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Sustainable BIM-based Evaluation of Buildings

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Abstract

For a sustainable building, the use of energy always concerns clients and designers. In this respect, the UK national regulation on energy performance and 'carbon' accounting has asked for a greater consistency of construction information to achieve the CO_2 emission target. Therefore, Clients and Industry should work closely together in developing plans to make the transition to low carbon buildings feasible in order to meet the CO_2 emission target. In this context, Building Information Modelling (BIM) can play a key role in addition to its capability to create more homogenisation of the construction supply-chain. For the energy analysis packages, the designers usually receive feedback on their design; such as how much energy the building will use, what are the anticipated CO_2 emissions and if the building will pass performance criteria (such as: LEED or BREEAM). BIM applications for energy analysis have been introduced to improve this process but mostly at the design stage. However, for the post-occupancy stage, there is a need for a proper and systematic methodology to monitor the behaviour of buildings and to make critical decisions to ensure that the energy criteria of the design are really met in practice. This paper introduces a conceptual BIM-based model that can improve the post-occupancy evaluation process and meet the industry requirements for sustainable buildings.

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Keywords: BIM; energy analysis; sustainable buildings

1. Introduction

Buildings operation accounts for about 40% of global energy and carbon dioxide emissions (Schlueter & Thessling, 2009). Therefore, sustainability in general and energy efficiency in particular becomes a key measure of building performance and several programmes such as Leadership in Energy and

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Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), CASBEE, SBTool and Green Globes have been adopted to certify buildings in terms of sustainability. In the UK, environmental regulations on buildings have been tightened three times in the last decade (Hetherington *et al.*, 2010). On the other hand, the implications of sustainability on the financial benefits to buildings have been approved. With a slight increase in upfront building cost of 2%, a lifecycle savings of about 20% of the initial building cost can be achieved (Azhar *et al.*, 2011).

The traditional design, construction, and operation stages of buildings have been affected by the consideration of sustainability, especially the use of energy. Several approaches and technologies have been developed to ensure that targets for energy savings and CO_2 emissions can be achieved by more sustainable design and more efficient use of energy. On the other hand, achieving the CO_2 emission target requires better monitoring to building performance and sharing accurate information among the stakeholders. Among the used technologies is the use of BIM to model energy usage, thermal flows, lighting patterns and other sustainability measures.

Despite the many advantages provided by BIM technologies, only 36% of companies in Western Europe use BIM for any purpose (The business value of BIM in Europe, 2010). A structured and consistent approach can drive a mass improvement in BIM taking-up over a well defined horizon to improve the cost, value and carbon performance. This study aims to investigate the feasibility of using BIM approach within the Scottish public departments to adopt a more efficient Post Occupancy Evaluation (POE) of buildings. From this identified general aim, this particular feasibility study has the following objectives:

- To identify the key variables of operational and carbon performance affect on the decision process, especially within the Scottish Government as a client, that should be embedded in BIM applications
- To identify the information at key stages to ensure consistency of clarity to the supply chain for a new BIM-driven procurement approach

This will help investigate the use of BIM to gather and utilize information and knowledge for POE of buildings to better maintain and operate the lifecycle of buildings. The methodology adopted to achieve these objectives was to interview with a number of professionals within the Scottish public departments (four departments) and industry practitioners (five Energy assessors). The main purpose of the interviews is to collect data on the current process of POE of buildings. Data will be also collected on the current use of BIM technology, the view on transforming the current procurement strategy into BIM-driven approach, what/how technologies including BIM technology are used to assess operational and carbon performance, and how the supply chain should be engaged in this process. The following sections will first review the concept of sustainable buildings and how BIM can be used in this respect. The outcome of the conducted interviews will then be detailed.

2. Using BIM for Sustainable Design

Building Information Modelling (BIM) includes ICT frameworks and technologies that can support stakeholders' collaboration over projects life-cycle by facilities to insert, extract, update or modify information in the BIM model. BIM applications produce more usable data and information for visualizations and simulations than the traditional and separate project application tools (e.g. technical 2D drawings and documents). BIM is believed to transform the way the built environment operates. Studies connected to BIM have moved from basically the functions to store, link and exchange the project based technical information to cover all data/information/knowledge analysis of the whole project lifecycle that benefits all stakeholders.

Currently, for the practices of sustainable design, the traditional computer-aided design (CAD) tools are used to model buildings. The design data is then entered into an energy simulation tool to analyse the building performance. Energy simulation packages, such as EnergyPlus, Ecotect and IES Virtual Environment, consider the building design features such as thermal insulation, climate response, glazing, shading, solar gain, solar penetration, air tightness, natural ventilation, mechanical ventilation HVAC systems, building dynamics and thermal mass (Cho *et al.*, 2010). In addition, local weather data and utility rates are considered when calculating thermal loads. The simulation engine of these packages runs the thermodynamic principles considering any assumptions to produce the annual hourly thermal loads in both text and graphical output. In case of any undesirable output, building designers can modify any design features such as window orientation, window size and building orientation and test the impact on the thermal loads and energy usage.

The main problem of the current practices is about the integration between these packages to avoid multiple data entry and also about the consideration of the changes in building features over its lifecycle due to operation and maintenance activities.

The required sets of data to analyse energy consumption in building is quite complex and includes data about the external environment, the shape and configuration of the building, equipment loads, lighting mechanical systems and air distribution. Therefore, for accurate prediction of energy consumption, integrated simulation tools should be used.

The development of Green BIM tools which integrates the design model and the simulation can analyse multi-disciplinary information in a single model which improves the analysis and eliminates errors of data handling (Azhar *et al.*, 2011). The intelligent information created by the BIM model can conduct whole-building energy analysis, simulate performance, and visualize appearance (GreenBIM, 2010). This provides building designers with direct feedback to test the design in order to improve building performance over the lifecycle of the building.

Typically, a BIM model of a building includes design features, Building type, construction materials, System types (Heating/Cooling), Room type (Zone management), Project location (weather files), etc. which can be exported to a building simulation tool. The typical output from the simulation tools includes: Energy/Thermal analysis, Lighting/Shading analysis, Acoustic, Value/Cost analysis.

The exported data from a BIM application may be formatted using IFC (Industry Foundation Class), aecXML, or gbXML (green building extensible markup language). These are schema that have been developed to ensure consistent data exchange and interoperability between several BIM applications including those for controlling energy use in buildings such as geometry modelling, HVAC design, energy analysis, and facility management.

2.1. Current problems in using BIM for sustainability

There are still some problems in using BIM for sustainable design. For example, using BIM for energy analysis currently relies on estimated values for loads, air flows and heat transfer for simulation which may result in unreliable estimates (Crosbie *et al.*, 2010). In an example of a LEED Gold certified university building in the U.S., Autodesk Ecotect underestimated thermal loads in all field measurements that were tested and overestimated illuminance levels in 98% of the field measurements (Vangimalla *et al.*, 2011). Therefore, using real data gathered from buildings can overcome this problem. This is the approach adopted for this research during the operation stage by integrating BIM models with Building Management Systems (BMSs) that use sensor devices (wired/wireless) to capture actual data.

Another problem is about the data flow between BIM models and energy analysis tools. While the design data can be exported from a BIM model to an energy simulation tool easily via IFC and gbXML schema, this process has still some difficulties in the other direction if there is a need to modify the building model to obtain better building performance. Manual configuration is still needed in such cases (Ferrari *et al.*, 2008). Therefore, further development is still required to make the use of BIM for sustainability more useable.

The following sections discuss the outcome of the investigation undertaken on the Scottish public buildings to assess the current practices of energy use and analysis. This will help identify how BIM can improve these practices.

3. Energy management in Scottish public buildings

As a discipline, Energy Management (EM) is about operating and maintaining many complex energy systems used by buildings' occupants. The interviews conducted for this research showed that the current process of POE for public buildings can be represented as shown in Figure 1. An in-house team is always responsible for the strategy and day-to-day management of energy at the operation stage. However, an outsourcing certified team is appointed to assess buildings and produce energy performance certificates. Figure 2 shows further details on the data flow for Energy Management in buildings during the operation stage.

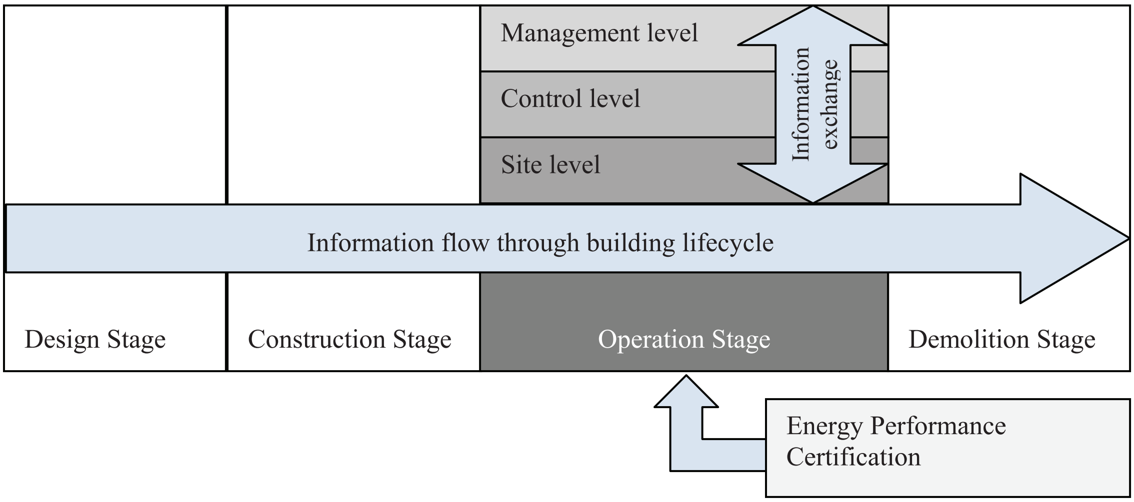

Fig. 1. Information flow through building lifecycle

3.1. Site level

The recent developments in building technologies and control strategies including the new building codes have improved the energy performance in buildings. For the majority of the public departments investigated in this study, there is an average of 250 - 300 buildings to be monitored by an energy team in each department. A holistic approach to monitor building performance requires consistent and simultaneous access to data from different sources. Majority of the buildings are now equipped with Automatic Meter Readings (AMR). There are few buildings which are monitored by manual meter readings, suppliers' files, or a type of Building Energy Management systems (BEMs) such as sensors.

Energy teams usually include a representative (e.g. caretaker) on sites to supervise the process and in majority of cases for meter readings. The team size and structure varies from department to another but with almost the same roles and responsibilities such as: Energy manager/adviser and Carbon manager. Their roles are mainly to collect site data and undertake further analysis then report the results to management teams for decisions.

3.2. Control level

In general, energy teams use Building Management Systems (BMSs) to store, integrate, analyse complex data sets from multiple data sources such as wired/wireless sensing devices and meters. In addition, data about the site and location of a particular building including all the individual zones, building specification, and weather data is also required to perform multi-dimensional analysis of building performance and to support decision-making process. This shows the potential use of technology such as BIM to help manage and process this data. BMSs help produce energy efficiency reports that should be accessible to energy managers and relevant stakeholders. The data stored on BMSs can be analysed and reported in different format suitable for different decisions (e.g. on monthly/hourly basis, for buildings in certain site, for certain zone of a certain building). Table 1 summarises the main types of data required for BMSs. Currently, there are many off-shelf BMSs for data management and for intelligent automatic energy control which automatically control the use of energy for electricity, gas, water, oil, and solid fuel. Improved building control systems can contribute to the reduction of energy-consumption and automatic building systems is often faster and less costly than insulate building shells. While the current BMSs allow all data collected from sites to be classified and reported for management decisions, any further analysis using Building specification and weather data needs additional tools to be used such as spreadsheets. No current integration exists between the BMSs and any other additional tools at the control level and also at Management level. This means the energy teams need to handle the data between these tools manually.

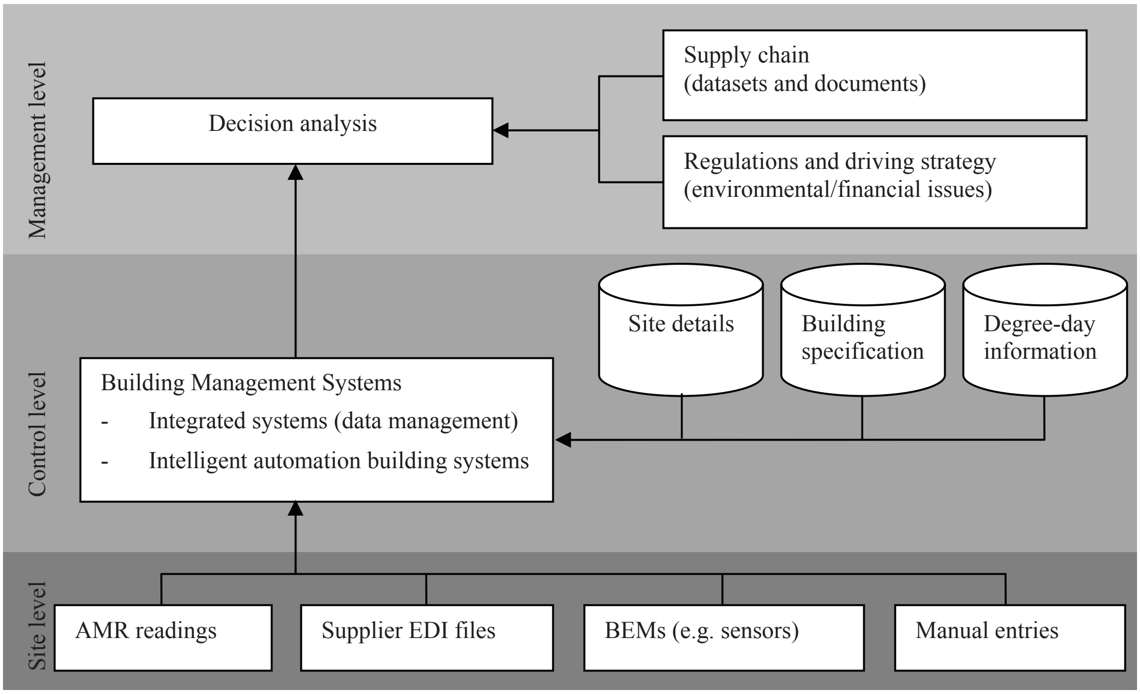

Fig. 2. The data flow for Energy Management in Buildings during the operation stage.

Table 1. Main types of data required for BMSs

Site details:	Name, code, address, contact names, floor area, zone spaces, volume, occupancy, population
Building specification:	Geometry and the thermal properties of all construction elements
Degree-day information:	Weather data and Degree-day adjustment to heating supplies
Meter details:	Supplier, Reference, MPAN, MPR, Targets, Tariff, VAT rate, Invoice

From the current practices, there are good opportunities to use BIM at this control level. BIM models can act as a collaboration tool to integrate all site and additional data at the control level. The collaboration and interoperability features of BIM applications can help the integration of analysis, eliminate errors of data handling, and improve the outcome at this level of control.

3.3. Management level

Decisions made at this level are based on data aggregation from lower levels in addition to open and extensible information exchange with the supply chain. Decisions made at this level consider many factors such as: the strategy adopted by the management team in terms of achieving the emission targets and the financial implications of any managerial and technical solutions for energy savings. The integration with the suppliers and other stakeholders such as buildings' staff/occupiers is an essential element of the decision. Manufacturers data systems can also be integrated to automatically generate execution details of the building systems with construction guidelines provided by the manufacturers. This will provide the information needed for quantity take offs and products used for various simulators and assessment tools. This could be to fix site problems or liaise with occupiers for better use of the buildings. It was addressed that building occupiers always play a key role in the process. As communications between the different members of each team at all levels is currently done through e-mails or via web browser, BIM environment can also improve the efficiency of the communications with better access to relevant information. It was also addressed that the current systems do not allow for knowledge sharing among energy managers across all public departments. It was highlighted that knowledge sharing can solve many typical and unusual problems specially for sites with special use such as historical buildings and can also improve the practices and add value to the used systems.

3.4. Energy Performance Certification

From the current practices, the National Calculation Method (NCM) (2010) is the methodology used to certify buildings. While NCM has got many criticisms in terms of the accuracy of the assessment, it is mandatory for new and existing buildings. NCM is used for the assessment of non-domestic buildings. The methodology, as shown in Figure 3, utilises certain parameters which include: Building geometry, Construction fabric, Usage pattern, and HVAC & lighting equipment. It also uses building models (usually a 2D model is generated by an energy assessor if not available, especially for existing buildings). These data is then manually transcribed into spreadsheet format prior to uploading into an Energy Performance analysis program, such as the (Simple Building Energy Model) iSBEM program or other accredited interface program to calculate the Building Emissions Rate (BER) in $kgCO_2/m^2/year$. The BER is to be compared with the Target Energy Rate (TER) calculated for a national building which has the same geometry of the actual building but with fixed glazing/rooflight fractions and fixed values for fabric thermal (U-values). The NCM exercise should meet the five criteria set by the Building regulation Part L, 2010 (in Scotland, Technical Handbook, section 6 Energy). Criterion one of this regulation mandates that

BER should be less than TER. The other criteria are mainly for guidance and include conditions to: control energy loss (e.g. insulation materials), reduce the need for air-conditionings systems (e.g. max glasses area in a room), ensure the as-built performance to deliver the design intent, and provide reasonable information to enable the building to be operated in an energy efficient manner. The NCM will result in producing the Energy Performance Certificate (EPC) which is always needed when a building is constructed, sold, or rented. The building also receives an asset rating and efficiency band (A^+ to G).

From the current practices, errors in the transcription process are expected and considerable time is spent by the multiple handling of data prior to final data capture by the programs such as iSBEM. Even if there is CAD building model (2D or 3D), there is no direct facility to import design data into these programs. One key issue that becomes a problem in using programs such as SBEM is the format of data storage under object tree structure which allows only basic representation of the building and makes the software incompatible with any other possible integrated environment such as BIM. There are other programs that offer streamlined data entry and can import a building model directly from a CAD based system. However, these programs are still constrained by the capability of the NCM algorithms and the object tree storage structure which makes them incompatible with BIM products.

While the NCM algorithm follows the steady-state principles, more advanced programs (such as: TAS and IES Virtual Environment) are based on Dynamic Simulation Modelling (DSM) algorithms to undertake dynamic assessment of a 3D non-abstract building model and apply hourly or sub-hourly analysis. These models also allow advanced analysis of micro-generation technologies and factors such as solar shading. The DSM programs can utilise direct data import from the CAD systems for a building without the restriction of the object tree structure. While the data from DSM is not currently specifically configured for external use in a BIM environment, these systems can be easily adopted for BIM.

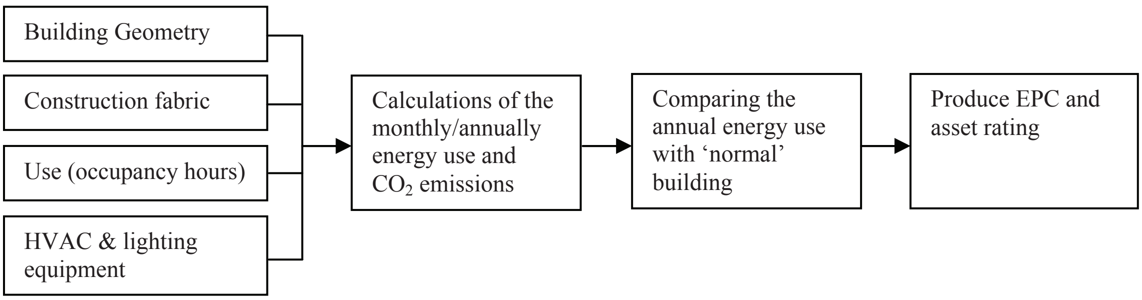

Fig. 3. The methodology of the National Calculation Method (NCM)

4. Sustainable BIM-based system for Buildings evaluation

From the studied operation stage in public buildings, as discussed above and shown in Figure 1, various information which comes from various phases of the building’s lifecycle should be available to operate and maintain the many complex energy systems used by buildings’ occupants. The amounts of building information is commonly fragmented, created over the building’s lifecycle by different teams with different objectives, and stored in different systems. The integration of this information is essential. Therefore, based on this research objective, an ontological framework of all types of energy-related information/knowledge and where they come from should be created and used during the design, construction, and operation phase of the building’s lifecycle. The ontology can be connected to a BIM modelled environment to spatially orientate necessary information/knowledge. The proposed ontology will help energy managers determine and evaluate the use of energy properly and also communicate well with the suppliers and contractors. The integration of the ontology with the BIM model and the relevant energy systems will help utilising these systems.

This investigation helped identify the main clusters of the required information, as shown in Figure 2. Once the ontology is fully developed, instances of the classes will populate the taxonomy embedded in the ontology and tied to BIM modeled environment, as proposed in Figure 4. The analyzed data flow is specific to energy practices in public buildings considered for this research.

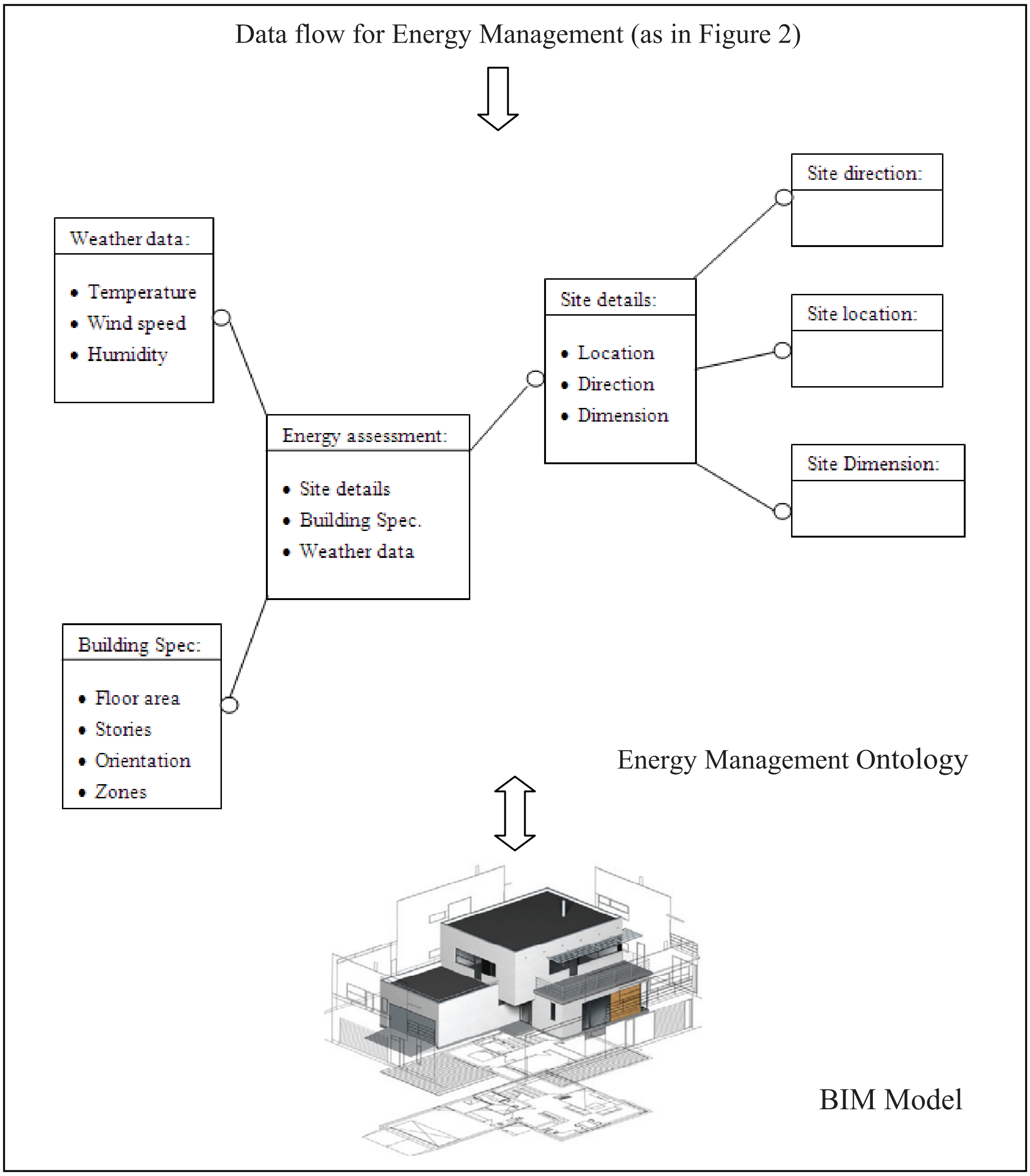

Fig. 4. Sustainable BIM-based system for buildings evaluation

5. Conclusions

The achievement of zero-carbon buildings requires monitoring and sharing the information/knowledge of building performance from the time the building is handed over to occupants. Therefore, there is a need to facilitate this sharing of information/knowledge among the stakeholders and supply chain. It becomes evident that BIM technology pioneers the discipline of collaboration among project teams. Practical implementations of BIM are mostly during the design and construction stage. There is limited research that links information/knowledge gained from energy practices and BIM models to improve the overall operations and energy efficiency of buildings. Therefore, this study aimed to identify the key operational and carbon performance variables needed for monitoring building performance and how a BIM approach can be used to utilise these variables in a better and consistent methodology to benefit all stakeholders. This will enable stakeholders to monitor building performance using unified language to achieve the CO_2 emission targets. On the other hand, sharing information/knowledge about the use of energy-efficient technologies will improve the means to reach occupants expectations and improve their working conditions. Using BIM technology to monitor building performance can also be used in designing suitable scenarios to maximise energy savings in order to match design and performance of buildings. This paper identified the information across the operation stage to support energy management activities in buildings. This information is used to develop an ontology of energy management to improve the process of energy savings and the quality of thermal comfort in buildings. The ontology will be linked to BIM modeled environment to ensure that relevant information for energy use and assessment is recorded throughout the lifecycle of the building. This will enable energy managers to access better organized information and allow for a spatial organization of the modelled information.

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