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Digital Montage-Based Visual Simulation to Evaluate Spatial Identity in the Idjen Street Heritage Corridor, Malang, Indonesia

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ABSTRACT

Historic urban corridors possess diverse visual characteristics and distinctive features that cannot be captured through conventional photographic survey techniques or through 3D modeling per building. This study aims to develop a digital montage-based simulation workflow to reconstruct and evaluate the spatial characteristics of the historic corridor of Jalan Idjen in Malang, Indonesia, a significant colonial landscape corridor currently undergoing rapid commercial transformation. The research method integrates sequential photo mapping, panoramic photo montage, low-polygon 3D modeling, and immersive rendering to reconstruct continuous visual sequences that represent spatial continuity, façade rhythm, and mass proportions along the corridor. Despite the growing use of digital visualization in heritage studies, most existing approaches focus on individual buildings or static reconstructions rather than corridor-scale spatial perception. This research addresses this gap by translating pedestrian-scale visual perception into a qualitative spatial identity evaluation through immersive digital montage modeling. The results indicate that visual quality, spatial legibility, and aesthetic coherence of the corridor are strongly influenced by the uniformity of building height and setbacks as well as the presence of vegetation, which reinforces the historic corridor identity. Conversely, dense signage, color inconsistencies, and fragmented building masses disrupt visual continuity and weaken the spatial coherence of the heritage streetscape. Furthermore, the proposed workflow framework demonstrates efficient and replicable analytical capabilities for diagnosing spatial identity in other historic urban corridors, providing a practical tool to support conservation policies and guide the visual management of rapidly transforming heritage streetscapes.

Keywords: Heritage Urban Corridor, Spatial Identity, Digital Montage, Urban Visual Simulation, Streetscape Visualization

ABSTRAK

Koridor perkotaan bersejarah memiliki karakteristik dan identitas visual yang kompleks yang tidak dapat sepenuhnya direpresentasikan melalui teknik survei fotografi konvensional maupun pemodelan tiga dimensi per bangunan. Penelitian ini bertujuan mengembangkan kerangka kerja simulasi digital berbasis montase untuk merekonstruksi dan mengevaluasi karakteristik spasial koridor bersejarah Jalan Idjen di Kota Malang, Indonesia, yang merupakan salah satu lanskap perkotaan kolonial penting yang saat ini mengalami transformasi komersial yang cepat. Metode penelitian mengintegrasikan pemetaan foto sekuensial, montase panorama, pemodelan tiga dimensi berteknik low polygon, serta rendering imersif untuk merepresentasikan rangkaian visual yang membentuk kontinuitas ruang, ritme fasad, dan proporsi massa bangunan sepanjang koridor. Meskipun pemanfaatan teknologi visualisasi digital dalam kajian warisan budaya semakin berkembang, sebagian besar pendekatan yang ada masih berfokus pada bangunan tunggal atau rekonstruksi statis, sehingga belum mampu menangkap persepsi spasial pada skala koridor perkotaan secara utuh. Penelitian ini mengisi kesenjangan tersebut dengan menerjemahkan persepsi visual pejalan kaki menjadi

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evaluasi identitas spasial melalui pemodelan montase digital imersif. Hasil penelitian menunjukkan bahwa kualitas visual, keterbacaan spasial, dan koherensi estetika koridor dipengaruhi secara signifikan oleh keseragaman tinggi dan setback bangunan serta keberadaan vegetasi yang memperkuat identitas koridor bersejarah. Sebaliknya, dominasi signage, ketidakkonsistenan warna fasad, serta fragmentasi massa bangunan menyebabkan terganggunya kesinambungan visual kawasan. Selain itu, kerangka kerja metodologis yang dikembangkan terbukti efisien dan mudah direplikasi untuk menganalisis segmen koridor bersejarah lainnya, sehingga dapat mendukung perumusan kebijakan konservasi serta pengendalian perkembangan visual dan spasial pada koridor perkotaan bersejarah.
Kata Kunci: Koridor Perkotaan Bersejarah; Identitas Spasial; Montase Digital; Simulasi Visual Perkotaan; Visualisasi Streetscape.

1. Introduction

Malang is a historic city on the island of Java, Indonesia, where the early growth of its urban space in the 20th century was heavily influenced by the planning work of Herman Thomas Karsten, a Dutch architect. Karsten adapted European urban planning principles to tropical climatic conditions, shaping the design of elite colonial residential districts such as the Idjen Boulevard housing area (Erine et al., 2022). During the Dutch colonial period, the spatial structure of Malang evolved through several architectural phases, including the Indische Empire style (1850–1900), early modern colonial architecture (1900–1915), and the Nieuwe Bouwen movement (1916–1940). These architectural and planning principles shaped the formation of several colonial urban corridors in Malang, including the Jalan Idjen corridor, which was designed as a ceremonial boulevard characterized by spacious setbacks, tree-lined streets, and colonial residential architecture (Gawryszewska et al., 2023). Today, the Jalan Idjen corridor functions not only as a transportation axis but also as an important urban landscape that reflects the historical identity and spatial structure of Malang City. (Lisa Dwi Wulandari et al., 2024).

This research is grounded in the legal framework of Malang City Regulation No. 4 of 2011, which establishes Jalan Idjen as part of the city's designated cultural heritage environment within the Spatial Plan of Malang (2010–2030). The regulation recognizes the corridor as an urban heritage landscape that contributes to the collective image and spatial memory of the city (Bagnolo & Manca, 2019). Buildings along the Jalan Idjen corridor accommodate a combination of contemporary commercial functions and historic streetscape elements, which collectively shape the distinctive character of the urban environment (Boumezoued et al., 2020). Representative commercial buildings selected in this study include Starbucks, Burger King, Family Mart, Times Indonesia, Kopi Kenangan, Kimia Farma, Happy Shoes, Latar Idjen, and Subway. The selection of these buildings illustrates the diversity of contemporary commercial entities within a representative heritage corridor (Santosa, Yudono, et al., 2023a).

The concept of spatial identity in historic urban corridors has been widely discussed in classical urban design theory. Kevin Lynch emphasizes that the legibility of spatial elements such as paths, edges, nodes, landmarks, and districts shapes urban identity. Gordon Cullen highlights the importance of sequential visual perception and the experiential quality of streetscapes through the concept of townscape. Aldo Rossi interprets the city as a collective artifact where historical structures and spatial patterns form long-term urban memory. Similarly, Norberg-Schulz introduces the concept of genius loci, emphasizing that the character of a place emerges from the relationship between architecture, landscape, and human perception (Gordon Cullen, 1961; Kevin Lynch, 1964; Rossi, 1982; Schulz, 1980). Within this perspective, the spatial identity of a historic corridor emerges from the interaction between architectural forms, visual sequences, and perceptual experiences that collectively define the character of the urban environment (Al-Shammari & Na'im Mohsin, 2024; Santosa et al., 2021). Digital visualization techniques have increasingly been used to document and analyze historic urban environments. These techniques are particularly useful for examining the continuity, articulation, and proportional relationships of streetscapes (Lisa Dwi Wulandari et al., 2024; Santosa, Yudono, et al., 2023b). This study, therefore, employs a structured visualization methodology to assess the spatial identity of the Jalan Idjen historic corridor through the reconstruction of façade rhythm, spatial proportions, and streetscape continuity using a combination of field photography and digital montage-based simulation (Santosa et al., 2020; Yudono et al., 2020).

However, most previous studies on digital heritage visualization focus primarily on individual buildings or static reconstructions, rather than analyzing spatial perception at the scale of urban corridors. Traditional photographic surveys often document buildings as isolated objects, which limits their ability to capture the continuous spatial experience of streetscapes (Santosa, Yudono, et al., 2023a). Therefore, this research offers a digital methodology that utilizes visual simulation based on a digital montage workflow that includes the following activity stages: integration of sequential field photography, panorama alignment, and digital rendering. The workflow strategy aims to construct spatial and visual dimensions and layout. The primary aim of the research is to examine the visual coherence and urban character of the Jalan Idjen corridor through the lens of human spatial perception. The research findings furnish a robust foundation for planning, conserving, and enhancing corridor spatial design, in addition to serving as a methodological reference for the sustainability of historic corridors (Wardhani & Wastunimpuna, 2025).

Various previous studies that have used digital visualization techniques on historic buildings have only focused on static materials or virtual reconstructions which do not yet represent pedestrians' perceptions of historic corridor spaces in everyday life. Most current methods treat building facades and streetscape elements as separate visual objects, underestimating that the entire spatial element is a continuous spatial sequence that helps define a city's identity. Standard photographic surveys can capture intricate detail, but struggle to convey the rhythmic organization, volumetric hierarchy, and perceptual coherence of the entire corridor space. While advanced 3D and virtual reality simulations can represent urban environments in detail, they frequently require substantial technical resources and are rarely integrated systematically with field-based photographic documentation (Yudono et al., 2020). As a result, methodological limitations remain in evaluating spatial identity at the corridor scale, particularly in historic urban areas experiencing rapid commercial transformation (Erine et al., 2022; Lisa Dwi Wulandari et al., 2024). This research addresses the existing gap by introducing a digital montage-based visual simulation methodology that amalgamates sequential picture mapping, 3D modeling, and immersive rendering into a coherent framework of visual identity markers.

To address this gap, this research proposes a digital montage-based visual simulation methodology that integrates sequential photo mapping, 3D low-polygon modeling, and immersive rendering. The proposed framework enables the reconstruction and evaluation of spatial identity at the corridor scale through a coherent set of visual indicators. The research is structured around three main objectives:

1. Reconstruct the spatial rhythm, façade articulation, and volumetric proportions of the Jalan Idjen corridor through field photography, digital montage, and 3D modeling;
2. Evaluate the spatial identity of the corridor based on visual harmony, spatial legibility, and perceived aesthetic quality.
3. Formulate planning and conservation recommendations that balance contemporary commercial transformation with the preservation of the historic character of Jalan Idjen.

2. Method

This research uses a digital montage-based visual simulation methodology that combines sequential photo mapping, 3D low polygon modeling, and immersive rendering to evaluate the spatial identity of the historic Jalan Idjen corridor in Malang, Indonesia. Historically, the Jalan Idjen corridor was part of the “Willis Weg” axis within the Bergenbuurt residential district, a planned colonial neighborhood developed in the early twentieth century (see Fig 1).

Figure 1. Map of the Study Area

Bergenbuurt was designed by the Dutch architect Thomas Karsten in the 1930s and is currently located in Klojen District. The district is characterized by a street naming system based on Indonesian mountains, including Semeru, Kawi, Arjuno, and Kelud streets. The central axis, Jalan Besar Ijen (Ijen Boulevard), was originally planned as a spacious tree-lined boulevard with strong visual orientation toward Mount Kawi, reinforcing the heritage value and symbolic urban character of the area.

The proposed workflow represents a medium-intensity level of digital heritage visualization, providing spatial continuity and analytical precision while requiring significantly fewer resources than full Building Information Modeling (BIM) or immersive virtual reality reconstruction (Noardo, 2020; Santosa et al., 2020). This methodological positioning is particularly suitable for historic corridors undergoing rapid commercial transformation, where diagnostic speed, visual clarity, and methodological replicability are essential (Pavelka, 2022; Sukwai et al., 2022). Recent advances in digital spatial documentation demonstrate that corridor-scale visualization can support spatial continuity analysis and identity-based conservation planning (Deng et al., 2025; Ezz et al., 2025).

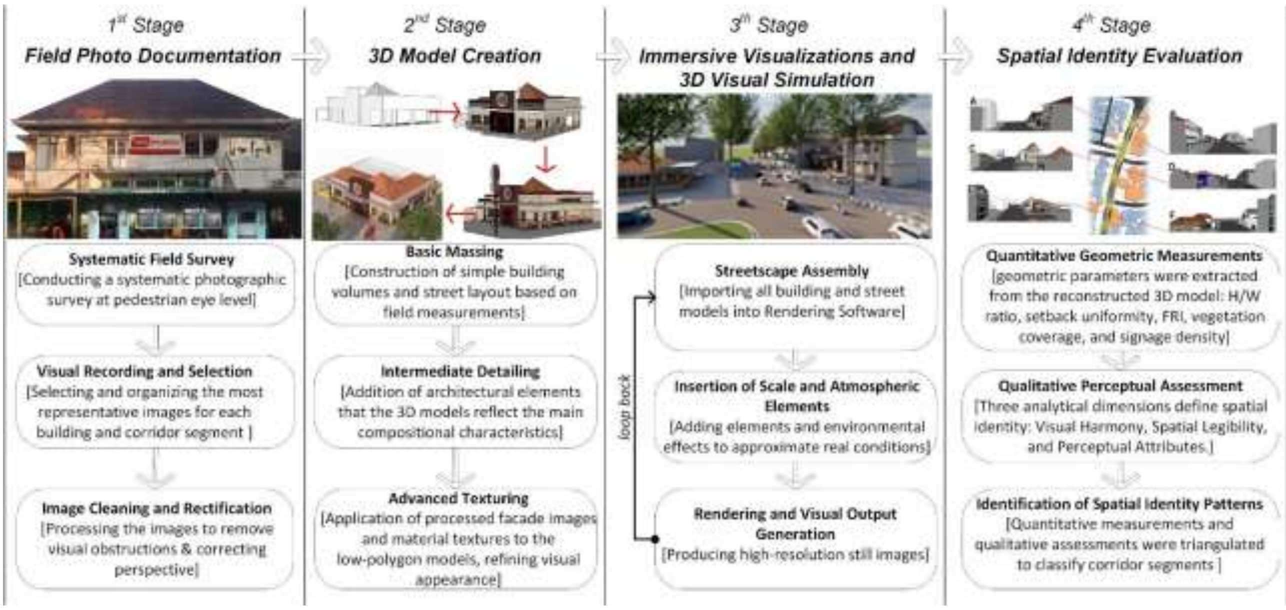

Figure 2. Digital Montage-Based Visual Simulation Workflow

The research design consists of four sequential stages (see Figure 2) namely (1) Systematic field photo documentation of architectural façades, vegetation structures, and street furniture along the Jalan Idjen corridor; (2) 3D low-polygon modeling using SketchUp software to reconstruct building massing, façade rhythm, and spatial proportions; (3) Immersive streetscape rendering using Lumion software to simulate environmental atmosphere and spatial continuity; and (4) Structured spatial identity evaluation based on quantitative and qualitative indicators derived from the digital simulation. This phased workflow is conceptually aligned with recent 3D spatial development studies on historic road corridors, which demonstrate the effectiveness of a combination of modeling and visualization platforms can support diagnostic analysis and policy-oriented management of historic areas (Santosa et al., 2020; J. Wang & Zakaria, 2025).

The spatial identity evaluation stage combines quantitative geometric measurements and qualitative perceptual assessment derived from immersive digital montage simulations. Geometric parameters extracted from the 3D model include building height-to-street width ratio (H/W ratio), setback uniformity, façade rhythm index (FRI), vegetation coverage, and signage density. These parameters were measured across six corridor segments (A–F) using orthographic overlay analysis and proportional indexing. This allows careful interpretation of the qualitative interactions between visual (façade articulation), spatial (mass hierarchy), and contextual (vegetation-street integration) elements that shape the corridor's heritage character (Deng et al., 2025; Santosa et al., 2025).

Height-to-width ratio (H/W) was calculated by dividing the average building height by the effective street width (façade-to-façade) to represent spatial enclosure. At the same time, setback uniformity was measured as the mean distance between building façades and the street edge with its standard deviation, indicating the consistency of building alignment within each segment. The formula of the calculated Height-to-width ratio (H/W) and the mean setback distance is as follows:

$$H/W = \bar{H} / W$$

Where:
H/W = height-to-width ratio
$\bar{H}$ = average building height within the segment (m)
W = effective street width measured from façade to façade (m)

$$\bar{S} = (\Sigma S_i) / n$$

Where:
$\bar{S}$ = mean setback distance
S_i = setback distance of building i from the street edge
n = number of buildings in the segment

The Façade Rhythm Index (FRI) was developed to quantify the regularity of façade module spacing along the historic urban corridor. The index is conceptually derived from the coefficient of variation (CV), a statistical indicator commonly used to measure the relative dispersion of interval distributions (Montgomery & Runger, 2019). In urban design theory, façade rhythm plays a crucial role in shaping the visual continuity and perceptual structure of streetscapes. Cullen (1961) emphasizes that rhythmic repetition of architectural elements contributes to the sequential visual experience of urban environments, while Lynch (1960) highlights that consistent spatial patterns enhance the legibility and identity of urban spaces. To operationalize this concept quantitatively, the Façade Rhythm Index is defined as:

$$FRI = 1 - (\sigma / \mu)$$

where:
σ = standard deviation of window spacing intervals
μ = mean spacing between façade modules

By inverting the coefficient of variation, the index expresses the degree of rhythmic consistency of façade articulation along the corridor. Values approaching 1 indicate highly regular façade spacing, while lower values indicate fragmented or irregular façade patterns. This metric provides a replicable analytical tool for comparing corridor segments and supports the evaluation of visual harmony and spatial identity in historic urban environments, consistent with contemporary approaches to measuring urban design qualities in streetscape studies (Ewing & Handy, 2009). The index ranges from 0 to 1, where values closer to 1 indicate stronger rhythmic consistency in façade articulation along the corridor.

Vegetation coverage was calculated as the percentage of visible green elements within each segment’s façade view field based on vegetation surface area in the 3D model. At the same time, signage density was measured by counting the number of visible signage elements per 10-meter façade length to represent the intensity of commercial visual information along the corridor. The formula for the calculated Vegetation coverage and signage density is as follows:

$$VC = (A\_v / A\_t) \times 100\%$$
Where:
VC = vegetation coverage (%)
A_v = visible vegetation surface area within the segment
A_t = total streetscape surface area within the segment

$$SD = N\_s / L\_f$$
Where:
SD = signage density (units per meter)
N_s = number of visible signage elements
L_f = total façade length of the analyzed segment (m)
Normalized per 10 meters: $SD\_10 = (N\_s / L\_f) \times 10$

Following the spatial metric extraction, the spatial identity of the Jalan Idjen corridor was assessed through a qualitative perceptual assessment of six representative viewpoints (A–F) derived from immersive streetscape simulations. Three analytical dimensions were used to interpret spatial identity through the identification of morphological indicators and key visual features:
1. Visual Harmony: Visual harmony evaluates façade rhythm, material transitions between buildings, and the integration of vegetation within the streetscape. Measurements include Façade Rhythm Index, material transition gradient, and vegetation alignment patterns.
2. Spatial Legibility: Spatial legibility assesses the clarity of spatial orientation and visual structure along the corridor using alignment vectors, coefficient of scale variance, landmark prominence, and intersection visibility.
3. Perceptual Attributes: Perceptual attributes evaluate the aesthetic and atmospheric qualities of the streetscape by interpreting how spatial configurations are visually perceived through proportional relational analysis, texture continuity metrics, historical–contemporary layering, and material shading interactions derived from immersive streetscape rendering.

These spatial indicators correspond with established urban design metrics used to evaluate streetscape quality, particularly enclosure, visual complexity, and imageability as conceptualized in the urban design measurement framework (Ewing et al., 2013). By combining morphological observation with quantitative spatial metrics, the analysis provides a structured approach to understanding how corridor-scale physical attributes influence streetscape perception and spatial identity.

The qualitative spatial evaluation was conducted using expert-based visual assessment of immersive renderings. Experts independently identified key morphological indicators and visual features. Subsequently, they evaluated the simulated viewpoints using a structured evaluation matrix across three analytical dimensions: visual harmony, spatial legibility, and perceptual attributes. The results of quantitative measurements and qualitative assessments were triangulated to classify corridor segments into three spatial identity categories: strong identity, moderate identity, and weak identity (Ito et al., 2024; Wardhani & Wastunimpuna, 2025).

3. Result and Discussion

This research reconstructs the historic corridor of Jalan Idjen in Malang City as a continuous spatial experience, enabling the identification and evaluation of façade rhythm, volumetric composition, building setback regularity, and vegetation structure under conditions of rapid commercial transformation. The research results synthesize quantitative geometric indicators and qualitative visual assessments. These results are used for three purposes: 1) identifying patterns of visual harmony, spatial legibility, and aesthetic perception across corridor segments; 2) explaining how contemporary commercial interventions reinforce or disrupt the coherence of the historic streetscape; and 3) providing evidence-based recommendations for conservation-oriented planning and design control in historic urban corridors.

3.1. Result

In the first stage, visual data collection targeted ten representative commercial buildings along the Jalan Idjen corridor (Subway, Times Indonesia, Kopi Kenangan, Family Mart, Bukopin, Kimia Farma, Happy Shoes, Burger King, Background Idjen, and Starbucks). These buildings were selected based on functional diversity, variation in facade articulation, and spatial distribution along the corridor to ensure a comprehensive sampling of spatial transitions. Photographs were captured using a high-resolution smartphone camera equipped with a 200 MP main sensor and 10 MP telephoto lens (3× optical zoom). Images were taken at pedestrian eye level (1.6 m), at 15–20 m from the façade, and using frontal panorama and angled views (±30°). Photographs were captured during consistent morning lighting conditions (08:00–10:00 WIB) to ensure uniform illumination and minimize shadow distortion.

The visual image capture of photographs is thoroughly recorded on each architectural facade (ornamentation, window rhythm, material texture), volumetric proportions (height, setback, mass), vegetation partitions (species, density, alignment), street furniture (benches, lighting, support pillars), and contextual relationships (building proximity to the street, intersection nodes), aiming to capture static compositions and dynamic spatial flows that are important for identity analysis. The photographic dataset documented façade articulation, volumetric proportions, vegetation structures, street furniture, and spatial relationships between buildings and the street corridor. The images were subsequently processed through graphic editing software to correct lens distortion, adjust perspective alignment, and assemble continuous visual montage sequences representing the corridor environment (see Figure 3).

Figure 3. Systematic Mapping of Existing Buildings on Idjen Street

In the second stage, 3D low-polygon modeling was developed to reconstruct the volumetric structure and spatial proportions of the Jalan Idjen corridor. The modeling workflow consisted of three main steps:

1. Volumetric base modeling based on traced façade outlines from field photographs
2. Addition of architectural elements such as roof geometry, window patterns, and façade articulation
3. Contextual streetscape modeling, including pavement layout, vegetation strips, and building setbacks.

The reconstructed corridor model reflects consistent building setbacks (4–6 m) and a height-to-width ratio of approximately 1.2–1.8, which contribute to the spatial enclosure of the street corridor. The model was validated using orthographic overlay comparison between field photographs and digital geometry to ensure proportional accuracy (see Figure 4).

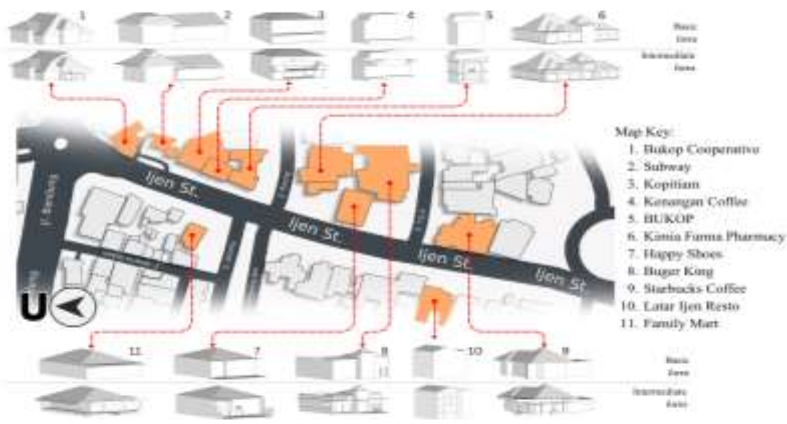

Figure 4. Modeling Progression: Basic Volumetric Forms to Intermediate Architectural Detailing

The advanced low-polygon texturing uses facade photos that are processed as UV-mapped material on each building surface via a planar projection technique to ensure the texture adheres well. The entire visual image of a photo preserves and records the weathering of actual materials, small changes in color, and surface details that are retained to reflect field conditions so that light can realistically interact with them at different times of the day. Low polygon optimization keeps the model simple (less than 5,000 surfaces per building) so assembly and rendering of corridors is light. Each final modeling result is checked for accuracy based on reference images to ensure correct proportions from small building details to broader street alignments. The lightweight model size (200–900 KB) provides photorealistic imagery suitable for immersive visualization of city landscapes (see Figure 5).

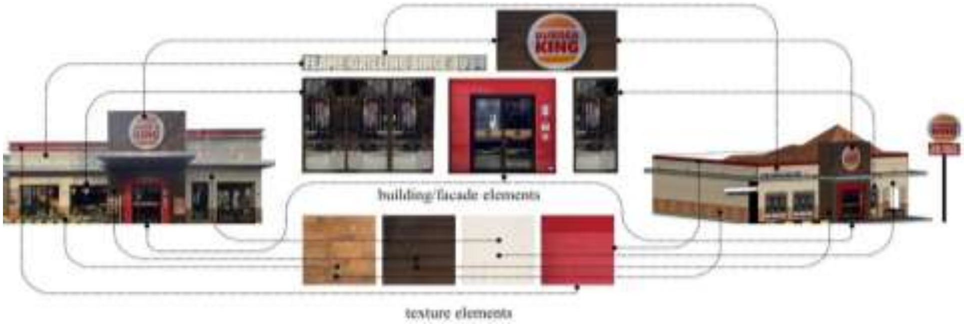

Figure 5. Advanced Texturing Workflow

In the third stage, the individual building models were assembled in Lumion software to reconstruct the full spatial configuration of the Jalan Idjen corridor. Six observation viewpoints (A–F) were established along the corridor to represent transitional areas, nodal intersections, and zones of commercial transformation. Each viewpoint was positioned at pedestrian eye level (1.6 m) with a viewing angle of 30–45°. The output consisted of high-resolution rendered images (4K, 16:9 ratio) that enabled visual comparison of spatial harmony, façade rhythm, and atmospheric coherence along the corridor (see Figure 6).

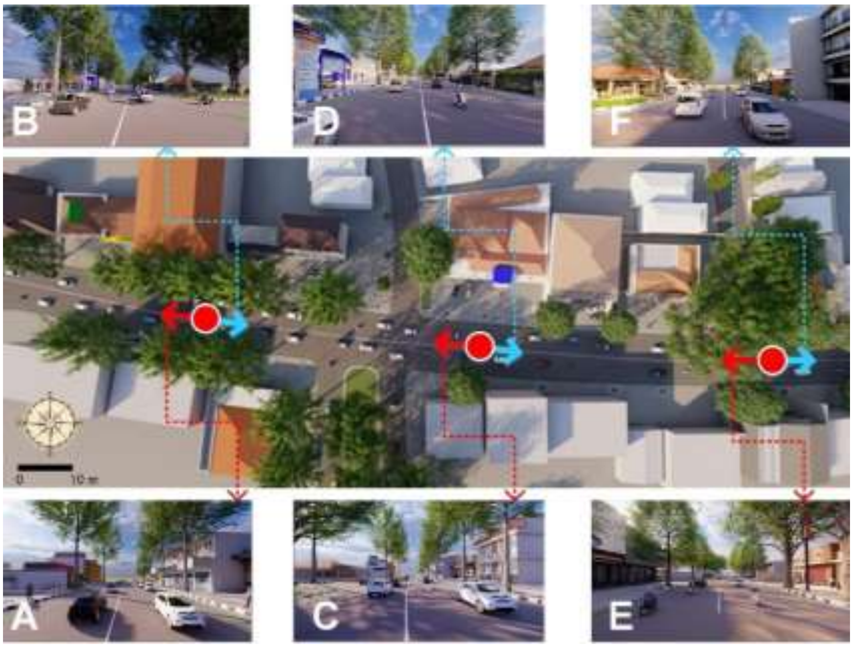

Figure 6. Immersive Visualization Results at Each Viewpoint

The immersive simulation revealed that the spatial identity of Jalan Idjen emerges from the interaction between proportional order, façade rhythm, and landscape framing. Comparative analysis between simulation outputs and field photographs demonstrates improved spatial legibility after removing visual obstructions in the digital montage, thereby revealing previously obscured façade continuity. In addition, the reconstructed spatial scale enables the quantification of street enclosure effects that are not clearly captured in conventional two-dimensional photographic documentation (see Table 1).

Table 1. Comparative Visualization Metrics across Workflow Stages

No.	Stage	Key Output	File Size	Spatial Information	Analytical Value
1.	Field Photos	Raw/Processed Frontals	5-10 MB/image	Isolated facades, details	Documentation baseline
2.	Basic 3D Forms	Volumetric Masses	100-300 KB	Proportions, alignments	Rhythm abstraction
3.	Intermediate Detail	Architectural Articulation	300-600 KB	Facade cadences, transitions	Character emergence
4.	Immersive Render	Full Streetscape + Scales	50-200 MB/scene	Complete spatial experience	Perceptual synthesis

The results of the digital simulation analysis demonstrate the reliability of the digital montage workflow for spatial identity assessment. Each analytical stage reveals progressively more complex spatial patterns, ranging from the proportional structural framework of the corridor to the experiential atmospheric representation generated through immersive rendering. The approach, therefore, provides planners with a practical visualization tool for communicating spatial conditions and supporting evidence-based conservation planning. Another advantage of the workflow lies in its resource efficiency, as the method can be implemented using mid-range computing hardware and widely accessible modeling software. This efficiency increases the potential for applying the method to other historic urban corridors experiencing similar pressures from rapid commercial transformation. This efficiency increases the potential for applying the method to other historic urban corridors experiencing similar pressures from rapid commercial transformation (Deng et al., 2025; Noardo, 2020).

Table 2. Quantitative Spatial Parameters Extracted from 3D Models by Segment (A-F)

Segment	H/W Ratio	Setback Uniformity (m)	Facade Rhythm Index*	Vegetation Coverage (%)	Signage Density (items/10m)
A (Transition)	1.35	4.6 ±0.9	0.63	24	3.4
B (Core Corridor)	**1.62**	**5.1 ±0.3**	**0.84**	**36**	**1.6**
C (Node)	1.72	5.5 ±0.4	0.80	**41**	2.2
D (Commercial Accent)	1.48	4.8 ±1.0	0.69	27	4.7
E (Vibrant Core)	**1.83**	**4.1 ±1.5**	**0.54**	**17**	**7.5**
F (Quiet Transition)	1.32	5.0 ±0.6	0.72	33	2.6
Avg.	1.55	4.85	0.70	30	3.7

*Facade Rhythm Index = consistency of window spacing intervals (0-1 scale)
Bold = strongest/weakest performance.

To quantify the spatial characteristics of the corridor and provide quantitative validation of the six viewpoints (A–F), geometric parameters were extracted from the reconstructed 3D model, including the height-to-width ratio (H/W), setback uniformity, façade rhythm index (FRI), vegetation coverage, and signage density (see Table 2). Overall, the corridor shows relatively stable proportional characteristics, although some segments indicate stronger commercial influence. Segments B and C, representing the core corridor, exhibit the strongest spatial performance. Segment B shows a balanced H/W ratio (1.62), the most consistent setbacks (5.1 ± 0.3 m), and the highest façade rhythm index (0.84), while Segment C presents a slightly higher enclosure ratio (1.72) and the highest vegetation coverage (41%). These parameters reinforce visual harmony, spatial legibility, and façade rhythm within the core corridor. In contrast, Segment E demonstrates the weakest spatial coherence, characterized by the highest signage density (7.5 items/10 m), the lowest vegetation coverage (17%), and the lowest façade rhythm index (0.54), indicating a fragmented streetscape influenced by intensive commercial activity. Meanwhile, transitional segments A and F show moderate spatial performance. Segment A exhibits heterogeneous building heights and irregular setbacks (H/W = 1.35). In contrast, Segment F presents a calmer streetscape with stronger vegetation presence (33%) and relatively stable façade rhythm (0.72), functioning as a spatial buffer that maintains corridor continuity.

Table 3. Spatial Identity Characteristics by Segment

Segment	Morphological Indicators	Key Visual Features	Visual Harmony	Spatial Legibility	Perceptual Attributes

A (Transition)	Varied building heights; mixed residential–commercial typology; irregular setbacks	Small shop houses mixed with residential buildings; discontinuous façade alignment	Moderate (varied massing)	Low (irregular edges and weak enclosure)	Gradual functional shift; heterogeneous streetscape perception
B (Core Corridor)	Consistent building heights; strong street-tree rhythm; continuous street wall	Continuous commercial frontage; boulevard-like tree canopy	Strong (rhythmic continuity)	High (clear corridor boundaries)	Strong sense of direction and corridor continuity
C (Node)	Intersection landmark massing; increased spatial openness	Distinctive roof form acting as a focal landmark	Strong (monumental emphasis)	High (orientation cues)	Orientation anchor and visual reference point
D (Commercial Accent)	Retail frontage concentration; façade color contrast	Pharmacy storefront signage and active shopfronts	Moderate (visual tension)	Moderate (accent-based orientation)	Localized visual focus along the corridor
E (Vibrant Core)	Dense commercial frontage; layered façade articulation	Intensive signage and branding create a busy visual field	Weak (fragmented composition)	Moderate (dynamic cues)	High visual stimulation and dynamic street activity
F (Quiet Transition)	Reduced building scale; increased residential presence; strong tree canopy	Less commercial signage; calmer frontage composition	Moderate (gradual shift)	High (clear spatial closure)	Visual calmness and spatial closure toward the corridor edge

In the final stage, the spatial identity of the Jalan Idjen corridor was evaluated through a qualitative visual assessment of six viewpoints (A–F) derived from immersive simulations, where each viewpoint represents a distinct spatial condition along the corridor (see Table 3). These quantitative findings in Table 2 provide the empirical basis for the subsequent qualitative evaluation, where expert assessments of immersive viewpoints are used to interpret how these spatial configurations influence the perceived identity of the corridor. Within this shared structural framework, immersive visualization reveals six distinct spatial identities across viewpoints A–F, each characterized by different levels of morphological indicators, key visual features, perceptual attributes, visual harmony, and spatial legibility.

Segment-based analysis reveals clear variations in spatial identity and visual legibility along the corridor. Segments B and C demonstrate the strongest spatial coherence, supported by both morphological and quantitative indicators. Segment B exhibits the highest façade rhythm index (0.84), consistent building alignment (5.1 ± 0.3 m setback), and relatively high vegetation coverage (36%), reinforcing corridor continuity and visual harmony. Segment C functions as a nodal landmark where increased spatial openness and the highest vegetation coverage (41%) enhance spatial orientation and corridor prominence. This observation is consistent with previous studies highlighting the importance of rhythmic façade alignment and spatial enclosure in shaping urban streetscape perception and visual coherence (Carmona, 2021; Cullen, 1961; Ewing et al., 2013; Ewing & Handy, 2009; Kevin Lynch, 1964; Li Xiaojing et al., 2015; Zhang et al., 2018).

In contrast, Segments D and E reflect increasing commercial intensity and a partial decline in spatial coherence. Segment D shows elevated signage density (4.7 items/10 m) and moderate façade rhythm (0.69), introducing localized visual tension within the corridor. This condition becomes more pronounced in Segment E, where the highest signage density (7.5 items/10 m), the lowest façade rhythm index (0.54), and the lowest vegetation coverage (17%) contribute to a fragmented streetscape composition and weaker visual harmony.

Segments A and F represent transitional conditions within the corridor structure. Segment A displays heterogeneous building heights and irregular setbacks, resulting in moderate enclosure (H/W = 1.35) and lower spatial legibility. In contrast, Segment F presents a calmer streetscape characterized by smaller building scales and stronger tree canopy presence, reflected in moderate vegetation coverage (33%) and clearer spatial closure.

Overall, the spatial identity of the Jalan Idjen corridor forms a spatial gradient rather than a uniform streetscape condition. Three spatial zones emerge: transitional segments (A and F), core corridor segments with strong spatial coherence (B and C), and commercially intensified segments (D and E). This spatial gradient reflects the ongoing negotiation between historic urban morphology and contemporary commercial transformation within evolving urban corridors (Carmona, 2021; Conzen, 1960; Cullen, 1961; Ewing et al., 2013; Ewing & Handy, 2009; Kevin Lynch, 1964; Li Xiaojing et al., 2015; Zhang et al., 2018).

The sequential viewpoints (A–F) also reflect a townscape progression, where changes in enclosure, architectural rhythm, and visual landmarks shape the experiential sequence of the corridor (Cullen, 1961). The selected spatial indicators correspond with established urban design metrics, particularly enclosure, visual complexity, and imageability, commonly used to evaluate streetscape quality (Ewing et al., 2013). Segments with stronger proportional order were characterized by higher façade rhythm, balanced H/W ratios, and greater vegetation presence, maintaining higher levels of visual harmony and spatial legibility. Conversely, segments with dense signage and fragmented façade articulation exhibit weaker corridor identity. These findings highlight the importance of signage regulation, façade alignment guidelines, and vegetation reinforcement in maintaining the visual coherence of historic urban corridors.

3.2. Discussion

This study proposes a digital montage–based visual simulation workflow to evaluate the spatial characteristics of historic urban corridors undergoing commercial transformation. The approach introduces a scalable, moderate-intensity methodology that combines sequential photographic documentation with simplified 3D modeling to reconstruct corridor morphology and assess spatial identity. By employing low-polygon modeling, the workflow enables planners to diagnose corridor segments that retain spatial coherence and those experiencing accelerated commercial change. This method supports conservation strategies focused on maintaining proportional order, such as skyline composition, façade alignment, and setback regularity, while preserving the overall volumetric rhythm of the street corridor (Ji et al., 2023).

The digital montage-based visual simulation method is part of a larger trend in cultural heritage visualization that aims to integrate geometric correctness with perceptual evaluation, moving away from seeing digital models as only outputs that represent something (Y. Wang et al., 2024). Recent research has shown that combining immersive and semi-immersive environments with structured visual metrics can greatly improve understanding of visual features and decision-making about urban heritage landscapes. This supports the effectiveness of a combined "objective + subjective" evaluation framework like the one used in this study (Peng et al., 2025; Y. Wang et al., 2024). The reconstruction process demonstrates that the spatial identity of Jalan Idjen emerges from a balance between repetition and variation in architectural elements, including façade articulation, roof profiles, and street-scale rhythms. The multi-stage modeling workflow—from basic volumetric representation to immersive visualization—gradually reveals the structural and perceptual qualities of the corridor (Santosa et al., 2020; Santosa, Sutikno, et al., 2023). Early modeling stages isolate proportional relationships and setback consistency that support corridor legibility. In contrast, later stages integrate façade rhythm, vegetation layers, and atmospheric textures, allowing the identification of segments where spatial continuity remains intact as well as segments where visual coherence begins to deteriorate (see Table 4).

Table 4. Stages of Progressive Visualization across Buildings on Idjen Street

The final modeling stage, as shown in Table 4, demonstrates a perceptual synthesis through the application of textures and materials through enhanced UV mapping. The computationally generated atmospheric integration of the built environment rejuvenates qualities hidden in field photographs through photometric calibration, thereby constructing a spatial identity through the synergistic interaction of geometric precision and textural authenticity (Santosa et al., 2021; Yue et al., 2023). The modelling strategy changes how we see the historic corridor by making it a hierarchical interpretive process. The multi-scale environmental dynamics show layered abstractions from basic framework modeling to experienced atmospheres that systematically show user-centered perceptual mechanisms, like the Gestalt principles of continuity and closure, that control navigation and spatial cognition in the historic corridor (Chen et al., 2024). Low-polygon models allow for scalable interactivity in parametric scenario testing, from simple orthographic views to more complex time adjustments and manipulation. They also make it easier to do sensitivity analysis to predict the effects of conservation with little extra computing power (Li et al., 2023; Wu & Chang, 2025). This workflow is an adaptive framework for managing both corridor and heritage areas (Chen et al., 2024).

Quantitative spatial metrics further confirm this pattern. Segments B and C demonstrate the strongest spatial coherence, characterized by balanced enclosure ratios, consistent setbacks, strong façade rhythm, and higher vegetation presence. These conditions reinforce corridor continuity and spatial legibility. In contrast, Segment E shows the weakest spatial performance due to high signage density, fragmented building massing, and reduced vegetation coverage, indicating perceptual degradation associated with intensive commercial activity (Redyantanu & Otto, 2025; Utami & Kharisma, 2025). Transitional segments A and F function as spatial buffers that maintain corridor continuity despite localized irregularities.

Table 5. Comparative Methodological Positioning of the Digital Montage Workflow

Approach	Data Source	Technical Complexity	Spatial Scale	Analytical Output	Applicability to Commercial Corridors
Photographic Mapping	Field photos	Low	Building-level	Descriptive inventory	Limited sequential analysis
Isovist/ Viewshed Analysis	2D plans/ laser scan	Medium	Corridor-wide	Visibility metrics	Static, non-immersive
Full BIM/VR Reconstruction	Laser scan + photogrammetry	High	Building/cluster	Interactive models	Resource-intensive
Digital Montage	Sequential photos + 3D	**Medium**	**Full corridor**	**Identity diagnosis**	**Optimal for dynamic areas**

Within the broader methodological landscape, the proposed workflow occupies a middle position between traditional photographic mapping and high-complexity BIM or VR reconstruction. Photographic mapping provides descriptive documentation but lacks sequential spatial analysis, while isovist or viewshed methods generate visibility metrics but remain largely static and non-immersive. Full BIM or VR reconstruction offers highly detailed immersive environments but requires extensive data and computational resources. In contrast, the digital montage workflow balances analytical capability and technical accessibility by enabling corridor-scale spatial analysis through simplified 3D modeling and immersive visualization (see Table 5). By integrating immersive visualization with spatial metrics, the workflow supports the diagnosis of spatial identity gradients along historic corridors and provides practical guidance for heritage-sensitive urban management (Lasorella & Cantatore, 2023). Planning interventions such as façade alignment regulation, signage control, and vegetation reinforcement can therefore be evaluated within a spatially continuous digital environment. More broadly, this study contributes to urban streetscape evaluation by integrating immersive visual simulation, segment-based spatial analysis, and quantitative urban design metrics. By structuring the analysis through sequential viewpoints, the research extends the concept of townscape progression (Cullen, 1961), interpreting corridor identity as a gradient of urban character rather than a static morphological condition. This integrated framework demonstrates how immersive modeling and spatial metrics can support more adaptive and evidence-based management of historic corridors undergoing commercial transformation.

4. Conclusion

This study demonstrates the potential of a digital montage–based visual simulation workflow for evaluating the spatial identity of historic urban corridors, using Jalan Idjen in Malang as a case study. By integrating sequential photographic documentation, simplified 3D modeling, and immersive streetscape visualization, the method reconstructs the proportional structure and experiential qualities of the corridor within a coherent analytical framework. The analysis reveals that relatively stable geometric parameters—such as height-to-width ratio and setback consistency—form the structural basis of corridor identity, while dynamic elements, including signage intensity, façade color variation, vegetation layers, and street activities, influence the perceived continuity or fragmentation of the streetscape.

The results indicate strong spatial coherence in segments B and C, where consistent enclosure ratios, façade rhythm, and vegetation continuity reinforce corridor legibility. In contrast, Segment E exhibits perceptual degradation due to dense commercial signage and fragmented building massing. These findings demonstrate that digital montage–based visualization can function as an effective diagnostic tool for identifying vulnerable segments and guiding targeted interventions, including façade alignment control, signage regulation, and vegetation reinforcement.

Methodologically, the proposed workflow contributes a medium-intensity visualization approach that bridges the gap between static photographic documentation and resource-intensive BIM or VR reconstruction. This scalable framework enables corridor-scale spatial identity analysis while remaining accessible for practical planning applications. Future research should expand this approach through user-based perception studies, multisensory environmental analysis, and comparative investigations across different historic corridors to further strengthen its applicability for heritage-sensitive urban planning.

References

Al-Shammari, R. J., & Na'im Mohsin, A. (2024). Visual Sustainability in Urban Renewal Projects Traditional Kut City Center as a Case Study. *Wasit Journal of Engineering Sciences*, *12*(1), 1–10. https://doi.org/10.31185/ejuow.vol12.iss1.516

Bagnolo, V., & Manca, A. (2019). Image Beyond The Form. Representing Perception of Urban Environment. *Architecture, Civil Engineering, Environment*, *12*(2), 7–16. https://doi.org/10.21307/acee-2019-018

Boumezoued, S., Bada, Y., & Bougdah, H. (2020). Pedestrian itinerary choice: between multi-sensory, affective and syntactic aspects of the street pattern in the historic quarter of Bejaia, Algeria. *International Review for Spatial Planning and Sustainable Development*, *8*(4), 91–108. https://doi.org/10.14246/irspsda.8.4_91

Carmona, M. (2021). *Public places urban spaces: The dimensions of urban design*. Routledge.

Chen, Y., Wu, H., & Wei, W. (2024). Different Patterns of Religious Settlements Based on the Historic Landscape Approach: Cases of Buddhist Grottoes in Hexi Corridor. *Religions*, *15*(12). https://doi.org/10.3390/rel15121531

Conzen, M. R. G. (1960). Alnwick, Northumberland: a study in town-plan analysis. *Transactions and Papers (Institute of British Geographers)*, (27), iii–122. https://10.1177/0309132509334948

Cullen, G. (1961). The Concise Townscape, Architectural Press. *Wielka Brytania, London*.

Deng, Y., Ma, Q., & Zhang, Y. (2025). Identification, evaluation, classification of the Chengdu-Chongqing Ancient Road cultural heritage corridor. *Npj Heritage Science*, *13*(1). https://doi.org/10.1038/s40494-025-02207-7

Erine, K. N., Rimasari, S., & Sapto, A. (2022). Eksistensi bangunan gaya kolonial Belanda di kawasan Kayutangan, Kota Malang pada tahun 1900-2021. *Historiography*, *2*(4), 588. https://doi.org/10.17977/um081v2i42022p588-602

Ewing, R., Clemente, O., Neckerman, K. M., Purciel-Hill, M., Quinn, J. W., & Rundle, A. (2013). *Measuring urban design: Metrics for livable places* (Vol. 200). Springer. https://10.5822/978-1-61091-209-9

Ewing, R., & Handy, S. (2009). Measuring the unmeasurable: Urban design qualities related to walkability. *Journal of Urban Design*, *14*(1), 65–84. https://doi.org/10.1080/13574800802451155

Ezz, M. S., Soliman, A. M., Aldelgawy, M., Salem, D. A. H., & Khalil, R. (2025). Utilizing 3D GIS for the sustainable management of UNESCO World Heritage Sites in Saudi Arabia. *Frontiers in Built Environment*, *11*(March), 1–11. https://doi.org/10.3389/fbuil.2025.1550124

Gawryszewska, B. J., Myszka, I., Banaszek, M., & Schwerk, A. (2023). Periurban Streetscape—Vernacular Front Gardens and Their Potential to Provide Ecosystem Services: A Case Study of Warsaw, Poland. *Sustainability (Switzerland)*, *15*(3). https://doi.org/10.3390/su15032450

Gordon Cullen. (1961). *Townscape*. The Architectural Press.

Ito, K., Kang, Y., Zhang, Y., Zhang, F., & Biljecki, F. (2024). Understanding urban perception with visual data: A systematic review. *Cities*, *152*. https://doi.org/10.1016/j.cities.2024.105169

Ji, H., Li, Y., Li, J., & Ding, W. (2023). A Novel Quantitative Approach to the Spatial Configuration of Urban Streets Based on Local Wind Environment. *Land*, *12*(12). https://doi.org/10.3390/land12122102

Kevin Lynch. (1964). *The Image of the City*. The MIT Press.

Lasorella, M., & Cantatore, E. (2023). 3Dcitymodels To Support Technical Knowledge and Management of Historic Built Environments. a Semantic Citygml-Based Model for the Ancient Core of Carovigno (Br), Italy. *Scires-It*, *13*(1), 101–116. https://doi.org/10.2423/i22394303v13n1p101

Li XiaoJiang, L. X., Zhang ChuanRong, Z. C., Li WeiDong, L. W., Ricard, R., Meng QingYan, M. Q., & Zhang WeiXing, Z. W. (2015). *Assessing street-level urban greenery using Google Street View and a modified green view index. https://10.1016/j.ufug.2015.06.006*

Li, Z., Zhang, Y., & Du, W. (2023). *The Forward Modeling and 3D Printing of a Historical Building*. https://www.researchsquare.com/article/rs-3696342/v1. https://doi.org/10.21203/rs.3.rs-3696342/v1

Lisa Dwi Wulandari, Noviani Suryasari, & Salsabila Larasati. (2024). Dynamics of Cultural Landscape on Idjen Boulevard as an Icon of Heritage Street Corridor in Malang City - Indonesia. *Evolutionary Studies in Imaginative Culture*, 1040–1053. https://doi.org/10.70082/esiculture.vi.992

Montgomery, D. C., & Runger, G. C. (2019). *Applied statistics and probability for engineers*. John wiley & sons.

Noardo, F. (2020). Architectural heritage information in 3D geospatial models: Developing opportunities and challenges. *Science and Digital Technology for Cultural Heritage - Interdisciplinary Approach to Diagnosis, Vulnerability, Risk Assessment and Graphic Information Models - Proceedings of the 4th International Congress Science and Technology for the Conservation of Cu*, (2011), 10–17. https://doi.org/10.1201/9780429345470-2

Pavelka, K. (2022). Photogrammetry, Laser Scanning and Hbim for Construction Diagnostic. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *46*(5/W1-2022), 171–176. https://doi.org/10.5194/isprs-archives-XLVI-5-W1-2022-171-2022

Peng, Y., Nijhuis, S., Geng, M., & Yu, Y. (2025). Enhancing visual attribute comprehension of urban heritage landscapes using combined GIS-based visual analysis methods: West Lake as a case study. *Environmental Impact Assessment Review*, *115*, 108032. https://doi.org/10.1016/j.eiar.2025.108032

Redyantanu, B. P., & Otto, F. (2025). Architecture as Programmatic Archive: Sustainable Conservation on Tunjungan Street History. *DIMENSI (Journal of Architecture and Built Environment)*, *52*(1), 83–94. https://doi.org/10.9744/dimensi.52.1.83-94

Rossi, A. (1982). *The architecture of the city (D. Ghirardo & J. Ockman, Trans.)*. MIT Press.(Original work published 1966).

Santosa, H., Fauziah, N., & Widisono, A. (2021). Management and Enhancement of Livable Urban Streetscape through the Development of the 3D Spatial Multimedia System A Case Study of Provincial Street Corridors in Malang, Indonesia. *International Review for Spatial Planning and Sustainable Development*, *9*(4), 10–30. https://doi.org/10.14246/irspsd.9.4_10

Santosa, H., Ramli, S., & Bahar, F. (2020). 3D Spatial Development of Historic Urban Landscape to Promote a Historical Spatial Data System. *The Academic Research Community Publication*, *4*(2), 01–13. https://doi.org/10.21625/archive.v4i2.751

Santosa, H., Sutikno, F. R., Yudono, A., Ahitama, M. S., & Zuliana, E. (2023). Exploring the Digitalization of Historic Buildings for Urban Heritage Governance in Kayutangan Heritage Malang. *Indonesia. The Indonesian Journal of Planning and Development*, *8*(1), 31–44. https://doi.org/10.14710/ijpd.8.1.31-44.

Santosa, H., Yasmin, A. P., Izzah, F., Lestari, D., Ratih, P., Putri, D., Sunu, N., & Giriwati, S. (2025). Urban Visual Index (Uvi) Based On Public Preferences For Evaluating The Visual-Spatial Comfort Of Kayutangan, Indonesia. *Journal of the Malaysian Institute of Planners VOLUME*, *23*(4), 199–214. https://doi.org/https://doi.org/10.21837/pm.v23i38.1788

Santosa, H., Yudono, A., Sutikno, F. R., Adhitama, M. S., Tolle, H., & Zuliana, E. (2023a). *Development of a Public Engagement Scenario in Metaverse Toward Maintaining the Sustainability of Valuable Historic Buildings in the Kayutangan Area, Malang, Indonesia* (pp. 263–275). https://doi.org/10.2991/978-94-6463-140-1_26

Santosa, H., Yudono, A., Sutikno, F. R., Adhitama, M. S., Tolle, H., & Zuliana, E. (2023b). Visibility Evaluation of Historical Landmark Building Using Photographic Survey Coupled with Isovist and Viewshed Analysis. *International Review for Spatial Planning and Sustainable Development*, *11*(4), 71–92. https://doi.org/10.14246/irspsd.11.4_71

Schulz, C. N. (1980). Genius loci: Towards a phenomenology of architecture. *New York: Rizzoli*, *17*, 22–23.

Sukwai, J., Mishima, N., & Srinurak, N. (2022). Identifying visual sensitive areas: an evaluation of view corridors to support nature-culture heritage conservation in Chiang Mai historic city. *Built Heritage*, *6*(1). https://doi.org/10.1186/s43238-022-00071-z

Utami, W., & Kharisma, V. (2025). Signage As a Medium To Strengthen Cultural Identity: a Case Study At Kampung Budaya Sindang Barang Bogor. *Journal Sampurasun : Interdisciplinary Studies for Cultural Heritage*, *11*(1), 42–62. https://doi.org/10.23969/sampurasun.v11i1.23438

Wang, J., & Zakaria, S. A. (2025). Design Application and Evolution of 3D Visualization Technology in Architectural Heritage Conservation: A CiteSpace-Based Knowledge Mapping and Systematic Review (2005–2024). *Buildings*, *15*(11), 1–31. https://doi.org/10.3390/buildings15111854

Wang, Y., Wang, S., Pan, Y., Li, C., Chen, C., & Wang, J. (2024). Immersive virtual reality and computer vision for heritage: visual evaluation and perception of the industrial heritage sites along the Yunnan–Vietnam railway (Yunnan section). *Heritage Science*, *12*(1), 1–15. https://doi.org/10.1186/s40494-024-01145-0

Wardhani, D. K., & Wastunimpuna, B. Y. A. (2025). Study of Placemaking for Urban Sustainability. *Jurnal Koridor*, *16*(1), 1–6. https://doi.org/10.32734/koridor.v16i1.18959

Wu, T. C., & Chang, C. W. (2025). Establish a reasonable assessment method using 3D simulation technology for the safety of historical tunnel. *Journal of Asian Architecture and Building Engineering*, *00*(00), 1–10. https://doi.org/10.1080/13467581.2025.2517907

Yudono, A., Santosa, H., & Tolle, H. (2020). *The Three Dimension (3D) Spatial Urban Heritage Informatics of Malang City, Indonesia*. *195*(Hunian 2019), 124–129. https://doi.org/10.2991/aer.k.200729.020

Yue, M., Mohd Ariffin, N. F., Abdul Aziz, F., Xiao, H., & Mengyao, Y. (2023). The Transformation of Rural Spatial form and its Contributing Factors in China: A Literature Review. *International Journal of Academic Research in Business and Social Sciences*, *13*(11), 1894–1913. https://doi.org/10.6007/ijarbss/v13-i11/19574

Zhang, F., Zhou, B., Liu, L., Liu, Y., Fung, H. H., Lin, H., & Ratti, C. (2018). Measuring human perceptions of a large-scale urban region using machine learning. *Landscape and Urban Planning*, *180*, 148–160.