estimation of direct, indirect, and interaction effects, which is critical for testing the complex mediation and moderation hypotheses central to this study. The analysis was conducted using SmartPLS 4, with a bootstrap resampling procedure of 5,000 iterations to ensure the stability and reliability of the results [24].

Composite Reliability (CR) and Average Variance Extracted (AVE) were calculated to assess internal consistency and convergent validity, respectively. All constructs demonstrated strong reliability (CR > 0.7) and adequate convergent validity (AVE > 0.5). Discriminant validity was confirmed using the Heterotrait-Monotrait Ratio (HTMT), with all HTMT values below the threshold of 0.85. The calculations are:

$$CR = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum(1-\lambda_i^2)} \tag{1}$$

$$AVE = \frac{\sum \lambda_i^2}{n} \tag{2}$$

$$HTMT = \frac{E(HT)}{E(MT)} \tag{3}$$

The structural model's predictive accuracy was evaluated using the coefficient of determination (R^2) and effect size (f^2). The moderation and mediation effects were tested using interaction terms and indirect paths, respectively. The calculations are:

$$R^2_{PRS} = \frac{SS_{reg},PRS}{SS_{total},PRS} \tag{4}$$

$$f^2_{VQ,PRS} = \frac{R^2_{PRS,incl.VQ} - R^2_{PRS,excl.VQ}}{1 - R^2_{PRS,incl.VQ}} \tag{5}$$

A multi-group analysis (Sarstedt et al., [49] was conducted to compare path coefficients across different campus environments. The formula used to compare these coefficients across the three models was:

$$PRS = \frac{\left(\hat{\beta}Model1 - \hat{\beta}Model2 - \hat{\beta}Model3\right)^2}{SEModel1^2 + SE^2_{Model2} + SE^2_{Model3}} \tag{6}$$

Analysis results

Measurement analysis

The measurement model's reliability and validity were assessed using Partial Least Squares Structural Equation Modeling (PLS-SEM) via SmartPLS 4. The internal consistency of the constructs, evaluated by Cronbach's Alpha (α) and Composite Reliability (CR), yielded values that exceeded the threshold of 0.7, indicating strong reliability (Table 1). This finding suggests that the items within each construct consistently measure the intended latent variables, thereby providing confidence in the internal coherence of the constructs. Moreover, the analysis demonstrated adequate convergent validity, as evidenced by Average Variance Extracted (AVE) values surpassing the recommended threshold of 0.5 (Table 4). This indicates that a significant portion of the variance in the observed variables is explained by the underlying constructs, underscoring the constructs' effectiveness in capturing the intended dimensions of the theoretical model. For instance, in the Core Depression (CD) dimension, the AVE values for the three models ranged from 0.624 to 0.640, affirming the robustness of this construct.

Table 4 Reliability and convergent validity

	Model I ($n=275$)					Model II ($n=286$)					Model III ($n=257$)				
	λ	VIF	CR	α	AVE	λ	VIF	CR	α	AVE	λ	VIF	CR	α	AVE
ZUNG Self-rating Depression Scale (ZSDS)															
Core Depression (CD)			0.930	0.914	0.624			0.933	0.918	0.636			0.934	0.919	0.640
CD01	0.844	2.618				0.812	2.253				0.776	2.018			
CD02	0.776	2.046				0.779	2.034				0.809	2.366			
CD03	0.773	2.248				0.815	2.616				0.794	2.498			
CD04	0.805	2.203				0.763	1.917				0.732	1.921			
CD05	0.742	2.057				0.777	2.192				0.834	3.086			
CD06	0.820	2.378				0.821	2.388				0.736	1.913			
CD07	0.800	2.421				0.814	2.557				0.895	4.726			
CD08	0.756	2.080				0.795	2.416				0.811	2.447			
Cognitive (Co)			0.906	0.862	0.707			0.895	0.844	0.682			0.883	0.823	0.654
Co01	0.841	3.082				0.805	2.072				0.796	2.022			
Co02	0.863	2.212				0.866	2.196				0.850	1.953			
Co03	0.854	2.815				0.824	2.578				0.814	2.280			
Co04	0.805	1.833				0.806	1.766				0.773	1.583			
Anxiety (An)			0.865	0.765	0.681			0.867	0.770	0.686			0.870	0.776	0.691
An01	0.862	2.699				0.882	3.286				0.886	3.200			
An02	0.831	2.163				0.797	1.957				0.806	1.972			
An03	0.781	1.436				0.802	1.522				0.800	1.549			
Somatic (So)			0.889	0.812	0.727			0.883	0.800	0.715			0.867	0.770	0.686
D05	0.869	1.857				0.806	1.541				0.789	1.451			
D07	0.851	1.783				0.875	1.923				0.874	1.837			
D09	0.837	2.215				0.854	2.295				0.819	2.372			
Perceived Greeness (PG)			0.968	0.916	0.630			0.937	0.923	0.650			0.939	0.926	0.660
PG01	0.811	2.245				0.819	2.356				0.829	2.620			
PG02	0.814	2.378				0.789	2.100				0.805	2.356			
PG03	0.772	1.932				0.842	2.630				0.849	2.771			
PG04	0.809	2.277				0.876	3.252				0.859	3.089			
PG05	0.772	2.032				0.842	2.702				0.809	2.311			
PG06	0.775	1.990				0.777	2.122				0.764	1.978			
PG07	0.798	2.136				0.716	1.694				0.808	2.341			
PG08	0.797	2.131				0.780	2.085				0.771	2.102			
Perceived Restoration Scale (PRS)			0.964	0.960	0.596			0.961	0.957	0.581			0.966	0.963	0.616
PRS01	0.793	2.638				0.748	2.152				0.852	3.493			
PRS02	0.773	2.347				0.711	1.928				0.850	3.725			
PRS03	0.792	2.481				0.790	2.467				0.849	3.395			
PRS04	0.724	2.069				0.692	1.855				0.825	3.147			
PRS05	0.828	2.934				0.775	2.317				0.765	2.536			
PRS06	0.787	2.536				0.737	2.148				0.798	2.622			
PRS07	0.689	1.893				0.772	2.311				0.785	2.517			
PRS08	0.758	2.247				0.826	2.905				0.775	2.603			
PRS09	0.759	2.291				0.719	2.072				0.644	1.740			
PRS10	0.798	2.576				0.790	2.499				0.747	2.212			
PRS11	0.748	2.159				0.680	1.762				0.704	2.051			
PRS12	0.791	2.516				0.854	3.247				0.830	3.169			
PRS13	0.810	2.682				0.766	2.297				0.651	1.792			
PRS14	0.762	2.280				0.767	2.299				0.839	3.314			
PRS15	0.784	2.454				0.746	2.159				0.785	2.495			
PRS16	0.707	1.872				0.749	2.319				0.828	3.133			
PRS17	0.846	3.379				0.835	3.084				0.750	2.377			
PRS18	0.725	2.007				0.734	2.059				0.805	2.955			

Additionally, the assessment of multicollinearity through the Variance Inflation Factor (VIF) revealed that all VIF values were below the threshold of 5, indicating that multicollinearity does not pose a significant issue in this model (Table 4). For example, the VIF values for the Cognitive (Co) construct across the models ranged between 1.583 and 3.082, well within acceptable limits. This absence of multicollinearity is critical as it ensures that the relationships among the constructs are not artificially inflated, allowing for more accurate estimation of the structural paths.

Discriminant validity was further confirmed through the Heterotrait-Monotrait ratio (HTMT), with all values remaining below the critical threshold of 0.85, as shown in Fig. 5. This crucial finding suggests that each construct is distinct and captures unique aspects of the theoretical framework, ensuring that the constructs are not overlapping in their measurements. The discriminant validity is particularly evident in the comparison between the Anxiety (An) and Somatic (So) constructs, where the HTMT values indicated clear differentiation between these two dimensions.

To further assess the predictive accuracy of the model, the Predictive Relevance (Q^2) was calculated for each construct (Table 5). The Q^2 values for key constructs such as Core Depression (Cd), Anxiety (An), Cognitive (Co), and Somatic (So) were all significantly positive, indicating that the model has substantial predictive relevance. Specifically, the Q^2 values for Cd and Co were 0.593 and 0.602, respectively, which are well above the minimum threshold of 0, demonstrating strong predictive power for these constructs. Similarly, the Anxiety and Somatic constructs also showed Q^2 values of 0.561 and 0.593, confirming their relevance within the predictive framework. Meanwhile, The Q^2 value for FR (0.408) was also relatively high, indicating that the construct contributes substantially to the model's predictive power.

However, it is noteworthy that the Q^2 values for Perceived Greenness (0.137) and Convenience (0.023) are relatively low, indicating limited predictive power for these constructs. This suggests that the model's ability to predict outcomes related to these variables is weaker, which may point to the need for additional indicators or a refinement in measurement. Lastly, the Q^2 value for PR was 0.208, indicating a modest level of predictive relevance.

Structural analysis

The structural analysis investigates the relationships between depression, perceived greenness, frequency of green space use, and perceived restorative effects across different campus environments. The analysis includes an in-depth examination of moderation effects and control variables to systematically derive the implications of green spaces on perceived restoration. The primary relationships in the model (Table 6 and Fig. 6), specifically between the Self-Rating Depression (SD) and the Perceived Restoration (PR), were consistently positive and significant across all campus types. However, the strength of these relationships varied depending on the campus environment, with the strongest effects observed in low-density, large campuses (Model III).

The direct path between SD and PR was highly significant in all three models. For Model I, $\beta = 0.275$ ($t = 3.949$, $p < 0.01$), indicating a positive and significant relationship. This relationship became stronger in Model II ($\beta = 0.323$, $t = 5.284$, $p < 0.01$) and was even more pronounced in Model III ($\beta = 0.339$, $t = 3.535$, $p < 0.01$), suggesting that the perceived restorative effects increase with campus size and openness.

A critical observation from the models is the differential influence of SD on PG and FR. This nuanced finding reveals that the psychological state of individuals can significantly impact their perception and usage

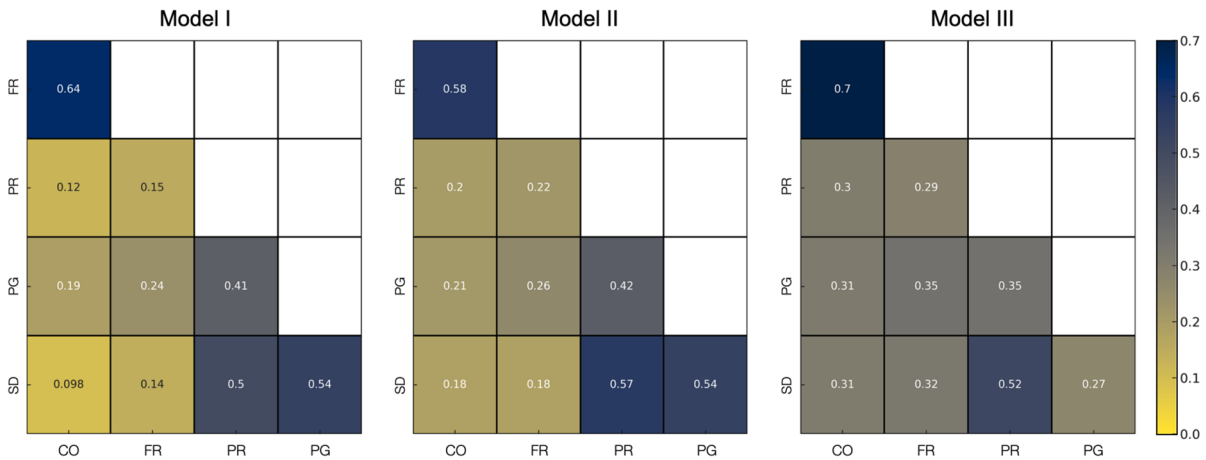

Fig. 5 Discriminant validity

Table 5 Predictive relevance (Q^2)

	SSO	SSE	Q^2 (= 1-SSE/SSO)
SD			
Core Depression	6544.000	2661.883	0.593
Anxiety	2454.000	1078.153	0.561
Cognitive	3272.000	1303.214	0.602
Somatic	2454.000	999.191	0.593
Perceived Greeness	6544.000	5649.711	0.137
Convenience	818.000	799.223	0.023
Frequency	818.000	484.037	0.408
PR	14,724.000	11,657.323	0.208

of green spaces, which underscores the importance of considering mental health variables when analyzing environmental preferences and behaviors. Specifically, the direct path from SD to PG was significant across all models, with the highest influence observed in Model II ($\beta = 0.517$, $t = 10.637$, $p < 0.01$). This suggests that in medium and compact campus environments, depression may significantly influence students' perception of green spaces, potentially indicating a greater reliance on environmental factors to improve well-being in such contexts. In Model III, although the relationship was still significant ($\beta = 0.262$, $t = 3.008$, $p < 0.01$), it showed a slightly reduced impact compared to more compact environments, possibly reflecting the higher availability of natural resources in expansive campuses.

The moderation effects of PG and FR were also assessed. The interaction terms PG × SD and FR × SD were included in the models to determine how these factors influence the relationship between depression and perceived restorative effects. The analysis revealed that perceived greenness significantly moderates this relationship, particularly in Model II (medium and compact campus) and Model III (low-density and large campus). In Model II, the interaction effect of PG on the relationship between SD and PR was significant ($\beta = 0.181$, $t = 2.952$, $p < 0.05$), indicating that higher perceived greenness amplifies the restorative effects of green spaces for students with depression. In Model III, the interaction effect of PG was also significant ($\beta = 0.143$, $t = 1.614$, $p < 0.10$), suggesting that in more expansive campus environments, perceived greenness plays a crucial role in enhancing their healing potential.

In contrast, the moderation effect of FR on the relationship between SD and PR was more variable. While FR significantly moderated this relationship in Model II ($\beta = 0.151$, $t = 2.389$, $p < 0.05$), its effect was less pronounced in Model III ($\beta = 0.127$, $t = 1.460$, $p < 0.10$), and not significant in Model I (small and highly compact campus). These findings suggest that the frequency of green space use is more impactful in medium and large campuses, where students may have more opportunities to engage with green spaces, thereby enhancing their restorative experiences.

The analysis also controlled for potential confounding variables, such as gender and education level, to isolate the effects of the main variables of interest. The results showed that gender had a significant impact on PR in Model I and Model III, with a path coefficient of 0.139 ($t = 1.466$, $p < 0.10$) in Model I and −0.184 ($t = 1.396$, $p < 0.10$) in Model III, indicating that male and female students might experience the restorative effects of green spaces differently. Education level also exhibited

Table 6 Structural model results

	Model I			Model II			Model III		
	β	f^2	t	β	f^2	t	β	f^2	t
Control relationships									
Gender- > PRS	0.139*		1.466*	−0.070		0.801	−0.184*		1.396*
Education- > PRS	0.029		0.636	0.025		0.532	0.097*		1.570*
Direct path									
SD- > PR	0.275***	0.072***	3.949***	0.323***	0.111***	5.284***	0.339***	0.136***	3.535***
SD- > PG	0.512***	0.355***	9.734***	0.517***	0.365***	10.637***	0.262***	0.074***	3.008***
SD- > FR	0.032	0.001	0.642	0.012	0.000	0.223	0.089*	0.014*	1.548*
SD- > CO	0.095*	0.009*	1.527*	0.181***	0.034***	3.219***	0.305***	0.103***	3.686***
PG- > PR	0.257***	0.066***	3.624***	0.249***	0.068***	4.245***	0.286***	0.097***	3.247***
FR- > PR	0.086	0.006	1.278	0.115**	0.014**	1.879**	0.032	0.001	0.359
CO- > PR	0.078	0.005	1.132	0.081*	0.007*	1.411*	0.140*	0.015	1.586*
Moderating									
FR x PG—> PR	0.127*		1.460*	0.151**		2.389**	0.251**		1.934**
CO x PG—> PR	0.143*		1.614*	0.181**		2.952**	−0.026		0.242

Note: *$0.05 \le p \le 0.10$;**$0.01 \le p \le 0.05$;***$p \le 0.01$

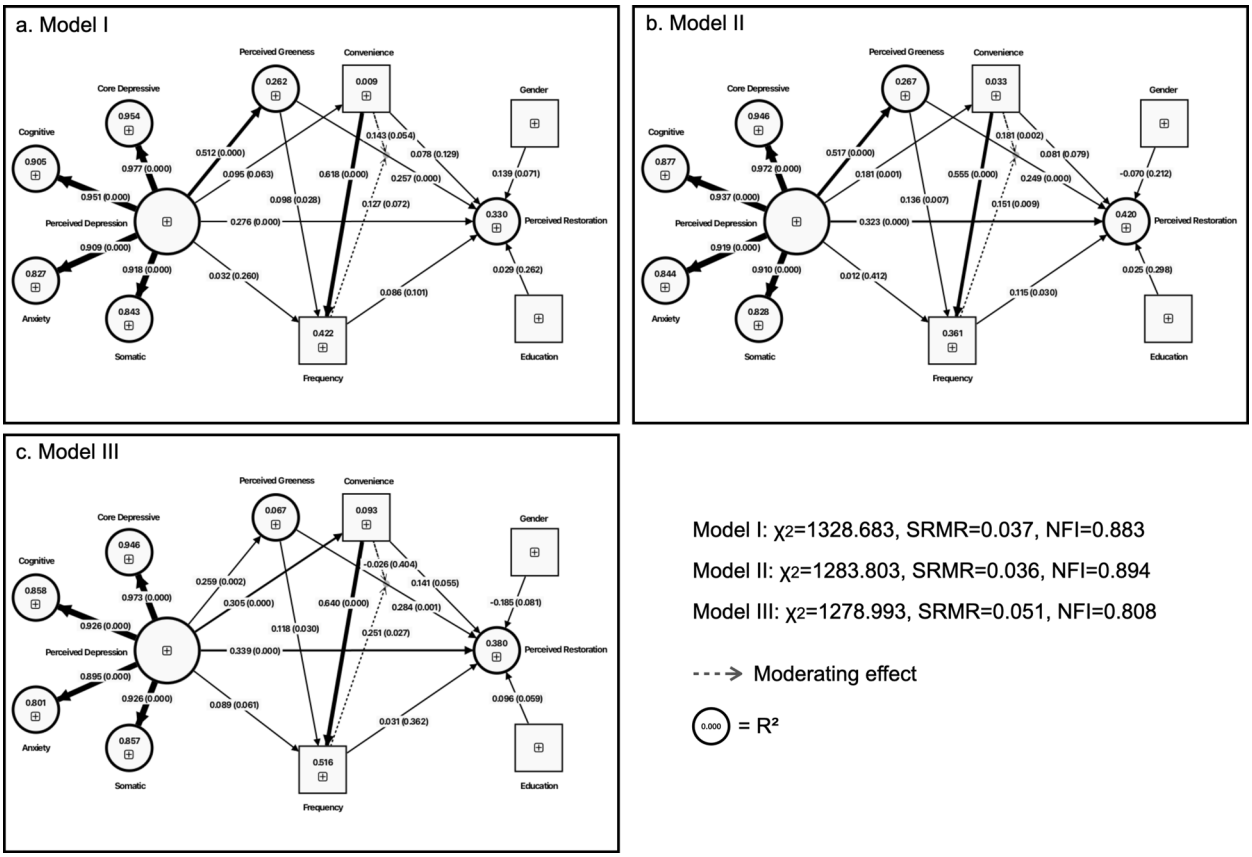

Fig. 6 Analysis results of the models

a significant effect on PR in Model III (β = 0.097, t = 1.570, $p < 0.10$), suggesting that students with higher educational attainment may perceive the restorative benefits of green spaces more strongly, potentially due to different levels of stress or cognitive engagement.

Mediation analysis

The mediation analysis examined the indirect effects of the SD on the PR through the mediating variables PG, FR, and CO across the three campus models, as detailed in Table 7. The analysis provides crucial insights into the mechanisms through which depression influence the perceived restorative effects of green spaces.

The mediation analysis revealed that the indirect effect of SD on PR through PG was consistently positive and significant across all three models, indicating that perceived greeness serves as a key mediator in the relationship between depression and the healing effects experienced by students. In Model I, the indirect effect was significant (B = 0.132, t = 3.395, $p < 0.01$), while Model II showed similar strength (B = 0.129, t = 3.789, $p < 0.01$), and Model III exhibited a slightly reduced effect (B = 0.075, t = 2.045, $p < 0.05$). These results suggest that perceived greenness plays a particularly important role in enhancing the restorative effects of green spaces, especially in compact campus environments where such spaces may be more valued due to their limited availability.

In contrast, the mediation effect of FR on the relationship between SD and PR was not consistently supported across the models. In Model I, the mediation effect was not significant (B = 0.004, t = 0.888), while in Model II, the mediation effect was marginally significant (B = 0.012, t = 1.596, $p < 0.10$). However, in Model III, this mediation effect was again non-significant (B = 0.003, t = 0.292). These findings indicate that while the frequency of green space use may contribute to restorative experiences, its mediating role is context-dependent and appears to be less impactful in expansive campus environments where green spaces are more readily accessible.

The mediation analysis also explored the role of CO as a mediator. The indirect effect of SD on PR through CO was not supported in Models I and II, with B values of 0.007 and 0.015, and t-values of 0.775 and 1.196, respectively. However, in Model III, the mediation effect approached significance (B = 0.043, t = 1.330,

Table 7 Mediation analysis

Hypotheses	B	t	p	Bias-Corrected lower	Bias-Corrected upper	Remark
Model I						
SD->CO->FR->PR	0.005	0.934	0.175	0.001	0.016	Not Supported
SD->PG->FR->PR	0.004	0.888	0.187	0.000	0.013	Not Supported
SD->PG->PR	0.132	3.395	0.000	0.084	0.183	Partial
SD->FR->PR	0.004	0.888	0.320	-0.001	0.014	Not Supported
SD->CO->PR	0.007	0.775	0.219	0.000	0.033	Not Supported
Model II						
SD->CO->FR->PR	0.012	1.596	0.055	0.005	0.023	Partial
SD->PG->FR->PR	0.008	1.373	0.085	0.003	0.018	Partial
SD->PG->PR	0.129	3.789	0.000	0.087	0.175	Partial
SD->FR->PR	0.001	0.189	0.425	-0.004	0.012	Not Supported
SD->CO->PR	0.015	1.196	0.116	0.003	0.034	Not Supported
Model III						
SD->CO->FR->PR	0.006	0.335	0.369	-0.013	0.032	Not Supported
SD->PG->FR->PR	0.001	0.285	0.388	-0.001	0.007	Not Supported
SD->PG->PR	0.075	2.045	0.020	0.036	0.129	Partial
SD->FR->PR	0.003	0.292	0.385	-0.003	0.020	Not Supported
SD->CO->PR	0.043	1.330	0.092	0.010	0.091	Partial

$p < 0.10$), suggesting that in low-density, large campuses, convenience may play a more substantial role in mediating the relationship between depression and perceived restorative effects. This finding highlights the potential importance of convenience in enhancing the restorative experience in environments where green space is abundant, but further investigation is warranted to confirm this effect.

By focusing on the chain mediation pathways, the mediation analysis demonstrates that these combined indirect effects vary depending on campus context, highlighting the significant roles of CO and PG in promoting FR, which in turn contributes to perceived restorative outcomes. Specifically, the pathway from SD through CO to FR and ultimately to PR was partially supported in Model II (B = 0.012, t = 1.596, $p < 0.10$), indicating that convenience followed by frequency of green space use plays a role in influencing restorative outcomes in medium and compact campuses. Additionally, the pathway from SD through PG to FR and then to PR also demonstrated partial mediation in Model II (B = 0.008, t = 1.373, $p < 0.10$), suggesting that perceived greenness, when combined with the frequency of use, has an indirect effect on perceived restoration, particularly in medium and compact campus environments, where green spaces are limited but strategically integrated.

Multi-group analysis

The multi-group analysis (MGA) (Sarstedt et al., [49] conducted using parametric tests provides a detailed comparison of the structural relationships across different campus environments—specifically, the small but highly compact campus (Model I), the medium and compact campus (Model II), and the low-density, large campus (Model III). The analysis focuses on examining the differences in path coefficients (Δβ) and t-values (Δt) between these models, as presented in Table 8.

The MGA results indicate that the direct effect of SD on PR did not show statistically significant differences across the models (Δβ values of −0.048, −0.015, and −0.063, with Δt values all below the threshold for significance). This suggests that the effect of depression on perceived restorative outcomes is stable regardless of the campus size or density, implying that green spaces consistently contribute to alleviating depressive symptoms across different campus contexts.

However, significant differences were found in the paths from SD to PG and from SD to CO. The path from SD to PG showed significant differences between Model II and Model III (Δβ = 0.258, Δt = 2.763, $p < 0.01$) and between Model I and Model III (Δβ = 0.252, Δt = 2.604, $p < 0.05$). These results indicate that the influence of depression on perceived greenness is stronger in larger, low-density campuses (Model III) compared to the smaller, more compact campuses (Model I). This may be due to the expansive and varied visual environments in larger campuses, where students with depression might find greater relief and comfort through exposure to nature. The path from SD to CO also showed significant differences, particularly between Model I and Model III (Δβ = −0.210, Δt = 2.006, $p < 0.05$). This suggests that convenience as

Table 8 Multi-group analysis

	Model I vs. Model II		Model II vs. Model III		Model I vs. Model III	
	Δβ	Δt	Δβ	Δt	Δβ	Δt
SD->PR	-0.048	0.520	-0.015	0.138	-0.063	0.532
SD->PG	-0.005	0.073	0.258***	2.763***	0.252**	2.604**
SD->FR	0.020	0.278	-0.077	0.890	-0.056	0.699
SD->CO	-0.086	1.032	-0.124	1.247	-0.210**	2.006**
PG->PR	0.008	0.087	-0.036	0.348	-0.028	0.242
FR->PR	-0.029	0.324	0.084	0.777	0.054	0.481
CO->PR	-0.003	0.030	-0.059	0.575	-0.062	0.538

Note: *0.05≤p≤0.10;**0.01≤p≤0.05;***p≤0.01

Smaller difference — Lager difference

a factor plays a more significant role in the relationship between SD and PR in larger, less dense campuses. In these environments, convenience might be influenced by the accessibility and usability of green spaces, which may contribute to students' perceived restorative benefits differently compared to compact campuses where green spaces are more readily accessible but possibly limited in scope.

Other pathways, such as those involving FR and PR, did not show significant differences across the models. Specifically, the paths from SD to FR, PG to PR, and CO to PR showed minimal changes in path coefficients (Δβ) and were not statistically significant. This consistency suggests that while individual factors like convenience and perceived greenness may vary in their influence depending on campus environment, the broader relationships between green space use and perceived restoration remain relatively stable.

The interaction effects of FR and PG on PR, while significant in the structural analysis, did not exhibit substantial differences across the models in the multi-group analysis. This indicates that the synergistic effect of frequent green space use and high perceived greeness on restorative outcomes is consistent across different types of campuses, reinforcing the idea that both factors are crucial for maximizing the healing potential of green spaces.

Discussion

Key findings

This study provides a comprehensive analysis of the impact of campus green spaces on the mental health of university students, with a focus on depression. By examining three distinct campus environments, this research addresses a significant gap in the existing literature, which has largely overlooked how different campus types might differentially influence the restorative impact of green spaces on depression.

The findings related to perceived greeness align with established research that underscores the importance of aesthetically pleasing and well-maintained green spaces in promoting mental health [20, 23]. This study extends these findings by demonstrating that the impact of perceived greeness is particularly pronounced in larger, low-density campuses. The findings demonstrate that the impact of perceived greenness is particularly pronounced in larger, lower density campuses. This suggests that expansive green spaces with diverse natural features play a more substantial role in providing relief from depressive symptoms, likely due to the more varied and immersive natural environments that are characteristic of larger campuses. In smaller, high-density campuses, students may rely more heavily on the quality of their immediate surroundings to alleviate stress, emphasizing the importance of well-maintained and visually appealing green spaces. This suggests that expansive green spaces with diverse natural features play a more substantial role in providing relief from depressive symptoms, likely due to the more varied and immersive natural environments that are characteristic of larger campuses. In smaller, high-density campuses, students may rely more heavily on the quality of their immediate surroundings to alleviate stress, emphasizing the importance of well-maintained and visually appealing green spaces.

Conversely, the role of frequency of green space use revealed both expected and novel insights. While frequent interaction with natural environments is known to enhance psychological benefits, [1, 41], this study found that the frequency of use was particularly significant in medium and large campuses, where the availability of space allows for more frequent and varied interactions with green spaces. However, in small, high-density campuses, the frequency of use had a less pronounced impact on mental health, suggesting that when green spaces are scarce or heavily utilized, their quality may be more critical than the frequency of interaction. This distinction

highlights that, regardless of campus type, the quality of green spaces remains a crucial factor in enhancing restorative outcomes, and its importance becomes even more pronounced where space is limited.

The importance of convenience of access to green spaces also aligns with prior research, particularly the work of Gidlow et al. [22], which emphasizes the role of accessibility in facilitating regular engagement with natural environments. However, this study introduces a new perspective by showing that in large, low-density campuses, convenience not only facilitates usage but also amplifies its psychological benefits by promoting spontaneous and prolonged engagement with nature. The ability to easily access these expansive environments encourages frequent interactions, which, in turn, leads to more effective mental health benefits. This finding challenges the traditional view that convenience merely increases usage,instead, it demonstrates that in larger, expansive campuses, convenience enhances the overall restorative impact by fostering deeper and more meaningful interactions with green spaces.

Previous research has suggested that demographic factors, including gender, educational level, and age, play a role in how green spaces affect restorative outcomes [2, 37, 39]. Bagot et al. [2] found that children experience restorative benefits differently based on natural features and play-related activities, highlighting age as a key factor. Liu et al. [37] and Lu and Fu [4], focusing on university students, emphasized the importance of naturalness and environmental preferences in shaping restoration, suggesting that the restorative experiences of university students may differ significantly from those of younger populations. Although previous studies have not explicitly examined variations by educational level among university students, our findings suggest that gender and educational attainment may shape perceived restoration, these observations remain preliminary. The present study highlights potential trends, indicating that demographic factors may contribute to differential experiences of green spaces across campus environments. However, these trends should be interpreted cautiously, as the research does not deeply explore the underlying social and psychological contexts of educational attainment or its interaction with stress and cognitive engagement. A more nuanced understanding of these relationships requires further investigation.

The analysis controlled for potential confounding variables, revealing that gender influenced restorative outcomes differently across campus models. Specifically, male and female students experienced the restorative effects of green spaces differently in smaller, higher compact campus and larger, lower-density campus, suggesting that gender-specific preferences shape how students interact with and benefit from these environments. Additionally, the analysis revealed a significant relationship between educational attainment and perceived restoration, particularly in larger campuses. Students with higher educational attainment appeared to perceive greater restorative benefits from green spaces, potentially reflecting variations in academic demands and cognitive engagement. While these findings highlight the importance of demographic factors in shaping restorative experiences, the broad categorizations used in this study may not fully capture the diversity of student experiences. Nevertheless, this nuanced understanding underscores the importance of considering demographic diversity when designing campus green spaces, as different groups may have varying restorative needs and preferences.

The mediation analysis provided critical insights into the underlying mechanisms through which green spaces influence mental health. While existing research has largely focused on direct relationships, this study found that perceived greeness mediates the relationship between depression and perceived restorative effects, particularly in high-density, small campuses. Moreover, the chain mediation pathways involving both convenience and frequency of green space use emphasized the layered impact of accessibility and quality in influencing restorative outcomes. These findings underscore the complexity of the interactions between green space accessibility, quality, and usage frequency in enhancing mental health outcomes, particularly in compact environments where well-designed green spaces are crucial. These insights align with Kaplan's theoretical concept of 'soft fascination,' which posits that natural environments help reduce mental fatigue by capturing attention in an effortless manner, thus contributing to psychological restoration [31]. On another hand, the moderation analysis revealed that high-quality green spaces combined with frequent use create a synergistic effect that enhances restorative outcomes, particularly in medium and large campuses. This finding adds a new dimension to the literature by suggesting that the combined effect of green space quality and usage frequency results in a greater overall benefit than either factor alone. In larger educational environments, where space is abundant, ensuring both quality and encouraging frequent interactions with nature can significantly maximize the mental health benefits of green spaces. This synergy reinforces the idea that optimizing both elements is crucial to achieving the best possible outcomes for student well-being.

Finally, the multi-group analysis provided valuable insights into how these relationships differ across campus types. While previous research has often treated the benefits of green spaces as uniform across different environments, this study shows that the impact of green spaces varies significantly depending on the campus context.

In large, low-density campuses, both perceived greeness and frequency of use had more pronounced effects on restorative outcomes, suggesting that expansive green spaces with diverse natural features and frequent interactions contribute significantly to mental health benefits. Conversely, in smaller, compact campuses, the quality of green spaces played a more direct role in alleviating depressive symptoms, indicating that where space is limited, the visual appeal and maintenance of these green areas become paramount. This differentiation challenges the assumption that the benefits of green spaces are universally applicable, instead highlighting the need for tailored approaches in campus design. Strategic design interventions should aim to maximize both the accessibility and quality of green spaces in a way that caters to the specific spatial and psychological needs of different student populations, ensuring that all students can experience the restorative potential of these environments.

Limitations

The study's findings, while significant, are tempered by several limitations that warrant consideration. First, the cross-sectional design constrains the ability to infer causality between green space characteristics and mental health outcomes, leaving the temporal direction of these relationships ambiguous. Longitudinal studies are needed to clarify whether enhancements in green space quality or increased frequency of use lead to sustained improvements in depression, or if students with better mental health are simply more inclined to engage with these environments. Second, the classifications of educational levels (e.g., undergraduates, postgraduates, and doctoral students) adopted in this study may not fully capture the diverse experiences within these groups. Academic stages and associated stress levels likely influence interactions with green spaces in more complex ways, which could affect the interpretation of restorative outcomes. Additionally, while the study focused on perceived greeness, frequency of use, and convenience of access, it did not account for other influential environmental factors such as biodiversity, noise levels, and air quality, which could also play critical roles in the restorative potential of green spaces. Including these variables in future research would provide a more comprehensive understanding of how different aspects of green spaces contribute to mental health. Lastly, the moderation and mediation analyses, though insightful, are constrained by the assumptions inherent in the statistical models employed. The complex and potentially non-linear interactions between variables may not be fully captured by these methods, suggesting that advanced modeling techniques, such as structural equation modeling or machine learning approaches, could be beneficial in future studies to more accurately explore these dynamics.

Conclusion

To our knowledge, this study provides critical contributions into the role of campus green spaces in mitigating depression among university students, highlighting the varying impacts across different campus types. The findings emphasize that while perceived greeness, frequency of use, and convenience of access are significant determinants of the restorative potential of green spaces, their influence is context-dependent, with different campus environments necessitating tailored approaches. Policymakers and university administrators might consider these elements when designing or enhancing campus landscapes, ensuring that green spaces are conveniently located, visually appealing, and accessible year-round. Such design policies could play a critical role in supporting the mental health and academic success of students by providing restorative environments that foster regular engagement with nature.

The study also contributes to the broader literature by challenging the assumption of uniform green space benefits, instead revealing the nuanced ways in which environmental and spatial factors interact to influence mental health. Despite its limitations, including the cross-sectional design and the exclusion of certain environmental variables, this research underscores the importance of considering both the physical characteristics of green spaces and the unique needs of student populations in campus planning. Future studies should investigate the specific roles of demographic factors, such as educational levels, in shaping restorative outcomes. Employing more granular classifications of academic stages could provide greater clarity on how stress and cognitive demands influence the use and perceived benefits of green spaces. This approach would help uncover the nuanced interactions between academic contexts and restorative experiences that were beyond the scope of this study. Moreover, longitudinal designs and advanced modeling techniques should be employed, and will be essential to further elucidate these relationships and guide the development of more effective strategies for integrating green spaces into educational environments to support student well-being. In addition, future studies could extend beyond the Chinese context to incorporate comparative analyses of other regions, such as East Asia and the Global South. Exploring how variations in urban density, architectural styles, and cultural attitudes toward green spaces interact with mental health outcomes in diverse settings would provide a broader and more comprehensive understanding of these dynamics. Such comparative investigations would enhance the generalizability of the findings and contribute to the global discourse on mental health and urban design.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-21356-9.

Supplementary Material 1.

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Authors' contributions
HL and YW are equal first author who have analyzed the data and performed all analysis, and wrote the first draft of the paper. QH, XW and CC contributed to writing, data analysis and data collections. CC contributed all figures drawing. XW and YG reviewed the manuscript. YG contributed final revising of the manuscript. The final version of this manuscript has been approved by all authors before submission.

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Data availability
The datasets presented in this study can be found in online repositories: DOI: https://doi.org/10.17605/OSF.IO/VY5QH.

Declarations

Ethics approval and consent to participate
Macau University of Science and Technology Medical Ethics Committee approved the study (Approval Number: MUST-20240430001).

Human Ethics and Consent to Participate
The study was conducted in accordance with the Declaration of Helsinki, all questions in investigation questionnaire were reviewed and approved by the Institutional Review Board (or Ethics Committee) of MACAU UNIVERSITY OF SCIENCE AND TECHNOLOGY (protocol code: MUST-20240430001 date of approval: 05–10-2023]. Informed consent to participante were provided at the beginning of the questionnaire for each participant, which clearly state the use of information and privacy protection policies for agreement.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

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