A Context-Aware Recommender Framework for Personalized Cultural Heritage Experiences

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***Abstract*—The enhancement of cultural heritage experiences requires digital systems capable of adapting cultural content, visit routes, and user support services to the specific needs of visitors and to the conditions of the surrounding environment. This work presents a framework based on Context-Aware Recommender Systems designed to improve cultural experiences in archaeological parks and museum-like settings. The proposed approach integrates Internet of Things technologies, contextual data, user preferences, semantic knowledge, chatbot interaction, Digital Storytelling, and Augmented Reality services. The framework is structured into four functional layers: a Sensors Layer, a Knowledge Layer, an Inference Engine Layer, and a Services and Applications Layer. Its core component is a context-aware recommendation engine based on matrix factorization and contextual biases, which generates personalized suggestions by considering user-item affinity together with contextual dimensions such as weather, crowding, distance, and available time. The framework was developed and validated in-situ. The results show that the proposed system can provide reliable recommendations and improve the perceived quality of the cultural experience, with high levels of user satisfaction across usability, recommendation quality, interaction, presentation, support, and enjoyment.**

***Index Terms*—Cultural Heritage; Context-Aware Recommender Systems; Internet of Things; Digital Storytelling; Adaptive Learning Path.**

I. Introduction

After the period marked by the COVID-19 pandemic, museums and archaeological parks have experienced renewed interest from visitors. This revival has highlighted the importance of improving the quality of cultural experiences, especially in contexts characterized by large numbers of visitors, complex spatial layouts, and heterogeneous user needs. Archaeological parks, in particular, present specific challenges: visit routes may be long or rigid, points of interest may be difficult to prioritize, outdoor conditions can influence the visit, and crowding may reduce the quality of the experience.

A traditional visit often provides the same path and the same information to all users, regardless of their interests, available time, physical position, or contextual conditions [1]. However, visitors differ in motivations, preferences, cultural background, and expectations. Some may prefer short thematic routes, others may be interested in specific historical periods, while others may want to avoid crowded areas or adapt the visit according to weather conditions. For this reason, personalization has become a key requirement for the design of effective digital services in cultural heritage.

Recommender Systems offer a suitable solution to this problem, since they can filter information and suggest relevant content or points of interest according to user preferences. Nevertheless, in cultural heritage contexts, recommendations cannot be based only on static user profiles or generic item ratings. The context in which the visit takes place strongly affects the suitability of each suggestion. For example, a point of interest may be highly relevant for a user but unsuitable in a specific moment because it is too far away, too crowded, or not compatible with the remaining visit time.

To address these issues, the attached work proposes a framework based on Context-Aware Recommender Systems, specifically designed to personalize cultural experiences by integrating user preferences and contextual conditions [2]. The system was developed and tested in the archaeological parks of Pompeii and Paestum-Velia, combining IoT-based data acquisition, contextual modeling, a recommendation engine, chatbot interaction, Digital Storytelling, and Augmented Reality services .

The main idea is to move from a static cultural visit to an adaptive experience, in which the system continuously considers the user, the environment, and the available cultural resources. In this perspective, the visit becomes a dynamic path built step by step, where each suggested point of interest is selected according to both cultural relevance and contextual suitability.

II. The Proposed Framework

The proposed framework is organized into four technical and functional layers: the Sensors Layer, the Knowledge Layer, the Inference Engine Layer, and the Services and Applications Layer [3]. This layered structure allows the

system to acquire data, organize knowledge, infer personalized recommendations, and deliver interactive services to visitors.

The Sensors Layer is responsible for acquiring contextual data from the environment and from the user's interaction with the cultural space. In archaeological parks, relevant contextual factors include weather conditions, crowding near points of interest, user location, available visit time, and proximity to cultural objects. These data are collected through IoT devices, such as cameras for outdoor crowd counting, entrance and exit sensors for indoor spaces, and weather stations. The framework also uses boards such as Raspberry Pi and Arduino devices to collect and pre-process sensor data before sending them to an IoT cloud platform through REST API services.

The Knowledge Layer represents the storage and organization core of the architecture. It collects data from sensors, external APIs, multimedia content, user profiles, points of interest, and interaction histories. This layer manages structured and semi-structured data and prepares them for the recommendation and service generation phases. It also includes pre-processing procedures aimed at cleaning, organizing, and enriching the collected information. In addition, the Knowledge Layer stores the information required to support Digital Storytelling and chatbot services, including cultural content, semantic descriptions, and user feedback.

A relevant component of the framework is the Information Grabber from User Experience, which updates the system based on user interactions and feedback. This mechanism is important because the user experience itself becomes a source of knowledge. The system can therefore progressively improve its ability to model preferences, understand needs, and adapt future recommendations.

The Inference Engine Layer is the computational core of the framework. It includes three main modules: the Context Module, the Recommendation Engine, and the Digital Storytelling Module. The Context Module organizes contextual information using two complementary approaches: the Context Dimension Tree and an ontology. The Context Dimension Tree provides a structured representation of context according to dimensions such as who, what, where, when, why, and how. In the case of archaeological parks, these dimensions include the user, the point of interest, the position, the time of the visit, the visit aim, the weather, and the level of crowding.

The ontology enriches the framework with semantic knowledge related to the cultural heritage domain. It formalizes concepts, attributes, hierarchical relations, semantic links, and logical rules. This semantic layer supports both contextual reasoning and chatbot interaction. In particular, it allows the system to interpret user questions, classify topics, and associate them with appropriate answers or cultural content.

The central component of the Inference Engine is the Recommendation Engine, based on a Context-Aware Recommender System. The proposed approach belongs to the family of collaborative filtering model-based methods and uses matrix factorization, particularly Singular Value Decomposition, to estimate the affinity between users and points of interest. The main innovation lies in the integration of contextual information through contextual biases.

Instead of considering each contextual variable separately, the framework represents the context as an embedded tuple composed of several contextual dimensions, such as weather, crowding, distance, and time. This allows the system to preserve a global representation of the visit situation while avoiding the higher computational cost associated with tensor factorization approaches. The recommendation model learns the interaction between users, points of interest, and embedded contexts, generating rating predictions that are sensitive to the actual situation of the visit.

This strategy is particularly useful in cultural heritage applications because the system must update recommendations rapidly and operate with a limited amount of data. The framework also addresses the cold start problem by using chatbot interaction to collect initial user preferences. At the beginning of the visit, the chatbot can ask questions about interests, available time, and visit goals. These answers are then used to initialize the user profile and guide the recommendation process.

The Digital Storytelling Module uses the output of the Recommendation Engine to present cultural content in a more engaging and non-linear way. Rather than simply listing points of interest, the system can organize cultural information into personalized narratives. This makes the visit more immersive and meaningful, especially when combined with Augmented Reality.

The Services and Applications Layer provides the final interface between the framework and the visitor. It includes a chatbot, an interactive map, recommendation services, Digital Storytelling content, and Augmented Reality features. The chatbot supports users during the visit by answering questions, collecting preferences, and providing contextualized information. The interactive map helps visitors navigate the archaeological site and reach suggested points of interest. Augmented Reality enriches the experience by allowing users to visualize reconstructions, digital replicas, or additional cultural content directly connected to the physical space.

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