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# A Data-Driven Framework for Sustainable Retrofit Assessment in Music Halls: Acoustic Perception, Green Retrofit Acceptance, and Audience Satisfaction

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**Abstract**

Sustainable retrofit has become an important pathway for improving the environmental performance and user experience of existing public cultural buildings. However, current retrofit assessment still tends to emphasize energy efficiency, system upgrading, and carbon reduction, while less attention has been paid to how users perceive retrofit outcomes in performance-oriented buildings. Taking music halls as a typical public cultural building type, this study develops a data-driven post-occupancy assessment model to examine how perceived sustainable retrofit strategies influence concert environment satisfaction. Four perceptual dimensions were identified: Green Acoustic Material Perception, Green Environmental Control, Eco-Spatial Integration, and Low-Carbon Operation Perception. Green Retrofit Acceptance was further introduced as a mediating variable to explain the cognitive mechanism through which retrofit-related perceptions are transformed into overall environmental evaluation. Based on 729 valid questionnaires collected from audiences with music hall attendance experience, exploratory factor analysis, confirmatory factor analysis, structural equation modelling, and bootstrapping tests were conducted. The results show that all four dimensions of perceived sustainable retrofit have significant positive effects on Concert Environment Satisfaction. Among them, Green Acoustic Material Perception shows the strongest direct effect, indicating the central role of acoustic comfort in performance-oriented retrofit evaluation. Green Environmental Control, Eco-Spatial Integration, and Low-Carbon Operation Perception also contribute significantly to satisfaction. In addition, Green Retrofit Acceptance partially mediates these relationships, suggesting that sustainable retrofit can generate stronger experiential value when audiences perceive it as necessary, credible, effective, and compatible with the performance context. This study extends sustainable retrofit assessment from technical and energy-oriented evaluation to user-oriented, data-driven post-occupancy evidence and provides practical implications for the low-carbon renewal and operation of music halls and other public cultural buildings.

**Keywords:** data-driven assessment; sustainable retrofit; music halls; acoustic perception; acoustic comfort; green retrofit acceptance; audience satisfaction; structural equation modelling

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## 1. Introduction

The sustainable transformation of existing buildings has become a critical issue in the global transition toward low-carbon, resource-efficient, and human-centred development. In the building sector, sustainability is no longer limited to the design and certification

of new green buildings but increasingly depends on how existing building stock can be retrofitted, operated, assessed, and optimized throughout its life cycle. In the context of existing buildings, sustainable transformation denotes an integrated process of building retrofit and operational improvement aimed at enhancing environmental and functional performance, reducing energy consumption and carbon emissions, and meeting occupants' needs [1]. According to the Global Status Report for Buildings and Construction released by UNEP and GlobalABC, buildings and construction remain major contributors to global energy consumption, material use, and carbon emissions, making the sustainable retrofit of existing buildings essential for achieving long-term decarbonization targets [2]. Compared with new construction, however, sustainable retrofit is usually constrained by existing structures, spatial layouts, operational continuity, material compatibility, technical feasibility, and user expectations. Previous studies have therefore argued that building retrofit should not be understood as the simple installation of energy-saving equipment or the replacement of building systems but as an integrated renewal process involving environmental performance, indoor environmental quality, operational management, life cycle sustainability, and user needs [3,4]. In recent years, data-driven approaches have become increasingly important in building energy assessment and sustainable retrofit decision-making. While energy consumption records, simulation outputs, sensor-based monitoring, and operational data are widely used to support performance diagnosis and retrofit evaluation [5], user perception data also provide valuable evidence for understanding whether retrofit strategies are effective in actual building use. Studies on indoor environmental quality and occupant satisfaction have shown that users' evaluations of buildings are shaped by thermal comfort, air quality, lighting, acoustics, cleanliness, spatial experience, and other environmental factors [6–9]. Therefore, sustainable retrofit assessment should not rely solely on technical indicators but should also incorporate post-occupancy evidence reflecting users' perceived environmental performance [10].

Music halls represent a distinctive type of public cultural building in which sustainable retrofit must be carefully coordinated with performance-oriented spatial and environmental quality. Unlike ordinary public buildings, the value of a music hall is not determined merely by architectural form, seating capacity, equipment configuration, or energy performance. It is shaped by the interaction among acoustic environment, indoor comfort, material expression, spatial atmosphere, circulation order, operational service, and embodied audience perception. Concert hall acoustics research has long shown that reverberation time, early reflections, clarity, loudness, spatial impression, and sound-field uniformity play fundamental roles in shaping auditory quality and audience experience [11–13]. However, concert environment satisfaction is not produced by acoustic performance alone. Thermal and humidity conditions, air freshness, lighting atmosphere, spatial openness, material perception, wayfinding, and operational order also influence how audiences evaluate the overall quality and sustainability of the venue. In the context of sustainable retrofit, this means that music halls must respond to energy-saving and low-carbon requirements without weakening acoustic quality, environmental stability, cultural atmosphere, or audience convenience. If retrofit measures improve technical indicators but are not perceived as supporting the actual concert-going experience, their sustainability value may remain incomplete. Therefore, the evaluation of sustainable retrofit in music halls should move beyond conventional technical performance assessment and incorporate data-driven post-occupancy evidence based on audience perception.

Based on the functional characteristics of music halls and the multidimensional nature of sustainable retrofit, this study conceptualizes audience perception of music hall retrofit through four dimensions: Green Acoustic Material Perception, Green Environmental Control, Eco-Spatial Integration, and Low-Carbon Operation Perception. Green Acoustic

Material Perception refers to audiences' evaluation of environmentally responsible acoustic materials, low-emission interior finishes, and their perceived contribution to sound clarity, reverberant balance, spatial impression, and listening comfort. Green Environmental Control reflects audiences' assessment of temperature and humidity regulation, air quality, lighting, ventilation, and intelligent control systems in terms of comfort, stability, health, and energy-conscious operation. Eco-Spatial Integration describes the perceived coordination between natural elements, green landscapes, daylight, spatial openness, natural materials, transitional spaces, and the architectural environment. Low-Carbon Operation Perception captures audiences' awareness of energy-saving management, resource conservation, digital services, green guidance, waste reduction, and low-carbon information communication in the venue. These four dimensions correspond respectively to the material, environmental, spatial, and operational layers of sustainable retrofit. However, the influence of perceived retrofit strategies on concert environment satisfaction may not occur only through direct experiential pathways. In actual building use, environmental stimuli are often transformed into satisfaction through users' cognitive evaluation, value judgment, and psychological acceptance. The theory of planned behavior suggests that individual evaluation and behavioural intention are shaped by attitudes, subjective norms, and perceived behavioural control [14], while the technology acceptance model indicates that users' acceptance of a technology or system is closely related to perceived usefulness and perceived ease of use [15]. Research on sustainable technology acceptance further shows that perceived benefits, trust, environmental values, perceived risks, and contextual compatibility influence public acceptance of green technologies [16]. Accordingly, this study introduces Green Retrofit Acceptance as a mediating variable to explain how audiences translate perceived retrofit measures into overall concert environment satisfaction. The selection of these four dimensions was guided by existing multi-criteria retrofit assessment approaches and the specific functional characteristics of music halls. Previous studies have emphasized that sustainable retrofit should be evaluated through multiple dimensions, including environmental performance, indoor environmental quality, operational management, and user experience. However, existing frameworks have mainly focused on general building types, while performance-oriented cultural buildings require additional consideration of acoustic quality and audience experience. Therefore, this study develops a perception-based framework consisting of four complementary dimensions, Green Acoustic Material Perception, Green Environmental Control, Eco-Spatial Integration, and Low-Carbon Operation Perception, representing material, environmental, spatial, and operational aspects of sustainable retrofit. The framework is primarily designed for post-occupancy evaluation by identifying key perceptual factors influencing user satisfaction. Meanwhile, these dimensions can also provide guidance for future retrofit planning by highlighting important experiential considerations, although the framework is not intended to evaluate the technical performance of specific retrofit technologies or predict actual energy and carbon outcomes.

Although existing studies have advanced knowledge on building energy assessment, sustainable retrofit, indoor environmental quality, post-occupancy evaluation, and concert hall acoustics, several research gaps remain. First, current retrofit studies have mainly examined residential buildings, office buildings, educational buildings, and general public buildings, with particular attention to net-zero carbon pathways, energy performance, thermal comfort, occupant behaviour, and post-occupancy performance [17,18]. However, performance-oriented public cultural buildings, especially music halls, have received comparatively limited attention, despite their need to reconcile low-carbon transformation with acoustic quality, cultural atmosphere, and immersive audience experience. Second, existing data-driven building assessment research tends to rely more heavily on technical data, such as energy consumption, equipment operation, simulation results, or environmental

monitoring, whereas user perception data remain underexplored as an evaluative source for understanding retrofit effectiveness in actual use. Third, research on music halls and concert venues has long focused on acoustic parameters, room geometry, sound diffusion, reverberation, visual–auditory interaction, and technical optimization [19,20], while limited attention has been paid to how audiences perceive sustainable acoustic materials, environmental control, ecological spatial integration, and low-carbon operation as part of the overall retrofit outcome. Fourth, existing studies on building satisfaction and green technology adoption often treat environmental factors or green measures as direct antecedents of user evaluation, whereas the psychological acceptance process through which perceived retrofit measures are transformed into satisfaction remains insufficiently explained [21,22].

To address these gaps, this study proposes a data-driven post-occupancy assessment model for sustainable retrofit in music halls. By integrating four dimensions of audience-perceived retrofit—Green Acoustic Material Perception, Green Environmental Control, Eco-Spatial Integration, and Low-Carbon Operation Perception—with Green Retrofit Acceptance and Concert Environment Satisfaction, the model constitutes a multidimensional evaluation framework. It assesses both how audiences experience different aspects of retrofit and how these perceptions relate to their acceptance of the retrofit and satisfaction with the concert environment. The proposed relationships are tested using 729 valid questionnaires from audiences with music hall attendance experience. Exploratory factor analysis and confirmatory factor analysis are used to examine the measurement structure, while structural equation modelling and bootstrapping test the direct and mediated relationships. This study makes three main contributions. First, it incorporates audience perception data into the post-occupancy assessment of sustainable retrofit. Second, it brings acoustic, indoor environmental, spatial, and operational perceptions into a coherent evaluation framework for music halls. Third, it examines the role of Green Retrofit Acceptance in linking these perceptions to Concert Environment Satisfaction. The findings provide evidence to inform the sustainable renewal and post-occupancy evaluation of music halls and other performance-oriented public cultural buildings.

## 2. Literature Review and Research Hypothesis

The four dimensions were selected to represent complementary domains through which audiences may perceive sustainable retrofit in music halls: acoustic materials, indoor environmental control, ecological spatial integration, and low-carbon operation. Their selection reflects the acoustic demands of performance spaces and the audience experience across the auditorium, circulation areas, and building services. Conceptually, Green Acoustic Material Perception concerns the perceived acoustic and environmental properties of interior materials, whereas Green Environmental Control concerns the conditions delivered by thermal, ventilation, air-quality, and lighting systems. Eco-Spatial Integration captures the relationship between natural elements and spatial experience; Low-Carbon Operation Perception concerns the visibility and perceived quality of resource-conscious management during building use. Although these domains may intersect within the same spaces, they distinguish material, environmental, spatial, and operational aspects of retrofit in the proposed evaluation framework.

### *2.1. Multi-Criteria Evaluation Frameworks for Sustainable Retrofit*

Sustainable retrofit evaluation has gradually shifted from single-objective performance assessment toward multi-criteria frameworks that integrate environmental, functional, operational, and user-related considerations. Early retrofit studies primarily focused on energy efficiency and carbon reduction; however, recent research has emphasized that retrofit decision-making requires the simultaneous consideration of multiple objectives, including

indoor environmental quality, life cycle performance, operational management, and occupant experience. Multi-criteria decision-making (MCDM) approaches have therefore been increasingly applied in building retrofit research because they provide a systematic method for balancing different performance objectives and stakeholder requirements during retrofit planning and evaluation.

Existing studies have demonstrated that sustainable retrofit is a complex process involving technical, environmental, functional, and organizational factors rather than isolated technological upgrades. Bu et al. highlighted that green retrofit design requires consideration of multiple interconnected aspects, including functional requirements, technical solutions, environmental objectives, and operational issues, rather than focusing exclusively on individual building systems [23]. Similarly, Ma et al. emphasized that retrofit strategies should integrate energy performance, indoor environmental quality, economic feasibility, and user requirements to achieve comprehensive improvement of existing buildings [3].

In addition, post-occupancy evaluation (POE) research has shown that the success of retrofit interventions cannot be determined solely through predicted performance or technical indicators. User experience and perceived environmental quality provide essential evidence regarding whether renovated buildings effectively support occupants' needs in actual operation [24]. However, most existing multi-criteria retrofit frameworks have been developed for residential buildings, offices, and institutional facilities, where energy efficiency and general occupant comfort are usually dominant concerns. Performance-oriented cultural buildings, such as music halls, present additional challenges because sustainable transformation must preserve acoustic quality, environmental stability, spatial atmosphere, and audience experience.

Therefore, a context-specific framework is required to evaluate how users perceive sustainable retrofit outcomes in music halls. Based on the multidimensional characteristics of retrofit and the functional requirements of performance buildings, this study identifies four complementary perceptual dimensions: Green Acoustic Material Perception, Green Environmental Control, Eco-Spatial Integration, and Low-Carbon Operation Perception. Together, these dimensions represent material, environmental-system, spatial, and operational layers of sustainable retrofit perception and provide a user-centred perspective for evaluating green transformation in music halls.

### *2.2. Green Acoustic Material Perception and Concert Environment Satisfaction*

In music halls, acoustic materials should not be regarded as passive interior finishes but as active architectural elements that regulate the interaction between sound energy, spatial surfaces, and audience perception. The acoustic experience of a music hall is shaped by the combined effects of room volume, surface geometry, material absorption, diffusion, scattering, and the temporal structure of reflected sound. Kuttruff argued that room acoustics is essentially concerned with how sound energy is distributed, reflected, absorbed, and perceived within enclosed spaces, indicating that material surfaces play a decisive role in the formation of indoor acoustic fields [25]. Similarly, Cox and D'Antonio emphasized that absorbers and diffusers are not interchangeable decorative components but acoustic devices with distinct physical mechanisms and spatial consequences [26]. These studies suggest that the material configuration of a music hall is closely related to perceived sound clarity, reverberant balance, spatial impression, and listening comfort.

With the increasing emphasis on sustainable building renovation, acoustic material selection has moved beyond conventional performance criteria such as absorption coefficient, surface density, fire resistance, durability, and installation feasibility. Green acoustic materials are expected to integrate acoustic effectiveness with environmental responsibility, including low emissions, recycled or renewable sources, reduced embodied impacts,

recyclability, and compatibility with healthy indoor environments. Asdrubali, Schiavoni, and Horoshenkov provided a systematic review of sustainable materials for acoustic applications, showing that natural materials, recycled materials, mixed composites, green roofs, and green walls can contribute to sound absorption and noise control while reducing the environmental burden of building materials [27]. Arenas and Crocker also noted that porous sound-absorbing materials are widely used for noise control, because they dissipate incident sound energy through internal friction and viscous losses, and that recent developments increasingly focus on material efficiency, sustainability, and application diversity [28]. These findings indicate that green acoustic materials can no longer be evaluated solely from a technical acoustic perspective; rather, they should be understood as a material interface connecting acoustic performance, environmental quality, and user perception.

This issue is particularly important in music halls, where audiences are more sensitive to acoustic change than users of ordinary public buildings. A material intervention that improves environmental performance but weakens tonal balance, sound diffusion, or listening intimacy may fail to produce a positive evaluation of the concert environment. Conversely, when audiences perceive that the acoustic materials used in a music hall are low-emission, environmentally responsible, and capable of supporting clear, balanced, and comfortable sound, such perception may enhance their overall environmental evaluation. From a post-occupancy perspective, Concert Environment Satisfaction is not generated by objective physical performance alone but by the audience's perceived correspondence between environmental design and performance-viewing needs. Green Acoustic Material Perception therefore contains both sensory and evaluative dimensions: it involves the perceived quality of sound shaped by acoustic materials, as well as the perceived health and sustainability attributes of those materials.

In this study, Green Acoustic Material Perception refers to audiences' integrated evaluation of environmentally oriented acoustic materials, low-emission interior finishes, and their perceived contribution to acoustic quality and indoor environmental experience. In a music hall, acoustic panels, wall linings, ceiling systems, seating fabrics, timber surfaces, and other interior materials are not only visually present but also acoustically operative. When these material elements are perceived as improving sound clarity, maintaining appropriate reverberation, reducing acoustic disturbance, and supporting a healthier indoor atmosphere, audiences are more likely to evaluate the concert environment positively. Based on this reasoning, the following hypothesis is proposed:

**Hypothesis 1 (H1).** *Green Acoustic Material Perception has a significant positive effect on Concert Environment Satisfaction.*

### *2.3. Green Environmental Control and Concert Environment Satisfaction*

Green Environmental Control refers to the capacity of a music hall to regulate indoor environmental conditions in a manner that reconciles energy efficiency, environmental quality, and audience comfort. In music halls, environmental control is not limited to the technical operation of mechanical systems; rather, it concerns the perceived stability, appropriateness, and responsiveness of the indoor environment during the performance-viewing process. Audiences usually remain seated for a relatively long period, with limited behavioral adjustment opportunities once a performance begins. Under such conditions, temperature, humidity, ventilation, air freshness, lighting atmosphere, and the absence of environmental disturbance become important determinants of how the performance environment is evaluated. Therefore, Green Environmental Control should be understood as a building-environment mechanism through which low-carbon operation and human comfort are coordinated within a culturally and acoustically sensitive setting.

Thermal comfort theory provides an important basis for understanding the relationship between environmental control and user satisfaction. Fanger's thermal comfort model established a systematic framework for explaining how air temperature, mean radiant temperature, air velocity, humidity, clothing insulation, and metabolic rate jointly influence occupants' thermal sensation and comfort evaluation [29]. Later, the adaptive comfort model proposed by de Dear and Brager further demonstrated that comfort is not a fixed physiological response but is shaped by contextual conditions, prior thermal experience, expectation, and perceived environmental control [30]. This adaptive perspective is particularly relevant to public cultural buildings, where audiences' comfort judgments are affected not only by absolute indoor temperatures but also by whether the environmental conditions are perceived as suitable for the performance context. ASHRAE Standard 55 also emphasizes that thermal environmental conditions should be evaluated according to the combinations of factors that produce acceptable comfort for the majority of occupants [31]. These studies suggest that a stable and context-appropriate thermal environment is a prerequisite for positive spatial experience and satisfaction.

Indoor air quality and ventilation constitute another core dimension of Green Environmental Control. Music halls are characterized by intermittent but high-density occupancy, which places considerable pressure on ventilation, air distribution, and pollutant dilution. If ventilation is insufficient, audiences may perceive stuffiness, odour, fatigue, or discomfort, all of which can weaken their evaluation of the performance environment. Wargocki et al. showed that increasing outdoor air supply rates can improve perceived air quality and reduce sick-building-related symptoms, indicating that ventilation quality is closely related to occupants' subjective experience and well-being [32]. For music halls, however, ventilation control must also avoid generating airflow noise, draught discomfort, or acoustic interference. This means that green environmental control in music halls cannot simply pursue higher ventilation rates; it requires an integrated strategy that balances air quality, acoustic quietness, thermal stability, and energy consumption.

Lighting control also contributes to Concert Environment Satisfaction, especially because music halls rely on carefully managed visual atmospheres. Lighting in performance buildings is not only a functional requirement for visibility and safety but also an environmental medium that shapes spatial mood, perceived quality, and audience immersion. Veitch and Newsham found that lighting quality can influence users' mood, comfort, satisfaction, and health-related evaluations [33]. In the context of music halls, appropriate lighting control can strengthen the transition between public circulation areas, waiting spaces, seating areas, and performance spaces, while excessive brightness, glare, uneven illumination, or poorly coordinated lighting scenes may disturb the audience's emotional and perceptual engagement. Therefore, green lighting control should not be reduced to energy-saving illumination but should be considered as a balance between visual comfort, atmospheric coherence, operational efficiency, and environmental responsibility.

Taken together, Green Environmental Control reflects the audience's perceived evaluation of a music hall's ability to provide a comfortable, healthy, stable, and energy-conscious indoor environment. It integrates thermal regulation, humidity control, air quality, ventilation, lighting, and intelligent environmental adjustment into a unified experiential condition. In a music hall, where audiences are highly attentive to both sensory comfort and the continuity of performance experience, well-perceived environmental control can reduce discomfort, support concentration, enhance spatial atmosphere, and improve the overall judgment of the venue. Therefore, when audiences perceive that a music hall effectively coordinates environmental comfort with green and low-carbon operation, they are more likely to report higher Concert Environment Satisfaction. Based on this reasoning, the following hypothesis is proposed:

**Hypothesis 2 (H2).** *Green Environmental Control has a significant positive effect on Concert Environment Satisfaction.*

### *2.4. Eco-Spatial Integration and Concert Environment Satisfaction*

Eco-Spatial Integration refers to the extent to which ecological elements, natural spatial interfaces, landscape resources, and architectural environments are coherently integrated within the spatial experience of a music hall. Unlike a narrow understanding of greening as the addition of plants or landscape decoration, Eco-Spatial Integration emphasizes the relational organization between architecture and nature, including visual connection with greenery, spatial openness, transitional spaces, natural materials, landscape continuity, daylight access, and the perceptual continuity between indoor and outdoor environments. In music halls, such integration is particularly meaningful because the audience experience is not confined to the performance hall itself. It also includes arrival, waiting, circulation, social interaction, intermission, and post-performance movement. These transitional experiences shape the audience's overall evaluation of the venue environment.

The theoretical basis for the influence of Eco-Spatial Integration can be found in restorative environment research. Attention Restoration Theory argues that natural environments support recovery from directed-attention fatigue by providing "soft fascination," a sense of being away, extent, and compatibility between environmental characteristics and human purposes [34]. Stress Recovery Theory further suggests that exposure to unthreatening natural settings can elicit positive affective responses and reduce physiological stress [35]. Although these theories were initially developed in relation to natural landscapes, their implications have been increasingly extended to built environments through biophilic design research. In this view, ecological spatial elements are not only aesthetic resources but also environmental cues that can regulate affective states, restore attentional resources, and improve the perceived quality of architectural experience.

Recent empirical syntheses provide further support for this argument. Gaekwad et al. conducted a meta-analysis of experimental evidence related to the biophilia hypothesis and found that exposure to natural environments produces measurable emotional benefits, especially in increasing positive affect and reducing negative affect [36]. Similarly, Yao et al. reported that exposure to natural environments has significant positive effects on emotional well-being compared with built environments [37]. More recent reviews of biophilic design in the built environment have also emphasized that nature-integrated design is associated with improved health, well-being, affective experience, and environmental quality, although its effects may vary according to building type, user group, spatial scale, and design strategy [38,39]. These findings suggest that the experiential benefits of nature are not limited to outdoor landscapes but can be translated into architectural settings through carefully organized spatial and ecological integration.

For music halls, Eco-Spatial Integration may influence Concert Environment Satisfaction through several pathways. First, ecological spatial elements can improve the affective quality of the venue by softening the spatial transition from the urban exterior to the performance interior. Music halls often involve a sequence of public foyers, entrance plazas, corridors, waiting areas, and seating zones. When greenery, daylight, natural textures, courtyard views, or landscape interfaces are integrated into these sequences, audiences may experience a more gradual and pleasant transition into the performance atmosphere. Second, ecological integration may reduce perceived crowding and environmental pressure, especially before and after performances or during intermissions, when audiences concentrate in shared public spaces. Third, the presence of natural elements and spatial openness can strengthen the perceived cultural quality of the venue by framing the music hall not

only as a functional performance facility but also as a restorative and socially meaningful public place.

In addition, Eco-Spatial Integration has a distinctive relevance to green retrofit. In existing music halls, green retrofit is often constrained by established building structures, acoustic requirements, and operational conditions. Therefore, ecological intervention cannot be reduced to extensive landscape insertion; it must be carefully coordinated with circulation, visibility, acoustics, indoor environmental quality, and the symbolic atmosphere of the music hall. A well-integrated ecological spatial strategy can make sustainability perceptible without disrupting the primary cultural function of the building. When audiences perceive that natural elements, green landscapes, spatial openness, and architectural form are coherently organized, they are more likely to evaluate the music hall environment as comfortable, refined, restorative, and environmentally responsible.

Based on the above discussion, this study argues that Eco-Spatial Integration is an important spatial antecedent of Concert Environment Satisfaction. Audiences who perceive a higher level of ecological-spatial coherence in a music hall are more likely to experience psychological ease, spatial pleasure, and environmental quality, which in turn may enhance their overall satisfaction with the concert environment. Therefore, the following hypothesis is proposed:

**Hypothesis 3 (H3).** *Eco-Spatial Integration has a significant positive effect on Concert Environment Satisfaction.*

### *2.5. Low-Carbon Operation Perception and Concert Environment Satisfaction*

Low-Carbon Operation Perception refers to audiences' perceived evaluation of whether a music hall operates in an energy-efficient, resource-conscious, and environmentally responsible manner. Different from design-stage sustainability, low-carbon operation is embedded in the daily management of the venue, including energy management, equipment operation, waste reduction, water conservation, green mobility guidance, digital ticketing, resource recycling, and communication of low-carbon information. For music halls, operation is not a background process detached from audience experience. It is closely associated with the cleanliness, order, convenience, environmental atmosphere, and perceived professionalism of the venue. Therefore, low-carbon operation may function as an experiential signal through which audiences judge whether the music hall's green retrofit is effectively implemented in actual use.

From the perspective of building operation research, carbon reduction in public buildings depends not only on design strategies but also on how buildings are managed and used during the operational stage. Janda argued that buildings themselves do not use energy; rather, energy performance is shaped by the interaction between buildings, users, and operational practices [40]. Recent reviews on carbon emissions in public buildings have similarly emphasized that energy systems, building equipment, operational management, and retrofit strategies are central to reducing carbon emissions during the use phase [41]. This suggests that low-carbon operation should be considered a key component of green retrofit evaluation, especially in public cultural buildings where intensive but intermittent occupancy creates high demands for energy, lighting, ventilation, cleaning, and service management.

The relationship between Low-Carbon Operation Perception and Concert Environment Satisfaction can also be interpreted through the Stimulus–Organism–Response framework [42]. In this framework, visible low-carbon practices, such as clear waste sorting, energy-saving lighting, digital service processes, green guidance, and transparent sustainability communication, can be understood as environmental and service stimuli. These

stimuli may shape audiences' internal evaluations of the venue, including perceived responsibility, service reliability, environmental value, and consistency between green claims and actual operation. Recent research on eco-friendly service contexts has shown that green practices and service quality can significantly contribute to customer satisfaction, particularly when users perceive that environmental practices are not symbolic but integrated into the service experience [43,44]. Similarly, expectation–confirmation theory suggests that satisfaction emerges when actual experience meets or exceeds users' prior expectations [45]. In music halls, audiences may increasingly expect public cultural venues to demonstrate environmental responsibility. When low-carbon operations are perceived as visible, efficient, and compatible with the performance-viewing process, they are more likely to confirm these expectations and strengthen satisfaction.

For music halls, the effect of low-carbon operation is especially dependent on its experiential compatibility. If energy-saving measures reduce comfort, delay services, weaken lighting quality, or create inconvenience, audiences may not evaluate them positively. By contrast, when low-carbon operation is perceived as improving service order, reducing waste, enhancing environmental cleanliness, facilitating digital access, and maintaining comfort without compromising the performance atmosphere, it can contribute to a more favorable evaluation of the concert environment. Thus, Low-Carbon Operation Perception reflects not only awareness of carbon reduction but also audiences' judgment of whether sustainability is operationally credible and experientially well integrated.

Based on the above discussion, this study argues that Low-Carbon Operation Perception is an important operational antecedent of Concert Environment Satisfaction. When audiences perceive that a music hall implements low-carbon operation in a professional, visible, and experience-compatible manner, they are more likely to report higher satisfaction with the concert environment. Therefore, the following hypothesis is proposed:

**Hypothesis 4 (H4).** *Low-Carbon Operation Perception has a significant positive effect on Concert Environment Satisfaction.*

The hypotheses are organized into two sets of relationships. H1–H4 examine the direct effects of the four perceived retrofit dimensions on Concert Environment Satisfaction. H5–H8 examine the corresponding indirect effects through Green Retrofit Acceptance, which captures audiences' appraisal of the retrofit's appropriateness and value. This structure distinguishes the dimensions' direct contributions to satisfaction from the proposed mediating role of retrofit acceptance.

### *2.6. The Mediating Role of Green Retrofit Acceptance Between Green Acoustic Material Perception and Concert Environment Satisfaction*

In music halls, acoustic materials are not merely technical devices for regulating sound energy; they are also material carriers through which audiences perceive the quality, intention, and environmental orientation of architectural retrofit. Their influence extends beyond sound clarity, reverberant balance, diffusion, and spatial envelopment. In the context of green retrofit, acoustic materials may also be interpreted as evidence of whether the venue has reconciled acoustic excellence with environmental responsibility, indoor health, and cultural continuity. Thus, Green Acoustic Material Perception is not a simple sensory response, but a compound judgment shaped by acoustic experience, material awareness, and sustainability evaluation.

The mediating role of Green Retrofit Acceptance can be explained through the Stimulus–Organism–Response (S-O-R) framework, which suggests that environmental stimuli influence individual responses through internal psychological states rather than through a purely direct route [42]. In this study, green acoustic materials constitute a

material-based environmental stimulus, while Green Retrofit Acceptance reflects audiences' evaluation of the legitimacy, necessity, and functional appropriateness of the retrofit. When audiences perceive green acoustic materials as low-emission, environmentally responsible, and acoustically competent, they are more likely to regard the retrofit as a substantive architectural improvement rather than a symbolic sustainability gesture. Cognitive appraisal theory further indicates that individuals respond to environmental conditions according to the meanings and consequences attributed to them [46]. For music halls, this appraisal is especially important because acoustic material intervention is closely bound to the building's core cultural function. If green acoustic materials are perceived as acoustically uncertain, visually intrusive, or inconsistent with the performance atmosphere, their environmental attributes may not be sufficient to enhance satisfaction. Conversely, when they are appraised as supporting acoustic quality, indoor health, and sustainability simultaneously, they are more likely to strengthen acceptance of the retrofit.

Recent studies on sustainable acoustic and bio-based building materials show that material innovation increasingly seeks to integrate sound absorption, durability, low emissions, recyclability, embodied environmental performance, and renewable material systems [47,48]. However, these material advantages become meaningful to audiences only when they are perceptible and compatible with the expected acoustic and spatial quality of the music hall. Innovation diffusion theory similarly suggests that acceptance depends on perceived relative advantage, compatibility, and observability [49]. Recent green building and sustainability-oriented consumption studies also indicate that green attributes influence satisfaction more effectively when translated into perceived value, trust, and acceptance [44,50]. Therefore, Green Retrofit Acceptance may serve as an interpretive bridge through which Green Acoustic Material Perception is converted into Concert Environment Satisfaction.

Based on the above reasoning, this study proposes the following hypothesis:

**Hypothesis 5 (H5).** *Green Retrofit Acceptance mediates the relationship between Green Acoustic Material Perception and Concert Environment Satisfaction.*

### *2.7. The Mediating Role of Green Retrofit Acceptance Between Green Environmental Control and Concert Environment Satisfaction*

Green Environmental Control in music halls should be understood as more than the technical regulation of indoor environmental parameters. It concerns the extent to which thermal conditions, ventilation, air quality, lighting, humidity, and intelligent control are perceived as stable, comfortable, energy-conscious, and compatible with the performance setting. In music halls, audiences usually remain seated for an extended period and have limited opportunities to adapt or intervene once the performance begins. Environmental control therefore becomes an unobtrusive yet decisive component of the concert experience: it should support comfort, concentration, and atmosphere without introducing noise, draught, glare, stuffiness, or operational disturbance. This mediating mechanism can be interpreted through Person–Environment Fit Theory, which suggests that environmental evaluation depends on the degree of correspondence between environmental provisions and users' needs, expectations, and activity contexts [51]. In the present study, Green Environmental Control represents a retrofit strategy through which low-carbon operation is aligned with the experiential requirements of music hall attendance. When audiences perceive that thermal regulation supports prolonged sitting, ventilation maintains air freshness without acoustic interference, and lighting control reinforces visual comfort and performance atmosphere, they are more likely to regard the green retrofit as contextually appropriate and functionally justified.

Perceived Control Theory further indicates that people's responses to environmental conditions are shaped not only by objective comfort levels but also by whether the environment appears predictable, reliable, and professionally managed [52]. Although music hall audiences cannot directly control indoor environmental systems, they may still develop a sense of confidence when the venue provides a stable and well-calibrated environment. Recent studies on occupant-centric control similarly emphasize that building operation is shifting from system-centred optimization toward the integration of indoor environmental quality, occupant needs, feedback, and human–building interaction [53–55]. This perspective suggests that green environmental control can gain acceptance only when energy efficiency and experiential comfort are not perceived as competing goals but as mutually coordinated outcomes.

Accordingly, Green Retrofit Acceptance may serve as the evaluative bridge between Green Environmental Control and Concert Environment Satisfaction. When audiences perceive environmental control as comfortable, low-carbon, reliable, and consistent with the performance context, they are more likely to accept the green retrofit as necessary, credible, and effective. This acceptance, in turn, strengthens their overall satisfaction with the concert environment. Therefore, the following hypothesis is proposed:

**Hypothesis 6 (H6).** *Green Retrofit Acceptance mediates the relationship between Green Environmental Control and Concert Environment Satisfaction.*

### *2.8. The Mediating Role of Green Retrofit Acceptance Between Eco-Spatial Integration and Concert Environment Satisfaction*

Ecological spatial strategies make green retrofit visible and experiential within music halls. Eco-Spatial Integration is reflected in greenery, daylight, landscape interfaces, natural materials, transitional spaces, and the visual continuity between indoor and outdoor environments. These elements shape the audience's experience across arrival, waiting, circulation, intermission, and departure, extending environmental evaluation beyond the auditorium itself. Restorative environment theory suggests that nature-related settings can support attentional recovery, emotional ease, and stress reduction through soft fascination, coherence, and compatibility with human purposes [34,35]. Recent evidence on biophilic design further indicates that nature-integrated environments can improve affective experience, perceived environmental quality, and well-being in built settings [36,37].

In existing music halls, ecological intervention is meaningful only when it is perceived as coherent with the building's spatial order, cultural atmosphere, acoustic requirements, and performance experience. Recent studies argue that biophilic design should be assessed not by the amount of visible greening alone but by its capacity to connect environmental quality, human well-being, and sustainability within specific building contexts [38,39]. From this perspective, Eco-Spatial Integration may strengthen Green Retrofit Acceptance when audiences perceive ecological elements as purposeful, context-sensitive, and aligned with the venue's cultural function. Such acceptance allows ecological space to be interpreted as a substantive component of green retrofit rather than as decorative addition.

Accordingly, Green Retrofit Acceptance may convert ecological-spatial perception into Concert Environment Satisfaction. When audiences perceive that Eco-Spatial Integration improves spatial transition, environmental comfort, restorative quality, and the cultural atmosphere of the music hall, they are more likely to accept the green retrofit as necessary, credible, and experientially appropriate. This acceptance, in turn, may enhance their overall satisfaction with the concert environment. Therefore, the following hypothesis is proposed:

**Hypothesis 7 (H7).** *Green Retrofit Acceptance mediates the relationship between Eco-Spatial Integration and Concert Environment Satisfaction.*

### *2.9. The Mediating Role of Green Retrofit Acceptance Between Low-Carbon Operation Perception and Concert Environment Satisfaction*

Low-carbon operation extends green retrofit from architectural intervention to everyday venue governance. In music halls, Low-Carbon Operation Perception is formed through visible practices such as energy-efficient facility management, digital ticketing, waste sorting, resource recycling, green mobility guidance, low-carbon information disclosure, and orderly public service. These operational practices allow audiences to judge whether sustainability is embedded in the actual use of the building, rather than remaining at the level of design narrative. Since building operation accounts for a substantial share of energy consumption and energy-related emissions, the operational stage has become a critical arena for assessing the credibility of green retrofit [56,57].

Expectation–Confirmation Theory provides a suitable basis for explaining the mediating role of Green Retrofit Acceptance. Satisfaction is shaped by the extent to which actual experience confirms users' prior expectations [45]. In public cultural buildings, audiences increasingly expect green claims to be supported by reliable and experience-compatible operational practices. When low-carbon operation is perceived as visible, efficient, convenient, and consistent with the concert-going process, audiences are more likely to accept the green retrofit as authentic and effective. If low-carbon measures create inconvenience, reduce comfort, or appear symbolic, their contribution to satisfaction may be weakened. Green Retrofit Acceptance therefore functions as the evaluative link between operational perception and environmental satisfaction.

Recent service and sustainability studies support this logic. Green practices can strengthen user evaluation when they are integrated with service quality, perceived value, and environmental responsibility [58,59]. Perceived sustainability also tends to influence satisfaction more effectively when it is transformed into perceived value rather than presented as an isolated environmental claim [44]. Applied to music halls, audiences who perceive low-carbon operation as professional, credible, and compatible with the performance experience are more likely to accept the green retrofit, which in turn enhances Concert Environment Satisfaction. Accordingly, this study proposes the following hypothesis:

**Hypothesis 8 (H8).** *Green Retrofit Acceptance mediates the relationship between Low-Carbon Operation Perception and Concert Environment Satisfaction.*

The preceding review identifies four distinct but complementary dimensions of audience-perceived sustainable retrofit and proposes Green Retrofit Acceptance as a mechanism linking these perceptions to Concert Environment Satisfaction. Figure 1 synthesizes these arguments into the proposed theoretical model. Figure 1 depicts the direct relationships specified in H1–H4 and the corresponding mediated relationships specified in H5–H8, providing the conceptual basis for the questionnaire design and the subsequent empirical testing. Figure 2 illustrates the four dimensions in a schematic music hall.

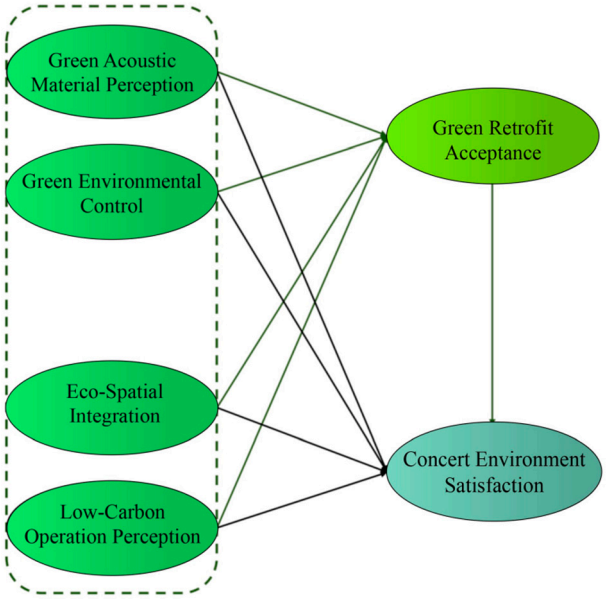



**Figure 1.** Proposed model diagram.

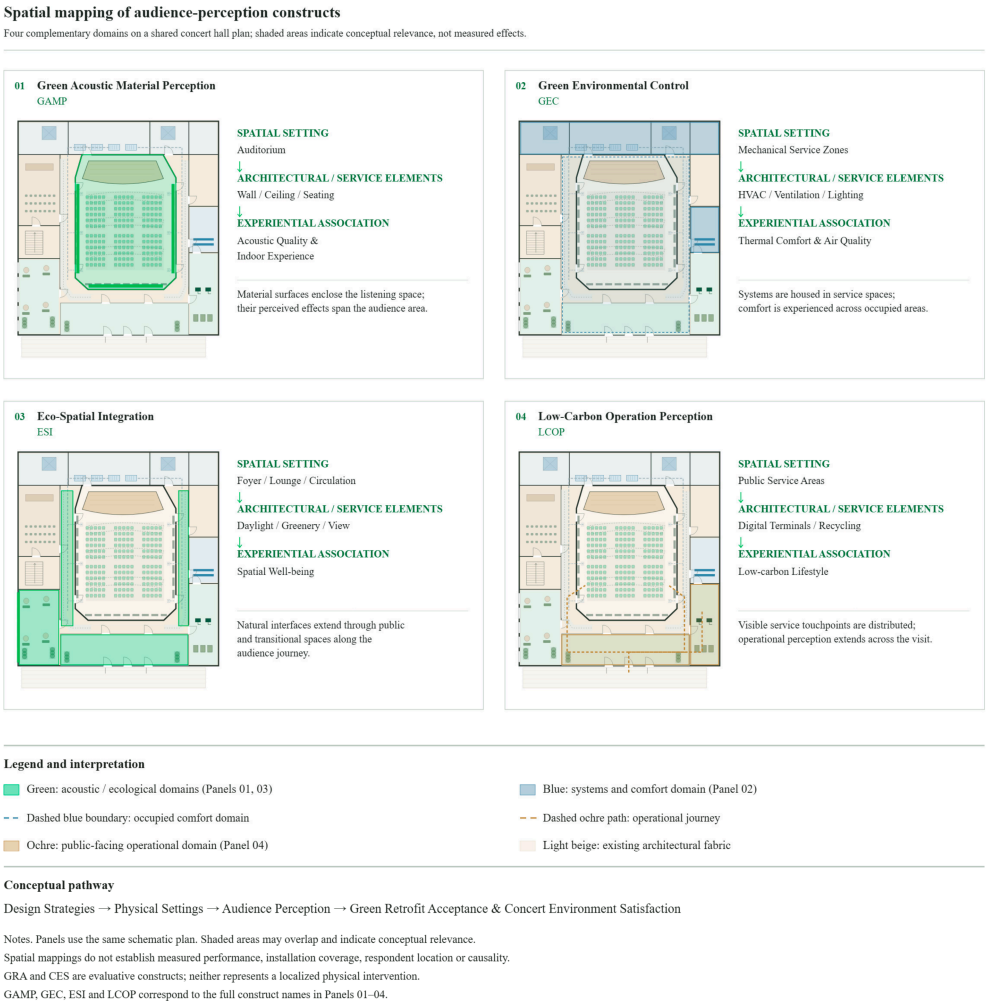



**Figure 2.** Spatial mapping of audience-perceived green retrofit dimensions in music halls. The arrows indicate conceptual links between spatial settings, architectural or service elements, and audience experience.

## 3. Research Design

### *3.1. Overall Research Approach*

This study adopted a cross-sectional questionnaire design within a perception-based post-occupancy evaluation framework. The individual audience member was the unit of analysis. As summarized in Figure 1, four perceived retrofit dimensions—Green Acoustic Material Perception (GAMP), Green Environmental Control (GEC), Eco-Spatial Integration (ESI), and Low-Carbon Operation Perception (LCOP)—were specified as predictors of Concert Environment Satisfaction (CES), with Green Retrofit Acceptance (GRA) as the mediator. H1–H4 address the direct associations between the four dimensions and CES, whereas H5–H8 address the corresponding indirect associations through GRA. The complete model therefore comprises six constructs, of which only four represent perceived retrofit dimensions.

The analytical strategy combined preliminary data assessment, common method bias screening, exploratory analysis of the measurement structure, confirmatory factor analysis (CFA), structural equation modelling (SEM), and bootstrap mediation analysis. This sequence links the theoretical framework to the assessment of measurement quality and the testing of the proposed relationships. The questionnaire captures perceived environmental and operational attributes rather than independently measured energy savings, carbon reductions, or before-and-after retrofit changes. Accordingly, the estimates are interpreted as associations within the sampled audience population.

### *3.2. Study Context and Data Collection*

#### 3.2.1. Study Context and Reference Venues

The survey was conducted in the Chinese-language context of mainland China and concerned audiences with first-hand music hall attendance experience. In this setting, sustainable retrofit is evaluated in relation to the venue's continuing performance function, including acoustic quality, indoor comfort, spatial experience, and operational services. The questionnaire thus addresses whether perceived environmental improvements are compatible with the experience of attending a live musical performance; it does not assume that a venue's technical or environmental credentials necessarily translate into audience satisfaction.

Responses concerned different music halls rather than a single common case. The items use the venue-specific wording "this music hall" (Appendix A), and the intended reference is one music hall personally attended by each respondent. Evaluations are analysed at the audience level rather than as ratings of a uniform retrofit package. A respondent-linked inventory identifying the venues, their retrofit histories, and sample allocations is not reported for the analysed dataset. Consequently, the present evidence does not permit verification of a common retrofit exposure across respondents or comparisons of individual music halls. The scope of inference is therefore the relationship among audience-reported perceptions, acceptance, and satisfaction.

#### 3.2.2. Recruitment and Questionnaire Screening

Data were collected through on-site audience invitations and online dissemination. During on-site recruitment, members of the research team approached audience members after performances or during the exit period, explained the study purpose and questionnaire requirements, and invited voluntary participation. Additional respondents with relevant music hall attendance experience were recruited through participant referrals and online sharing. This audience-intercept and snowball recruitment approach broadened the recruitment channels but did not establish a probability sample of music hall audiences or national representativeness.

A total of 850 questionnaires were reported as distributed, and 789 were returned. Responses were screened for incomplete answers, abnormal response times, and obvious logical inconsistencies. After excluding 60 returned questionnaires, 729 valid responses were retained. The proportion returned was 92.82% (789/850), the valid proportion among returned questionnaires was 92.40% (729/789), and the valid proportion relative to the reported distribution count was 85.76% (729/850). These proportions distinguish questionnaire return from retention for analysis.

The retained sample comprised 415 men (56.9%) and 314 women (43.1%). Respondents aged 18–35 years accounted for 42.9% of the sample, those aged 36–45 years for 28.9%, and those aged 46 years or above for 28.1%. A total of 488 respondents (66.9%) reported an interest in music performances or music hall attendance, while 241 (33.1%) reported a moderate level of interest. Table 1 summarizes the demographic profile. These distributions characterize the recruited sample rather than demonstrate its representativeness.

**Table 1.** Demographic profile of the respondents.

| Variable | Category | Frequency (N) | Percentage (%) |
|---|---|---|---|
| Gender | Male | 415 | 56.9 |
| | Female | 314 | 43.1 |
| Age | 18–35 years | 313 | 42.9 |
| | 36–45 years | 211 | 28.9 |
| | 46 years and above | 205 | 28.1 |
| Income | Able to meet daily expenses | 587 | 80.5 |
| | Unable to meet daily expenses | 142 | 19.5 |
| Interest in music performances | Interested | 488 | 66.9 |
| | Moderate | 241 | 33.1 |
| Education | Junior college degree or above | 517 | 70.9 |
| | Below junior college level | 212 | 29.1 |

### *3.3. Measurement Instrument*

All constructs were measured using a five-point Likert scale, ranging from 1 = "strongly disagree" to 5 = "strongly agree". To ensure semantic equivalence and contextual validity, the measurement items were translated into Chinese and then back-translated by independent researchers. The wording of the items was further refined according to the research context of music hall green retrofit and audience evaluation.

The measurement scale was developed by adapting established instruments and theoretical measurement frameworks from post-occupancy evaluation, indoor environmental quality, architectural acoustics, biophilic design, green building operation, sustainable technology acceptance, and satisfaction research. Green Acoustic Material Perception was measured with four items derived from the acoustic satisfaction dimension of the CBE Occupant Indoor Environmental Quality Survey [60] and further informed by acoustic material theory and sustainable acoustic material research [26,27]. Green Environmental Control was measured with three items adapted from indoor environmental quality and comfort-related frameworks, including thermal comfort standards and perceived air quality research [31,32]. Eco-Spatial Integration was measured with four items developed from restorative environment theory and biophilic design patterns, with emphasis on natural elements, spatial openness, daylight, natural materials, and indoor–outdoor continuity [34,61]. Low-Carbon Operation Perception was measured with four items adapted from green building operation and perceived sustainability research, focusing on energy-saving management,

resource conservation, digital services, green guidance, and low-carbon information communication [40,44].

Green Retrofit Acceptance was specified as the mediating variable and measured with six items adapted from perceived sustainability, sustainable technology acceptance, and green perceived value research [16,44]. The items captured audiences' acceptance of the necessity, authenticity, effectiveness, credibility, and contextual compatibility of music hall green retrofit. Concert Environment Satisfaction was specified as the dependent variable and measured with five items adapted from post-occupancy evaluation and expectation–confirmation-based satisfaction research [45,60]. These items assessed audiences' overall satisfaction with the concert environment in terms of acoustic experience, spatial quality, environmental comfort, performance-viewing support, and expectation fulfilment.

The instrument comprised 26 items measuring six latent constructs: GAMP (four items), GEC (three), ESI (four), LCOP (four), GRA (six), and CES (five). The first four constructs describe perceived material, environmental, spatial, and operational attributes; GRA captures acceptance of retrofit, while CES captures the overall evaluation of the concert environment. The same six-construct structure was examined in the exploratory and confirmatory stages. The questionnaire and response options are presented in Table A1 in Appendix A.

### *3.4. Data Analytical Procedures*

Analysis proceeded in six stages. SPSS 23.0 was used for descriptive and exploratory analyses, and AMOS 23.0 was used for CFA, SEM, and bootstrap estimation. The procedures and assessment criteria are described here; their numerical outcomes are reported in Section 4.

First, the retained data were summarized using frequencies and percentages for respondent characteristics and means and standard deviations for measurement items. Item skewness and kurtosis were examined using absolute values below 2 and 7, respectively, as screening criteria for marked univariate non-normality. These item-level diagnostics do not establish multivariate normality. The descriptive statistics and distributional results are presented in Table 2.

Second, Harman's single-factor test was used as a preliminary diagnostic for common method bias. The percentage of variance explained by the first unrotated factor was compared with a 50% screening threshold. This procedure was interpreted as a check for a dominant single factor, rather than a conclusive test of the absence of common method bias.

Third, the exploratory factor analysis (EFA) stage examined all 26 items rather than only the items for the four predictor dimensions. Suitability was assessed using the Kaiser–Meyer–Olkin (KMO) statistic and Bartlett's test of sphericity, with KMO above 0.70 and a significant Bartlett's test used as criteria. The reported exploratory procedure used principal component analysis (PCA), eigenvalues greater than 1 for component retention, and Varimax orthogonal rotation. Thus, the exploratory results are component-based and are distinguished from the latent measurement model subsequently examined by CFA. Primary loadings above 0.50 and cross-loadings below 0.40 were used to assess the rotated pattern.

Fourth, CFA assessed the six-construct measurement model. Standardized loadings above 0.60, composite reliability (CR) above 0.70, and average variance extracted (AVE) above 0.50 were used to evaluate indicator performance, composite reliability, and convergent validity. Discriminant validity was assessed using the Fornell–Larcker criterion: the square root of each construct's AVE was compared with its correlations with the other constructs [62].

Fifth, the structural model was estimated using maximum likelihood in AMOS 23.0. Model fit was evaluated using CMIN/DF, GFI, AGFI, NFI, TLI, IFI, CFI, RMR, and RMSEA.

CMIN/DF below 3 and the reported incremental and goodness-of-fit indices above 0.90 were used as benchmarks; RMR and RMSEA were considered as residual and approximation-error measures. Standardized coefficients were used to describe path magnitudes, and the associated *p*-values were used to assess statistical significance. The four direct paths to CES correspond to H1–H4; the paths into and out of GRA form the proposed mediation pathways. CMIN/DF denotes chi-square divided by degrees of freedom; GFI and AGFI denote the goodness-of-fit and adjusted goodness-of-fit indices; NFI, TLI, IFI, and CFI denote the normed, Tucker–Lewis, incremental, and comparative fit indices; and RMR and RMSEA denote the root mean square residual and root mean square error of approximation.

Sixth, the indirect associations through GRA were evaluated using 5000 bootstrap samples. Both bias-corrected and percentile 95% confidence intervals were calculated. An indirect association was considered statistically significant when its confidence interval excluded zero. Direct and indirect estimates were considered jointly to interpret mediation. These cross-sectional estimates characterize statistical indirect associations and do not establish temporal or causal mediation.

**Table 2.** Item descriptive statistics and distributional assessment.

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| GAMP1 | 729 | 1 | 5 | 3.829 | 1.062 | −0.564 | −0.480 |
| GAMP2 | 729 | 1 | 5 | 3.830 | 1.175 | −0.645 | −0.641 |
| GAMP3 | 729 | 1 | 5 | 3.753 | 1.131 | −0.538 | −0.584 |
| GAMP4 | 729 | 1 | 5 | 3.684 | 1.048 | −0.477 | −0.554 |
| GEC1 | 729 | 1 | 5 | 3.850 | 1.188 | −0.829 | −0.136 |
| GEC2 | 729 | 1 | 5 | 3.807 | 1.155 | −0.786 | −0.193 |
| GEC3 | 729 | 1 | 5 | 3.853 | 1.186 | −0.805 | −0.137 |
| ESI1 | 729 | 1 | 5 | 3.776 | 1.076 | −0.913 | 0.493 |
| ESI2 | 729 | 1 | 5 | 3.786 | 1.051 | −0.844 | 0.423 |
| ESI3 | 729 | 1 | 5 | 3.717 | 1.085 | −0.784 | 0.173 |
| ESI4 | 729 | 1 | 5 | 3.767 | 1.078 | −0.726 | 0.053 |
| LCOP1 | 729 | 1 | 5 | 3.705 | 1.193 | −0.604 | −0.557 |
| LCOP2 | 729 | 1 | 5 | 3.580 | 1.137 | −0.351 | −0.787 |
| LCOP3 | 729 | 1 | 5 | 3.657 | 1.237 | −0.544 | −0.763 |
| LCOP4 | 729 | 1 | 5 | 3.505 | 1.176 | −0.286 | −0.838 |
| GRA1 | 729 | 1 | 5 | 3.664 | 1.202 | −0.667 | −0.460 |
| GRA2 | 729 | 1 | 5 | 3.668 | 1.242 | −0.704 | −0.451 |
| GRA3 | 729 | 1 | 5 | 3.844 | 1.187 | −0.747 | −0.435 |
| GRA4 | 729 | 1 | 5 | 3.521 | 1.200 | −0.359 | −0.837 |
| GRA5 | 729 | 1 | 5 | 3.727 | 1.185 | −0.656 | −0.568 |
| GRA6 | 729 | 1 | 5 | 3.731 | 1.161 | −0.636 | −0.491 |
| CES1 | 729 | 1 | 5 | 3.674 | 1.193 | −0.717 | −0.308 |
| CES2 | 729 | 1 | 5 | 3.656 | 1.269 | −0.647 | −0.595 |
| CES3 | 729 | 1 | 5 | 3.802 | 1.185 | −0.697 | −0.463 |
| CES4 | 729 | 1 | 5 | 3.549 | 1.162 | −0.411 | −0.665 |
| CES5 | 729 | 1 | 5 | 3.705 | 1.142 | −0.697 | −0.282 |

Notes: N = number of valid responses; Std. Deviation = standard deviation. GAMP = Green Acoustic Material Perception; GEC = Green Environmental Control; ESI = Eco-Spatial Integration; LCOP = Low-Carbon Operation Perception; GRA = Green Retrofit Acceptance; CES = Concert Environment Satisfaction.

## 4. Results

Following the analytical sequence described in Section 3.4, this section reports preliminary data assessment, common method bias screening, exploratory structure, measurement-model assessment, structural paths, and mediation results. The distinction between four per-

ceived retrofit dimensions and six constructs is maintained throughout: GRA and CES represent acceptance and satisfaction, respectively, rather than additional retrofit dimensions.

### *4.1. Preliminary Data Assessment*

As shown in Table 2, item means ranged from 3.505 to 3.853. Skewness ranged from −0.913 to −0.286, and kurtosis from −0.838 to 0.493. All items fell within the stated univariate screening criteria. These results indicate no marked univariate non-normality under those criteria but do not establish multivariate normality or, by themselves, justify the estimation method.

### *4.2. Common Method Bias Assessment*

The first unrotated component accounted for 39.835% of the total variance, below the 50% screening threshold. A single component therefore did not dominate the item covariance structure under this diagnostic. Nevertheless, this finding does not exclude common method bias arising from the use of a single self-report questionnaire, and the subsequent associations should be interpreted with that limitation in mind.

### *4.3. Exploratory Factor Analysis*

The KMO value was 0.947, and Bartlett's test of sphericity was significant ($p < 0.001$), supporting the suitability of the item correlation matrix for exploratory analysis. Six components with eigenvalues greater than 1 were retained, accounting for 70.252% of total variance (Table 3).

**Table 3.** Variance explained by the exploratory component solution.

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 10.357 | 39.835 | 39.835 | 10.357 | 39.835 | 39.835 | 4.133 | 15.896 | 15.896 |
| 2 | 2.136 | 8.214 | 48.050 | 2.136 | 8.214 | 48.050 | 3.393 | 13.049 | 28.945 |
| 3 | 1.734 | 6.671 | 54.720 | 1.734 | 6.671 | 54.720 | 2.966 | 11.409 | 40.353 |
| 4 | 1.430 | 5.500 | 60.220 | 1.430 | 5.500 | 60.220 | 2.845 | 10.943 | 51.296 |
| 5 | 1.374 | 5.284 | 65.503 | 1.374 | 5.284 | 65.503 | 2.734 | 10.515 | 61.811 |
| 6 | 1.235 | 4.749 | 70.252 | 1.235 | 4.749 | 70.252 | 2.195 | 8.441 | 70.252 |
| 7 | 0.601 | 2.311 | 72.563 | | | | | | |
| 8 | 0.514 | 1.979 | 74.542 | | | | | | |
| 9 | 0.498 | 1.914 | 76.456 | | | | | | |
| 10 | 0.462 | 1.778 | 78.233 | | | | | | |
| 11 | 0.458 | 1.763 | 79.996 | | | | | | |
| 12 | 0.451 | 1.734 | 81.730 | | | | | | |
| 13 | 0.429 | 1.650 | 83.380 | | | | | | |
| 14 | 0.412 | 1.584 | 84.965 | | | | | | |
| 15 | 0.396 | 1.524 | 86.489 | | | | | | |
| 16 | 0.382 | 1.471 | 87.959 | | | | | | |
| 17 | 0.367 | 1.411 | 89.370 | | | | | | |
| 18 | 0.364 | 1.401 | 90.771 | | | | | | |
| 19 | 0.347 | 1.336 | 92.107 | | | | | | |
| 20 | 0.337 | 1.297 | 93.404 | | | | | | |
| 21 | 0.320 | 1.229 | 94.633 | | | | | | |
| 22 | 0.304 | 1.171 | 95.804 | | | | | | |
| 23 | 0.297 | 1.142 | 96.946 | | | | | | |
| 24 | 0.282 | 1.085 | 98.031 | | | | | | |
| 25 | 0.266 | 1.022 | 99.052 | | | | | | |
| 26 | 0.246 | 0.948 | 100.000 | | | | | | |

Notes: Extraction used principal component analysis (PCA); components were retained when eigenvalues exceeded 1. Rotation used Varimax. All 26 items were included.

The six-component solution corresponds to the full instrument: four perceived retrofit dimensions (GAMP, GEC, ESI, and LCOP), one mediator (GRA), and one outcome (CES). It does not imply that sustainable retrofit perception comprises six dimensions. In the rotated

matrix (Table 4), the item groups appear in the order GRA, CES, LCOP, ESI, GAMP, and GEC. Primary loadings ranged from 0.666 to 0.835, while the largest cross-loading was 0.287. The resulting item pattern was consistent with the proposed six-construct measurement structure and provided preliminary support for the subsequent CFA.

**Table 4.** Rotated component matrix for the six-construct instrument.

| | Component | | | | | |
|---|---|---|---|---|---|---|
| | **GRA** | **CES** | **LCOP** | **ESI** | **GAMP** | **GEC** |
| GRA1 | **0.777** | 0.168 | 0.114 | 0.177 | 0.176 | 0.082 |
| GRA6 | **0.771** | 0.189 | 0.125 | 0.037 | 0.167 | 0.147 |
| GRA5 | **0.758** | 0.219 | 0.155 | 0.142 | 0.121 | 0.164 |
| GRA2 | **0.749** | 0.206 | 0.170 | 0.156 | 0.169 | 0.151 |
| GRA3 | **0.732** | 0.133 | 0.214 | 0.135 | 0.178 | 0.132 |
| GRA4 | **0.689** | 0.241 | 0.208 | 0.136 | 0.156 | 0.177 |
| CES5 | 0.226 | **0.793** | 0.139 | 0.136 | 0.174 | 0.128 |
| CES2 | 0.190 | **0.763** | 0.177 | 0.116 | 0.113 | 0.093 |
| CES1 | 0.221 | **0.749** | 0.162 | 0.215 | 0.172 | 0.110 |
| CES4 | 0.251 | **0.696** | 0.221 | 0.130 | 0.218 | 0.199 |
| CES3 | 0.202 | **0.666** | 0.191 | 0.190 | 0.185 | 0.120 |
| LCOP3 | 0.185 | 0.175 | **0.815** | 0.039 | 0.119 | 0.056 |
| LCOP1 | 0.195 | 0.166 | **0.783** | 0.095 | 0.163 | 0.068 |
| LCOP4 | 0.170 | 0.151 | **0.774** | 0.047 | 0.178 | 0.058 |
| LCOP2 | 0.164 | 0.194 | **0.744** | 0.094 | 0.131 | 0.083 |
| ESI1 | 0.138 | 0.127 | 0.048 | **0.835** | 0.139 | 0.118 |
| ESI2 | 0.148 | 0.144 | 0.047 | **0.800** | 0.109 | 0.143 |
| ESI3 | 0.071 | 0.172 | 0.051 | **0.742** | 0.123 | 0.112 |
| ESI4 | 0.182 | 0.129 | 0.116 | **0.721** | 0.108 | 0.067 |
| GAMP4 | 0.153 | 0.154 | 0.148 | 0.122 | **0.821** | 0.125 |
| GAMP1 | 0.232 | 0.233 | 0.135 | 0.169 | **0.761** | 0.139 |
| GAMP2 | 0.267 | 0.214 | 0.248 | 0.161 | **0.709** | 0.135 |
| GAMP3 | 0.287 | 0.245 | 0.251 | 0.199 | **0.677** | 0.170 |
| GEC1 | 0.221 | 0.145 | 0.084 | 0.126 | 0.120 | **0.784** |
| GEC2 | 0.189 | 0.094 | 0.078 | 0.142 | 0.186 | **0.783** |
| GEC3 | 0.167 | 0.217 | 0.073 | 0.163 | 0.107 | **0.772** |

Notes: Bold values indicate each item's primary component loading. GAMP = Green Acoustic Material Perception; GEC = Green Environmental Control; ESI = Eco-Spatial Integration; LCOP = Low-Carbon Operation Perception; GRA = Green Retrofit Acceptance; CES = Concert Environment Satisfaction.

### *4.4. Measurement Model Assessment*

Table 5 summarizes the CFA-based measurement results. Standardized loadings ranged from 0.678 to 0.844, CR from 0.801 to 0.908, and AVE from 0.570 to 0.648. These values met the stated criteria, supporting composite reliability and convergent validity for the six constructs. These measurement results concern the quality of the construct indicators; they do not by themselves test the structural hypotheses.

Table 6 presents the discriminant-validity assessment. The square roots of AVE ranged from 0.755 to 0.805 and exceeded the corresponding inter-construct correlations, whose largest reported value was 0.581. The six constructs therefore met the Fornell–Larcker criterion. This distinction is substantively relevant because it separates perceptions of retrofit attributes from acceptance of the retrofit and overall satisfaction with the concert environment.

**Table 5.** Results of confirmatory factor analysis.

| Construct | Item | Factor Loading | CR | AVE |
|---|---|---|---|---|
| GAMP | GAMP1 | 0.805 | 0.880 | 0.648 |
| | GAMP2 | 0.811 | | |
| | GAMP3 | 0.833 | | |
| | GAMP4 | 0.769 | | |
| GEC | GEC1 | 0.762 | 0.801 | 0.573 |
| | GEC2 | 0.748 | | |
| | GEC3 | 0.761 | | |
| ESI | ESI1 | 0.844 | 0.840 | 0.570 |
| | ESI2 | 0.798 | | |
| | ESI3 | 0.686 | | |
| | ESI4 | 0.678 | | |
| LCOP | LCOP1 | 0.800 | 0.858 | 0.603 |
| | LCOP2 | 0.732 | | |
| | LCOP3 | 0.810 | | |
| | LCOP4 | 0.761 | | |
| GRA | GRA1 | 0.795 | 0.908 | 0.622 |
| | GRA2 | 0.813 | | |
| | GRA3 | 0.768 | | |
| | GRA4 | 0.772 | | |
| | GRA5 | 0.808 | | |
| | GRA6 | 0.774 | | |
| CES | CES1 | 0.808 | 0.889 | 0.616 |
| | CES2 | 0.746 | | |
| | CES3 | 0.725 | | |
| | CES4 | 0.808 | | |
| | CES5 | 0.832 | | |

Notes: Loadings are standardized CFA estimates. CFA = confirmatory factor analysis; CR = composite reliability; AVE = average variance extracted. GAMP = Green Acoustic Material Perception; GEC = Green Environmental Control; ESI = Eco-Spatial Integration; LCOP = Low-Carbon Operation Perception; GRA = Green Retrofit Acceptance; CES = Concert Environment Satisfaction.

**Table 6.** Discriminant validity.

| | GAMP | GEC | ESI | LCOP | GRA | CES |
|---|---|---|---|---|---|---|
| GAMP | **0.805** | | | | | |
| GEC | 0.454 ** | **0.757** | | | | |
| ESI | 0.435 ** | 0.384 ** | **0.755** | | | |
| LCOP | 0.503 ** | 0.287 ** | 0.258 ** | **0.777** | | |
| GRA | 0.577 ** | 0.482 ** | 0.406 ** | 0.486 ** | **0.789** | |
| CES | 0.578 ** | 0.448 ** | 0.444 ** | 0.500 ** | 0.581 ** | **0.785** |

Notes: Diagonal entries are square roots of average variance extracted (AVE); off-diagonal entries are inter-construct correlations. ** $p < 0.01$. GAMP = Green Acoustic Material Perception; GEC = Green Environmental Control; ESI = Eco-Spatial Integration; LCOP = Low-Carbon Operation Perception; GRA = Green Retrofit Acceptance; CES = Concert Environment Satisfaction. Bold values mark the diagonal entries.

### *4.5. Structural Model and Hypothesis Testing*

The structural model yielded CMIN/DF = 1.414, RMR = 0.038, and RMSEA = 0.024. GFI, AGFI, NFI, TLI, IFI, and CFI were each reported as exceeding 0.90. Taken together, these indices were consistent with acceptable structural-model fit under the stated assessment

approach. Figure 3 summarizes the estimated paths, while Table 7 provides the standardized and unstandardized coefficients and their inferential statistics.

The four hypothesized direct paths to CES were positive and statistically significant: GAMP → CES (β = 0.236, $p < 0.001$; H1), GEC → CES (β = 0.129, $p = 0.004$; H2), ESI → CES (β = 0.151, $p < 0.001$; H3), and LCOP → CES (β = 0.211, $p < 0.001$; H4). These results support H1–H4 within the estimated model. GAMP had the largest standardized direct coefficient numerically, followed by LCOP, ESI, and GEC. This ordering is descriptive: no formal test of differences between these coefficients is reported.

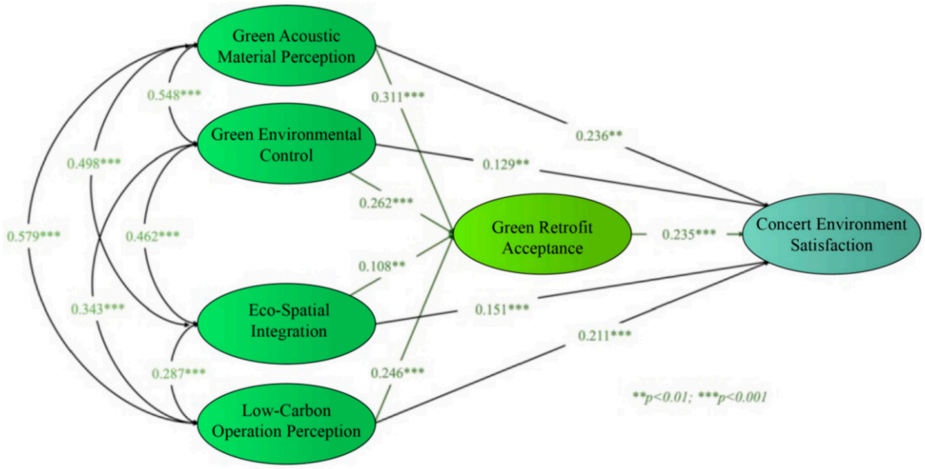



**Figure 3.** Results of the structural equation model.

**Table 7.** Path coefficients.

| Path | | | Standardized Coefficient | Unstandardized Coefficient | S.E. | t | *p* | Result |
|---|---|---|---|---|---|---|---|---|
| GRA | ← | GAMP | 0.311 | 0.348 | 0.057 | 6.152 | *** | Significant |
| GRA | ← | GEC | 0.262 | 0.276 | 0.047 | 5.907 | *** | Significant |
| GRA | ← | ESI | 0.108 | 0.114 | 0.042 | 2.730 | 0.006 | Significant |
| GRA | ← | LCOP | 0.246 | 0.247 | 0.042 | 5.897 | *** | Significant |
| CES | ← | GAMP | 0.236 | 0.266 | 0.057 | 4.645 | *** | H1 supported |
| CES | ← | GEC | 0.129 | 0.137 | 0.047 | 2.895 | 0.004 | H2 supported |
| CES | ← | ESI | 0.151 | 0.160 | 0.041 | 3.873 | *** | H3 supported |
| CES | ← | LCOP | 0.211 | 0.214 | 0.043 | 5.010 | *** | H4 supported |
| CES | ← | GRA | 0.235 | 0.237 | 0.048 | 4.911 | *** | Significant |

Notes: β = standardized path coefficient; B = unstandardized path coefficient; S.E. = standard error of B; t = the test statistic as labelled in the original output table. *** $p < 0.001$. H1–H4 concern the four direct paths to CES; the remaining paths are constituent paths of the mediation model. GAMP = Green Acoustic Material Perception; GEC = Green Environmental Control; ESI = Eco-Spatial Integration; LCOP = Low-Carbon Operation Perception; GRA = Green Retrofit Acceptance; CES = Concert Environment Satisfaction.

The paths forming the proposed acceptance mechanism were also positive. GAMP (β = 0.311, $p < 0.001$), GEC (β = 0.262, $p < 0.001$), ESI (β = 0.108, $p = 0.006$), and LCOP (β = 0.246, $p < 0.001$) were associated with GRA, which in turn was associated with CES (β = 0.235, $p < 0.001$). These paths are compatible with an acceptance-related pathway, but their individual significance is not treated as a substitute for testing the indirect associations. H5–H8 are therefore evaluated using the bootstrap intervals in Section 4.6.

### *4.6. Mediation Analysis*

Table 8 reports total, direct, and indirect estimates together with bias-corrected and percentile bootstrap confidence intervals. For GAMP → GRA → CES, the indirect estimate was 0.073, with a bias-corrected 95% confidence interval of [0.034, 0.129] (H5). The corresponding estimates were 0.062 [0.030, 0.108] for GEC (H6), 0.025 [0.007, 0.056] for ESI (H7), and 0.058 [0.029, 0.101] for LCOP (H8). All four bias-corrected intervals excluded zero; the percentile intervals led to the same conclusion. Thus, H5–H8 were supported.

**Table 8.** Bootstrap estimates of total, direct, and indirect effects.

| Path | Effect Value | Bias-Corrected 95%CI | | Percentile 95%CI | |
|---|---|---|---|---|---|
| | | Lower | Upper | Lower | Upper |
| GAMP → CES total effect | 0.31 | 0.191 | 0.431 | 0.191 | 0.432 |
| GAMP → GRA → CES indirect effect | 0.073 | 0.034 | 0.129 | 0.032 | 0.126 |
| GAMP → CES direct effect | 0.236 | 0.113 | 0.355 | 0.113 | 0.355 |
| GEC → CES total effect | 0.19 | 0.087 | 0.292 | 0.088 | 0.294 |
| GEC → GRA → CES indirect effect | 0.062 | 0.03 | 0.108 | 0.028 | 0.102 |
| GEC → CES direct effect | 0.129 | 0.026 | 0.235 | 0.026 | 0.235 |
| ESI → CES total effect | 0.176 | 0.079 | 0.276 | 0.078 | 0.275 |
| ESI → GRA → CES indirect effect | 0.025 | 0.007 | 0.056 | 0.006 | 0.052 |
| ESI → CES direct effect | 0.151 | 0.05 | 0.255 | 0.048 | 0.254 |
| LCOP → CES total effect | 0.269 | 0.18 | 0.365 | 0.177 | 0.362 |
| LCOP → GRA → CES indirect effect | 0.058 | 0.029 | 0.101 | 0.026 | 0.095 |
| LCOP → CES direct effect | 0.211 | 0.124 | 0.307 | 0.122 | 0.304 |

Notes: CI = confidence interval. Bootstrap resamples = 5000. Bias-corrected and percentile intervals are reported at the 95% level; intervals excluding zero indicate statistically significant effects. Indirect rows correspond to H5 (GAMP), H6 (GEC), H7 (ESI), and H8 (LCOP). Effect values and interval endpoints are retained from the reported analysis. GAMP = Green Acoustic Material Perception; GEC = Green Environmental Control; ESI = Eco-Spatial Integration; LCOP = Low-Carbon Operation Perception; GRA = Green Retrofit Acceptance; CES = Concert Environment Satisfaction.

The corresponding direct associations also remained positive and significant, and their bootstrap confidence intervals excluded zero. This joint pattern is consistent with partial statistical mediation: acceptance accounts for part, but not all, of the association between perceived retrofit attributes and satisfaction. Among the four indirect estimates, GAMP was numerically largest and ESI smallest. As with the direct paths, these numerical differences were not subjected to a formal between-effect comparison. The results support the proposed pattern of relationships, while the cross-sectional design prevents an inference that retrofit perceptions temporally caused acceptance or satisfaction.

## 5. Discussion

### *5.1. Discussion of Direct Effects*

The findings of this study demonstrate that audiences' perceptions of sustainable retrofit dimensions significantly contribute to Concert Environment Satisfaction, suggesting that the evaluation of green retrofit in music halls involves a multidimensional experiential process rather than a single technical performance assessment. Previous research on sustainable retrofit and post-occupancy evaluation (POE) has increasingly recognized that building performance should be evaluated not only through objective indicators, such as energy consumption, carbon reduction, and environmental monitoring data, but also through users' perceptions of comfort, usability, and environmental quality [1–6]. However, existing retrofit evaluation frameworks have primarily focused on residential, office, and general public buildings, while performance-oriented cultural buildings remain compara-

tively underexplored. By introducing audience perception into the assessment of music hall retrofit, this study extends existing POE research by demonstrating how sustainability interventions are interpreted through actual user experience.

The strong contribution of Green Acoustic Material Perception highlights the distinctive functional characteristics of music halls. Previous acoustic studies have demonstrated that material configuration plays a fundamental role in shaping sound absorption, diffusion, reverberation characteristics, and spatial impression in performance spaces [25,26]. Recent empirical studies on concert hall evaluation further indicate that subjective acoustic preference is closely associated with perceived clarity, reverberance, and overall listening experience [20]. Consistent with these findings, the present study confirms that acoustic quality remains a central component of audience evaluation. However, this study extends previous acoustic research by demonstrating that, within the context of sustainable retrofit, acoustic materials are not evaluated solely according to their physical acoustic performance. Instead, audiences also interpret green acoustic materials as indicators of environmental responsibility, indoor health, and compatibility between sustainability goals and artistic performance. This finding is particularly meaningful because sustainable acoustic materials have traditionally been investigated mainly from a material science or engineering perspective. Previous research has shown that natural materials, recycled materials, and innovative composite systems can provide acoustic benefits while reducing environmental impacts [27,28]. Nevertheless, the practical success of these materials in performance buildings depends not only on their technical properties but also on whether users perceive them as supporting the core function of the venue. The present study therefore extends sustainable acoustic material research by highlighting the importance of perceptual compatibility between environmental innovation and auditory experience. In music halls, where acoustic quality represents a fundamental aspect of architectural value, green retrofit strategies are likely to be more effective when sustainability and acoustic performance are perceived as mutually reinforcing objectives.

The positive influence of Green Environmental Control is consistent with previous research on indoor environmental quality (IEQ), which has demonstrated that thermal comfort, ventilation, air quality, lighting, and humidity conditions influence occupants' satisfaction with indoor environments [29–33]. Existing thermal comfort theories further suggest that environmental satisfaction depends not only on physical parameters but also on contextual factors, user expectations, and activity characteristics [29,30]. The present study extends these findings by showing that environmental control in music halls involves specific experiential requirements. Unlike offices or residential environments, audiences in music halls usually remain seated for extended periods and have limited opportunities to adjust environmental conditions during performances. Therefore, green environmental control should achieve a balance between energy efficiency and environmental stability while avoiding airflow noise, thermal discomfort, or visual disturbance that may interrupt performance immersion.

Eco-Spatial Integration also contributes positively to Concert Environment Satisfaction, supporting previous research on biophilic design and restorative environments. Studies based on Attention Restoration Theory and Stress Recovery Theory suggest that natural elements, daylight, and ecological interfaces can improve psychological restoration and perceived environmental quality [34,35]. Recent empirical and meta-analytic evidence further indicates that biophilic design can enhance positive emotional responses and user well-being in built environments [36–39]. However, compared with acoustic and environmental control dimensions, the relatively weaker contribution of Eco-Spatial Integration provides additional insight into the application of ecological design in specialized cultural buildings. Unlike healthcare or workplace environments where restoration may represent a primary

objective, music halls are fundamentally performance-oriented spaces. Therefore, ecological spatial strategies may influence satisfaction mainly through transitional experiences, including entrances, foyers, circulation areas, and social spaces, rather than directly determining the core listening experience. This finding extends existing biophilic design research by emphasizing that ecological interventions should be adapted to building-specific functional requirements rather than applied as independent visual features.

The contribution of Low-Carbon Operation Perception further supports previous research emphasizing that sustainable building performance depends not only on physical design but also on operational management during the use stage [40,41]. Janda argued that buildings do not consume energy independently; rather, energy performance emerges from interactions among buildings, users, and operational practices [40]. Recent sustainability research has also demonstrated that perceived environmental responsibility can influence user satisfaction when green practices are integrated into service experiences [44]. Extending these findings, the present study shows that audiences evaluate operational sustainability through visible and experiential signals, including energy-saving management, digital services, waste reduction, and environmental communication. Therefore, low-carbon operation becomes meaningful when sustainability measures are perceived as authentic, convenient, and compatible with the overall concert experience.

Overall, the direct-effect findings indicate that sustainable retrofit in music halls should be understood as an integrated experiential system combining acoustic quality, environmental comfort, spatial experience, and operational responsibility. This study confirms previous research on user-centred building evaluation while extending existing knowledge by identifying the specific perceptual dimensions through which audiences evaluate green retrofit outcomes in performance-oriented public cultural buildings.

### *5.2. Discussion of Mediating Effects*

The mediation results further clarify the mechanism through which green retrofit perception influences Concert Environment Satisfaction. Green Retrofit Acceptance partially mediated the relationships between all four green retrofit perception variables and Concert Environment Satisfaction, indicating that audiences' satisfaction is not shaped only by their direct experience of acoustic materials, environmental control, ecological spatial integration, and low-carbon operation. It is also influenced by whether they accept these retrofit measures as necessary, credible, effective, and compatible with the music hall context. This finding responds to the second objective of this study by demonstrating that green retrofit perception operates through both a direct experiential pathway and an indirect cognitive-evaluative pathway. In this sense, audiences are not passive receivers of green building strategies; they actively interpret whether these strategies are meaningful and appropriate for the performance environment.

The mediation findings reveal that Green Retrofit Acceptance functions as an important cognitive mechanism linking perceived retrofit strategies with Concert Environment Satisfaction. Rather than directly translating environmental improvements into satisfaction, retrofit perceptions influence satisfaction through both immediate experiential evaluation and cognitive judgement regarding whether retrofit measures are necessary, credible, effective, and compatible with the music hall context. This finding extends previous research on sustainable technology acceptance and behavioural intention. Existing studies based on the Theory of Planned Behavior and technology acceptance models have demonstrated that perceived usefulness, compatibility, trust, and perceived value influence users' acceptance of sustainable innovations [14–16]. However, previous acceptance research has mainly focused on individual technologies, household energy systems [63], or consumer products. The present study extends this theoretical perspective by demonstrating that acceptance

mechanisms also operate in architectural retrofit contexts, where users evaluate not only technological benefits but also the appropriateness of interventions within specific spatial and cultural environments.

The mediating role of Green Retrofit Acceptance can also be explained through the Stimulus–Organism–Response (S-O-R) framework [42]. In this framework, environmental stimuli influence behavioural responses through internal cognitive processes. Applied to the present study, perceived retrofit dimensions represent environmental stimuli, Green Retrofit Acceptance represents users' cognitive appraisal, and Concert Environment Satisfaction represents the final experiential response. This mechanism suggests that audiences are not passive recipients of sustainable building strategies. Instead, they actively interpret whether retrofit measures represent meaningful improvements or merely symbolic interventions.

The differences among the indirect pathways may reflect the varying perceptual distance between retrofit interventions and audience experience. Acoustic materials and environmental control systems are directly experienced during performances; therefore, audiences can more easily associate these interventions with comfort, sound quality, and overall satisfaction. By contrast, ecological spatial strategies and operational sustainability practices often influence experience indirectly through atmosphere, service quality, or environmental awareness. This difference does not indicate a lower value of ecological or operational strategies but suggests that their contribution depends more strongly on whether audiences recognize their relevance and integration within the music hall environment.

The partial mediation pattern also provides theoretical implications for sustainable retrofit evaluation. Previous expectation-confirmation research suggests that satisfaction emerges when actual experience confirms users' expectations [45,64]. Similarly, recent studies on green services indicate that sustainability practices enhance satisfaction when users perceive them as valuable and consistent with service experience [44,59]. The present findings extend these perspectives by demonstrating that in public cultural buildings, satisfaction formation involves both experiential confirmation and cognitive acceptance. Therefore, Green Retrofit Acceptance provides an explanatory bridge between environmental perception and user satisfaction, enriching existing post-occupancy evaluation frameworks.

### *5.3. Practical Implications*

The practical value of this study lies primarily in the contextual application of green retrofit strategies to music halls. The results indicate that perceived green retrofit can significantly improve Concert Environment Satisfaction; however, this effect is not produced by "greenness" itself but depends on whether retrofit strategies are translated into perceptible improvements in the audience environment. For music halls, concert halls, and multipurpose performance venues undergoing renovation, retrofit, or operational optimization, green retrofit should not be narrowly understood as the replacement of energy-saving equipment, the use of green materials, or the addition of landscape elements. Rather, it should be organized as an integrated architectural renewal process centred on acoustic quality, indoor environmental stability, spatial experience, and operational order. Its application is conditional on the premise that green retrofit must support the core performance-viewing function of the music hall, without compromising acoustic performance, environmental comfort, or audience convenience.

In terms of specific retrofit priorities, acoustic materials, environmental control, and low-carbon operation should be treated as key components of music hall green renewal. The selection of green acoustic materials should not rely only on low-emission, recyclable, durable, or environmentally responsible attributes; it should also consider their effects on sound clarity, reverberation control, diffusion quality, and auditory comfort. Green Environmental Control should not pursue energy reduction alone but should maintain stable

temperature and humidity, adequate air freshness, comfortable lighting, and low-noise ventilation during performances. Low-Carbon Operation should also be embedded in the full audience service process, including ticketing, entry, performance-viewing, intermission, and departure, rather than remaining at the level of symbolic communication or isolated management measures. For architects, acoustic consultants, building service engineers, and venue operators, the key task is not to improve a single green technical indicator but to translate material, system, and operational strategies into environmental quality that audiences can perceive.

Eco-Spatial Integration and Green Retrofit Acceptance further suggest that music hall green retrofit should address both spatial organization and the legibility of environmental strategies. Ecological design may be most effective in public and transitional areas, such as entrances, foyers, waiting areas, intermission zones, circulation routes, and social spaces. Through natural materials, daylight, green interfaces, and indoor–outdoor visual connections, these spaces can improve audiences' experience during arrival, waiting, social interaction, and departure. The emphasis should not be on increasing the quantity of greenery but on integrating ecological elements into circulation organization, spatial hierarchy, and cultural atmosphere. At the same time, because many green retrofit measures are embedded in acoustic structures, building systems, and backstage operations, audiences may not automatically recognize their value. Music halls can therefore use restrained spatial signage, digital displays, ticketing platforms, or guided interpretation to connect green retrofit with concrete experiential outcomes, such as sound-field optimization, indoor health, energy-saving comfort, and crowd-flow organization. In this way, green retrofit can move beyond technical intervention and become an architectural experience that audiences can understand, perceive, and accept.

The results also suggest that music hall operators and retrofit designers should establish a feedback-oriented evaluation mechanism based on audience perception data. During the planning stage, questionnaire-based post-occupancy data can help identify priority retrofit dimensions, such as acoustic materials, environmental control, low-carbon operation, or ecological spatial improvement. During the implementation stage, audience feedback can be used to examine whether retrofit measures are perceived as comfortable, credible, and compatible with the performance context. During the operation stage, repeated data collection can support continuous optimization by comparing changes in retrofit acceptance and concert environment satisfaction over time. Such a feedback mechanism would allow sustainable retrofit to move from one-time technical intervention toward an iterative, evidence-based process of building performance improvement.

## 6. Conclusions

This study developed and empirically examined a data-driven post-occupancy evaluation framework to investigate how audiences perceive sustainable retrofit in music halls and how these perceptions contribute to Concert Environment Satisfaction. Rather than evaluating the technical performance of specific retrofit technologies or verifying the actual energy-saving, carbon-reduction, or environmental performance of individual renovation measures, this study aimed to identify the key perceptual dimensions through which users interpret and evaluate green retrofit outcomes in performance-oriented cultural buildings.

Based on audience perception data, this study identified four major dimensions of perceived sustainable retrofit: Green Acoustic Material Perception, Green Environmental Control, Eco-Spatial Integration, and Low-Carbon Operation Perception. The findings demonstrate that these four perceptual dimensions collectively contribute to audiences' evaluation of the concert environment, indicating that sustainable retrofit in music halls should be understood as an integrated experiential process involving acoustic quality,

indoor environmental comfort, spatial experience, and operational sustainability. Among these dimensions, acoustic-related perception showed particular importance, reflecting the distinctive role of auditory experience in determining the quality of performance-oriented buildings. Meanwhile, environmental control, ecological spatial integration, and low-carbon operation further contributed to satisfaction by shaping users' perceptions of comfort, environmental responsibility, and venue quality. Furthermore, this study revealed the mediating role of Green Retrofit Acceptance, demonstrating that audiences do not evaluate green retrofit solely through direct sensory experience. Instead, they also form cognitive judgements regarding whether retrofit strategies are necessary, credible, effective, and compatible with the functional and cultural characteristics of music halls. This finding extends existing sustainable retrofit and acceptance research by highlighting a cognitive pathway through which perceived environmental improvements are transformed into overall user evaluation.

The theoretical contribution of this study lies in extending conventional sustainable retrofit assessment from a predominantly technology- and performance-oriented perspective toward a user-centred perception-based framework. By integrating acoustic, environmental, spatial, operational, and cognitive dimensions, the proposed framework provides a more comprehensive understanding of how sustainable transformation is experienced by users in public cultural buildings. The study therefore contributes not by determining the superiority of particular retrofit technologies but by identifying the key perceptual factors that influence whether sustainable retrofit is recognized and valued by building users. From a practical perspective, the findings suggest that successful green retrofit in music halls requires coordination among architectural design, acoustic optimization, environmental control, ecological spatial strategies, and operational management. Retrofit decision-making should consider not only technical objectives but also whether sustainability measures are perceived by audiences as improving the overall performance environment while preserving the fundamental functions of the venue.

Several limitations should be acknowledged. First, the cross-sectional questionnaire design identifies associations among perceived retrofit dimensions, Green Retrofit Acceptance, and Concert Environment Satisfaction but does not establish definitive causal relationships. Second, this study relies primarily on subjective audience evaluations and does not incorporate objective measurements of energy consumption, carbon emissions, acoustic parameters, or indoor environmental performance. Third, the proposed framework was developed based on audiences with music hall experience and requires further validation across different types of performance buildings, retrofit contexts, and cultural regions. Future research could therefore combine subjective perception data with objective environmental monitoring, adopt longitudinal or pre–post-retrofit research designs, and further explore additional psychological mechanisms, such as perceived authenticity, trust, place attachment, and environmental responsibility, that may influence users' evaluation of sustainable retrofit.

**Author Contributions:** Conceptualization, M.L. and H.P.; methodology, M.L. and H.P.; validation, M.L. and H.P.; formal analysis, M.L. and H.P.; investigation, M.L. and H.P.; writing—original draft preparation, M.L. and H.P.; writing—review and editing, M.L. and H.P.; visualization, M.L. and H.P.; supervision, M.L. and H.P.; project administration, M.L. and H.P. All authors have read and agreed to the published version of the manuscript.

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**Institutional Review Board Statement:** The Biomedical Ethics Committee of Anhui University issued a protocol approval report (BECAHU-2026-039), effective 28 September 2026. All participants were aged 18 years or above and participated voluntarily. Prior to completing the questionnaire, participants

were informed of the purpose of the study, the intended use of the collected data, and their right to withdraw from the survey at any time. Informed consent was obtained from all participants before questionnaire completion. No personally identifiable information was collected, and all responses were anonymized and used exclusively for academic research purposes.

**Data Availability Statement:** The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A. Measurement Items

**Table A1.** Questionnaire for music hall audiences.

| Questionnaire for Music Hall Audiences | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Category** | | **Measurement Items** | **1** | **2** | **3** | **4** | **5** |
| Green Acoustic Material Perception | GAMP1 | The acoustic materials used in this music hall appear to be environmentally friendly and low-emission. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | GAMP2 | The acoustic materials in this music hall help create clear, balanced, and comfortable sound. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | GAMP3 | The interior acoustic finishes of this music hall give me a sense of health, safety, and material quality. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | GAMP4 | The green acoustic materials are well integrated with the aesthetic and performance atmosphere of the music hall. | ◎ | ◎ | ◎ | ◎ | ◎ |
| Green Environmental Control | GEC1 | The temperature, humidity, and air quality in this music hall are well controlled during the performance. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | GEC2 | The lighting and ventilation conditions in this music hall are comfortable and do not disturb the performance experience. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | GEC3 | The environmental control system of this music hall provides stable comfort while supporting energy-efficient operation. | ◎ | ◎ | ◎ | ◎ | ◎ |
| Eco-Spatial Integration | ESI1 | Natural elements and green landscapes are well integrated into the spatial environment of this music hall. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | ESI2 | The visual connection between indoor spaces and outdoor/natural environments enhances my spatial experience. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | ESI3 | Daylight, natural materials, or landscape interfaces create a pleasant and restorative atmosphere in this music hall. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | ESI4 | The ecological spatial design is consistent with the cultural and performance character of this music hall. | ◎ | ◎ | ◎ | ◎ | ◎ |

**Table A1.** *Cont.*

| Questionnaire for Music Hall Audiences | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Category** | | **Measurement Items** | **1** | **2** | **3** | **4** | **5** |
| Low-Carbon Operation Perception | LCOP1 | This music hall shows clear efforts in energy-saving operation and facility management. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | LCOP2 | This music hall provides visible low-carbon practices, such as waste sorting, recycling, or resource conservation. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | LCOP3 | Digital services, green guidance, or low-carbon service processes in this music hall are convenient for audiences. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | LCOP4 | The low-carbon operation of this music hall appears professional, transparent, and credible. | ◎ | ◎ | ◎ | ◎ | ◎ |
| Green Retrofit Acceptance | GRA1 | I believe that the green retrofit of this music hall is necessary. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | GRA2 | I believe that the green retrofit of this music hall can effectively improve its environmental quality. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | GRA3 | The green retrofit of this music hall appears authentic rather than superficial. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | GRA4 | The green retrofit is compatible with the acoustic, spatial, and cultural functions of the music hall. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | GRA5 | I am willing to support the green retrofit measures adopted in this music hall. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | GRA6 | Overall, I accept the green retrofit of this music hall. | ◎ | ◎ | ◎ | ◎ | ◎ |
| Concert Environment Satisfaction | CES1 | Overall, I am satisfied with the concert environment of this music hall. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | CES2 | The concert environment of this music hall meets my expectations. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | CES3 | The acoustic, spatial, and environmental conditions support a pleasant performance-viewing experience. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | CES4 | I am satisfied with the comfort and quality of the music hall environment during the performance. | ◎ | ◎ | ◎ | ◎ | ◎ |
| | CES5 | The overall concert environment of this music hall is better than I expected. | ◎ | ◎ | ◎ | ◎ | ◎ |

Select one ◎ per item. Scale (1: strongly disagree, 2: disagree, 3: neither agree nor disagree, 4: agree and 5: strongly agree).

## References


1. Cabeza, L.F.; Bai, Q.; Bertoldi, P.; Kihila, J.M.; Lucena, A.F.P.; Mata, É.; Mirasgedis, S.; Novikova, A.; Saheb, Y. Buildings. In *Climate Change 2022: Mitigation of Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2022; pp. 953–1048. [CrossRef]
2. United Nations Environment Programme. *Global Status Report for Buildings and Construction 2025–2026: As Climate Risks Rise and Cities Grow, We Must Rethink How We Build to Create Better Lives for All*; United Nations Environment Programme: Paris, France, 2026. [CrossRef] [PubMed]
3. Ma, Z.; Cooper, P.; Daly, D.; Ledo, L. Existing building retrofits: Methodology and state-of-the-art. *Energy Build.* **2012**, *55*, 889–902. [CrossRef]
4. Pombo, O.; Rivela, B.; Neila, J. The challenge of sustainable building renovation: Assessment of current criteria and future outlook. *J. Clean. Prod.* **2016**, *123*, 88–100. [CrossRef]
5. López-Escamilla, Á.; Herrera-Limones, R.; León-Rodríguez, Á.L. Evaluation of environmental comfort in a social housing prototype with bioclimatic double-skin in a tropical climate. *Build. Environ.* **2022**, *218*, 109119. [CrossRef]
6. Frontczak, M.; Wargocki, P. Literature survey on how different factors influence human comfort in indoor environments. *Build. Environ.* **2011**, *46*, 922–937. [CrossRef]
7. Altomonte, S.; Schiavon, S. Occupant satisfaction in LEED and non-LEED certified buildings. *Build. Environ.* **2013**, *68*, 66–76. [CrossRef]
8. Khoshbakht, M.; Gou, Z.; Xie, X.; He, B.; Darko, A. Green building occupant satisfaction: Evidence from the Australian higher education sector. *Sustainability* **2018**, *10*, 2890. [CrossRef]
9. Girón, S.; Martel, J.; Galindo, M.; Herrera-Limones, R. Building and environmental acoustics in obsolete residential neighbourhoods: The case of San Pablo, Spain. *Heliyon* **2023**, *9*, e19414. [CrossRef] [PubMed]
10. Clavijo-Núñez, S.; Núñez-Camarena, G.M.; Herrera-Limones, R.; Hernández-Valencia, M.; Millán-Jiménez, A. The importance of citizen participation in improving comfort and health in obsolete neighbourhoods affected by energy poverty. *Energy Policy* **2024**, *191*, 114177. [CrossRef]
11. Beranek, L.L. *Concert Halls and Opera Houses: Music, Acoustics, and Architecture*; Springer: New York, NY, USA, 2004.
12. Barron, M. *Auditorium Acoustics and Architectural Design*, 2nd ed.; Spon Press: London, UK, 2010.
13. *ISO 3382-1:2009*; Acoustics—Measurement of Room Acoustic Parameters—Part 1: Performance Spaces. International Organization for Standardization: Geneva, Switzerland, 2009.
14. Ajzen, I. The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* **1991**, *50*, 179–211. [CrossRef]
15. Davis, F.D. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q.* **1989**, *13*, 319–340. [CrossRef] [PubMed]
16. Huijts, N.M.A.; Molin, E.J.E.; Steg, L. Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. *Renew. Sustain. Energy Rev.* **2012**, *16*, 525–531. [CrossRef]
17. Weerasinghe, L.N.K.; Darko, A.; Chan, A.P.C.; Blay, K.B.; Edwards, D.J. Measures, benefits, and challenges to retrofitting existing buildings to net zero carbon: A comprehensive review. *J. Build. Eng.* **2024**, *94*, 109998. [CrossRef]
18. Colclough, S.; O'Hegarty, R.; Murray, M.; Lennon, D.; Rieux, E.; Colclough, M.; Kinnane, O. Post occupancy evaluation of 12 retrofit nZEB dwellings: The impact of occupants and high in-use interior temperatures on the predictive accuracy of the nZEB energy standard. *Energy Build.* **2022**, *254*, 111563. [CrossRef]
19. Shtrepi, L.; Aletta, F.; Aspöck, L.; Astolfi, A.; Fels, J.; Hornikx, M.; Jambrošić, K.; Jeong, C.-H.; Kahle, E.; Llorca-Bofí, J.; et al. Ten questions concerning architectural acoustics. *Build. Environ.* **2024**, *265*, 112012. [CrossRef]
20. Santika, B.B.; Lee, H.; Jeon, J.Y. Investigation of acoustic attributes based on preference and perceptional acoustics of Korean traditional halls for optimal design solutions. *Build. Simul.* **2024**, *17*, 723–738. [CrossRef]
21. Darko, A.; Chan, A.P.C.; Ameyaw, E.E.; He, B.J.; Olanipekun, A.O. Examining issues influencing green building technologies adoption: The United States green building experts' perspectives. *Energy Build.* **2017**, *144*, 320–332. [CrossRef]
22. Mooses, V.; Pastak, I.; Kamenjuk, P.; Poom, A. Residents' perceptions of a smart technology retrofit towards nearly zero energy performance. *Urban Plan.* **2022**, *7*, 20–32. [CrossRef]
23. Bu, S.; Shen, G.; Anumba, C.J.; Wong, A.K.D.; Liang, X. Literature review of green retrofit design for commercial buildings with BIM implication. *Smart Sustain. Built Environ.* **2015**, *4*, 188–214. [CrossRef]
24. Graham, L.T.; Parkinson, T.; Schiavon, S. Lessons learned from 20 years of CBE's occupant surveys. *Build. Cities* **2021**, *2*, 166–184. [CrossRef]
25. Kuttruff, H. *Room Acoustics*, 6th ed.; CRC Press: Boca Raton, FL, USA, 2017. [CrossRef]
26. Cox, T.J.; D'Antonio, P. *Acoustic Absorbers and Diffusers: Theory, Design and Application*, 3rd ed.; CRC Press: Boca Raton, FL, USA, 2017. [CrossRef]
27. Asdrubali, F.; Schiavoni, S.; Horoshenkov, K.V. A review of sustainable materials for acoustic applications. *Build. Acoust.* **2012**, *19*, 283–311. [CrossRef]

28. Arenas, J.P.; Crocker, M.J. Recent trends in porous sound-absorbing materials. *Sound Vib.* **2010**, *44*, 12–17.
29. Fanger, P.O. *Thermal Comfort: Analysis and Applications in Environmental Engineering*; Danish Technical Press: Copenhagen, Denmark, 1970.
30. de Dear, R.J.; Brager, G.S. Developing an adaptive model of thermal comfort and preference. *ASHRAE Trans.* **1998**, *104*, 145–167.
31. *ANSI/ASHRAE Standard 55-2023*; Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers: Peachtree Corners, GA, USA, 2023.
32. Wargocki, P.; Wyon, D.P.; Sundell, J.; Clausen, G.; Fanger, P.O. The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity. *Indoor Air* **2000**, *10*, 222–236. [CrossRef] [PubMed]
33. Veitch, J.A.; Newsham, G.R. Lighting quality and energy-efficiency effects on task performance, mood, health, satisfaction, and comfort. *J. Illum. Eng. Soc.* **1998**, *27*, 107–129. [CrossRef]
34. Kaplan, S. The restorative benefits of nature: Toward an integrative framework. *J. Environ. Psychol.* **1995**, *15*, 169–182. [CrossRef]
35. Ulrich, R.S.; Simons, R.F.; Losito, B.D.; Fiorito, E.; Miles, M.A.; Zelson, M. Stress recovery during exposure to natural and urban environments. *J. Environ. Psychol.* **1991**, *11*, 201–230. [CrossRef]
36. Gaekwad, J.S.; Sal Moslehian, A.; Roös, P.B.; Walker, A. A meta-analysis of emotional evidence for the biophilia hypothesis and implications for biophilic design. *Front. Psychol.* **2022**, *13*, 750245. [CrossRef] [PubMed]
37. Yao, W.; Chen, F.; Wang, S.; Zhang, X. Impact of exposure to natural and built environments on positive and negative affect: A systematic review and meta-analysis. *Front. Public Health* **2021**, *9*, 758457. [CrossRef] [PubMed]
38. Al Khatib, I.; Samara, F.; Ndiaye, M. A systematic review of the impact of therapeutical biophilic design on health and wellbeing of patients and care providers in healthcare services settings. *Front. Built Environ.* **2024**, *10*, 1467692. [CrossRef]
39. Tekin, B.H.; Izmir Tunahan, G.; Disci, Z.N.; Ozer, H.S. Biophilic design in the built environment: Trends, gaps and future directions. *Buildings* **2025**, *15*, 2516. [CrossRef]
40. Janda, K.B. Buildings don't use energy: People do. *Archit. Sci. Rev.* **2011**, *54*, 15–22. [CrossRef]
41. Gao, Z.; Liu, H.; Xu, X.; Xiahou, X.; Cui, P.; Mao, P. Research progress on carbon emissions of public buildings: A visual analysis and review. *Buildings* **2023**, *13*, 677. [CrossRef]
42. Mehrabian, A.; Russell, J.A. *An Approach to Environmental Psychology*; MIT Press: Cambridge, MA, USA, 1974.
43. Chang, R.; Chanda, R.C.; Vafaei-Zadeh, A.; Hanifah, H.; Gui, A. Assessing green practices on eco-friendly hotel customer loyalty: A partial least squares structural equation modeling and fuzzy-set qualitative comparative analysis hybrid approach. *Sustainability* **2024**, *16*, 3834. [CrossRef]
44. Shih, I.-T.; Silalahi, A.D.K.; Baljir, K.; Jargalsaikhan, S. Exploring the impact of perceived sustainability on customer satisfaction and the mediating role of perceived value. *Cogent Bus. Manag.* **2024**, *11*, 2431647. [CrossRef]
45. Oliver, R.L. A cognitive model of the antecedents and consequences of satisfaction decisions. *J. Mark. Res.* **1980**, *17*, 460–469. [CrossRef]
46. Lazarus, R.S. *Emotion and Adaptation*; Oxford University Press: New York, NY, USA, 1991.
47. Korjakins, A.; Sahmenko, G.; Lapkovskis, V. A short review of recent innovations in acoustic materials and panel design: Emphasizing wood composites for enhanced performance and sustainability. *Appl. Sci.* **2025**, *15*, 4644. [CrossRef]
48. Ye, F.; Wei, H.; Xiao, Y.; Berardi, U.; Quaranta, G.; Demartino, C. Bio-based insulation materials in sustainable constructions: A review of environmental, thermal and acoustic insulation, durability, and mechanical performances. *Renew. Sustain. Energy Rev.* **2025**, *223*, 115872. [CrossRef]
49. Rogers, E.M. *Diffusion of Innovations*, 5th ed.; Free Press: New York, NY, USA, 2003.
50. Wang, S.; Chen, S.; Nah, K. Exploring the mechanisms influencing users' willingness to pay for green real estate projects in Asia based on technology acceptance modeling theory. *Buildings* **2024**, *14*, 349. [CrossRef]
51. Zhang, Z.; Zhang, W.; Zhang, S.; Chen, Y.; Wang, X.; Fujii, Y.; Furuya, N. Person-environment fit theory in built environment: A scoping review. *J. Asian Archit. Build. Eng.* **2025**, *24*, 2447–2463. [CrossRef]
52. Averill, J.R. Personal control over aversive stimuli and its relationship to stress. *Psychol. Bull.* **1973**, *80*, 286–303. [CrossRef]
53. Nagy, Z.; Gunay, H.B.; Miller, C.; Hahn, J.; Ouf, M.M.; Lee, S.; Hobson, B.W.; Abuimara, T.; Bandurski, K.; André, M.; et al. Ten questions concerning occupant-centric control and operations. *Build. Environ.* **2023**, *242*, 110518. [CrossRef]
54. Yuan, Y.; Song, C.; Gao, L.; Zeng, K.; Chen, Y. A review of current research on occupant-centric control for improving comfort and energy efficiency. *Build. Simul.* **2024**, *17*, 1675–1692. [CrossRef]
55. Soleimanijavid, A.; Konstantzos, I.; Liu, X. Challenges and opportunities of occupant-centric building controls in real-world implementation: A critical review. *Energy Build.* **2024**, *308*, 113958. [CrossRef]
56. International Energy Agency (IEA). *Buildings: Energy System*; IEA: Paris, France, 2024.
57. Wagner, A.; O'Brien, L. (Eds.) *Occupant-Centric Building Design and Operation*; IEA EBC Annex 79 Final Report; EBC Executive Committee Support Services Unit: Ghent, Belgium, 2025.

58. Dang-Van, T.; Vo-Thanh, T.; Wang, J.; Nguyen, H.V.; Nguyen, N. Green hotel practices and consumer revisit intention: A mediating model of consumer promotion focus, brand identification, and green consumption value. *J. Vacat. Mark.* **2024**, *30*, 677–693. [CrossRef]
59. Yang, J.; Reza, M.N.H.; Al Mamun, A.; Masud, M.M.; Rahman, M.R.C.A. Predicting guest satisfaction and willingness to pay premium prices for green hotels. *Humanit. Soc. Sci. Commun.* **2024**, *11*, 1487. [CrossRef]
60. Zagreus, L.; Huizenga, C.; Arens, E.; Lehrer, D. Listening to the occupants: A Web-based indoor environmental quality survey. *Indoor Air* **2004**, *14*, 65–74. [CrossRef] [PubMed]
61. Ryan, C.O.; Browning, W.D.; Clancy, J.O.; Andrews, S.L.; Kallianpurkar, N.B. Biophilic design patterns: Emerging nature-based parameters for health and well-being in the built environment. *Int. J. Archit. Res.* **2014**, *8*, 62–76. [CrossRef]
62. Fornell, C.; Larcker, D.F. Evaluating structural equation models with unobservable variables and measurement error. *J. Mark. Res.* **1981**, *18*, 39–50. [CrossRef]
63. Scheller, F.; Morrissey, K.; Neuhoff, K.; Keles, D. Green or greedy: The relationship between perceived benefits and homeowners' intention to adopt residential low-carbon technologies. *Energy Res. Soc. Sci.* **2024**, *108*, 103388. [CrossRef]
64. Bhattacherjee, A. Understanding information systems continuance: An expectation-confirmation model. *MIS Q.* **2001**, *25*, 351–370. [CrossRef]


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