An Internet of Things approach for Cultural Heritage enhancement

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Abstract

The emergence of the Internet of Things has led to the creation of technological environments that smartly manage various applications, such as those typically in a Smart City. These applications can enhance the administration of various services by providing dynamic responses based on sensor data to suggest, for instance, where to park, which public transportation to use, or which event to attend. In this scenario, even the world of Cultural Heritage could benefit. This paper aims to introduce a new approach, based on the Internet of Things (IoT) paradigm, to enhance Cultural Heritage fruition. One of the most significant challenges in this sector is classifying and predicting visitor behavior by collecting their activities, preferences, and needs. The proposed approach aims to present an Internet of Things framework geared toward data collection, which feeds a model capable of reproducing and therefore predicting the dynamics associated with visitors' interactions with cultural heritage, i.e., points of interest (POI), and with the available technologies. A prototype was developed and tested in the Salerno downtown area for experimental purposes, obtaining promising results.

Keywords: Internet of Things, Cultural Heritage, Recommender Systems

1 Introduction

The emergence of the Internet of Things has led to the development of technological environments that intelligently manage different applications and services, such as services typical of a Smart City [1, 2, 3]. These applications can improve the management of different services, such as providing dynamic responses based on data from sensors to suggest, for example, where to park, which public transport to use, or which event to attend [4]. In this scenario, even the world of Cultural Heritage could benefit. In fact, several applications in this field are developed to connect users through physical and virtual places [5, 6]. In general, digital enjoyment systems are designed to enhance the dissemination of knowledge of cultural heritage and, in addition, the visitor experience. In this way, intelligent applications and services push us towards creating new cultural spaces that actively involve visitors. All stakeholders involved in the promotion and use of cultural assets are required to undergo a change in governance due to the rise in visitor culture, the development of novel technologies, the adoption of new media, and the abrupt change in the platforms on which knowledge is shared [7, 8]. Within these technological ecosystems, there are objects and people equipped with technological devices, which allow them to communicate and share data in a smart way. Therefore, it is still necessary to develop an IoT system suitable for typical Cultural

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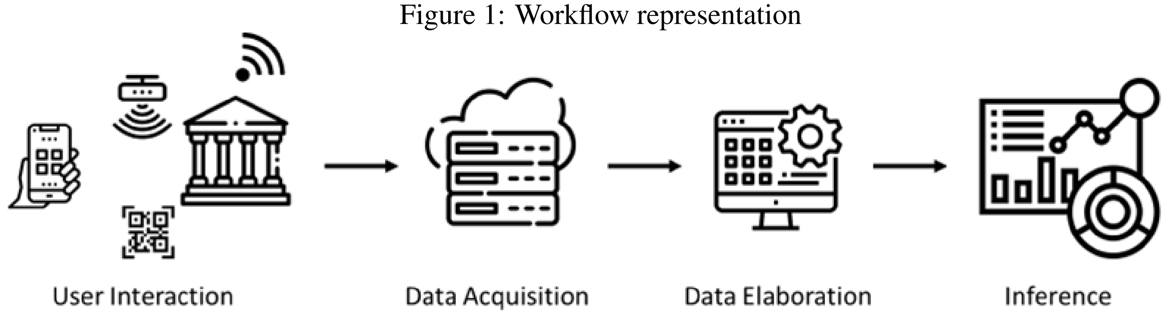
Heritage scenarios. Such a framework is necessarily designed to be based on sensors that collect data from a real environment of cultural heritage [9, 10]. Such data must be collected and structured to build an appropriate knowledge base. The system's ability to store data and organize it into an information flow that may then be inferred. The system's ability to store data and organize it into an information flow that may then be inferred. The analysis of such data is addressed through the use of different approaches consolidated in the literature that refer to the Semantic Web, the use of contextual data, and analysis using Machine Learning techniques designed to predict user behavior during the visit of a cultural asset [11, 12, 13]. The vastness of Italy's cultural heritage generates the need to be supported by technological and sustainable solutions to improve accessibility, communication, and understanding, establishing a connection between space, cultural artifacts, and visitors. Based on a network of services and applications, ICT technologies can characterize a virtual cultural space. In this sense, the visit can be completely personalized and modeled through new fruition, dynamic and engaging ways. The primary objective of such a system should be to enhance the visitor's experience; it should be able to do so more effectively if it takes into account the visitor's type, the context consisting of prior knowledge, perspectives, and interests, as well as the physical context; and it should be able to fulfill a genuine need.[14, 15, 16]. Numerous proposals for applications for the cultural heritage sector that also aim to use the IoT paradigm have been made [6, 17, 18]. One of the most recent and fascinating applications of pervasive and ubiquitous technology is the arrangement of advanced information facilities in public spaces, such as cultural heritage sites. A challenging area of research focuses on a number of factors, such as interoperability with existing museum assets, non-invasive technologies, and the provision of multimedia content customized to visitor behaviors and needs — the design and implementation of systems capable of supporting visitors within cultural environments. In reality, new multimedia technologies could be leveraged to provide new methods for appreciating and comprehending cultural heritage, for instance, through the use of artifacts that are sentient and aware of their context [19, 20]. According to this viewpoint, the IoT paradigm fully develops the idea of an intelligent environment with multiple practical application implications. According to the IoT paradigm, devices can join a network of networked objects that convert a conventional place into an intelligent space, along with cultural items, tourist attractions, and museum settings. Different enabling technologies, such as wireless sensor networks, Bluetooth Low Energy, radio frequency identification, Near Field Communication, and QR-codes, enable the development of these environments [21]. There are several possible applications, and the most interesting solutions concern the automatic management of knowledge integrated with context-aware data for tourism [22, 23, 24]. In addition, the most common solutions concern the design of an appropriate network of museum sensors designed to monitor the presence, location, and integrity of the works of art on display, and used to measure other parameters such as temperature, humidity, and light intensity inside the rooms. However, such data should also be supplemented with information on the perspective of people's knowledge and enjoyment. In addition, other solutions involve employing sensor networks for the preservation of works of art and agent-based ambient intelligence techniques that send information about nearby points of interest. This paper aims to introduce new approaches in the cultural heritage sector, based on the IoT paradigm, which aim to improve fruition. Within these environments, one of the main challenges lies in classifying and predicting visitor behaviors by collecting their movements, choices, and needs. In this article, we describe an IoT system geared toward data collection, which feeds a model capable of reproducing and therefore predicting the dynamics associated with visitors' interactions with cultural heritage, i.e., points of interest (POI), and in particular with the available technologies.

2 IoT Framework

The general information system for data gathering and forecasting is described in this section. Users and Internet of Things sensors interact using this system. Every action a user makes while using a mobile device is precisely recorded and forwarded to a server. The objective is to gather specific behavioral information about consumers using the IoT system, such as location data, interactions with given media information, and profile data. The data can be activated at the point of interest through sensors or QR code. Subsequently, these data are processed and organized to form a structured knowledge base. Structured data can be explored using appropriate data-mining algorithms. Finally, some machine learning techniques are used to infer the data. This is shown in Figure 1 The framework intends to enable interaction between artifacts and sites of interest with other surroundings and other artifacts and to convey to users with the necessary knowledge via multimedia structures. Technology must be able to link the physical and digital worlds in an intelligent cultural environment in order to expand knowledge and, more importantly, to engage visitors as active participants who may enjoy the pleasures of perception and the curiosity of learning new things. The general architecture of the system, in which the sensors are integrated with their surroundings to make the communication system available, is shown below. These sensors are designed to turn creative objects and tourist attractions into intelligent systems that can communicate with one another and with visitors over the network; this acquired identity is essential to the intelligence of a cultural area. Consequently, an application prototype has been created in order for this system to fulfill its purpose and enhance the transfer of knowledge to end users. People can then take advantage of a customized and individualized cultural experience that takes into consideration context-relevant environmental characteristics.

Figure 1: Workflow representation



3 The Proposed Architecture

The purpose of this section is to present a general architecture to support the framework presented earlier. This architecture must allow the use of cultural paths through a network of IoT sensors and contextual information. The proposed approach is able to share various methodologies that are the basis of models that work in different areas, such as smart cities and the enhancement of cultural heritage. In particular, in contributing to the intended objective of recommending the right cultural path to users based on the context, reference is made to Ontologies, Context Dimension Trees (CDT), and Bayesian Networks (BN) [25]. These methodologies, used in the management of complex scenarios, are part of the proposed framework in order to provide users with multimedia content near the places visited and according to different factors capable of influencing the cultural path such as time available, weather conditions, and user attitudes. As can be seen from Figure 2, the proposed architecture consists of three main blocks:

- Acquisition layer
- Inference Layer
- Information layer

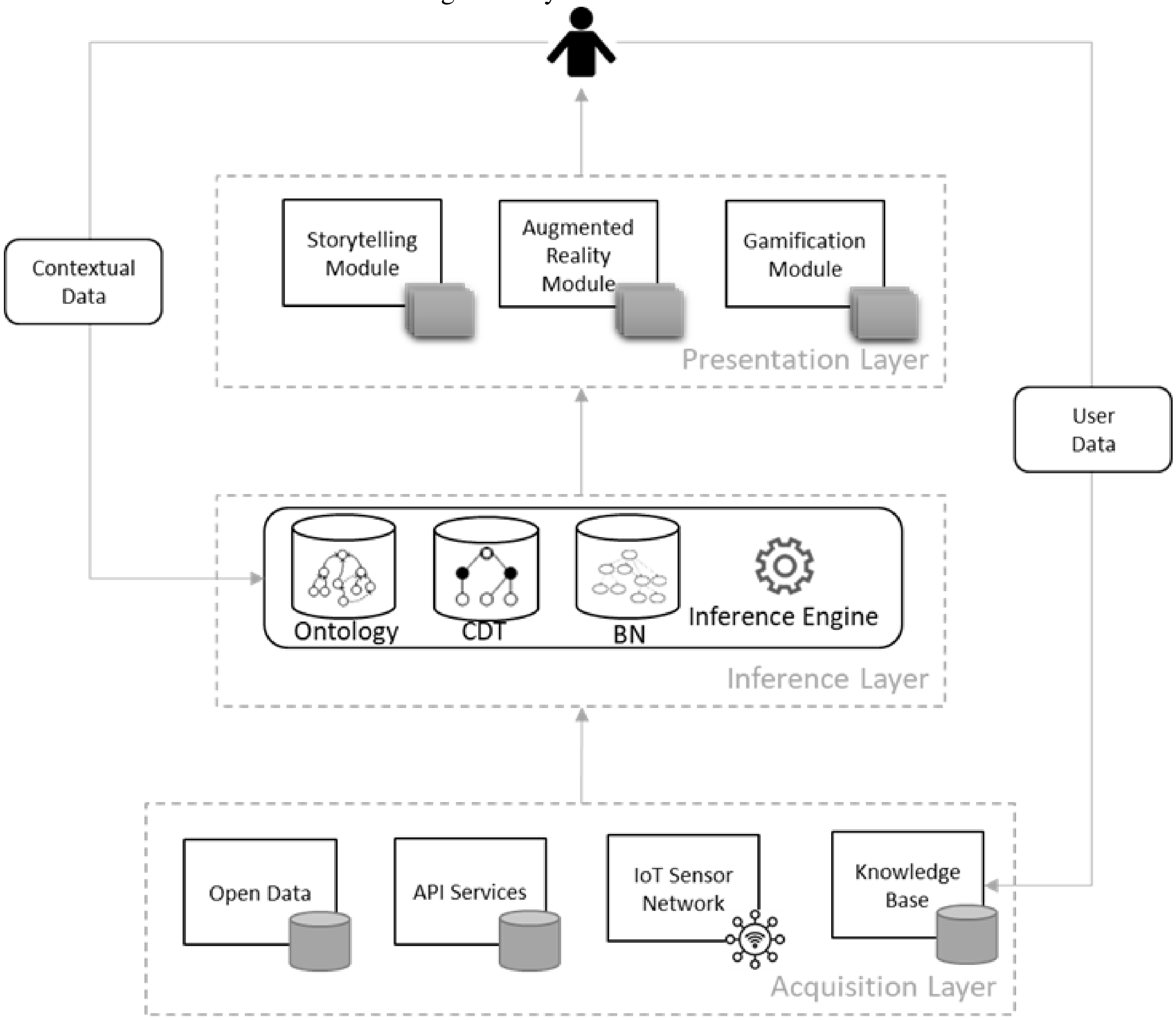
3.1 Acquisition Layer

Methodologies and approaches for obtaining data from numerous sources are gathered by the acquisition layer. This layer's goal is to retain as much information as it can, homogenize it, and make it usable; together, these elements make up an effective and practical knowledge base for the inference layer. The following layer receives this data once it has been orchestrated using an orchestration technique. The global knowledge base is composed of open data on the web, API services (made ad hoc or already available), and a system knowledge base in addition to depending on data from the IoT sensor network. The system can offer more insightful responses than other services because of the aggregation of these facts. As a result, information about various support services is merged, including maps, weather reports, descriptions of artwork, narratives of interesting places, personal anecdotes, etc. Additionally, service information, such as booking and purchasing tickets, or other educational material that would round out the cultural experience, can be integrated through API to improve cultural understanding. In order to provide a comprehensive image of the local areas of interest that will be analyzed by various tools, all of these data are processed by fusing them with the user's traits and preferences.

3.2 Inference Layer

It is vital to effectively handle the information coming from the information layer, compatible with the contextual data, in order to define appropriate cultural routes helpful to the various target audiences. The inference engine, which has the ability to apply several approaches, is the primary component of this layer. The inference engine makes use of Bayes networks, a methodology with predictive power, as well as Ontologies and CDT [26, 27, 28], which are based on the description and awareness of the context. This layer's goal is to give the user personalized routes that take them to the appropriate locations at the appropriate times. For instance, it offers indoor sightseeing routes if it is raining, and it shortens the educational visit route if the user enters an event on the calendar and leaves the visited location in time to engage in other activities. Modeling the context is one of the phase's primary goals. Ontologies and the Context Dimension Tree are two graph methods that enable this (CDT). Through a formal, widespread, and clear representation, ontologies enable an area of interest. To be more precise, it is an axiomatic first-order theory that can be represented in descriptive logic. Ontologies, particularly those that take the shape of graphs, can interact with tools like CDT and Bayesian networks. Through a decision tree made up of the triad r, N, and A, where r is the tree's root, N is the collection of nodes it is made up of, and A is the set of arcs that connect these nodes, the CDT enables to manage all potential situations. In particular, dimensional nodes and conceptual nodes are the two categories into which CDT's nodes are separated. Concept nodes compile all the potential values that a dimension may take, while dimension nodes represent the potential dimensions of the application domain. Based on the potential context chosen, this model may efficiently interface with and query a database to choose the appropriate services. The inference engine's predictive capability is another essential component. Bayesian networks are used to make the prediction. A directed acyclic graph is used to describe a set of stochastic variables with their conditional dependencies in Bayesian networks, which are probabilistic graphs (DAG). These models use Bayes' theorem to forecast the likelihood that a specific event will occur. Furthermore, Bayesian networks can effectively interface with the CDT because of their structure. There are three primary steps to the suggested strategy. The design of the ontology and CDT is the initial stage. This phase

Figure 2: System Architecture



provides the system with context awareness, which is accomplished by describing reality and identifying all potential contexts for application. The second stage focuses on creating the Bayesian network using techniques for machine learning and industry specialists. This framework enables us to determine the likelihood that a specific event will occur. The final stage focuses on how the various graph techniques put out interact with one another. These interactions give rise to the system's replies, which are tailored to the users' specific cultural routes and are contextually appropriate. The suggested architecture can build personalized pathways that can change in real-time to meet the demands of the user and adapt to the context. The user is also provided with a range of services, including:

- Designing automated modular routes. In addition, the route's assisted and simplified design can be customized, giving the user a chance to select options that are more suited to the traits of his profile;
- setting up trips with guides. the ability to use services to reserve activities like visits to museums when it is convenient to do so and avoid lines;

- changing the route dynamically in response to user behavior, the environment, or any crises;
- to improve cultural insights through traveling to unexpected locations and supporting local heritage, adventure paths are recommended. These paths use the gamification technique.

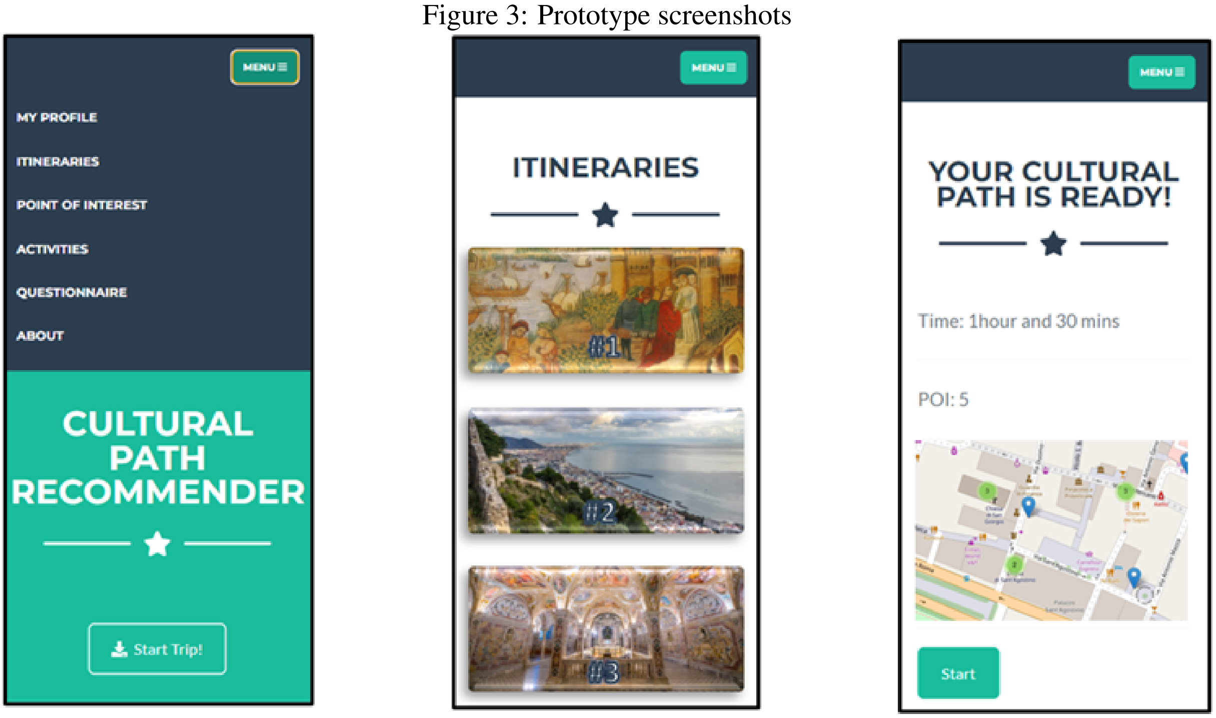
3.3 Information Layer

The user will be shown the inference engine's recommendations through this layer. With the thorough information about cultural options and routes, this information is given to the user through a straightforward and easy interface. With augmented reality techniques that make it simple and natural to learn the crucial steps of the course, the aim is to offer personalized outcomes using storytelling strategies that integrate visuals, narratives, games, and interactions. Multimedia content is the end result of this process, and it contains information on places to see, connections between places to see and itineraries, and quizzes and activities designed to gauge the success of the trip or deepen the cultural experience.

4 Experimental Results

By creating a prototype based on the suggested architecture, the recommended methodology's evaluation procedure was carried out (Figure 3). A server component and a mobile hybrid app make up the prototype. The server-side Rest API service was built using the Java-based Hibernate framework, and mobile applications were developed using the Apache Cordova Framework. Three routes with different

Figure 3: Prototype screenshots



themes that were connected to the city of Salerno were used in the experimentation phase. Although the proposed architecture allows the system to access various open data on the web, in this first experimental phase, the prototype was modeled with particular attention to the three selected thematic paths. It contains a number of points of interest connected to the cultural routes, enabling the system to construct the corresponding custom cultural routes. The many sites of interest have been added so that the demands of various users (children, adults, and experts) can be gathered during the trip. A total of 131 users were involved, trying to divide them homogeneously by different age groups and characteristics who were unaware of the purpose of the research. Each participant received a smartphone loaded with the application's prototype, and they were free to explore Salerno's various roads and multimedia cultural offerings. Three groups of users were created, as follows:

- Group 1. Route: On the trail of the Salerno Medical School
- Group 2. Route: The places of the City of Salerno
- Group 3. Route: The heart of the ancient center of Salerno

Downstream of the experience of using the contents, all users were offered a questionnaire divided into the following sections:

A Presentation

1 The information has been presented appropriately.

2 The information provided was comprehensive.

B Reliability

1 The cultural routes provided were adapted to the needs of the user.

2 The application was able to support the entire path.

C Recommendation

1 The services and contents offered have met the user's needs based on personal preferences and the current context.

2 The system has managed to adapt to changes in the context.

D Usability

1 The application interface is easy to use.

2 Response times are adequate.

E Future developments

1 It would be useful to include interaction with social networks in the application.

2 It would be interesting to apply the same approach to other scenarios.

Each section of the questionnaire, based on the Likert scale, presented two assertions to which five possible answers were associated: I totally disagree - TD, I disagree - D, Undecided - U, I agree - A, I totally agree - TA. The answers were collected in Table 1. In addition, a new experimental phase involving a smaller group of participants was requested in order to assess the system's efficiency in making service recommendations. For this reason, just five sites of interest were chosen for each route, and users were given a chance to indicate through the prototype whether the suggested point of interest was pertinent given their needs and circumstances. The following categories are used to group the participants who took part in the experimental phase for a second time:

- Group 1. Path: On the trail of the Salerno Medical School (18 users)

- Group 2. Route: The places of the City of Salerno (16 users)
- Group 3. Route: The heart of the ancient center of Salerno (12 users)

The information gleaned from prior users' experiences was added to the system's knowledge base during this experimental phase. The outcomes have been compiled in the form of a confusion matrix, which expresses the applicability of the suggested areas of interest in relation to the context and needs (Figure 4, Figure 5, Figure 6). The level of satisfaction among the 131 participants is displayed in Table 1. Users concur that the system is able to offer modules that are customized and appropriate for the situation. The results are visually reported in Figure 7. Users are particularly pleased with the capability to suggest the appropriate training path given the context. The confusion matrices in Figure 4, Figure 5, Figure 6 show that the system was able to recommend the correct routes to users based on users' profiles and time needs. All confusion matrices report an overall accuracy of more than 70%, which is very encouraging. Figure 5 shows an overall accuracy of more than 85%; this extraordinary result can be due to two factors. One factor could be the choice of points of interest that are particularly suitable for the selected place. The second factor could be related to the nature of the itinerary, which unlike others, has points of interest of a general nature and a homogeneous density with respect to the route. However, all the results obtained are very encouraging and could improve over time in accordance with user experiences.

Table 1: Questionnaire answers

Section	Answer				
	TD	D	U	A	TA
A	9	11	45	94	73
B	10	14	28	116	64
C	9	2	13	121	87
D	6	33	41	102	50
E	19	14	23	104	72

Figure 4: Confusion Matrix I

Prediction \ Reference	POI #1	POI #2	POI #3	POI #4	POI #5
POI #1	46	5	2	5	1
POI #2	6	36	9	3	5
POI #3	1	3	45	3	7
POI #4	2	1	6	48	2
POI #5	1	2	4	3	49

Overall Accuracy : 75,93%

5 Conclusion

The objective of this document was to present an architecture, based on the Internet of Things, able to create and recommend cultural routes automatically. The aim of this work is to provide tailor-made cultural content making the tourist experience adaptable to the context and needs of the user. The novel aspect of the suggested methodology is the use of graph tools that can fully utilize context awareness,

Figure 5: Confusion Matrix II

Prediction \ Reference	POI #1	POI #2	POI #3	POI #4	POI #5
POI #1	74	6	4	0	2
POI #2	2	73	6	1	4
POI #3	1	7	68	7	3
POI #4	3	1	3	73	6
POI #5	0	2	5	1	78

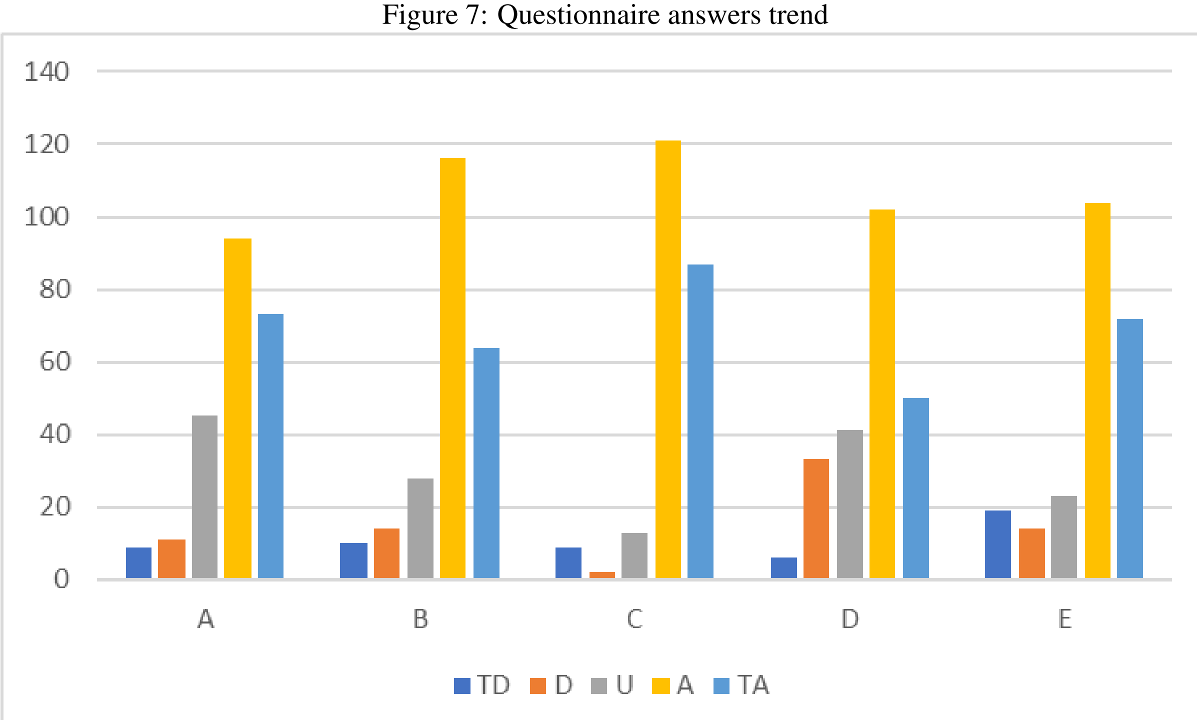
Overall Accuracy : 85,11%

Figure 6: Confusion Matrix III

Prediction \ Reference	POI #1	POI #2	POI #3	POI #4	POI #5
POI #1	55	9	1	3	0
POI #2	9	41	9	4	5
POI #3	0	7	45	9	7
POI #4	7	1	8	47	5
POI #5	0	8	4	5	51

Overall Accuracy : 70,29%

Figure 7: Questionnaire answers trend



such as ontologies and context dimension trees. In many settings and mobile apps, the suggested architecture might not be appropriate. The testing findings are intriguing and reassuring, demonstrating that the system can successfully plan cultural paths and that the produced prototype is useful from a variety of angles. The people who participated in the testing campaign gave the prototype high marks for dependability and usefulness. The system's ability to make recommendations has also improved to a high degree of accuracy. Future upgrades to the established prototype will likely involve expanding the database, adding more points of interest to widen cultural routes, and adding services to deepen cultural routes.

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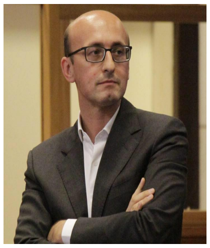

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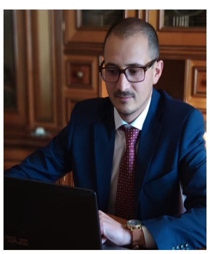
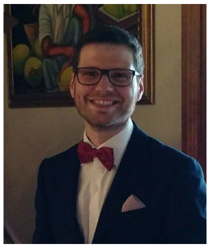


Angelo Lorusso is a Ph.D. Student at the University of Salerno (Department of Industrial Engineering), and has research experience in Computer Science, the Internet of Things, BIM, and Digital Twin. He is the author of more than 15 papers in Computer Science, some of which were published in international journals. He is a member of the Knowman research group (knowman.unisa.it) and collaborates with the research group on several projects funded by the Italian Ministry of University and by the European Community.



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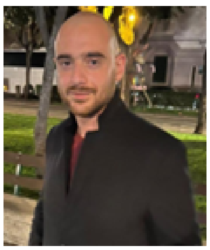

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