INTEGRATION OF BIM AND LIVE SENSING INFORMATION TO MONITOR BUILDING ENERGY PERFORMANCE

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ABSTRACT

In order to monitor the building energy performance management, it is important to set up real-time connection between live sensor data, Building Information Model (BIM) and other relevant information. This paper presents our research work on developing an Integrated Building Information Service based on the emerging information standards and information service standards from sensing technologies, Architecture, Engineering, Construction and Operations (AECO) domain and geo-spatial domain. This extensible Web information service framework can provide live information support for various applications. A demonstration prototype has been developed to show building energy performance in 3D by linking the BIM and live sensor data together in the Centre for Communication Systems Research (CCSR) of the University of Surrey.

Keywords: Building Information Model (BIM), IFC, sensor web, web service, energy management

1. INTRODUCTION

Nowadays, energy consumption in buildings is responsible for roughly 40% of the total energy use in the European Union. The European Commission recently pledged to cut the annual consumption of primary energy by 20% by 2020 (McGlinn etc. 2010). The emerging Building Information Model (BIM), as a shared knowledge resource during a building's life cycle, can be used as a basis for building energy management. In actual fact, BIM-based building energy management and analysis has attracted much attention for research and development work (Sumedhar etc. 2008; Bazjanac 2008; Ramtin 2010). According to GSA-003 (2009), the following energy relevant information needs to be taken into account during a building's design stage:

- Building Geometry including the layout and configuration of spaces;
- Building orientation;
- Building construction including the thermal properties of all construction elements including walls, floors, roofs/ceilings, windows, doors, and shading devices;
- Building usage including functional use;
- Internal loads and schedules for lighting, occupants, and equipment;
- Heating, ventilating and air conditioning(HVAC) system type and operating characteristics;
- Space conditioning requirements;
- Utility rates;
- Weather data.

However, for most of our current existing buildings, such information is not available. Many older and inefficient buildings have great potential for energy savings by taking advantage of improved technologies and materials. One such area is sensing technologies. It has been widely recommended to use sensing technologies to perform measurements as a means of monitoring energy usage and reducing the energy consumption (Srivastava

2010; Guinard etc. 2009). Many commercial and office buildings have installed various sensors and metering equipment to monitor building conditions and improve energy efficiency, comfort and cost effectiveness. With the development of sensing technologies, it is easy and cheap to install sensors in the existing building. Using these sensors, the condition inside a building, e.g. the room temperature, humidity, lighting, occupancy & movement etc., can be captured to provide real time information necessary for those in charge of building operation and maintenance. Thus allowing them to recognise problems and to prioritise building maintenance tasks (Menzel 2008).

By setting up real-time connection between live sensor data and the comprehensive BIM, building operators can literally see where the energy problems are with the help of building models. However, combining these different kinds of information, which are usually created in different formats on different platforms, is a big challenge.

This paper presents our preliminary research work on developing an Integrated Building Information Service to combine relevant information together. The focus is to combine the sensor data models with semantic building information models. This paper will first review the research efforts on developing information standards and information service in BIM and Sensor web domains. Then this paper will present the design of a conceptual framework to achieve the integrated building information service. Finally, this paper will report that how our current BA building in the University of Surrey has been used as a case study to develop a real time 3D building energy performance monitoring platform. Based on this test case, the paper will discuss the future work for this integrated building information service.

2. BIM/IFC AND BUILDING ENERGY

During recent years, there has been a BIM fever around the world. This section will present the concepts BIM and IFC and give a brief review their current development before exploring the potential of BIM as an information integrating framework for building energy management.

2.1 BIM and Building Energy

BIM actually can be two concepts: Building Information Modelling and Building Information Model. According to BuildingSMART (2012), Building Information Modelling means a business process for generating and leveraging building data, which allows all stakeholders to have access to the same information at the same time through interoperability between technology platforms. Building Information Model is the digital representation of physical and functional characteristics of a facility, which can serve as a shared knowledge resource for information about a facility, forming a reliable basis for decision support during the whole life cycle of a facility from planning, through construction and usage, to its demolition.

During recent year, BIM has attained widespread attention around the world in Architectural, Engineering, Construction and Operation (AECO) industry. Some countries (e.g. UK, USA and Finland etc.) have made their strategic plans to achieve BIM in the AECO industry in specific time scale. However, it seems that there will be a long way to go for the whole sector to adopt BIM. The main reason is because that BIM requires a robust linkage between construction delivery and life-cycle management process and technology which have not been existing in the main stream work practice in the AECO sector (Arayici etc. 2011; Eastman etc 2008; Gu 2010). In order to tackle this issue, major design-build primes have been working on the new practice to enable better collaboration, communication, and trust among the different stakeholders during recent years (AIA 2007; BuildingSMART 2008).

BIM-based Energy management is still an immature domain. Most of current BIM applications have mainly focused on design and construction phase. Building operation/maintenance systems consisted by sensors, actuators and controllers are not well represented in BIM yet although there have been efforts of using BIM in facility management. Although new buildings have been or will be designed/constructed/managed using BIM, many more existing buildings do not have operational BIM models or even digital models. Producing a BIM model for existing buildings can be a very costly process. It can be said that most buildings would not have a full BIM for a very long time. All thease could affect the use of BIM in building energy management.

However, do we need a full BIM for energy management? The answer is no. People in buildings mainly inhabit and interact with spaces inside the building. Actually a lightweight BIM which can describe indoor space without much construct details should be enough for monitoring energy management. Using some commercial or even open source software to produce basic BIM models for existing buildings is a feasible solution. It can be anticipated that BIM will play a big role in building energy management in future.

2.2 IFC and Energy Related Entities

Industry Foundation Class (IFC) has been designed as an international standard for semantic building models by BuildingSMART. IFC is a neutral and open specification which is commonly used for BIM. The IFC model not only describes full 3D geometry but also relationships, process, material, cost and other behaviour data.

From the energy management aspect, IFC has already defined the HVAC, lighting, electrical related entities. Also, an IfcOccupant has been defined as a type of actor who is in the form of occupant of a property. The property can be a site, building, building storey or space or their compositions. The characteristics relating to the occupant (e.g. name, organization details, roles etc.) can also be described. The recent development in the new IFC4 version has added some energy related new entities e.g. IfcSensor and IfcSpatialZone (BuildingSMART 2013).

According to the definition of BuildingSMART, a sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument (BuildingSMART 2013). IfcSensor defines the occurrence of any sensor; common information about sensor types is handled by IfcSensorType which is described by common type name, usage (predefined type), properties, materials, ports, composition, assignments, and representations. The IfcSensor may be connected to other objects like a flow element, the exterior of an element, an element in certain location using the indicated relationship.

Another newly entity is IfcSpatialZone. With this new entity for spatial zones, the zone can have own location, shape and functional type as required e.g. in thermal, lighting and usable area zones.

The extensions of IFC make the IFC have the potential to represent the building performance. However, IFC still does not have the capability to represent the live sensor readings.

3. BIM WEB SERVICES

BIM brings the information together from all parties involved in the building life cycle. There is a strong technical need for an open, easy to use and flexible way to share data among stakeholders. Although there is no standardised BIM service interface, various BIM Web services have been developed to provide such a platform for BIM stakeholders. This section will present four BIM web service examples which show the efforts from academic research and software industry. Following that, there is a short comparison of these four BIM web services.

3.1 Four BIM Web Service examples

- **Building Feature Service**: The principal author has developed a prototype of BIM Web service named as Building Feature Service (BFS) (Wang and Hamilton 2009) while working in the University of Surrey. BFS is based on the Open Geospatial Consortium's (OGC) Web Feature Service (WFS) Interface Standard provides an interface allowing query requests for building components features across the web from IFC building models. The query result is represented by CityGML.
- **BIMServer:** Building Information Model server (BIMServer) is open source software developed in Netherland (http://bimserver.org/). BIMServer can host the information of any construction project centralized in a database based on the IFC open standard. BIMServer provides multi-user support therefore multiple people can work on their own part of the model and update the complete model on fly.
- **Onuma Planning System** (OPS)**:** The OPS is a commercial software product from the Onuma Inc. in USA. It offers a Web Services API (REST) to access data from the BIM Projects (https://www.onuma.com/products/WebServices.php). This OPS Web Service can be used to combine BIM data from the Web Services with IFC files from the OPS WFS in another Web Application and manipulate the data contained in.

- **IFC-TO-RDF Conversion Web Service:** IFC to RDF Conversion web service was built at UGent Multimedialab at Ghent University, Belgium (http://smartlab2.elis.ugent.be/smartlabportal/Research/IFCRDFWebService.aspx). It can facilitate the conversion from IFC into IFC/RDF graph (Pauwels 2010). An IFC file can be uploaded into this web service and made available on the world-wide semantic web. This allows an improved information reuse and a significant extension of the IFC information with information available throughout the semantic web.

3.2 Comparison of four BIM Web Services

BIM web services provide an open and flexible way to share data among stakeholders. The above four web services are compared from their output formats, implementation technologies, read/write support etc as shown in Table 1.

Table1: Comparison of four BIM Web Services

Name	Output	Semantic	Read/Write	Multi-user	Implementation	Usage
BFS	IFC, CityGML	no	R	Yes	OWS	Free to use
BIMServer	GBXML, IFC etc.	no	R/W	yes	Database	Open source
IFC-to-RDF	IFC/RDF	yes	R	yes	Web service	Free to use
OPS	IFC/many others	no	R/W	yes	REST	Commercial

4. SENSOR INFORMATION MODELLING

Sensing technology in commercial and office buildings has led to a greater awareness of the condition of buildings. Various sensing devices operating with different communication standards have been installed in many buildings. Interconnecting the heterogeneous sensors via sensor web (or sensor network) and standardising the sensor information could greatly facilitate the building operation and energy management based services for building managers, owners and inhabitants. This section will introduce the basic concepts of sensor and sensor web and standardised effort from the Open Geospatial Consortium (OGC) and the World Wide Web Consortium (W3C).

4.1 Sensor and Sensor network

Sensors are important for tagging, tracking, locating, and monitoring things, and for enabling things to be aare of the environment around them (Fairgrieve 2011). Sensors, as a key enabler of the Internet of Things (IoT), are produced by a variety of manufacturers, using many different protocols and formats. This makes the interoperability and large scale sensor integration required by the IoT difficult without standards.

A sensor web interconnects a group of distributed and heterogeneous sensors by a communication fabric (Fairgrieve 2011). Sensor Web can be seen as extensions of the World Wide Web with sensor-specific standards and interfaces that enable users and software to discover and utilize sensors anywhere.

The interoperable access to sensor data is an essential requirement for a broad range of applications certainly for monitoring building condition. For sensor data providers as well as for consumers the question coming up is which approach is the best for publishing or consuming sensor data. The data gathered from wireless sensor networks is usually saved in the form of numerical data in a central base station. The Open Geospatial Consortium (OGC) and the World Wide Web Consortium (W3C) has both worked in specifying standards for interoperability interfaces and metadata encodings that enable real time integration of heterogeneous sensor webs into the Internet.

4.2 OGC's Sensor Web Enablement (SWE)

OGC has been working on specifying interoperability interfaces and metadata encodings that enable real time integration of heterogeneous sensor webs into the information infrastructure. OGC's Sensor Web Enablement (SWE) includes a suite of standard encodings and web services (OGC 2008). The main specifications include:

- **Sensor Model Language (SensorML)** describes and models processes, sensors, and systems of sensors;
- **Observations and Measurements (O & M)** defines the format for encoding sensor observation data;
- **Sensor Observation Service (SOS)** provides archived and near real-time access to sensors and their data where sensors are described in SensorML and sensor data are described in O & M. Includes optional support for adding new sensors and publishing their observations …..
- **Transducer Model Language (TML)** is the conceptual model and XML Schema for describing transducers and supporting real-time streaming of data to and from sensor systems.

4.3 W3C's Semantic Sensor Network

While the OGC SWE standards provide description and access to data and metadata for sensors, they do not provide facilities for abstraction, categorization, and reasoning offered by semantic technologies. The W3C Semantic Sensor Network Incubator Group has recently developed the Semantic Sensor Network (SSN) ontology that enables expressive representation of sensors, sensor observations, and knowledge of the environment (Barnaghi 2009). The SSN ontology has merged sensor-focused (e.g. SensorML), observation-focused (e.g. O & M) and system-focused views to support domain independent sensor applications.

The SSN ontology is encoded in the Web Ontology Language (OWL) and has begun to achieve broad adoption and application within the sensors community. It is currently being used by various organizations for improved management of sensor data on the Web.

5. AN INTEGRATED INFORMATION SERVICE FOR BUILDING ENERGY MANAGEMENT

5.1 The rationale

To monitor Building Energy Performance, it is necessary to combine BIM with Sensor readings and other information together. For example, for better temperature control, not only the temperature sensor readings are needed, but also the function of the room (office or meeting room), volume of the room or type of occupant are necessary for the system.

As discussed in previous sections, BIM provides a shared knowledge resource for the whole life cycle of a building. Building geometric models and floor plans produced by CAD/BIM methods in design stage can be reused by building owners and other stakeholders for facility management, on-going refurbishment and building modifications. The review of the four BIM web services has shown that they all provide open data services although they are using different implementation methods

Similarly sensor readings are needed by different stakeholders for different applications as well. OGC's SOS defines data service interface to enable near real-time access to sensors and their data. OGC's SWE has made it possible for assess sensor information in an open and interoperable way.

Built upon these valuable works, the proposed integrated information service in this research should combine the BIM web service effort in AECO sector and OGC's SWE effort to allow data to be shared and reused across application and domain boundaries.

5.2 A conceptual Information Integration Framework

Based on BIM and BIM web service and OGC's SWE, we developed a conceptual information integration framework as shown in Figure 1.

In this framework, four information groups are considered:

- Building layout and equipment: the physical configuration of a building and its spatial relations, the instalment and equipment;

- Sensor/smart device: device configuration, data, their location, positioning and other attributes;
- Environmental geo-datasets: geo-location, weather (wind, temperature, sunshine etc.);
- Occupant: person, activities, movement.

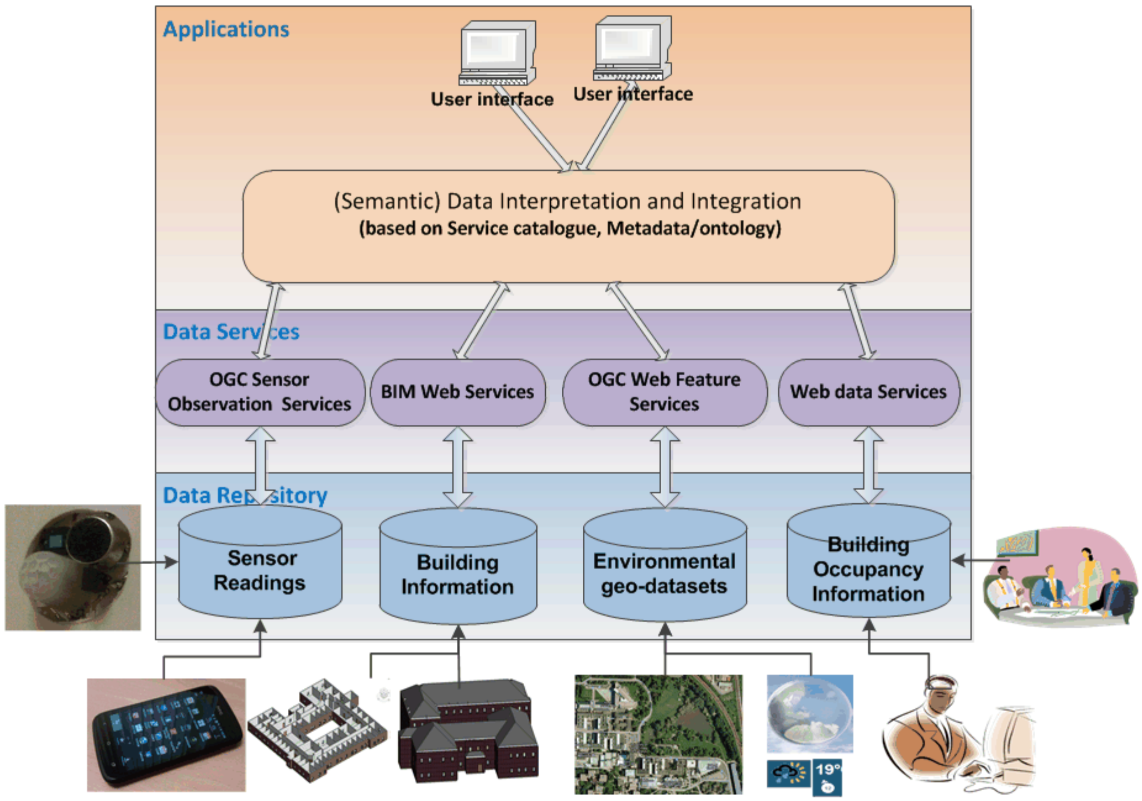

Figure 1: ensor-augmented Building Information Service for building energy management

Each of these information groups represents an aspect of the built environment and as such has impact on a building's energy performance. Our research focuses on providing an extensible framework in order to make it possible to add on other information whenever necessary. This enables us to carry out our work even without capturing the detailed data requirements.

This information service framework relies on every data owner publishing their data in a standardised format using web services. It does not matter to use which specific Building Web Services or Web Feature Service (WFS) as far as they publish their data in certain standards.

The client can assess these web services to get the required data in a standardised format like in IFC, or O&M or CityGML. It is up to the client to process the retrieved data to feed into their specific applications.

The construction of this information framework using Web services provides an integration service interface. It can bring OGC's SWE for outdoors geospatial environment into indoor locations therefore could cover the whole IoT world.

6. THE PROTOTYPE OF A REAL-TIME BUILDING ENERGY MONITORING PLATFORM

As part of the of Smart Campus research in the University of Surrey, we have successfully implemented an initial prototype, the Real-time Building Information Visualisation System (RBIVS), to monitor the BA building's operation and energy performance at the University of Surrey.

The BA building is a 3-storey research building containing offices, meeting rooms, laboratories etc. On-going experiments have been able to achieve the operation of a "smart" BA building with over 200 various sensors and meters installed in the offices and labs within the building. This work is the indoor deployment of the vision of Smart Campus research in CCSR which aims to explore how the Internet of Things (IoT) technologies can be utilised to benefit to the occupants.

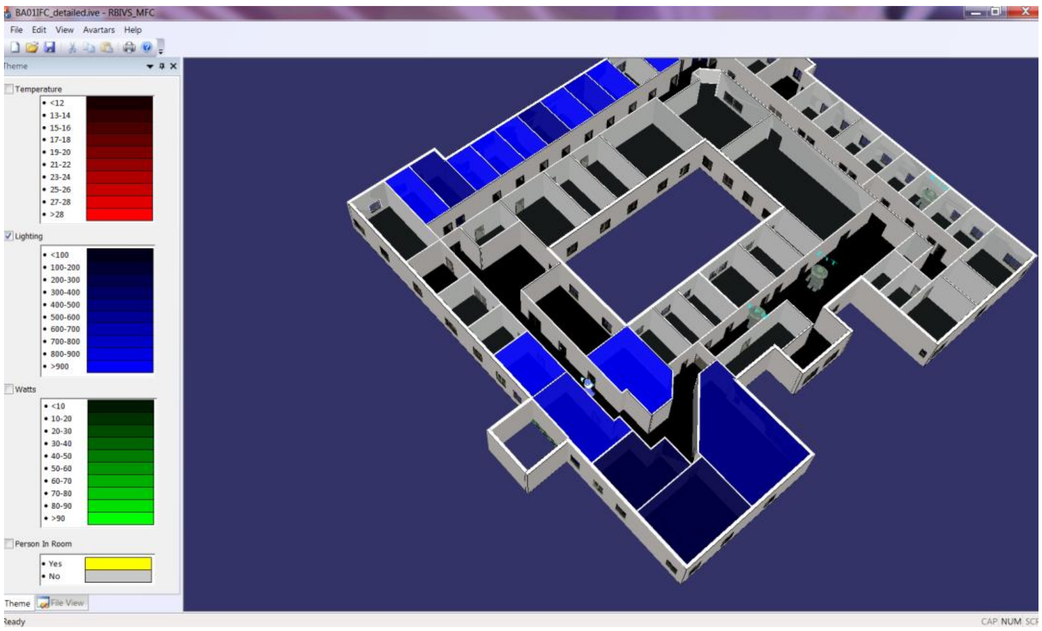

Figure 2:The Snapshot of the RBIVS showing room lighting and people's movement.

In order to provide information support for the development of the RBIVS prototype, we mainly have worked on two tasks. First, we created the BIM for the BA building using AuotDesk Revit 2012 based the 2D floor plan. We produced the BIM with details of the room/wall/window/door elements and sensors within the building which are sufficient for monitoring the building energy performance. Second task is to publish the sensor data (e.g. temperature, lighting, noise, infrared etc.) through the? REST web service as part of the implementation of the integration information service framework.

The initial RBIVS prototype was developed as a desktop application using Visual C++ programming language and Openscenegraph (for 3D rendering). The RBVIS is acting as a client application of our integrated information service framework. It accesses sensor readings through web services and links the sensor information with the room/corridor defined in BIM. The energy consumption/temperature/lighting of indoor element is visualised in 3D in real-time as shown in Figure 2.

The system can monitor the building's energy performance by both room-based query and sensor-based query. It can dynamically display sensor readings using colour coding based on rooms with the default changing frequency of 5 seconds. The system also supports individual sensor query in text by clicking a sensor in the 3D model or choosing a sensor from a list. The system can display individual sensor and room's historical reading in charts as shown in Figure 3.

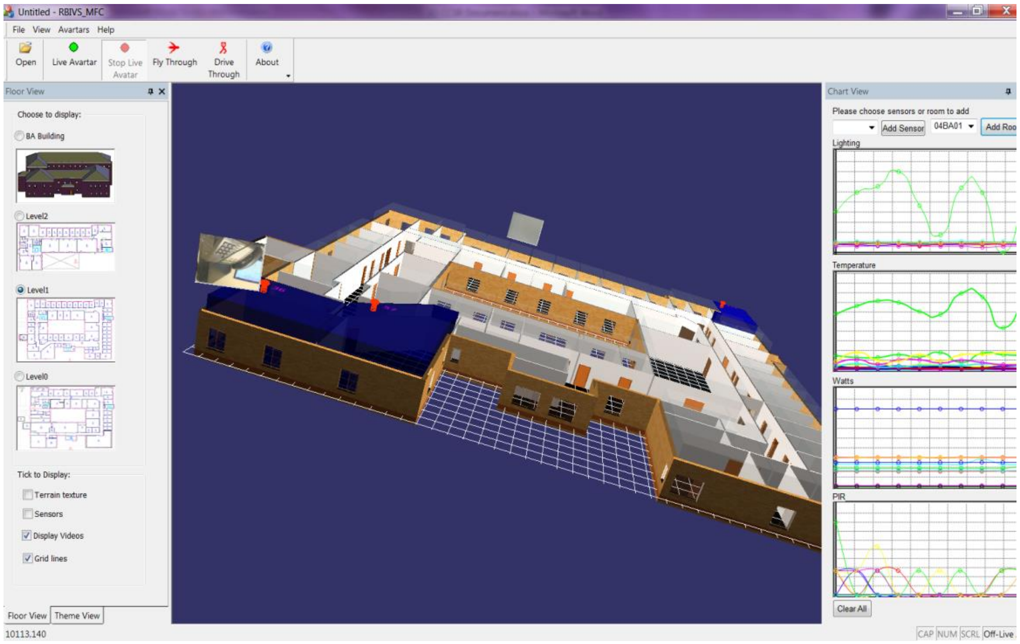

Figure 3: The Snapshot of the RBIVS showing sensor reading in charts.

Real-time data collection not only provides a clear roadmap about how a building is performing but also delivers data for evaluation & ratification of a three dimensional (3D) model in BIM. Although this initial RBIVS does not access the building information through BIM web service, it demonstrates the viability combining BIM with live sensor information using web service for monitoring the building energy performance.

7. DISCUSSIONS AND FUTURE WORK

The emerging BIM technologies integrated with sensor networks give new capabilities to monitoring building operation and therefore preventing energy waste. This research defined a conceptual web information service framework to support BIM and relevant information sharing. The initial prototype has demonstrated the idea for Smart Building by combining live sensor data with BIM using the web information service framework. By knowing the building status at any given time and location, which is largely unseen to most users, it is possible to change occupant behaviour, improve building safety, avoid unnecessary energy consumption and facilitate better working environments.

This paper reports the research we have carried out recently. There are some interesting issues that we would like explore in the near future.

- **Modelling sensing areas**: IFC is still limited in terms of the definitions of sensors and other devices which is of interest to the IoT domain (Grindvoll 2011). It is possible to extend the IFC model with the descriptions of sensors and the relevant sensing areas. A sensing area is essentially the scope of sensing for the sensor and can be described by a geometrical description. For example, for a movement detection sensor, the sensing area could be a sphere or part of a sphere. By defining this sensing area, it is easy to know whether there are areas where movements can't be detected.
- **Modelling building occupants' behaviour**: The occupants' behaviour in a building can greatly affect the energy consumption within. By capturing and analysing the occupants' behaviour (e.g. movement, equipment usage), it is possible to make the occupants better informed of their energy usage and therefore helping them change their behaviour to improve their energy efficiency.

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