electronics

MDPI

Article

RoomFort: An Ontology-Based Comfort Management Application for Hotels

Daniele Spoladore [1,*], Sara Arlati [1,†], Sara Carciotti [2], Massimiliano Nolich [2] and Marco Sacco [1]

1 Institute of Intelligent Industrial Technologies and Systems for Advanced Manufacturing, National Research Council, Via Previati 1/E, 23900 Lecco, Italy; sara.arlati@stiima.cnr.it (S.A.); marco.sacco@stiima.cnr.it (M.S.)
2 Department of Engineering and Architecture, University of Trieste, Via Alfonso Valerio 6/3, 34127 Trieste, Italy; scarciotti@units.it (S.C.); mnolich@units.it (M.N.)
* Correspondence: daniele.spoladore@stiima.cnr.it; Tel.: +39-0341-2350202
† Current address: Department of Electronics, Information and Bioengineering, Politecnico di Milano, Via Giuseppe Ponzio 34, 20133 Milano, Italy.

Received: 23 October 2018; Accepted: 19 November 2018; Published: 22 November 2018

Abstract: Business traveling is attracting growing attention due to the expansion of international markets. This fact calls for an increasing attention of the tourism sector toward the needs of business travellers, who often require services that are different from the ones desired by leisure tourists. The application of smart solutions coming from Context Awareness and Ambient Intelligence aimed at promoting guests' comfort and well-being, also in cases in which they have special needs, represents a promising solution to tackle business travellers' requirements and thus, to increase hotels attractiveness and incomes. In this context, this work introduces RoomFort, a smart comfort management system aimed at enhancing comfort of hotel room guests and leveraging on semantic representations of comfort, environment, and sensors. RoomFort provides a set of domain ontologies to formalize comfort-related metrics and to exploit the automatic reasoning capabilities provided by Semantic Web technologies, while gathering data through a network of sensors to ensure guests are provided with tailored comfort profiles during their stays in the hotel. Particular focus has been placed on visual comfort, since indoor lighting features constitute one of the main factors influencing the two main activities that most business travellers accomplish in their hotel room: working and relaxing.

Keywords: ontology-based application; ontology development; context awareness; hotel room comfort; indoor comfort

1. Introduction

Business travelling has been assuming a growing trend in the last years due to the globalization and expansion of international markets. World Travel & Tourism Council stated that there is a relation between business travel and economic growth, highlighting a direct correlation between international travel tourism and global trade growth [1]. The increase in demand will lead to higher tariffs, with a consequent increase of 3.7% for hotels incomes [2]. This trend, though with different rates, is the same worldwide: the Global Business Travel Association [3] has declared that the business travel sector has been undergoing a strong increase in the last years.

In such context, several sources have started highlighting that business travellers need to rely on comfortable hotel rooms, in which comfort metrics (temperature, illuminance and humidity rate) can be adjusted according to the guests' needs [4,5]. Moreover, frequent business travellers would like to customize comfort metrics according to the activities they are performing [6].

The requested features call for a novel idea of comfort, which can be approached to the holistic comfort, a concept that takes into account the traveller and both tangible and intangible environmental factors to deliver an optimal and tailored experience during guests' stay. This is particularly relevant for business travellers, who, in addition to normal activities performed in the hotel room by leisure tourists, may need to work in their room. They need to be alert, concentrated and not distracted by unpleasant or uncomfortable environments; thus, it is imperative for hotel owners to provide them with the highest and most tailored comfort possible. For this purpose, Ambient Intelligence (AmI) and Context Awareness (CA) are two fields of study that can provide some interesting features to the hotellerie industry, by making rooms and services "smarter". AmI and CA, in fact, can enhance the comfort quality of the guests' stay in the hotel by providing them tailored comfort sets and services.

This work presents RoomFort, a system that aims at providing guests with comfort metrics that are tailored to their needs (intended as both physical and physiological necessities, as well as desires) and adjusted according to the activities they are performing in their hotel room. RoomFort exploits formal (i.e., ontological) representations of "domains of knowledge" related to the guests and to the room's comfort metrics, and a network of sensors to measure, analyze and customize comfort metrics. Ontologies can provide a logic-based, formal and sharable interpretation of knowledge and can foster information integration, support automatic reasoning processes and allow to infer new information; therefore, they represent a promising tool for fostering the decision making in contexts—as hotellerie—where several domains of knowledge are involved [7]. The system can be exploited to customize temperature, humidity rate, air temperature (with Heating, Ventilation and Air Conditioning (HVAC) system) and air quality (by triggering the opening and closing of room's windows); nevertheless, the achievement of the optimal visual comfort has been chosen as the main objective of this work. This is due to both the strong influence that light conditions have on human alertness and performances [8] and to the ease with which light installations could be made in the hotel rooms, with respect to the renewal of the heating or of the air-conditioning systems. Finally, RoomFort grants data privacy for both customers and hotel manager, as personal data and hotel data are stored in separate private cloud space and only the parameters need to optimize the guest comfort inside a given hotel room are merged together, inside a private cloud enclave, to perform a reasoning in order to obtain the best actuation for the activity performed by that guest in that given room of that hotel.

The remainder of this work is organized as follows: Section 2 underlines some of the remarkable papers in the field of semantic and intelligent based technologies for comfort management in indoor environments; this Section highlights the lack of standard reference ontologies in a pivotal field of knowledge (i.e., representation of indoor comfort metrics). Section 3 introduces the concept of holistic comfort and links it to the hotel industry, highlighting some of the issues and desiderata belonging to business travellers, target of this work. Section 4 presents the current status of hotels' categorization in Europe, United States of America, Canada and other countries; this section also introduces the sample hotel room adopted for this work. Section 5 describes RoomFort system's architecture and delves into the description of the domain ontologies developed, with a specific focus on the methodology adopted for modelling, the RoomFort application and the information exchange among the architectural actors. Section 6 introduces the preliminary tests conducted to define the best luminous metrics for reading and relaxing in a hotel room; the results deriving from this tests are then discussed and modelled in the ontologies. Section 7 briefly points the attention on some particular use-cases, showing how RoomFort could be of potential benefit for a variety of travellers and how it can meet the concept of comfort understood as a service to be provided to guests. Finally, Section 8 summarizes the main outcome of this work and sketches the future directions it will undertake.

2. Related Work

Research on comfort has acquired a growing importance in the last decade with the spreading of CA systems, Ambient Assisted Living (AAL) and AmI. However, very few works relied on ontologies to provide a sound, sharable and reasonable knowledge base describing comfort-related concepts and measurements. The above-mentioned domains of knowledge share some similarities: they rely on sensors to capture environmental information and they exploit technologies to ease dweller's life, with a particular focus on frail segments of the population. Ontology also plays a pivotal role in tourism, where the exploitation of knowledge bases has lead to a variety of smart solutions.

2.1. Comfort in CA, AAL and AmI Systems

Most of the studies focusing on indoor comfort customization are for CA systems, AmI and AAL solutions and Smart Homes. Nevertheless, only a few of these works tackled the issue of modelling comfort metrics and measurements within ontologies, thus, limiting the semantic description to a restricted number of comfort-related concepts and neglecting the representation of measurements. Although leveraging on semantic web technologies, these works are more focused on the interoperability capabilities provided by ontologies rather than the possibility to provide a sound representation of comfort metrics. Tila et al. [9] described an indoor environmental comfort system taking advantage of a context ontology, in which concepts for the description of sensors and actuators were modelled with Resource Description Framework (RDF) [10]. The authors leveraged the ontology's capabilities to provide semantic interoperability among different data and to back-up the deployment of an IoT system for indoor environment control. Thus, this study is more focused toward the description of the interoperability among sensors and actuators, neglecting a formal description of comfort metrics involved in the system, and reasoning capabilities are dedicated to this goal as well. An ontological approach is the base of Flexergy [11], an ontology aimed at representing the domain of sustainable comfort; the semantic modelling of sensors, actuators, devices, environments and comfort is used as a tool to ease the interoperability of various data coming from different sources. The work links the possibility to provide tailored comfort metrics (air quality and thermal comfort) with energy-saving needs; anyhow, Flexergy's exploitation of ontologies is limited to the design of the energetic infrastructure of the indoor environment and does not involve the modelling of comfort-related concepts. Recently, Mahroo et al. [12] investigated the use of semantic-based technologies to enable a CA system and the possibility to deliver tailored services within a Smart Home, highlighting some of the challenges connected to the exploitation of ontologies and reasoning. In this work ontologies play a pivotal role in managing several aspects of the Smart Home, but no direct reference to indoor comfort management is described.

2.2. Modelling Comfort with Domain Ontologies

The growing interest for AAL, AmI and CA technologies and the possibility offered by ontologies to provide a formal and sharable description of domains of knowledge raised researchers' interest in the exploitation of semantic models for a variety of purposes. DogOnt [13], a widely known ontology dedicated to home automation, refers to the possibility to implement "comfort and energy savings", but the model lacks specific concepts for the description of indoor comfort metrics. Although there is a lack of comfort reference ontologies, several studies developed their own domain ontologies to represent some comfort-related concepts. In [14], ontology is used as a decision support system to improve the quality of three comfort metrics (temperature, humidity and CO_2 concentration) in indoor environments; leveraging on data acquired by sensors, reasoning processes can suggest to the human user the actions that could improve the quality of one or more comfort metrics in the environment. The ontology of this system is developed with Ontology Web Language (OWL) [15] and exploits Semantic Web Rule Language (SWRL) [16] rules to describe more complex actions—such as the influence of opening a window on indoor temperature. Adeleke et al. [17] proposed an "Indoor Environmental Quality" (IEQ) ontology for indoor air quality monitoring and control, formalizing some of the knowledge of the standard ISO 7730:2005; the aim of this semantic model is to analyze potential health risks related to comfort metrics and determine control actions. The IEQ ontology provides representations of several comfort-related concepts, such as human activities, observations and buildings. Stavropoulos et al. [18] developed BOnSAI (Smart Building Ontology for Ambient

Intelligence), an ontology for smart building and AmI, mainly focusing on services, hardware energy management, and encompassing some concepts regarding the context. Developed in OWL-S [19], BOnSAI takes into account the possibility to describe "environmental parameters", such as CO_2 level, Illuminance, Pressure, Humidity to express the functionality of smart devices and services. These parameters are used to express the functionalities of the devices deployed within the environment and, secondary, to increase user's comfort. Similarly, in [20] the authors developed the ThinkHome ontology to represent the whole smart home ecosystem, thus, encompassing some comfort-related concepts. ThinkHome encompasses the possibility to deduce the default comfort parameters according to dweller's age and gender leveraging reasoning mechanisms. The ontology, developed with OWL, provides the means to describe temperature, humidity and air quality. More detailed indoor comfort metrics are modelled in the Smart Home Simulator [21], an AAL Virtual Reality-based application leveraging semantic representations of concepts to provide inhabitants with customized services and comfort metrics (CO_2 concentration, humidity rate, illuminance and temperature) according to their health conditions.

2.3. Ontology and Tourism

Two recent surveys on recommender systems [22] and mobile technologies [23] applied in tourism highlighted how knowledge representation with ontologies is widely adopted to enable intelligent systems in providing customized suggestions tourists. This approach encompasses both the reuse of existing ontologies and the development of new ones from scratch. In particular, Petrina et al. [24] describe the provision of smart and personalized services to tourists interested in historical Points of Interest (POIs). Leveraging on an ontological representation of POIs, this recommender system can show tourists the nearest POIs taking into account tourist's preferences; moreover, it can also provide a list of other POIs historically related to the suggested POI. Smirnov et al. [25] rely on ontology to provide ad-hoc transportation scheduling able to take into account available schedules, foreseen availability and occupancy of the transportation means. As a result, a cyber-physical infomobility recommender system is developed, in which ontologies provide the common vocabulary for the description of transportation services, POIs and attractions. In [26], Moreno et al. describe a web-based system providing personalized recommendations of touristic activities in a Spanish region, Tarragona. Using specific ontologies, this system takes into account demographic data, travel preferences, tourists' ratings and opinions, to provide tailored suggestions.

These works are examples of how ontology can be adopted as a promising technology for the provision of personalized touristic information, also in the context of mobile technologies.

RoomFort exploits ontologies to provide a formal, sharable and simple conceptualizations of the most relevant indoor comfort metrics and their measurements, focusing its attention on the possibility to provide holistic and tailored comfort metrics to business travellers staying in a hotel. It is also worth noticing that no applications of such technologies in the field of hotel industry have been traced in literature.

3. The Concept of Holistic Comfort and Hotel Industry

Holistic comfort is a theory developed in the field of nursing care that asserts the measurability of comfort [27]. This theory encompasses the environment as one of the key features to reach an adequate level of comfort; although holistic comfort has been developed within a health-related context, its principles can be applied to the all the fields involving the humans and their interactions within an indoor environment, thus, to the hotellerie sector too.

3.1. Business Traveller

Tourism is a dynamic industry experiencing an increasing phase throughout the world. This industry encompasses both people travelling for leisure (leisure tourists) and people travelling for business (business travellers). In 2017, business travelling counted for the 23% of total tourism expenses, according to [2]. As further analyzed in the following subsections, business travellers' needs cover a pivotal role in the selection of the hotel where they decide to stay. In particular, the characteristics of the room and its services are important factors which strongly influence the choice of the hotel [28]. Recent research showed how business travellers are more inclined to take into account comfort-related services while choosing hotel rooms [29], thus, indicating that the attention towards Indoor Environmental Quality (IEQ) represents an economic value for them. Also, it is worth noticing that, contrary to leisure tourists, business travellers never consider their travel as a vacation, but always as a business and work-related issue. Therefore, they do not experience the travel as pleasant, but rather as a burden to bear to obtain better professional positions. Many business travellers report to work many hours—even beyond normal working hours—to finish their duties sooner, so that they can come back home earlier. This is due both to job-related concerns (e.g., more demanding workload on return) and to the willingness of seeing again family members and friends. These pressing—and often auto-imposed—demands turn into stress, burnout syndromes and unhealthy behaviours [30]. This is the main reason why comfort has become a relevant concern for business travellers: the hotel room alone cannot contribute in changing such behaviours, but may limit business travellers' unease by providing, from the one hand, a comfortable working environment promoting workers' concentration and alertness, and, on the other hand, a relaxing space to restore and recover after long working shifts [31].

3.2. Comfort in the Hotel Industry

Ariffin et al. argued that "tourist satisfaction is a psychological concept that involves the feeling of well-being and pleasure that results from obtaining what one hopes for and expects from an appealing product and/or service" [32]. Moreover, in the same work, the authors showed that the business travellers are more concerned with comfort and amenities of the hotel room than others quality factors. Thus, the enhancement of the experience passes through the consideration of air quality, temperature, acoustic (i.e., intangible environmental factors [33]), and furnishings, materials, smells, humidity, ventilation, brightness and hygiene (i.e., tangible factors) to design and provide comfortable and pleasant environments. The growing interest toward all these features has been highlighted by a recent study, which underlined how guests are willing to pay an extra charge on the room rate for enjoying more comfortable indoor conditions [29].

Thus, if the aim of hotels is to provide a more comfortable environment for customers, it is essential to satisfy their needs by proposing a holistic experience in the whole hotel building, and especially in the customers' room. However, to satisfy the holistic concept of comfort, taking care of all the above mentioned factors may still be not enough: it is necessary to consider also single person's needs and his/her personal feelings within the room environment.

For instance, the complaints of customers after an accommodation period in a hotel are commonly related to uncomfortable air temperatures and to the difficulty or impossibility of setting the preferred comfort metrics [34]. A survey of the literature showed that a more flexible thermal comfort standard brings environmental and economic improvement [34], while music influenced customers' relaxation [35]. Lighting and colour combinations influence the way guests perceive various spaces, and may also induce some modifications in their behaviour [32] and increase their productivity [36]. Other environmental conditions can produce effects on indoor environments' inhabitants, especially on their health. Asthma, allergies and respiratory diseases, for instance, can be tackled by intervening directly on air quality and temperature comfort metrics [36]. Finally, it has also been proven that having the chance of regulating a comfort-related parameter (i.e., illuminance) is something that people appreciate [37]; illuminance and light features could thus, be exploited to meet business travellers' expectations and promote their revisiting to the same hotel for their next trips.

3.3. Luminous Comfort: Meeting the Needs of Business Travellers

Lighting contributes in creating a mood and atmosphere inside a room, and thus, it may be adjusted to design an environment whose characteristics corresponds to the user's demand and expectation [38]. e.g., the lights of lamps projected on a table in a working area should be designed for reading and working with a laptop, thus, limiting reverberation and promoting paper-based text clearness. Indeed, lighting can influence working performances, especially those performances directly depending on vision. Several characteristics of lighting (such as illuminance, glare, spectrum of the light) can help a worker to stay alert and to focus his/her attention or motivation. In 1989, the National Electrical Manufacturers Association of the USA had already pointed out the link between lighting and rapidity of production of drawings in an indoor environment where bright reflections were reduced [4].

Baron et al. [39] investigated the role of illuminance and spectral distribution (i.e., the colour) of light on the performance of different tasks. Variations in illuminance and lamp typologies were found to exert a significant effect on several cognitive and work-related tasks, such as word categorization, preferring cooperation for resolving interpersonal conflicts (instead of avoidance), willingness to help others, sense of ability in performing a clerical task [40].

More recently, it was also demonstrated how lighting and students' learning performance are connected, better lighting leads to an increase in students' learning motivation [41]. Because of these reasons, a hotel room that allows being customized by the guests according to their needs or desires could play an important role in promoting the hotel's revenue. Indeed, it is attractive for the more demanding travellers and, consequently, can be considered as an added value for the hotel owner, who can improve the quality of the services he/she provides and increase the rate of returning visitors. This represents a strong need for hotel owners, who aim more and more at creating memorable experiences in their guests: travellers are usually prone to look for different accommodations in order to enrich their experience [5,42], and thus, they must be provided with strong motivations to return to an already-visited place. In fact, the increasing awareness of importance of comfort has led people to be more demanding and search for more and more the quality in their living environments, and thus, in the hotels' rooms as well. Light intensity and colour are two factors with impact on people's activity in the space that can help in achieving these objectives. Since illumination is known to cause behavioural responses in humans, such knowledge can be exploited in order to help hotel guest in staying either alert or concentrated, or relaxed [43]. According to the results of the study conducted in [44], the cool colours are perceived as pleasant, comfortable, and activating, while warm colours are perceived as more relaxing. Because of this, and considering the small economical effort required to change the room's lighting, hotel managers should consider applying these known concept on light colours in their facilities, so to influence guests' emotions and feelings [45].

With regard to business travellers' needs, highlighted in the subsection above, the possibility to provide a customized luminous comfort setting appears promising in easing their staying by helping them in better performing their jobs, or relaxing when needed.

To do this, it is necessary to go beyond what is defined in the "lighting standards" in working environments, which are regulated by the European norm EN 12464-1 that sets the minimum requirements for indoor illuminance of working places. This standard sets the minimum illuminance requirements of an actual working area (also defined as "task area") rather than of the entire room. For each of the working activities identified by the EN 12464-1, the norm specifies the ranges for a set of parameters concurring in the definition of the luminous environment (luminance distribution, illuminance, glare, colour rendering and colour appearance of light, daylight, glare, flicker). The norm also recommends the minimum amount of illuminance for each task area according to a set of factors:

- Psycho-physiological aspects such as visual comfort and well being;
- Requirements for visual tasks;
- Visual ergonomics;
- Safety;
- Economy.

In particular, EN 12464-1 stresses how the required maintained illuminance (E_m) should be increased in case of particular conditions, e.g., when there is the necessity of higher productivity, when the visual capacity of a worker is below normal, when the task requires a great amount of attention and/or time, etc. On the contrary, the maintained illuminance can be decreased in other particular conditions, e.g., the task is undertaken for an unusually short time or details on which worker's attention must focus are large or highly contrasted. In any case, the normative states that in continuously occupied area, the E_m cannot be less than 200 lux. The European standard considers only white light, though literature pointed out that the overall impression that a person gets of a space is contributed by three atmospheric elements: colour, light and style; the colour seems to be the most influential [46].

4. Hospitality Services in the Tourism Sector

Since providing a comfortable experience to its guest is usually a hotel's main goal, comfort in hotels is defined by the interactions that guests have with the environment (i.e., the hotel room and communal areas), which plays an important role in making the experience more memorable to the guests. The guest's interactions with the environment, when positive, have been proven to increase their satisfaction, and studies pointed out that the physical environment constitutes a fundamental component of hospitality itself [32]. Despite this known importance, when travellers search for their ideal hotel, they have to face a very large set of choices: environmental characteristics are usually not well described and making an informed decision is not easy, especially considering the lack of a unified international classification system for the hotel rooms and their comforts. In fact, different countries adopt various classification systems for hotels and diverse evaluation criteria for services and facilities [47].

For instance, in Europe, a star-based classification is commonly used, but the rooms belonging to the same category could have different characteristics from one country to another.

- France adopts a seven categories classification, ranging from "no star", to five stars and including also the "Palace" class for five-star hotels;
- Spain does not rely on a national classification system for hotels; each Regional Government ratifies its own classification systems—although the differences among the various regional classifications are minimal. Generally, hotels are classified according to a system of stars ranging from the one to five;
- in Germany, under the patronage of HOTREC (Hotels, Restaurants and Cafés in Europa) [48], a one to five stars system is used to classify hotel rooms and their services;
- in the United Kingdom a star rating system is adopted to describe all accommodations (hotels, B&Bs, inns, etc.).

Australia, South Africa and India also adopt a star rating system; in the United State of America and Canada the accommodations are classified according to a one to five rating system developed in 1977 by the American Automobile Association. The system is divided in five categories and uses "diamonds" instead of stars (one diamond being the lowest category and five diamonds being the highest category).

Italy has a hotel rating system that ranges from one to five stars (the higher the number of stars is, the higher is the quality level of the accommodation) and that aims at guaranteeing more competitiveness to the national tourism in the global market [49]. The Italian rating system is mandatory and managed by public authorities.

Such rating system defines the minimum national standards for services and facilities and classifies hotels according to a code represented by a number of stars. As the number of stars increases, the services provided by the hotel and its rooms proportionally increase. For example, a one-star room needs a minimum 14 m^2 of for a double bed (8 m^2 for single bed) and a five-star room requires 16 m^2 for a double bed (9 m^2 for single bed). For the purpose of this work, a typical Italian three-star room has been taken as sample. The characteristics of this type of room, are:

- services: 16/24 h of reception, daily cleaning of rooms, at least 1 foreign language and TV service in each room;
- minimum dimensions: 8 m^2 one single bedroom, 14 m^2 double bedroom, 3 m^2 bathroom;
- furniture: bed, table, chair, desk, wardrobe, mirror, luggage stool and bath furniture.

As the reader can see, the above-mentioned classification systems do not take into account IEQ metrics, but focuses on rooms' dimensions and on the services the hotel can provide to its guests. Therefore, improving IEQ would not act on improving the hotel rating, but rather toward promoting travellers' revisit and supporting an (appropriate) increase of the hotel room cost with respect to other rooms belonging to the same rating category.

5. A Modular Ontology-Based Architecture for Managing the Comfort in Hotel Room Environments

RoomFort system architecture encompasses both hardware and software technologies and its aim is to manage room environmental comfort in a personalized way. RoomFort measures indoor comfort metrics, and saves the acquired data using Semantic Web Standards (RDF and OWL). These data are stored in a private cloud repository, where they can be reasoned over to foster the optimal personalized actuation of indoor comfort. RoomFort has a two-sided authentication process: from one side the hotel shall register on the system, providing a description of all the equipment and of the environmental comfort facilities for both sensing and actuation; on the other side, the client, i.e., the hotel guest, shall describe his/her characteristics that can affect the perceived comfort during the staying at the hotel. The matching among these data is performed in the private cloud enclave of the guest, so that no personal data is directly transferred to the hotel; only the actuations to tailor guest's comfort—which are the results of the reasoning process computed on the private cloud of the guest—are visible to the guest. The association between the user and his/her room is allowed by the hotel personnel, which enables to transfer room ontology to the private user cloud. Guest data are stored in a protected enclave on a smart device, so that privacy and security related to sensitive personal data are safeguarded, as proposed in an application in the health-care sector [50]. Also, it is worth noticing that the information about the equipment of the hotel are preserved, since, in the reasoning process, only the parameters to be controlled are involved. The specific characteristics of each device, instead, remain in the hotel private cloud space. As all the personal and sensitive data are collected on a private secure enclave, and that the data are not transferred to any other party during the reasoning process, the RoomFort system architecture fulfills the General Data Protection Regulation (GDPR) principles of personal data privacy in the European Union.

The RoomFort system architecture is composed by the following elements:

- a set of sensors to detect illuminance, CO_2 concentration, temperature and humidity rate inside the room;
- a framework for semantic annotation of data gathered by the sensors, according to [51];
- a repository for indoor measurements (data gathered by sensors and semantically annotated);
- a reasoner able to provide customization of comfort metrics according to a set of conditions, described in ontologies;
- a set of ontologies, formalizing both the conditions and the rules to tailor indoor comfort metrics (described in detail in Sections 5.2–5.4);
- actuators, in this case a set of nine Philips Hue Lamps (six mounted on the ceiling and three on the table); the complete set of actuators encompasses also a PCE thermo-hygrometer and a Cozir Amb CO_2 concentration sensor;
- an application running on Android devices and allowing the guest to declare the activities he/she wants to perform and in which area of the room;
- a secure cloud service for hosting the hotel and the guest data, and for running the reasoning processing and producing the optimal comfort actuations for that guest performing a given activity inside such hotel room.

Therefore, to operate in the RoomFort framework, both hotel and guest characteristics are described in a set of ontologies. More in details, each hotel room needs to be described in an ontology encompassing concepts and measurements related to spaces, furniture and installed devices in order to provide interoperability among devices and a safe and sound control of comfort metrics. The guest should have his/her own data related to his/her health condition in an ontology-compliant format too; in fact, these data are retrieved by RoomFort in order to customize the room's indoor comfort metrics according to the guests' desires and activities.

Figure 1 shows a business traveller booking a room in a hotel which uses the RoomFort framework, bringing together his/her own personal and health-related ontologies. Leveraging on the possibility to access to all the knowledge formalized in the ontologies, RoomFort can operate as an application that configures the comfort metrics in the room according to the guest's needs and preferences [52]. The key feature of this proposed architecture is the focus on the guest, as an individual with specific needs or desires. In this context, RoomFort aims at providing him/her with tailored comfort metrics, with the final goal of increasing his/her satisfaction. As shown in Figure 2, RoomFort relies on a cloud-based architecture. The application operates on a private cloud enclave that stores the information of the booked room, the environmental sensing data and the ontologies related to the guest. In this way, the reasons behind an actuation are only available on the private enclave and stay hidden to hotel personnel, thus, safeguarding guests' privacy.

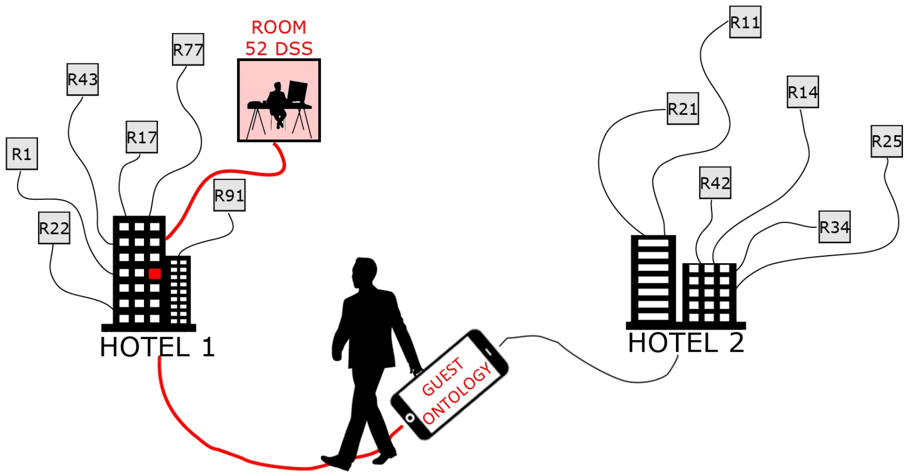

Figure 1. A schema describing the functioning of RoomFort: a business traveller can choose any hotel adopting the system and import his/her preferences.

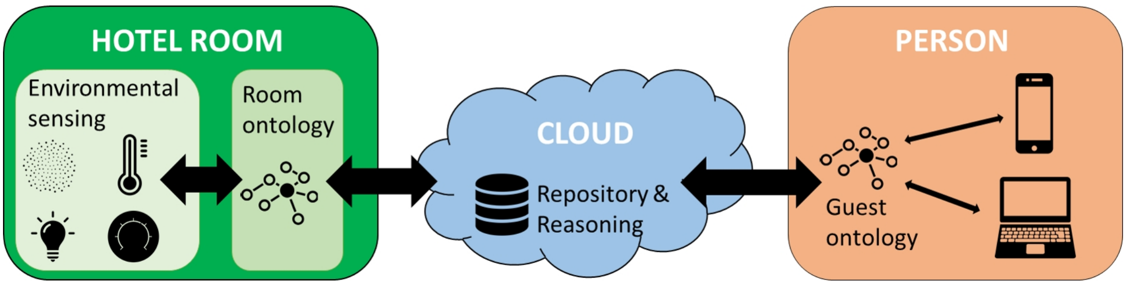

Figure 2. A schema describing RoomFort's architecture.

5.1. RoomFort's Ontologies: Modelling Methodology

Ontologies-explicit, shared and Description Logic-based conceptualizations of the knowledge and the relationships of the concepts composing a domain [53]—in RoomFort are used to model comfort-related concepts with W3C-endorsed languages Resource Description Framework (RDF) [10], Ontology Web Language (OWL) [15] and Semantic Web Rule Language (SWRL) [16].

Another interesting feature related to the use of ontologies is the possibility to derive new facts—which are not explicitly expressed in the ontology—through reasoning, thus, discovering new chunks of knowledge and adding value to several knowledge-based businesses and fields. RoomFort's ontologies were developed following the methodology described by Suárez-Figueroa et al. [54], the NeOn Methodology. Among the variety of semantic modelling methodologies, NeOn was chosen since it considerably simplifies the identification of the knowledge to be represented through the compiling of the Ontology Requirements Specification Document (ORSD) [55]; the ORSD allows to acquire useful indications regarding the granularity of the semantic models, their extents, the scope of the models, the identification of the end-users of the ontologies, the functional and non-functional requirements the ontologies must satisfy. Together with the NeOn Methodology, ORSD can simplify the development of the ontologies by specifying their extents. Following the scenarios depicted in the NeOn Methodology, the development of RoomFort's models foresees the reuse of already existing ontological resources and the development from scratch of new models.

As mentioned above, the domains of interest of this study regard:

- the guests and their health conditions Section 5.2; the International Classification of Functioning, Disability and Health (ICF) was found as a suitable ontology for the description of health-related conditions [56];
- the hotel room and the devices (sensors and actuators) in it Section 5.3, a domain divided into:
  - the hotel room, for the description of which the Accommodation Ontology Language Reference (ACCO) [57] and DogOnt [13] were the reused ontologies;
  - the devices deployed in the room, whose formal description is performed referring to the Smart Appliance REFerence Ontology (SAREF) [58];
- the comfort metrics to be monitored in order to provide a comfortable environment to the guest Section 5.4, for which RoomFort relies on ontologies developed from scratch and led by the embryonic work presented in [21,59]. A particular attention is posed on the luminous comfort, as stated in the previous Sections, as one of the most sensitive domains for business travellers.

These modules composing RoomFort ontology are developed using OWL-DL [60], a subset of OWL combining enough expressive power with full reasonability. The open-source ontology editor Protégé (version 5.3) was used for the development of the semantic models.

The following subsections delve into the description of the semantic modules developed for RoomFort architecture.

5.2. Guest Ontology

5.2.1. A Holistic Framework for Guest's Health Status Description

The description of the guests' health condition relies on a World Health Organization-endorsed standard: the International Classification of Functioning, Disability and Health (ICF) [61]. This classification conceptualizes the functioning of a person as an interaction between his/her health condition and the environment where the person lives. ICF is organized in two main parts: the first, "Functioning and Disability", provides a description of the components Body functions, Body structures and Activities and participation; and the second, "Contextual Factors", provides the means to describe the impact of the components Environmental factors and Personal factors. Each component can be further specified into Chapters, sections of the classification identifying a health-related domain. Through a progressive specification of chapters, ICF allows to assess the domains of the functioning and the disability of an individual. Each ICF component is characterized by a letter (b for Body functions, s for Body structures, e for Environmental factors, d for Activities and participation) and can be deepened by adding digits, as shown in Figure 3.

The magnitude of an impairment is determined by adding a qualifier to the corresponding ICF code (0 indicates the absence of impairments in a specific code, 1 stands for a mild impairment, 2 denotes a moderate impairment, 3 indicates a severe impairment, while 4 states a complete impairment). Therefore, the qualified code b21020.2 indicates a moderate impairment in the "Colour vision".

b "Body functions"	Component	
b2 "Sensory functions and pain"	Chapter	
b210 "Seeing functions"	***b230*** "Hearing functions"	Second level item
b2102 "Quality of vision"	***b2300*** "Sound detection"	Third level item
b21020 "Colour vision"	- - -	Fourth level item

Figure 3. An example of ICF illustrating the structure of the classification.

ICF is often exploited as a practical tool to ease the communication between health professionals and other stakeholders [59,62]; moreover, the classification is suited also to describe each context where health and environment interact: work reintegration [63], domestic age-care [64], AAL [65]. ICF has also been represented into an ontological model in RDF/OWL [56], which can be used as reference in the modelling of more complex ontologies. However, it has to be underlined that this model inherits some shortcomings belonging to the whole classification, such as problems regarding incongruent classification of some concepts, a lack of clarity between activities and their qualities, incorrect parent-child relationships [66] and overemphasis on subsumption [67].

5.2.2. Describing the Guest's Personal and Health Data

This module gathers the guest's registry records, data provided by the guest when he/she reserves his/her room. These data are modelled as objects of datatype properties and provide the means to represent the first name, last name, date of birth, tax identification number of the guest—who is represented as an individual. Using an object property, each guest is connected to his/her health condition, represented as an individual. The modelling of each health condition reuses the ICF ontology, as illustrated in Figure 4.

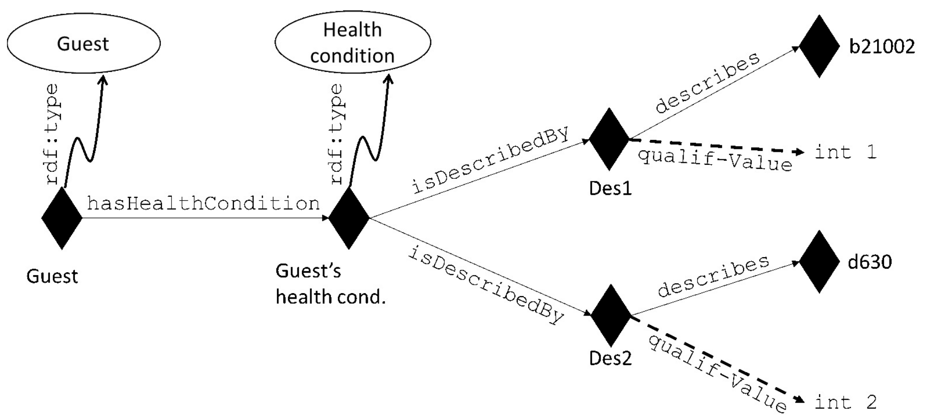

Figure 4. An example of the modelling of a guest's health condition; individuals are represented with diamonds, concepts are represented with circles, and roles are represented with arrows (dashed arrows indicate datatype properties, full-line arrows represent object properties). The type of an individual is stated with a curved arrow.

For each ICF code involved in the description of an impairment, a "descriptor" individual is used; descriptors are used to provide a univocal link for each ICF code and its qualifier, avoiding the use of a reification [68].

In this way, it is possible to represent the full extent of ICF qualifiers and to model complex health conditions, enabling the semantic representation of n-ary relationships without adding complexity to the whole application ontology.

5.2.3. Addressing the Needs of Travellers With Impairments

As described above, RoomFort relies on ICF to provide a description of travellers' health status. Having this piece of information, it is possible to further customize the luminous metrics according to traveller's specific disability. For instance, a traveller characterized by photophobia (hypersensitivity to light due to e.g., albinism or corneal abrasion) may be characterized by an impairment in the ICF code b21020-Light sensitivity—and may benefit from suffused lighting, also when working; a person characterized by macular degeneration can be described as having impairments in the following codes (according to Silva et al. [69]):

- b21001 Monocular acuity of distant vision;
- b21002 Binocular acuity of near vision;
- b2101 Visual field functions;
- b21020 Light sensitivity;
- b21021 Colour vision;
- b21022 Contrast sensitivity;
- b21023 Visual picture quality.

People suffering from maculopathy have issues in performing activities low illuminance and at night-time and reported to have difficulties in reading [70]. In this case, it is thus, recommendable to provide them with an intense and focused light, which can help them in distinguishing written text. RoomFort can provide these type of users with more appropriate environmental conditions by automatically adjusting the maintained illuminance, light colour and wall colour while they are performing working activities in the room. Of course, RoomFort cannot address all the physiological problems related to these conditions, neither it provides a permanent solution; instead, the system can make the working activity more comfortable to those who are particularly fragile in some vision-related dimension. Similarly, RoomFort can provide personalized comfort metrics related to persons who have some form of impairment in the perception of temperature (described by ICF codes b2700 Sensitivity to temperature; b550 Thermoregulatory functions; b5501 Maintenance of body temperature), respiratory issues (described with ICF range of codes related to the functions of the respiratory system b440-b449). In these cases, a guest travelling to a hotel equipped with RoomFort can upload (or ask his/her physician to upload) his/her physiological status (formalized in an RDF/OWL ontology) and a set of SWRL rules to adapt comfort metrics of the customized comfort set by increasing or decreasing the illuminance and changing light colour. The SWRL acquires the following form:

```
Guest_with_mild_b21002_imp(?g), selectsActivity(?g, ?a),
Activity (work), CustomizedLuminousComfortSetting (?clcs)->
provideComfortSetting (?clcs)
```

The Customized Luminous Comfort Setting (CLCS) is modelled as a "regular" comfort setting, but for instance in the case of a business traveller characterized by hypersensitivity to light, its comfort setting is adjusted as shown in the following Figure 5.

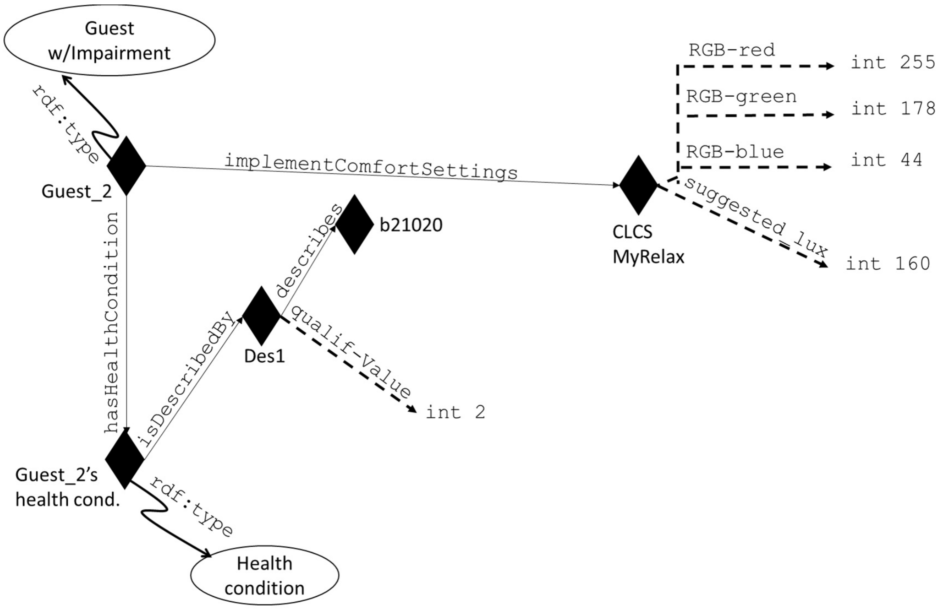

Figure 5. An example of the modelling of a Customized Luminous Comfort Setting (CLCS) for a traveller characterized by visual impairment. Individuals are represented with diamonds, concepts are represented with circles, and roles are represented with arrows (dashed arrows indicate datatype properties, full-line arrows represent object properties). The type of an individual is stated with a curved arrow.

5.3. The Room Ontology

5.3.1. Hotel Room and Its Features Description

The description of the hotel room relies on the Accommodation Ontology Language Reference (ACCO) [57], a vocabulary for modelling hotels, vacation homes, camping sites and other accommodations; originally thought for the description of these accommodations for e-commerce, ACCO can be adopted to provide sharable information regarding, for instance, a hotel room. It allows to specify the star-rating of a hotel and the star-rating adopted standard, the hotel features, the price of a specific room per night. ACCO also allows to specify the hotel room's features, such as: maximum number of occupants, the possibility to allow pets in the premises, the duration of the stay, etc. ACCO does not allow the description of the physical room, therefore to complete the modelling of a room DogOnt [13] was selected. This model is widely used to provide descriptions of smart environments, specifying the location in the built environment of devices (both sensors and actuators) with `dogont:isIn` object property, applicable for appliances, sensors and actuators. DogOnt also allows to model devices independently from the specific technologies, referring to their typology, functionality (the tasks a device can accomplish, `dogont:Functionality`) and state (the condition of the device, such as "on", "off" or "stand-by", `dogont:hasState`); these features and the classes and properties describing it can be mapped to other relevant device ontologies, as illustrated in the following subsection

5.3.2. Devices Deployed in the Room Module

Devices' description leverages the Smart Appliance REFerence Ontology (SAREF) [58] to describe some of the features of a device and to complete DogOnt's provided device location in the space; starting from the concept of Ďevice, this reference ontology provides the means to describe device's properties, location in the space, type; moreover, SAREF models the function of a device, such as a sensor and the metrics it measures. For example, a smoke sensor (belonging to the class `saref:Sensor`), performs a `saref:SensingFunction`. SAREF is suited to describe indoor environment devices and is created with RDF/OWL, as well as already exploited in several studies on interoperability among devices [71]. SAREF has been adopted to describe the devices deployed in the room used for RoomFort tests (see further Section 5); in particular, for each device its type (sensor, actuator, appliance, light, etc.) and specific ID are specified.

5.4. Comfort Metrics, Measurements and Luminous Comfort Settings Module

As stated above, there are no canonical and widely used comfort ontologies. Therefore, RoomFort's application ontologies relied on a different approach. The comfort metrics involved in a hotel room and analyzed in this work are "`Temperature`", "`Humidity rate`", "`Illuminance`": these metrics, modelled as classes, are further detailed with the respective "Comfortable" and "Uncomfortable" subclasses (respectively: "`ComfortableIlluminance`", "`UncomfortableIlluminance`"; "`ComfortableTemperature`", "`UncomfortableTemperature`"; "`ComfortableHumidityRate`", "`UncomfortableHumidityRate`"). Measurements acquired by a sensor are semantically annotated providing for each: a unique ID, the value of the performed measurement, a DateTime stamp of the measurement, the unit of measurement involved, the comfort metrics it is referred to. An example of measurements modelling is provided in Figure 6.

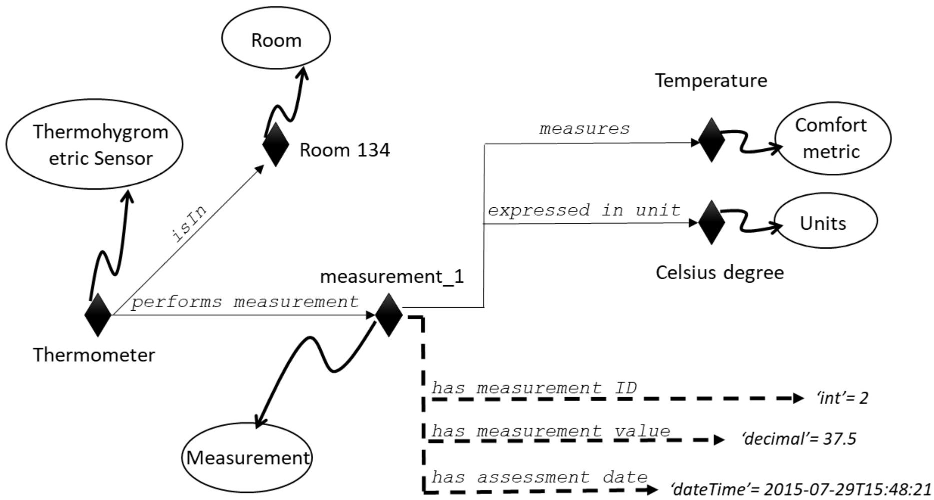

Figure 6. An example of the modelling of a measurement performed in the hotel room; individuals are represented with diamonds, concepts are represented with circles, and roles are represented with arrows (dashed arrows indicate datatype properties, full-line arrows represent object properties). The type of an individual is stated with a curved arrow.

Each measurement acquired by a sensor is then classified thanks to a set of SWRL rule. For instance, the following rule:

```
Guest(?g), selectsActivity(?g, ?a), Activity (work),
IlluminanceSensor(?ls), acquiresMeasurement (?ls, ?m),
Measurement(?m), hasMeasurementValue (?m, ?value),
greaterThanOrEqual(?value, 200), lessThanOrEqual(?value, 300)
-> ComfortableIlluminance(?m)
```

allows to classify an illuminance measurement when the guest specifies he/she wants to read in the room as comfortable or uncomfortable; in the latter case, uncomfortable measurements enable actuation and are used to suggest corrective actions. Moreover, as seen above, a similar modelling can be adopted for the description of both Luminous Comfort Settings (LCS) and CLCS. In this case, an individual representing the LCS is linked with its characteristics (through datatype properties indicating the RGB code of the color of the light and the E_m expressed in lux), as illustrated in Figure 7.

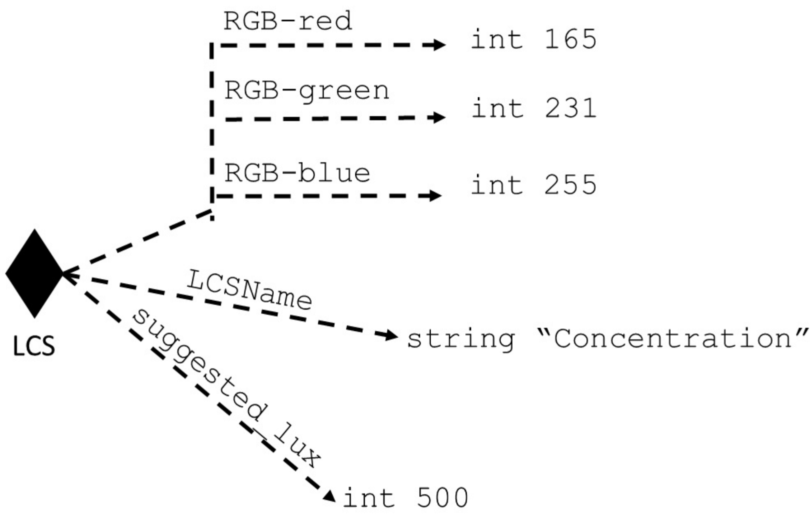

Figure 7. An example of the modelling of Luminous Comfort Setting (LCS); individuals are represented with diamonds, concepts are represented with circles, and roles are represented with arrows (dashed arrows indicate datatype properties). Please note that this specific LCS here represented is one of the results coming from the evaluation of visual comfort in a hotel room (described in Section 6).

5.5. The Semantic Repository and Reasoning Engine

The ontologies described above are hosted on a semantic repository, also defined as triple-store or RDF store [72], since it allows to query and retrieve data in semantic-compliant format. RoomFort's ontologies are hosted on Stardog, a widely known knowledge graph platform that supports querying activities and reasoning with RDF, OWL and SWRL.

Reasoning in Stardog is performed at query time, which means that the triples resulting from the reasoning process are not materialized (and automatically added into the ontologies) but, instead, for each query requiring the result deriving from the application of one or more SWRL, the reasoner solves only those rules necessary to solve the query. Consequently, the reasoning profile selected for RoomFort deployment on Stardog (version 5.3.4) [73] allows the treatment of rules in the SWRL form like those presented in the previous subsections.

5.6. The RoomFort Application: Querying and Retrieving Data From the Ontology

RoomFort application is developed with Unity 3D [74] to run on Android devices (smartphone and tablets). The applications' interface has been designed to be user-friendly and the more intuitive as possible. It allows the guest to select the activities and the area of the room (the bed or the desk, for example) in which he/she wants to perform such activity. Moreover, the application can be used to create novel CLCS according to guest's responses and save them in the semantic repository. Figure 8 shows a user while experiencing the RoomFort application.

The application can exchange information with the semantic repository (and the ontologies hosted in it) via a semantic middleware, a software developed with Java that allows to query the semantic knowledge base using predefined SPARQL (SPARQL Protocol and RDF Query Language) [75] queries. This program is run each time the guest decides to perform an activity inside the room and taps the related button on the smartphone application interface to state her/his intention. The moment the passenger taps the button on the application to perform an activity, the middleware program runs to generate a proper SPARQL query with necessary input data to be able to retrieve information regarding guest's health condition. These input data are passed from application to the middleware through a JSON (JavaScript Object Notation) file indicating the passenger's name, the activity she/he would like to perform, health-related data, the location where the activity is going to happen; the 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, on which a query similar to the following is performed:

```
PREFIX rf: <http://www.stiima.cnr.it/RoomFort>
PREFIX dog: <http://www.elite.polito.it/ontologies/dogont.owl>
SELECT ?lcs
WHERE
{ ?guest rf:selectsActivity rf:Relaxing ;
rf:setsActivityLocation dog:Bed .
?lcs rf:isSuitableForActivity rf:Relaxing .
}
```

a query that allows retrieving the luminous conditions suitable for relaxing on the bed. Similarly, though the use of the SPARQL command `INSERT` a guest can add one or more LCS to the ontology—in this case, to his/her preferences. The middleware operates by translating SPARQL queries' results into JSON files and feeding them to the actuators, the lamps near the bed, in this specific case.

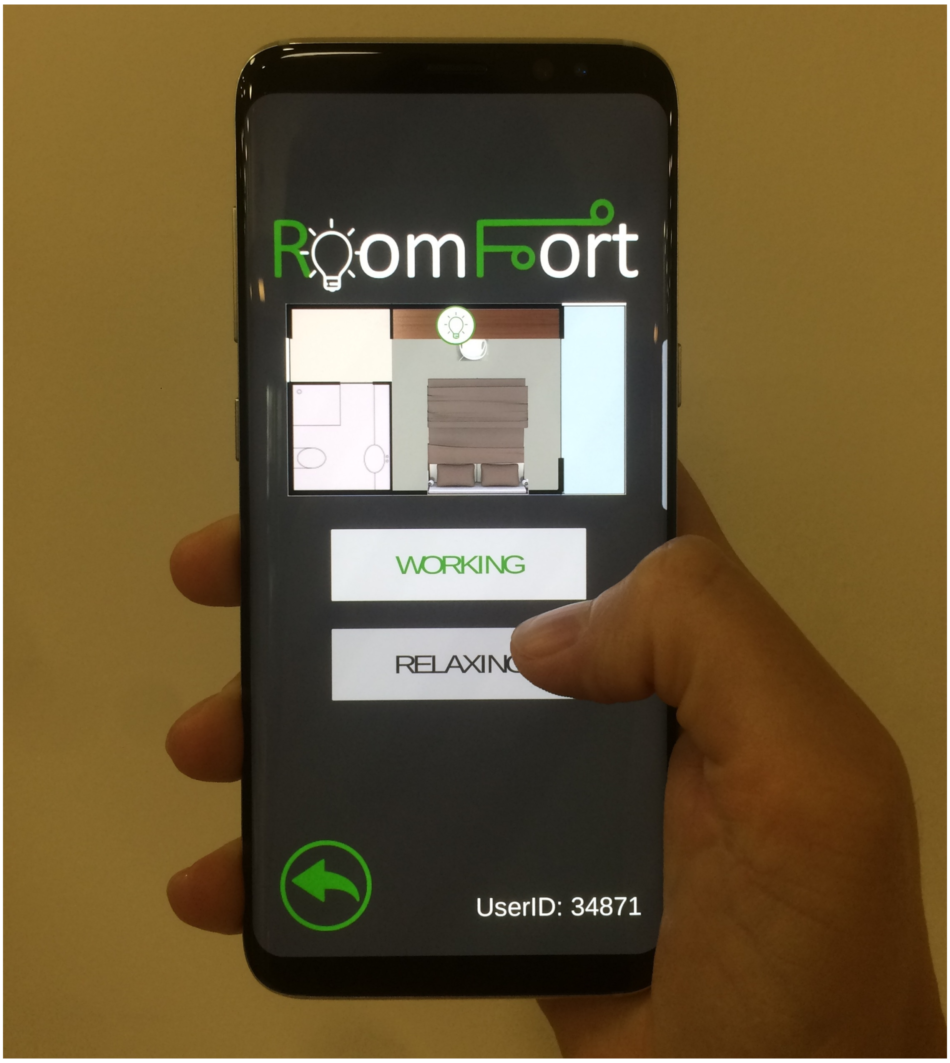

Figure 8. A screenshot of the RoomFort application for Android devices. The user (identified by his/her own ID number) selects an activity.

6. Evaluation of the Visual Comfort

The development of the above-mentioned ontology constitutes a key feature to enable the adaptation of the comfort conditions according to the guest's current activity and to his/her preference. Such adaptation occurs automatically when the guest has set his/her own preferences or has introduced his/her health status description in the system; however, the first time the guest (without impairments) starts an activity in the hotel room, the system is unaware of his/her preference and thus, requires some initial conditions, which have to be decided and described in RoomFort in advance. A possible solution may be the application of European standard EN 12464-1 as initial conditions. Nevertheless, this has two possible drawbacks: (1) standards often correspond to the minimum requirements, and not to a "comfortable" condition [76]; (2) standards are applied according to the activity that guests are expected to perform in a certain place: e.g., at the desk, people are expected to read or to write, not to relax while listening to music. Therefore, light conditions at the desk will correspond to the standard value for reading, i.e., 200–500 lux, which is indeed too bright for a relaxing activity. To try to reduce the level of discomfort caused by the strict application of normative-based values, setting "activity-related" initial conditions (namely, the LCS)—regardless of the place in which such an activity occurs, appears as a reasonable solution. To verify this hypothesis, we designed a repeated-measure study whose aim is evaluating whether specific light conditions can improve the user's perceived comfort, while staying sit at the hotel room desk and accomplishing two different activities resembling the two main activities of a business travellers: reading while being concentrated and relaxing.

6.1. Methods

6.1.1. Participants

Twenty-eight adults aged 44.25 ± 17.09 have been enrolled in the study. All were in a good general health status. Exclusion criteria were: moderate to severe vision or motor impairment; severe pain; cognitive decline; inability to read Italian language; inability to provide informed written consent. All the other demographic and clinical characteristics of the study participants are reported in Table 1.

Table 1. Sample's characteristics; M = male; F = female.

Participants	28
Gender (M/F)	12/16
Age	44.25 ± 17.09
Education (Years)	15.63 ± 3.13
Mild vision impairment	$71\% : \begin{cases} \textit{Astigmatism}: & 43\% \\ \textit{Myopia}: & 46\% \\ \textit{Presbyopia}: & 21\% \\ \textit{Hyperopia}: & 11\% \end{cases}$

The subjects participating in the study provided informed written consent.

6.1.2. Equipment

The test took place in an indoor environment simulating a three-star hotel room. As depicted in Figure 9, the guest enters the room through the entrance area that acts as an anteroom between the bathroom and sleeping area. From this area, the guest can then access to the outdoor terrace. The room dimensions—including the bathroom— were 3×6 m^2; room height was 2.20 m. The room's three functional areas were furnished as follows:

- Entrance: wardrobe
- Sleeping area: bed 1 and 2, bedside Tables 1 and 2, chair 1, desk, minibar, TV
- Terrace: chair 2, table

The space and furniture organization inside the room matches the characteristics of the environment described in the ontology. The room and the terrace were equipped with networked devices able to monitor the environment and to deliver appropriate comfort metrics according to each guest's preferences and to the activity he/she is performing. For luminous comfort provision, six Philips Hue spotlights were mounted on the ceiling and three table lamps mounting Philips Hue bulbs were placed close to the table (see Figure 9). The light beams of these three lamps were directed toward the white wall behind the table, so that light colors and temperature could be experienced at their best by an individual sit at the table; this also allows to change the colour of the wall, according to the selected LCS. A window allowing the daylight illumination of the room was present on the shortest wall, however, not to influence the test results, it was covered with a dark curtain for the whole tests' duration (with the exception of the questionnaires' answering time). To accomplish the reading task, the users were provided with white-paper pages; the texts were taken from the Italian edition of the books "*La coscienza di Zeno*" (Zeno's Conscience, Italo Svevo, 1923) and "*Utopia*" (Utopia, Thomas Moore, 1516). The choice of extracts not too easy to comprehend was intentional, to encourage the user in concentrating during the activity accomplishment. Both texts were written with a serif typeface (Georgia), pt. 12.

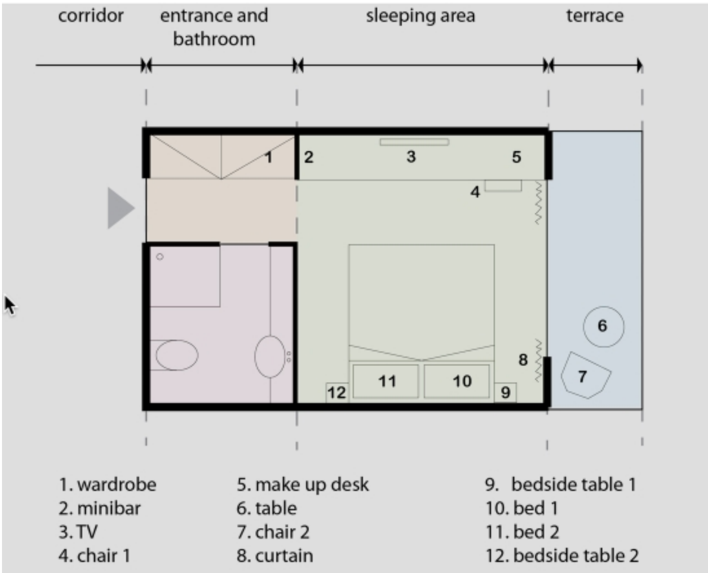

Figure 9. Functional areas in a room.

6.1.3. Protocol

Each subject performed the test in the above-mentioned environment, been administered with all light conditions for the duration of both the activities. Each session started with one minute of dark adaptation [77]. Each light condition lasted 2 min per activity, thus, resulting in: 2 min of reading with condition (1), administration of the questionnaire (see Measures paragraph), 2 min of relaxing with condition (1), administration of the questionnaire. At the end of such a series, one minute of dark adaptation was performed and the light condition was changed. The whole test lasted about 25–30 min per subjects. The four light conditions are presented in Table 2 and in Figure 10. Standards represent the average illumination required for reading, i.e., the general condition that one can expect to find in correspondence with a hotel room's table. The other three conditions, namely "Relax", "Concentration" and "Red" were similar to the Philips Hue predefined light sets.

The choice of using predefined lighting sets is justified from the lack of scientific literature regarding this topic; since to our knowledge no other studies investigating lighting comfort while reading and relaxing in a hotel room have been conducted, we relied on the know-how and the knowledge of a world-known manufacturer, such as Philips.

Table 2. Characteristics of the four light conditions used for the validation. RGB (Red, Green and Blue) is the color model adopted.

	Relax	Concentration	Red	Normative
Illuminance (lux)	200	500	300	400
RGB	(255, 178, 44)	(165, 231, 255)	(255, 15, 15)	(255, 255, 255)
Correlated Color Temperature (K)	2600	7500	1000	5600

Figure 10. The four light conditions: "Normative", "Relax", "Concentration" and "Red".

6.1.4. Measures

To evaluate the rates of perceived comfort, an ad-hoc questionnaire—adapted from [37,78]—has been developed. The questionnaire foresees three items aimed at investigating the satisfaction of the users with respect to the light conditions during the accomplishment of a specific activity, and two items about the user's personal feelings.

(Q1) I am satisfied with the amount of light for reading;
(Q2) I am satisfied with the amount of light for relaxing;
(Q3) I like the vertical surface brightness;
Q4) I feel concentrated;
(Q5) I feel relaxed.

In all cases, the user had to indicate his/her level of agreement on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree).

6.1.5. Statistical Analyses

Data resulting from the questionnaire were analyzed using one-way repeated measures ANOVA; post-hoc tests were performed using Turkey range test and 95% confidence. Matrix of inter-correlations were used to assess whether a correlation exists between age and light preferences and between visual impairments (i.e., wearing glasses) and light preferences. All tests were performed using MiniTab 18.

6.2. Results

Results of the questionnaires for the two considered activities are reported in Table 3.

Table 3. Results of the questionnaires. Grouping information using the Turkey method and 95% confidence level (means that do not share a letter are significantly different). Conc. = Concentration.

Reading				*Relaxing*			
Relax	**Conc.**	**Red**	**Normative**	**Relax**	**Conc.**	**Red**	**Normative**
5.11 ±1.26 ^{A}	4.39 ±1.26 ^{A}	3.39 ±1.69 ^{B}	4.50 ±1.32 ^{A}	5.39 ±1.17 ^{A}	4.21±1.77 ^{B}	4.14 ±1.63 ^{B}	4.36 ±1.81 ^{A,B}
4.64 ±1.6 ^{B}	6.11 ±1.23 ^{A}	2.86 ±1.65 ^{C}	5.89 ±1.10 ^{A}	4.61 ±1.59 ^{B}	5.82 ±1.49 ^{A}	3.04 ±1.86 ^{C}	5.50 ±1.35 ^{A,B}
4.64 ±1.62 ^{A}	5.21 ±1.45 ^{A}	3.54 ±1.77 ^{B}	4.89 ±1.47 ^{A}	4.54 ±1.88 ^{A,B}	5.11 ±1.66 ^{A,B}	3.75 ±1.82 ^{B}	4.43 ±1.57 ^{A,B}
4.93 ±1.68 ^{A}	4.43 ±1.57 ^{A,B}	3.36 ±1.75 ^{B}	4.61 ±1.50 ^{A}	5.21 ±1.57 ^{A}	4.32 ±1.66 ^{A,B}	4.00 ±1.75 ^{B}	4.14 ±1.76 ^{A,B}
4.74 ±1.72 ^{A}	5.36 ±1.57 ^{A}	3.00 ±1.72 ^{B}	5.04 ±1.57 ^{A}	4.46 ±1.53 ^{A}	4.89 ±1.73 ^{A}	3.11 ±1.77 ^{B}	4.43 ±1.73 ^{A}

No correlations were found between demographic characteristics and light preferences.

6.3. Discussion of Test Results

The results showed that, in general, users preferred the "relax" condition (i.e., a low color temperature and a quite low illuminance) for the reading activity and the "concentration" condition (medium color temperature and medium illuminance) for the relax. "Red" was judged as not suitable for any activities, while the normative-based conditions were evaluated always as quite good (between 4 and 5 points of the Likert-scale). Beside the "red" condition, which was expected [78] to be worse than the others, the obtained results are in contrast with both Philips definitions and previous studies. Iszo [79], for instance, found that people reported to feel more relaxed when the illuminance was lower and more active when the light was more intense. Viola et al. [80] reported and increased alertness with blue-enriched white light (17,000 K); Wang et al. [78] demonstrated that relatively lower CCTs are regarded as more comfortable and preferred for relaxing, while higher CCTs are considered more comfortable and preferred for working. A possible explanation for the results of the present study may be found in the different setup and, in particular, in the quantity of light diffused in the environment or in the glare present on the papers. This lack of generalizability has been already highlighted [78] and luminance (i.e., the luminous power perceived by the human eye) has been suggested as the variable to estimate when evaluating visual comfort, instead of illuminance (i.e., the measurement of the amount of light falling onto (illuminating) and spreading over a given surface area) [37]. This aspect calls for more studies aimed at defining new light-related metrics and motivates the implementation of the above-mentioned light conditions in RoomFort ("**relax**" for reading and "**concentration**" for relaxing), though in contrast with what reported by other studies. One last important point to mention is the inefficacy of the normative-based lights to elicit visual comfort for both the two tested activities.

6.4. Luminous Comfort Settings Deriving from the Tests

The two LCSs, "**relax**" for the reading activity and "**concentration**" for the relaxing activity, depicted in Table 2—obtained by the above-mentioned tests are modelled into the RoomFort ontology, according to the design pattern presented in Section 5.4. The results of the modelling are provided in Figure 11, which summarizes the two LCSs and their suggested use inside the hotel room.

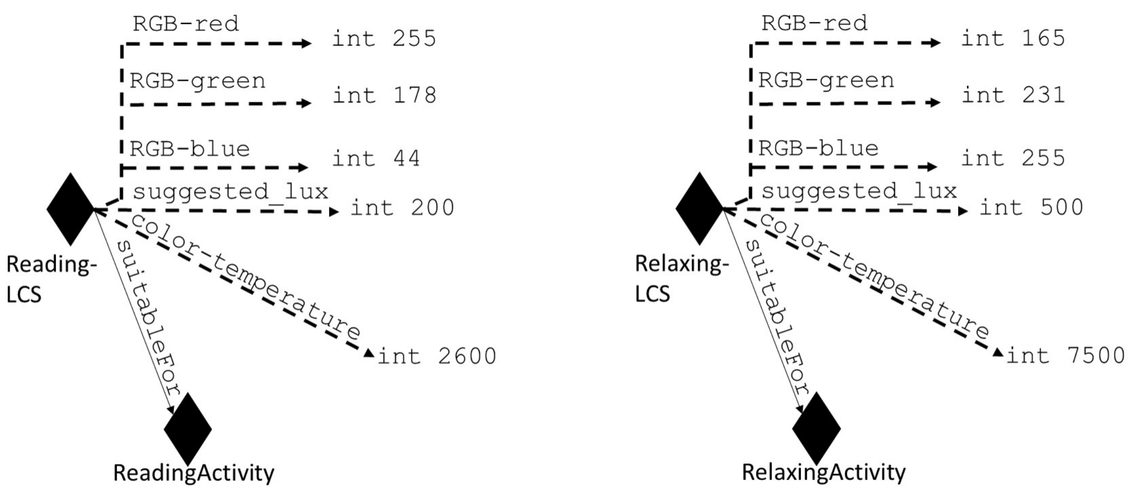

Figure 11. The modelling of the two Luminous Comfort Setting (LCS) deriving from the tests conducted on luminous comfort evaluation. Individuals are represented with diamonds, concepts are represented with circles, and roles are represented with arrows (dashed arrows indicate datatype properties).

7. Considerations on the Applicability of RoomFort and Its Validation

This Section highlights some aspects related to RoomFort's applicability in hotels, the proposed validation for the prototypical application developed and contextualizes the work in the field of a novel paradigm for IEQ.

7.1. Comfort as a Service

As RoomFort aims at providing guest-based comfort for some indoor metrics, a novel paradigm for indoor comfort management has starting to spread: Comfort as a Service (CaaS). In a recent research paper, Juan Gómez-Romero et al. [81] suggest that dwellers should hand over the control of their comfort-management systems to a energy-savings companies. The purpose of this action aims at generating an automatic optimal control strategy for the indoor domestic equipment, able to provide the inhabitants with adequate comfort levels while ensuring energy-savings. Moreover, CaaS approach releases building occupants from operating with the comfort equipment, which usually generates energy wasting, uncomfortable indoor comfort and an increase in costs. The idea suggested in [81] turns the traditional model of paying per consumed energy in favor of a model of paying per provided comfort, thus, making comfort a service.

In relation to RoomFort, CaaS relies on a different technological AmI framework, including also IoT, predictive computing and Big Data to deliver comfort management and energy-saving. Nevertheless, with particular reference to the hotel industry, the idea of CaaS, in which the guests can purchase tailored and energy-saving comfort settings, seems to be supported by studies in the tourism field, as underlined by [32,33]; besides, Buso et al. [29] recently pointed out how guest are willing to pay an extra charge on the room rate for enjoying more comfortable indoor conditions.

Therefore, RoomFort can potentially be seen as a component of a CaaS system, thus, providing more comfortable rooms, sustaining energy-saving and meeting guests' needs, and also generating a win-win situation for both guests and hotel owners.

7.2. Applicability of RoomFort to Hotellerie

RoomFort relies on semantic representations of comfort, health and device-related concepts leveraging ontologies to formalize the relationships among these domains of knowledge. Although Semantic Web technologies are widely used in several fields and applications, their adoption in everyday life is still a work in progress. Nevertheless, RoomFort's deployment relies on an architecture that exploits several well-established concepts and technologies AmI, AAL and CA applications. One of the limits of RoomFort's current configuration consists in the possibility to provide to the hotel guest's ICF-health data. Although this problem does not jeopardize the adoption of the whole application, it is mainly caused by the following issues.

ICF is an international standard fully understandable by clinical personnel, but, even if its terms are quite transparent in their meanings—people who are unaware of the classification functioning may find it difficult to use. A solution to this issue is represented by the possibility for the guest to have an ICF-based representation of his/her health condition performed by his/her physician. In this way, the guest's health condition will always be portable and can be delivered as (ontological) data.

With regard to the portability of the guest's health data, it worths noticing that the same approach can be adopted also for personalized LCS: in this sense, a guest arriving in a hotel can set up his/her own personalized LCS. This means that the customization of visual comfort inside an indoor environment can potentially be done even without recurring to reasoning processes; in this particular case the guest, when booking a hotel room, submits his LCS together with his/her health-related data.

Being a semantic-based application, RoomFort's wide adoption in hotel industry requires single accommodations to agree on a common representation of the knowledge related to the guests, their health condition, the comfort metrics measured, the measurements performed in the room and the devices to be deployed in the environment (i.e., sensors and actuators). In this way, each hotel may rely on a safe and shared model to formalize guests' data and comfort. Therefore, for a pervasive adoption of RoomFort hotel industry must agree on a shared and sound ontological description of the domains of interest, even considering the lack of ontological standards, as described in Sections 2 and 5. Using a shared vocabulary (as the one described in Section 5), each hotel can therefore describe itself, its rooms and the services it provides. Nonetheless, RoomFort's horizontal scalability allows the system to be exploited also for the customization of comfort metrics in relation to other activities performed in the room (eating, working with a laptop, watching the television, etc.).

RoomFort can be further developed into a Decision Support System (DSS); in fact, being aware of the guests' health condition and his/her needs, RoomFort can potentially provide the guest with a set of most suitable LCS, CO_2 concentration, indoor temperature and humidity rate to maximize his/her comfort; in the particular case of guests afflicted by vision-related, respiratory-related or sensitivity to temperature-related health problems the expedients provided by the DSS can potentially help the guests in coping with their impairments while performing specific activities.

Finally, RoomFort—even if originally thought for business travellers due to their particular necessities—can be adjust to work also for leisure tourists, especially in the context of CaaS, in which leisure tourists can decide whether to purchase or not an additional, automatic and optimal comfort settings.

7.3. Proposed Validation Framework of RoomFort Application

Once the RoomFort mobile application will be completed including the possibility of varying all the comfort metrics potentially changeable within the RoomFort framework, it will be validated in a study enrolling healthy adults. Participants will be asked to work for half a day (4 h) in the environment reprising the hotel room (described in Section 6.1.2) with their own laptop (and paper-based documents) and to relax whenever they like, either on the bed or while staying at the desk. Before undergoing the study, all the participants will be briefly instructed on the RoomFort application functionalities and on the variables which they can modify throughout the day. No further instructions will be given. After the end of the test, participants will be administered a questionnaire aimed at evaluating (1) whether they liked the possibility to change the environmental conditions, (2) whether they liked the predefined sets for each activity and (3) whether they would have preferred not having an application to adjust the different comfort metrics, through 7-point Likert questions. In addition, System Usability Scale (SUS) [82] and Technology Acceptance (TAM) [83] questionnaires will be administered too, to evaluate respectively the user-friendliness of the application and its perceived ease-of-use and usefulness.

8. Conclusions and Future Works

To satisfy guest's needs, the research proposes RoomFort, a semantic-based application aimed at providing a holistic comfort experience in the business travellers' rooms; RoomFort leverages a novel ontology-based architecture able to personalize indoor comfort metrics inside the room according to guests' needs, desires and activities. In this work, the authors focused on the possibility to provide customized luminous comfort settings suited for two pivotal activities for business travellers: working and relaxing. The results of a study conducted on 28 participants allowed to model into ontologies the best luminous comfort settings, which can be included in RoomFort's semantic knowledge base with the aim of providing business travellers with the best indoor conditions to ensure alertness and well-being.

RoomFort's ontologies can also provide the means to manage indoor CO_2 concentration, temperature and humidity rate, thus, actuating responses from the HVAC system of the hotel room. Furthermore, leveraging on an international representation of humans' health conditions, the system provides the possibility to customize the indoor comfort of the hotel room basing on guest's needs and characteristics. This feature can play an important role as an attraction tool for the more demanding customers but, consequently, can be also a valuable asset for hotel owner—in fact, by reducing the uncomfortable feeling and increasing the comfort perception, the attractiveness of the hotel could exponentially increases. RoomFort's system architecture assures that no guest personal data is stored in the hotel environment, so that privacy is preserved.

Future studies foresee the evaluation of RoomFort application for smartphones, following the validation framework proposed in this work. A set of tests, aimed at validating RoomFort's capabilities to actuate modifications in temperature and humidity rate—by triggering the activation of the HVAC system of the room—will also be deployed; then a test with participants will be aimed at evaluating the quality of the provided actuation. Together with the management of visual comfort, this feature can constitute a step towards the adoption of tailored holistic comfort in indoor environments. Moreover, RoomFort will be tested also with leisure tourists, to understand their possible acceptance of this technology in the context of providing optimal and energy-saving comfort management as an additional service.

Author Contributions: D.S. developed the ontologies presented in this work, set the semantic repository, contributed to the development of RoomFort architecture and supervised the writing of the first draft of this paper. S.C. provided the description of the room and contributed to the enrollment of the 28 participants and to the administration of the study together with M.N.; S.A. developed the study protocol, analyzed the outcomes, wrote the study methods and results, and revised the whole manuscript; M.N. developed the application with the help of S.A. and D.S., contributed to the development of RoomFort architecture and to the administration of the study; M.S. contributed to the development of RoomFort and revised the manuscript together with S.A.

Funding: This research received no external funding.

Acknowledgments: This work has been founded by "Convenzione Operativa No. 19365/RCC" in the framework of the project "Future Home for Future Communities". Authors would like to acknowledge the 28 participants who took part to the study.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AmI	Ambient Intelligence
CA	Context Awareness
HVAC	Heating, Ventilation and Air Conditioning
RDF	Resource Description Framework
OWL	Ontology Web Language
SWRL	Semantic Web Rule Language
IEQ	Indoor Environmental Quality
ICF	International Classification of Functioning, Disability and Health
CLCS	Customized Luminous Comfort Setting
LCS	Luminous Comfort Setting
DSS	Decision Support System

References

1. World Travel & Tourism Council. Available online: https://www.wttc.org (accessed on 18 October 2018).
2. WTTC. *Travel & Tourism Global Economic Impact & Issues 2018*; WTTC: London, UK, 2018; p. 11.
3. Global Business Travel Association. Available online: https://www.gbta.org/membership-and-communities/chapters-and-regions/europe (accessed on 18 October 2018).
4. Boyce, P.R.; Berman, S.M.; Collins, B.L.; Lewis, A.L.; Rea, M.S. *Lighting and Human Performance: A Review*; National Electrical Manufacturers Association (NEMA) and Lighting Research Institute: Washington, DC, USA, 1989.
5. Lovelock, C.; Wirtz, J.; Tat Keh, H.; Lu, X. *Services Marketing in Asia: Managing People , Technology and Strategy*, 2nd ed.; Prentice Hall, Pearson: Singapore, 2005; Volume 13.
6. Veitch, J.A.; Hine, D.W.; Gifford, R. End users: Knowledge, beliefs, and preferences for lighting. *J. Inter. Des.* **1993**, *19*, 15–26. [CrossRef]

7. Blomqvist, E. The use of Semantic Web technologies for decision support—A survey. *Semant. Web* **2014**, *5*, 177–201.
8. Vimalanathan, K.; Ramesh Babu, T. The effect of indoor office environment on the work performance, health and well-being of office workers. *J. Environ. Health Sci. Eng.* **2014**, *12*, 113. [CrossRef] [PubMed]
9. Tila, F.; Kim, H. Semantic IoT System for Indoor Environment Control—A Sparql and SQL based hybrid model. *Adv. Sci. Technol. Lett.* **2015**, *120*, 678–683.
10. Pan, J.Z. Resource Description Framework. In *Handbook on Ontologies*; Springer: Berlin/Heidelberg, Germany, 2009; pp. 71–90.
11. Zeiler, W.; Van Houten, M.; Savanović, P.; Zeiler, W.; Van Houten, R.; Boxem, G.; Savanovic, P.; Van Der Velden, J.; Wortel, W.; Haan, J.F.; et al. *Flexergy: An Ontology to Couple Decentrilised Sustainable Comfort Systems with Centralised Energy Infrastructures*; Technical Report; Technische Universiteit Eindhoven: Eindhoven, The Netherlands, 2009.
12. Mahroo, A.; Spoladore, D.; Caldarola, E.G.; Modoni, G.; Sacco, M. Enabling the Smart Home Through a Semantic-Based Context-Aware System. In Proceedings of the PerLS'18—Second International Workshop on Pervasive Smart Living Spaces IEEE International Conference on Pervasive Computing and Communication, Athens, Greece, 19–23 March 2018.
13. Bonino, D.; Corno, F. DogOnt—Ontology modeling for intelligent domotic environments. In *International Semantic Web Conference*; Springer: Berlin/Heidelberg, Germany, 2008; pp. 790–803.
14. Frešer, M.; Cvetković, B.; Gradišek, A.; Luštrek, M. Anticipatory system for T–H–C dynamics in room with real and virtual sensors. In Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing Adjunct—UbiComp '16, Heidelberg, Germany, 12–16 September 2016; pp. 1267–1274.
15. McGuinness, D.L.; Van Harmelen, F. OWL Web Ontology Language Overview. W3C Recomm. 2004. Available online: http://www.w3.org/TR/owl-features/ (accessed on 18 October 2018).
16. Horrocks, I.; Patel-schneider, P.F.; Boley, H.; Tabet, S.; Grosof, B.; Dean, M. SWRL: A Semantic Web Rule Language Combining OWL and RuleML. *W3C Memb. Submiss.* **2004**, *21*, 1–20.
17. Adeleke, J.A.; Moodley, D. An Ontology for Proactive Indoor Environmental Quality Monitoring and Control. In Proceedings of the 2015 Annual Research Conference on South African Institute of Computer Scientists and Information Technologists—SAICSIT '15, Stellenbosch, South Africa, 28–30 September 2015; pp. 1–10.
18. Stavropoulos, T.G.; Vrakas, D.; Vlachava, D.; Bassiliades, N. BOnSAI. In Proceedings of the 2nd International Conference on Web Intelligence, Mining and Semantics—WIMS '12, Craiova, Romania, 6–8 June 2012; p. 1.
19. Martin, D.; Burstein, M.; Hobbs, J.; Lassila, O.; McDermott, D.; McIlraith, S.; Narayanan, S.; Paolucci, M.; Parsia, B.; Payne, T.; et al. OWL-S: Semantic markup for web services. *W3C Memb. Submiss.* **2004**. Available online: https://www.w3.org/Submission/OWL-S/(accessed on 18 October 2018).
20. Reinisch, C.; Kofler, M.J.; Kastner, W. ThinkHome: A smart home as digital ecosystem. In Proceedings of the 4th IEEE International Conference on Digital Ecosystems and Technologies, Dubai, UAE, 13–16 April 2010; pp. 256–261.
21. Spoladore, D.; Arlati, S.; Sacco, M. Semantic and Virtual Reality-Enhanced Configuration of Domestic Environments: The Smart Home Simulator. *Mob. Inf. Syst.* **2017**, *2017*, 3185481. [CrossRef]
22. Borràs, J.; Moreno, A.; Valls, A. Intelligent tourism recommender systems: A survey. *Expert Syst. Appl.* **2014**, *41*, 7370–7389. [CrossRef]
23. Kim, D.; Kim, S. The role of mobile technology in tourism: Patents, articles, news, and mobile tour app reviews. *Sustainability* **2017**, *9*, 2082. [CrossRef]
24. Petrina, O.; Petrina, O.B. Smart Spaces Based Construction and Personalization of Recommendation Services for Historical e-Tourism of Recommendation Services for Historical e-Tourism. *Int. J. Adv. Intell. Syst.* **2016**, *9*, 85–95.
25. Smirnov, A.; Shilov, N.; Kashevnik, A.; Ponomarev, A. Cyber-physical infomobility for tourism application. *Int. J. Inf. Technol. Manag.* **2017**, *16*, 31. [CrossRef]
26. Moreno, A.; Valls, A.; Isern, D.; Marin, L.; Borràs, J. SigTur/E-Destination: Ontology-based personalized recommendation of Tourism and Leisure Activities. *Eng. Appl. Artif. Intell.* **2013**, *26*, 633–651. [CrossRef]
27. Kolcaba, K.Y. Holistic comfort: Operationalizing the construct as a nurse-sensitive outcome. *Adv. Nurs. Sci.* **1992**, *15*, 1–10. [CrossRef]

28. Chu, R.K.; Choi, T. An importance-performance analysis of hotel selection factors in the Hong Kong hotel industry: A comparison of business and leisure travellers. *Tour. Manag.* **2000**, *21*, 363–377. [CrossRef]
29. Buso, T.; Dell'Anna, F.; Becchio, C.; Bottero, M.C.; Corgnati, S.P. Of comfort and cost: Examining indoor comfort conditions and guests' valuations in Italian hotel rooms. *Energy Res. Soc. Sci.* **2017**, *32*, 94–111. [CrossRef]
30. Striker, J.; Luippold, R.S.; Nagy, L.; Liese, B.; Bigelow, C.; Mundt, K.A. Risk factors for psychological stress among international business travellers. *Occup. Environ. Med.* **1999**, *56*, 245–252. [CrossRef] [PubMed]
31. Gilbert, D.C.; Morris, L. The relative importance of hotels and airlines to the business traveller. *J. Contemp. Hosp. Manag.* **1995**, *7*, 19–23. [CrossRef]
32. Ariffin, A.A.M.; Aziz, N.A. The Effect of Physical Environment's Innovativeness on the Relationship between Hosting Quality and Satisfaction in Hotel Services. *Int. J. Trade Econ. Financ.* **2012**, *3*, 337–342. [CrossRef]
33. Ryu, K.; Jang, S.C.S. The Effect of Environmental Perceptions on Behavioral Intentions Through Emotions: The Case of Upscale Restaurants. *J. Hosp. Tour. Res.* **2007**, *31*, 56–72. [CrossRef]
34. Bohdanowicz, P.; Martinec, I.; Martinac, I. Thermal comfort and energy-savings in the hotel industry. In Proceedings of the Conference on Biometeorology and Aerobiology Joint with the 16th International Congress on Biometeorology, Kansas City, MI, USA, 28 October–1 November 2002; Volume 1, pp. 396–400.
35. Magnini, V.P.; Parker, E.E. The psychological effects of music: Implications for hotel firms. *J. Vacat. Mark.* **2009**, *15*, 53–62. [CrossRef]
36. Fisk, W.J. Health and Productivity Gains from Better Indoor Environments and their Relationship with Building Energy Efficiency. *Annu. Rev. Energy Environ.* **2000**, *25*, 537–566. [CrossRef]
37. Van Den Wymelenberg, K.; Inanici, M. A critical investigation of common lighting design metrics for predicting human visual comfort in offices with daylight. *LEUKOS J. Illum. Eng. Soc. N. Am.* **2014**, *10*, 145–164. [CrossRef]
38. Abbas, N.; Kumar, D.; McLachlan, N. The psychological and physiological effects of light and colour on space users. In Proceedings of the IEEE Engineering in Medicine and Biology 27th Annual Conference, Shanghai, China, 17–18 January 2006; Volume 2, pp. 1228–1231.
39. Baron, R.A.; Rea, M.S.; Daniels, S.G. Effects ofindoor lighting (illuminance and spectral distribution) onthe performance of cognitive tasks and interpersonalbehaviors: The potential mediating role of positive affect. *Motiv. Emot.* **1992**, *1*, 1–33. [CrossRef]
40. Samani, S.A.; Samani, S.A. The impact of indoor lighting on students' learning performance in learning environments: A knowledge internalization perspective. *Int. J. Bus. Soc. Sci.* **2012**, *3*, 127–136.
41. Shamsul, B.; Sia, C.; Ng, Y.; Karmegan, K. Effects of Light's Colour Temperatures on Visual Comfort Level, Task Performances, and Alertness among Students. *Am. J. Public Health Res.* **2013**, *1*, 159–165. [CrossRef]
42. Ariffin, A.A.M.; Maghzi, A. A preliminary study on customer expectations of hotel hospitality: Influences of personal and hotel factors. *Int. J. Hosp. Manag.* **2012**, *31*, 191–198. [CrossRef]
43. Küller, R.; Ballal, S.; Laike, T.; Mikellides, B.; Tonello, G. The impact of light and colour on psychological mood: A cross-cultural study of indoor work environments. *Ergonomics* **2006**, *49*, 1496–1507. [CrossRef] [PubMed]
44. Odabaşioğlu, S.; Olguntürk, N. Effects of Coloured Lighting on the Perception of Interior Spaces. *Percept. Mot. Skills* **2015**, *120*, 183–201. [CrossRef] [PubMed]
45. Siamionava, K.; Slevitch, L.; Tomas, S.R. Effects of spatial colors on guests' perceptions of a hotel room. *Int. J. Hosp. Manag.* **2018**, *70*, 85–94. [CrossRef]
46. Countryman, C.C.; Jang, S. The effects of atmospheric elements on customer impression: The case of hotel lobbies. *Int. J. Contemp. Hosp. Manag.* **2006**, *18*, 534–545. [CrossRef]
47. Minazzi, R. Hotel Classification Systems: A Comparison of International Case Studies. *Economica* **2012**, *4*, 64–86.
48. HOTREC Hotels, Restaurants & Cafés in Europa. Available online: https://www.hotrec.eu (accessed on 18 October 2018).
49. Gazzetta Ufficiale. Decree 21 October 2001, in the Gazzetta Ufficiale n. 34, 11 February 2009. Available online: http://www.gazzettaufficiale.it/eli/gu/2009/02/11/34/sg/pdf (accessed on 18 October 2018).
50. Cuzzocrea, A.; Grasso, G.M.; Nolich, M. Effective and efficient distributed management of big clinical data: A framework. *Int. J. Data Min. Model. Manag.* **2018**, in press.

51. Wei, W.; Barnaghi, P. Semantic annotation and reasoning for sensor data. In *European Conference on Smart Sensing and Context*; Springer: Berlin/Heidelberg, Germany, 2009; pp. 66–76.
52. Buqi, R.; Carciotti, S.; Cipriano, M.; Ferrari, P.; Nolich, M. Cruise cabin as a home: Smart approaches to improve cabin comfort. In Proceedings of the NAV 2018: 19th International Conference on Ship and Maritime Research, Trieste, Italy, 20–22 June 2018; pp. 647–654.
53. Gruber, T.R. A Translation Approach to Portable Ontology Specifications. *Knowl. Acquis.* **1993**, *5*, 199–220. [CrossRef]
54. Pérez, A.; Baonza, M.D.F.; Villazón, B. *Neon Methodology for Building Ontology Networks: Ontology Specification*; Technical Report February; Departamento de Inteligencia Artificial, Facultad de Informática, Universidad Politécnica de Madrid: Madrid, Spain, 2008.
55. Fernández-López, M.; Gómez-Pérez, A.; Juristo, N. METHONTOLOGY: From Ontological Art Towards Ontological Engineering. In Proceedings of the AAAI-97 Spring Symposium on Ontological Engineering, Stanford, CA, USA, 24–26 March 1997; pp. 33–40.
56. International Classification of Functioning, Disability and Health. Available online: https://www.bioportal.bioontology.org/ontologies/ICF (accessed on 18 October 2018).
57. Hepp, M. *Accommodation Ontology Language Reference*; Technical Report; Hepp Research GmbH: Innsbruck, Austria, 2013.
58. Daniele, L.; den Hartog, F.; Roes, J. Created in Close Interaction with the Industry: The Smart Appliances REFerence (SAREF) Ontology. In *Lecture Notes in Business Information Processing*; Springer: Cham, Switzerland, 2015; Volume 225, pp. 100–112.
59. Spoladore, D.; Arlati, S.; Nolich, M.; Carciotti, S.; Rinaldi, A. Ontologies' definition for modeling the cabin comfort on cruise ships. In Proceedings of the NAV 2018: 19th International Conference on Ship and Maritime Research, Trieste, Italy, 20–22 June 2018; pp. 877–884.
60. Motik, B.; Sattler, U.; Studer, R. Query answering for OWL-DL with rules. *Web Semant. Sci. Serv. Agents World Wide Web* **2005**, *3*, 41–60. [CrossRef]
61. World Health Organization. *International Classification of Functioning, Disability and Health: ICF*; World Health Organization: Geneva, Switzerland, 2001.
62. Spoladore, D. Ontology-based decision support systems for health data management to support collaboration in ambient assisted living and work reintegration. In Proceedings of the 18th IFIP WG 5.5 Working Conference on Virtual Enterprises, Vicenza, Italy, 18–20 September 2017; Volume 506, pp. 341–352.
63. Arlati, S.; Spoladore, D.; Mottura, S.; Zangiacomi, A.; Ferrigno, G.; Sacchetti, R.; Sacco, M. Architecture of a virtual reality and semantics-based framework for the return to work of wheelchair users. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*; Springer: Cham, Switzerland, 2017; Volume 10325, pp. 74–85.
64. Okochi, J.; Utsunomiya, S.; Takahashi, T. Health measurement using the ICF: Test-retest reliability study of ICF codes and qualifiers in geriatric care. *Health Qual. Life Outcomes* **2005**, *3*, 46. [CrossRef] [PubMed]
65. Spoladore, D.; Sacco, M. Semantic and Dweller-Based Decision Support System for the Reconfiguration of Domestic Environments: RecAAL. *Electronics* **2018**, *7*, 179. [CrossRef]
66. Della Mea, V.; Simoncello, A. An ontology-based exploration of the concepts and relationships in the activities and participation component of the international classification of functioning, disability and health. *J. Biomed. Semant.* **2012**, *3*, 1. [CrossRef] [PubMed]
67. Andronache, A.S.; Simoncello, A.; Della Mea, V.; Daffara, C.; Francescutti, C. Semantic aspects of the International Classification of Functioning, Disability and Health: Towards sharing knowledge and unifying information. *Am. J. Phys. Med. Rehabil.* **2012**, *91*, S124–S128. [CrossRef] [PubMed]
68. Noy, N.; Rector, A.; Hayes, P.; Welty, C. Defining N-Ary Relations on the Semantic Web. W3C Work. Group Note. 2006. Available online: https://www.w3.org/TR/swbp-n-aryRelations/ (accessed on 18 October 2018).
69. Da Silva, M.R.; de Souza Nobre, M.I.R.; de Carvalho, K.M.; de Cássia Ietto Montilha, R. Visual impairment, rehabilitation and International Classification of Functioning, Disability and Health. *Rev. Bras. Oftalmol.* **2014**, *73*, 291–301. [CrossRef]
70. Owsley, C.; McGwin, G.; Scilley, K.; Kallies, K. Development of a questionnaire to assess vision problems under low luminance in age-related maculopathy. *Investig. Ophthalmol. Vis. Sci.* **2006**, *47*, 528–535. [CrossRef] [PubMed]

71. Daniele, L.; den Hartog, F.; Roes, J. How to keep a reference ontology relevant to the industry: A case study from the smart home. In *International Experiences and Directions Workshop on OWL*; Springer: Cham, Switzerland, 2016; Volume 9557, pp. 117–123.
72. Rohloff, K.; Dean, M.; Emmons, I.; Ryder, D.; Sumner, J. An Evaluation of Triple-Store Technologies for Large Data Stores. In *OTM Confederated International Conferences "On the Move to Meaningful Internet Systems"*; Springer: Berlin/Heidelberg, Germany, 2007; pp. 1105–1114.
73. Stardog 5—Knowledge Graph Platform. Available online: https://www.stardog.com/docs/ (accessed on 18 October 2018).
74. Unity. Available online: https://unity3d.com/ (accessed on 18 October 2018).
75. Sirin, E.; Parsia, B. SPARQL-DL: SPARQL query for OWL-DL. In Proceedings of the OWLED 2007 Workshop on OWL: Experiences and Directions, Innsbruck, Austria, 6–7 June 2007.
76. Oral, G.K.; Yener, A.K.; Bayazit, N.T. Building envelope design with the objective to ensure thermal, visual and acoustic comfort conditions. *Build. Environ.* **2004**, *39*, 281–287. [CrossRef]
77. Ohta, N.; Robertson, A. *Colorimetry: Fundamentals and Applications*; John Wiley & Sons: Hoboken, NJ, USA, 2006.
78. Wang, Q.; Xu, H.; Zhang, F.; Wang, Z. Influence of color temperature on comfort and preference for LED indoor lighting. *Optik* **2017**, *129*, 21–29. [CrossRef]
79. Izsó, L.; Láng, E.; Laufer, L.; Suplicz, S.; Horváth, Á. Psychophysiological, performance and subjective correlates of different lighting conditions. *Light. Res. Technol.* **2009**, *41*, 349–360 [CrossRef]
80. Viola, A.U.; James, L.M.; Schlangen, L.J.M.; Dijk, D.J. Blue-enriched white light in the workplace improves self-reported alertness, performance and sleep quality. *Scand. J. Work Environ. Health* **2008**, *34*, 297–306. [CrossRef] [PubMed]
81. Gómez-Romero, J.; Molina-Solana, M.; Ros, M.; Ruiz, M.D.; Martin-Bautista, M.J. Comfort as a service: A new paradigm for residential environmental quality control. *Sustainability* **2018**, *10*, 3053. [CrossRef]
82. Brooke, J. SUS-A quick and dirty usability scale. *Usabil. Eval. Ind.* **1996**, *189*, 4–7.
83. Venkatesh, V.; Davis, F.D. A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Manag. Sci.* **2000**, *46*, 186–204. [CrossRef]