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Article

Application of factor analysis in evaluating the biomechanical and visual quality of rural tourism landscapes—A case study of the adjacent areas of Hunan, Guangxi, Guizhou and Chongqing

Meng Wang[1,2], Weijun Zhao[2,*], Chenyi Wang[2]

[1] Hunan Women's University, Changsha 410000, China
[2] Hunan University of Technology, Zhuzhou 412007, China
*** Corresponding author:** Weijun Zhao, zwj706@163.com

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Abstract: Background: Ecological, cultural, and aesthetic values are considered vital in developing sustainable tourism within the rural tourism landscapes of Hunan, Guangxi, Guizhou, and Chongqing. Inadequacies in conducting biomechanical and visual analysis have led to a failure in creating a safe, comfortable, and aesthetically pleasing rural tourism landscape. The following study conducts an assessment of biomechanical and visual factors that shape the rural tourism landscape, indicating that an interdisciplinary approach is essential in addressing challenges from this perspective. **Objective:** The research will focus on integrating an analytic framework from biomechanical stability to aesthetic perspectives into molecular and cellular biomechanics to guide sustainable landscape design in rural tourism. **Methodology:** A mixed-methods approach combined literature review, expert input, public participation, and structured questionnaires. Factor analysis and reliability tests were conducted on 218 responses to assess key indicators such as terrain stability, vegetation resilience, spatial coherence, and cultural authenticity. This research also points out the possibility of developing methods of landscape evaluation even at the molecular level, considering cell wall composition and microbial community interactions. The results showed three factors that explain 63.26% of the variance: Natural Landscape, Rural Settlement Landscape, and Cultural Landscape. The Natural Landscape factor explained 52.34% of the variance and relates to resistance that vegetation has to resist wind and terrain usabilities, whereas in Rural Settlements, it shows coherence in space. The cultural landscape emphasized heritage conservation and aesthetic variation with the season. New dimensions that can be given for landscapes to enhance their stability and harmony further could be given to molecular biomechanics, vegetation behavior considering environmental stressors and interaction of soil-plant-microorganisms. **Conclusion:** This paper presents a biomechanical and visual framework for analyzing sustainable rural tourism landscapes. Integrating molecular and cellular biomechanics can help develop a deeper understanding of vegetation stability and its interaction with aesthetics, helping policymakers and designers plan and implement safer, functional, and visually appealing landscapes that support sustainable tourism and ecological preservation.

Keywords: biomechanical quality; visual quality evaluation of rural tourism landscape; sustainable landscape design; factor analysis

1. Introduction

The Rural Revitalization Strategy opens up a new chapter for rural tourism development. For example, the Opinions of the CPC Central Committee and The State Council (2018) have stressed that rural tourism is an important method for revitalizing rural areas. As a branch of rural tourism, mountain tourism holds particular significance because of its ecological and cultural appeal. According to the Report of World Mountain Tourism Development Trend 2019, compared with 2018, the number of domestic mountain tourists continued to grow, reaching 1.22 billion globally. Therefore, mountain tourism has become an important tourism branch, rooted in abundant natural resources, special geographic landscapes, and active cultural traditions, seeing Lin et al. [1]. Since the pandemic, post-pandemic tourism has boosted public demand for healthy and nature-based tourism. Due to this, middle- and short-distance countryside travel is becoming the hot travel style nowadays. However, unclear thematic positioning, a lack of theoretical guidance, and incomplete biomechanical and visual evaluations often hinder the sustainable development of rural tourism landscapes.

In essence, the landscape of rural tourism should be evaluated based on biomechanical and visual factors, especially for the regions of Hunan, Guangxi, Guizhou, and Chongqing, as cultural and ecological diversity comes with complicated terrain, seeing **Figure 1**. Biomechanics, in this regard, refers to land stability, vegetation elasticity, and transportation conditions, while visual quality focuses on coherence, cultural incorporation, and aesthetic beauty. Most traditional evaluation models separate these two sections and do not consider their interactions. In addition, most research on this topic is conducted within more developed international regions, paying little attention to the specific rural conditions of China, referring to Zhang and Liu [2].

The research, therefore, attempts to fill these lacunas by analyzing the biomechanical and visual quality of the rural tourism landscapes with an integrated framework. Factor analysis identifies key determinants of landscape quality, and the findings contribute to sustainable design principles. Future research is also directed toward incorporating molecular and cellular biomechanics. For example, the mechanical strength of vegetation at the cellular level is influenced by cell wall composition, and environmental stress responses strongly influence biomechanical stability and visual coherence. Linking molecular-level processes to macro-level outcomes, this study will provide a comprehensive framework for sustainable and aesthetically engaging rural tourism landscapes that bridge biomechanical, ecological, and visual domains.

2. Literature review

This kind of assessment of the rural tourism landscape has evolved extensively with time, informed by rapid advances in methodologies, indicators, and theoretical frameworks. The literature review incorporates a discussion of the major international and domestic studies, and it identifies and addresses the gaps and opportunities in biomechanical and visual quality assessment, particularly at the molecular and cellular levels.

2.1. International landscape assessment research

Since the early studies on landscape evaluation in the 1960s for forest and nature reserve planning, methodologies have evolved. Four major schools of thought influence the various approaches toward landscape evaluation: Expert-based, psychophysical, cognitive, and experiential. The earliest applications are expert-based and use professional judgment to evaluate visual and ecological qualities. Psychophysical methods obtain quantitative data from the general public, which relates preferences to certain characteristics within the landscape. Cognitive approaches tend to emphasize the mental processing of what is seen, while the experiential models merge personal and cultural experiences.

Quantitative methodologies only came to the fore in the 1970s when various mathematical models were advanced for visual landscape analysis. For example, PCA and cluster analysis have been widely adopted to investigate relationships between landscape features and human perception. In Europe and North America, several multi-parameter approaches have been developed further by research, such as that conducted in the U.S.

Bureau of Land Management's Visual Resource Management system and the UK's Landscape Character Assessment framework. These models assess biomechanical and visual quality through slope, vegetation density, and colour contrast. Such frameworks underpin the interdependence of biomechanical stability, visual coherence, and visitor comfort, seeing Hafezi et al. [3]. Despite their success in developed regions, these models are poorly applicable to rural and less developed areas. Their focus is mostly macroscopic, whereby the molecular and cellular biomechanical factors that underpin vegetation stability and aesthetic balance have been largely overlooked. For instance, how vegetation cell walls microscopically respond to environmental stressors such as wind and rain and its implications for landscape design remain vaguely studied. Future studies aim to integrate molecular-level information to bridge these knowledge gaps.

2.2. Domestic landscape evaluation research

In China, the Methodology of landscape evaluation in the early stages focused on several qualitative methods emphasizing ecological aesthetics of natural scenery. Quantitative evaluations were introduced in the late 1980s, drawing methodologies from various types of research conducted in the European and American systems but modified to comply with rural China's geographical context and cultural understanding, seeing Li et al. [4]. Beginning domestic studies highlight the ecological and cultural understanding of landscapes to date. For example, Qi et al. [5] explored how Visual heterogeneity impacted the satisfaction in agricultural landscapes by visitors through mapping, using GIS and Remote Sensing analysis of vegetation types, water bodies, and a settlement layout within the studied range.

Most studies in China depend on expert-based evaluation methods, where the general public has limited participation in such assessments. Few photo-based assessment techniques introduced internationally, such as eye-tracking techniques, have been applied in China, referring to Fang et al. [6]. Recent research, such as Dupont et al. [7], has begun to fill this gap by integrating global best practices with expert evaluations relevant to the local context. For example, Yao et al. [8] have applied public preference surveys and eye-tracking heat maps to evaluate the visual quality of rural landscapes in Southwestern Guizhou.

However, these studies have not yet integrated molecular biology tools or investigated biomechanical stability at the cellular level, such as the vegetation structure composition and its ability to resist environmental stressors.

2.3. Integration of biomechanical and visual quality

Biomechanical and visual qualities are inextricably interrelated, yet most research has approached them as distinct areas of inquiry. Biomechanical is described by topography gradient, vegetation resilience, and soil stability, which directly influences the visual coherence of landscapes and the safety of visitors. Contemporary findings have promoted the integration of the abovementioned dimensions. Zhang et al. found that rugged terrain with steep slopes creates less preference because of a perceived threat to safety, while an orderly path improves physical and visual comfort.

The critical elements of vegetation stability are microscopic biomechanical mechanisms, including plant cell walls' composition and mechanical strength. Cellulose, hemicellulose, and lignin provide rigidity to the cell wall, which decides the ability of plants to resist environmental stresses such as wind and rainfall, seeing Chen et al. [9]. Recent developments in molecular biology, including gene sequencing and editing, allow the identification of wind-resistant plant species to be applied for vegetation optimization with both biomechanical and visual coherence of landscapes seeing Reilly [10].

However, these insights have yet to find widespread application in rural tourism landscape research, seeing Du et al. [11]. The role of microbial communities in soil stability and vegetation health has not been widely discussed. Soil microorganisms can affect the physical and chemical properties of the soil, thus influencing vegetation growth and ecological function, seeing Ma et al. [12]. Understanding these microbial interactions at a molecular level could provide important insights into biomechanical and ecological stability and contribute to the overall quality of rural tourism landscapes.

2.4. Gaps and opportunities

Despite the remarkable progress made, a few key points are left as gaps in the literature. Most international models are developed with a strong bias toward the developed regions with a lack of considering rural China's cultural and ecological contexts. Domestic studies often lack effective public participation in biomechanical and visual quality interaction. Besides, the existing Methodology has focused more on macroscopic assessment and lacked molecular and cellular biomechanics considerations, seeing Westerbeek and Eime [13]. This implies that developing research to bridge these gaps needs to be truly interdisciplinary, combining molecular biology, biophysics, ecology, and landscape design, seeing Ďuriš et al. [14]. For example, gene editing could be contemplated for changes in the makeup of plant cell walls, improving its mechanical strength and resilience to environmental stress. Such changes would be tested through cell mechanics testing and linked to eye-tracking or public preference surveys to study the implications of affecting aesthetic and functional landscape performance [15].

2.5. Proposed framework for molecular-level biomechanical analysis

Drawing from the identified gaps, the current study proposes an integrated framework for conducting rural tourism landscape evaluation using biomechanics integration at molecular and cellular levels. This will include the following; Vegetation Cell Structure Analysis: In mechanical property studies on the composition of plant cell walls, attention is directed at cellulose, hemicellulose, and lignin composition. Assess how these properties influence vegetation stability and resistance to environmental stressors.

Microbial community dynamics: Evaluate the role of the soil microorganism in biomechanical and ecological stability. Understand how shifts in microbial communitie impact vegetation growth and soil cohesion, with implications for landscape stability and aesthetic quality. Interdisciplinary Research Methods: Molecular biology tools like gene sequencing and genetic markers are combined with biophysical techniques, such as stress testing, cell mechanics, and ecological surveys. Apply GIS and remote sensing tools to molecular-level findings and their linkage with macroscopic landscape characteristics.

Integration with visual quality assessment: Include plant physiological processes such as nutrient transport and pigmentation in visual quality assessment. Assess the influence of microscopic biomechanical properties on aesthetic attributes, including leaf morphology, texture, and color. Policy and design implications: Develop guidelines for choosing wind-resistant vegetation and optimizing terrain stability in biomechanically and visually integrated landscapes. Promote sustainable rural tourism based on integrated biomechanical and visual quality assessments.

Figure 1. Map of the adjacent areas of Hunan, Guangxi, Guizhou and Chongqing.

3. Overview of the region

This western part of China involves Hunan, Guangxi, Guizhou, and Chongqing, a complicated landform with abundant cultural diversity characterizes it. The whole area is entirely of gentle or steep slopes, enjoys high biodiversity, and owns unique ethnic traditions, providing a perfect place for rural tourism development [16]. The Miao, Dong, and Tujia ethnic groups in this area add unique architectural features, folk arts, and agricultural production to the cultural heritage. It is a place of outstanding natural beauty, but because of the inconsistent landscape management and biomechanical safety, it has never reached its full potential in tourism. Added values, including molecular and cellular biomechanics, may investigate such landscapes. For instance, assessing vegetation cell wall composition should provide insight into local flora responses to environmental stresses by assessing lignin and cellulose use. Biomechanical stability and aesthetic harmony may be enhanced when vegetation responds to the forces of environmental stresses. Thus, soil microbial dynamics may point to their involvement with vegetation health and functional features of landscapes, ensuring appropriate tourism development and balancing the ecology, safety, and visual quality of these attractive areas.

4. Determination of visual quality evaluation index of mountain and rural tourism landscape

The flowchart of this section is as follows (in **Figure 2**):

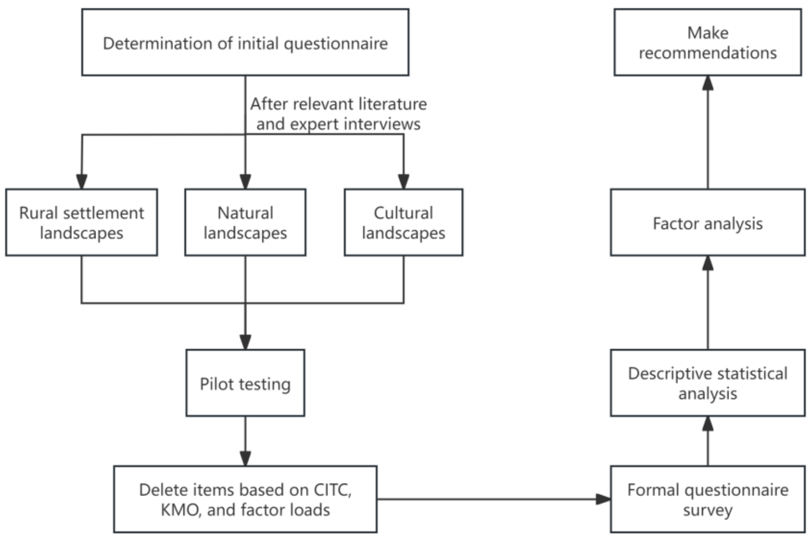

Figure 2. Flow chart of the fourth chapter.

4.1. Determination of initial questionnaire

Determining the initial questionnaire was a very well-structured process with a multidisciplinary approach, including a systematic review of relevant literature, consultation with experts in landscape architecture, biomechanics, molecular biology, and tourism planning, and rigorous pilot testing, referring to Sorra et al. [17]. Each step has been undertaken to ensure comprehensiveness and scientific robustness to determine the critical factors influencing biomechanical and visual quality in rural tourism landscapes. This revised version incorporates deeper molecular and cellular biomechanics elements, aligning the study with the journal's focus while retaining the strengths of the original framework.

4.2. Literature review and theoretical basis

The initial structure of the questionnaire drew strongly from a literature review on landscape evaluation methods, and in this paper, particular attention was paid to biomechanical and visual quality. Quantitative assessment of visual quality received frameworks from international studies, while domestic studies emphasized cultural and ecological dimensions. However, all these existing methodologies have largely neglected molecular and cellular mechanisms that influence vegetation stability, affecting landscapes' aesthetics and functionality.

In this respect, there is a need to complete the literature gap by complementing the traditional approach with insights coming from molecular biology and biophysics. By way of illustration, biomechanical cell wall composition investigates cellulose, hemicellulose, and lignin roles in vegetation stability under environmental stressors. Integration into the review was also used to show the contribution of these molecular structures to macroscopic biomechanical stability represented by slope resistance and visual harmony.

4.3. Expert consultation

Expert consultations were undertaken by a multidisciplinary panel of landscape architects, biophysicists, ecologists, and molecular biologists. The panel strongly recommended that future studies be conducted to understand better how microscopic biomechanical properties translate to macroscopic landscape quality. They especially suggested the inclusion of items on.

Cell structure of vegetation questions on the role of cell wall stiffness in resisting environmental factors like wind and rain.

Molecular biology tools: The potential use of gene editing and sequencing in identifying wind-resistant plant species and their visual impacts.

Microbial ecology: Soil microbial communities and their role in Vegetation biomechanical properties and landscape aesthetics.

These were integrated into three main dimensions: Natural Landscape, rural settlement landscape, and cultural landscape. Then, specific items were added to capture the biomechanical aspects of the various factors under each dimension, both at the molecular and cellular levels. For example, the category 'Natural Landscape' included some items about Vegetation's mechanical properties and visible features; also, 'cultural landscape' was checked against plant physiological aspects affecting the given cultural aesthetic pattern.

4.4. Item development and scaling

This questionnaire was developed with a total of 40 items that aimed to evaluate either biomechanical or visual quality. Questions were divided into three cores.

Natural Landscapes: Terrain stability and comfort, for example: "Vegetation with high cell wall rigidity should affect the stability of the terrain".

Vegetation resilience under stress vegetation with robust cell wall composition enhances biomechanical stability and visual harmony.

Water quality and recognizability of natural features.

Landscapes of rural settlements:

Structural coherence, for instance, would be: "The structure of settlements incorporates Vegetation with high mechanical properties".

Accessibility and functionality.

Integrations with surroundings' landscape.

Cultural Landscapes: Cultural authenticity and historical preservation.

Visual harmony is influenced by the plants' physiological traits, such as leaf morphology and pigmentation, that contribute to cultural aesthetics.

Items were on a 5-point Likert scale, ranging from 1 = Strongly Disagree to 5 = Strongly Agree, to capture subtle variations in the respondents' perceptions. The scale had positive and negative items to ensure a balanced biomechanical and visual quality evaluation.

4.5. Pilot testing

The total sample was 30 participants for a pilot test comprising landscape designers, biophysicists, and molecular biologists to ascertain that the items are clear, relevant, and reliable. In the process, the participants had to provide an opinion about whether or not the questions covered all aspects, whether there was completeness regarding molecular and cellular biomechanics issues, and whether it reflected problems arising from the fields in question.

Reliabilities for the internal consistency of all subscales were above 0.7, indicating a very reliable test. Corrected item-total correlation analyses highlighted the items that provided the least value for overall scale reliability. Items below 0.3 CITC were rewritten or deleted. For example, plant pigmentation questions were rewritten to link cellular processes to an aesthetic focus explicitly.

4.6. Expert validation and content validity

Therefore, the content validity of the revised questionnaire was scrutinized by a panel of five subject-matter experts who reviewed the representativeness of the items regarding theoretical constructs and whether the molecular and cellular dimensions of biomechanics were being represented. This yielded a few changes in item phrasing after some suggestions were provided on clarity and relevance.

For example, the following item was transformed from "Vegetation resilience increases landscape stability to Vegetation with strong cell wall rigidity enhances biomechanical stability and aesthetic balance".

4.7. Final structure of questionnaire

After expert validation and pilot testing, the final questionnaire included 28 items across the three dimensions. Natural Sceneries (12 items) w.

Focused on land stability, vegetation resistance, and water features identifiability.

Rural settlement landscapes (9 items): Treated structural coherence, accessibility, and integration with Natural Landscapes.

Cultural landscapes (7 entries): It emphasized cultural authenticity and historic preservation while seeking visual harmony.

4.8. Data collection and distribution

It has been distributed to more than ten influential universities in China and targeted faculty and students specializing in landscape design, molecular biology, and tourism planning. This way, the number of valid questionnaires distributed in this research totals 400 copies, with a return rate of 54.5% (218 copies). Experts were selected in various fields in order to give multidisciplinary consideration.

Data quality assurance: The results were valid and reliable, as confirmed by statistical tests:

Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy: 0.95—very good to proceed with factor analysis.

Bartlett's test of sphericity: Significant at $p < 0.001$, thus confirming that the correlations among the variables were adequate for factor analysis.

Cronbach's alpha: All dimensions were above 0.8, showing good internal consistency. In the end, the initial development of questionnaires drew on interdisciplinary knowledge and combined knowledge in a strong molecular and cellular biomechanics framework toward the evaluation of rural tourism landscapes. This structured approach ensures that the questionnaire captures the complexity of biomechanical and visual quality, providing a solid foundation for subsequent analyses.

4.9. Formal questionnaire survey

Questionnaires were used to evaluate the evaluation indicators of the visual quality of mountainous rural tourism landscapes to obtain a representative sample. More than ten uniquely influential Chinese universities' design colleges have been given questionnaires targeting landscape design and tourism planning experts, referring to Yao and Sun [18]. This approach was followed to ensure that academics and professionals with vast knowledge of rural tourism landscapes represent various opinions, comprehensively evaluating the indicators. Questionnaires were distributed for three months, and follow-ups were conducted for high response rates. Four 400 questionnaires were distributed, of which 218 valid responses were retrieved, giving a response rate of 54.5%. These questionnaires have been designed to include biomechanical and visual factors such as terrain stability, vegetation resilience, and culture authenticity. This preceded a substantial data set to be used in conducting factor analysis and reliability tests.

5. Analysis of questionnaire survey results

5.1. Descriptive statistics

Based on the descriptive statistical analysis (as shown in **Table 1** and **Figure 3**), the mean values of respondents' agreement with each indicator ranged from 3.18 to 3.85. This indicates that the respondents generally acknowledge the evaluation indicators for the visual quality of mountainous rural tourism landscapes. Furthermore, the standard deviation is low, indicating a concentrated distribution of the data.

Table 1. Results of descriptive statistics.

Rural Settlement Landscapes			**Natural Landscapes**			**Cultural Landscapes**		
Items	**Mean**	**Std Dev**	**Items**	**Mean**	**Std Dev**	**Items**	**Mean**	**Std Dev**
JL01	3.68	0.97	ZR01	3.33	1.07	RW01	3.76	1.09
JL02	3.67	0.98	ZR02	3.51	1.02	RW02	3.63	1.08
JL03	3.28	1.18	ZR03	3.53	1.03	RW 03	3.51	1.10
JL04	3.67	1.06	ZR04	3.49	1.14	RW 04	3.56	1.09
JL05	3.65	0.99	ZR05	3.52	1.04	RW 05	3.66	1.00
JL06	3.34	1.11	ZR06	3.34	1.19	RW 06	3.70	1.02
JL07	3.58	1.06	ZR07	3.40	1.12	RW 07	3.43	1.16
JL08	3.18	1.26	ZR08	3.51	1.05	RW 08	3.76	0.97
JL09	3.58	1.01	ZR09	3.50	1.06	RW 09	3.85	0.93
			ZR10	3.65	1.05	RW 10	3.67	0.97
			ZR11	3.58	1.13	RW 11	3.51	1.04
			ZR12	3.61	1.06	RW 12	3.67	0.93
			ZR13	3.64	1.09	RW 13	3.59	1.00
			ZR14	3.58	1.11	RW 14	3.52	1.05
						RW 15	3.69	0.96

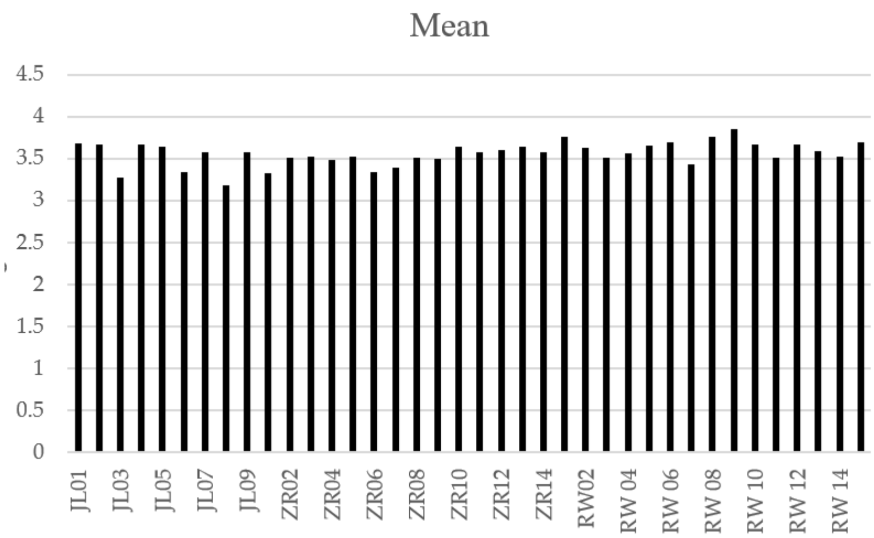

Figure 3. Descriptive statistics.

5.2. Factor analysis results

Sometimes it is possible to define reliability (and hence also validity) in terms of internal consistency. A higher reliability coefficient indicates greater consistency.

In assessing the internal consistency of the measurement items for each research variable, Cronbach's α coefficient analysis can be conducted. In basic research, a Cronbach's α value > 0.7 is considered a high reliability, < 0.35 is considered a low reliability, 0.5 is the minimum acceptable level of reliability.

Firstly, a reliability analysis is conducted on the measurement items of each latent variable, and items with low reliability are deleted. The following methods can be used: (1) The corrected-item total correlation (CITC) is used.

$$\text{CITC} = \rho(X, Sum) = \rho(X, Y + Z + \cdots).$$

The item can be deleted if the CITC value is less than 0.3 and deleting it will increase the Cronbach's α coefficient. The reliability among the measurement items are assessed by Cronbach's α coefficient and the Cronbach's α value should exceed 0.5.

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K} S_i^2}{S_x^2}\right).$$

S_x^2 is the variance of the total sample, is variance of the current observation sample, and is the number of questions in the questionnaire. sample.

Secondly, we examine the suitability of variables for factor analysis. Correlation among variables is measured by suitability checks. In this study, Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and Bartlett's Test of Sphericity are used to determine whether factor analysis is suitable. The KMO statistic is used to compare the simple correlations and partial correlations between variables, and it is calculated as follows:

$$\text{KMO} = \frac{\sum\sum_{i\neq j} r_{ij}^2}{\sum\sum_{i\neq j} r_{ij}^2 + \sum\sum_{i\neq j} p_{ij}^2}.$$

where r_{ij} is the simple correlation coefficient between variable i and variable j, and p_{ij} is the partial correlation coefficient between variable i and variable k. The KMO value ranges from 0 to 1, with values closer to 1 indicating that the sum of the squared simple correlations among all variables is greater than the sum of the squared partial correlations, indicating greater suitability for factor analysis. Conversely, smaller values indicate poorer suitability for factor analysis. Kaiser provides the following KMO value standards: 0.9 < KMO, very suitable; 0.8 < KMO < 0.9, suitable; 0.7 < KMO < 0.8, fair; 0.6 < KMO < 0.7, not very suitable; KMO < 0.5, unsuitable.

Bartlett's Test of Sphericity is based on the correlation coefficient matrix of variables, with the null hypothesis that the correlation matrix is an identity matrix [19]. The test examines the null hypothesis by calculating the Bartlett's Test of Sphericity statistic and its associated probability. If the probability associated with the statistic is less than the significance level, the null hypothesis is rejected, indicating the presence of correlations among the original variables and suitability for factor analysis; otherwise, it is not suitable for factor analysis.

Finally, factor analysis is performed on the variables that meet the requirements. In factor analysis, this study uses Principal Component Analysis (PCA) to extract factors and uses varimax rotation, also known as orthogonal rotation, to minimize the number of variables with high factor loadings on each factor, thereby enhancing the interpretability of the factors [20].

The method of finding common factors by principal component analysis is as follows:

Suppose that the principal component is solved from the correlation matrix, and p variables are set, then p principal components can be found. The obtained p principal components are arranged in the order from large to small, and are counted as $Y_1, Y_2, \cdots, Y_p$, then there is a relationship between the principal components and the original variables as follows:

$$\begin{cases} Y_1 = \gamma_{11}X_1 + \gamma_{12}X_2 + \cdots + \gamma_{1p}X_p \\ Y_2 = \gamma_{21}X_1 + \gamma_{22}X_2 + \cdots + \gamma_{2p}X_p \\ \quad \vdots \\ Y_p = \gamma_{p1}X_1 + \gamma_{p2}X_2 + \cdots + \gamma_{pp}X_p \end{cases}.$$

In the above formula, γ_{ij} is the component of the eigenvector corresponding to the eigenvalue of the correlation matrix of the random vector X. Because the eigenvectors are orthogonal to each other, the transformation relationship from X to Y is reversible, so it is easy to obtain the transformation relationship from X to Y:

$$\begin{cases} X_1 = \gamma_{11}Y_1 + \gamma_{21}Y_2 + \cdots + \gamma_{p1}Y_p \\ X_2 = \gamma_{12}Y_1 + \gamma_{22}Y_2 + \cdots + \gamma_{p2}Y_p \\ \quad \vdots \\ X_p = \gamma_{1p}Y_1 + \gamma_{2p}Y_2 + \cdots + \gamma_{pp}Y_p \end{cases}.$$

For each of the above equations, we only need to retain the first m principal components and replace the latter part with ε_i, then the above equation is transformed into:

$$\begin{cases} X_1 = \gamma_{11}Y_1 + \gamma_{21}Y_2 + \cdots + \gamma_{m1}Y_m + \varepsilon_1 \\ X_2 = \gamma_{12}Y_1 + \gamma_{22}Y_2 + \cdots + \gamma_{m2}Y_m + \varepsilon_2 \\ \quad \vdots \\ X_p = \gamma_{1p}Y_1 + \gamma_{2p}Y_2 + \cdots + \gamma_{mp}Y_m + \varepsilon_p \end{cases}.$$

The standard deviation of Y is the square root of the characteristic root is $\sqrt{\lambda_i}$. Then, let $F_i = Y_i / \sqrt{\lambda_i}$, $a_{ij} = \sqrt{\lambda_i}\gamma_{ji}$, then the above equation becomes:

$$\begin{cases} X_1 = a_{11}F_1 + a_{12}F_2 + \cdots + a_{1m}F_m + \varepsilon_1 \\ X_2 = a_{21}F_1 + a_{22}F_2 + \cdots + a_{2m}F_m + \varepsilon_2 \\ \quad \vdots \\ X_p = a_{p1}F_1 + a_{p2}F_2 + \cdots + a_{pm}F_m + \varepsilon_p \end{cases}.$$

This leads to the load matrix A and a set of initial common factors (not rotated). In general, let $\lambda_1, \lambda_2, \cdots, \lambda_p$ be the eigenvalues of the sample correlation matrix R, and $\gamma_1, \gamma_2, \cdots, \gamma_p$ be the corresponding standard orthogonalized eigenvectors. Suppose $m < p$, then a solution of the factor loading matrix A is:

$$\hat{A} = \left(\sqrt{\lambda_1}\gamma_1, \sqrt{\lambda_2}\gamma_2, , \sqrt{\lambda_m}\gamma_m\right).$$

And the statistical significance of the factor loading is

$$cov(X_i, F_j) = cov\left(\sum_{j=1}^{m} a_{ij}F_j + \varepsilon_i, F_j\right)$$
$$= cov\left(\sum_{j=1}^{m} a_{ij}F_j, F_j\right) + cov(\varepsilon_i, F_j) = a_{ij}.$$

That is, a_{ij} is the covariance of X_i and F_j, and also the correlation coefficient of X_i and F_j.

Denote $g_j^2 = a_{1j}^2 + a_{2j}^2 + \cdots + a_{pj}^2 (j = 1, 2, \cdots, m)$, then g_j^2 is called the variance contribution of the common factor F_j to the original variable vector X, which is an index to measure the relative importance of the common factor. The larger the g_j^2 is, the greater the influence and effect of the common factor F_j on X is.

When selecting common factors, apart from selecting the top k factors based on the cumulative variance contribution rate, attention should also be paid to the size of the corresponding eigenvalues. Eigenvalues can be seen as an indicator of the extent to which the principal component explains the information of the original variables. Generally, eigenvalues greater than 1 are required. Then, the common factors are named and their meanings are explained before further analysis. The usual practice for factor interpretation is to rank the variables based on their factor loadings on the same factor, and variables with loadings below 0.5 can be removed from that factor.

This study utilized principal component analysis for factor analysis on evaluation indicators, aiming to identify the key factors that influence the visual quality of mountainous rural tourism landscapes. Following the criteria mentioned earlier, the CITC values and Cronbach's α values were used for reliability analysis of each indicator. Additionally, the suitability of factor analysis was assessed using the KMO test and Bartlett's sphericity test, and based on this, factor analysis was performed on the eligible latent variables. Lastly, principal component analysis was performed to extract factors with factor loadings exceeding 0.5 and eigenvalues surpassing 1. Subsequently, appropriate names were assigned to these factors. The results of exploratory factor analysis are presented below.

As shown in **Table 2**, all CITC coefficients for the questionnaire items exceeded 0.3, and removing any item did not increase the Cronbach's α coefficient. Therefore, all items for further exploratory factor analysis, these were retained. Factor analysis suitability tests indicate KMO value of 0.952 and Bartlett's sphericity test value of 3421.530 (p < 0.000), the overall suitability of the scale for factor analysis. Items that loaded on all factors with loadings of less than 0.5 or loaded on more than two factors with loadings of greater than 0.5 were eliminated during the factor analysis process. Finally, 6 items were finally selected for rural settlement landscape evaluation indicators, 12 items for Natural Landscape evaluation indicators and 5 items for cultural landscape evaluation indicators.

Figure 4 shows that the first factor's eigenvalue is much higher than that of the other factors, so the interpretation of the original item is contributed by it; after the third factor, the eigenvalue of the factor is small and can be neglected. Therefore, it is better extracted three factors.

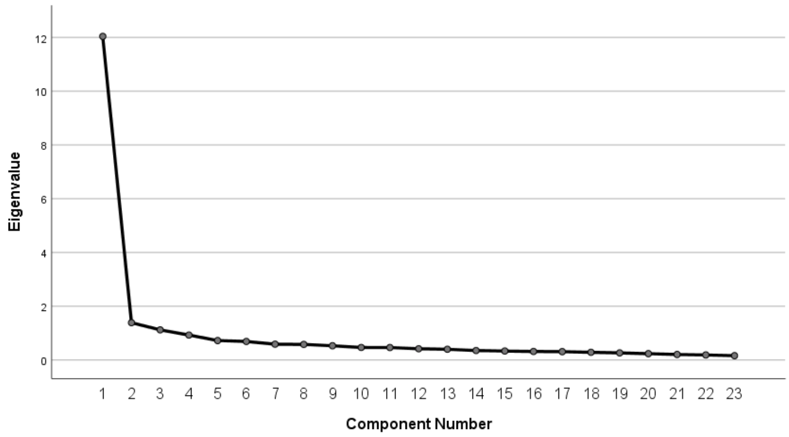

Figure 4. Scree plot.

The outcomes of the factor analysis are summarized in **Table 2**, the factor score matrix as shown in **Table 3**, and the factor loading diagram of the rotating space is shown in **Figure 5**.

Table 2. Factor analysis results.

Items	**Factors**			**Cronbach's α**	**Cumulative Variance Explained (Eigenvalues)**
	1	**2**	**3**		
B04	0.808			0.939	52.341% (12.039)
B06	0.737				
B01	0.699				
B08	0.667				
B09	0.658				
B03	0.654				
B13	0.638				
B11	0.636				
B14	0.624				
B02	0.621				
B12	0.610				
B07	0.609				
A01		0.781		0.872	58.380% (1.339)
A02		0.753			
A03		0.689			
A04		0.657			
A06		0.636			
A05		0.555			

Table 2. (*Continued*).

Items	**Factors**			**Cronbach's α**	**Cumulative Variance Explained (Eigenvalues)**
	1	**2**	**3**		
C14			0.817		
C15			0.765		
C13			0.684	0.878	63.257% (1.122)
C10			0.531		
C06			0.504		
Factor Name	Natural Landscape	Rural Settlement Landscape	Cultural Landscape	0.956	

KMO = 0.954; Bartlett's sphericity test value = 3421.530 ($p < 0.000$).

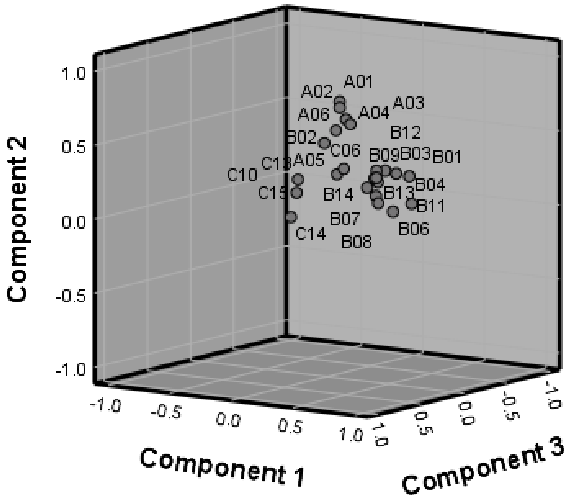

Figure 5. Factor load diagram of rotating space.

Table 3. Factor score matrix.

	Factor1	**Factor2**	**Factor3**
A01	−0.118	0.371	−0.134
A02	−0.110	0.336	−0.100
A03	−0.072	0.274	−0.079
A04	−0.050	0.251	−0.086
A05	−0.113	0.160	0.104
A06	−0.091	0.211	0.025
B04	0.271	−0.119	−0.129
B01	0.225	0.020	−0.225
B06	0.219	−0.153	−0.021
B03	0.176	0.025	−0.157
B08	0.156	−0.120	0.034
B09	0.134	0.017	−0.074
B11	0.138	−0.086	0.021
B13	0.113	−0.017	−0.007
B14	0.108	−0.017	−0.002

Table 3. (*Continued*).

	Factor1	Factor2	Factor3
B02	0.125	−0.025	−0.025
B12	0.104	0.020	−0.037
B07	0.096	−0.059	0.059
C14	−0.122	−0.173	0.471
C15	−0.138	−0.075	0.398
C13	−0.151	−0.008	0.338
C10	−0.026	0.000	0.168
C06	−0.010	0.019	0.131

As shown in **Table 2**, a total of 23 items were retained in the visual quality evaluation scale for rural tourism landscapes, and 3 factors were extracted and named as follows: Natural Landscape, Rural Settlement Landscape, and Cultural Landscape. All factor loadings ranged from 0.504 to 0.808, with eigenvalues of 12.039, 1.339, and 1.122, respectively. The cumulative variance explained reached 63.257%, with the first factor (Natural Landscape) contributing 52.341% of the variance, the second factor contributing 6.039%, and the third factor contributing 4.877%. These results indicate that among the three extracted common factors, Natural Landscape is relatively the most important, followed by Rural Settlement Landscape and then Cultural Landscape. The Cronbach's α coefficients and overall Cronbach's α coefficient were 0.939, 0.872, 0.878, and 0.956, respectively, indicating good reliability for measuring the visual quality of mountainous rural tourism landscapes.

From **Table 3**, the score expression of the common factor of Factor1, Factor2, Factor3 can be obtained as

$$\begin{aligned}
Factor1 = {} & -0.118A01 - 0.110A02 - 0.072A03 - 0.050A04 - 0.113A05 - 0.091A06 \\
& + 0.271B04 + 0.225B01 + 0.219B06 + 0.176B03 + 0.156B08 + 0.134B09 \\
& + 0.138B11 + 0.113B13 + 0.108B14 + 0.125B02 + 0.104B12 + 0.096B07 \\
& - 0.122C14 - 0.138C15 - 0.151C13 - 0.026C10 - 0.010C06, \\
Factor2 = {} & 0.371A01 + 0.336A02 + 0.274A03 + 0.251A04 + 0.160A05 + 0.211A06 \\
& - 0.119B04 + 0.020B01 - 0.153B06 + 0.025B03 - 0.120B08 + 0.017B09 \\
& - 0.086B11 - 0.017B13 - 0.017B14 - 0.025B02 + 0.020B12 - 0.059B07 \\
& - 0.173C14 - 0.074C15 - 0.008C13 + 0.000C10 + 0.019C06, \\
Factor3 = {} & -0.134A01 - 0.100A02 - 0.079A03 - 0.086A04 + 0.104A05 + 0.025A06 \\
& - 0.129B04 - 0.225B01 - 0.021B06 - 0.157B03 + 0.034B08 - 0.074B09 \\
& + 0.021B11 - 0.007B13 - 0.002B14 - 0.025B02 - 0.037B12 + 0.059B07 \\
& + 0.471C14 + 0.398C15 + 0.338C13 + 0.168C10 + 0.131C06.
\end{aligned}$$

6. Discussion

This research has presented factor analysis based on the biomechanical and visual quality of rural tourism landscapes in adjacent areas of Hunan, Guangxi, Guizhou, and Chongqing, seeing Luo [21]. This will provide critical information on how biomechanical and visual factors interact with the causes of variations in landscape quality and how that influences sustainable tourism development.

Interplay of Biomechanical-Visual Quality From these, three extracted factors landscape, rural settlement landscape, and cultural landscape-show the critical positions that biomechanical stability and aesthetic harmony play in determining the quality of the landscape, referring to Matyukira et al. [22]. Natural landscape factor contributes about 52.34% of the variance, indicating the importance of terrain stability, vegetation resilience, and water elements. It provides evidence that terrain slopes and wind-resistant vegetation significantly contribute to biomechanical stability while offering visual harmony. For example, stable terrains provide comfort and perceived safety, while wind-resistant vegetation ensures functional usability and aesthetic appeal in adverse environmental conditions.

However, in this analysis, the biomechanical stability at the level of molecule cells has not been considered in Li et al. [23]. More detailed structural vegetation properties, including cell wall composition and mechanical strength, could enhance the understanding of vegetation stability as affected by environmental stress and, consequently, landscape quality, referring to Song and Liao [24].

For example, the response of plant cell walls to wind and rainfall may account for their resistance to deformation and contribution to soil stability, thereby linking microscopic biomechanics to macroscopic terrain usability and visual coherence.

6.1. Microscopic biomechanics and vegetation stability

Vegetation stability is one of the important biomechanical factors affecting both ecological and aesthetic dimensions in rural landscapes. In the cell wall of plants, cellulose, hemicellulose, and lignin determine the mechanical properties at the cellular level. Cellulose is reinforced by tensile strength, hemicellulose through flexibility, and lignin by rigidity. These enable vegetation to resist environmental stressors like strong winds and heavy rainfall, thus maintaining stability and ensuring longevity.

In any case, future research also needs to explain how the change in cell wall composition affects vegetation’s mechanical properties and landscape stability. For instance, plants containing higher amounts of lignin will have greater stiffness and resistance to wind force bending, reducing the likelihood of plant uprooting and erosion, referring to Chen et al. [25]. Such insight could inform species selection for rural tourism landscapes, with preferred species having better biomechanical properties that offer an aesthetic bonus for stability and appearance. Furthermore, plant cells have physiological activities osmoregulation and nutrient transportation. These then determine and shape the growth habits or general appearance. Leaf morphology would, therefore, be determined, among other things, because such processes establish its pigmentation or texture, characteristics essential to determining aesthetic quality for landscape purposes. By elucidating the specific cellular mechanisms of these processes, better insight can emerge as to plant health and thus the appearance making for visual and ecological harmony or otherwise.

6.2. Microbial communities and soil biomechanics

Another area that deserves deeper investigation is the role of microbial communities in soil stability. Soil microorganisms, including bacteria and fungi, impact soil's physical and chemical properties, such as porosity, compaction, and nutrient availability. These properties, in turn, affect vegetation growth and biomechanical stability. For example, mycorrhizal fungi form symbiotic relationships with plant roots, enhancing nutrient uptake and root anchorage and contributing to soil cohesion and slope stability.

The changes in the composition of the microbial community directly affect soil biomechanical properties, which can be reflected in vegetation health and landscape quality. For example, the loss of beneficial microbes might cause soil erosion, which reduces the biomechanical stability of terrain and upsets the balance in scenic beauty. Future work might use techniques in molecular biology, such as metagenomic sequencing, to examine the relationship between microbial diversity and the stability of both soil and vegetation. This interdisciplinary approach would deeply embed the interaction between biomechanical and ecological factors in setting rural tourism landscapes.

6.3. Biomechanical-aesthetic interrelations

The interdependence of biomechanical stability and visual aesthetics further supports this. Stability in terrains and resilience in vegetation enhance safety and functionality and the aesthetics of landscapes visually. For example, well-maintained paths and slopes evoke a sense of order and coherence, while diverse and healthy vegetation results in visually engaging patterns and textures.

The relationship between biomechanics and aesthetics can be investigated on the molecular level by looking into physiological attributes that determine plant appearance, referring to Khodayari et al. [26]. For example, the turgor pressure of the leaf epidermal cells determines the surface texture and light reflectance, both important determinants of visual beauty. Similarly, through chloroplast activity, pigmentation processes determine leaf color and, through seasonal color changes, most of the aesthetic value of landscapes.

By studying such microscopic processes, each may develop strategies to optimize biomechanical and visual quality in conjunction, such as selecting plant species with strong cell structure and bright-colored pigmentation, which could lead to landscapes that are hardy against environmental stress and visually appealing. Furthermore, underpinning the fundamental scientific issues in landscape design may help resolve the often-conflicting pressures on any landscape for functionality, safety, and aesthetics.

6.4. Interdisciplinary approaches for the optimal solution to landscape

Understanding the complexity of rural tourism landscapes explicitly demands a transdisciplinary approach: Molecular biology combined with biophysics and ecology, as put in conjunction with landscape design, delivers new perspectives for the accomplishment of genuinely sustainable landscape planning, like using plant trait editing with cell wall composition and root architecture important for biomechanical stability and aesthetic appeal.

An integrated gene analysis may allow cell mechanics tests to further an ecological survey or a simple visual assessment that encapsulates a holistic understanding of landscape dynamics. In their basic form, these would consider a design incorporating genetic manipulations targeted at improved mechanical strengths by increased cellulose synthesis in plants that prevent potential wind damage and erosion, modifications assessed alongside ecosystem functioning and biodiversity in influencing aesthetic quality.

One very promising track involves applying biomechanical simulations of vegetation and terrain stability concerning environmental stressors. Feeding these could be cellular-level information derived from controlled-condition, stress-testing protocols for plants to determine the predictive behavior of plants under field conditions. Together with visual impact assessment, knowledge gained could show ways visually cohesive but robust landscapes could be created.

6.5. Policy and design implications

These findings have important implications for policymakers, landscape designers, and tourism developers. Emphasizing the interdependence of biomechanical and visual factors, this research provides a theoretical framework for designing rural tourism landscapes that are safe, functional, and aesthetically pleasing. Some specific recommendations in this regard could be.

Selection of vegetation: Plant species with good biomechanical properties, like high lignin content rich in rigidity, have strong root systems; hence, more stability with higher aesthetic value.

Terrain modeling: The pathways and gradients should be designed to balance practicality with aesthetic values, comfort, and safety for the visitors while maintaining visual coherence.

Cultural integration: Respect traditional architecture and other historical buildings through biomechanical resistance by incorporating plants that provide protection and using structural reinforcements respectfully in Fan and Lai [27]. Additionally, the study identifies landscape planning that needs to begin integrating at lower scales of inquiry-molecular and cellular levels of resolution so new design practices in the formulation of policies by policymakers and developers may effectively generate sustainable landscapes that are adaptive to changing conditions.

6.6. Limitations and future directions

While this study laid a robust framework for evaluating rural tourism landscapes, several limitations should be conceded according to Zhang and Liu [28]. First, the analysis was mainly macroscopic, focusing on biomechanical and visual assessments at the landscape level; microscopic processes like cellular and molecular biomechanics were not directly considered. Further studies should fill this gap by incorporating advanced techniques such as cell mechanics testing and gene expression analysis that permit the exploration of molecular determinants of vegetation stability and visual quality.

Secondly, the research only confines itself to Hunan, Guangxi, Guizhou, and Chongqing. While most relevant case studies should generally be sourced from these catchment areas, generalizations into other ecological and cultural configurations are best not carried out rashly. A framework's enhanced application and universality would apply more with an expansion beyond various landscapes present worldwide, such as China in Wu et al. [29] and Turkey in Merkez and Yilmaz [30]. Finally, reliance on self-reported data introduces potential biases; aesthetic perceptions are inherently subjective. In the future, objective measures such as wearable sensors or eye-tracking technologies will be used to mitigate these biases and yield more reliable estimates of visual quality in Alkier et al. [31]. (**Figure 1**) Map of the adjacent areas of Hunan, Guangxi, Guizhou and Chongqing

7. Conclusion

The study has proposed a novel framework for the assessment of the visual quality and biomechanical aspects of the rural tourism landscape of Hunan, Guangxi, Guizhou, and Chongqing in adjacent areas. Factor analysis was done to extract crucial determinant factors affecting the natural scenery landscapes, settlement countryside landscapes, and cultural landscapes in an area for which the total quality depended entirely. While those findings indeed point out the interdependence of biomechanical stability and visual aesthetics, further integration of molecular and cellular biomechanics is essential to go forward with the scientific understanding of such interactions.

In the future, the structure and mechanical properties of the cell walls of vegetation should be researched, as well as the contribution of cellulose, hemicellulose, and lignin to biomechanical stability. This understanding of how these cellular components respond to environmental stresses, such as wind and rainfall, will be important to understand vegetation resilience and its implications for landscape stability. The physiological processes of plant cells, by which nutrients are transported and pigments biosynthesized, for example, need to be understood in relation to aesthetic attributes such as the morphology, color and texture of leaves.

Further exploration of the intrinsic link between biomechanics, ecology, and aesthetics is also required. Recent studies have emphasized that microbial communities in soils have significant effects on soil cohesion, vegetation development, and ecosystem function. Scientists will look at how these microbiome-vegetation interactions drive changes in biomechanical stability and aesthetic appeal through interactions at the molecular scale. To understand these complexities and harness them for human benefit, scholars can leverage interdisciplinary approaches drawing on molecular biology, biophysics, ecology, and landscape design. In this direction, manipulation of genes, testing of cell mechanics, and ecological surveys are some of the techniques that could be used to develop resilient yet visually appealing landscapes.

It represents a very interdisciplinary approach, important in applications to policymakers, landscape designers, and tourism developers. Integrating molecular and cellular biomechanics into landscape planning would allow the design of sustainable tourism environments to balance functionality with safety and aesthetic appeal. These perceptions should be further confirmed in future studies by expanding the geographical scope and applying objective biomechanical measurements to ensure broader applicability and more valuable scientific contributions. This work finally lays a good foundation for furthering the integration of biomechanics into sustainable rural tourism landscape design.

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