

Sensor Placement for BPM Analysis of Buildings in Use to Implement Energy Savings Through Building Performance Simulation

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Abstract

The article presents the process of placing sensors in a multi-sensorial network, dynamically incorporating a large number of heterogeneous input sources able to provide accurate monitoring data related with space occupancy, energy consumption, comfort levels and environmental quality. To evaluate this multi-sensorial network on real life conditions and on the specific business domains addressed by the Project, this sensing network will be based on heterogeneous sensors (light, motion, CO₂, CO, temperature, relative humidity, existing infrastructure on video-surveillance, depth/range image generators, energy consumption, etc.) in order to provide an all-inclusive perspective of covered spaces. The article is part of a global project to develop privacy-preserving human detection and tracking toolkit, with the implementation of algorithms for calibration of multiple-depth sensors in the architectural sketch up of a building (BIM), and the development of techniques for extraction of occupancy-related statistics in the spatio-temporal domain of a building. It is an architectural prototype agile and scalable, integrated with the extended LS middleware, que permite the training and calibration as decision making toolkit for Facility Managers.

Keywords: Sensors, BPM, Building, Energy Efficiency, Simulation

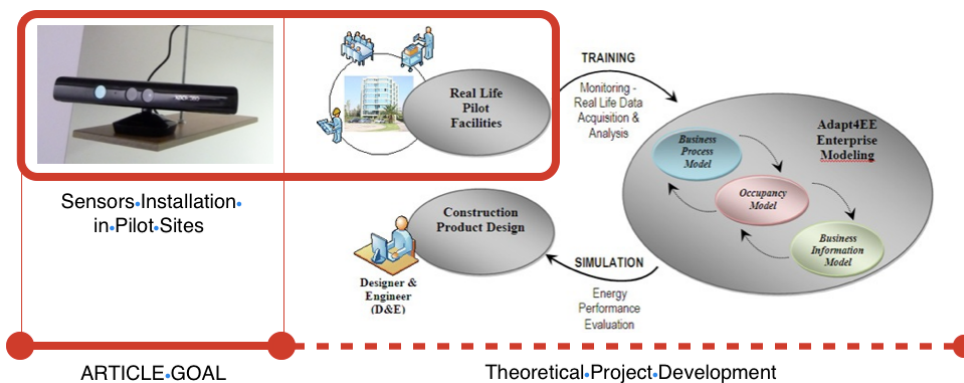


Fig. 1. Graphical Abstract

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1. Introduction

1.1 Trends in Building Performance Simulation

Building Performance Simulation BPS software (OpenStudio, Energy Plus, etc.) is being used more and more frequently [1], not only to achieve the energy saving goals required by the different governments in the EU or acquire a certain level of certification but also to size HVAC equipment and to predict electric consumption of the building. However, simulated results sometimes deviate significantly from measured data, having a great impact in the monthly bills. [2] [3] [4]

In the current available building performance simulation programs the presence of occupants and their influence on a building are (at best) based on predefined activity/presence schedules [5]. These schedules however, are often assumption rather than based on measured observations and result in descriptive and predicting models. Schedules and diversity factors from ASHRAE, which are the most commonly used, are generated using large-scale building survey data and observations, but they often differ from reality. [6] [7] [8]

The most recent works are oriented to the fusion of two disjoint worlds of Building Information Modelling (BIM) and Business Process Modelling (BPM) by delivering vocabularies and ontologies that associate the relationships among these domains [9], including key performance indicators (KPIs) and skeleton activities [10] [11]. KPI model combines energy performance attributes with business performance and occupant comfort attributes. Skeleton activity specification enables to describe necessary characteristics of business activity such as resources needed, involved roles and relations too the activities for the construction of business process map. [12] [13] [14]

1.2 Scope of Adapt4ee Project

The activities described in this article are encompassed in the Adapt4EE project (funded by the EU 7th frame program) which aims to address several shortcomings of existing and rather complex building tools such as the lack of a holistic and systems-based view of buildings, the efficient separation of algorithms and simulation that will stimulate key players (D&E community) to easily assess the energy use on specific attributed domains.

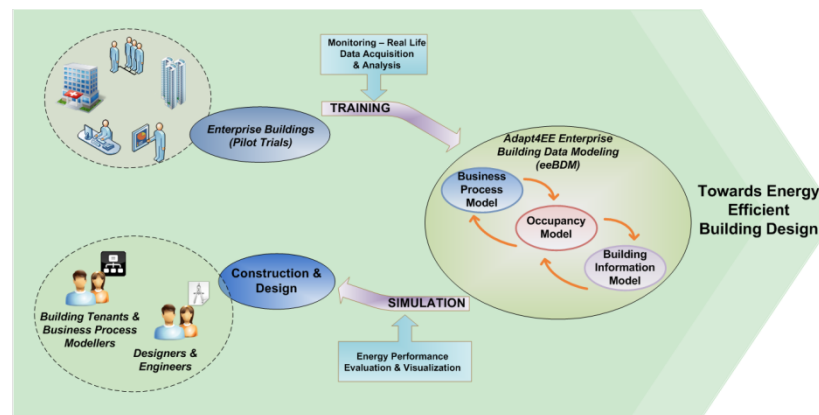


Fig. 2: Adapt4EE Project Concept Overview

The main purpose of the project is to develop a building simulation framework focusing on the early design phases of a construction product, which will be able to provide the key stakeholders with the necessary simulation results that fully take into account both the descriptive data of a building (material, components, equipment, space layout, etc.) and the information related to the dynamic behaviour of the building due to its occupancy fully taking into account the organization that is going to be “housed” within the building. [15] [16] [17]

The incorporation of information about the dynamic behaviour of a building (e.g. organization that will be “housed” in the building) at the early design stages of a building will further improve the ability of designers, engineers and respective stakeholders (business modellers and/or building owners and facilities managers) to analyse the optimisation of its energy consumption based on multi-criteria constraints [18]. Moreover, design decisions on energy performance optimization should be based on sound and realistic estimations of the actual future energy consumption of constructions during operation, taking also into account potential consequences on business operations affected by early design decisions and vice versa, reconciling the differences between the energy performance of “real” and “simulated” construction products. [19]

1.3 Pilot Sites

The project is developed in two pilot sites: the Clinic University of Navarra (CUN) in Spain and the Coimbra Stadium in Portugal. In both cases involve complex mixed-use buildings.

This article focuses on the methodology used to implement sensors in CUN by its special architectural implications: it constitutes a commercial building with multifaceted areas consisting of subareas with well defined everyday business operations highly correlated to specific “business” services, respective business episodes and occupancy patterns. It also belongs to commercial domains of great importance and difficulty for the D&E (Design & Engineering) Industry. [20]

It is important to remember that in a hospital building like this, to safeguard the privacy of the patients and staff involved has been the key point for the development of other issues as we will see.

2. Methodology

2.1. General Approach

The steps followed during the project to finalize the installation of the sensors were these:

1. Definition of the evaluation scope and goals.
2. Identification of the evaluation criteria to be used in the Pilots.
3. Definition of the performance indicators to be considered.
4. Definition of evaluation scenarios and end-user preparation.
5. Definition of the Pilots execution strategy and work plan.
6. Design, survey and analysis of the two pilots (Coimbra Stadium, CUN).

In order to minimize the risks posed by unexpected problems with the Pilots installation (for instance unexpected problems with a specific sensor model, problems in achieving optimal positioning for location-sensitive sensors, problems with the data provided by specific types of sensors) three phases were defined:

- Phase 0 consisted of integrating and testing a very small but representative set of sensors, in controlled environments, in order to refine the integration of the sensors platform and provide early testing data to software integration activities. These testbeds are outside the scope of this report. (Figure 3)
- Phase 1 (also designated as pre-pilot, in some other documentation), for field installation of sensors in a reasonably manageable but already representative part of the areas of each of the two pilots. One of the goals of Phase 1 is to trigger as early as possible the installation of support services such as local area network, VPN (Virtual Private Network) server for secure remote access to the Pilot and the NTP (Network Time Protocol) server for clock synchronization. The other goal is to test the installation, configuration, calibration and integration of the various types of sensors.

- Phase 2, focused mainly on enlarging the coverage provided by each of the two Pilots, with the addition of more sensors on new areas, in order to extend its dimension and its representativeness of attractive use cases.

The main criteria for selecting the areas of Phase 1 and Phase 2, for each of the two Pilots, related with this notion of progressive installation, manageability of the process and, of course, the ability to address a relevant amount of interesting use cases for evaluation of the project framework.

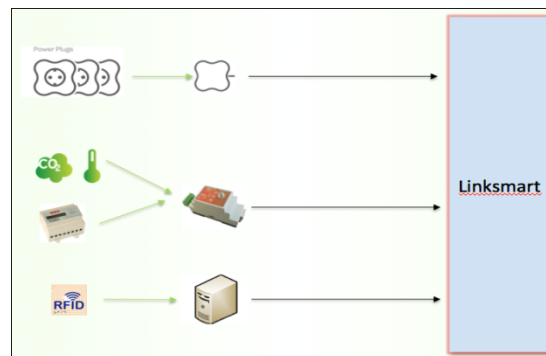


Fig. 3: All the Sensors Installed at Pilot Have Been Made Accessible to the Adapt4EE Platform, and Their Measurements are Being Regularly Collected and Analysed by the Platform Middleware

2.2 Sensors Integration

Sensors are fully integrated with the Pilot models defined, with complete association between sensor IDs and the locations, occupants, appliances and business processes previously modelled by the platform. Most of these associations are already reasonably stable, allowing for the kick-off of more ambitious processing and correlation of the collected data. Other sensors are being experimented in various roles and locations in order to better understand the Pilots dynamics. Pluggable energy meters are the most notable case of such experiments, which were already expected and necessary for the on-going research process. [21]

2.3 Occupancy Tracking

The occupancy tracking is the support of multiple instances and occupant merging from different viewpoints (in the overlapping areas of camera viewpoints), and of course for the final occupancy statistics, which can be summarized as follows:

- Based on the occupancy profiles, which becomes support for the visualization of occupancy flows (Facility Management Use Case)
- Extraction of statistics for building zones, individual spaces and occupants, including both real-time and off-line processing. Transition matrices among spaces as well as distance traveled are also calculated
- Several occupancy-related events (space occupancy, occupants positions, trajectories and event-based messages, such as occupant moves from one space to an other) are propagated to the LS middleware

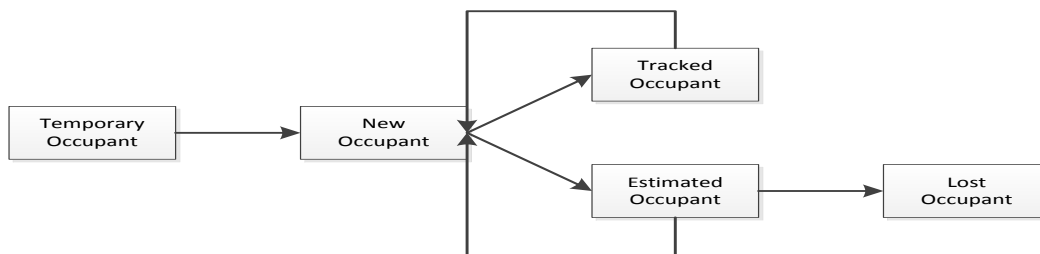


Fig. 4: Tracking Supports Mainly New, Tracked, Estimated and Temporary Occupants in the Spatio-Temporal Domain

2.4. Description of Sensors and Cameras

For the need of the pilot realization and assessment, a set of different sensors have been installed at various places, to allow their effective monitoring for the research purposes of the project in terms of:

- **Consumption Measurements:** Smart plugs and single/three-phase energy meters with wired/wireless connectivity will be installed, to acquire real-time measurements of electrical consumption of appliances, along with HVAC installations.
- **Occupancy Monitoring:** An important factor in the realization of the pilot will be the monitoring of the occupancy per space. For example, depth image sensors (such as Kinect cameras) will be used in order to extract the exact number of people within selected areas. Finally, in order to track the actual positioning of certain individuals, RFID wall mounted receivers will be installed and RFID cards will be carried by individuals willing to participate in the tests. [22]
- **Environmental Metering:** Sensors will be used to estimate the internal temperature of each monitored space as well as its humidity.

All sensors utilized during the pilot will not acquire any sensitive personal data nor violate personnel's privacy, following ethics deontology. Furthermore, all areas that will be monitored with any type of sensors and equipment are appropriately marked with Notification Posters, describing in detail equipment used and monitoring procedures taking place towards project's objectives.

2.4.1. Sensors

Different sensors, monitoring and control equipment to be installed and used is explained in tables 1 and 2.





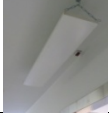

Image sensor	Description	Purpose of use in the project	Requirements
	iMeterRail. Electricity meter for electric switch boards.	The sensor monitors the consumption of an electrical circuit to deduct the level and kind of activity in each moment.	
	Power Plug. Measurement of electrical consumption and control of electric devices.	The sensor monitors the consumption of an electrical device.	Just insert the sensor into a 230 V socket. The devices to be monitored should be connected to sensor. This sensor measures power consumption from a device connected to it. Max current: 16 A.
	Clamp. Measurement of electrical consumption (current) of circuits.	The sensor monitors the consumption of a building's section to deduct the level and kind of activity in each moment.	This sensor measures current consumption of an electric circuit. Simply install the clamp across a wire of the circuit we want to measure and connect it to the transmitter. Max current: 50 A.
	Air monitor. Indoor Air quality modules with 4 different sensors: temperature, relative humidity, CO2 and CO.	The sensor monitors air quality of a space to deduct the people density in that space.	Needs a 230 V power supply. It can be placed on a table, on a wall, over a cabinet, on a shelf.
	RFID Receiver. Equipment to track RFID cards passing by.	Track Individual occupants carrying RFID cards.	
	RFID Cards. Radio Frequency Cards to be tracked by RFID Receivers.	To be carried by Individual Occupants participating in Individual-Based scenarios.	

Table 1: Major Monitoring and Control Equipment




Image sensor	Description	Purpose of use in the project	Requirements
	Gateway. Receives data from RF 868 MHz and RS485 devices and send over a TCP/IP connection.	The device acquires the data from several devices.	
	Gateway: receives data from ZigBee sensors and sends over a TCP/IP connection.	The device acquires the data from several devices	This device collects data from the sensor and sends it to database through a secure internet connection. Needs a 230 V power supply and a cabled (RJ45) internet connection.
	RF ID Reader. This module will be used to detect the proximity of a RFID tag.	The reader is used to track the position of a person or equipment inside the pilot's buildings.	

Table 2: Environmental Monitoring & Other Sensors (Actuators/Controllers) Auxiliary Equipment

2.4.2. Cameras

In this project, the use of cameras becomes essential. The final selection is the Microsoft Kinect Sensor, which uses an IR emitter to provide 3D information of the viewed scene, and collects depth-images to extract number of occupants within a space (the actual RGB color images will neither be processed nor stored). These cameras have a multi-utilization conception:

- Calibrated cameras and building (through BIM) have the same coordinate system.
- Cameras are not necessarily needed to have a common/overlapping area.
- Enabling occupancy detection and tracking across multiple-spaces.

The cameras are capable to make an adaptive dual-band background estimation, utilizing depth data to cope with dynamic changes that occur in building scenes (e.g. change the position of an object), and they enable quickly retention of low-height objects to the background, whilst occupants are very slowly incorporated.

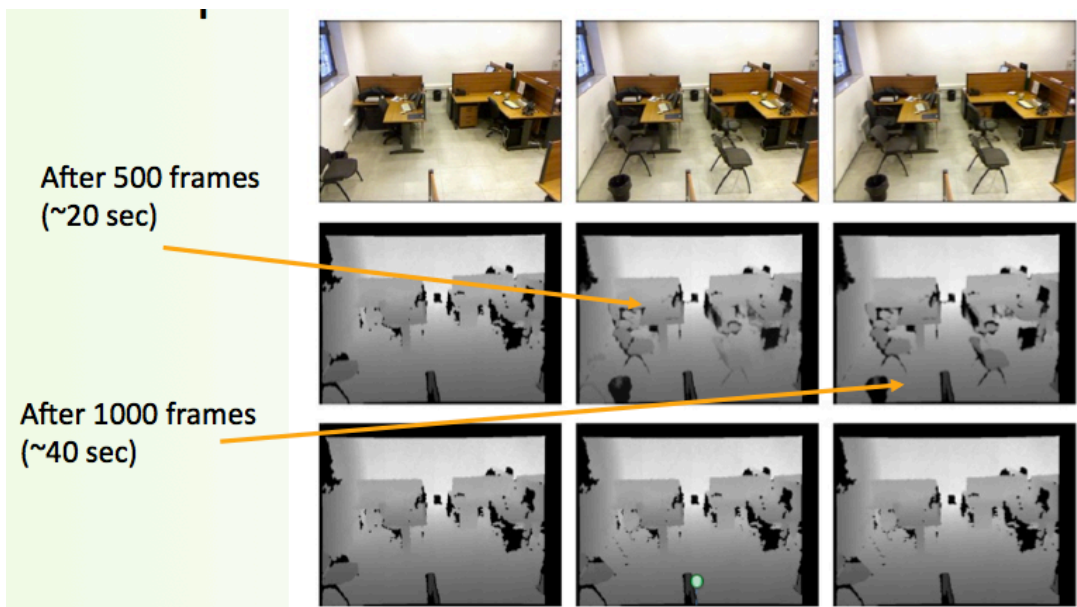


Fig. 5: Example of Incorporating of Low-Height Moving Objects to the Background Using the Dual-Band Background Estimation Algorithm

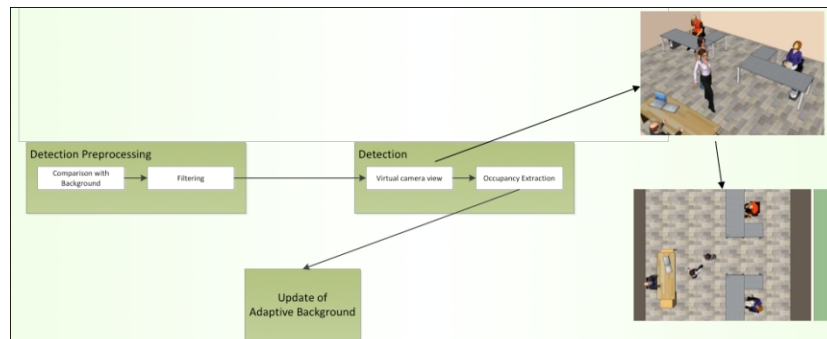


Fig. 6: Internal Conceptual View of the Occupancy Detection Module

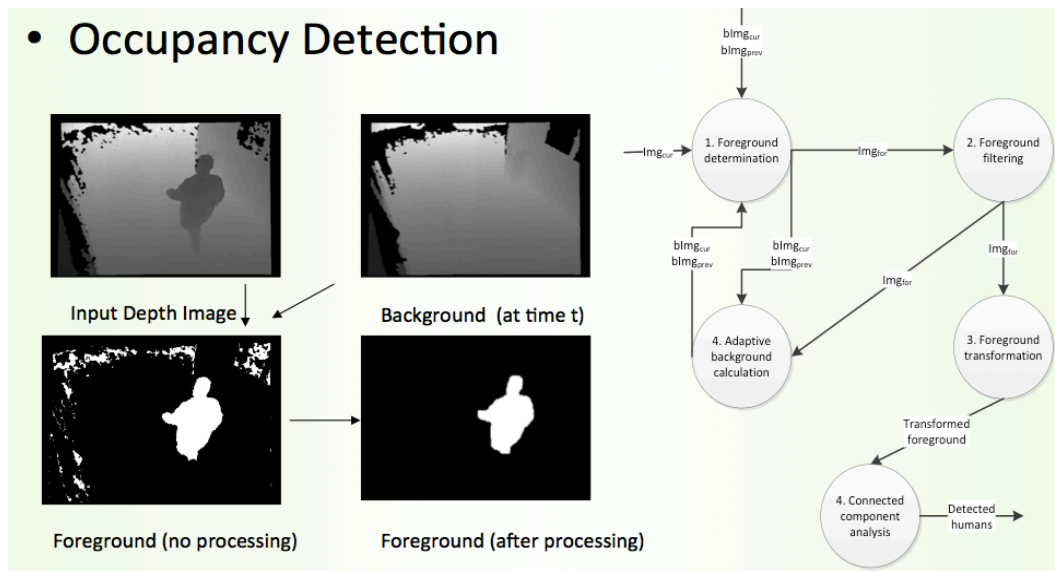


Fig. 7. Occupancy Detection Scheme with an Example of Morphological Filtering Used to Remove Noisy Pixels

3. Sensors Installation in CUN Pilot Site

This section provides a description of the installation activities that already took place at one of the pilot sites, the Clínica Universidad de Navarra (CUN). The other Adapt4EE Pilot area (located in Coimbra, Portugal) has the same procedures installation and this is why is not considered its description here.

3.1. Areas Selected

Areas selected for Phase 1 of the project correspond to a subset of the Pilot areas on the 8th Floor around the Medical Oncology Department and the MIR (*Médicos Internos Residentes*) meeting rooms, which have been modelled in high detail. Phase 2 of the Pilot covers selected subsets of the remaining areas of the 8th floor. (Figure 8)

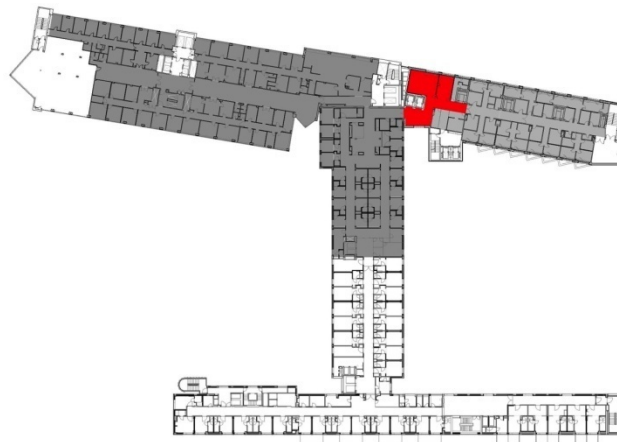


Fig. 8: Pilot Areas on the 8th Floor (Marked Grey, Phase 1 Highlighted Red)

3.2. Modeling Activities

The freeware software OpenStudio was used to model the energy performance of the Pilot areas, to support the tasks of measurement and sensor calibration and to support the configuration of Adapt4EE software. Figure 9 presents the gbXML view of the CUN Pilot area (Phase 1). [23] [24]

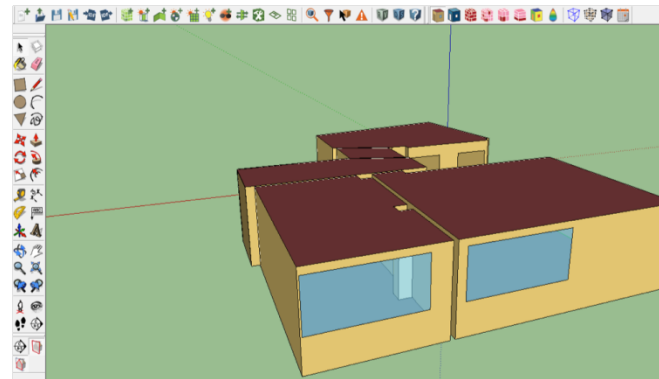


Fig. 9: gbXML view of the (CUN, Phase 1)

The process of collecting information and creating models of the Pilot Site (a common energy simulation model and a model supporting the Adapt4EE Building Measurement Framework) is described in Figure 10.

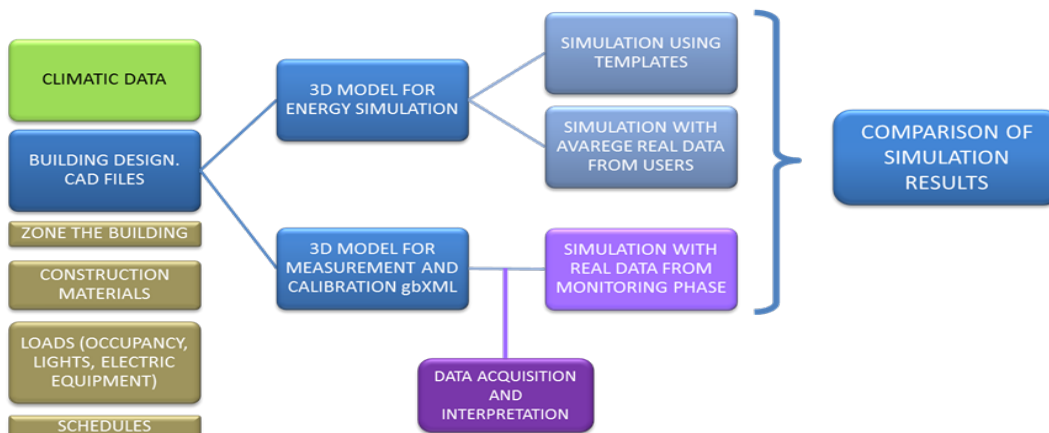


Fig. 10. OpenStudio Workflow

3.3. Physical Deployment

Physical deployment of the Pilot at CUN was performed according to the following items: the local communications network; the depth image-based occupancy sensors; the RFID-based occupancy sensors, energy consumption submeters and environmental sensors. Next we discuss each of these components.

3.3.1. Local Communications Network

The local communications network built at CUN partially shares the physical infrastructure of the already existing Hospital LAN and it is based on switched fast Ethernet technology (100-Base-TX, with fiber optics backbones), with a dedicated VLAN (Virtual LAN) defined for the Pilot, for security and privacy reasons.

A local server provides multiple functionalities: NAT router/Firewall, DHCP, DNS, NTP and VPN server for remote access to the testbed. This network interconnects the various devices requiring local network connectivity. Configuration of the network and installation of additional cabling were performed by the researchers and CUN staff.

3.3.2. Depth Image-based Occupancy Sensors

A total of 12 depth-image sensors were installed during Phase 1, served by 11 client units and one aggregator. Figures 11 and 12 present those locations and the adopted mount solution.

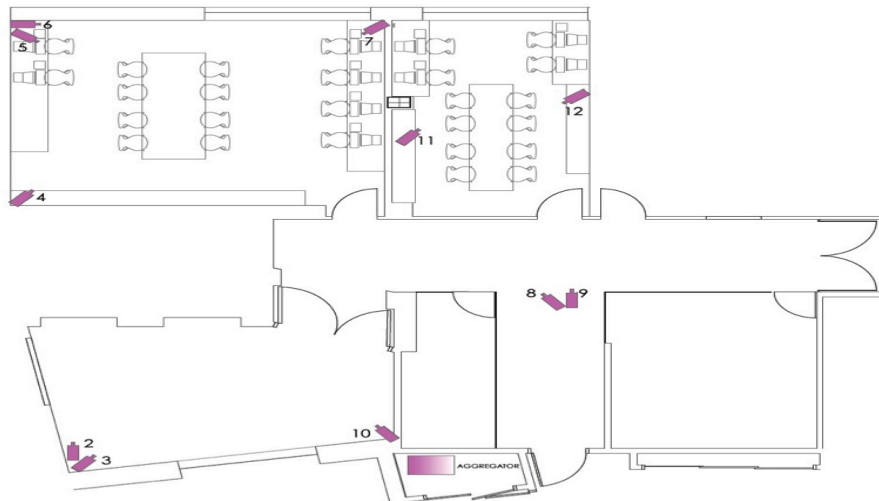


Fig. 11: Installed Occupancy Sensors (CUN, Phase 1)



Fig. 12: Mount Solution (CUN, Phase 1)

The mounting solution reduces permanent damage to the plasterboard ceilings and improve aesthetics (taking into account the different nature of CUN occupants). The next figures illustrate the devised solution. Client units are hidden in the dropped ceiling. In those figures it is also visible the information panels that are associated with the sensors, to inform the space occupants about the project. Installed sensors have been collecting occupancy data for some time, with no major issues detected.



Fig. 13: Depth Image-based Sensors (CUN, Phase 1)



Fig. 14: Depth Image-based Sensors (CUN, Phase 1)

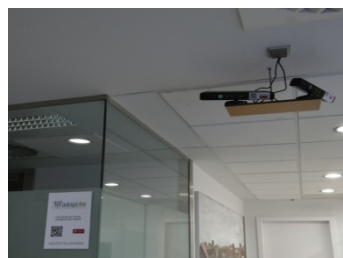


Fig. 15: Depth Image-based Sensors (CUN, Phase 1)

Calibration of the cameras was performed using a reference visual target with well-known patterns and dimensions. By using this target, together with the previously performed modelling of the physical spaces, it becomes possible to calibrate the cameras so that detected occupants are located with high precision within the space (with the side benefit of detecting when the same occupant is simultaneously detected by two sensors covering overlapping spaces). Figure 16 illustrates the calibration process. Finally, Figure 17 shows how occupants are located by the aggregator.



Fig. 16: Calibration Process for Depth Image-based Sensors

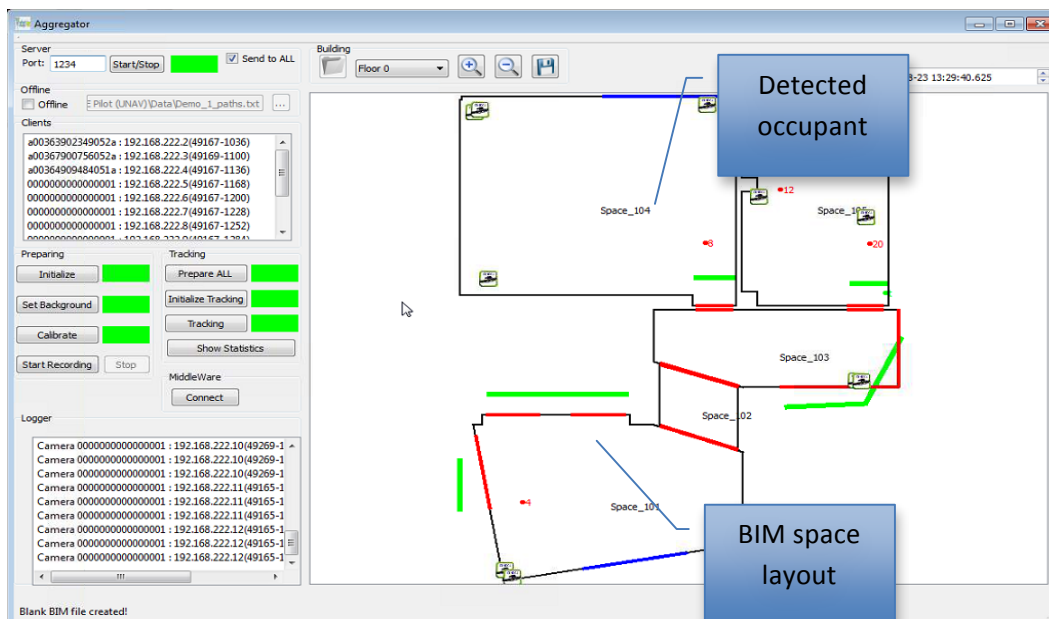


Fig. 17: Occupants Detected by the Depth Image Aggregator

3.3.3. RFID-based Occupancy Sensors

The RFID-based occupancy sensors for the Phase 1 of CUN are planned to cover the two MIR Meeting Rooms and the corridors close to those rooms. (Fig. 18)

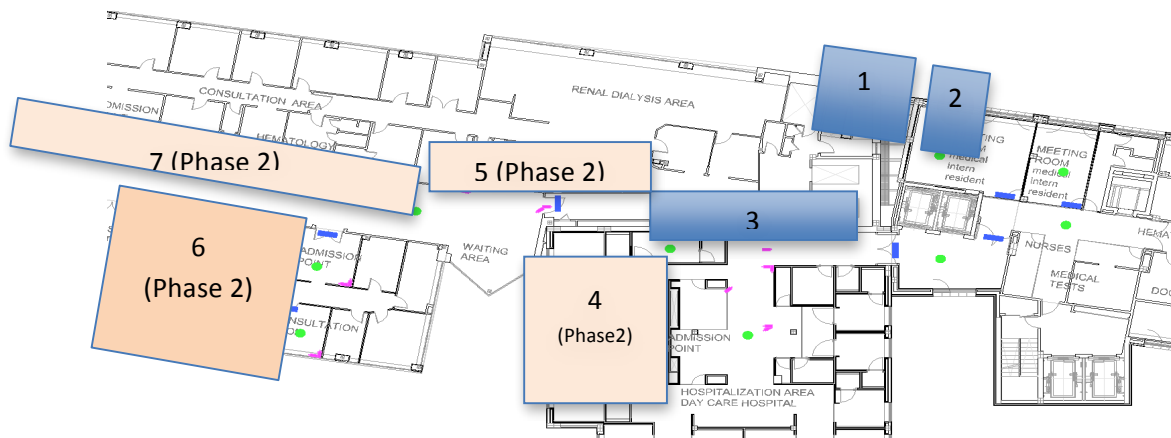


Fig.18: RFID Zones under Installation (CUN, Phase 1 and Phase 2)

3.3.4. Switchboard (rail-mount) Energy Meters

Several energy meters were installed in the switchboards of CUN, in order to provide the previously planned zone-based submetering. Covered areas in the Phase 1 correspond to zones 1-2 of Figure 19.

The detailed definition of the consumption data to collect for each zone provide splitting measurements for lighting, HVAC and wall sockets.

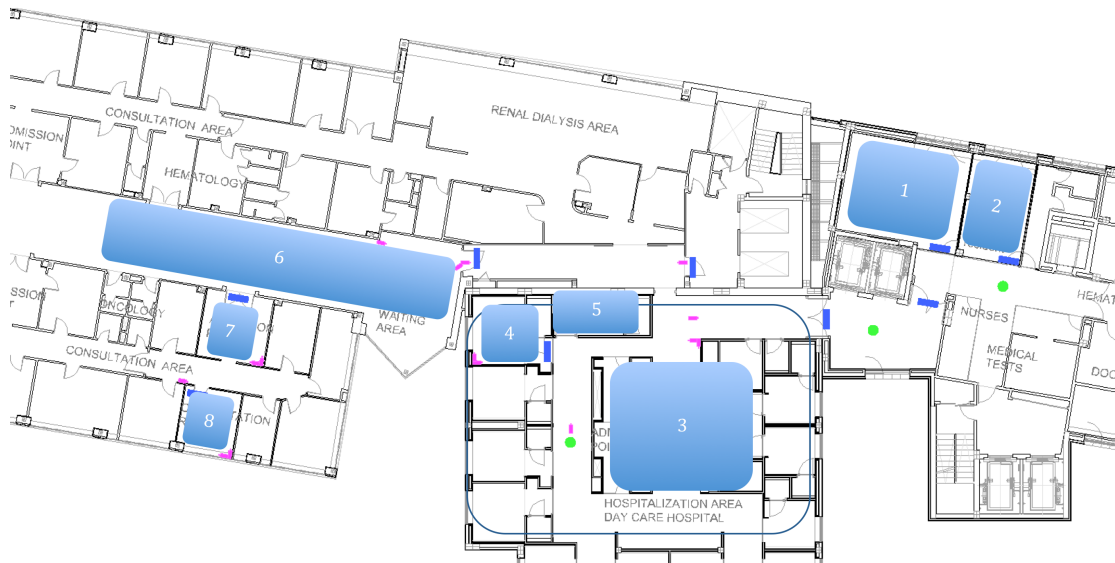


Fig.19: Zones for Meters and Environmental Sensors

3.3.5. Other Sensors

A number of power outlet meters were added to the Pilot, to complement the consumption data provided by switchboard meters with measurements for individual appliances or small groups of appliances served by the same outlet. Around 10 power outlets are currently being used for testing and experimenting with the various appliances installed in the Pilot.

Environmental sensors use the same reference zones as the energy meters. For each of the defined zones, 4 measurements are collected: temperature, humidity, CO2 and luminance.

4. Results and Discussion

El principal problema para ejecutar una instalación de este tipo, con tal variedad de sensores, recogiendo una cantidad ingente de información, es garantizar la privacidad de los usuarios del edificio, y más en un entorno como el hospitalario.

The main problem to run an installation like this, with such a variety of sensors and collecting a wealth of information, is to ensure the privacy of the users of the building in an environment like the hospital.

Regarding the acquisition and storage of human related information, project has followed the appropriate ethics guidelines. These guidelines aim at preserving the privacy of the user, protecting his/her private data and limiting the risk of interception to the minimum. The integrity of the information is important for the project, and thus the following requirements have been fulfilled:

1. The investigator/system operator of the pilot tests have informed the participants with clarity about the procedure of the pilot tests, the system operation and the objectives of the data retrieval and storage.
2. No sensitive personal data are collected. In no case more personal data will be collected than the necessary ones, according to the requirements of the Spanish laws. [25]
3. A data minimization policy have been adopted at all levels of the project and have been supervised by the ethical/privacy component of the project. This will ensure that no data which are not strictly necessary to the completion of the current study have been collected.
4. No data have been collected without the explicit consent of the individuals under observation.
5. No data collected have been sold or used for any purposes other than those of the current project.
6. Participants have the right to access their personal data filled in the questionnaires as well as to their extracted profiling parameters.
7. Participants are able to quit the experiment at any point, if they wish, without any consequences. He/she can exercise his/her right to access, correct and delete his/her data at any moment.
8. The research to be conducted will be in full compliance with the principles and guidelines of “Ethics for Researchers” to Facilitate Research Excellence in FP7, prepared by the EC Governance and Ethics Unit in 2007.

Eventhough a comprehensive analysis and description of the device managers for the specific sensors utilized within the project has been made before, there is a very high level analysis of the energy profiles of the devices (lighting, equipment, HVAC) that are involved in the measurement and – later on – simulation phase of the project. Actually, there has been made a high level analysis and description of the methodology that will be followed for the definition of the energy profiles of devices. [26]

In a material way, all wiring required by the sensors could be easily installed thanks to the existence of a ceiling that houses the rest of the hospital facilities. It must not be forgotten that, for reasons of hygiene, the placement of sensors and wiring without hiding had to be as small as possible. For example, the CPU required by the cameras are located in the interior of the existing ceilings.

Al though the object of this article is only to describe the placement of the sensors, a complex element that must take into account by the researchers who would replicate the setests, it is the storage and processing of all data obtained.

It is note worthy indicate how this methodology can be used in other areas, as has happened with the work of researchers associated with particle physics and fire protection, because we are able to have a significant amount of data on the trajectory of people interior spaces in real use. [27]

5. Conclusions

The Project is characterized by the utilization of low-cost and privacy-preserving sensors for the development of a novel occupancy extraction system in buildings, and the development of a prototype system that is able to analyze and extract effectively occupancy-related parameters with high granularity for human presence and movement analysis in Buildings for Energy Efficiency.

All works described in this article enables the replication of this original installation by other research groups for its use in the area of energy building, although they can be utilized for other purposes.

Final results provided indicate that the sensor networks are an important support for decision making and facility management based on real-time occupancy extraction, but there are equally important points that may be summarized as follows:

- This is a relatively inexpensive installation placement but requires significant technical expertise for execution and coupling with networks of communication.
- A robust occupancy extraction system has been designed, developed and deployed to pilot sites, obtaining a high granularity of extracted occupancy enables reliable training of agent-based models for their later use in Building Performance Simulation framework.
- Being a live network, facilities managers, architects, engineers... can access to instantaneous data of the real operation of the building.
- Based on the above it is concluded that the user integrity and his/her personal data protection must be ensured at any moment.

Acknowledgments

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