Use of Context-aware Social Computing to Improve Energy Efficiency in Public Buildings

State of the Art and System Overview

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***Abstract*—The promotion of changes in users' behaviors with the aim of saving energy consumption in public buildings is a complex task that requires the use of multiple technologies. In this sense, context-aware technologies such as Wireless Sensor Networks and Real-Time Locating Systems, along with the use of Collaborative Learning, Virtual Organizations of Agents and Social Computing, provide a great potential for the development of serious games that foster the acquisition of good energy and healthy habits among workers and users in the public building. This paper presents the development of a serious game to change the users' behaviors when using resources in public buildings using CAFCLA, a framework that allows the integration of multiple technologies that facilitate both context-awareness and social computing.**

Keywords— behavioral change; serious games, context-awareness; collaborative learning; energy efficiency; social computing; virtual organizations

I. Introduction

During the last years, energy efficiency has become a priority policy for many countries around the world, being widely recognized as the most cost-effective and readily available way to address multiple energy-related issues, such as energy security, the social and economic impacts of high-energy prices, and concerns about climate change [1]. Consequently, many efforts have been focused to develop sophisticated hardware and control structures to measure energy consumption in grids, buildings and households, being these solutions proved to be technologically affordable and sustainable [2].

In this regard, one of the most important challenges to afford is energy consumption in public spaces and workplaces. In these environments, the building sector plays a very important role as far as energy consumption is concerned [3]. However, energy waste in these areas is elevated because of several reasons. Old buildings usually lacks of the implementation of technological solutions that enable an efficient energy use, and the comfort level of users is hard to be modeled due to the disparity of needs among each other [4]. Furthermore, the most important issue that affects the waste of energy in public buildings is their users' behavior, who are generally careless with these resources, mostly because they do not cover directly and consciously the energy costs.

Wireless Sensor Networks (WSN) emerge as an optimal technology to address the efficient use of energy in public buildings [5]. In order to give feedback and educate users, there are some solutions based on the analysis of devices consumption using smart meters, while other systems go further and develop intelligent control systems to act on resources, such as the HVAC, or even consider the integration of automation platforms [6]. Nonetheless, these intelligent systems do not usually take into account users' needs and not all of them encourage changes in users' behavior.

Furthermore, most of the approaches mentioned require that users analyze information and change modify their behavior to reduce power consumption [2]. In order to improve this, it is necessary mechanisms that encourage and educate users on the efficient consumption of energy. In this sense, serious games have a great potential as they are designed to attractively educate and foster changes in the behavior of their players [7]. In addition, the performance of these games over long periods can reinforce the goals achieved, so that users acquire behavioral changes gradually and transparently over the time [8]. Several serious games have been developed in combination with sensor networks [9]. The development of serious games is a challenge because by means of them motivation should be improved, participation encouraged and the learning process enhanced. In order to address this challenge, *Context-aware Learning* represents as an interesting approach as it facilitates the characterization of the environment in which the game is taking place, making use of Wireless Sensor Networks (WSN) and Real Time Locating Systems (RTLS) to collecting real-time data [10].

Nevertheless, it is necessary to provide custom tools that take into account the habits, preferences, ambitions and interactions of people when combining WSNs and serious games. The implementation of *Social Computing* and *Virtual Organizations of Agents* (VOAs) emerge as the best alternative to afford these challenges. This issue requires the use of mechanisms that connect multiple devices and manage the

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information collected intelligently [11]. This allows a more efficient management of hardware resources collecting context information, the services provided to users, as well as the management of the own game.

This paper presents a work aimed to providing newer perspectives when addressing the behavioral change required by people to improve energy efficiency. More specifically, the paper presents a serious game in which users must improve their habits regarding the efficient use of energy in public buildings. The development of the serious game is performed by means of CAFCLA (*Context-Aware Framework for Collaborative Learning Applications*) framework as a basis for its technical and social features [12]. A social computing perspective has been considered when designing the framework and this allows making use of social and contextual information. Contextual information is gathered by means of the of WSNs that facilitate the acquisition of data related to the energy consumption, the presence of users in rooms or the efficient use of electronic devices and HVAC systems. Furthermore, the RTLS allows determining which behavioral habits users follow and provides with guidelines to improve these habits in their workplace. A VOA supports the framework, providing intelligence to the game and the learning process [13] by managing the process of the game, updating contextual information, monitoring users' actions and providing players with information. The use of these technologies within the paradigm of social computing has generated an innovative game by customizing it for each user and offering the possibility to interact among them, working together to achieve a common goal.

Section II describes the context surrounding the work presented, including behavioral change for energy efficiency, the use of serious games to reach behavioral change and the potential of context-aware leaning to deploy these kinds of games. Section III depicts the deployed system to perform the serious game, including a comprehensive description of the framework and each of the components included in the different layers that compose it. Finally, section IV presents the main conclusions, as well as the future work.

II. State of the Art

This section analyzes the state of the art of different solutions that makes use of serious games to improve energy efficiency. More specifically, our work emphasizes the benefits of context-aware learning to collect the changes in the users' behaviors, paying particular attention to the sensors infrastructure. Finally, as any system as this should be properly managed, social computing and virtual organizations of agents are presented.

A. Behavioral change for energy efficiency

Energy efficiency is widely recognized as the most cost-effective and readily available means to address numerous energy-related issues, at the same time, increases competitiveness, and promotes consumer welfare. Buildings are responsible for the largest share of European final energy consumption (40%) and they represent the greatest potential to save energy. Buildings are long-term assets expected to remain useful for 50 or even more years and 75-90% of those standing today are expected to remain in use in 2050 [14]. Energy efficiency investments in public buildings are unique in that the public owner can perceive both the energy savings, productivity and value improvements, as well as the public benefits of raise of employment, reduction of emissions and improvements to public accounts. Recently various energy policies around the efficient use of energy have been implemented [14]. In order to achieve their goals, some of these initiatives directly require a change in the behavior of users and in the energy consumption practices undertaken. In this sense, there are studies and trends that give more value to the change of consumption practices than to the technical implementation itself [15].

Therefore, it is necessary to model the behavior of users to determine how they do things. The design of models that promote the user behavioral change differs whether it is domestic or non-domestic users. While home users have a direct contact with the cost of energy, the policies implemented in the non-domestic sector are made at the organizational level, lacking a direct relationship with the behavior, habits and benefits for users or workers. For this reason, motivate users to acquire habits that allow a more efficient use of energy is a hard task that requires the use of attractive tools that support and assert the acquisition of these habits [14].

Researches on energy efficiency has recently generated a vast literature. Due to the direct relationship between users and their expenses related with energy consumption in homes, most of the researches address this area [16]. In order to better understand how energy consumption is at homes, firstly the behavior of its inhabitants must be understood. Among the proposed solutions within households are those based on providing feedback to users about their consumption by using smart meters or displays reporting real time consumption [17], and some proposals extrapolate the solutions used in homes to offices [18]. However, promoting behavioral change in users requires aware them about the benefits of the efficient use of energy, as well as the efficient use of the most used resources, such as MELs (Miscellaneous Electric Loads, including PC, scanners, printers, etc.), which consume more than 25% of energy in offices [19].

B. Serious Games

Serious games are a broad trend in which traditional mechanisms of games are used in multiple environments such as public policies, business management, healthcare, or energy saving [2]. The main objective of these games is to educate, paying special attention to the educational purpose beyond entertainment, and these games allow users to acquire skills through play-based activities by using their inherent playfulness and interactive characteristics. They also facilitate the motivation, training and engagement of participants, which learn by improving the performance of a specific objective through the acquisition of new knowledge and skills.

Serious games have optimal characteristics to face the behavioral change for energy efficiency in the public sector and working environments, and they have been used in different areas to promote this change [20]. Various approaches to serious games in the energy sector are being piloted or commercially deployed, each adopting differing gamification techniques and having different key objectives [2]. A common factor is their use of granular and real-time energy data, which allows them to provide instantaneous feedback. The use of serious games in office environments is hardly used and are mostly based in giving awareness about energy consumption and promoting energy saving [2].

Despite the multiple solutions and researches that has been analyzed, the use of supporting technologies is not fully exploited. One of the main lacks is the underuse of Wireless Sensor Networks when designing and deploying serious games for energy efficiency. Although some technologies, mostly smart meters, are used to obtain power consumption, WSNs offer a great potential to collect parameters that affect the behavior of users during the game and create richer activities. Thus, the contextual information provided by the sensors becomes a great source of information that allows monitoring and customizing the game and giving feedback and encourage awareness among users.

C. *Context-aware Learning*

Dey in 2001 refers *context* to “any information that can be used to characterize the situation of an entity” while “an entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves” [21]. *Context-aware Learning* arises with the inclusion of context-awareness in the learning process [22]. Thus, the educational process takes advantage of the flexibility provided by the use of real-time environmental information within the process. Moreover, the use of technologies that allow obtaining contextual information, such as WSNs and RTLSs enriches the learning process [23].

Furthermore, serious games benefit when contextual and location data is include in its design and development, as multiple research lines address [24]. This use gives us an idea of the potential that contextual information offers to the design of games in which the objective is that the participants acquire habits that enable them to make use of the energy in a more efficient way. However, many games developed for encouraging an efficient use of energy do not consider the use of sensor networks and real-time location of users to enrich the learning process.

From this new perspective, sensor networks facilitate to obtain an accurate “energy picture” of the environment in which the game is played [6]. Likewise, sensors allow acting automatically on the environment once the parameters of behavior of participants are determined. In addition, the ability to locate users in real time allows launch challenges that promote and enhance both energy saving and the acquisition of good habits. Otherwise, the use of intelligent management techniques is not taking into account in the researches; these techniques improve the game and the behavioral change by the prediction, adaptation and anticipation to users’ actions [25]. Finally, the behavioral change pretended with the solutions mentioned above is not addressed from the point of view of social computing.

D. *Social Computing*

Recent tendencies have led to the social computing paradigm for designing social systems that helps us to build such sociotechnical tools. Thus, it is possible to design tools where humans and machines collaborate to resolve social problems. These tools have a high level of complexity and require the use of artificial intelligence to manage artificial societies, but provide capacities for the effective collaboration between humans and machines [26]. Agent technology, which makes it possible to form dynamic virtual organizations of agents, is particularly well suited as a support for the development of these open systems [27]. Modelling open multi-agent organization makes it possible to describe structural compositions and functional behavior, and it can incorporate normative regulations for controlling agent behavior, the dynamic entry/exit of components and the dynamic formation of agent groups [28].

On the one hand, Social computing paradigm aims to the creation of social entities managed both by technology and social processes known as Social Machines. These entities allow systems to generate recommendations to users, such as the social machine developed by Amazon [29]. Several social machines are oriented to the prediction of social dynamics by behavior data gathered form Twitter. On the other hand, Social networks have become one of the most used Internet activities. At present, most Internet users are social network users who spend more and more time in social network activities. It is also known that social networks enhance engagement to activities or games. There are currently many initiatives to engage people in behavioral change using known social networks such as Facebook or Twitter.

Regarding behavioral change for energy efficiency, there are a number of proposals that address the problem resolution by using serious games through social networks [30]. However, human-machine interactions are not deeply addressed in these solutions leaving aside, for example, contextual information that may be useful in the field in which we focus. In addition, there is no proposal that addresses the problem from a global point of view of social computing, neither proposals offering working infrastructures that allow the integration of different technologies, communication protocols or diverse ways to promote social relations based on the needs that the game to be raised presents. Our work presents a framework based on social computing and context-awareness that allows the creation of learning scenarios, such as serious games, through which encourage and enhance a change in users’ behavior to use energy efficiently in public buildings.

III. System Overview

This section addresses all the issues that are needed to deploy a serious game in an public building environment to encourage users to improve an efficiency use of the resources and, finally, to achieve a change in their behaviors and habits. As explained in the previous section, it is required to have a strong and sufficiently broad technology base that allows working with different communication technologies, integrating WSNs and RTLSs and manage the relations among humans and between humans and material resources. The work depicted here uses the CAFCLA (*Context-Aware Framework for Collaborative Learning Activities*) [12] framework, designed by BISITE and focused on collaborative learning by means of the use of contextual information. CAFCLA is optimal to deploy the serious game because of the facilities it offers to cover technological and users' requirements and to integrate intelligent management.

A. Background

As mentioned above, CAFCLA is a framework whose main purpose is the integration of different technological resources to facilitate the design and development of learning activities based on contextual information and social computing. Within this context, CAFCLA allows its users to have multiple offered resources so that, through them, the use of contextual information and social interactions is simplified. In addition, this integration not only facilitates the design of learning activities, but also allows quicker start by reducing the development time.

CAFCLA has been used for collaborative learning activities that use contextual information in museums [31], gardens [12] and other educational settings [23]. In the present work, CAFCLA is used in a non-academic environment with a specific purpose: to educate, raise awareness and facilitate behavioral change in the efficient use of energy in public buildings. To this end, it has designed and developed a serious game that allows to perform this process of awareness of users, so that naturally can acquire good habits and behavioral change that save energy by making a more efficient use of it.

The game developed under CAFCLA aims the users of a research laboratory to reduced energy consumption and acquire good energy habits. By means of a WSN the use of lighting, the use of HVAC systems, consumption of each of the users' site job (if they turn off or suspend the computer) and their location are monitored continuously (and even if users use the elevator or stairs to get into the lab). All these data will allow checking if users meet certain energy efficiency targets and good habits. If so, users are rewarded or penalized with virtual coins.

B. Framework Description

The game designed using CAFCLA requires the integration of different physical devices and technologies. As shown in Table I, CAFCLA has been designed following a scheme of interconnected layers. Each layer includes a set of technologies that support the requirements that the game needs. These devices and technologies support communication, sensor data collection, contextualization of the environment, provide intelligence to the system and even facilitate the development of the application used by players.

TABLE I. CAFCLA LAYERS DIAGRAM AND TECHNOLOGIES ASSOCIATED WITH EACH ONE

Layer	***Technologies***
Physical	Tablet, smartphone, temperature, luminosity, on/off and consumption sensors, location beacons
Communication	Wi-Fi, ZigBee, 4G/3G/GPRS
Context-awareness	WSNs, Real Time Locating System
Management	Social Computing, Virtual Organization of Agents
Application	API, Web interface game

1) Physical Layer. At the lowest level of the CAFCLA layers diagram is the physical layer, which includes all devices that will be used by the framework. An important part of this layer is the infrastructure necessary to collect all the contextual information. More specifically temperature on/off, luminosity sensors and consumption sensors, integrated into plugs that monitor the power consumption of each site job, are integrated. Location beacons are also included to facilitate the position of users and each of them will wear an identification tag. Tablets, laptops and smartphones have been integrated into CAFCLA. Through these devices user access and use the game interface. Furthermore, communication between devices requires some physical infrastructure. In this case, Internet access points via Wi-Fi and Ethernet, as well as data collectors and hubs that send, via Internet, the data collected by sensors and the RTLS. In addition, the system requires a server to store data and run the application. All these technologies are integrated by CAFCLA transparently to users, making an appropriate use of each depending on the needs raised by the game at any time of its performance.

2) Communication Layer. In order to send and receive information between different physical devices, CAFCLA integrates different communication protocols. In this case of use, the framework integrates the following wireless communication protocols: Wi-Fi, ZigBee and 4G/3G/GPRS. On the one hand, Wi-Fi and 4G/3G/GPRS protocols are mostly used to transmit data to players or for the communication between mobile devices. On the other hand, ZigBee is the protocol used by the WSN that transmits the data from any sensor (including RTLS detection of tags by beacons) to the collectors and hubs that forward it to the server.

3) Context-awareness Layer. Within the game designed using CAFCLA, contextual information plays a key role. Through it, the energy consumption, which resources are being used and whether this use is being done efficiently is known at all times. This information allows players to better understand the challenges they face and, through incentives generated by the rules, they can make more efficient use of energy resources they have in their work environment. In turn, the behavioral change of players occurs transparently through the acquisition of good energy habits and awareness of not to waste energy unnecessarily. To develop effectively the above explained features, CAFCLA has carried out the integration of a WSN and RTLS platform. This technology allows to know at all times, on the one hand, the physical quantities that permit the system to determine the contextual status of the environment (temperature and luminosity sensors), instant and historical energy consumption of each job site (electricity consumption sensors), the status of lighting and HVAC systems (on/off) and, on the other hand, the location of the participants of the game. Thus, the system is able to determine the occupancy of the rooms, use of the elevator or if they are at their job site. The platform selected to deploy the wireless sensor network is n-Core [32], which allows integration of all the sensors used in this case of use. The n-Core platform uses the ZigBee communication protocol (IEEE 802.15.4), which enables communication of the sensors (n-Core Sirius RadIon along with IOn-E devices, shown on Fig. 1) with the other devices of the system in a very simple way: the sensor data are sent through the ZigBee network to data collectors which, in turn, send the information collected by these to the server hosting the database through the Wi-Fi protocol. All the data collected and stored and the states generated are used for the development of the game. The n-Core platform also facilitates the deployment of the indoor location system that allows locate each user in real time. In this case, CAFCLA integrates n-Core Polaris [32], which is also based on the ZigBee wireless communication protocol that allows to determine the position of users up to one meter accuracy. To carry out the location, n-Core requires the deployment of a set of beacons that collect the signal sent by tags (n-Core Sirius Quantum devices, see Fig. 1) that are worn by the players. That signal, and its associated data, is sent to the server that implements the location engine that calculates the position of each player. Players wear a n-Core Sirius Quantum tag responsible for sending that signal and provided with an accelerometer that determines whether the user is moving. The beacons (n-Core Sirius RadIOn devices) forward these data to the server in the same way that the sensor data are sent, through Wi-Fi data collectors. n-Core allows the deployment of the wireless sensor network and the location system using the same platform and physical infrastructure. Thus, the sensors integrated in the ZigBee network can act themselves as beacons for the location system, reducing costs and energy consumption. Furthermore, both systems share data collectors for forwarding data to the server. For the game, the location system can distinguish several areas where players can be found: personal job sites, meeting rooms, elevators and stairs, in order to define the context in which each player is at a given time towards the development of the game. As we can see in Fig. 2, during the design of the game different points that measure temperature and luminosity have defined, sensors consumption in each position have been placed, on/off sensors which determine the state of the lighting and HVAC system have been placed and the different areas where users the game is taking place have been defined (two meeting rooms, working area, 2nd and ground floor stairs and 2nd and ground floor lifts).

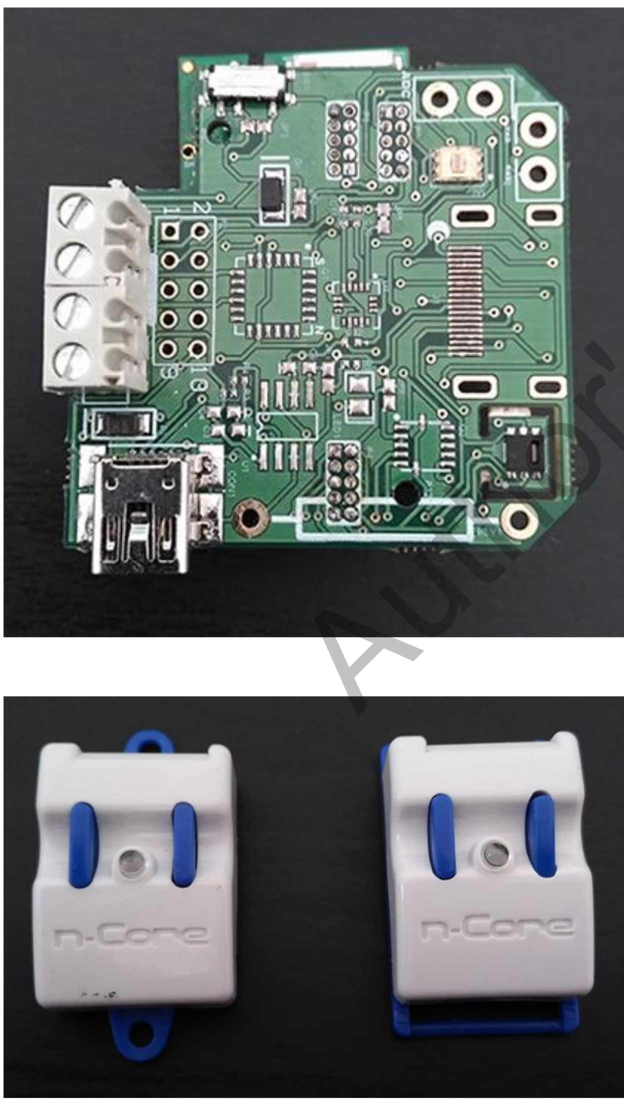

Fig. 1. n-Core Sirius IOn-E device (top), n-Core Sirius RadIOn device (bottom left) and n-Core Sirius Quantum device (bottom right).

4) Management Layer. This layer integrates the social machine which is in charge of the context-awareness and communication layers operation in a distributed, effective and predictable way. One of the biggest challenges that the development of *Social Computing* systems has to face is the communication and coordination between the participating entities, whether human or machine [33]. To address this challenge, current trends recommend the use of *Virtual Organizations* (VO), that can be defined as a set of individuals and institutions that are needed to coordinate and manage, across institutional boundaries, services and resources [34]. This work considers that a VO is an open system composed of heterogeneous entities that collaborate with each other and whose difference of form and function required to define the behavior of each one. Moreover, *VO agents* (VOAs) technology has facilitated the resolution of challenges related to autonomy, training, collaboration or management of communication between groups [11] because it allows the creation of dynamic agent organizations, especially useful for the development of the game here presented. Its use favours the description of functional behaviors such as schedules, tasks or services and describe logical structures and interactions, relationships or roles. The main purpose of the management layer is to implement the social machine using VOAs. Those VOAs will support the context-aware game. As can be seen in Fig. 3, the proposed architecture includes different organizations:

a) Data Gathering Organization: Highlights all author and affiliation lines. The data that the system has available come from different sources that require a thorough control. This organization is responsible for managing these heterogeneous sources, such as sensor networks, the location system or even information published or consulted, among others.

b) Data Management Organization. This organization is responsible of maintaining the integrity of data during the game. It makes the decision of what data should be developed and stored at all times. The game performance depends on data availability, so this issue is determining during the process. It is related with the Data gathering organization, that gathers new information, and the Game organization that makes the decision of what information has to be stored or requests a concrete data. This VOA also classifies the information to be delivered, depending on the context and social information that surrounds the player at a particular time while developing the game.

c) Context-aware Organization. This organization manages the information collected by the sensor network. It need to be coordinated with the Data management organization in order to keep updated the information from any physical service implemented by the sensor network.

d) Game Organization. The whole activity is under control of this organization (management and coordination). All the information from the social machine (players, contextual data, information, etc.) is received and managed by this organization. It finally decides which information is provided to player according with the state in which the performance of the game is.

e) Social Machine Organization. This organization is responsible of performing analyses that extract socially relevant information related with the interaction among different agents. *Player agents*: grouped in organizations, they store all the information related to the game process. This organization allows the interaction player-player and player-machine. *Configuration agent*: this agent creates, modifies and monitors the development of the game and establishes the social rules of the social machine organization. *Collaborative agent:* grouped in organizations, this agent monitors the process of the communication with the Context organization and the Activity organization.

f) Challenges & Recommendations Organization. This organization produces engaging personalized actions for the players to meet the objectives set in the Activity organization.

5) Application Layer. The top layer in CAFCLA schema is the application layer. This supports the game development and provides the interface for players and game organizers, as

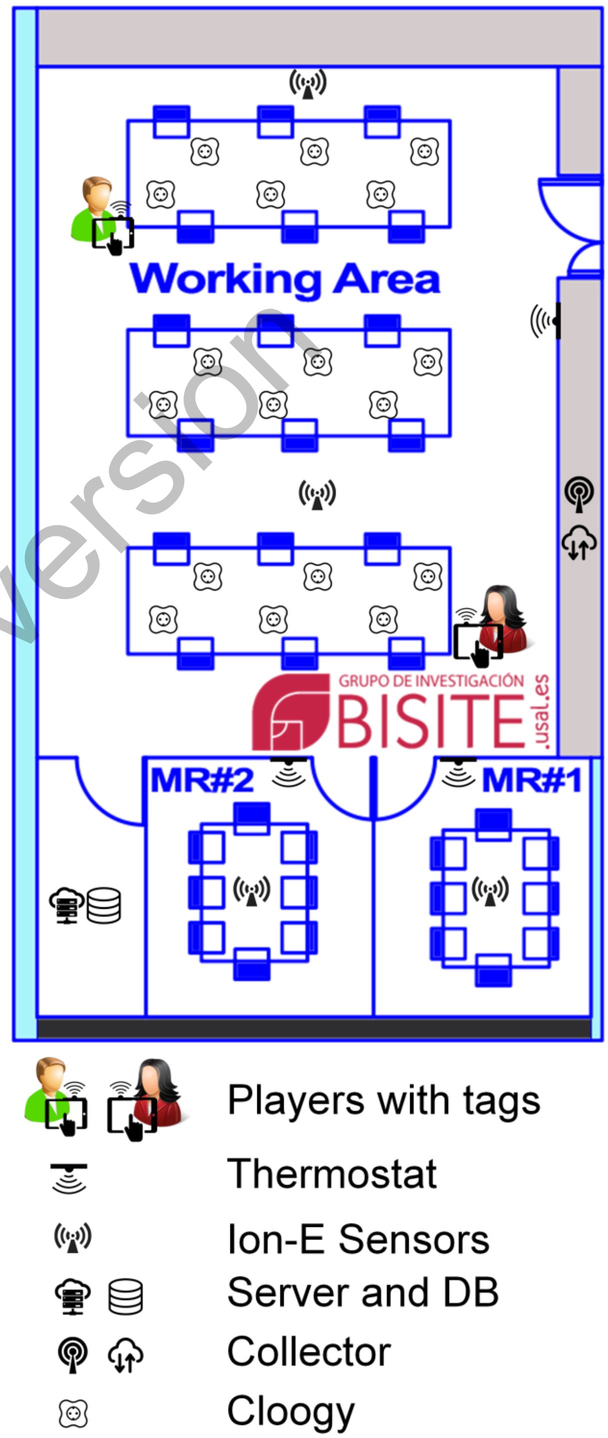

Fig. 2. Distribution of sensors in the laboratory.

well as for other components that are part of it, such as the configuration of different devices. To determine the features that this layer may provide, as well as for the integration of the necessary technologies, it has been considered a social and serious games approach. Thus, firstly the game is defined and design using CAFCLA and then technologies that support it are chosen. In this case, a specific game where players will be rewarded or penalized regarding their behavior within energy savings within their work environment is carried out. The scenario in which the game takes place is one of the working laboratory of the BISITE research group in the I+D+I building at the University of Salamanca. This lab has 18 workstations in a common working area and two separate meeting rooms. It is located on the second floor of the building, which can be accessed by lift or stairs. Through the various technologies

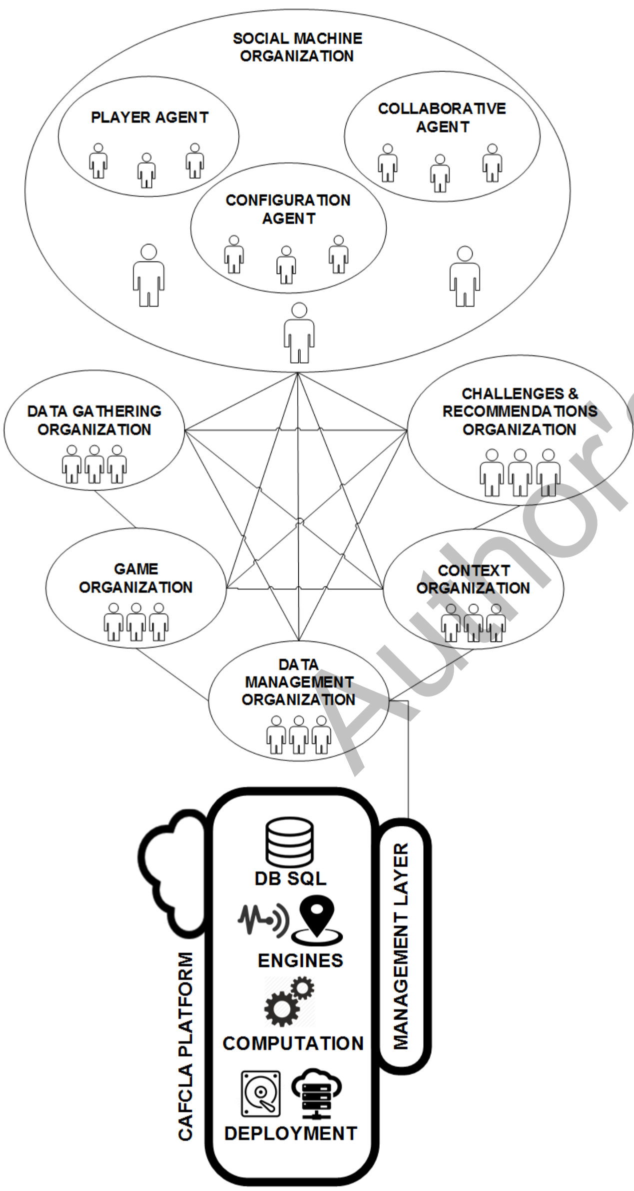

Fig. 3. The management layer architecture of the system.

implemented by CAFCLA it is controlled at all times contextual information of the working environment and the position of each of the participants. Contextual information is given by the following parameters: temperature and luminosity of each of the zones (working area and meeting rooms), status (on/off) of lighting and HVAC in each area, measurement of electrical consumption of each job site and the position of each of the people working in the laboratory. All workers are involved in the game (18 in total) whose main objective is to get virtual coins through energy efficient behaviors. Milestones to achieve or lose virtual coins are as follows:

- Determination of the use of light in the meeting room: if one or more users are in the meeting room and do not use artificial lighting if natural lighting is greater than 200 Lux, each of the user gets 10 virtual coins. Otherwise, it is penalized.
- Determining the use of HVAC in the meeting room: if users do not make use of the HVAC system to change the room temperature if it is above 18ºC in winter or below 25ºC in summer, each of them will be rewarded with 10 virtual coins. Otherwise, it is penalized.
- Use the elevator and stairs: every time a player goes up or down the stairs will be rewarded with 10 virtual coins. The use of the lift is penalized.
- If the last user leaving the laboratory turns off lights and HVAC system, he or she receives 10 virtual coins.
- Energy consumption: all player whose consumption of electricity during the day are below the average for the previous day will receive 10 virtual coins.

To encourage participants, 250 virtual coins permits players to grab a coffee or a soft drink for free.

IV. Conclusions and Future Work

This paper presents a serious game based on the social computing paradigm that integrates advanced technologies through the framework CAFCLA, including WSN and RTLS. This integration allows the resolution of the human-machine interaction and context-awareness issues so that users acquire good energy habits in public buildings. The use of wireless WSN and RTLS presents a great potential for the development of systems that are intended to promote a behavioral change in the habits of energy consumption in users. In this case, players know at all times the energy consumption of their job sites, interact with others to improve their consumption and receive incentives and real-time recommendations to improve the acquisition of good habits and energy consumption savings. CAFCLA provides added value compared with other solutions as the integration of multiple technologies and communication protocols can substantially improve the context-awareness, covering a larger number of potential cases of use to be implemented.

Future work includes the development of a experimentation stage in the BISITE Research laboratory in order to test the system, observe the changes in the users' behaviors and measure the derived reduction in power consumption, in comparison with other systems.

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