BIM based FM and building operation

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BIM as a centre piece for optimised building operation

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ABSTRACT: It is a natural business need to have our building stock operating efficiently. A building that operates efficiently is one where most characteristics of the building can be measured, monitored and recorded while responding with relevant actuation. BIM has proved over time to be a valuable asset in contributing to the management of relevant building data. This paper examines how current implemented research in the area of Optimised Building Operation can be used to further the role BIM can play. It also examines experiences using an open source BIM tool and considers the technological approach taken by such a tool as a positive step to achieving a synchronous BIM when integrated with current building performance data gathering techniques.

1 INTRODUCTION

The function, general usage and opinion of BIM in industry are reminiscent of a repository of digitized building material. While BIM offers the potential of hosting all data associated with the building lifecycle, there is evidence to suggest that some phases of the building lifecycle are represented in a much more diluted fashion with respect to their presence in a BIM.

BIM's effectiveness becomes stronger with less manual interaction. Depending on human interaction to amend BIM based material can result in missing and duplicate data. Slow interaction with BIM based building models may possibly embed inaccurate and obsolete information.

BIM's ability to host objects affords some breathing space to capture accurate information using a more dynamic approach. This paper investigates how such a dynamic BIM can be supported through integrating wired and wireless sensed building data sources.

1.1 *What is BIM?*

Literature is very well furnished with definitions of a Building Information Model as well as detailing the differences between the *Model* and *Modeling* (Eastman, 2011). The explanation that will be adopted here supports the requirements of what various stakeholders would want from a Building Information Model. This brief overview of requirements is influenced by interaction with ITOBO's (Information Technology for Optimised Building Operation) (Menzel, 2010) Industry partners and BIM work associated with the Environmental Research Institute (ERI) building, University College Cork (UCC), Ireland (ERI, 2012).

Supporting the Facility Management (FM) body as the first stakeholder there is interest in as much prior history of the building as possible. FM companies will always encounter challenging levels of poorly maintained building documentation, if any exists. Couple this with poor records of building occupancy, energy consumption and levels of prior building maintenance it becomes clear that the FM body enters into a building maintenance contract with a certain degree of risk.

A number of general requirements emerge relating to BIM from a FM perspective. (1) A BIM shall support documentation revision control providing FM staff access to documentation specific to a point in time; (2) A BIM shall accommodate the most important meter readings at any point in time; (3) A BIM shall accommodate the building's legal, fire safety and submittal documentation.

From the landowner's point of view a number of BIM requirements also emerge. (1) The landowner shall have access to a BIM specific to the relevant building; (2) The BIM shall support occupant letting history, occupant energy usage history, building maintenance and high cost building expenses history.

The occupant can also influence what should be supported in a BIM. Occupants at the ERI consist of researchers from backgrounds concerning Sustainable Energy, Environmental Engineering, Environmental Chemistry, Environmental Microbial Genomics, Biodiversity to name but a few academic areas. The use of toxic chemicals, the production of waste products or the use of high cost equipment are daily activities at the ERI. BIM functional requirements that emerge in this instance include; (1) BIM shall accommodate occupant roles within a building; (2) BIM shall support a history of hazardous material usage; (3) BIM shall support a history of hazardous waste production and disposal.

Finally, some requirements worth mentioning that can assist all stakeholders. (1) The BIM shall support wired, wireless and simulated building performance data; (2) The BIM shall support optimum performance data with regard to renewable energy sources within a building; (3) The BIM shall support a modeling facility to quickly visualise, amend and further develop building models.

1.2 *Technology for BIM*

This research has focused on using an object oriented BIM tool supporting a web browser based client. ITOBO uses BiMserver (BiMserver, 2012), an open source software supporting the following key features:

- Industry Foundation Class (IFC), ifcZIP and ifcXML building drawing file formats,
- IFC versioning,
- Geographic Information System,
- Filter and querying,
- Web-service Interface,
- Web-browser Interface.

The BiMserver is certainly not a fileserver and uses the model-driven architecture approach. The uploaded IFC data is brought through a translation process where it is processed into an Eclipse Modeling Framework (EMF) interpretable eCore file. The process of translation involves running the IFC data through a series of parsers compliant with ISO 10303 part 21 where the use of an express dictionary for express to eCore conversion is utilized. The generated eCore file is required to maximize the full benefits of the EMF. Following this translation process, what was once an IFC file is now a series of eCore objects stored in the BiMserver's underlying Java based Berkley database.

The translation process is twofold. The clear advantages of handling IFC data and the packaging of IFC data into objects, is the ease with which object element queries and filtration can be achieved. In addition, object elements can be isolated for further analysis. In the interests of ITOBO, where the production of simulated and real-time sensed building data is abundant, a mechanism to amend object embedded parameters within a BIM is appealing.

The philosophy behind BiMserver is to allow users an opportunity to further develop this BIM approach by providing all relevant software as open source. Deployment of the BiMserver is straight forward and what is evident is the hardware demands are quite low. During a testing phase, ITOBO has hosted BiMserver on a regular PC running a Windows7 64-bit operating system. The PC has no special RAM or disk space requirements. BiMserver runs smoothly. One limitation that has been observed is when multiple users ($<$10 users) try to login to the BiMserver at the same time, BiMserver complains about a deficiency of memory with the result that a number of users cannot login to the system. The same error occurs during the IFC file upload process. This phenomenon escalates when memory hungry applications are running on the host PC in parallel. A recommendation here would be to run BiMserver on a dedicated server/PC running a server specific operating system. In addition, ITOBO tests have seen that large IFC files, in excess of 30 MB failed to fully upload to the BiMserver. This proved to be a limitation with wireless LAN facilities outside the UCC LAN.

1.3 *Berkley database*

As mentioned the underlying database for the BiMserver is the Berkley Database written in Java and implemented through Berkley DB Java Edition (Oracle, 2012). In short, this allows BiMserver to be supported on many hardware platforms from mobile devices to servers.

The Berkley DB offers users a number of database strategies. The strategy adopted and used by BiMserver is the ability to store data using a key value approach. A key value store arranges data in a set of named tables supporting two columns reserved for key and value. The storage size of both key and value nodes can be arbitrary even though the key node has a much more fixed byte size. As is a database norm, all keys are ordered and never duplicated.

Each key node is comprised of a Project ID, an Object ID and a Revision ID. In addition, Class ID is optionally supported. 16 bytes (128 bits) can be reserved from the key node. The value node, as mentioned, is more arbitrary with its byte size. All value nodes are written in an EMF defined order and include all super class structural features (BimServer2, 2012).

In a nutshell, if a developer is looking for a database with more functionality than what is currently available from a relational database, it is recommended to consider using a Berkley (Oracle, 2012). The Berkley DB Java edition supports the storage of key value data in a b-tree data structure which accommodates efficient data queries, sorts, insertions and deletions.

Berkley DB emphasises support for revision control. From a BiMserver perspective, all models are stored as projects. New revisions of a model also adopt their own specific project. All project revisions utilize the Berkley DB b-tree data structure. This facility allows users to retrieve older revisions of models while also supporting a seamless amendment to objects from the same model and revision.

Currently, ITOBO uses Oracle 11g data warehouse software to host and process its wired and wireless sensor data. In addition, ITOBO uses a series of Java based applications to examine and retrieve gathered data for building performance graphical representations, sensor device detailing, and data download facilities.

What is also of real interest to ITOBO as far as BIM is concerned is the ability to focus in on relevant IFC objects that contain potential to detail and host building performance data. In addition, the ability to enrich these objects with data obtained from simulations and from the ITOBO data warehouse offers an opportunity to embrace the concept of synchronous BIM. Using an object based BIM database complements the object based approach adopted by ITOBO. The Berkley DB based BiMserver offers an efficient fit for an ITOBO BIM solution.

2 IFC OBJECT ANALYSIS

2.1 *Key IFC objects*

ITOBO currently gathers the following wired and wireless sensor data from the ERI; CO_2, Humidity, Relative Temperature, Lighting (Lux), Wind Speed, Wind Direction, External Air Humidity, Total Solar Radiation, Diffuse Solar Radiation, Sunshine Hours, Outside Air Temperature, HVAC Air Velocity, HVAC Air Temperature, Water Flow, Water Temperature, Under-floor Heat, Electricity and Gas. Access to this data is achieved through a series of online ERI Building floor monitoring web interfaces (Figure 1) (ITOBO1, 2012).

In parallel, ITOBO has maintained a BiMserver with revisions of ERI building models. Contributors to these models constitute a cohort of students from the UCC School of Engineering based MEngSc IT in Architecture, Engineering and Construction [ITinAEC, 2012].

Students were asked to focus on different areas of the ERI building with emphasis on specific topics such as lighting, plant, HVAC and wireless sensing infrastructures. Students were asked to download a base version model of the ERI and amend detail to this model. They were then asked to upload their models to the BiMserver and encouraged to use the BiMServer IFC object query tool for further analysis. Figure 2 details a layout of the student contributions to the BiMserver.

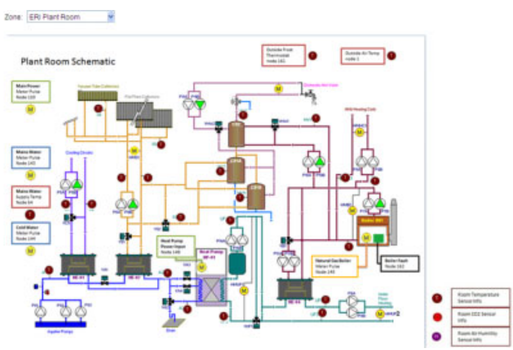

Figure 1. ERI energy monitoring tool.

Name	Last revision
UCC Main	22 by b.cahill
Boole	No revisions
Civil Engineering Building	2 by cormacmac
Architectural	2 by cormacmac
Building Analysis	No revisions
Lighting Analysis	No revisions
Thermal Analysis	No revisions
Facilities Engineering	No revisions

Figure 2. ITOBO BiMserver projects menu.

The BiMserver allowed student to save their IFC models using the IFC 2x Edition 3 version (buildingSMART, 2012). Closely inspecting this IFC version, domains of interest include Facilities Management, Electrical, HVAC, and Building Controls.

One approach in isolating specific IFC objects of interest is to examine what relevant enumeration types are supported. An obvious enumeration type for ITOBO purposes is *IfcSensorTypeEnum* which defines the range of different types of sensors that can be specified. Table 1 defines the exact terminology used for this enumeration type and if the value supports a property set.

This enumeration type is used by entity *IfcSenserType* which is one of five entities defined under the *IfcBuildingControlsDomain* schema where concepts relevant to alarm, automation, control and instrumentation are supported.

Temperature sensors have a large presence in ITOBO Living Laboratories such as the building of the ERI.

On closer examination the relevant property set in this case is *Pset_SensorTypeTemperatureSensor*. The property definitions are of particular interest in that specific IFC elements are identified and have the potential to support single data values at a point in time. Table 2 details the property definitions for *Pset_SensorTypeTemperatureSensor*.

From this listing of property definitions it is observed that *PEnum_TemperatureSensorType*, *Ifc ThermodynamicTemperatureMeasure* of either type *IfcPropertySingleValue* or *IfcPropertyBoundedValue* and *IfcTimeMeasure* of type *IfcPropertySingleValue* can be used to store relevant sensed data in a Berkley DB supported BiMserver.

Further BIM data storage potential arises when the following IFC schemas are analysed; *IfcActuator*

Table 1. *IfcSensorTypeEnum* (buildingSMART, 2012).

Value	*Definition*	*Pset*
CO2SENSOR	A device that senses or detects carbon dioxide.	YES
FIRESENSOR	A device that senses or detects fire.	YES
FLOWSENSOR	A device that senses or detects flow.	YES
GASSENSOR	A device that senses or detects gas.	YES
HEATSENSOR	A device that senses or detects heat.	YES
HUMIDITYSENSOR	A device that senses or detects humidity.	YES
LIGHTSENSOR	A device that senses or detects light.	YES
MOISTUREENSOR	A device that senses or detects moisture.	NO
MOVEMENTSENSOR	A device that senses or detects movement.	YES
PRESSURESENSOR	A device that senses or detects pressure.	YES
SMOKESENSOR	A device that senses or detects smoke.	YES
SOUNDSENSOR	A device that senses or detects sound.	YES
TEMPERATURESENSOR	A device that senses or detects temperature.	YES
USERDEFINED		
NOTDEFINED		

Table 2. *Pset_SensorTypeTemperatureSensor* (buildingSMART, 2012).

Name	Property & Data Type
Temperature-SensorType	IfcPropertyEnumeratedValue (Enumeration that Identifies the types of temperature sensor that can be specified) PEnum_TemperatureSensorType HighLimit LowLimit OutsideTemperature OperatingTemperature RoomTemperature Other NotKnown Unset
Temperature-SensorSetPoint	IfcPropertySingleValue The temperature value to be sensed) IfcThermodynamicTemperatureMeasure / THERMODYNAMICTEMPERATUREUNIT
Temperature-SensorRange	IfcPropertyBoundedValue (The upper and lower bounds for operation of the temperature sensor. May also be termed 'deadband') IfcThermodynamicTemperatureMeasure / THERMODYNAMICTEMPERATUREUNIT LowerBound: ? UpperBound: ?
AccuracyOf-TemperatureSensor	IfcPropertySingleValue (The accuracy of the sensor) IfcThermodynamicTemperatureMeasure / THERMODYNAMICTEMPERATUREUNIT
TimeConstant	IfcPropertySingleValue (The time constant of the sensor) IfcTimeMeasure / TIMEUNIT

Figure 3. BiMserver query facility.

TypeEnum, *IfcControllerTypeEnum*, *IfcFlowInstrumentTypeEnum*, *IfcUnitaryControlElementTypeEnum*, *IfcActuator*, *IfcAlarm*, *IfcController*, *IfcController Type*.

2.2 *BiMserver object queries*

The BiMserver facilitates IFC object queries on a per revision basis. A query can be run where the user can pick an object reference for a full IFC schema object dropdown listing. The resultant query generates an express file that can be saved to a local device for review (Figure 3).

What has been observed is querying for the *ifcSensorType* objects produced no findings from a random ERI BiMserver based model. Querying *IfcProperty* produced an abundance of data from the same model. Such data included:

```
#3761676= IFCPROPERTYSINGLEVALUE
('Layername',$,IFCLABEL('Walls'),$);
```

```
#3858402= IFCPROPERTYSINGLEVALUE
('Power',$,IFCREAL(17223.7636
1419389),$);
```

```
#3760769= IFCPROPERTYSET
('3vK6xRLGXAhAo8y5Z3N13n',#3709863,
'PSet_Revit_Electrical -
Lighting',$,(#3843052,#3816535));
```

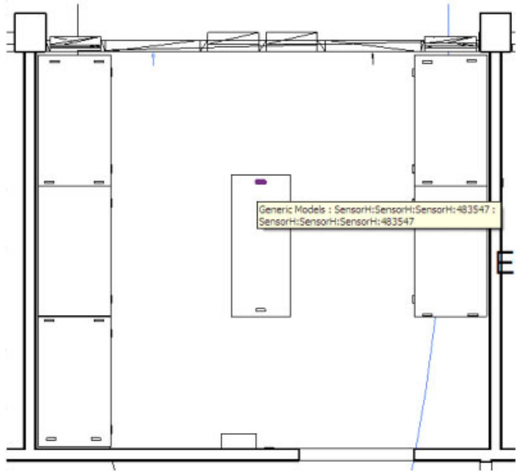

Figure 4. Room LG04 ERI.

```
#3842978= IFCPROPERTYSINGLEVALUE
('Dimming Lamp Color Temperature
Shift',$,IFCINTEGER(0),$);
```

```
#3843005= IFCPROPERTYSINGLEVALUE
('Light Loss Factor',$,
IFCINTEGER(0),$);
```

On closer inspection, the relevant examined model focuses on lighting fixtures on the first floor of the ERI.

Another model that was analysed involved detailing two ITOBO experimental zones (room 1.23 and LG04 (Figure 4)) within the ERI. These zones are equipped with wired and wireless sensors. What is interesting is that the student uses *IfcBuildingElementProxy* schema to detail sensor data. The following is relevant express output from the relevant model;

```
#1577738=IFCBUILDINGELEMENTPROXY
('0uIer99rT0GBONSJtPtPML',#33,
'SensorH:SensorH:SensorH:523226',$,
'SensorH',#1577737,#1577734,
'523226',.ELEMENT.);
```

```
#1566102=IFCBUILDINGELEMENTPROXY
('3vWRWGFbTCMfVZ73wBoOqx',#33,
'SensorH:SensorH:SensorH:483547',$,
'SensorH',#1566101,#1566098,
'483547',.ELEMENT.);
```

IfcBuildingElementProxy is used when the relevant IFC release does not have a specific semantic explanation of the modeled object. In this case the model should be utilisiing IfcSensorType schema but the modeling tool used does not support a direct IFC object labeling of components. The student was forced to use IfcBuildingElementProxy.

An additional challenge encountered is to correctly use an IFC object that encompasses sensor location details. ITOBO examines the use of wireless sensors

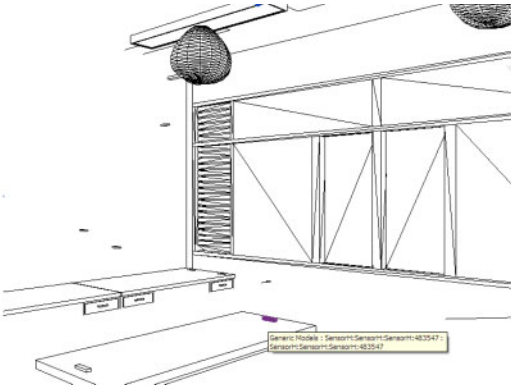

Figure 5. Room LG04 ERI – Wireless sensor location.

at different levels within its test zones. In the ERI, three levels are supported [Figure 5]:

1. User Level – User Comfort Assessment,
2. 0.3 m from ground – User Comfort Assessment,
3. Ceiling level – Thermal Model development.

It is envisaged that an ITOBO BiMserver solution would enrich relevant IFC objects with sensors location data. In addition it is envisaged that integrating Geo data co-ordinates relevant to the sensor location would also assist in having as accurate sensor positional data as possible.

3 COLLECTED ITOBO DATA

3.1 *What collected data fits BIM?*

As already mentioned ITOBO has developed a series of wired and wireless sensor web based monitoring tools (Figure 6). These tools are Java Netbean applications using web services to query the ITOBO Data Warehouse.

Currently ITOBO maintains a number of research demonstrators. The International Demonstrator, situated in HSG Zander Hotel and Training Centre, Frankfurt, Germany and the ERI, UCC, Ireland are the focus of this paper.

The International Demonstrator supports an array of wireless sensors examining HVAC performance, and training room environmental conditions. Sensed data consists of Air Velocity, Air Humidity, fan coil water temperature and flow, and fan electricity. In the seminar room interest is distilled down to light, temperature, humidity, presence detection and CO_2.

What is appealing about this demonstrator is how a user can monitor the performance of the HVAC unit from the air intake to the serviced room. Figure 7 details a typical graphical output from this monitoring tool.

Examination of the ERI is more detailed as it incorporates wired sensor data from the ERI's Building Management System. Amendments to this monitoring tool will support wireless data. Figure 8 details a typical graphical output from this monitoring tool.

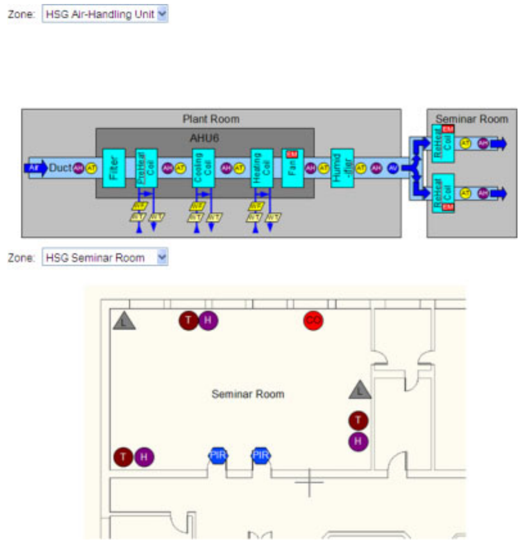

Figure 6. ITOBO International Demonstrator.

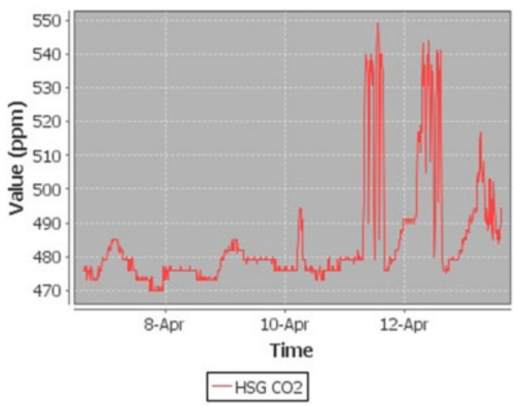

Figure 7. CO_2 reading: International Demonstrator.

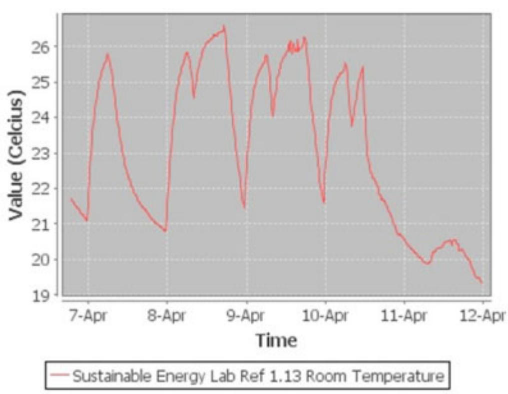

Figure 8. Room temperature reading: ERI demonstrator room LG04.

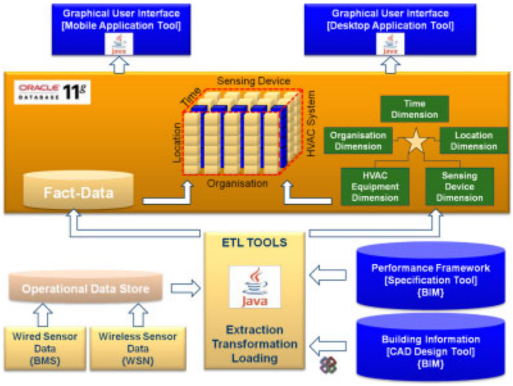

Figure 9. ITOBO data management architecture.

4 BIMSERVER DATA SUPPORT

4.1 *ITOBO data management architecture*

ITOBO implements a data management system that collects wired sensor data from building management systems and wireless sensor data from wireless devices with onboard sensors or integrated with off-the-shelf metering devices (Gökçe, 2009). Utilising features from Oracle 11g Data warehouse software, all data is stored in the operational data store for data cleansing and redundancy checks. Using the Extraction, Transformation and Loading (ETL) feature of oracle, the pre-processed data is loaded to the fact data area of the data warehouse. BIM plays a role in this process. The dimensional data area of the data warehouse is populated with relevant parametric data from the BIM. The fact and dimensional data is aggregated with emphasis on the needs of identified stakeholders. In the case of ITOBO, relevant stakeholders are the Landlord, Facility Manager and the Tenant. A series of graphical user interfaces were developed to assist with displaying data relevant to the mentioned stakeholders (Stack, 2009).

Figure 9 (Gökçe, 2009) illustrates the implemented ITOBO data management architecture. The core components of this system consist of:

– Data warehouse core,
– Extraction, Transformation, Loading Tool (ETL),
– Information Representation Tools.

4.2 *Where does BIM data fit in?*

As already mentioned, terminology such as *aggregate*, *dimension*, and *fact* are being used to describe a system that provides stakeholders with optimum decision support, in this case, for building performance management.

To provide suitable decision support, simply displaying the latest sensor reading on a web based monitoring client is not enough. Data needs to be amalgamated in a meaningful way.

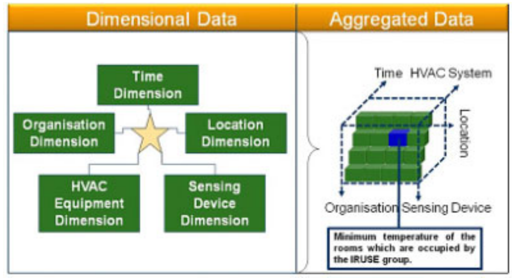

Figure 10. Room temperature reading: ERI demonstrator room LG04.

Aggregated data is situated in the decision support level of a multi-dimensional data warehouse which accommodates pre-calculated and pre-stored aggregated data. As mentioned, sensed data populates the fact data area of the data warehouse. Fact data becomes meaningful when it is associated with dimensional data and provides stakeholders with an opportunity to view collected data in a way that can satisfy a business need. The result of this process is a data cube or data view from a multi-dimensional model. The data cube (Figure 10 (Gökçe, 2009)) can be adapted for different stakeholder requirements where parameters such as time, location, energy reading, costs, to name but a few, can be supported.

Currently BIM supports dimensional data by providing data from its collection of building models. The potential for BIM to provide much more is great. In conjunction with UCC's facility management department, Buildings and Estates, a current initiative is underway to achieve ISO 50001 (ISO, 2011) certification for all buildings on campus. Part of this process involves the definition of Energy Performance Indicators (EnPI). It is envisaged to use BIM and the ITOBO data management solution to maximise the ability for the organisation to define and monitor relevant EnPIs and initiate optimum decision support and appropriate actuation.

BIM can also benefit from an integrated data warehouse. In re-engineering ITOBO's data warehouse, it is envisaged that relevant IFC object terminology be used to standardise how the Data Warehouse describes its tables, attributes and materialised views. This may lead to the concept that a Data Warehouse and BiMserver being IFC compliant while also facilitating convenient data exchange between a data warehouse and BiMserver.

5 SUMMARY AND CONCLUSIONS

This paper examined current implementations of BiMServer and the ITOBO data management systems. Relevant IFC objects were identified that could potentially support a static data value from a sensor data source.

Expanding on the concept of supporting data within BiMserver based IFC objects, harnessing EnPI data by implementing data warehouse materiallised views and embedding this data into a BiMServer based model will assist current and future building stakeholders in making appropriate building lifecycle decisions while in procession of a BIM that provides a true picture of the relevant Buildings status.

ITOBO is currently looking at methods to automate a process of identifying appropriate IFC object components that can accommodate relevant Data Warehouse data. Keeping a BIM in sync with the latest building performance data will only further strengthen the need for BIM.

Use of the TNO developed BiMserver was a success. Further initiatives with the Informatics Research Unit for Sustainable Engineering (IRUSE), School of Engineering, UCC, Ireland will expand BiMserver's functionality and its ability to receive and process data from ITOBO's data warehouse.

ACKNOWLEDGEMENTS

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