CEYLON TWIN: Enhancing Tourism Digital Twins with Real-Time, Bilateral Data Across Sri Lanka

Abstract—**Heritage tourism destinations are increasingly confronted with challenges linked to overcrowding, safety management, and lack of real-time visitor support. The adoption of digital twin technology is mostly static and confined to offline visualization in the tourism domain, although its implementations have been successful in smart cities and industrial environments. This paper presents CEYLON TWIN, a mobile-based bilateral digital twin framework for smart tourism management, with Sigiriya as the main case study. The proposed system introduces a dynamic digital twin that continuously synchronizes real-world conditions with a virtual environment through real-time crowd detection, external weather and environmental Application Programming Interfaces (API), visitor feedback, and Artificial Intelligence (AI) techniques. Real-time monitoring and visualization of crowd density, environmental conditions, and potential risk indicators are integrated into the framework. It also offers smart location-based guidance through customized destination mapping, historical image visualization, and personalized itinerary recommendations. The intelligent conversational portal enables natural-language interaction, with which visitors will be able to gain predictive guidance on best periods to visit, based on crowd and weather analysis. Destination analytics derived from visitor feedback and demographic data support informed decision-making and targeted marketing strategies for site managers.**

Experimental results also show that the system has the potential to improve situational awareness, visitor engagement, and adaptive destination management. The results described above have significant potential for sustainable management of heritage sites through dynamic tourism digital twins.

Keywords—Digital Twin, Tourism, Internet of Things, Real-Time Visualization, Bilateral Autonomy, Mobile Application, Sigiriya

I. INTRODUCTION

The rapid growth of digital technologies has significantly changed the tourism industry, driving the adoption of smart systems that enhance visitor experiences, streamline operations and promote sustainable destination management. Among these technologies, Three- Dimensional (3D) Digital Twin (DT) systems have become valuable tools for creating virtual replicas of physical environments that update in real time. At the beginning, DTs were developed for industrial and smart city applications, but recently DTs are being applied in tourism to model destinations and support decision-making through continuous data exchange between the physical and virtual environments [1]. Using this method, stakeholders can keep an eye on the live environment conditions, examine crowd behavior and offer timely insights that improve site management and visitor experience.

Despite the growing interest in digital twin applications, many existing tourism solutions remain static or rely on offline data, lacking integration with real-time information on crowd densities, environmental & weather conditions, and potential safety risks [2]. These limitations reduce the effectiveness of DTs in handling modern tourism challenges, which includes dynamic visitor experience, overcrowding and safety concerns. The absence of real-time feedback loops between the physical environment and its digital model highlights the need for a framework that supports continuous live updates, interactive engagement and predictive analytics, especially at heritage sites where visitor counts and environmental conditions fluctuate regularly.

The use of Internet of Things (IoT) is critical for monitoring visitor count by enabling real-time crowd detection at tourism sites. Cameras and sensors placed in strategic locations can track crowd densities and transfer this data to central systems for analysis and visualization purposes [3]. Other data such as environment conditions, weather conditions and contextual data are collected through external APIs, to make sure the DT remains informed with live and up-to-date information. When combined with mobile platforms, this system provides tourists and site managers with interactive, location-aware services, including personalized recommendations, safety alerts and dynamic guidance. A mobile application like CEYLON TWIN operates as an effective platform for delivering these insights, turning real-time and aggregated data into actionable experiences and interactive visualizations.

Moreover, conversational interaction, visitor flow forecasting and adaptive customized itinerary planning are all made possible by AI technologies like Natural Language Processing (NLP) and predictive modeling. Tourism applications can anticipate traffic, lower safety risks and offer personalized guidance by integrating AI with real-time data and DT frameworks. Nevertheless, most of the current research examines these technologies independently rather than as a component of a single digital twin platform.

To address the above limitations, this research presents CEYLON TWIN, a mobile-based tourism DT system that combines real-time monitoring & visualization, IoT & destination analytics, smart location services, and AI-driven interaction within a single platform for Android and iOS. Through the promotion of two-way synchronization between the physical location and the DT, CEYLON TWIN improves visitor interactions as well as destination management. It showcases the potential of the DT technology within a smart destination setting.

II. LITERATURE REVIEW

The digital transformation has also had major impacts on the tourism industry, promoting the use of smart technologies for the purposes of enhancing tourist experience and destination management. Among the technologies being promoted, digital twins, location-based services, predictive analytics, and AI systems have received attention. This section reviews relevant literature and highlights existing limitations that motivate the proposed research.

A. Digital Twins and Real-Time Visualization in Tourism

DTs are virtual representations of physical sites that support monitoring and decision-making. In tourism research, DTs are mainly used as static or conceptual models aimed at visualization, planning and sustainable analysis, based on data previously collected or simulated [1]. Research show that most of the DTs lack real-time synchronization with the physical environment, limiting their ability to reflect live destination conditions [1].

Though researchers talk about the potential of DTs to address overtourism, governance and sustainability challenges, current tourism implementations are largely on static 3D models or offline analytical tools [2], [3], [4]. As a result of static 3D models, these systems cannot respond effectively to dynamic changes such as fluctuating environmental, weather conditions, visitor levels and safety risks at heritage sites.

In contrast, dynamic DTs have been successfully applied in smart cities and industrial domains for pro-active decision-making [5], [6]. The absence of similar real-time visualizations of environment, weather conditions and crowd levels reveals a clear research gap and emphasizes the novelty of systems that integrate live environment monitoring and predictive alerts into a unified tourism digital twin framework.

B. Location-Based Smart Guidance and Historical Interpretation

Location-based services (LBS) are often employed in tourist applications to deliver navigation and location specific information. Previous works indicate that GPS-assisted mobile applications can provide tourist recommendations, routes and personalized itineraries [7], [8]. However, most current tourist applications are developed using Google Maps or other location services, which mainly emphasize well-known places and lack representation of lesser known and important locations within heritage destinations.

Several tourism applications improve location-based guidance by presenting contextual information such as descriptions, images and historical content linked to specific geographic points [9], [10]. These approaches allow visitors to understand the culture and historical importance of a place by viewing the descriptions and past visual images of locations when they visit a specific point. Displaying historical images along with the present-day location details helps to improve visitor engagement and learning by connecting physical spaces with their historical context [10].

Despite these implementations, most location-based guidance systems operate separately from DTs and lack personalized destination mapping as well as real-time integration. Existing solutions rarely provides detailed representations of lesser-known site areas or adapt guidance based on live conditions and predictive insights [7], [9]. This limitation brings the need for integrated systems that combine location mapping, historical interpretation and intelligent guidance within a unified DT framework to enhance the visitor experience and decision-making at heritage sites.

C. AI- Based Conversation Portal and visitor interaction

AI-powered conversational portals are increasingly used in tourism industry to enhance visitor interaction and delivering of information. Unlike traditional chatbots, these portals can understand and respond to questions asked in natural human language, providing tourists with detailed and contextually relevant information about heritage sites [11], [12]. By leveraging advanced NLP techniques, conversational portals improve accessibility and let users to interact intuitively without relying on predefined commands or rigid interfaces.

These intelligent systems can provide predictive advices by analysing historical trends of visitor arrivals, crowd densities and weather patterns to recommend best travel periods for visiting sites like Sigiriya [12]. This helps tourists to make decisions about best times to visit. They can avoid peak congestion and bad weather, making their visit more enjoyable. By combining predictions with a conversational platform, the advice can be customized for each visitor and the current situation at the site.

Despite their potential, most existing conversational platforms in tourism work as standalone tools and are not connected to any real-time monitoring or dynamic DT environments [11]. Due to this reason, their guidance is general and does not consider what is happening at the site right now. Integrating a conversational portal with live 3D models, predictions and visitor feedback can give smart, personalized and useful advice. This can improve how visitors experience the site and how the site is managed.

D. Visitor Feedback Analytics and Destination Management

Reviews and feedbacks from visitors are critical to understand what tourists like and how satisfied they are. Sentimental analysis techniques have been applied to analyse online reviews of heritage sites, identified strengths, weaknesses and operational issues [13]. These insights help site managers make services better and solve visitor problems.

Beyond operational improvements, visitor analytics also helps in strategic destination marketing. Research shows that by analysing tourist origin data and behavioural patterns enables targeted marketing strategies and demand optimization [14], [15]. Dividing visitors by age, interests or other traits lets sites create special ads and manage crowds better.

Despite these benefits, visitor feedback analytics and marketing intelligence are rarely integrated into real-time tourism systems. Most research looks at feedback after the visit instead of using it continuously to improve site management in real-time.

III. Research Methodology

This study adopts a Design and Development Research (DDR) methodology to design, implement, and evaluate an intelligent tourism digital twin framework that integrates real time, bilateral data to improve destination awareness, visitor safety, and decision-making throughout Sri Lanka. The proposed methodology focuses on development of a real-time, data driven digital environment using Sigiriya as a representative heritage destination. The proposed frame work integrates Artificial Intelligence (AI), Machine Learning (ML), NLP, and immersive visualization techniques to address main challenges in tourism management including crowd congestion, safety risks, delayed decision making.

CEYLON TWIN is composed as a unified digital twin comprised of multiple tightly integrated components, each designed to address main challenges in visitor management and tourism experience. The methodological design ensures each component's functional workflow directly aligns with its intended research objectives.

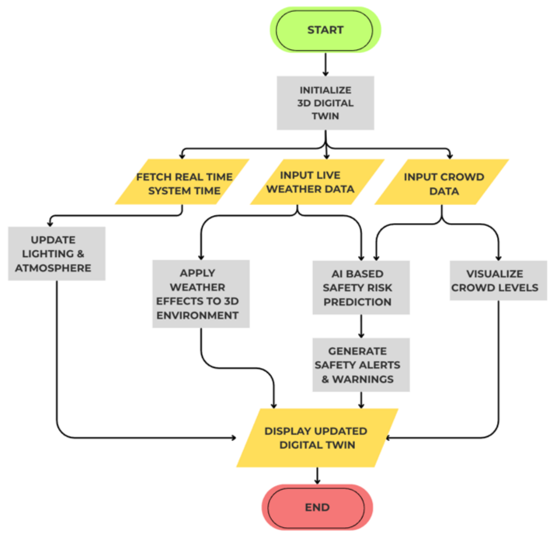

Fig. 1. Real-Time Monitoring & Visualization Module

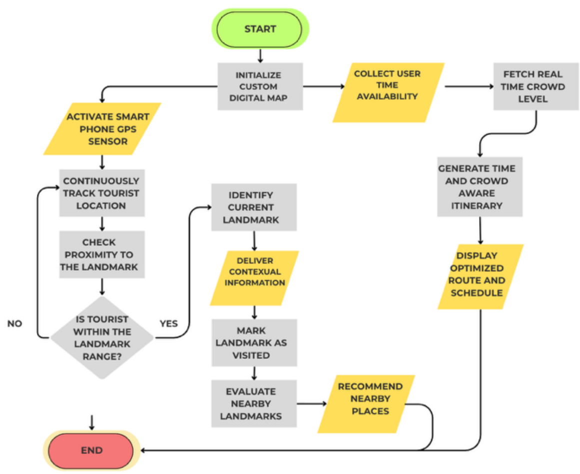

Fig. 2. Smart Location-Based Details Gathering

A. Real-Time Monitoring and Visualization

The real-time monitoring and visualization module is designed to construct a dynamic tourism digital twin that reflects real- world environment, weather conditions, crowd, and safety conditions at the Sigiriya heritage site. The methodology focuses on continuously synchronizing live data streams with a 3D virtual environment to enhance visitor experience, tourist awareness and on-site safety.

As illustrated in Fig. 1, the workflow begins with initialization of 3D digital twin model of Sigiriya. First the system time is used to dynamically update the lightning conditions, sky color, and atmospheric nature within the digital twin. Simultaneously, live weather data is retrieved from Weather APIs. Weather conditions such as heavy rain, drizzle rain, high and low fog are visually represented using Flutter. Tourist distribution in key landmarks is represented using visual markers. Using the combined inputs from weather parameters and crowd density levels, AI based risk prediction model is applied to identify potential risks. Logistic Regression, Random Forest, and Gradient Boosting models are trained using historical weather data, crowd density patterns. The model predicts fog risk, slippery risk, and heat stress and translate the risks into safety alerts and warning messages.

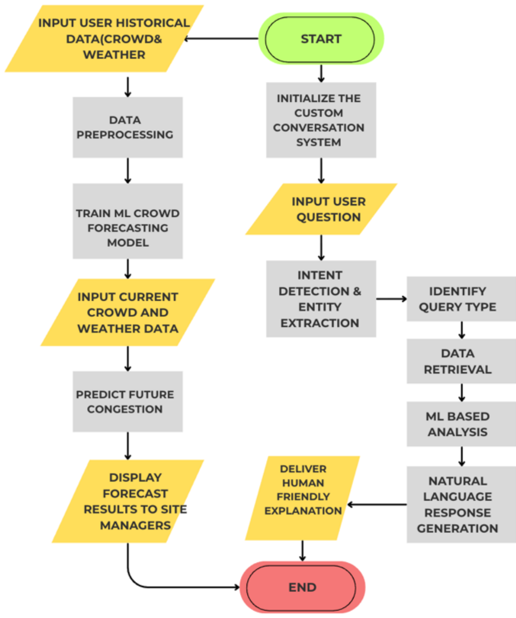

Fig. 3. Interactive NLP & Predictive Optimization Module

B. Smart Location-Based Guidance

The smart location-based guidance acts as a main personalized navigation support based on the visitor's real-time geographic position within the Sigiriya heritage site. The methodology focuses on accurate landmark detection, automatic information delivery and itinerary generation by integrating Global Positioning System (GPS) data, spatial mapping, and real time crowd levels.

As illustrated in Fig. 2, the workflow begins with the initialization of a custom digital map that represents all significant site locations as pinpoints associated with precise GPS coordinates. The mobile application continuously tracks tourists' real-time location using smartphone's GPS sensor and checks the proximity to the pinpoints. Upon the landmark detection, the system delivers contextual information regarding the location. After the landmark is explored, the system evaluates nearby landmarks and recommends nearby landmarks to the tourists. Additionally, at the beginning of the visit, tourists specify their available visiting time. Using this input, the system generates a personalized itinerary by considering estimated visiting durations, walking distances between landmarks, the tourist's real-time position, and current crowd levels at each location.

C. Interactive NLP and Predictive Optimization

The NLP and predictive optimization functions as the intelligent communication and decision-support layer of the digital twin. The methodology integrates natural language understanding, real time data processing, predictive modeling, and context-aware generation.

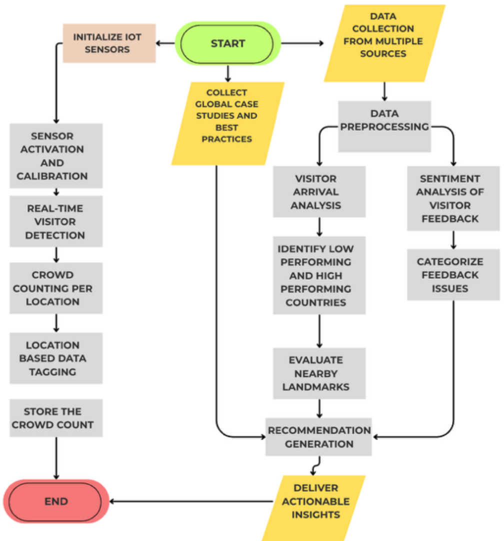

Fig. 4. Destination Analytics & Crowd Management System

As shown in the Fig. 3, users first interact with system through a conversational interface, submitting natural-language queries regarding crowd levels, visiting times, weather conditions. The NLP engine process these queries to identify user intent and deliver human-friendly explanation to the tourists.

Following query processing, the system retrieves historical crowd datasets, current crowd level and weather data. Machine learning model trained on historical crowd movement, congestion patterns, and weather trends generate forecasts of future crowd densities at key locations. Finally the system translates analytical insights into natural language responses and give alerts to site managers on future congestion.

D. Destination Analytics and Crowd Management

The destination analytics and dynamic crowd management focuses on capturing real time visitor counts, analyzing tourism trends, evaluating visitor feedback, and generating actionable recommendations to improve site management and marketing strategies. The methodology integrates IOT-based crowd monitoring, visitor arrival analysis, sentiment evaluation, and knowledge-base-driven decision support.

As shown in the Fig. 4, the first step involves detecting crowd density at key locations. These sensors continuously count visitors, generate time-stamped data, and forward the information for aggregation and visualization with the digital twin. The second step performs visitor arrival analysis to determine number of visitors from different countries and analyze to identify high performing countries with strong tourist inflows and low performing countries with low tourist arrival.

Additionally, the system evaluates visitor feedback collected from google and identify common complaints related to Sigiriya using sentiment analysis. Then the system integrates insights from both visitor arrival and feedback analysis with a knowledge base of global studies and best practices. Based on identified issues or low-performing countries, the system generates actionable recommendations, such as targeted marketing campaigns, operational

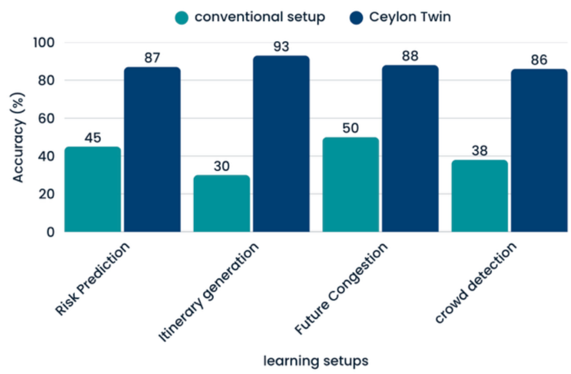

Fig. 5. Post Accuracy Comparison

improvements, or promotional offers, enabling site managers and tourism authorities to enhance visitor experience and optimize tourism operations.

IV. EXPERIMENTS AND RESULTS

A comprehensive experimental study was conducted to evaluate the effectiveness of the proposed real-time tourism digital twin framework in comparison with conventional tourism management. The primary goal of the experiment was to assess improvements in visitor experience, crowd management, situation awareness and decision support effectiveness when utilizing the proposed digital twin system at Sigiriya.

A. Experimental Design and Study Environment

The study was conducted at Sigiriya, a UNESCO world heritage site and one of the most visted tourist destinations in Sri Lanka. The study was divided into two setups: a conventional system and a digital twin-enabled setup.

In the conventional setup, site operations relied on manual crowd observation, traditional post feedback analysis, delayed weather updates. Tourists view context information through brochures and navigate through on-site boards.

In contrast, the experiment deployed the proposed digital twin system with real time weather APIs, crowd sensors, NLP driven interaction and 3D visualization. Unlike conventional setup, the digital twin continously synchronized real-world conditions with the virtual environment.

B. Data Collection Methods

Data collection was conducted using real time sensor feeds, system-generated logs, mobile application interaction records, and managerial response reports. Crowd density data were continuously collected from IOT-based sensors installed at high congestion areas.

Weather related data, including rainfall intensity, fog levels, temperature, and humidity, were retrieved in real-time through external weather APIs. Tourist movement and interaction data were captured through GPS tracking.

For comparative analysis, historical records and manual observations from conventional setup were used as the baseline. All collected data were anonymized and aggregated to ensure ethical compliance and privacy protection.

C. Real-time awareness and visualization performance

The results depict a substantial improvement in real-time situational awareness through the proposed digital twin system. As illustrated in Fig. 5, The visualization module accurately depicts the risk predictions. Compared to static risk prediction methods, the digital twin achieved 87% accuracy, enabling tourists on better site conditions.

D. Crowd Management and Time Efficiency Analysis

Positive improvements were observed in crowd detection and visitor flow management. The integration of real time crowd data with itinerary planning resulted in 45% reduction in congestion at high concentration places in Sigiriya.

Tourists using the CEYLON TWIN completed site exploration with an average 35% reduction in idle waiting time compared to those relying on conventional methods. The system's ability to dynamically recommend alternative landmarks based on crowd levels and available time contributed directly to smoother visitor movement and reduced overcrowding. For site managers, real time crowd management enabled faster crowd operation approximately by 45%.

E. Decision Support, Engagement and predictive accuracy

The NLP interaction module significantly enhanced the tourist satisfaction and decision support efficiency. Tourists actively interact with the system to inquire Sigiriya related questions, resulting in 90% interaction success rate. Future congestion prediction model achieved an average accuracy of 88% in forecasting future crowd congestion as shown in Fig. 5. The prediction capacity allowed site managers to effectively deploy staff and control the congestion on key points at Sigiriya.

Sentiment analysis of visitor feedback further strengthened the decision support capability of the digital twin by identifying recurring issues at Sigiriya. With Fully integrated knowledge base, the system successfully generated actionable recommendations for tourism authorities with proven global best practices.

F. Comparative Discussion

Overall, the experimental results clearly depict that the proposed digital twin outstands traditional tourism management and conventional approaches. While conventional methods provided limited, delayed insights, CEYLON TWIN continuously synchronized in real-time and communicate bilaterally between tourists and site managers.

The integration of IOT sensors, AI, NLP- based interaction and significant visualization resulted in improved visitor awareness, enhances visitor experience, efficient crowd management and data driven strategic-planning. These findings confirm the effectiveness of real-time, bilateral digital twin architectures as a significant solution for managing complex tourism environments in Sri Lanka and similar heritage destinations.

V. CONCLUSION

This research presented CEYLON TWIN, a real time, bilateral tourism twin framework designed to improve visitor experience, safety awareness and destination management at heritage sites in Sri Lanka with Sigiriya using as the primary case. Experimental evaluation showed that the digital twin significantly outperforms conventional tourism management methods in situational awareness, crowd management efficiency, decision-support accuracy, and user engagement. Results have shown that integration of real-time data and predictive intelligence enables proactive safety alerts, optimized visitor flow, and data-driven managerial decisions. Overall, this study identifies the potential of real-time, AI-enabled tourism digital twins for effectively and scalable managing complex tourist destinations, supporting sustainable tourism development, and improving operational efficiency in smart tourism ecosystems.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to the academic supervisors and lecturers for their valuable guidance, continuous support, and constructive feedback throughout the course of this research. Their insights and expertise greatly contributed to shaping the direction and quality of this study.

The authors also wish to acknowledge the support provided by the institution for facilitating the necessary resources and research environment required to conduct this work. Special appreciation is extended to all individuals and organizations who contributed data, domain knowledge, and technical assistance that enabled the successful development and evaluation of the proposed tourism digital twin system.

REFERENCES

[1] F. B. e. A. I. B.-P. D. Sampaio de Almeida, ""Digital twins in tourism: a systematic literature review"," *arXiv preprint,* Jan. 2025.

[2] A. V. M. A. V. M. T. Ljubisavljević, ""Digital twins in smart tourist destinations"," vol. 6, no. 4, 2025.

[3] L. Florido-Benítez, ""The use of digital twins to

address smart tourist destinations' future challenges"," vol. 2, no. 4, 2024.

[4] M. W. e. al., ""Digital twins for extended reality tourism"," 2025. [Online]. Available: https://arxiv.org/.

[5] J. T. e. al., ""Digital twin-driven smart manufacturing"," *IEEE Access,* 2019.

[6] P. K. e. al., ""Data-driven crowd risk management"," *Safety Science,* 2023.

[7] A. G. e. al., ""Smart tourism foundations"," *Electronic Markets,* 2015.

[8] M. C. e. al., ""Intelligent tour guide systems"," *Sustainability,* 2020.

[9] T. J. R. tom Dieck, ""Value of augmented reality in tourism"," *Journal of Destination Marketing & Management,* 2017.

[10] K. B. e. al., ""A survey of augmented reality in cultural heritage"," *Journal on Computing and Cultural Heritage,* 2018.

[11] K. Wüst, ""AI chatbots in tourism"," *Information,* 2025.

[12] A. P. e. al., ""Conversational AI in tourism"," *Journal of Hospitality and Tourism Management,* 2025.

[13] M. J. M. F. e. al., ""Sentiment analysis of heritage tourism reviews"," *Sustainability,* 2024.

[14] I. Ö. U. Gunter, ""Forecasting tourism demand"," *Tourism Economics,* 2016.

[15] S. C. e. al., ""Machine learning in tourism forecasting"," *Annals of Tourism Research,* 2020.