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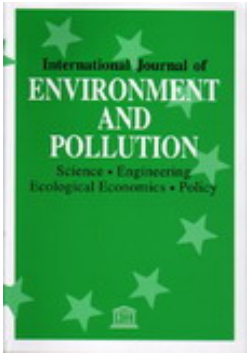

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Visualising micro-renewal in rural landscapes: design and application of co-creation tool

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Abstract: The growing urban-rural disparity in China has exacerbated rural depopulation and weakened vitality. This study integrates image entropy calculations and visual analysis to innovate rural landscape renewal, offering a technology-driven and community-centred approach to revitalisation. Central to this research is a co-creation tool enabling residents to actively participate in enhancing rural landscapes and improving perceptual experiences and satisfaction. By applying entropy image analysis, the study assesses key visual elements – clarity, openness, density, complexity, and expressiveness –

revealing their influence on residents' perceptions of beauty, comfort, and pleasure. The entropy-based visual analysis framework underpins the development of a co-creation tool that fosters greater resident engagement, as surveys confirm enhanced satisfaction and involvement in renovation projects. This tool facilitates collaboration among developers, locals, and visitors, ensuring alignment with community needs and preferences. Ultimately, the study advances rural development by leveraging technology to empower residents and create more engaging, appealing landscapes.

Keywords: micro-renewal; visualisation; co-creation tool; rural landscape; rural scene optimisation.

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1 Introduction

1.1 The importance and challenges of rural scene optimisation

Optimising rural scenes is vital for rural revitalisation, encompassing natural aesthetics, infrastructure upgrades, sustainable practices, and cultural heritage conservation. This optimisation attracts tourists, boosts rural economies, preserves culture, and improves residents' living environments. As rural revitalisation strategies progress, scene optimisation has become key to sustainable development, promoting tourism, economic growth, and quality of life. Through the use of modelling and business surveys to

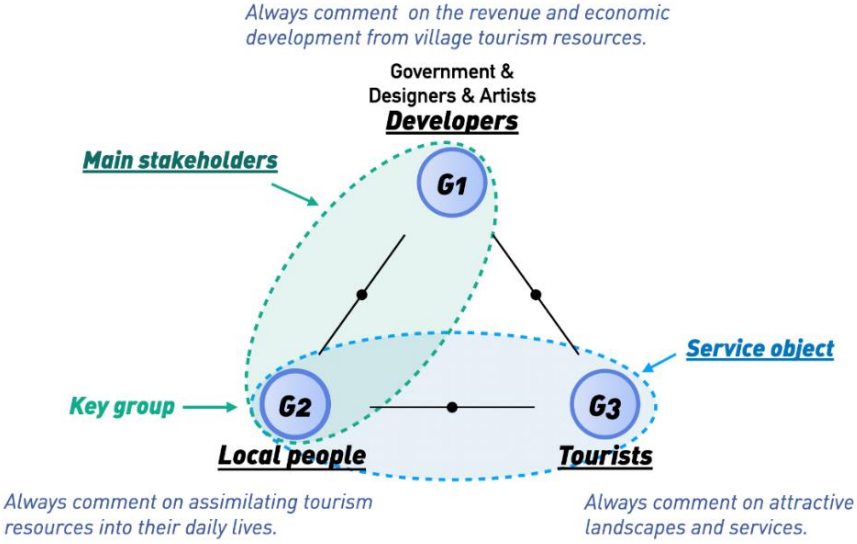
evaluate economic effects, visitor surveys, tourism statistics, and revenue trends, as well as social indicators to track changes in residents' well-being, the study seeks to determine the long-term effects of suggested optimisations on tourism, the economy, and the quality of life of locals. Scene micro renewal, critical in transforming rural environments, relies heavily on villagers' participation. The rise of participatory design has diminished designers' traditional dominance, highlighting the need for villagers' active involvement despite often inadequate participation levels. Co-creation, involving deep resident engagement, is increasingly recognised. Co-creation power dynamics include balancing local inhabitants' and developers' demands, interests, and goals. To develop lasting, community-focused initiatives, strategies include admitting inequities, fostering trust, encouraging equality in decision-making, implementing win-win solutions, embracing power-sharing models, and preserving community participation. Co-creation design tools enhance community renewal and environmental improvement, facilitating collaboration throughout the design process, particularly during conceptualisation and implementation, offering innovative methods for optimising rural landscapes.

Entropy image analysis, a method for evaluating the quantity and complexity of information in an image, contributes significantly to the optimal design of rural landscapes. This technique enhances the attractiveness of rural areas by enabling meticulous spatial planning, functional improvement, and visual amenity assessment (Mueller and Neuschaeffer, 2021). Co-creation tools supporting participatory involvement at the design stage offer digital and physical platforms for collaborative engagement. Integrating these tools into rural landscape optimisation underscores the necessity for an inclusive approach to sustainable rural development (Marchetti et al., 2017). The use of co-creation design tools facilitates the incorporation of diverse viewpoints. It needs stakeholders, including government officials, residents, tourists, and designers, thereby fostering more inclusive and innovative design solutions. With advancements in digital technology and the expanded application of entropic image analysis, new methods have emerged for examining and enhancing rural landscapes. The entropic visual framework facilitates multidisciplinary cooperation by clearly visualising complicated data. It encourages interactive problem-solving and cross-disciplinary understanding within teams by enabling real-time updates, stakeholder interaction, and feedback. Despite the recognised importance of optimising rural landscapes for revitalisation, the challenge of applying these designs scientifically and efficiently remains.

As shown in Figure 1, historically, village construction in China has predominantly followed a 'top-down' approach, where governments, designers, and artists collaboratively undertake direct construction projects within villages. Notably, developers and residents are primary stakeholders in rural development. These groups also cater to the locals and tourists, the primary beneficiaries of such developments. However, there is a significant disparity in the objectives of these stakeholders. Developers prioritise economic returns and growth, whereas residents focus on integrating tourism resources into their daily lives. Locals mostly use Western Zhejiang's tourist resources for indirect interaction. Still, obstacles including ignorance, cultural disconnection, financial disincentives, poor infrastructure, environmental concerns, and opposition to commercialisation hamper their full potential obstacles including ignorance, cultural disconnection, financial disincentives, poor infrastructure, environmental concerns, and opposition to commercialisation hamper their full potential. Consequently, this misalignment often leads to various relational issues, including arguments,

dissatisfaction, and complaints. Despite these frequent conflicts, there is a noticeable absence of effective communication and consultation within regulatory frameworks.

Figure 1 Relationship between developers, local people and tourists (see online version for colours)



1.2 Research objectives

Previous studies have predominantly focused on traditional design principles and intuitive assessment methods, with relatively few employing quantitative tools like entropy image analysis to inform design decisions. While the utility of co-creation tools in urban planning and commercial space design is widely acknowledged, their application and systematic evaluation for optimising rural landscapes remain underdeveloped (Di Fazio and Modica, 2018). For evaluating rural landscapes, entropy-based picture analysis is a useful technique because it highlights details, recognises important elements, monitors environmental changes, and adjusts to intricate textures and lighting. It is helpful for landscape planning and design as it captures natural and cultural factors and offers an unbiased assessment of visual complexity. Despite notable advancements in rural landscape optimisation, several practical challenges persist. First, an unequal distribution of resources frequently hampers the implementation of effective landscape optimisation projects in numerous villages because of financial, technical, and human resource constraints. Second, insufficient resident participation presents a major obstacle: numerous rural initiatives have not adequately integrated local opinions and needs, rendering designs disconnected from residents' daily lives (Santoro et al., 2020). Finally, in the quest for visual appeal and tourism value, some design solutions neglect the essential harmonious coexistence of local culture and the ecological environment, leading to cultural homogenisation and environmental degradation. These issues underscore the necessity for designers, governments, and communities to collaboratively seek more balanced and sustainable strategies for rural scene optimisation (Visentin and Bertocchi, 2019).

The primary contributions of this study are twofold. First, by leveraging image entropy and its impact on user experience, we systematically categorise and analyse images' visual attributes and aesthetic sensibilities in rural settings, constructing a quantitative visual attribute framework and developing co-creative design tools to foster multi-stakeholder participation. Second, we employed entropy image analysis and co-creative tools in real rural renewal scenarios to investigate their utility and effectiveness in enhancing rural landscape design. Through robust community collaboration, these approaches improve design adaptability and resident satisfaction and strengthen their sense of involvement, demonstrating the synergistic benefits of technical analysis and community engagement.

2 Literature review

2.1 Scene micro-renewal strategies for resident participation

Recent research has shifted away from the micro-renewal of rural landscapes and communities, predominantly orchestrated by professional designers, towards an increased emphasis on resident participation and community sustainability. In rural micro-renewal initiatives, the entropic image visual framework facilitates multidisciplinary cooperation by encouraging communication, problem-solving, and data-driven decision-making. It guarantees sustainability and cultural sensitivity, balances environmental and cultural factors, and optimises resource allocation. Agnoletti and Rotherham (2015) explored the interconnections among rural landscapes, nature conservation, and cultural preservation from a European perspective, advocating a model that seamlessly integrates social, economic, and environmental aspects within a spatiotemporal framework. Depopulation in rural areas weakens community identity by negatively affecting indigenous languages, social networks, and cultural activities. Economically, it results in decreased infrastructure investment, a declining agricultural sector, and a diminishing labour force. Reviving rural economies and conserving cultural heritage are necessary to address these difficulties. Fagerholm et al. (2019) investigated the perceived benefits of ecosystem services in multifunctional landscapes, noting the importance of outdoor recreation, aesthetic appreciation, and social interactions in rural settings that are directly linked to residents' well-being. Community micro-regeneration, an evolved form of urban regeneration, focuses on enhancing local community environments through minor spatial modifications, emphasising the meticulous crafting of small-scale localised areas (Tang et al., 2022; Wu et al., 2022). This strategy represents a substantial shift from conventional large-scale planning, positioning communities at the forefront of advancing their sustainability and resilience (Porfiriev et al., 2017; Webb et al., 2018). Resident participation is becoming increasingly recognised as a crucial component of community dynamics (Yang et al., 2022; Grisales-Bohórquez et al., 2022), marking a departure from traditional approaches where rural landscape planning was primarily the domain of professional designers, often sidelining residents' perspectives and needs.

As democratic principles advance and community regeneration practices evolve, the significance of citizen empowerment is increasingly recognised. Actively listening to and integrating residents' perspectives have become crucial aspects of scene micro-regeneration (Mavrodieva et al., 2019). However, resident participation in several community micro-renewal projects remains limited and is often characterised by passive

involvement (Arnab et al., 2019). This constrained participation limits opportunities for residents to enact meaningful change. Co-creation, an innovative approach to public governance, broadens the traditional boundaries of community micro-regeneration and fosters enhanced communication and innovation (Riar et al., 2022; Wang et al., 2022). By incorporating sociological and anthropological insights, co-creation presents additional opportunities to address design challenges not met by conventional planning methodologies (Smeenk, 2022; Han and Abdrahim (2023)). Businesses, tax receipts, and public services are all impacted by the labour shortages, economic downturn, and ageing populations that result from rural depopulation. As more educated people move to cities, this erodes neighbourhood identity and social cohesiveness. Along with worsening poverty and affecting land usage and the environment, depopulation also deepens the gap between urban and rural areas.

In conclusion, community residents' proactive involvement and co-creation are vital for sustainable and resilient community micro-renewal. However, deep resident engagement remains challenging. Interdisciplinary research methods provide broader perspectives and holistic solutions, promoting more integrated and diversified approaches.

2.2 Application of entropy in image analysis and its design implications

Entropy was first introduced in thermodynamics and statistical physics to describe a system's degree of chaos or uncertainty. To effectively communicate entropy analysis to them, simplify difficult ideas, employ relatable analogies, concentrate on practical results, employ visual aids, highlight the usefulness of entropy analysis, involve non-technical audiences in interactive activities, and provide tangible takeaways for applying entropy insights to local problems. In the 20th century, Shannon (1948), the founder of information theory, applied entropy to quantify information in information science. Entropy assesses image complexity and information content in image processing, becoming a key index for measuring image richness (Kunt et al., 1985). With advancements in computer science and digital image processing, entropy is widely used in image quality assessment and feature extraction (Wang et al., 2022).

Image entropy analysis is prevalent in visual art and design, where designers use it to optimise visual complexity and attractiveness (Edison et al., 2021). Researchers have developed frameworks combining human and machine vision in image coding to generate bitstreams for semantic analysis or human vision (Fan et al., 2021). Entropy techniques improve product classification efficiency using histogram equalisation to enhance greyscale image features (Thomas et al., 2014). A new RGB entropy measure based on a multivariate approach has shown effectiveness for colour images compared to multiple deep learning methods (Yi et al., 2023; Busse et al., 2023.

Studies have explored the relationship between aesthetic judgement and spatial complexity, finding correlations between image complexity and aesthetic preferences (Javid et al., 2016). Fuzzy logic methods, based on specific entropy functions, align well with subjective human perceptions, validating the utility of entropic images for assessing visual complexity (Cardaci et al., 2006). Despite these advances, there is a research gap in effectively integrating entropy analysis into design practices. Future research should balance image information with visual appeal and adjust entropy application strategies according to different design goals (Wang et al., 2023).

2.3 Development and application of co-creation design tools

The origins of co-creation design tools trace back to the late 20th and early 21st centuries, coinciding with the democratisation of the design process. As user-centred design concepts and information technology advanced, co-creation tools emerged to foster active stakeholder participation. Developments in UCD and IT are essential for co-creation tools because they improve data analysis, networking, and teamwork. AI and cloud computing enhance automation and scalability. With an emphasis on iterative design and ongoing input, UCD guarantees responsive, inclusive, and easy-to-use products. This results in lively, approachable, and easy-to-use co-creation tools. For example, Lego and other materials have been used as prototyping tools to enhance teamwork and strategy building (Busse, 2023; Steen, 2013). The application of Extended Reality (XR) technology has shown significant potential for improving collaboration efficiency in design (El-Jarn and Southern, 2020), suggesting XR tools as viable digital co-creation platforms (Ricci et al., 2022).

The maturation of democratic design processes and tools for non-experts reflects the growing inclusiveness of design methods (Maselli and DI Cecca, 2022). Co-creation tools have enhanced social science research by improving the design of visual information systems (León and Breiter, 2020). In rural scenario optimisation, these tools facilitate communication between community members and designers, ensuring that design solutions meet community needs (Trischler et al., 2019). In rural tourism, co-creation design tools increase tourist participation, enhancing the tourism experience (Campos et al., 2016). In rural tourism, co-creation technologies let visitors customise their trips, interact with locals, and support environmental and cultural projects. To improve the visitor experience, they include interactive features like gamification, virtual reality, and sustainable practices. Research indicates a positive correlation between co-creation experiences and tourist satisfaction, consumption levels, and well-being (Buonincontri et al., 2017; Trischler et al., 2018). Case studies show that co-creation strategies stimulate community participation, set goals, and promote rural tourism development (Lee and Hong, 2016). (Subramanyam Boyapati and Kaur, 2021) examines how e-commerce affects rural economic growth through internet-inclusive financing. Comparing rural to urban settings strongly influences income levels, entrepreneurship, and company growth. Enhancing financial inclusion and internet connectivity can improve economic possibilities and close the gap between urban and rural areas (Boyapati and Kaur, 2021). The digital economy is transforming communication and commercial processes at a rapid pace, driven by online connections. Devi et al. (2024) studies how the digital economy affects sustainable entrepreneurial growth and the modernisation of industrial structures (DE-ISU-SEG). Utilising statistical data from 25 Chinese areas from 2014 to 2022, the paper addresses the issue of insufficient energy for enhancing China's local industrial structure. It validates the benefits of DE and SEG on ISU. The results emphasise SEG's intermediate role in this process by demonstrating that DE growth favours ISU.

In summary, co-creation design tools promote multi-party participation, reflecting the trend of democratisation in design. They also significantly improve collaboration efficiency through new technologies and materials. Their application is growing in tourism and other fields, with related research deepening, highlighting their importance in advancing design practices and theoretical development.

3 Method

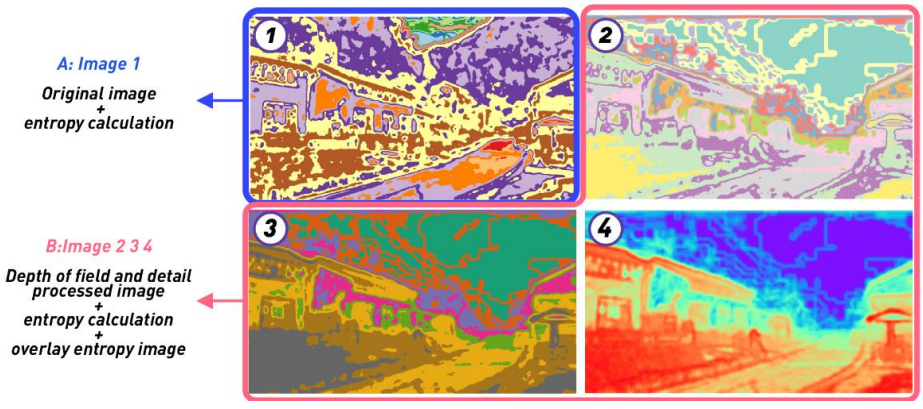
This study adopted a mixed research design approach, combining quantitative analysis and qualitative assessment, to explore co-creation strategies in rural micro-renewal. The mixed research design employs qualitative and quantitative techniques to comprehend the investigation's goals fully. While qualitative insights are obtained through focus groups and interviews, quantitative data is acquired to find trends. This method helps with well-informed decision-making by guaranteeing quantifiable results and individual experiences. Initially, the study was conducted by selecting four representative images of rural scenes and using image-processing software to calculate their image entropy values. These were used as quantitative indicators to assess visual complexity and information content. To improve picture clarity and detail, entropy-based upgrades were applied, emphasising building textures in cultural or architectural photographs and subtle textures in natural settings. These changes preserved the photographs' original realism while balancing contrast in intricate settings and improving visibility without warping the picture. Based on the image entropy value and experts' suggestions, the study assigned descriptive words to each image (e.g., 'rich', 'complex', 'clear', 'clear', 'colourful', 'complex', 'clear', 'clear', 'clear', 'clear', 'clear', 'clear', 'clear', 'clear', 'clear', 'clear', 'strong colour contrast', etc.) for each image, and a questionnaire was constructed accordingly.

This survey primarily engaged villagers and tourists in assessing the perceptual characteristics of images and gathering their optimisation suggestions. This study focused on image attributes: complexity, openness, density, orderliness, and clarity. Visual aesthetics were evaluated across four dimensions: colour, texture, shape, and aesthetic sensibility.

For the empirical research, this study selected a typical mountainous countryside landscape in western Zhejiang Province that had undergone optimisation. Western Zhejiang is a perfect place to investigate tourist-driven optimisations because of its varied landscapes, expanding ecotourism potential, and rural economy that relies on tourism and agriculture. Its similarities to other mountainous rural areas allow for worldwide applicability. Four distinct images were utilised to analyse the usual impacts of these optimisations, each showcasing the landscape with varying depth of field and detail enhancement techniques. As shown in Figure 2, the Figures were processed using different colour mappings to highlight the entropy characteristics and enhance visual perception analysis. Image 1 retained its original properties to serve as a baseline. Images 2, 3, and 4 were subjected to detailed enhancements to explore the effects of different visual processing techniques on perception and entropy. 325 randomly selected residents and tourists aged 10 years and older with experience in rural scene optimisation design participated in the questionnaire survey. This study used SPSS software to explore the relationship between image entropy features, visual perception, and tourism experience through quantitative data analysis, including paired-sample t-tests and correlation analyses. The study used Adobe Photoshop with RGB colour mode and 300 dpi resolution for picture processing. Programs like Healing Brush, Clone Stamp, and Gaussian Blur were employed for edge detection and noise reduction. IBM SPSS Statistics was used for data analysis, which included multiple regression, factor analysis, ANOVA, t-tests, and missing value analysis. Based on these findings, this study developed a set of co-creation design tools to enhance villagers' and tourists' participation in the optimal design of rural scenarios, thereby improving the aesthetic

value and residential experience. This study adhered to strict ethical guidelines to ensure informed consent and data anonymity for all participants. It provided a scientific assessment method and practical tool for the optimal design of rural settings.

Figure 2 Images chosen in the questionnaire (see online version for colours)



4 Result

4.1 Images comparison

This study conducted a comparative analysis of the grey-level histograms of four images to elucidate the distributional properties of information content using entropy results (Figure 3). Part A's histogram shows multiple peaks and valleys, indicating significant luminance variations and a higher entropy value due to diverse textures and shapes, reflecting greater visual complexity and detail. Conversely, Part B's histogram is smoother with fewer peaks, suggesting pixel values are concentrated within a narrower luminance range. The high entropy value in Part B stems from subtle variations at a microscopic level, indicating richer mid-tone details but not necessarily visual complexity. Figure 1 highlights more pronounced visual changes and a stronger dynamic range, suitable for applications emphasising robust visual content. In contrast, Part B's smoother histogram and higher entropy suggest a detailed, consistent foundation ideal for co-creation design, fostering flexibility and creativity. High-entropy images are advantageous for image processing and machine learning, providing rich datasets for pattern recognition and feature extraction.

4.2 Differences in groups

The study found significant differences in perceptions of colour, texture, shape attractiveness, and overall aesthetic sensibility across age groups (Table 1). Adolescents under 18 and seniors aged 55-65 showed greater sensitivity to these attributes than those aged 35-55. Additionally, the 55-65 age group exhibited higher aesthetic sensibility than adults aged 19-35. The study suggests that design tools should accommodate diverse aesthetic preferences by incorporating an intelligent recommendation system that uses users' ages and personal information to suggest preferred design elements. In rural

landscape design, designers should gather and utilise feedback from all age groups to ensure solutions meet varied aesthetic expectations. Its usability is essential to a co-creation tool's efficacy and engagement. To find areas that need development, user feedback is utilised. Frequent iterations improve user experience, address problems, and develop functionality. Security, customisation, and collaborative features are important factors to consider. Building a tool that adapts to user demands is the ultimate objective. Pre-implementation testing across age groups is essential to ensure universally enjoyable experiences, with design optimisations based on user testing insights.

Figure 3 Greyscale histogram of entropy calculation (see online version for colours)

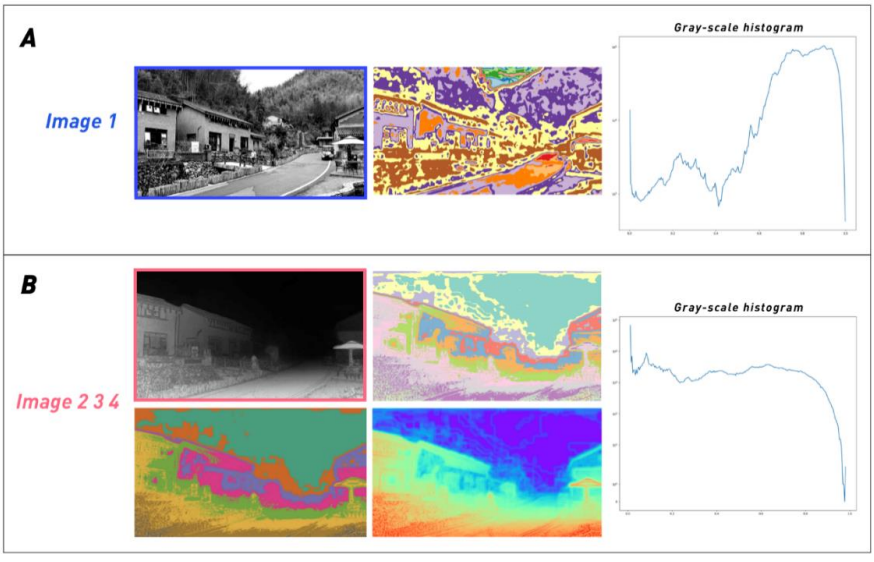


Table 1 Result of colour, texture, shape attractiveness, and overall aesthetic sensibility across different age groups

Age (*mean* ± *standard deviation*)	*Colour attractiveness*	*Textural attractiveness*	*Shape attractiveness*	*Aesthetic sensibility*
A. Under 18 years (n = 40)	6.250 ± 0.750	6.417 ± 1.010	6.083 ± 0.878	5.583 ± 1.665
B. 19–35 years old (n = 164)	4.965 ± 1.284	4.640 ± 1.329	4.560 ± 1.447	4.310 ± 1.673
B. 25–35 years old (n = 10)	5.375 ± 1.237	4.000 ± 0.354	4.375 ± 0.884	4.250 ± 1.061
C. 35–55 years (n = 21)	3.750 ± 1.357	3.167 ± 1.557	3.104 ± 1.670	2.979 ± 1.463
D. 55–65 years (n = 90)	5.983 ± 0.729	5.817 ± 0.909	5.900 ± 0.817	5.900 ± 0.812
F	6.621	8.632	7.814	6.801
P	0.000**	0.000**	0.000**	0.000**

*p < 0.05; **p < 0.01.

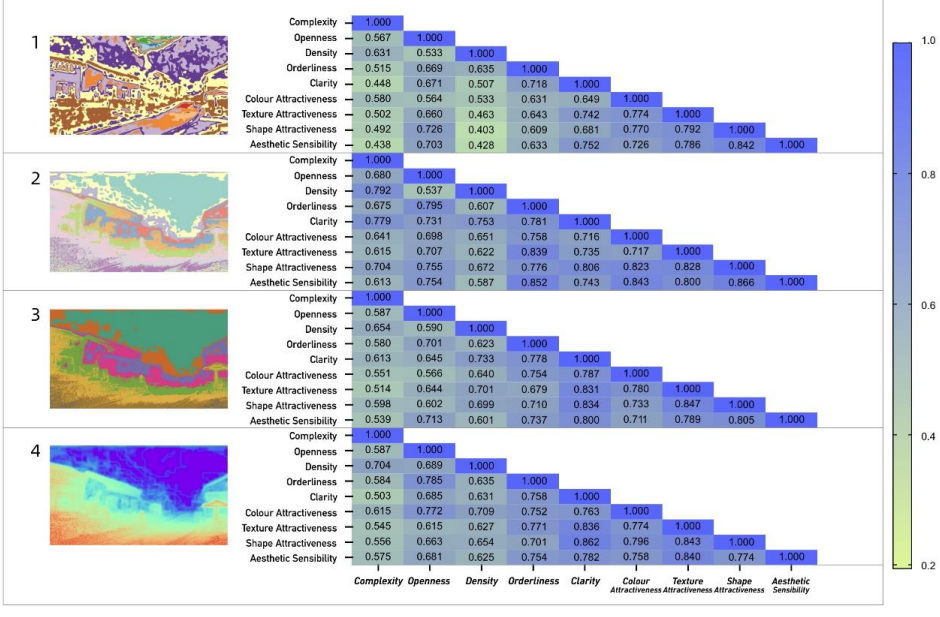
4.3 Relationship between user experience, image attributes, and visual presentation

4.3.1 Correlation between image feature attributes and visual presentation

This study analysed the relationship between core image attributes (complexity, openness, density, orderliness, and clarity) and visual aesthetic elements (colour attractiveness, texture attractiveness, shape attractiveness, and aesthetic sensibility) using the Pearson correlation test (Figure 4). Complexity, openness, density, orderliness, and clarity are crucial for rural optimisation. Density balances infrastructure and population, orderliness fosters organised planning, complexity draws attention to interrelated systems, clarity guarantees effective stakeholder communication, and openness promotes connectedness. Significant positive correlations were found between all image attributes and visual aesthetic elements. Entropy value changes were independent of colour changes, confirming the stability of image entropy values.

Specifically, colour attractiveness was strongly correlated with clarity ($r = 0.649$) and orderliness ($r = 0.631$), suggesting enhancements in these areas can boost colour attractiveness. Texture attractiveness was highly correlated with clarity ($r = 0.742$), and shape attractiveness was associated with clarity ($r = 0.681$) and openness ($r = 0.726$). Colour attractiveness also strongly correlated with openness ($r = 0.698$) and orderliness ($r = 0.758$). The strongest correlation was between texture attractiveness and orderliness ($r = 0.839$). Aesthetic sensibility was most significantly correlated with orderliness ($r = 0.852$).

Figure 4 Correlation between image feature attributes and visual presentation (see online version for colours)



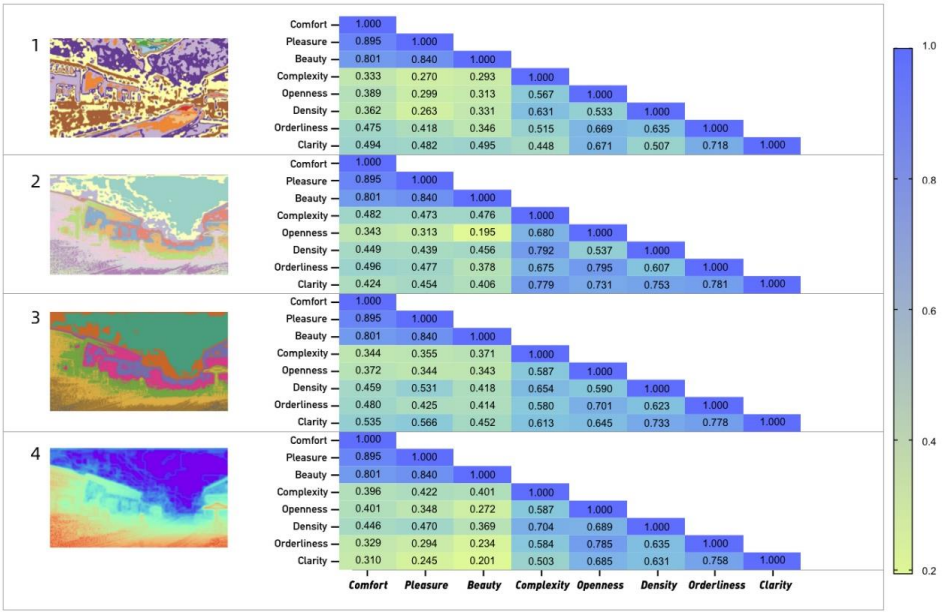
Figures 3 and 4 further highlight the importance of clarity and openness in enhancing colour, texture, shape attractiveness, and overall aesthetic sensibility. Pearson correlation

tests confirmed that core image attributes significantly enhance visual aesthetic elements, with clarity and orderliness particularly impactful. These findings guide refining image-processing techniques and offer practical recommendations for scene design optimisation.

4.3.2 Correlation between image feature attributes and scene experience

This section examines the relationship between image attributes (complexity, openness, density, orderliness, and clarity) and three dimensions of user experience (comfort, pleasure, and beauty) through correlation analysis (Figure 5). Using Pearson's correlation test, we analysed four images. Figure 1 shows comfort is significantly and positively correlated with complexity ($r = 0.333$), openness ($r = 0.389$), density ($r = 0.362$), orderliness ($r = 0.475$), and clarity ($r = 0.494$), with clarity having a pronounced effect on comfort.

Figure 5 Correlation between image feature attributes and scene experience (see online version for colours)



Pleasure is mainly influenced by orderliness ($r = 0.418$) and clarity ($r = 0.482$). The strongest correlations for beauty are clarity ($r = 0.495$) and orderliness ($r = 0.346$). Figure 2 indicates comfort is most correlated with orderliness ($r = 0.496$) and complexity ($r = 0.482$), with openness, density, and clarity also showing positive correlations. Pleasure is highly correlated with orderliness ($r = 0.477$) and complexity ($r = 0.473$), highlighting their importance in enhancing user pleasure. Aesthetics primarily correlates with complexity ($r = 0.476$) and density ($r = 0.456$), suggesting a preference for complex and dense images.

Analyses of images 3 and 4 show similar trends: comfort is significantly positively correlated with clarity ($r = 0.535$) and orderliness ($r = 0.480$), and both pleasure and beauty are influenced considerably by clarity. Figure 4 shows complexity, openness, and density positively correlate with all user experience dimensions. These findings

underscore that clarity and orderliness are pivotal in enhancing user experience, particularly comfort and pleasure. While complexity, openness, and density positively impact user experience, their effects are modest. Therefore, future design practices should prioritise refining clarity and orderliness to improve overall user experience.

In summary, user experience dimensions – comfort, pleasure, and beauty – positively correlate with image attributes like complexity, openness, density, orderliness, and clarity. Clarity and orderliness are crucial for enhancing user experience. Optimising these attributes and carefully increasing complexity and density in rural scene updates can improve user interactions, especially in comfort and beauty. This study emphasises incorporating unique local visual and cultural elements into rural scene updates. Adjusting image attributes enhances rural scene attractiveness and enriches the overall user experience, resonating with the countryside's cultural and visual nuances.

4.4 Entropy image-based co-creation tool application

The user interface of the co-creation design platform developed in this study includes several functional areas and tools to facilitate users' active participation and design idea contributions. The main components of the interface (Figure 6) and their functions are as follows:

1 *Colour-choosing area*: This area offers a variety of colour options and preset templates, allowing users to select and apply colours based on their preferences.

2 *Operating area*: The primary design space at the centre of the interface displays entropy-processed images and supports activities such as drawing and adding text.

3 *Toolbar*: Located at the top, providing essential options like undo, redo, save, and share, along with adjustable tools such as a text editor, brushes, and erasers.

4 *Entropy image output*: Situated in the upper-right corner, displaying a real-time entropy value chart detailing complexity, openness, density, orderliness, and clarity, providing instant feedback.

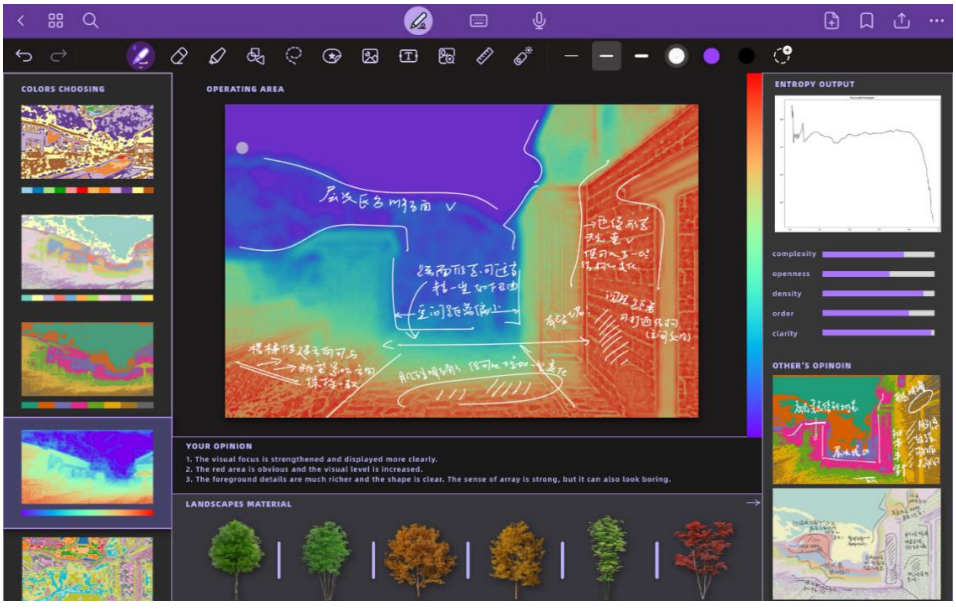
5 *Personal opinion*: Located below the operating area, this section automatically recognises user activities, displays suggested text and icons, and allows users to verify content accuracy.

6 *Landscape material*: Positioned below the operating area, this feature features a gallery of landscape materials, like trees, that users can integrate into their designs with real-time entropy image updates.

7 *Others' opinions*: In the lower-right corner, display feedback or versions of the current design from other users, facilitating interactive comments and viewing.

The upper left corner also includes navigation buttons such as 'Back' and 'Settings' to help users navigate different interfaces or adjust settings. The entire interface design adheres to principles of usability and readability, supporting extensive user creation, editing, and sharing functions. A thoughtful layout and tool design encourages broader user involvement in design exchanges and community participation.

Figure 6 User interface design and functional description (see online version for colours)



4.5 Cross-domain evaluation analysis of entropy image usefulness

Data's correctness, dependability, and credibility depend on the validation and cross-verification of information measures. This improves decision-making, eliminates mistakes, and prevents prejudice. Data becomes more reliable and helpful for well-informed decision-making through increased accountability, openness, and public confidence. The effectiveness of the entropy images across different age groups was examined using ANOVA to determine the impact of age on perceived helpfulness (Table 2). The analysis revealed that age significantly affects helpfulness at a statistical significance level ($p < 0.05$). The study used a significance threshold of 0.05 to minimise mistakes and identify significant effects. Pearson's correlation analysis was performed to investigate correlations between continuous variables, and groups were compared using paired-sample t-tests. These techniques guaranteed reliable, valid results when examining treatments and the correlations between variables. Specific results indicated that age differences are profoundly significant in helpfulness, achieving a significance level of 0.01 ($F = 4.232$, $p = 0.004$). Further insights from the post-hoc tests revealed marked differences in the mean scores between groups, notably showing that individuals below 18 years of age reported greater helpfulness than those aged 35–55, and respondents aged 55–65 reported higher helpfulness than those aged 19–35. The post-hoc comparison highlighted that the group aged 55–65 consistently rated entropy image usefulness higher than the 19–35 and 35–55 age groups.

This study used an independent sample t-test to evaluate the impact of design-related professional background on the perceived usefulness of entropy images. The results showed no statistically significant differences ($p > 0.05$) between participants with and without a design background, suggesting a uniformly positive appraisal of entropy image utility. Notably, 77.5% of participants found entropy images beneficial, indicating broad acceptance across professional fields.

Table 2 Feedback from different groups of people

	Design-related work (mean ± standard deviation)			
	A. Yes (n = 201)	*B. No (n = 124)*	*t*	*p*
Helpful	5.393 ± 1.133	5.340 ± 1.493	0.165	0.869

*$p < 0.05$; **$p < 0.01$.

With rapid advances in information technology and widespread educational outreach, individuals from various fields are becoming familiar with the applications and benefits of entropy images. This convergence of perceptions across domains underscores the potential and general validity of entropy imaging as an analytical tool. Our findings reinforce the notion of entropy images as universally accepted analytical tools and highlight their extensive application potential across various fields.

5 Discussion

5.1 Mapping core visual attributes of images and landscape optimisation for rural scenes

This section delineates strategies for optimising rural landscape design by enhancing core visual attributes – clarity, order, complexity, openness, and density. Each attribute is crucial in harmonising rural environments' aesthetic and functional aspects.

1 *Clarity enhancement*: Clarity enhancement is essential in rural landscapes, particularly to ensure that roads and directional signs are visible at night. Improved navigation can be achieved using reflective materials or enhanced nighttime lighting.

   Additionally, distinct landscape elements such as ancient trees, traditional buildings, and characteristic terrain should be accentuated with strategic lighting and viewpoint guidance to boost their visual appeal.

2 *Enhancement of orderliness*: Enhancing orderliness in rural areas primarily involves planning a clear layout of fields and distinctly demarcating functional areas. Employing natural boundaries such as hedges or streams to separate residential from agricultural zones helps maintain the traditional structure and order of the countryside. Moreover, visually ordered rows and column arrangements can significantly improve a landscape's aesthetics.

3 *Adjustment of complexity*: Increasing plant species, diversity, and ecological variation involves designing varied landscapes that integrate the countryside's natural features and cultural characteristics. Differences in access, ecology, and culture may impact the effectiveness of treatments. Communication methods, decision-making processes, and cultural norms affect how an intervention is received. Climate change vulnerabilities, resource availability, and environmental circumstances also influence the applicability of findings. For solutions to be effective, they must be customised to meet the unique demands of rural areas. Local arts and crafts can enhance a landscape's visual and ecological complexities, enriching visual and cultural experiences.

4 *Openness enhancement*: Enhancing the openness of rural scenes includes maintaining and augmenting open views, such as avoiding the construction of tall buildings that obstruct views and utilising expansive views of fields and mountains. Furthermore, designing open public spaces such as village squares or marketplaces facilitates community interaction and cultural activities.

5 *Appropriate configuration of density*: It is vital to carefully plan the density of settlements to preserve the village's tranquillity and privacy while providing essential community services and facilities. Strategically added vegetation and small architectural elements can create a comfortable and visually appealing environment.

5.2 Strengths of the entropic image visual framework in co-creation tools

This study identifies three principal strengths of the Entropic Image Visual Framework as a co-creation tool: interdisciplinary collaboration and community engagement, real-time feedback and dynamic adjustment, and continuous evaluation and cooptimisation.

1 *Interdisciplinary collaboration and community engagement*: Entropic Image tools facilitate collaboration among urban planners, designers, residents, and tourists. Developers guide design direction while residents and tourists provide immediate feedback, ensuring designs meet diverse needs and expectations.

2 *Real-time feedback and dynamic adaptation*: Participants can observe how their input influences design in real-time, enhancing engagement, adaptability, and satisfaction. Developers quickly incorporate new data and suggestions, and feedback shapes project outcomes.

3 *Continuous evaluation and cooptimisation*: The tool supports ongoing evaluation from initial design to post-implementation, informed by user experiences and feedback. This process improves design quality and community ownership, fostering continuous improvement.

In summary, the Entropic Image visualisation framework enhances stakeholder participation and engagement as a co-creation tool, significantly boosting project success and sustainability. It supports innovative and adaptive design practices, dynamic collaboration, and tailored urban and rural planning and landscape design solutions.

5.3 Participatory design in micro-renewal dynamics

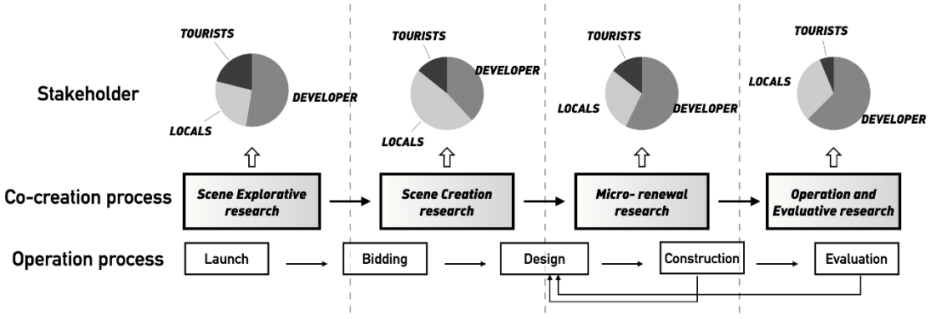
The diagram illustrates a paradigm where designers take significant initiatives in design implementation and conceptual phases while governments facilitate key micro-renewal dynamics. Micro-renewal strategies, a departure from conventional top-down urban regeneration approaches, include community participation in the planning and design stages. This participatory strategy, which emphasises localised, gradual interventions, has demonstrated sustainability and efficacy in building social capital and resilient, empowered communities. Designers often engage in micro-regeneration projects as representatives of third-party organisations, enhancing efforts by connecting with other community projects and organisations. Residents, as coordinators, play crucial roles by acting as informants and users, helping designers understand and translate community needs into actionable design concepts (Li et al., 2023). Co-creation leverages established

research and design principles to forge solutions that enhance user experience and offer innovative services to businesses (Dorta et al., 2019). While not novel, this approach to collaborative problem-solving aligns with John Dewey's 1997 advocacy for organisational cooperation in problem-solving processes, where participants collectively explore, discuss, define, and solve problems (Dewey, 1986). In this context, enquiry starts with a problematic situation and progresses towards a solution through a strategic blend of action and reflection. Dewey described enquiry as 'the controlled or directed transformation of an uncertain situation into a unified whole, emphasising the goal of fostering collective exploration, experimentation, learning, and change in a desired direction (Steen, 2013; Shneiderman et al., 2020).

This collaborative ethos is central to participatory design, such as co-creation and co-design. Participatory and collaborative design practices leverage diverse individual skills and experiences revealed through continuous and evolving exchanges (Schuler and Namioka, 1993; Uhomoibhi et al., 2020). Such methodologies underscore the value of collective input and iterative dialogue in shaping design processes that are highly responsive to user needs and contextual challenges (Figure 7).

Communication dynamics have substantially transformed following the adoption of visual co-creation tools. Initially characterised by one-way exchanges, communication has evolved into a deeper, multidirectional interaction. As shown in Figure 8, Villagers now engage more willingly and articulately with developers and present their ideas with greater clarity. Similarly, tourists and locals initiate discussions with developers, enhancing problem-solving efficiency and proactively contributing to their perspectives. This shift has fostered stronger relationships built on mutual trust and a shared understanding of design and future development.

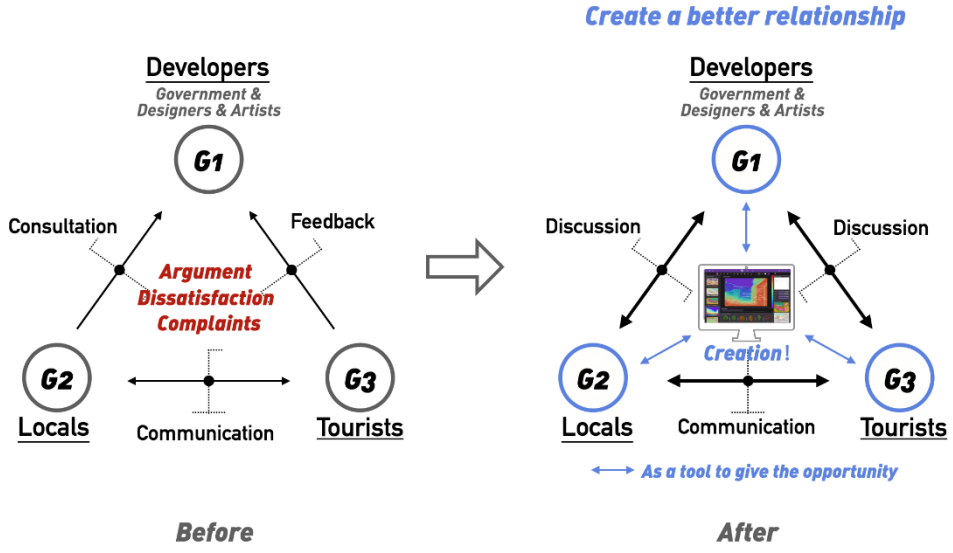
Figure 7 Co-creation process and operation process



Design teams across various industries seek to refine the idea-generation process, particularly in formulating initial ideas based on product requirements or external stakeholder inputs. A key strategy involves increasing opportunities for iterative idea generation to expand the pool of ideas and explore innovative design solutions (Karakaya and Demirkan, 2015). Teams are often divided into smaller groups to develop ideas, which are later reviewed collectively. However, less confident members may struggle to share insights due to inexperience, low confidence, or time constraints. Virtual collaboration can address these challenges by fostering a culture of innovation through increased idea generation and iterations (Dennett, 1995). This approach encourages unconventional ideas and emphasises errors as pivotal learning opportunities (Dalsgaard,

2017). Therefore, Teams are encouraged to present ideas early without fear of criticism, leveraging the design's 'fuzzy front end' for more precise outcomes. Additionally, cultivating brief and dynamic conceptual discussions often leads to unexpected discoveries.

Figure 8 Change of the relationship between different roles (see online version for colours)



6 Conclusion

This study examines the relationship between user experience and entropic image attributes, focusing on how these attributes influence perceptual and emotional reactions through visual expressiveness. Comprehensive analyses revealed that clarity, openness, density, complexity, and visual elements like colour, texture, shape, and aesthetic sensibility significantly affect users' aesthetic appreciation, pleasure, and comfort. The findings highlight the importance of clarity, orderliness, and density in enhancing user experience within a scene, supporting the visual framework's suitability for co-creative rural landscape design.

This study optimises rural scene design by integrating entropy image analysis and co-creation tools. Entropy image analysis quantifies visual and functional attributes, providing a methodological guide for rural landscape design. Co-creation tools enhance communication and collaboration between designers and community members, ensuring design solutions align with residents' needs and preferences. The synergy of entropic image analysis and co-creation tools improves design rigour, practicality, and community involvement. Despite challenges like technological complexity and sustained engagement, future research should simplify tool usability and develop strategies to motivate and engage community members in continuous rural landscape design optimisation.

Conflicts of interest

All authors declare that they have no conflicts of interest.

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