Enhancing International Collaboration in Heritage Preservation Through GIS and Spatial Syntax: A Strategic Approach for Sustainable Tourism in the Medina of Sousse

Khelil Cherfi Khadidja [*1], Merzelkad Rym[2], Hamza Benacer[3]

[1]PhD Candidate(Algeria), khelilcherfi_khadidja@univ-blida.dz
[2]Senior Lecturer(Algeria), merzelkad_rym@uni-blida.dz
[3]Senior Lecturer(Algeria), benacer.hamza@univ-oeb.dz

Abstract: Heritage preservation in historic urban environments faces growing challenges due to rapid urbanization, unregulated tourism, and environmental pressures. UNESCO-listed sites, such as the Medina of Sousse, require strategic management approaches to ensure long-term sustainability while maintaining cultural and historical integrity.This study builds upon our previous research on this site that utilized Geographic Information Systems (GIS) and space syntax analysis to assess tourist flow, spatial vulnerabilities, and conservation challenges in the Medina of Sousse. While these methods provided valuable insights, the study identified limitations in optimizing spatial management strategies. To address these gaps, a systematic review of ten international case studies was conducted, examining advanced GIS applications, space syntax methodologies, and digital heritage conservation techniques.The findings highlight best practices for enhancing heritage site documentation, mitigating congestion, and integrating emerging technologies such as Digital Twins, Virtual Reality (VR), and Augmented Reality (AR) to balance accessibility and conservation. By refining GIS-based monitoring, predictive spatial modeling, and participatory mapping, this study demonstrates that heritage sites like Sousse can achieve more effective tourism management and long-term preservation.The proposed framework offers a scalable model for sustainable heritage conservation, emphasizing the importance of international collaboration, digital innovation, and participatory approaches. This research contributes to the modernization of heritage conservation practices by bridging the gap between theoretical spatial analysis and practical conservation strategies.

Keywords: GIS, space syntax, heritage, systematic review, Medina of Sousse.

Introduction:

Heritage preservation in historic urban environments faces increasing challenges due to rapid urbanization, unregulated tourism, and environmental degradation. UNESCO-listed sites, such as the Medina of Sousse, require strategic and data-driven management approaches to ensure long-term sustainability while preserving their cultural and historical integrity. Geographic Information Systems (GIS) and space syntax analysis have proven to be effective tools for analyzing urban movement, identifying congestion hotspots, and optimizing spatial accessibility. However, a previous study on the Medina of Sousse identified limitations in spatial management strategies, emphasizing the need for a more refined, comparative approach. This study hypothesizes that by systematically analyzing GIS and space syntax applications in other UNESCO heritage sites, spatial management strategies for Sousse can be significantly enhanced. To achieve this, a systematic review of ten international case studies was conducted, examining successful methodologies from heritage sites in Uzbekistan, Spain, Egypt, Saudi Arabia, Lebanon, Iran, and other historic contexts. The study aims to reassess Sousse's spatial organization, extract best practices from global conservation strategies, and develop an enhanced intervention framework, this research contributes to the modernization of heritage conservation, providing data-driven recommendations for balancing tourism development, spatial accessibility, and long-term preservation of historic medinas and kasbahs.

1. Research methodology

This study employs a systematic review methodology to analyze the application of GIS and space syntax in heritage preservation and sustainable tourism management. The research follows a structured process, including paper selection, screening, data extraction, and comparative analysis, ensuring a rigorous and transparent approach.

1.1 Paper Selection

To address the research question, a systematic search was conducted using academic databases such as Semantic Scholar, Scopus, and Google Scholar. The search targeted peer-reviewed journal articles, conference proceedings, and case studies published in the last two decades, focusing on GIS and space syntax applications in UNESCO-listed heritage sites. A total of 50 relevant studies were initially retrieved based on keywords including *GIS, space syntax, heritage conservation, sustainable tourism, digital heritage, and urban spatial analysis*.

1.2 Screening Criteria

The retrieved studies were screened based on the following inclusion and exclusion criteria:

Inclusion Criteria:

- Studies focusing on UNESCO heritage sites or comparable historic urban environments.
- Research utilizing GIS, space syntax, or digital heritage technologies for spatial analysis.
- Studies addressing sustainable tourism management and visitor flow optimization.
- Empirical research with clear methodological frameworks and data-driven findings.

Exclusion Criteria:

- Studies lacking quantitative spatial analysis or empirical validation.
- Research focused solely on architectural history without GIS or space syntax applications.
- Articles with limited methodological transparency or grey literature without peer review.

After applying these criteria, ten high-quality studies were selected for in-depth analysis.

1.3 Data Extraction and Comparative Analysis

For each selected study, key methodological components were extracted, including:

- Research Approach: Case study, empirical research, systematic review, or theoretical framework.
- Analytical Techniques: GIS-based modeling, space syntax analysis, 3D modeling, HBIM, or Digital Twin integration.
- Geographic Context: The location and relevance of the case study to the Medina of Sousse.
- Technology Implementation: Use of VR, AR, UAVs, photogrammetry, laser scanning, and participatory GIS.
- Findings & Limitations: Key results, challenges, and recommendations for improving heritage conservation.

The extracted data were systematically compared to identify patterns, best practices, and gaps in existing research. This comparative analysis informed the development of a refined intervention framework tailored to the Medina of Sousse, integrating GIS-based monitoring, predictive spatial modeling, and digital conservation tools.

1.4 Limitations of the Methodology

While the systematic review provides valuable insights, it is subject to certain limitations:

- The study relies on secondary data and does not include on-site validation or real-time visitor tracking.
- Potential publication bias may exist, as studies published in non-English sources were not included.
- The findings are based on case studies from different geographic and cultural contexts, which may not fully generalize to the specific socio-economic conditions of Sousse.

By employing a systematic review approach, this study ensures a comprehensive evaluation of GIS and space syntax applications in heritage conservation and sustainable tourism. The methodology allows for evidence-based recommendations to enhance spatial planning and conservation efforts in the Medina of Sousse, promoting a balanced approach between preservation and accessibility

2. Advanced Technologies for Heritage Conservation and Sustainable Tourism

2.1 Characteristics of Included Studies

A systematic review of ten scholarly studies reveals a range of innovative methodologies that can significantly enhance heritage preservation efforts in the Medina of Sousse. Each study presents a distinct analytical approach, which, when integrated, provides a comprehensive framework for addressing urbanization-related challenges and tourism pressures affecting the Medina.

Table 1. case studies summary table

Study	Research Focus	Methodology	Geographic Context	Technology Implementation
Chakraborty and Ji, 2024	Integration of space syntax with Heritage Impact Assessment for urban sustainability	Systematic review of 60 scholarly papers	Theoretical/Conceptual Study	Space Syntax analysis, 3D modelling
Hegazi et al., 2022	Socio-spatial vulnerability assessment of heritage buildings	Empirical research using mixed methods	Cairo, Egypt	Space syntax analysis using Depthmap 4 software
López-González and García-Valldecabres, 2023	Integration of HBIM and GIS for heritage management	Empirical research using Design Science Research	Valencia, Spain	HBIM, GIS, 3D laser scanning, photogrammetry

	and tourism planning			
Markopoulos et al., 2021	Application of Virtual Reality (VR) and Augmented Reality (AR) in heritage preservation	Exploratory study	Multiple locations (Egypt, Tunisia, Oman, Finland)	Virtual Reality (VR), Augmented Reality (AR)
Mazzetto, 2024	Integration of emerging technologies with Digital Twins for heritage conservation	Systematic review with expert interviews	Saudi Arabia	Digital Twins, BIM, 3D laser scanning, Machine Learning, IoT
Misilmani et al., 2024	BIM-GIS integration for urban heritage management	Case study	Beirut, Lebanon	BIM, GIS, laser scanning, photogrammetry
Rueda Márquez de la Plata et al., 2022	Non-invasive technologies for heritage preservation and sustainable tourism	Case study	Mérida, Spain	GPR, UAVs, VR, AR, 6D GIS-BIM
Salimi et al., 2025	GIS in participatory heritage conservation	Case study analysis and literature review	Multiple locations (Iran, USA, Finland, Egypt, Spain)	GIS
Vileikis et al., 2017	GIS integration for heritage documentation	Empirical research	Bukhara, Itchan Kala, Samarkand, Uzbekistan	GIS
Chakraborty and Ji, 2024	Integration of space syntax with Heritage Impact Assessment for urban sustainability	Systematic review of 60 scholarly papers	Theoretical/Conceptual Study	Space Syntax analysis, 3D modelling
Hegazi et al., 2022	Socio-spatial vulnerability assessment of heritage buildings	Empirical research using mixed methods	Cairo, Egypt	Space syntax analysis using Depthmap 4 software
López-González and García-Valldecabres, 2023	Integration of HBIM and GIS for heritage management and tourism planning	Empirical research using Design Science Research	Valencia, Spain	HBIM, GIS, 3D laser scanning, photogrammetry

Markopoulos et al., 2021	Application of Virtual Reality (VR) and Augmented Reality (AR) in heritage preservation	Exploratory study	Multiple locations (Egypt, Tunisia, Oman, Finland)	Virtual Reality (VR), Augmented Reality (AR)
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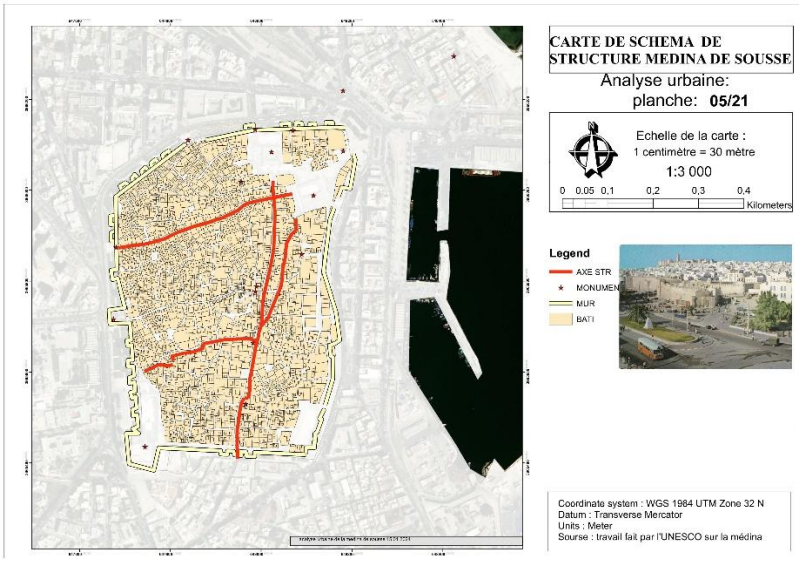
Source: Khelil Cherfi, 2025

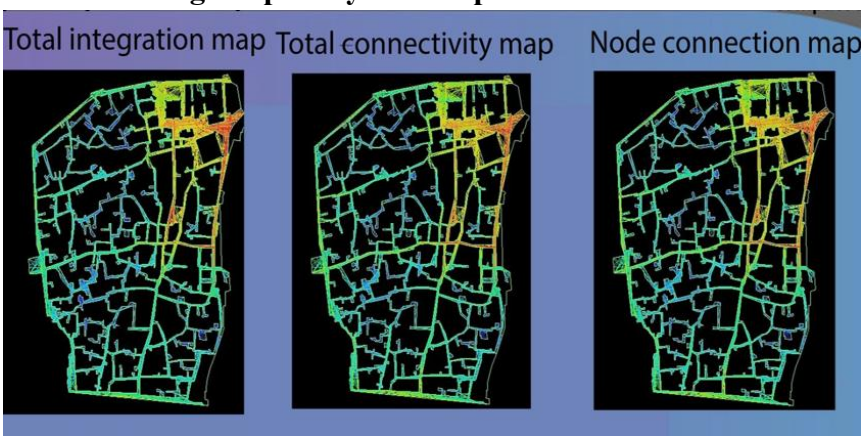
2.2 Space Syntaxe and GIS Reading of the Medina from the Previous Researchs:

Fig.1. structure layout of the Medina



Source: Khelil Cherfi et Al, 2024

Fig.2. Space syntax maps of the Medina



Source: Khelil Cherfi, 2023

Table 2. GIS and Space Syntax Findings

Category	Indicator	Value	Interpretation
Spatial Configuration	Average Global Integration (AGI)	0.75	High accessibility and movement potential in the northern sector.
	Average Connectivity Index (ACI)	12	Core streets are well-connected; peripheral streets (ACI < 5) are less integrated.
Road Infrastructure	Network Density Index (NDI)	6.5 km/km²	Moderately dense network with disconnection in the southwest.
	Primary Road Coverage Ratio (PRCR)	42%	Major roads account for nearly half of the road network.
	Secondary Road Coverage	33%	Significant contribution but lower than primary roads.
	Tertiary/Local Road Coverage	25%	Less developed, mainly serving local accessibility.
Functional Distribution	POI Concentration	70%	Most commercial and service activities are along the most integrated streets.
	Facility Accessibility Index (FAI)	0.68	32% of the urban fabric remains underserved by key functions.
Structural Scheme	Land Use Intensity Index (LUII)	0.72	High land utilization along accessible corridors; peripheral areas (< 0.50) remain underdeveloped.
Pertinence Area Analysis	Spatial Accessibility Score (SAS)	0.64	Moderate but uneven access to key urban elements; peripheral zones < 0.50 need requalification.

Source: Khelil Cherfi, 2025

The previous study provides critical insights into the spatial morphology of the Medina of Sousse, identifying the relationship between tourist congestion, accessibility, and heritage vulnerability. The findings emphasize that tourism is heavily concentrated along the **main axial routes connecting Bab El Kebli, the Great Mosque, and the Ribat**, leaving other historically significant sites underutilized.

1. High-Pressure Zones and Risks to Heritage

- The Ribat of Sousse, an iconic fortified religious structure, experiences the highest influx of visitors due to its direct alignment with Rue d'Angleterre and Rue de la Kasbah. The study highlights that this continuous foot traffic accelerates, particularly around the entrance archway and watchtowers.
- The Great Mosque of Sousse, situated along the main commercial axis, suffers from excessive tourist presence, leading to structural stress on the courtyard.
- The Kasbah and the Archaeological Museum, despite housing Roman mosaics and ancient artifacts, remain relatively under-visited. The study suggests that improved signage and digital interpretation tools could enhance engagement without overburdening the site.

2. Underutilized Zones and Missed Tourism Opportunities

- The Zaouïa Zakkak complex, encompassing a mausoleum, medersa, and mosque, is located along a less-integrated pathway. The study suggests that this site could serve as a secondary attraction to alleviate pressure from the Great Mosque.
- The Bou Ftata Mosque, one of the oldest examples of Kufic-script architecture in North Africa, is overlooked by visitors due to its narrow approach pathways. The study advocates for pedestrian-friendly enhancements to improve accessibility.
- The Citernes de la Sofra, an ancient Byzantine water reservoir system, remains largely inaccessible to tourists. The study proposes an interpretive route linking this site with the Bab El Gharbi gate, allowing for a thematic exploration of medieval urban infrastructure.

3. Interpretation of results

3.1 Contributions of Systematic Review Studies to Heritage Preservation in Sousse

The systematic review of ten scholarly studies provides valuable insights into innovative methodologies that can enhance heritage preservation efforts in the Medina of Sousse. Each study presents a distinct analytical approach, which, when integrated, forms a comprehensive framework for addressing the challenges posed by urbanization and tourism-related pressures in historic environments.

1. GIS-Based Documentation and Spatial Analysis

The application of GIS and spatial syntax in heritage site documentation has been extensively studied in various contexts, including Uzbekistan (Vileikis et al., 2017) and Beirut (Misilmani et al., 2024). These studies emphasize GIS as a tool for standardizing documentation, enabling the creation of unified databases that facilitate international collaboration.

Applying GIS-based methods to Sousse can enable:

Detailed mapping of historic sites to monitor structural vulnerabilities.

Visitor movement analysis to prevent overcrowding in sensitive areas.

Predictive spatial modeling to optimize tourism flow while ensuring conservation.

Additionally, López-González and García-Valldecabres (2023) demonstrated the effectiveness of GIS and HBIM (Heritage Building Information Modeling) in managing Valencia's historic core. A similar approach in Sousse could allow three-dimensional documentation of key monuments, including the Ribat, the Great Mosque, and the Kasbah, aiding in predictive maintenance and conservation planning.

2. Space Syntax for Socio-Spatial Vulnerability Assessment

Studies by Chakraborty and Ji (2024) and Hegazi et al. (2022) demonstrate how space syntax analysis can assess socio-spatial vulnerabilities within heritage cities. Hegazi's research on Cairo applied axial and visual graph analysis to identify areas susceptible to degradation due to excessive tourist activity.

When applied to Sousse, space syntax analysis can:

Identify congestion hotspots, such as the Bab El Kabli gate corridor, where excessive foot traffic threatens the integrity of historic structures.

Assess underutilized zones, such as the Zaouïa Zakkak complex, to propose alternative tourist routes that alleviate pressure on overcrowded sites.

Improve spatial planning by identifying pedestrian pathways that enhance accessibility without compromising conservation efforts.

Chakraborty and Ji's framework also integrates Heritage Impact Assessments (HIA) with space syntax, which can be particularly useful in classifying high-risk zones in Sousse, such as the narrow alleys leading to the Zaouïa Zakkak, ensuring that conservation strategies are implemented proactively.

3. Emerging Technologies for Sustainable Heritage Management

Several studies, including Mazzetto (2024) and Rueda Márquez de la Plata et al. (2022), emphasize the integration of Digital Twins, Augmented Reality (AR), and non-invasive technologies for heritage monitoring.

The Medina of Sousse can greatly benefit from these innovative technologies, particularly in:

Mapping subterranean structures such as the Byzantine-era Citernes de la Sofra using UAVs and Ground-Penetrating Radar (GPR).

Real-time monitoring of environmental stressors .

Implementing VR/AR experiences to enhance visitor engagement while reducing physical strain on fragile sites.

4. Sustainable Tourism Strategies and Visitor Flow Optimization

Studies by Xing (2024) and Salimi et al. (2025) propose GIS-based tourism management models that optimize visitor distribution while reducing stress on critical heritage sites.

In Sousse, space syntax analysis has identified that tourists are over-concentrated in key areas such as the Ribat and the Great Mosque. To address this issue, possible solutions include:

Developing guided pathways to redirect visitors to lesser-known but historically significant sites, such as Dar Echaraa or the Kasbah Museum.

Implementing carrying capacity assessments, as used in Valencia and Finland, to establish visitor thresholds for sensitive areas like the Tour de Khalef, ensuring that tourism remains sustainable.

5. Participatory Approaches and International Collaboration

Research by Salimi et al. (2025) highlights the importance of community involvement in heritage **conservation. In Sousse, Participatory GIS (PGIS) can:**

Engage local artisans, historians, and residents in heritage management decisions.

Integrate oral histories and cultural practices into digital documentation.

Ensure conservation efforts align with local values, preventing excessive commercialization.

Additionally, Vileikis et al. (2017) propose a GIS-based international collaboration framework that can be adapted to establish conservation partnerships between Sousse and other historic medinas, such as Tunis and Marrakech, facilitating knowledge exchange and joint restoration initiatives.

3. Key Findings and Novelty of the Approach

By systematically analyzing international case studies, this research bridges the gap between theoretical spatial analysis and practical conservation strategies. The systematic review offers three major contributions:

Comparative Insights on GIS and Space Syntax Applications

Studies conducted in Uzbekistan, Beirut, and Valencia demonstrate how GIS-based heritage documentation enhances conservation planning. In Sousse, this method enables precise mapping of high-risk zones, such as the Ribat and the Great Mosque, allowing for preventative rather than reactive preservation.

Space syntax models applied in Cairo reveal how visitor movement patterns contribute to structural vulnerabilities. Implementing this approach in Sousse identifies congestion points, such as Rue d'Angleterre leading to the Kasbah, and suggests alternative pathways to redistribute tourist flow.

Emerging Technologies in Conservation and Tourism Management

Case studies from Saudi Arabia and Spain highlight the integration of Digital Twins, UAVs (Unmanned Aerial Vehicles), and VR/AR (Virtual and Augmented Reality) for real-time heritage monitoring and immersive tourism experiences.

The Medina of Sousse could benefit from these tools by reducing physical strain on fragile sites while enhancing visitor engagement through virtual storytelling and digital interpretation models.

Carrying capacity assessments, as successfully implemented in Valencia and Finland, provide a model for controlling visitor density and preventing excessive wear on high-traffic heritage zones.

International Collaboration and Participatory Mapping for Sustainable Heritage Management

Studies from Iran, Egypt, and Spain demonstrate that stakeholder engagement is crucial for long-term heritage sustainability.

In Sousse, implementing participatory GIS could involve local artisans, historians, and residents in conservation efforts, ensuring that intangible cultural heritage is preserved alongside physical structures.

The GIS-based international collaboration framework proposed by Vileikis et al. (2017) could be adapted to establish cross-regional conservation partnerships between Sousse and other historic medinas such as Tunis and Marrakech, facilitating knowledge exchange and best practices in heritage restoration and tourism management.

Conclusion

This study confirms that the integration of Geographic Information Systems (GIS) and space syntax analysis enhances heritage preservation and sustainable tourism in the Medina of Sousse. The findings validate the hypothesis that applying global best practices improves spatial management strategies in historic urban environments.

By leveraging GIS for documentation and monitoring, heritage sites can achieve precise mapping of structural vulnerabilities and visitor movement patterns, enabling more effective conservation planning. Space syntax analysis identifies congestion points and underutilized areas, allowing for the strategic redistribution of visitor flow to reduce pressure on high-traffic heritage zones.

The incorporation of emerging technologies, such as Digital Twins, Virtual Reality (VR), and Augmented Reality (AR), enhances both heritage conservation efforts and visitor engagement, ensuring a balance between accessibility and preservation. Additionally, participatory approaches and international collaborations play a crucial role in promoting long-term heritage sustainability by integrating local knowledge and fostering cross-regional partnerships.

Recommendations

Implement GIS-based monitoring for real-time visitor flow and structural assessment.

Develop guided pathways to distribute tourism more evenly and reduce overcrowding.

Adopt Digital Twins, VR, and AR to enhance digital heritage interpretation and reduce physical strain on historic sites.

Engage local stakeholders in participatory GIS initiatives to ensure community-driven heritage conservation.

Strengthen international conservation partnerships to facilitate knowledge exchange and best practices in heritage management.

Future Perspectives

Future research should incorporate real-time visitor behavior tracking and assess the socioeconomic impacts of digital heritage technologies. Additionally, Artificial Intelligence (AI) and Machine Learning could further refine predictive conservation models, enhancing decision-making for heritage site management.

Limitations

This study relies primarily on secondary data and does not include real-time fieldwork, which may limit the precision of some findings. Additionally, sociopolitical and economic constraints affecting the implementation of digital technologies were not extensively examined.

Final Consideration

Balancing heritage preservation with sustainable tourism requires the integration of innovative digital tools, participatory approaches, and global collaboration. By adopting these strategies, heritage sites

like the Medina of Sousse can ensure their long-term protection while maintaining cultural authenticity and accessibility.

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