Smart Cabin: A Semantic-Based Framework for Indoor Comfort Customization Inside a Cruise Cabin

Atieh Mahroo, Daniele Spoladore, Massimiliano Nolich, Raol Buqi, Sara Carciotti and Marco Sacco

Abstract This paper introduces Smart Cabin, a semantic-based framework for indoor comfort metrics customization inside a cruise cabin. Smart Cabin merges Ambient Intelligence, Ambient Assisted Living and Context Awareness perspectives to provide customized comfort experience to the cruise's passengers. Considering that passengers may be afflicted by some impairments, Smart Cabin aims at mitigating discomfort situations by providing tailored comfort settings. The framework leverages ontological representations of passengers' health conditions, activities, cabin's environment, and available devices to provide passengers with indoor temperature, humidity rate, CO_2 concentration, and luminance suitable for their health conditions and to the activities they want to perform inside the cruise cabin. Passengers' interactions with Smart Cabin are performed with a simple smartphone application, while the ontologies composing the knowledge base are reasoned and hosted on a semantic repository. Two use cases depict the framework's functioning in two typical scenarios: saving energy when the passenger leaves the cabin while reestablishing customized comfort when she/he returns, and adapting indoor comfort metrics when two or more passengers decide to perform different activities inside the same cabin.

A. Mahroo (✉) · D. Spoladore · M. Sacco
Institute of Intelligent Industrial Technologies and Systems for Advanced Manufacturing (STIIMA), National Research Council of Italy (CNR), 23900 Lecco, Italy
e-mail: atieh.mahroo@stiima.cnr.it

D. Spoladore
e-mail: daniele.spoladore@stiima.cnr.it

M. Sacco
e-mail: marco.sacco@stiima.cnr.it

M. Nolich · R. Buqi · S. Carciotti
DIA-University of Trieste, 34127 Trieste, Italy
e-mail: mnolich@units.it

R. Buqi
e-mail: rbuqi@units.it

S. Carciotti
e-mail: scarciotti@units.it

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1 Introduction

In recent decades, the naval industry has faced a growing concern regarding the passenger's comfort inside the cruise ship in general and inside the cabin in particular. There have been many studies concerning the indoor comfort inside other transportation vehicles; however, little study has been conducted in regards to the comfort inside cruise ships. Indoor comfort metrics have been the topic of many studies and much is known about an "able-bodied" person inside any indoor environment. However, little is known about the comfort requirements for a person with disabilities. Nevertheless, in the context of Ambient Assisted Living (AAL) [1], it is important to ensure Ambient Intelligence (AmI) [2] and Context Awareness (CA) [3] to guarantee smart services.

The aim of these services is to help elderlies and people with disabilities to live more independently, in a safe, healthy, and socially connected environment [4]. AmI encompasses the ideas of ubiquitous computing, by adding intelligent automation and human–computer intuitive interaction. This requires incorporating sensors and actuators as physical means and artificial intelligence (AI) as a reasoning brain behind the system.

This work describes Smart Cabin, a framework for passenger's comfort in a cruise ship cabin, including people with disabilities. Smart Cabin exploits Semantic Web technologies and the protocol of Internet of things (IoT) [5], to enable the interoperability among different knowledge domains. This can be done through the exchange of information between the ubiquitous devices mounted inside the cabin, interchanging and manipulating the knowledge underlying the framework, and near real-time reasoning over data to retrieve the most relevant information and adaptability.

In order to make the cabin smarter, several factors are considered including passenger presence, health conditions, preferences, activities, and feedbacks. Therefore, the cabin must be equipped with a synergic system consisting of heterogeneous devices (sensors and actuators) mounted inside the cabin to gather data about the current status of the indoor environment, a comprehensive knowledge base provisioning passenger's information, a reasoning system to make decisions according to the gathered information coming from sensors and actuators—which actually make the decisions happen.

In this context, Semantic Web technologies could be a promising solution to tackle the knowledge representation of information coming from different domains. Knowledge needs to be captured, processed, recycled, and interconnected to be considered as relevant. Thus, exploiting the ontology to manage knowledge bases, and enriching the knowledge bases by deriving new facts using reasoning techniques, can be a robust solution.

Smart Cabin relies on domain ontologies—formal and explicit specifications of shared conceptualizations [6]—modeled with Resource Description Framework (RDF) [7], Web Ontology Language (OWL) [8] and Semantic Web Rule Language (SWRL) [9]—which are W3C-endorsed standard languages.

Smart Cabin allows some indoor comfort metrics to be adjusted according to the passenger's health conditions and needs; in particular, the framework takes into account indoor temperature and humidity rate, CO_2 concentration, and lighting.

The remainder of this paper is organized as follows: Section. 2 highlights some of the relevant works in the field of indoor comfort customization; Section. 3 delves into Smart Cabin's architecture; Section. 4 depicts two use cases and Smart Cabin's features; finally, the Conclusions summarize the main outcomes of this paper and sketch the future works.

2 Related Works

Passengers' comfort on a cruise ship is a little-debated topic in scientific literature; there are works addressing the cabin as a social space [10], investigating the acoustic comfort for passengers [11], and examining the leisure cruise service environment [12], but only a few papers addressed the issue of indoor cabin comfort. Recently, Buqi et al. [13] addressed the possibility to provide customized indoor comfort to cruise passengers relying on a smartphone app and a decision support system; similarly, Spoladore et al. [14] envisioned the possibility to rely on Semantic Web Technologies to provide tailored comfort inside a cabin. These two works highlight how a cabin can be seen as a—downsized—living environment, in which AmI and CA technologies can be adopted to foster indoor comfort personalization.

There exists a variety of works related to the provision of customized indoor comfort metrics, but only few of them adopt the user's health condition and preferences as one of the determinants for comfort customization and actuation. In [15], the authors leveraged semantic representations of domestic environment, comfort metrics, and dwellers' health conditions to configure the indoor comfort settings of a smart home. Tila et al. [16] adopted a context ontology-based approach to manage indoor comfort metrics, providing also the means for the description of actuators and sensors. Frešer et al. [17] developed a decision support system to improve the quality of temperature, humidity rate, and CO_2 concentration in an indoor environment, leveraging on reasoning processes enabled by the exploitation of Semantic Web Technologies. Adeleke et al. [18] proposed an ontology for indoor air quality monitoring and control, formalizing some of the knowledge of the standard ISO 7730:2005. Stavropoulos et al. [19] developed an ontology for smart building and AmI, mainly focusing on services, hardware energy management, and some concepts regarding the context. In the context of AmI and CA, Smart Cabin provides a semantic-based framework able to deliver customized comfort to passengers; furthermore, encompassing AAL vision, it takes into accounts passengers' specific disabilities to provide them with a tailored and comfortable experience inside the cruise cabin.

3 The Architecture of the Smart Cabin

This section describes the architecture of the Smart Cabin framework and its modules in detail. As mentioned in Sect. 1, in the context of AAL, the possibility of enabling indoor environment responsiveness to the inhabitants' needs and comfort requirements plays a pivotal role. In this context, this work proposes the Smart Cabin, a system that aims at providing the maximum level of comfort within the cruise cabin considering the diverse groups of people including people with disabilities, and adjusting the system according to the various activities they might be performing. In this regard, the first issue to be addressed is the physical environment and its substantial smart devices to ensure the passengers' comfort. The cabin must be equipped not only with proper living furniture, but also with necessary smart and ubiquitous devices to be prepared for exploitation by the Smart Cabin framework. Thus, a strong and solid network of sensors and actuators is needed to sense, measure, and exchange the data both from sensors to the application—where a decision is made—and from the application to the actuators. The application designed in this project is a user interface mobile application that is installed on the passenger's smartphone prior to boarding. The passenger may log in for more secure and tailored services and provide the basic information to the application such as name, gender, and disability status. The Smart Cabin considers a range of activities to be done by the passenger inside the cabin, thus it modifies the indoor environment to leverage the comfort metrics according to that specific passenger's needs and preferences.

For example, the passenger decides to read: she/he selects the type of reading she/he would like to dedicate to (relax, study or work) on her/his smartphone application. She/he also chooses the position inside the cabin where she/he would like to read (bed, desk, or balcony). The cabin system is aware of passenger's impairment, and adapts the comfort metrics according to her/his need, activity and position. In order to make this happen, Smart Cabin needs a comprehensive framework composed of four different layers as follow:

a. Physical cabin equipped with smart devices to be connected to the application;
b. User interface smartphone application where the passenger can log in and interact with the system;
c. Knowledge base including the domain ontologies, hosted on a Stardog semantic repository equipped with SL reasoner to run SPARQL Protocol and RDF Query Language (SPARQL) [20]; and
d. Middleware Java program to communicate between (b) and (c), translating the information from Smart Cabin application to semantic repository and vice versa.

Figure 1 sketches the high-level perspective of the framework architecture and communication between its modules, which enables the interoperability between different layers of the platforms. Data lifecycle in this scenario starts from the smart devices (physical layer), routes to the Smart Cabin application, passes through a middleware program, is manipulated inside the semantic repository, and then comes back through the middleware, and is submitted back to the application to trigger the actuators in the cabin.

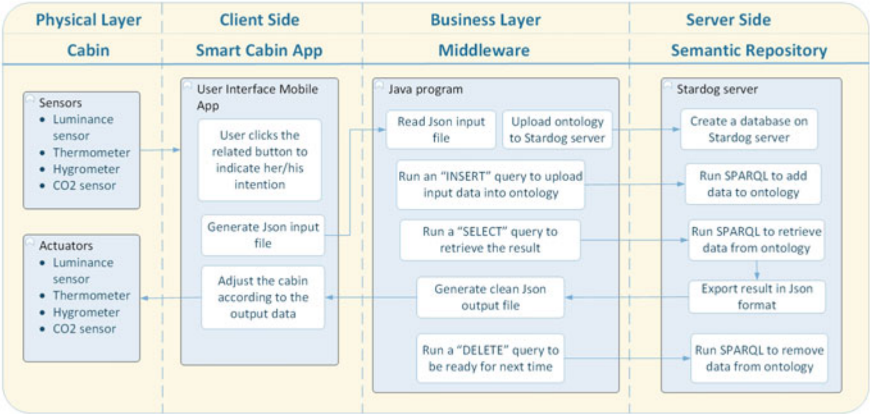

Fig. 1 Overall architecture of the framework divided into four main modules

3.1 *Real Cabin*

In this work, a cabin of 3×6 m^2 is being considered and it has been provided by Fincantieri company in the University of Trieste for system deployment. As it is shown in Fig. 2, the cabin is divided into four different functional areas—entrance and bathroom; living area (including sofa, wardrobe, TV, desk, and a chair); sleeping area (including a double bed, and two bedside tables); and balcony (including a chair and a small table).

In addition to the cabin's furniture, the physical layer of this architecture consists of a network of interconnected devices, which produces data streams transmitted by means of active transponders to proper receivers—thus, making the cabin equipped

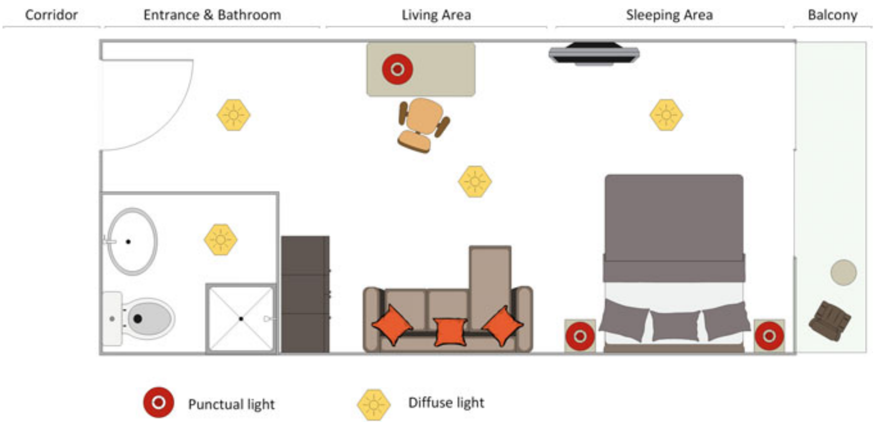

Fig. 2 Cabin plan divided into four functional areas

with a set of sensors and actuators to communicate between the environment and the framework. These smart devices could be divided into two categories as follow:

a. Sensors (illuminance, temperature, humidity, and CO_2 concentration sensors);
b. Actuators (Philips Hue lamps, and PCE thermo-hygrometer).

3.2 Smart Cabin User Interface Application

Smart Cabin App is an application developed using Android Studio. Its aim is to help the passengers to reach a state of comfort inside the cruise cabin. User Interface (UI) design focuses on anticipating what users need; the visual interface is original, minimal, intuitive, and functional. The Home Page layout of the application is divided into four parts:

a. General settings,
b. Weather (weather situation, location, outside and inside temperature),
c. Functionality (cabin, activity, atmosphere, devices), and
d. User's settings.

The UI has elements that are easy to access, understand, and use, thanks to the grid's disposition [21]. The four "functionality" icons of the Home Page are arranged in the main part of the screen. The central position allows the user to view the situation of the devices, to check the cabin's characteristics, to choose the desired atmosphere, or to initiate a new activity.

Figure 3 shows three different activities that passenger can choose to perform in order to have different light settings within different functional areas of the cabin.

The simplicity and ease of access are two main factors for designing the application, due to the fact that one of the main objectives of the project is to include the elderly and people with disabilities.

3.3 Knowledge Base and Semantic Repository

As discussed in Sect. 3.1, a set of sensors and actuators has to be mounted within the cabin to measure, analyze, and adapt the indoor comfort metrics. However, there must be a control center—with special sets of rules and reasoning logic—between the sensors and the actuators in which decisions have to be made. In other words, sensors measure the data about indoor comfort, send them to the semantic repository to be saved and reasoned over in the knowledge base, and finally, decisions provided by reasoning process are sent to the actuators to initiate the required action. Smart Cabin's knowledge base, its different domains' ontologies, semantic repository, and

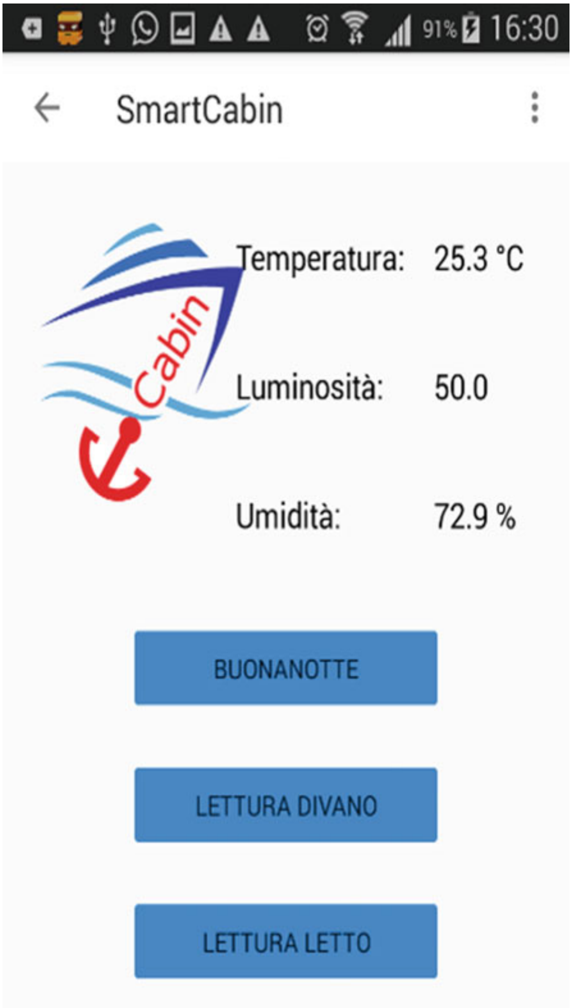

Fig. 3 A snapshot of Smart Cabin application indicating some indoor comfort metrics

reasoner are stored on a private server to be available anytime while being protected. Thus, the second layer of this framework architecture consists of the following:

a. A set of ontologies for semantic representation of knowledge about both the cabin environment and the passenger's characteristics and health conditions modeled with RDF and OWL;
b. A set of rules defined in SWRL to infer new pieces of information;
c. A reasoner engine to reason over data, rules (SWRL), ontologies' constraints, and axioms to infer new data;

d. A semantic repository to upload the ontologies on the server to allow querying and retrieving data; and
e. SPARQL to query over the semantic repository and allowing to insert, retrieve, and delete the information modeled in the ontologies.

The semantic model—discussed in [14]—is composed of several modules to describe different domains of knowledge, composing a comprehensive knowledge representation of the cabin and its passengers. The ontologies developed for the Smart Cabin framework are:

a. Passenger's status ontology. This semantic model provides the means to describe the passenger, her/his registry records (gathered from the purchase she/he has made for the cruise ticket) and her/his health condition. The modeling of the health condition of the passengers relies on the International Classification of Functioning, Disability and Health (ICF) [22]—which allows Smart Cabin knowledge base to reuse an existing and WHO-endorsed ontology. In this way, it is possible to describe the passenger's functional impairments: in fact, ICF is a shareable and standard language for disability description that conceptualizes the functioning of an individual as a "dynamic interaction between a person's health condition, environmental factors, and personal factors" [23]. ICF provides a set of codes, each indicating a specific impairment that can be completed with qualifiers in order to state the magnitude of the impairment (1st qualifier) and—only for impairments in body structures—the origin of the impairment (2nd qualifier) and its location (3rd qualifier). Figure 4 provides an example of the passenger's health condition modeling. In this case, the passenger suffers from light sensitivity and has an impairment in the eyelid of her/his right eye.

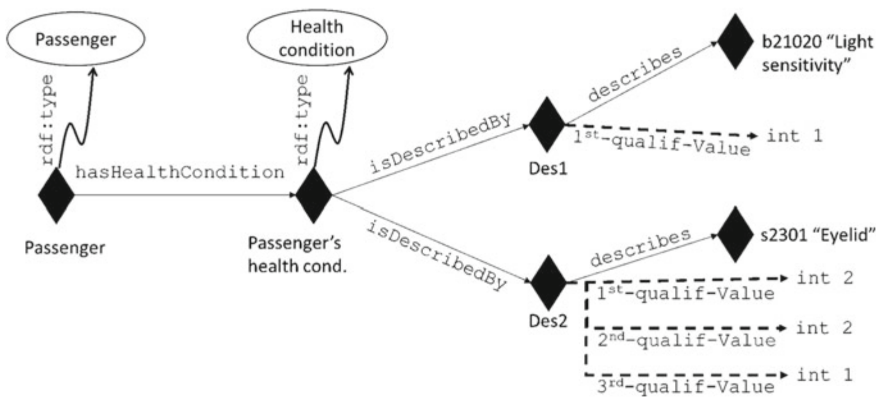

Fig. 4 An example of Passenger's health condition modeling with ICF. Diamonds represent individuals, circles represent concepts, arrows represent roles (dashed for datatype property, full-line for object properties); the type of an individual is stated with a curved arrow

b. Passenger's preferences ontology. Passenger's preferences regarding comfort metrics (such as light intensity, indoor temperature, etc.) are also modeled and saved relying on a set of datatype properties.
c. Activities performable by a passenger. A list of typical activities that a passenger can perform inside a cabin is modeled in an application ontology (reading, relaxing, sleeping, watching TV, etc.).
d. Cabin and devices ontology. The space composing the cabin is described leveraging on a simple model created from scratch, which provides the means to describe the areas composing a cabin. The devices deployed in the cabins (sensors, appliances, and actuators) are described by reusing the Smart Appliances REFerence (SAREF) ontology [24], an ontology providing the means to formally describe the appliances and their measurements; measurements provided by sensors are also modeled with reusing an existing ontology design pattern [25].

3.4 Middleware Java Program

This section describes the middleware program between the semantic models and the smartphone application. This middleware program is developed to connect the smartphone application to the semantic knowledge base and make them communicate with each other and exchange information in various ways.

The Smart Cabin application needs to access the semantic repository to retrieve the information, insert new pieces of data coming from sensors, and/or delete the old information. However, modifying the ontology, which is already on the server, is not a trivial task to do due to the Open-World Assumption (OWA) of monotonic nature of Description Logic (DL) [26]. One of the consequences of the adoption of OWA is the impossibility for a deductive reasoner to infer the existence of a new instance unless it is already modeled in the knowledge base. As a result, inserting a new piece of information into the semantic repository is not a task supported by DL-based technologies [27]. On the other hand, retrieving precise information from the semantic repository must be done through the execution of SPARQL queries in which the exact passenger's data should be provided to run the query. Moreover, running the proper query to retrieve the most accurate and relative information at each moment, is something that has to be done automatically.

As a result, Smart Cabin relies on a Java-based program acting as a middleware between the smartphone application and the semantic repository to solve all of these issues. This program runs each time the passenger decides to perform an activity inside the cabin and taps the related button on the smartphone application to state her/his intention. The moment the passenger taps the related button on the application to perform an activity, the middleware program runs to generate a proper query with necessary input data to be able to retrieve information regarding the passenger's preferences and indoor comfort. These input data are passed from application to the middleware through a JSON file indicating the passenger's unique ID, the activity she/he would like to perform, and the place in which she/he would like to perform that activity. This JSON file is fed into the middleware as an input to generate the precise SPARQL queries to insert that specific situation inside the ontology, retrieve the inferred data according to the new data inserted, and finally, delete the inserted data to have the ontology ready for the next execution. After generating the correct SPARQL query, the middleware program runs the Stardog server—in which the ontology is saved—and executes three different SPARQL queries generated by the program in the following order:

a. INSERT query, to add new triple data about the passenger's activity she/he intends to perform, and the place in which she/he would like to perform her/his activity;
b. SELECT query, to retrieve triple data about the passenger's comfort metrics and preferences based on her/his health condition, the activity she/he intends to perform, and the place in which she/he would like to perform her/his activity; and
c. DELETE query to remove triple data from ontology on Stardog repository which had been inserted in (a), to be free for further reuse.

4 Use Cases Scenarios

Smart Cabin framework combines various technologies to enable the AAL, AmI, and CA environment running. Considering the complexity of the technological problem, it is important to define some use case scenarios to depict the interaction between the passengers and the Smart Cabin to demonstrate how these smart features could help users to perform their activities more conveniently. In the following use cases, a cabin is considered to be related to a middle-aged couple traveling together in order to demonstrate how these smart features could help them to perform their activities inside the cabin more conveniently.

4.1 "Find Indoor Comfort as You Left It" Mode

The first use case illustrates how Smart Cabin optimizes the energy consumption within the cabin. Smart Cabin is equipped with the presence sensors to be able to detect the presence of the passengers inside the cabin while one or both of them are inside the cabin. The cruise ship is equipped with a network of Bluetooth Low Energy (BLE) beacons as a proximity sensor to locate the passengers on the ship due to the fact that it is not possible to rely on Global Positioning System (GPS) as there is no Internet connection on the ocean. When the passengers leave the cabin and reach a certain distance from her/his cabin, the system switches the status of the Smart Cabin to the power-saving mode to maximize energy saving. However, when the passengers return to the cabin, Smart Cabin sets the environment prior to passenger's arrival when they reach a certain distance from the cabin. The system resumes the indoor comfort metrics as the passengers left them before leaving. In this way, Smart Cabin offers the possibility to save energy and preserve passenger's comfort.

4.2 Having Two Passengers Inside a Cabin Performing Different Activities

The second use case demonstrates how Smart Cabin adapts itself to the different needs of the passengers performing different activities to boost the level of comfort and welfare. Smart Cabin is able to customize the comfort requirements based on the activity the passenger is performing. Considering only one passenger in a cabin, it could be done easily, however, having two passengers traveling together in a cabin makes it more challenging. Assume a middle-aged couple is traveling together. While the wife has no particular impairment, the husband suffers from light sensitivity—a condition modeled in his ontology with ICF, as depicted in Fig. 4. In this case, the Smart Cabin provides him with the specific light with a precise amount of intensity, the right direction, and color to support his need. This feature is important when it comes to activities that need focus and alertness like reading. When the husband decides to read at the desk, he has to reveal his intention to the system through the smartphone application indicating the type of reading he would like to perform (such as study, work, or hobby), the particular type of support for reading (such as book, magazine, newspaper, digital book, etc.), and his position within the cabin (such as sitting behind the desk, sitting on the couch, lying on the bed, or sitting in the balcony area). Smart Cabin then tunes the closest punctual light to him with proper settings (180 lx intensity, 2500 K temperature) adjusted to his need to support the entire reading session for him with constant and suitable luminance. In this way, the wife can relax while listening to music in another area of the cabin, and Smart Cabin provides her with a relaxing luminous setting (120 lx intensity, 1800 K).

5 Conclusion and Future Works

This work introduces Smart Cabin, a semantic-based framework aimed at enhancing indoor comfort for cruise cabin passengers. The framework relies on Context Awareness, Ambient Intelligence, and Ambient Assisted Living paradigms to encompass also passengers with disabilities' needs; according to evidences [25, 28], Semantic-based technologies provide a sharable and machine-understandable representation of passengers' health condition and can trigger environmental actuation to help them in performing several activities. Smart Cabin relies on a server-based architecture and can be operated by the passengers via a simple smartphone application.

Future works foresee the validation of the Smart Cabin framework and, in particular, the validation of the smartphone application using standard questionnaires and tests—such as the Mobile App Rating Scale (MARS) test, the Technology Acceptance Model 2 (TAM2), and the System Usability Scale (SUS).

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