Creative Construction Conference 2015 (CCC2015)

3I Buildings: Intelligent, Interactive and Immersive Buildings

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Abstract

This research presents the architecture of a technology platform capable of integrating different types of data from building sensors and providing an interface to manage and operate facility devices, which is supported by advanced optimization algorithms. This interface is potentiated by a BIM-based interface presenting real-time data of the building.

The solution, called 3i buildings - Intelligent, Interactive, and Immersive Buildings, is a tool to monitor and manage smart buildings, as well as optimize users experience, energy consumptions and environment quality. This is achieved by a grid of sensors and devices that continuously gather information (structural conditions of the building, occupancy, comfort of occupants, energy consumptions and CO_2, COV's and Humidity levels, etc.), which is processed by predictive models able to learn over time.

The 3D representation of the models allows managers to take advantage of the virtual environment, by augmenting the facility model and including information about the facility, making it easier and perceptible to users and owners, helping them to make better decisions.

To support our research, the system will be installed in three different environments, Luz's hospital, Lisbon Aquarium and Norte Shopping, to test the solution under different conditions, objectives and users. In the first two cases the objectives are to monitor building air quality, consumptions and occupancy and in the Norte Shopping case the objectives are to monitor people flows, interact with tem and help the response in case of crisis according to the adopted emergency plan.

These types of systems might help reducing energy consumptions as well as increasing comfort and satisfaction of occupants, maintaining a constant concentration of CO_2 and humidity within the facility. The optimized algorithms will allow the system to learn, predicting and reacting to different conditions, giving a more reliable and smooth response to occupants needs.

Keywords: Intelligent Buildings; Energy Efficiency; Optimization algorithms; BIM; IFC

1. Introduction

Buildings and cities face significant challenges towards energy efficiency, sustainability and improved performance. Gradually, a new generation of construction projects emerges, more complex, more creative and more intelligent, in which new information technologies (IT) play a major role: on one hand they transform the way buildings and cities are designed, constructed and managed; on the other hand they change the buildings' behavior and their interaction with users.

Building Information Modelling (BIM) is one of the current technology trends in construction, contributing to an efficient integration and management of engineering information [1]. With the adoption of BIM the different parties involved in a project have a tool to communicate and share information and ideas through a single point, the BIM model [2]. BIM allows generating and managing digital representations of physical and functional characteristics of a facility during its entire life cycle, improving collaboration, information management and advanced simulation [3].

Building intelligence and the "internet of the things" (IoT) are other relevant technology trends to be considered within the construction industry innovation framework. In brief, building intelligence can be referred to as the autonomous ability of buildings to optimize its processes and its functions, based on artificial models and algorithms. The IoT concept is based on the idea of a universal presence of "things" or "objects", such as Radio Frequency Identification (RFID) tags, sensors, actuators, mobile phones, etc., with digital identification and addressing schemes that enable them to cooperate with neighbors in order to achieve some common goals [4]. Several innovative projects already apply these technologies to optimize buildings and cities performance [5,6,7], focusing the optimization of specific systems, such as those related to energy efficiency, usage of renewable energy in buildings, waste recovery or sustainable construction. Others are centered on the management and optimization of large information flows used to enhance certain processes of organizational decision-making.

However, few research projects recognize the fundamental role that key infrastructures have in efficient management of cities, together with a persistent inability to " urbanize " the existing technologies, what leads to a generalized adoption and use of several energy efficiency tools but without existing an integrated system capable of gathering building data using sensors and IoT and optimizing building performance and behavior using BIM-based interfaces and interoperable intelligent instruments. The 3i Buildings system proposed will face this challenge and will be able to display real-time data gathered from sensors installed in the facility, as well as to deliver an optimize building's performance and behavior using advanced optimization algorithms and intelligent "objects" installed in the facility. To test our solution three different facilities were considered, Luz's Hospital, Norte Shopping and Lisbon Aquarium.

2. Literature Review

As it can be seen by the amount of research projects and scientific papers that have appeared in the last few years, buildings intelligence will certainly play a major role on the construction industry innovation paradigm [8]. Smart buildings are becoming a trend of next-generation's buildings, which will facilitate intelligent control of the building to fulfill occupants' needs [9]. Build reactive, interactive and immersive buildings is one of the inevitable visions for intelligent building systems, which should improve buildings' performance and optimize their functionality.

The first step of these intelligent systems has already started. In fact, a diversity of tools and models has been developed to endow buildings with adaptive and sensorial capacity. In literature several innovative works can be identified within this field, such as the work of Clark and Mehta [10], who developed a management system supported by artificial intelligence, capable of an optimized management of HVAC systems or the work of Guillemin and Morel [11], who developed an interior illumination control system (natural and artificial) with the capacity of adapting to the space in which is deployed, by detecting the presence of persons and considering the internal and external conditions of luminosity. Similarly, Fong et al. [12] used evolutionary programing to manage smart buildings and Guinard et al. [13] worked in the optimization of a network of wireless sensors to support

buildings information gathering. A growing number of studies discuss, in particular, alternative approaches that can deliver healthier and more comfortable thermal conditions to occupants with acceptable energy consumption. For example, recognizing that the thermal environment in an office or building is not always optimal from an energy saving and occupant satisfaction perspective, as air-conditioning systems are controlled without taking the occupants' needs into account, Murakami et al. [14] proposed a system to control air-conditioning systems via occupants' requests. Luo et al. [15] designed a longitudinal field study in a mixed-mode building where mechanical air conditioning and natural passive cooling coexist in the same case building, i.e. building where both air conditioning and natural ventilation modes are utilized. This study was designed to measure the extent to which occupants' thermal perception can be influenced by space conditioning strategy in mixed-mode buildings, and to determine the optimal approach for assessing occupants' thermal perception in such buildings. Xu et al. [16] present a systematic statistical method to determine the set of building design factors to minimize the building heating and cooling loads and energy consumption using the fractional factorial design method. Rocha et al. [17] point out that although building managers are encouraged to adapt their energy operations to real-time whether conditions, most fail to do so as they rely on conventional building energy management systems that have static temperature set points for heating and cooling equipment. With regard to occupancy in buildings, Feng et al. [19] grounded on a comprehensive review and comparison of literature on occupancy modelling to identify four types of occupancy models, which are categorized according to the problems they try to address: (1) building level and number of occupants, (2) space level and occupied status, (3) space level and number of occupants, and (4) occupant level. Gul and Patidar [20] analyze the relationship between the electrical energy demand profiles and user activities for a university building. One of the findings was that the detailed information on the occupancy patterns could help the management team to redesign control strategies for optimum energy performance of the building.

Although recognizing the significance of the above-mentioned works, and others not referred here, it was possible to conclude that a technological platform capable of integrating, in real time, different types of data regarding factors such as structural conditions of the building, occupancy, comfort of occupants, energy consumption and CO_2, COV's and humidity levels, and capable of learning over time, is still missing. Therefore, this study intends to develop an optimized algorithm capable of allowing the system to learn, predict and react to different conditions inside a building, while simultaneously optimize the comfort of occupants, energy consumption and occupancy. A particularly relevant contribution of the presented research project has to do with the real-time data visualization. A BIM viewer will be implemented to improve information integration and provide a consistent decision support system for intelligent buildings. Nowadays 3D BIM viewers are appearing and becoming more and more used. Besides reflecting the data generated throughout the buildings life cycle [21], BIM is used as a graphical interface and information repository associated with facilities management systems, presenting data about energy consumptions and other variables related with the state of the facility [22, 23] and continuous research is being made to improve the existing solutions [1, 2, 21]. However, BIM viewers face innumerous challenges. For instance, when handling complex models, navigation may turn too slow to be considered real-time data visualization and in some cases real time representation viewers hide objects or incorrectly present them in order to allow real time visualization [2]. Also, viewers' interoperability is a major reason of concern. In order to handle such amount of building information, including data from various types of sensors and imported from different software, we need a solid and neutral file format for data exchange. IFC (Industry Foundation Class) is the BIM open and neutral format to enable an efficient exchange of construction projects information [24], being able to collect information from the entire project life cycle but it has some limitations. IFC handles building information using predefined classes, which are not sufficient to include all types of building information, so additional "Property Sets" must be created.

So, the research project presented will work to combine the benefits of an interoperable BIM viewer, which allows displaying all the information of the building and, at the same time, to monitor the state of the building in real time, with a well-structured sensor system connected to an optimization module capable of increasing buildings' intelligence and interactivity.

3. Methodology

For this research project three major use cases were defined, considering complementary visions. In the first case, the Luz's Hospital, the main objective was to improve energy efficiency and occupants' comfort. To achieve these objectives, the 3iBuildings system will detect visitors' mobility and measure humidity, temperature and users satisfaction, optimizing the HVAC configuration (taking into account historical data). The system will be able to predict changes earlier than the current systems, which will allow improving comfort and efficiency. Also, the system will be able suggest alternative rooms when the primary one achieves the maximum level of occupation (considering the most effective environmental configuration).

The second use case focused the Lisbon Aquarium and had the major objective of identifying visitors' mobility and managing spaces occupancy by interacting with them. In this sense, intelligent objects and IoT will be used to communicate with visitors and obtain their feedback.

The third use case focused a shopping mall (Norte Shopping) and its objective was to map visitors' mobility and, based on this information, provide them an interactive experience. The system will be able to analyze which spaces visitants more commonly use, which can be useful for commercial but also for security reasons. The system will be able to help visitors during emergencies, for instance by indicating the best emergency route for each visitor. 3D interfaces will be developed for all the use cases, which will help facility managers to visualize and monitor real-time data and support decision-making.

4. Developments

4.1. Optimization model

As stated previously, to support our research, the system will be installed in three different environments, Luz's hospital, Lisbon Aquarium and Norte Shopping. In the first case, the objective is to optimize the thermal comfort of occupants and the energy consumption (dependent variables), considering as independent variables the set point temperature, the occupancy rate, the CO_2, COV's and Humidity levels. In the second case, the dependent variables to be optimized are occupancy rate and energy efficiency, considering as independent variables the set point temperature, the outdoor temperature, the visitor location, and the CO_2, COV's and Humidity levels. The parameters area and volume are also included in the optimization algorithm, for both first and second case. In the Norte Shopping case, objectives are to monitor people flows, and help the response in case of crisis according to the adopted emergency plan.

Considering that for these three cases we have completely different objectives, an optimization algorithm per each case will be developed, which make this research even more challenging. In order to support the development of the optimization algorithm, a theoretical model per each case was developed. For example, Figure 1 illustrates the model for optimizing the thermal comfort of occupants and the energy consumption for the Luz's Hospital case study (Fig. 1). This algorithm considers whether the system is in learning or in operation, whether we include the comfort' opinions of occupants or not, and we want to optimize the energy consumption or not. In this way, the manager responsible for managing and controlling the system will have different options, regarding the functioning of the system. This system will collect occupants' opinions on the level of comfort, will triangulate this information with the current occupancy rate, the set point temperature, the CO_2, COV's and Humidity levels and automatically take decision whether it is necessary to act on the set point temperature or not. The set point temperature is determined based on the balance between occupants' thermal comfort and energy consumption.
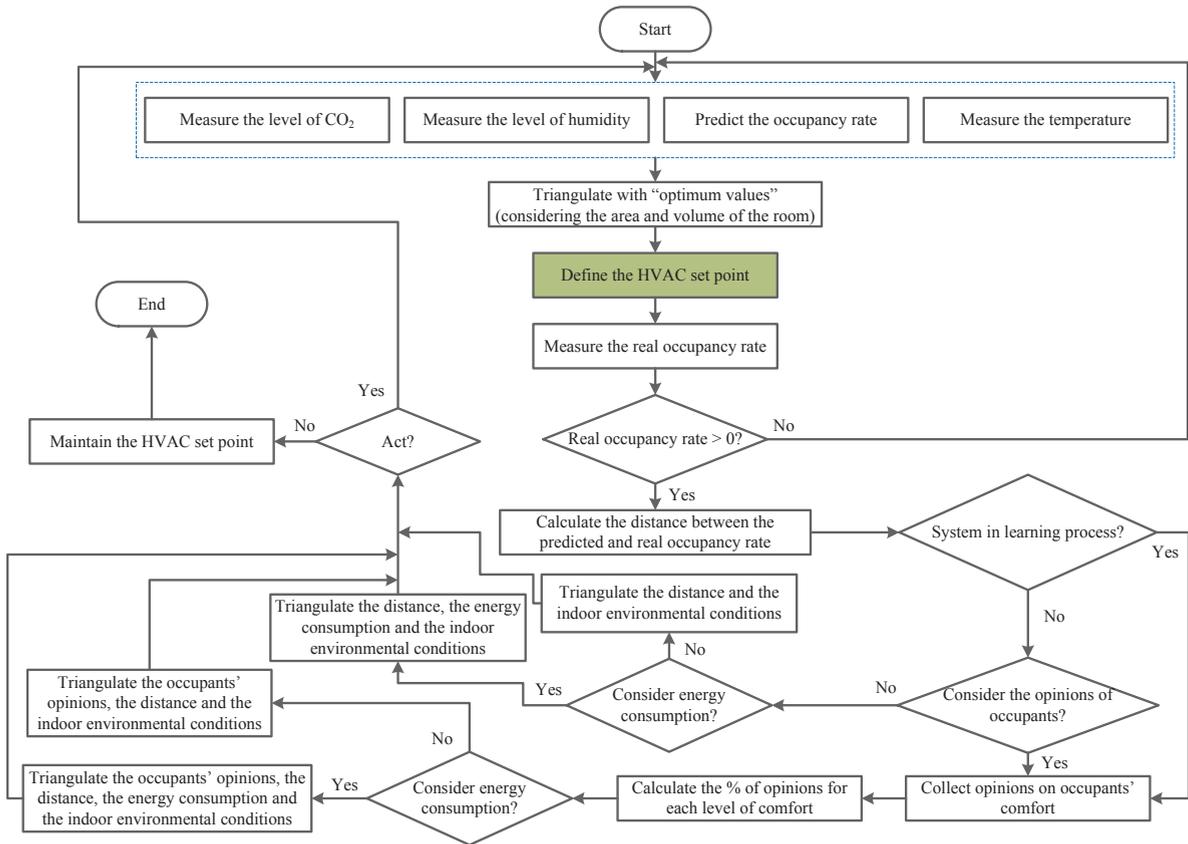
Figure 1: Optimization algorithm: Luz's hospital

4.2. BIM Interface

The 3iBuilding's interface will be created combining BIM technology with the Unity3D game engine. Unity is a game development tool, used to create 2D and 3D contents providing a rendering engine integrated with tools to allow simple and intuitive development of games. As this system is multiplatform it will allow the deployment for both desktop and mobile devices, thus enabling 3IBuildings to be deployed and executed in Android IOS, Mac OS X, Windows and web.

The interface of 3iBuildings will be divided into three different parts, presentation, management and communication layers. The presentation layer is the one with which the users interact and visualize the 3D representation of the BIM model. To do this, this layer imports the IFC model and converts it to a format that is recognized by Unity3D (Fig. 2), in this case the FBX format [21]. This layer will allow users to navigate through the facility and interact with each represented object, i.e. walls, doors, HVAC system, etc., providing all BIM information about the selected object. The layer will also provide a functionality to see the status of each room (Fig. 3), it's occupation, CO2 levels, temperature, size of the room, etc., providing to buildings managers a real-time data graphical display able to help in the decision making process. The Management layer will be used to manage and store the internal representation of the data received from the BIM model. This layer will be closely related with the communication layer, to the extent that latter connects with the data servers, where the data gathered from facilities sensors are stored and organized. To provide fully support to BIM models, 3IBuildings system is connected to a

BIM server where BIM models are stored (in this case the IFC model of the facility). This server stores and manages all facilities' properties and information and communicates with the presentation layer whenever is needed.

Figure 2: Snapshot of the 3IBuilding's interface (Lisbon Aquarium)

Figure 3: Snapshot of the 3IBuilding's interface (Luz's Hospital)

4.3. 3i Building Technology Architecture

For this research project an interoperable architecture was developed that enables to collect data from the several case studies. For that purpose it was necessary to set an IT infrastructure capable of aligning the specific needs of each case study and neutralize the effects of latency Wide Area Network (WAN), providing an enjoyable and usable environment for users, who can access to the management system through cloud computing (Fig. 4). Given the geographic dispersion of the study areas and location of the research teams, the IT infrastructure had the central location at the laboratory of Siemens headquarters, in Portugal. The laboratory is equipped with servers and router to communicate with the equipment installed at each case study.

The 3i Buildings solution protocol can be regarded as an additional layer over TCP, adding (i) a security model; (ii) a layout name and address to support multiple services on a same port and multiple name servers within the same IP address; (iii) a framework mechanism; and (iv) a new request for closure. The goal is to make the solution closest possible to the standard TCP, but taking into account present requirements of web. Supported by the HTML this technology enabled the creation of a bidirectional communication channel, persistent, real-time, on a single socket. To prevent security problems, a set of best practices were implemented such as the encryption through the Transport Layer Security (TLS) protocol. The way to protect a web application against Cross Site Scripting (XSS) attacks was to ensure that the application validates all the data received as input, including headers, form fields, cookies, query words and hidden fields.

The comparative performance test between the 3i Buildings server and prototype has shown that the protocol used enables a more efficient bandwidth use and a smaller number of messaging for the same amount of information. The protocol has been developed for especial use in Web browsers and servers, and to support Web applications that require real-time communications.
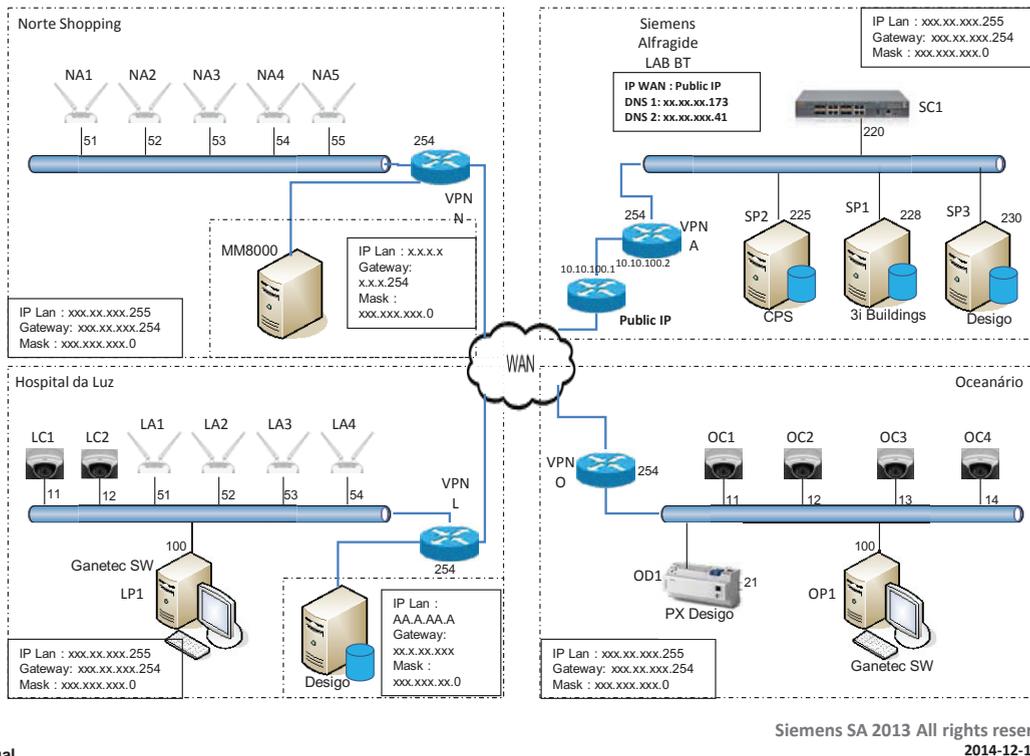
Figure 4: 3i Buildings IT Architecture

5. Conclusions

The 3iBuldings promotes the link between the content generated by people and by "things", creating an integrated intelligent network of building services able to adapt the building and interact with their users.

The system has been implemented in three different case studies and the results are now being collected, such as temperatures, occupation, user satisfaction, CO_2 and Humidity levels as well as people flows between closed spaces. At same time the optimization algorithms are being developed and improved, based on the collected data.

Globally the results obtained until now are very positive and aligned with the initial expectations. The 3D environment is seen as a value added tool for managers and the intelligent system is capable of improving energy efficiency and users satisfaction.

Acknowledgements

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