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Published Version:
Smart Campus: Fostering the Community Awareness Through an Intelligent Environment / Prandi, Catia*; Monti, Lorenzo; Ceccarini, Chiara; Salomoni, Paola. - In: MOBILE NETWORKS AND APPLICATIONS. - ISSN 1383-469X. - ELETTRONICO. - 25:3(2020), pp. 945-952. [10.1007/s11036-019-01238-2]

Availability:
This version is available at: https://hdl.handle.net/11585/686110 since: 2019-05-06

Published:
DOI: http://doi.org/10.1007/s11036-019-01238-2

Noname manuscript No.
(will be inserted by the editor)

Smart Campus: fostering the community awareness through an intelligent environment

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Received: date / Accepted: date

Abstract Interconnected computational devices in the Internet of Things (IoT) context make possible to collect real-time data about a specific environment. The IoT paradigm can be exploited together with data visualization techniques to put into effect intelligent environments, where pervasive technologies enable people to experience and interact with the generated data. In this paper, we present a case study where these emerging areas and related technologies have been explored to benefit communities, making their members actively involved as central players of such an intelligent environment. To give practical effect to our approach, we designed and developed a system, named *Smart Campus*, composed of: i) an infrastructure made of sensors to collect real-time data in a University Campus, and ii) a rich web-based application to interact with spatio-temporal data, available in a public interactive touch monitor. To validate the system and grasp insights, we involved 135 students through a survey, and we extracted meaningful data from the interactive sessions with the public display. Results show that this Campus community understood the potential of the system and students are willing to actively contribute to it, pushing us to better investigate future scenarios where students can participate with ideas, visualizations/services to integrate into the web-based system, as well as sensors to plug into the infrastructure.

Keywords Smart Campus · IoT · Data Visualization · Smart Environment

1 Introduction

As the history of the first university of the west world teaches us, central to such an establishment is its community that can be built in any *place* where students are willing to meet with teachers with the goal to share and absorb

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knowledge. This is the origin of the University of Bologna, born in 1088 as the home of free teaching and the first place where absolute freedom of research was ratified [2]. The University was founded by students and for students. Coming into the city during the XI century from many lands, students of the middle age organized themselves in order to hire and pay teachers and to nominate the rector, attending the lectures directly in the teacher's private houses. While the concept of University is itself grown around a community of students sharing learning spaces and resources, the first use of the word *campus* was done to describe a field nearby the University of Princeton, in 1774 [1]. Nowadays, the term *campus* is used to identify buildings and ground, or more generally places, where a university is situated.

In order to investigate new futures for higher educational spaces and experiences, recently, different concepts of *smart campus* emerged [3], with the aim of enhancing the experience of studying and sharing learning contexts, in time and space where smart devices, building management systems, and artificial intelligence shape communities. Two dimensions drive this evolution: (i) the availability of sophisticated smart environment technologies, applied to the specificity of a learning space, which produces and uses data, and (ii) the presence of lively student community, mainly composed by digital native equipped with smart devices and willing to actively participate.

In other words, the smart campus concept is a refinement of the umbrella term *intelligent environment*, defined as a physical environment where innovative and pervasive information and communication technologies enable people to experience and interact with space and generated data [8]. In such intelligent environments, the role of users is becoming more and more relevant [15], moving from passive beneficiaries of services to active participants [21], data explorers [22] and contributors [14], also by means of their activities on social media [25]. This is the context where the concept of hyperlocal data emerged as crucial for empowering a community. Such term expresses the information generated within a specific geolocalized community, that can be used to better inform the community members and improve their experience in interacting with the community spaces. To inform such a community about the collected hyperlocal data, making its members participates, the interaction with data is fundamental; this can be carried out in different ways, such as by exploiting data visualization methodologies, providing information is a visual way [10].

In this work, we present our approach in creating a smart campus system, providing a set of intelligent environment tools targeted to the need of a specific community [16]. As a real-world case study, we considered a new building, hosting the Cesena Campus of the University of Bologna (one of the five campuses part of the University of Bologna) working on three main aspects: i) augmenting a University campus with low-cost smart technologies and sensors, ii) deploying displays in public settings to let users interact with the hyperlocal data, being informed about specific phenomena in a spatial-temporal dimension, and iii) including the community members as active participants in exploring and in benefiting from the intelligent environment and the data it produces.

The remainder of this paper is organized as follows. Section 2 presents main works related to smart campus, while Section 3 describes the system architecture, presenting the sensors used and the Data Visualization interfaces. In Section 4, we present the mixed methods analysis we performed collecting both qualitative and quantitative data. Finally, Section 5 concludes the paper with a discussion on how to empower students exploiting our platform and the next planned steps.

2 Related Work

In this section, we briefly present some projects and studies based on the concept of *smart campus*.

The idea of *smart campus* is at the basis of several studies [19,3]. However, it is not clear what designing and building a smart campus means in practice. It is worth mentioning that currently there is no common and shared definition of smart campus, even if some researchers conveyed the definition on the basis of different approaches [17]. Three main different groups of such approaches can be identified: (i) technology driven, (ii) smart city concept adoption, and (iii) based on the development of an organization or business process [26].

Taking into account the technological approach (the first group of approaches), a smart campus results from the development of a digital campus, by exploiting IoT service providers [16] and cloud computing [11]. The idea behind this approach is transforming common objects which can be traditionally found in a university environment into a unique intelligent campus environment [9].

On the other side, the smart city concept adoption (at the basis of the second group of approaches) is based on the assumption that a smart campus shows several similarities with a smart city. By using the same paradigm, a smart campus should adopt modern technology to support different users (students, researchers and professors, employees, visitors, etc.) [13]. Summing up, a smart campus can be intended as a small and self-contained city, taking into account the number of functions, users, activities, and connections [19, 7]. In this second group of approaches, the users (as members of a specific community) can play a key and active role, being involved in crowdsourcing and/or crowdsensing activities [20], [23].

Finally, according to the third group of approaches, a smart campus is developed through the effective use of resources, by providing services to environmental communities [3], reducing costs and improving the quality of life (inside and outside the campus) [6]. In this sense, collecting data about environmental aspects (i.e., air quality, by monitoring pollutants, such as CO2 and Particulate Matters, or PM, [5], [24]) can play a fundamental role and can be improved by the adoption of the first two concepts too.

The smart campus system we propose in this work applies approaches coming from these three groups, since it exploits IoT and smart environment technologies (group i), it involves the community members through crowd-

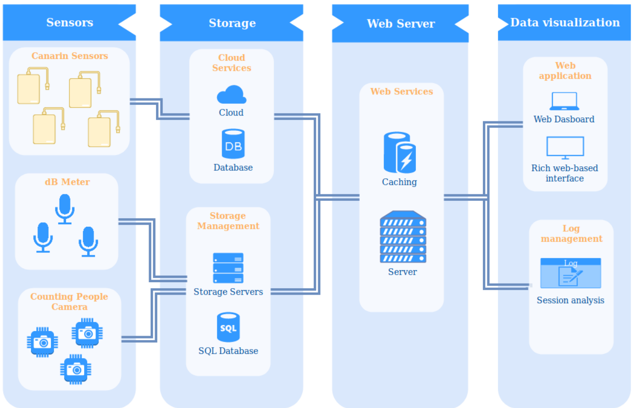

Fig. 1 Our Smart campus architecture.

sourcing and crowdsensing initiatives (group ii), with the aim of developing an effective use of the resources, improving the quality of life of the whole university community (group iii).

3 The system architecture

In this Section, we present the architecture of our smart campus system. As presented in Figure 1, the system includes four main components: i) the sensors infrastructure; ii) the storage/database management; iii) the data visualization interfaces; and iv) the web server. In the following, we provide a detailed description of the main layers (more details can be found in [16]).

3.1 The sensors layer

The campus has been built including a sensors infrastructure (building management system - BMS) with the aim of increasing the sustainability of the building. Such sensors can monitor and manage CO2, temperature, light, and other values. Even if these data are interesting to analyzed, we were intrigued by augmenting such infrastructure by including other sensors, both for indoor and outdoor measurements. We took this approach with three goals in mind: i) to collect data about other environmental conditions and phenomena; ii) to validate the collected data comparing the different data sources; iii) to make the data collected with our sensors available thought open-data repositories [24]. At the current stage, our sensors infrastructure is composed of environmental sensors (indoor and outdoor), noise sensors, infrared and thermal cameras.

Focusing on the collection of environmental data, we relied on sensor stations (i.e., Canarin II [4]), equipped with different sensors: sensors to detect air contaminants, gathering formaldehyde, PM 1.0, PM 2.5 and PM 10 values, temperature, relative humidity, and air pressure. At this stage, we placed these sensor stations: i) outside the building (3 in total), in strategic positions facing different pollution sources and urban and natural conditions; and ii) inside (2 in total), to monitor peculiar interior spaces, such as the library warehouse that requires a specific temperature and humid degree to avoid damaging the books. Moreover, to collect data about the indoor conditions, we are exploiting CO2 sensors provided by the BMS that have been placed in every classroom and laboratory so as to monitor the quality of air, in order to activate the heating, ventilation, and air conditioning (HVAC) system when needed.

Concerning the noise monitoring and measurement, after an analysis of accurate and low-cost microphones, we opted for a USB condenser microphone named *"Mini Akiro"* which has an omnidirectional pattern, a signal-to-noise ratio 85 dB and a frequency response from 100 Hz to 16,000 Hz. This sensor provides us with an interface for monitoring, collecting, storing and then analyzing the surrounding sound signals. To compute the signals caught by the microphone we used a Raspberry Pi 2 model B, a powerful, versatile and low-cost single-board computer. Furthermore, we used an USB Wi-Fi module for enabling the communication with the web server using the wireless network managed by the University of Bologna. The signals captured by the sensor are then computed by the Raspberry Pi before being stored in the database. To do that, we exploited a Python package called SoundMeter[1] that returns a RMS (Root Mean Square) value every 30 seconds. This value is then converted in Decibel. The idea is to provide campus staff with the possibility of automatically receives a notification in case of strong noise detected.

Considering, in particular, the indoor campus services, we focused our attention on how much the classrooms and the laboratories are exploited with respect to their actual capacity. In this sense, in order to count the number of people in an area, we are testing three different technologies to understand the one which can better suit our needs, considering also the balance between costs and performances. The three investigated technologies are: i) a RealSense camera[2], ii) a Sony PlayStation Camera[3], and iii) a thermal camera. We placed them in three classrooms, with different layouts, to test the accuracy of each approach. In the future, we plan to provide all the classrooms and laboratories as well as the library and study rooms, with a counting people system to provide more and better services to the community.

3.2 The database layer

Thanks to the database layer, the data collected real-time by the sensors can be stored and queried, and made available to the web-based application. In details, the sensed data are stored in a MySQL database every 30 seconds/one minute, depending on the sensor typology and the purpose. For example, air

[1] https://pypi.org/project/soundmeter/
[2] https://realsense.intel.com/
[3] https://www.playstation.com/en-gb/explore/accessories/playstation-camera/

quality and noise data are saved every 30 seconds, while camera data every 1 minute. Considering the environmental sensors stations, each entry stored in the database is represented by the raw sensed data, the timestamp, and the georeferenced coordinates.

In addition to the databases for the real-time sensed data, we are also exploiting an open data collection[4] of information related to the University community, and in particular, relevant for the students. This dataset is made freely accessible by the University of Bologna and includes a variety of data, ranging from the lessons timetable to a collection of georeferenced point of interests. To interact with the open data, we used *ckan*[5], an open-source DMS (data management system).

The use of different sources of information allows us to provide the community with data covering different aspects of the University life on campus. For this reason, we designed and implemented the system so as to be easily configured, letting the integration of external data repositories.

3.3 The Data Visualization layer

The Data Visualization layer is composed of two different web applications: i) a rich web-based application that allows the Campus community to interact with the hyperlocal data, making them more aware of the data generated by the campus, as a whole system (see Figure 2); ii) a log management web interface that enables to perform analysis and visualize data about the students sessions (an example of a visualization is presented in Figure 3). Both the applications have been implemented using standard web technologies, including HTML5 and CSS3, JavaScript, and specific libraries to visualize and represent the data, such as D3.js and Chart.js.

The rich web-based interface can be explored by the campus community thanks to a public touchscreen display (32" capacitive touch panel monitor), located at one of the two entrances of the main building (see Figure 2, on the right). The interface is composed mainly of three main UI components corresponding to four interaction modes, as detailed below.

The map-based interaction. The application has been designed focusing on the map-based interaction. In fact, the main component of the interface is the 2D map of the campus building levels. The implemented interface is based on an open source project [12] that we customized and extended to suit our needs and requirements. The map-based interaction enables the user to select a specific level in the SVG map. After selecting a level (floor), it is possible to visualize all the points of interest and to interact with them. Moreover, in all the SVG maps it is possible to visualize the facilities, such as toilets, stairs, and elevators. Once selected a specific point of interest (PoI), the information collected about it are popped-up in a panel at the bottom of the screen, and the location is highlighted in the map with an animated, color-coded marker.

4 https://dati.unibo.it/

5 https://github.com/ckan/ckan

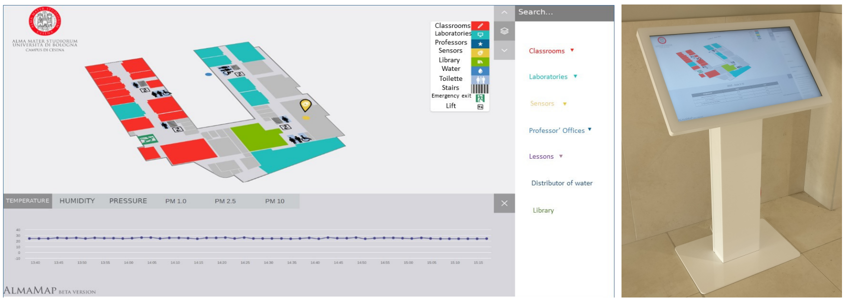

Fig. 2 The Smart Campus application: on the left, a visualization of the data gather by an indoor sensor; on the right, the kiosk hosting the application

The search-based interaction. The search-based interaction enables users to access the information exploiting a search function to filter content by keywords. In this way, it is possible to easily access information without knowing the actual position of the related PoI. The system provides a list of all the PoIs including the searched keyword. Selecting a specific PoI from the list, the application displays the right floor where the PoI is located, with a market to highlight the actual location.

The interaction by categories. The right side of the interface is used to present collapsed categories. Each category can be expanded to provide a list of different PoIs in such a category. In particular, the represented categories are: classrooms, laboratories, professors' offices, courses lessons, and sensors. Selecting a specific PoI, the map opens at the right level, presenting its location and the associated information.

The sensed data interaction. Besides the information about the PoIs in the campus (e.g., classrooms, professors office, libraries), we exploited data visualization techniques to represent in an intuitive way data gathered by the sensors that compose our smart infrastructure. The interface presents the real-time data, with values refreshed every minute, as well as historical data, with the possibility to interact with the timeline. This allows users to become aware of environmental conditions (both indoor and outdoor) concerning the University campus. Figure 2 (left) shows an example of visualization of sensed data in an indoor space. To manage real-time sensed data visualization we exploited some libraries, such as Socket.IO[6] that enables real-time, bidirectional and event-based communication between the browser and the server.

4 System evaluation

To evaluate our approach, we collected qualitative and quantitative data by exploiting two different methods. Firstly, we analyzed data collected automatically from the students' interactions with the public display, then, we provided students with a questionnaire to better understand some phenomena

[6] https://socket.io/

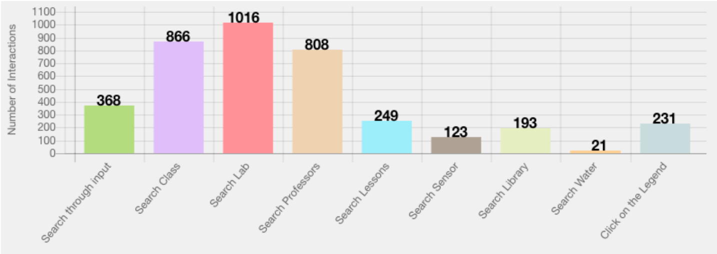

Fig. 3 A chart representing the typologies of interactions (captured from the log manager interface)

emerged from the activity logs and to enrich that information with qualitative observations and feedback.

4.1 Sessions analysis

We stored all the interactions happened with the rich web-based interface along a month (30 days). These data are related to: i) multi-touch interactions (information about the selected DOM object and its position in x,y coordinates); ii) typing in the search input box; iii) sessions duration (such as average, each session lasted 1 minute and 45 seconds). Integrating this information enables us to understand how students use the system, interact with the public display, and enjoy the hyperlocal data. A first interesting result emerges analyzing the way students look for information (e.g., typing a search keyword or touching the map). Data show that the majority of students experienced the provided information through the map-based interface. In fact, the number of meaningfully map-based interactions (#3495) is more than three times the number of interactions happened with the aside menu (#1036) and almost ten times the number of typing in the search input box (#375). This is a confirmation of our intuition to provide hyperlocal data on a map-based interface, letting emerge their spatial dimension.

We also analyzed the exploited content, aggregating the different interaction modes on the basis of the needed information. Figure 3 shows the data aggregated per typology of the exploited content. The data clearly reveal that students commonly look for classrooms and laboratories (for a total of almost 2,000 interactions). From the data emerges that there were only a few interactions and exploitation of data coming from the sensors. The explanation can be found in some comments collected from the questionnaire. In fact, some students emphasized and understood the relevance of using those data to provide new services, but they also maintained that *"[...] representing real-time data in their raw format can make difficult to extract meaningful information of the ongoing phenomena, making difficult to figure out their importance"*. Thanks to these important comments, we are working on improving the visualizations to let emerge meaningful scenarios.

4.2 Survey research

To collect qualitative and quantitative data we provided students with an online questionnaire and we shared it with students of the bachelor's degree of the Computer Science and Engineering programme of the University of Bologna, campus of Cesena, attending the Web Technologies course. The decision to involve this specific target audience was driven by the fact that these students are acquiring competencies and skills in web technologies, layout design and user experience. For this reason, they were able to provide detailed comments and feedback, with a more accurate and expert point of view. The questionnaire was divided into seven sections, based on different topics, for a total of 36 items, including open-ended, multiple answers and Likert scale questions.

A first important result was concerning the amount of participation in the study: 135 students (out of a class of 152) voluntarily answered to the questionnaire, expressing their interest in the project. The group was composed of 108 (80%) males and 24 (17.8%) females (three students preferred to not declare their gender). The participants age ranks between 20 and 42, with 89 (66%) having 21 years-old. Nonetheless, 16.3% (#22) are working-students, only 8 declared to come to the campus rarely (#5) or just for taking exams (#3). Within this context, it is interesting to report that 61 students (45%) declared that they enjoy the campus every working day (the building is closed during the weekend) for studying or attending the lessons, while 65 (48%) answered that their being into the campus is strictly related to the days they attend lessons. These data reveal that the majority of the students who participated in our study (126 out of 135) spend considerable time of their week inside the Campus spaces.

Entering in the details of the system usage through the public display, 56% of users (76 out of 135) interacted at least once with the system. On the basis of this answer, we presented users with different items to better investigate the reason behind this choice, both in the positive and the negative case. Starting from the latter, the major motivations behind the not usage of the system are two: i) students (#22) didn't notice the public display at all, falling in the so called "display blindness" issue [18]; ii) students (#49) didn't feel attracted or interested in the system, motivating the rationale behind this feeling in different ways. Some examples are: *"I was already confident with the location of classrooms and laboratories, so I didn't find it useful"*; *"I've never felt the need of using it but I am aware of its relevance in providing information about the campus"*. Regarding the former group (76 students who used the system at least once), 46% (#35) of students used it two or three times; 42% (#32) interacted with it just one time; 11% (#9) more than three time. The majority of students in this group considered the system usable (#38); information easy to find (#40); and with a good interaction (#45). All the values are presented in Figure 4, using a 5-values Likert scale from 1 (strongly disagree) to 5 (strongly agree). We also asked the students to assign a value to their experience (from 1 to 5): 36 (out of 76) selected 4 and 8 (out of 76) selected 5.

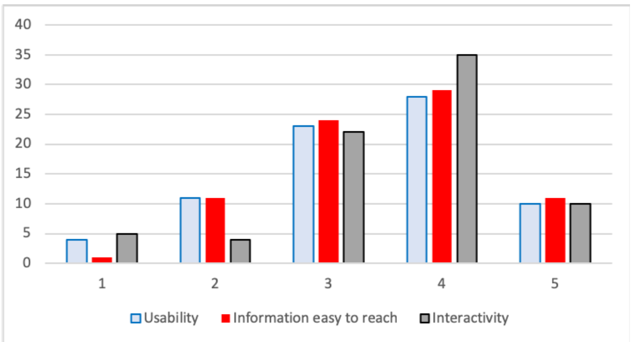

Fig. 4 Students' opinions on usability, information easy to reach and interactivity, using a 5-values Likert scale

To all the students (135), we asked feedback, ideas and suggestions, and critical issues to improve the user experience and the utility of the system. Students showed a strong interest and motivation in using the data to create new services. For example, a student suggested to exploit the data collected by the cameras used to count people for providing empty classrooms and labs to use such a space for studying activities. Different students provided ideas for services exploring different sensors. For example, a proposal was related to notifying students about the number of available shared bikes (located in a kiosk outside the building). Moreover, some students express the desire to enjoy the system also as a mobile application, with the aim of integrating location-based services, such as indoor navigation supported by short-range communications technology (e.g., iBeacon).

5 Conclusion and future works

In this paper, we present a *Smart Campus* system, designed and deployed in a new campus of the University of Bologna. Such a system acts as a proof of concept of the importance of considering the community members as key players of an intelligent environment, not only as passive beneficiaries but also as active contributors. In order to prove our concept i) we deployed an IoT infrastructure to gather data about different environmental conditions, concerning both indoor and outdoor phenomena, and ii) we designed and put available with a public installation a rich web-based interface, to let students interact with hyperlocal data. To evaluate the system, we employed a mixed methods approach, collecting and analyzing both qualitative and quantitative data through a survey (involving 135 students), and web session logs (for a total of more than 10.000 interacts). Positive results push us to expand the project, including other scenarios of students involvement. In fact, we are planning to make our data available (with APIs and open data) to students, letting them free to contribute at the system with ideas, services and applications, IoT nodes to plug into the infrastructure, and data visualization layers. In fact, the campus hosts undergraduate and graduate students of the Computer science and Engineering, Electronic Engineering, and the Architecture and Design degrees. Therefore, students living the campus are developing all the skills needed to suggest services based on their needs and to actively participate in the design and development of such services. Hence, the platform can act as a tool to facilitate the participation of students and to increase the potential of hyperlocal data, with the final goal of benefiting the whole campus community.

Acknowledgements The authors would like to thank Enrico Facciani for his valuable contribution to the implementation of the web-based interface. Moreover, we would like to thank all the students who participated in the study, providing interesting feedback.

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