Title:

A framework for the utilization of BMS data in BIM to bridge gaps between building design and operation

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Abstract

Research on digitizing the various aspects of a typical building project has been on the increase since the advent of Building Information Modelling (BIM). Most efforts build on information technology capabilities already achieved in the various professional domains associated with different stages of the building life cycle. It is predicted that BIM will help to drastically reduce errors, fast-track project delivery time and save implementation costs. As such BIM is now being utilized in the various professional domains and project stages. However, research suggests that the building operation and management stage is being left behind despite the abundance of data collected using building management systems (BMS) of varying degrees of sophistication. It is therefore important to consider exploring BIM applications that encompasses the building operation phase. This will enhance the evaluation of building performance in use and provide feedback to the design stage which could help eliminate design-related performance issues. A framework for utilizing feedback loops from building energy consumption to inform and improve design and facility management in a BIM environment is therefore proposed. A prototype illustrating the framework is implemented in .NET framework interfaced with a BIM-enabled tool and tested in the refinement of a pre-designed school using data from the operations phase of another school delivered previously. We conclude that the framework developed in this research can contribute to bridging existing gaps between the design, construction and operation phases of a building's life-cycle.

Keywords: BIM; Building performance, Data acquisition, Facilities management

1 Introduction

The advent of BIM promises to greatly reduce the seeming complexities inherent in the facilities manager's tasks as well as those of other professionals in the construction sector. Current research on building information modelling (BIM) focuses on digitizing the various aspects of a typical building project as part of the design and perhaps construction stages. Hence, research efforts towards addressing BIM use in the operational phase is still at its infancy [1, 2].

Most of the current research efforts are built on the BIM/computer-aided capabilities already achieved in the various professional domains associated with the different stages of the building life-cycle such as planning, design, construction and, perhaps operations. For example, the object-based features and parametric modelling capabilities displayed by contemporary BIM-enabled systems are improvements on CAD systems and the earlier achievements made in the graphical representation of solid geometry [3, 4]. Similarly, domain-specific tools (e.g. for structural analysis and design, architectural drafting) have been in use and improved over the years as advances were made in information technology and communication. Perhaps this approach to software development resulted in persistent issues with interoperability, and thus barriers to seamless information exchange. The overall aim of the developing contemporary BIM approach is to provide consistent digital information that can be reused by stakeholders throughout the building life-cycle [4, 5]. It is predicted that BIM will help to drastically reduce errors, fast-track project delivery time and save implementation costs, as well as assisting with asset management.

As the scope of BIM gradually expands towards asset management, there is the need to learn from building performance by establishing and utilising feedback loops to the appropriate stages in the project life-cycle. This can be achieved through the establishment of frameworks such as the one implemented in this research. The envisaged benefits of using BIM for asset management include providing instantaneous results on anticipated building performance and identifying areas (such as energy modelling and sustainable material selection) of weaknesses in design and specifications so that they can be improved in forthcoming projects. Although sustainability (including energy) analysis tools for early planning and design purposes exist, the performance data they generate are disconnected and separate from their ultimate downstream use by facility management systems [6]. This also means that there is a gap in the upstream flow of feedback from the building's operational phase. The general consensus from literature [1, 6] is that the building operations phase is disconnected from the earlier phases of the project life cycle in terms of delivering the product and information exchange. It is alleged as a tradition but also as a key obstacle against asset owners extracting maximum value from their investments [6]. Thus, the anticipated value of design-operation integration can only be fully accrued if feedback loops from the building operations phase can be established.

In order to meet the relevant standards, design specifications usually identify materials and systems for production/construction according to anticipated performance mainly based on laboratory tests and manufacturers' claims on performance. The Literature suggest that the design stage offers a good opportunity to influence cost and sustainability [7, 8]. It is therefore important that performance information is verified from actual historical performance data collected during the operations phase. However, professional domains have not sufficiently explored this opportunity as identified in Oti and Tizani [9] and Wang et al [10]. Alwan et al [6] remarked that assets have been often made attractive by declarations of design aspirations while an ever expanding performance gap exists. In facilities management (FM), existing information gaps with design are partly because of the way projects are being delivered with little or no consideration for the integration of FM issues unless a Client consciously requires this to be done [6].

This paper aims to devise a framework for such integration. It illustrates how feedback loops from operations to design can be established by incorporating building management system (BMS) data into a federated BIM to inform the designer and the facility manager. Its objectives are to: (i) ascertain challenges in the integration of building operation and BIM (section 2), (ii) identify building energy consumption data acquisition and feedback options to BIM (Section 2.2), (iii) establish a framework for BMS data utilization in BIM (Section 4), (iv) implement a prototype to link BMS data to BIM (Section 5.1) and (v) test the system implementation in a real-life project (Section 5.2).

The paper is divided into seven sections. An introduction and insight into the research problem is given in Section 1. Section 2 provides a background on the role of performance data acquisition in facility management with respect to BIM leading to the description of the adopted research methods in Section 3. Sections 4 and 5 respectively present the proposed implementation framework for BMS data utilization and integration in BIM and illustrate a test case using the developed prototype. Section 6 discusses the research limitations including likely areas of future expansion and Section 7 concludes the paper.

2 Operations Data acquisition and integration in BIM

There are potential areas for BIM application in facilities management where feedback can be useful. Some areas already identified by Becerik-Gerber et al [1] include locating building components, facilitating real-time performance data access, visualization and marketing, considering ease of maintenance, creating and updating digital assets, space management, planning and feasibility studies for noncapital construction, emergency management, controlling and monitoring energy consumption, and personnel training and development.

While the modalities of BIM implementation may differ in all these areas, what will perhaps be common to all is the process of harnessing feedback from the model to inform and improve asset performance and vice versa. This process will require more than just engaging the facility manager in the design stage as suggested in Wang et al [10]. It will require careful planning, mapping and integration of the facility management operations into the BIM approach. This paper stems from this premise and evaluates the option of integrating building management system (BMS) into a federated BIM.

The use of building energy consumption data collected using BMS to improve the design and operation of buildings is an active area of research. It is concerned with the active control of energy-dependent systems in the operation phase of the building [11]. The technological advances in BIM offer opportunities to integrate BMS data. This area needs to be fully explored. The existing gaps in linking BMS data to BIM has been noted for contributing to the inconsistencies in graphical energy data generated from manual input of repetitive energy management system data [1].

The technological advances made in the development of building energy performance data acquisition systems are well acknowledged [1, 12, 13]. However, there have been challenges in utilizing such data to meaningfully inform and improve subsequent project design and delivery. The Big Data syndrome is also associated with the streaming of energy performance data from such acquisition systems [14]. More often than not, energy performance data collected from acquisition systems grow very large in size and is too unstructured to put to immediate beneficial use without some form of structuring and analysis.

2.1 Potential areas and tools for data acquisition during operations phase

Large amounts of data and information are produced at each stage of a building project. Detailed design information is produced for the successful delivery of the built asset and its end-use. Data is also generated during the life-time of the building until it reaches the end of its life. Most data that is generated in this latter stage is energy consumption data. Data may also be gathered on the maintenance activities and on occupancy levels. The energy performance of a building has an important impact on its overall performance. Literature suggests that the incorporation of energy efficient measures in buildings could improve the economic value of buildings [15-17]. Thus, clients and tenants prefer properties that will cost less to operate and maintain. Integration of BMS data into BIM may assist in this if a framework which helps make sense of abundant BMS data on energy consumption to reduce consumption levels can be developed. One of the current problems associated with this integration is that BMS data reveals how much energy is being consumed but it cannot on its own determine why this much energy is being consumed. Yu et al., [18] summarises factors influencing total energy consumption of a building into 5 main categories: (i) Climate, (ii) Building-related characteristics (type, area, orientation etc.), (iii) Building services systems and operation (space cooling/heating, hot water etc.) (iv) User-related Characteristics (user presence/occupancy) and (v) Building occupants' behaviour which is a function of social and economic status as well as preferences for indoor environmental quality. The first four factors can be modelled into building energy simulation programmes with certain limitations especially with respect to occupancy. BMS can be used to collate energy data on operational performance to a large extent. However, it has been difficult to accurately capture data on occupants' behaviour in terms of its influence on energy consumption, and more importantly to automate the collection of such data. Thus to make better sense of inherent energy consumption levels in BIM applications, it will be useful to integrate the modelling of these five factors that influence energy consumption. However, this is difficult to achieve for two obvious reasons: 1) it is difficult and costly to automate data collection in certain areas, e.g. in occupancy; and 2) very rich and detailed data on occupants' behaviour, which is variable, is required to make sense of energy consumption levels. This research focuses on developing a framework that would enable the authors make sense of (iii) Building services systems and operation as a starting point.

Building energy consumption modelling tools that could be associated with the aim of this paper relate to design and facility management (Table 1). Most of the design tools utilize conceptual design information such as volumetric and spatial data which could be provided directly through modelling or imported using gbXML file formats. These tools have been found to be lacking in providing requisite feedback of performance histories to BIM. Thus, it is difficult to input raw or refined BMS data in these tools for the purposes of analysis and linking such performance data back to a building information model for a number of reasons. First, a large volume of data will usually be involved [19-21]. Second, these tools cannot be easily reconfigured to receive energy performance data in a manner that suits the operations phase of individual buildings. Third, facility management tools do not carry out energy design and analysis at the early project phases but have the capability of capturing and reporting data generated at the field or during building operation. Fourth, these tools are largely dependent on the internet and cloud services.

Another option is to integrate BMS data to a building information model. Although literature on verified applications in this field is scarce, there have been speculations that Data Acquisition Technology (DAT) has been integrated with Onuma Planning Systems [13]. Also, there are indications that a building information model can be populated with energy consumption data using Autodesk Project Dasher [13]. Some demonstrations of Autodesk Project Dasher as a visualization tool overlaying energy performance data on 3D BIM can be found in Attar et al. [22] and Khan and Hornbæk [23]. Onuma Planning Systems and Autodesk Project Dasher are commercial and dependent on Cloud services. Therefore, licences are likely to be costly. Besides this challenge, these approaches may need to be realigned to address user targets concerning post-occupancy evaluation, and the reconfigurations that may be required could be costly and time-consuming. Also there could be challenges with familiarity and technical know-how on the part of building occupants/users. Thus, building owners who may not come from the design and construction background may struggle to understand what systems they need and their associated operation compared to a bespoke developed plug-in such as that proposed in this research.

Table 1: Building energy management tools

TOOL	FUNCTIONAL DESCRIPTION
Building energy performance tools for design purposes	
Autodesk Ecotect	Sustainable design analysis software that offers a range of simulation and building energy analysis functionality to improve performance of existing buildings and new building designs. Its capabilities include Whole-building energy analysis, Thermal performance, Water usage and cost evaluation, Solar radiation, Daylighting and Shadows and reflections
Autodesk Green building studio	Cloud-based energy-analysis software used for whole-building analysis optimization of energy consumption and carbon-neutral building designs in early project phases. Functions include Whole-building energy analysis, Detailed weather data, Energy Star and LEED support, Carbon emissions reporting, Daylighting, Water usage and costs, Natural ventilation potential
DOE-2	A building energy analysis program that can predict the energy use and cost for all types of buildings. DOE-2 uses a description of the building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills.
eQUEST	A building energy use analysis tool that allows comparison of building designs and technologies by applying sophisticated building energy use simulation techniques.
BEopt	The BEopt™ (Building Energy Optimization) software can be used to evaluate residential building designs and identify cost-optimal efficiency. It can be used to analyse both new construction and existing home retrofits. It provides detailed simulation-based analysis based on specific house characteristics, such as size, architecture, occupancy, vintage, location, and utility rates.
Facility Management tools	
Artra (Trimble)	ArtrA provides seamless information links between the multiple engineering systems. It enables information to be provided in the relevant format for jobs and has mobile capability for delivering complex data.
Onuma Planning Systems	A web-based Building Information Modelling (BIM) tool that can be used for early planning, Project Program Development, Charrettes (BIMStorms), Schematic Design, Connect to other BIM applications, Cost estimating, Energy Analysis, Life Cycle Costing, Facility Management, Portfolio and Program Management
Autodesk Project Dasher	Project Dasher is a web-based application that helps to augment existing Autodesk® Revit® design models with real-time building sub-meter and sensor data on electricity and occupancy. It presents a comprehensive framework for monitoring building performance using a visualization hub where collected data from various sources is intuitively aggregated and presented in 3D to enhance the ability to infer more complex causal relationship pertaining to building performance and overall operational requirements.

2.2 Approaches to the integration of BMS data to BIM

BIM tools are still developing. Currently, they have not been fully furnished with facilities for carrying out energy analysis of data directly from BMS. The purpose of this paper is therefore to facilitate the understanding of how BMS data analysis can be used in BIM to aid building professionals/users. A pre-designed scheme, where buildings such as schools are built from an existing design with some modifications/variations should they become desirable or necessary, is used for illustration purposes. Such a scheme is chosen as it is considered to benefit most from feedback on the performance of the building during its use to successive design iterations. First, the most effective means to providing such feedback are identified. Then, a tool to extract and compare BMS data analysis is proposed to inform design iterations taking advantage of the recent technological developments in BIM and the increase in its uptake. The integration of facility management with BIM that particularly relates to the aim of this paper has two basic approaches to linking BMS data to BIM: (1) BMS – Energy Analysis Tool – BIM link and (2) Energy Consumption Viewer Plug-in – BIM link.

- **BMS – Energy Analysis Tool – BIM link**

In this approach (Figure 1), it is envisaged that BMS data can be sent to Energy Analysis tools (via file transfer, the internet or cloud services) to carry out requisite analysis before feeding the outputs to building models in a BIM-enabled tool. This approach can take advantage of database management systems, open file formats and common data environments. The linking of DAT to Onuma Planning Systems [13] falls into this approach. It is also possible to have the Energy Analysis Tool in a single module with the BIM tool (such as Autodesk Project Dasher) or integrated with the BMS data collection as presented in Attar et al [22] and Khan and Hornbæk [23]. These systems are economically demanding to acquire and require reconfiguration to become fit-for-purpose to address post-occupancy evaluation targets [13]. Although these tools may have some high level sophistication (having been developed by established commercial software developers), there are still challenges with flexibility in configuring them to stream data from existing BMS systems due to interoperability issues [19].

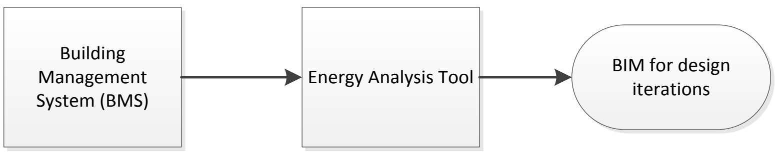


Figure 1: BIM - Energy Analysis Tool link

- **BIM – Energy Consumption Viewer Plug-in link**

Here, a BIM tool is bolted with an external application such as our proposed Energy Consumption Plug-in to enable the viewing of energy consumption profiles of buildings (Figure 2). A plug-in is an external application which can be continuously improved in sophistication through computer programming. The plug-in can use processed/refined BMS data and it can be linked to a BIM-enabled tool through associated application programming interface (API). Depending on the sophistication of the plug-in, aspects of consumption data analysis could also be carried out in the plug-in environment. The plug-in serves as a new external tool to the BIM environment which can be called up for the visual presentation of historical energy performance to ease understanding of non-experts such as building occupants. More importantly, it allows for the comparison of performance across a number of projects which have been built primarily to the same design. As a result, it becomes the initial step in determining the reasons behind different levels of performance in different buildings which would have had similar performance results during design simulations. This approach, thus, provides a flexible way to input refined BMS data into the prototype system for display in a BIM environment that can be used in refining the pre-designed schemes.

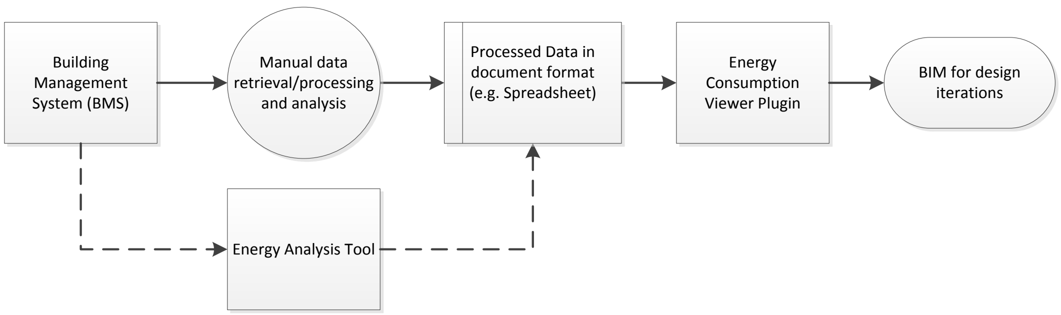


Figure 2: BIM - Energy Viewer Plugin link

3 Research method

One of the objectives of the research project is to achieve better integration of energy performance data from completed projects in a BIM environment. The research ideas about BMS-BIM integration are tested as part of the continuous improvement of a pre-designed scheme for schools, which is delivered as a turnkey project using a framework agreement. The pre-designed scheme is particularly important for this study as there is a clear advantage of using knowledge from the operations phase to continuously improve it and the associated federated model for successive clients. Also, facility managers may learn from historic performance records contained in the model to manage future consumption. In the sub-sections, further description is given about the test project and energy performance data gathering process. The approach adopted in modelling sourced data and the prototype developments are also described briefly as well as the context of key terms featuring in the paper.

3.1 Test project description and data sources

A real life case is chosen to evaluate how BMS data can be analysed and feedback sent to design iterations using BIM. The case is a new primary school project based on a pre-designed scheme with good energy performance. The school building is a single storey steel portal frame structure with a floor area of 1187 m^2. It has an overall Energy Performance Certificate (EPC) 'A' rating suggesting that the building excels in (i) All-electrical services strategy, (ii) Solar-thermal hot water system and (iii) Natural ventilation via windows/roof lights, etc. The performance targets for the building were set in terms of energy use, running costs and carbon emission levels for both regulated usage (building services such as heating, hot water and lighting) and un-regulated usage (IT server, kitchen equipment, plug in appliances etc.), which formed an integral part of carbon emission targets at the time this project was conceived.

A literature review has been carried out to establish research gaps and appropriate methodologies for achieving the set objectives. The review covered aspects relating to the modelling of building energy consumption histories from building energy management systems (BMS) to BIM environments. This helped in identifying research gaps associated with incorporating building performance information to BIM and possible process options for such communication.

3.2 Modelling approach

For the aspect of information modelling, established techniques such as the Rapid Application Development (RAD) approach [24] aided by IDEF3 modelling language, was used to develop a framework for utilizing performance histories in BIM and facilities management. The RAD methodology employs cycles of re-specify, re-design and re-evaluate on the prototype system from its conception to when it achieves a high degree of fidelity and completeness. The prototyping process is therefore characterized by increased speed of development and experiences of series of births rather than deadlines. It informed the implementation of a prototype in .NET Frameworks which entailed the interfacing of a

BIM-enabled tool with object oriented representation of information in C# programming language.

Series of system testing typical to the RAD approach were carried out to refine the prototype and check that underlying programming algorithms and assumptions are functioning correctly. To achieve the overall testing of the prototype, case-illustration has been employed using consumption data already acquired from a building management system on a school building project based on a pre-designed scheme. This opportunity arose from the on-going research collaboration on low-impact school procurement which has developed within a mutually acceptable ethical understanding. In addition to achieving programming requirements such as flexibility and ease of operation, suggestions from project stakeholders including the main contractor, the architects, the project managers and the energy experts were injected into refining the framework.

3.3 Definition of key terms

In this research, we build the framework for BMS data utilization in BIM around the digitized building model which is a representation of the physical building (life-building) to be built or already built. Just like the life-building undergoes transformation from stage to stage, the digitized building model also changes but at a very different pace as conceptually illustrated by the authors in Figure 3. At the early stages of planning/design the digitized models develop, in terms of extractable information, at a much faster pace than the life-building and then lags at the latter stage. Thus, the realisation (construction) of the life-building is dependent on the digitized building model (As –planned BIM) which in turn becomes dependent (updated with information as As-built BIM) on the realised (constructed) life-building. During building retrofitting, the As-built BIM may be used for retrofitting design or be updated with the new retrofitted information when completed. At the end-of-life of the physical building, the digitized building model (As-built BIM) can further be updated finally and archived for future uses. For better understanding, the terms As-planned BIM and As-built BIM are defined in the context of this paper.

(i) As-planned BIM

We refer to As-planned BIM as the digitized building model containing design specification as provided by building professionals for the purpose of construction on site. It encompasses all BIM developments that precede the completion and handover phase. As-planned BIM may include the individual digitized models of various professionals or the federated model of the individual profession BIMs.

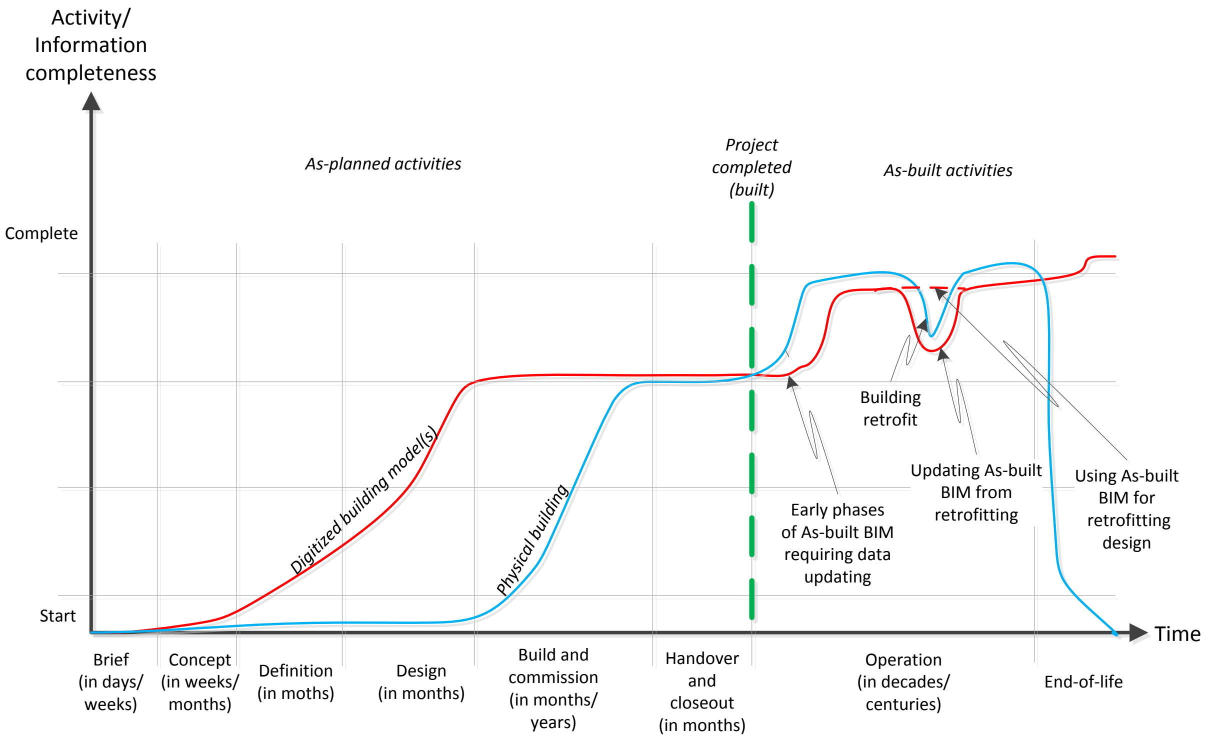


Figure 3: As-planned versus as-built information in building models

(ii) As-built BIM

The use of the term As-built BIM in this work is consistent with the literature which describes it to be the as-built or as-is representation of the constructed building at the state of survey [25]. As-built BIM may be developed from As-planned BIM, using progressive point cloud laser scanning, images from high resolution/density cameras etc. [26, 27]. Since it is a reflection of the building as-is (all elements – Architectural, structural, MEP etc. – in place), the federated model after the completion of construction is a good starting point for generating and updating the As-built BIM.

4 A proposed framework for data acquisition utilization in BIM

As the building in the case is a product of pre-designed scheme for schools, there are two levels of the digitized building model development in the BIM environment. First, there is a generic digitized building model level in which pre-designed models are continuously developed to strengthen the market offering. Second, there is the site-specific digitized building model level in which a pre-designed model is adopted to integrate it with other models (e.g. site and furniture) to form a site specific model. The development is illustrated in Figure 4. Upon confirmation of a project proposal, existing drawings, textual information and specifications from a generic digitized model are reproduced and then integrated with various digitized site models and supply chain models. These combinations can then be further tailored as site- specific building information models for construction and operation. These processes produce progressive As-planned BIM, As-built BIM and the live BIM which are used for the actual construction phase and during operations. They also serve as channels to supply feedback to the Model Preparation stage for the refinement of the generic building design model. The aspects that are of direct concern with the discussions in this paper have been highlighted by the broken line in Figure 4.

An aspect of demonstrating a learning process through feedback is explored in the proposed framework for data acquisition utilization in BIM is illustrated in Figure 5 using IDEF3[1] notations. The framework is aimed at ensuring the utilization of BMS data to facilitate continuous improvements in building design and facility management by learning from historical records of energy usage. This is achieved through identifying and modelling factors that influence consumption levels associated with various categories of energy usage. The process is decomposed to two lower levels: (1) Data acquisition and analysis process (DECOMP 4.1) and (2) Analysis of causes and effects (DECOMP 12.1) from the top level (Improve BIM through data acquisition).

[1] IDEF3 is a structured descriptive process modelling language used to capture sequence of events and express knowledge about the operation of systems 28. R.J. Mayer, C.P. Menzel, M.K. Painter, P.S. Dewitte, T. Blinn, B. Perakath, Information integration for concurrent engineering (IICE) IDEF3 process description capture method report, 1995, DTIC Document.

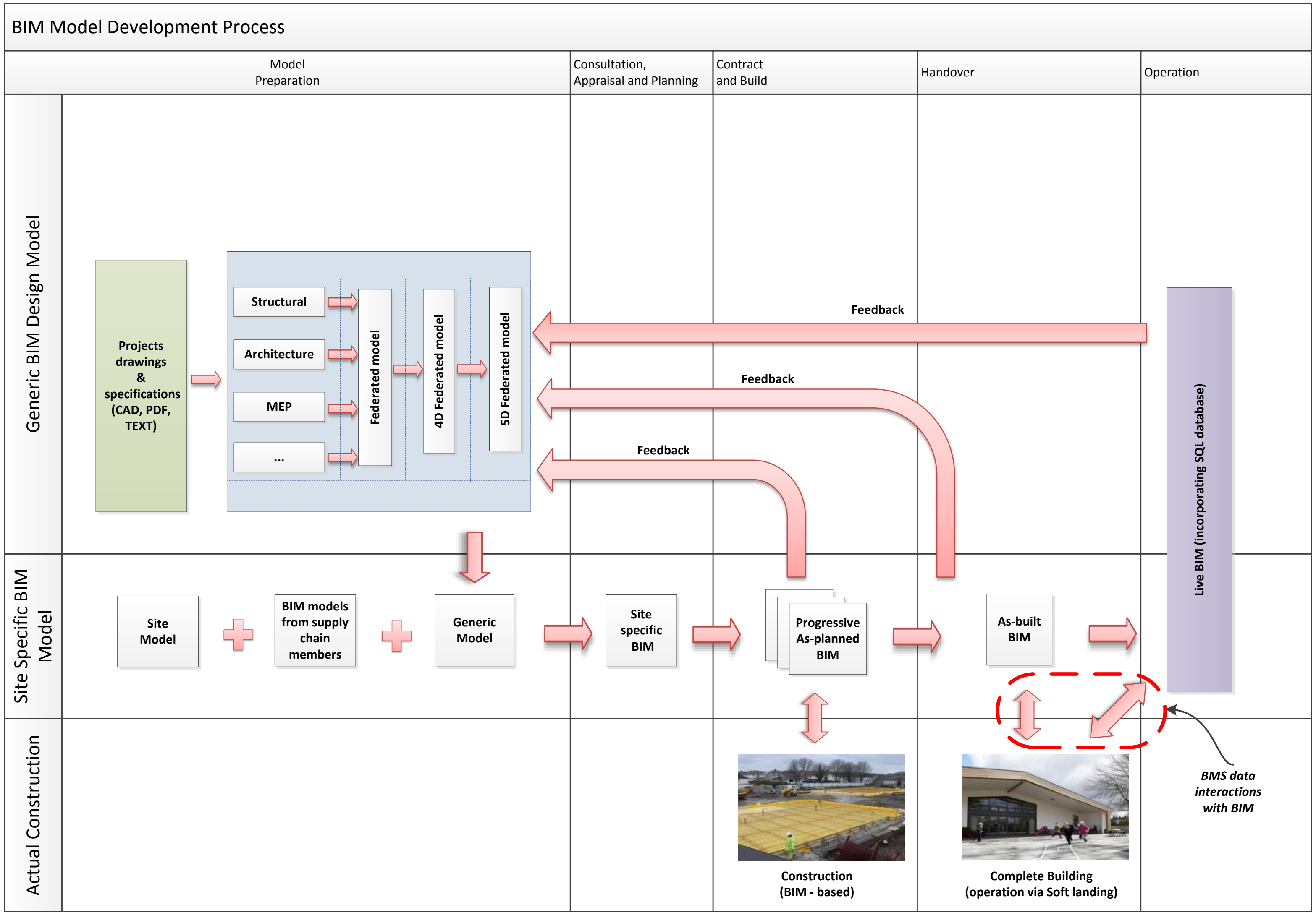


Figure 4: Using BIM to improve the turnkey process

4.1 Improve BIM through data acquisition

The Top Level of the framework (Figure 5) expresses the overall aim of improving BIM through data acquisition. It is comprised of 7 processes known as units of behaviour (UOBs), two of which are parallel – implying alternative routes of utilizing acquired data. UOB 1 is based on the assumption that a digitized building model, known as As-planned BIM, exists for a proposed building project. The proposed building is constructed and operated based on the As-planned BIM as indicated in UOBs 2 and 3. Feedback loops from UOBs 2 and 3 to UOB 1 have been indicated to capture modifications of design models as a result of interactions with construction/operation teams. It is at the operation stage, UOB 4, that actual building performance data is acquired for further utilization to meet various intended purposes. UOB 4 is expanded at the first decomposition level. However, the acquired data from this process can either be used to benchmark and reduce energy consumption (UOB 5) or utilized to improve design (UOB 6). These two processes converge to be integrated into the digitized building model (BIM) for future use in UOB 7. This is particularly relevant for the building information model in this case of the pre-designed building model for delivery. So, the knowledge gained from the analysis will be used for the development of the pre-designed building model and/or to learn from historical performance records contained in models to manage future consumption. One challenge that is worth careful consideration and perhaps further research is who will be responsible for feeding information back to the model at the building operation stage and how this will be done. This issue is discussed further in Section 6

4.2 Data acquisition and analysis process

In Figure 5, the highlight of data acquisition and analysis process (DECOMP 4.1) is the comparison of As-planned and As-built performances (UOB 4.1.9) from the preceding process of analysing the building performance (UOB 4.1.8). In UOB 4.1.8, data captured from the BMS is processed into formats showing energy consumption patterns for easy understanding and assimilation. This might require special skills peculiar to services engineers, HVAC specialists or the post-occupancy evaluation team, perhaps using purpose-built IT. For UOB 4.1.9, the comparison will yield two groups of information. The first group, represented by UOB 4.1.10, is the path where the As-built performance is lower than the As-planned performance. There could be a number of reasons resulting in this phenomenon. In addition to design errors and possible construction deficiencies, one other likely reason is that the facilities/systems may not yet have been occupied according to the capacity for which they have been designed. The second group indicated in UOB 4.1.11

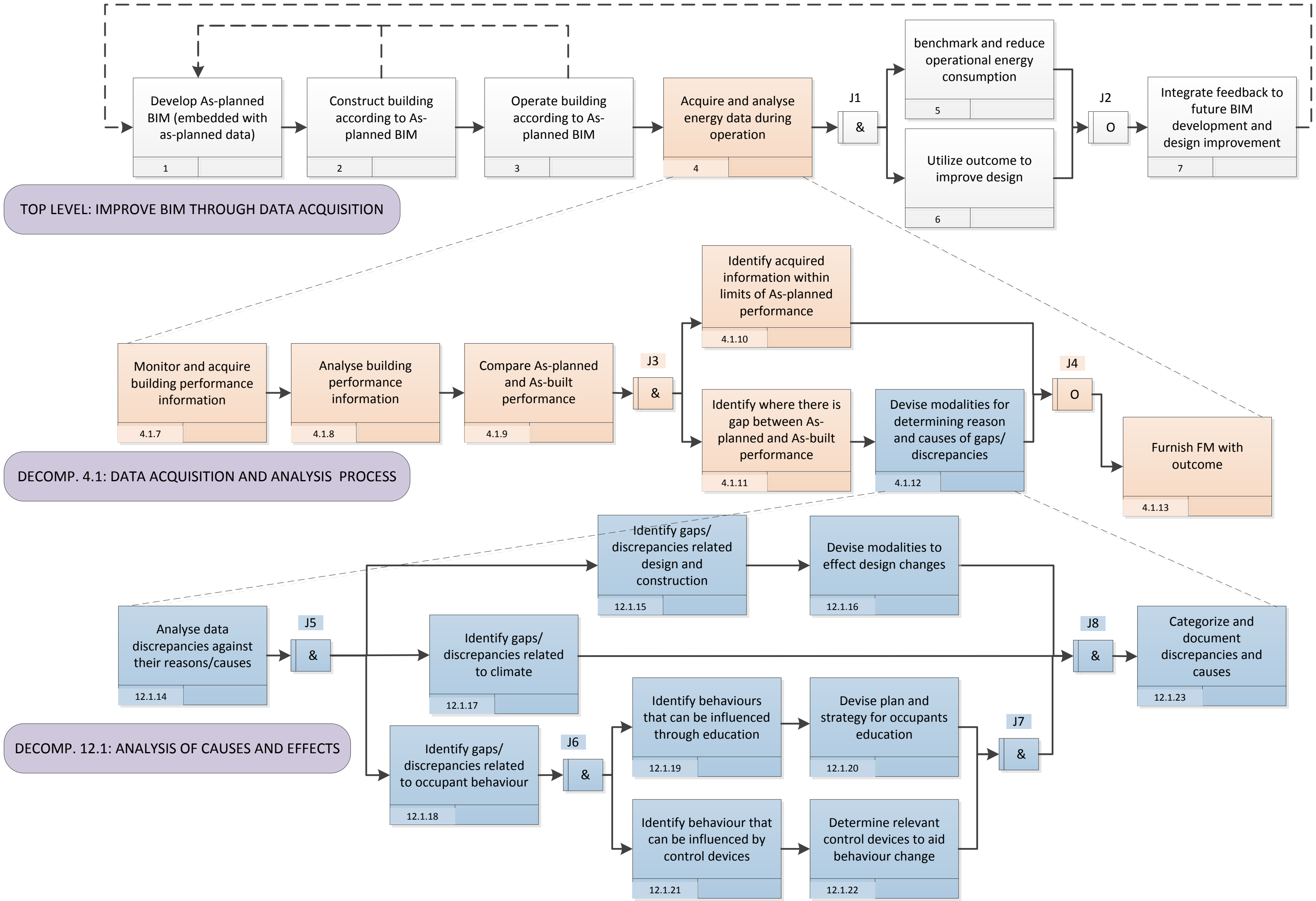
encompasses all As-built consumption levels that are greater than that of their planned/designed counterparts. The focus of further analysis is on this group. It entails determining reasons and causes of gap/discrepancies (UOB 4.1.12) resulting in As-built consumption levels rising above design benchmarks. The outcomes of these two parallel paths converge as information to be utilized by the Facility Management team for product improvement purposes. In the overall process, the resulting feedback lessons flow to planning and design for enhancing the process of delivery and the improvement of the product itself.

The importance of considering the overall consumption level of As-planned performance and As-built performance is worth mentioning. With varying levels of consumption categories, it is possible for the overall consumption level of As-built performance to be less than As-planned performance with some categories of As-built consumption levels exceeding that of their design counterparts. Even if this occurs perhaps as a result of the facility running under full capacity, it is still important to examine the categories of consumption that exceed design benchmark to ascertain causes and proffer solutions for the purposes of improving performance levels.

4.3 Analysis of causes and effects

In this third level (DECOMP 12.1), the reasons and causes of gap/discrepancies resulting in As-built consumption exceeding design benchmarks are determined. Three parallel paths are possible in determining the causes and effects of related discrepancies. First (UOB 12.1.15), lapses in design and construction of the building could be causing the problem. Instances could be failure to achieve the desired airtightness around openings such as windows and doors. If such causes are identified, it is possible to proffer remedies through retrofitting and renovation works. Second (UOB 12.1.17), climatic conditions can greatly influence behaviour of building occupants and as such result in high consumption levels. It is expected that prolonged extremely cold periods during the winter will result in higher energy usage for air conditioning and heating. In terms of remedy, not much can be done about the climate and as such difficult to correct discrepancies induced by the climate. Third (UOB 12.1.18), reasons why operational energy consumption levels exceed design benchmarks could also be attributed to occupants behaviour. There is some potential to achieve reduction in energy consumption level from this group because of the possibility of using education and technology to help humans adjust or control their behaviours. The framework therefore suggests exploring influencing human behaviour by means of education or the use of control devices based on the nature of the behaviour.

Thus, identifying the factors influencing consumption levels is a key element of the framework. The framework sums up that besides factors resulting from building design and construction modifications or errors, the climate of the environment and human behaviour are key contributors to varying levels of consumption. While not much can be done about the climatic conditions, aspects of behaviour can be controlled to achieve reductions in energy consumptions. A further challenge is in the identification of such behaviours and devising modalities to curtail them. The actual practicalities of achieving this requires further research involving field work and falls outside the scope of this paper. It is worth mentioning that there have been research efforts in this direction, albeit, to establish models that appreciably imitate human behaviour in energy simulation systems [29] and identify effects of occupant behaviour on consumption [18, 30].



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84 **Figure 5: Mapping of proposed utilization of BMS data**

5 A case illustration of framework implementation

The framework for data acquisition and utilization in BIM is implemented using a prototype as a demonstration of proof of concept. The technicality involved in developing the prototype is explained in this section including a scenario of using the prototype in a real-life project.

5.1 Features of the prototype for data acquisition utilization in BIM

The approach adopted in developing the prototype for data acquisition utilization in BIM is the BIM – Energy Consumption Viewer Plugin Link discussed in Section 2.2. The prototype is developed in Revit 2014. It can be configured to work in Revit 2015 or new versions to come. The implementation of the prototype system was carried out in C# using .NET and linked to the BIM enabled software (Revit 2014). The prototype plugin can be accessed via the external tools link in Revit 2014 IDE. It functions as an extension (See Figure 6) of plugin application of the earlier research work on the sustainability appraisal of structural steel framed building [31].

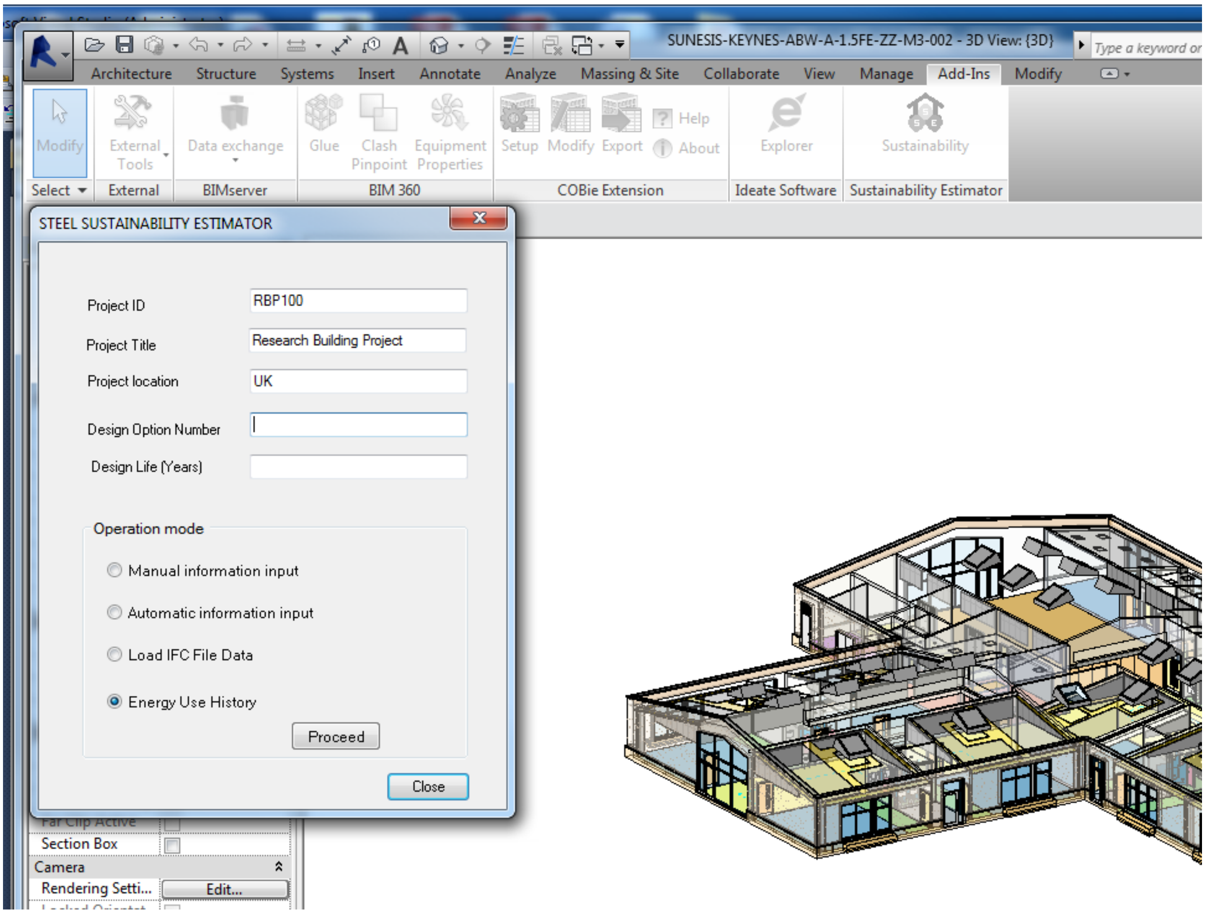

Figure 6: Plugin options selection

The prototype has been developed through the iterative testing of system components following the RAD approach. The RAD approach is characterized by increased speed of development and progressive system refinement to achieve early usability. The flowchart illustrating the actions and processes captured in the prototype system is given in Figure 7. Further details of the sequence of events regarding the functions (input and output) of the user (designer) and system are captured in Figure 8. The programme is called through the Energy Use History option of the sustainability Estimation Programme from a BIM enabled environment. On the selection of the project (by name) to examine, the type of information to further explore can then be specified. This offers the option of comparing Design benchmarks and Actual Consumption records or examining various energy consumption categories. These records are extracted by the system from spreadsheets saved in the various project names and containing pre-defined energy consumption data. The consumption categories can be examined for a single project or a combination of projects. The intention of such combination is to compare and contrast trends of similar consumption categories of different projects. The system then displays corresponding output charts; from this point, reports can be produced. The user can switch back and forth between different projects and consumption categories or quit the programme.

The prototype accesses design data and processed BMS (energy consumption) data saved in MS Excel file formats and expresses abstracted information on energy consumption in terms of ‘Design’ and ‘Actual’ performances for buildings. These values are compared at various levels of granularity to investigate waste and encourage the use of appropriate measures to reduce consumption levels and save cost. At the moment, the input data into the plugin need to be provided in Excel file format which requires manual processing of the BMS data. However, there is a possibility that this function of processing BMS data and saving in Excel Format can be done by appropriate energy analysis tools, if they become available. For the purposes of demonstration of concept, we have used manual processing by which we mean programming spreadsheet calculations to transform the BMS data to the required level and format. The resulting spreadsheet data resides in a folder within the solution programme of the prototype and serves as part of its input information for providing requisite energy consumption plots. Currently, the spreadsheet is residing on its own within the prototype environment and not linked to any BIM object. The data in the spreadsheet is rather accessed by the prototype when called up in the BIM environment. Future aspects of expansion will consider automating the processing of BMS data by incorporating this aspect within the prototype. Furthermore, we will explore the possibility of linking processed consumption data to BIM objects to achieve more precise object-information relationships.

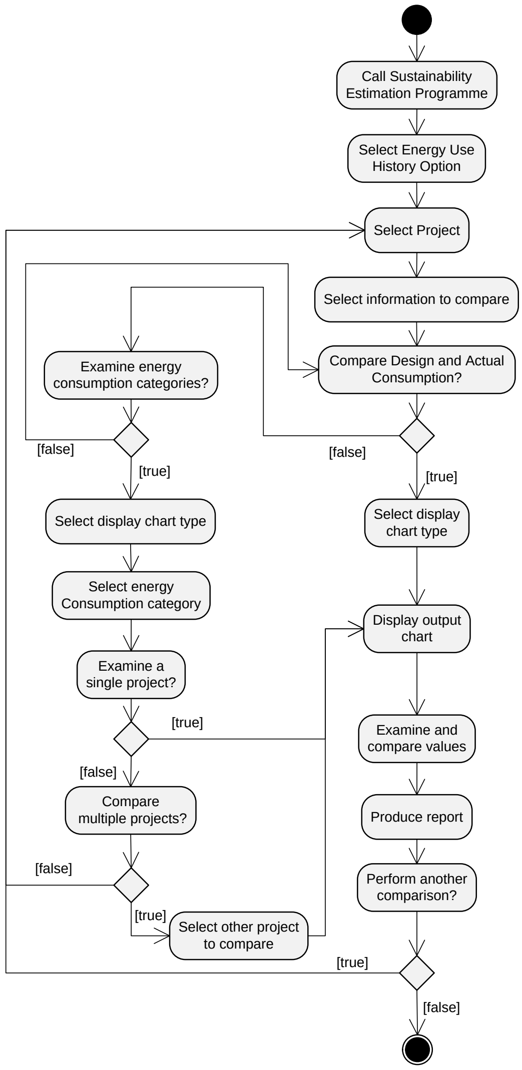

Figure 7: Prototype implementation flowchart

5.2 A test case of using the prototype

Three projects have been used to illustrate the testing of the prototype. The data from one of the projects (Project 1) has been obtained as part of a collaborative research project between a main contractor and a school. The data from the other two projects were generated as a variant of Project 1 in order to demonstrate the operation of the prototype. Project 1 is a primary school building in the UK completed and opened for use in October 2012 with a data acquisition system in place and running. Energy consumption data has been collected and processed in spreadsheets serving as ready input for the prototype. The spreadsheet resides in a folder within the programme solution of the prototype. The relevant information were extracted from the spreadsheet and recorded in formats for easy abstraction by the prototype. The example data used in this case is given in Table 2. It is worth mentioning here that the process of entering data into spreadsheet is generally prone to errors. In transferring BMS data to spreadsheets, a system to check data fidelity is important. This may be accomplished through independent revisions but it is much better to incorporate facilities to automatically transfer streamed BMS data directly to spreadsheets. The processed BMS data is imported from the spreadsheet into the prototype for further analysis and displayed in the BIM-enabled environment. Since the prototype can be called in a BIM-enabled environment, the operation history of consumption levels and design benchmarks of buildings can be compared.

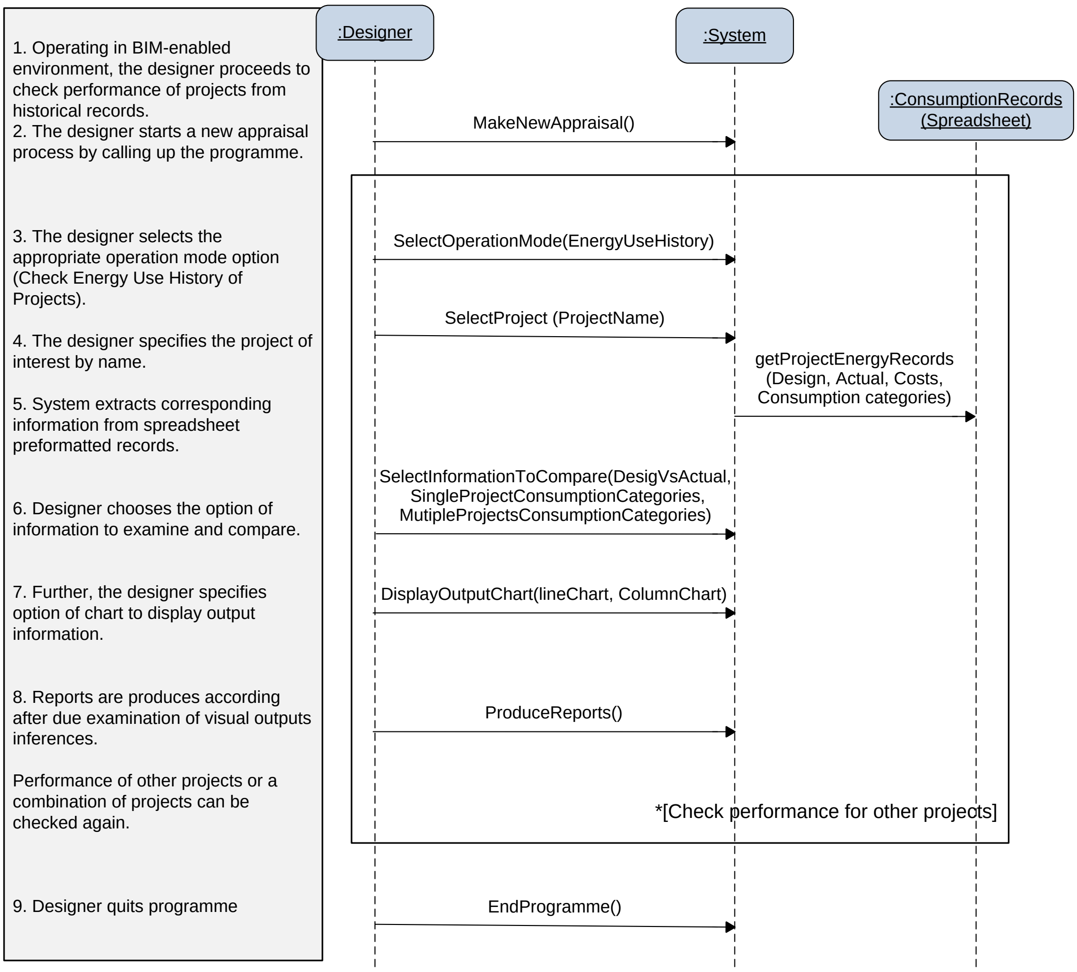

Figure 8: System sequence diagram

Table 2: Processed project consumption data

Description of consumption category		Average daily periodic consumption (kWhr/day)														Consumption for whole period (kWhr)	
		8 - 14 Nov 12	14 - 28 Nov 12	28 Nov - 20 Dec 12	20 Dec 12 - 5 Feb 13	5 Feb 13 - 7 Mar 13	7 Mar 13 - 25 Apr	25 Apr - 3 June	3 June - 11 July	11 Jul - 9 Sept	9 Sept - 14 Oct	14 Oct -5 Nov	5 Nov- 5 Dec	5 Dec - 25 Feb		Design	Actual
Heating	Heating	95.70	98.62	154.10	118.36	146.56	101.19	27.71	0.00	0.00	17.70	53.16	116.21	118.26		15266.80	25398.81
Hot Water	Hot Water	37.45	44.63	59.58	42.15	65.81	81.69	39.94	42.79	35.27	39.79	36.03	38.46	38.53		7477.95	18140.87
	Auxiliary - general	5.74	-5.05	9.40	6.20	9.27	10.50	3.69	0.98	0.64	2.38	5.73	7.04	8.41			
Auxiliary	Auxiliary - kitchen extract	2.64	2.55	16.38	59.41	53.83	29.02	1.15	2.68	7.26	15.55	1.55	1.04	9.92		5399.03	9710.50
	Lighting - DB01	1.11	4.82	1.17	0.25	0.68	0.02	6.06	11.39	5.05	14.69	13.05	18.99	13.73			
Lighting	Lighting - DB03	48.03	50.56	49.06	33.61	40.22	34.21	31.47	38.86	24.48	43.97	37.58	51.90	41.15		15316.63	16012.84
	Small power - DBP03	6.87	7.33	8.24	6.88	7.48	7.56	7.09	8.01	5.05	8.13	6.77	7.47	6.65			
ICT + Misc power	Small power - DBP04 (Server)	39.28	37.75	46.42	36.77	38.76	37.82	37.68	39.90	30.54	40.31	36.17	40.08	35.94		56158.49	17223.51
Kitchen Equip.	Kitchen Equipment	43.32	41.75	47.52	36.49	42.53	41.23	43.80	45.29	35.81	44.33	41.34	47.90	44.24		18504.98	15968.43
Ext. Lighting	External Lighting	19.56	19.48	24.15	23.66	20.96	16.56	13.09	11.69	13.89	18.66	21.75	23.86	24.00		1095.36	6833.30

Figures 9 and 10 show alternative chart views of the design and actual energy consumption figures (details in Table 2) of Project 1 from November 2012 to February 2014. Similar charts can be obtained for the other projects. Thus, project information need to be entered in prescribed Excel format and loaded into the prototype to appear in the list of Projects and Analysis listBox. The advantage of these charts to designers is that they will help to provide opportunity for quick review of design and performance benchmarks for more critical examination and analysis where required. For example, the designers' attention may be drawn to the Heating, Hot water and ICT sub-consumption categories for further investigation if the respective charts reveal some unexpected outputs. More specifically, the design and actual energy consumptions curves in Figure 9 show an unusual discrepancy on the ICT + Misc. power category. For ICT + Misc. power, the design value (56,158kWhr) is much higher than the actual consumption value (17,224kWhr) while lower for all other categories. Such revealed discrepancies call for further investigation, the outcome of which can be useful in refining the design or to the team operating the facility. For instance, it could be that the design assumptions for the ICT + Misc. power category may have been over board or the corresponding actual energy consumption is not yet running at full capacity. For either case, further investigation will reveal the true cause of the situation which can become useful information to inform future designs and project delivery.

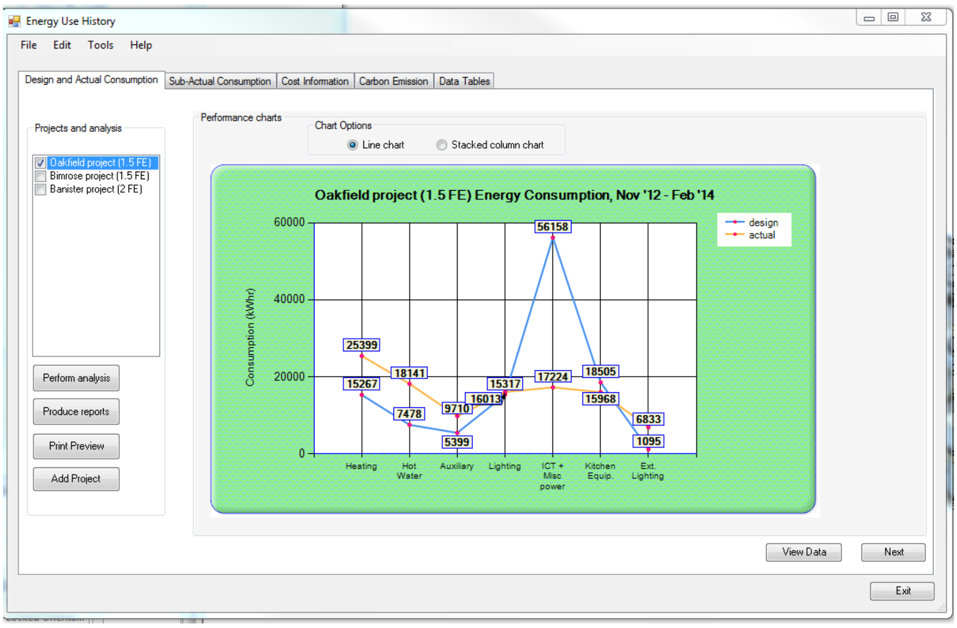

Figure 9: Comparison of Project 1 design and actual (line chart)

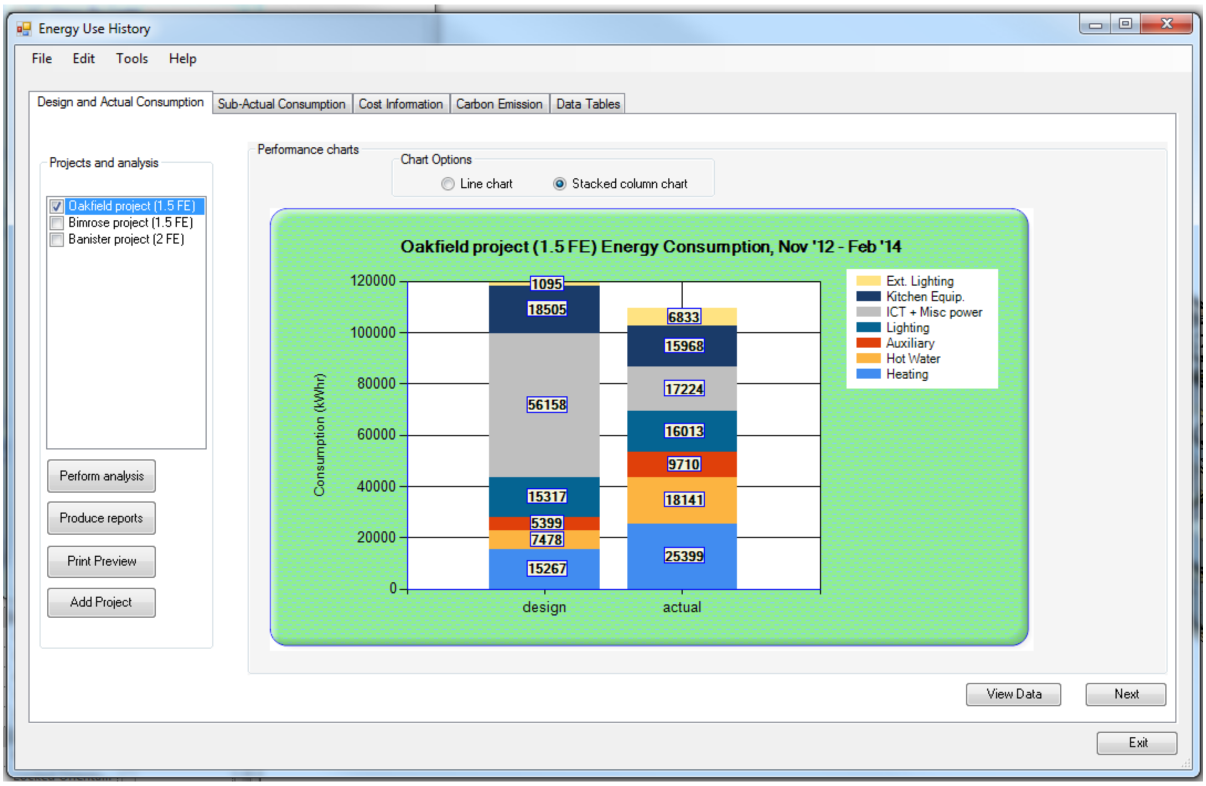

Figure 10: Project 1 design and actual stacked column comparison

Also, it is possible to view a combination of the sub-consumption categories (see Table 2 for data) as line or column charts as shown in Figure 11. Individual categories of energy sub-consumption such as Heating, Hot Water, Lighting etc can be further examined (Figure 12) for each of the listed projects or compared with other projects (Figure 13). Such comparison has the potential of revealing projects with abnormal consumption trends that warrant further investigation into possible causes and effects. Further, the prototype can compare information on energy costs for design and actual consumption of projects. As before, this can be done for any of the listed projects as illustrated in Figure 14 and also compared on a project basis (Figure 15). These charts and the underlying data can be viewed and printed for hard copy recording. The prototype is programmed to compare a number of projects but illegibilty of fonts may become an issue if there are more than 10 projects. Users can achieve some relative degree of ease in formating BMS data and loading such into the prototype if the intervals of data collection or streaming from the BMS is similar.

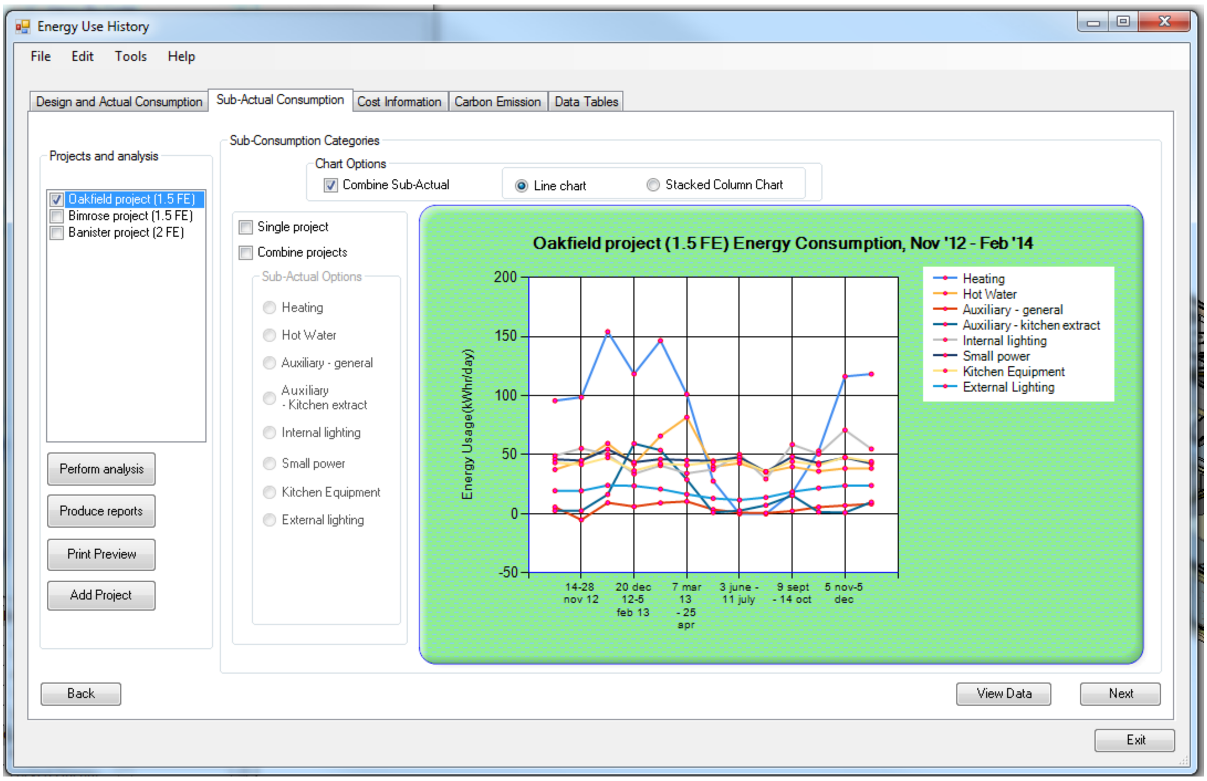

Figure 11: Sub-actual consumption categories for Project 1

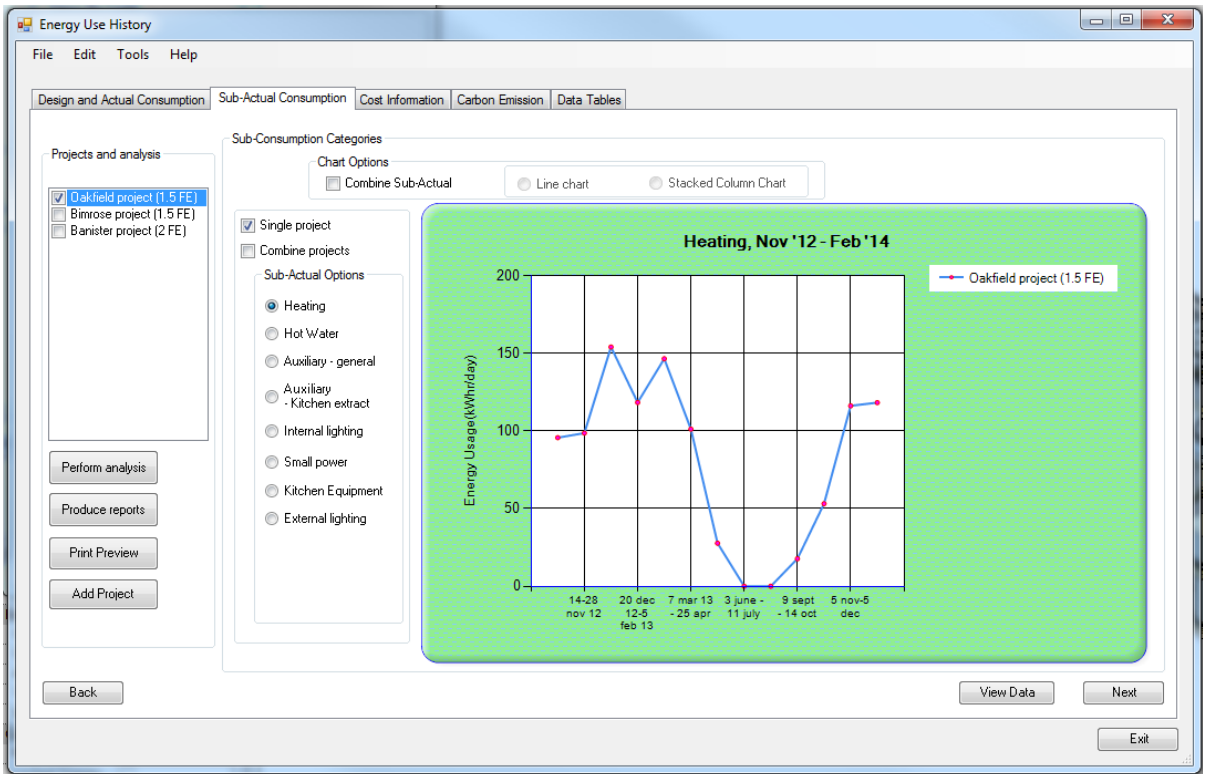

Figure 12: Individual sub-actual consumption category

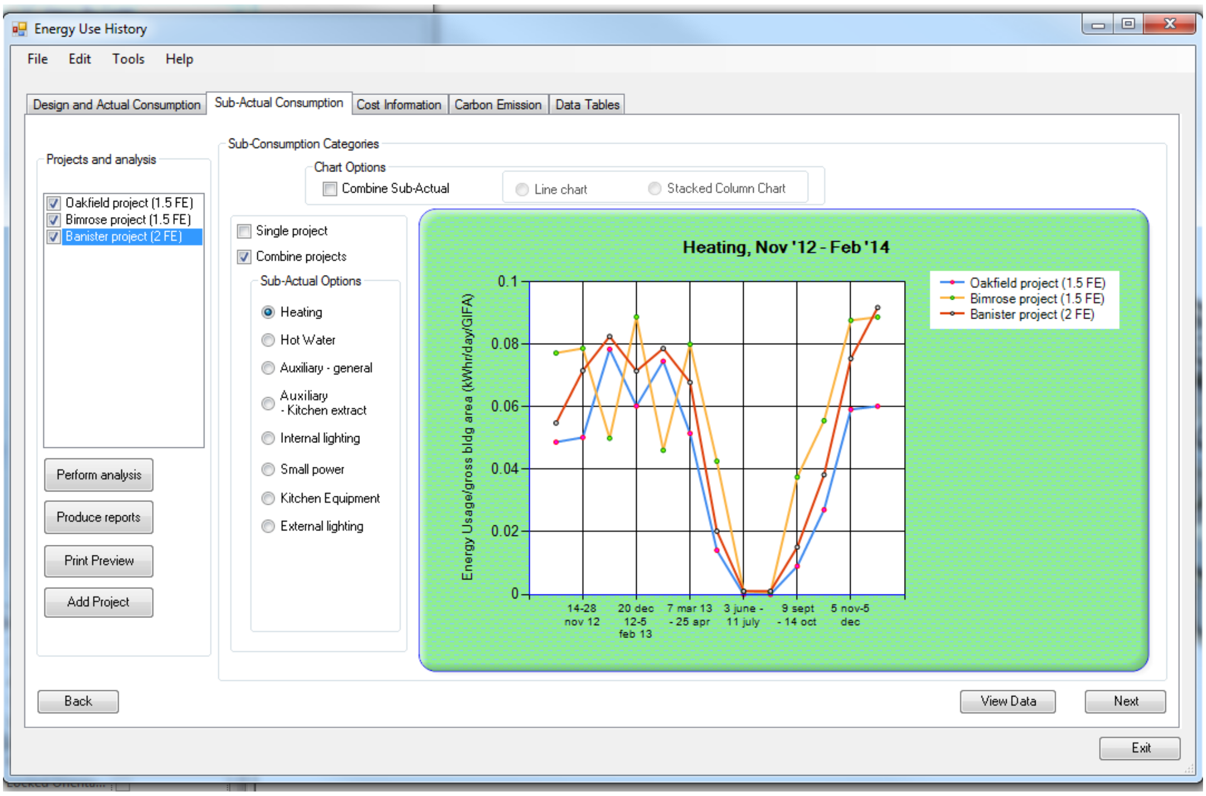

Figure 13: Individual sub-actual consumption comparison of projects

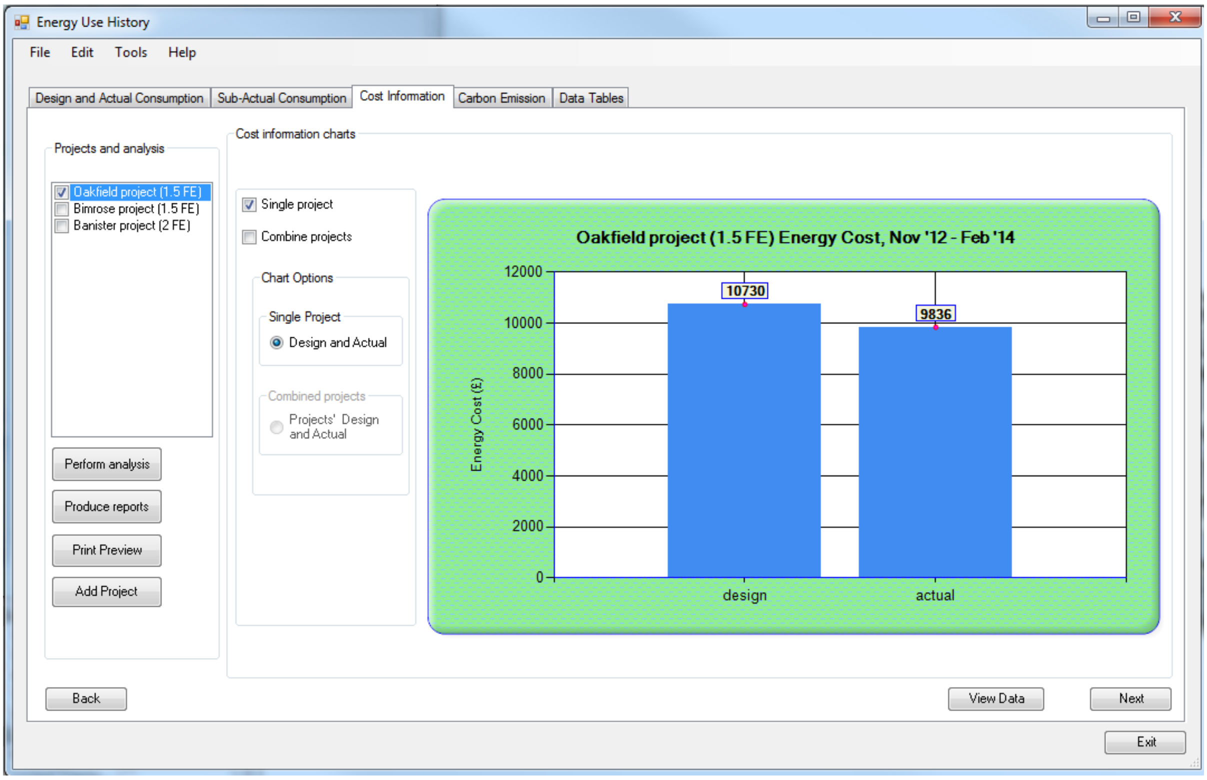

Figure 14: Design and cost actual cost comparison

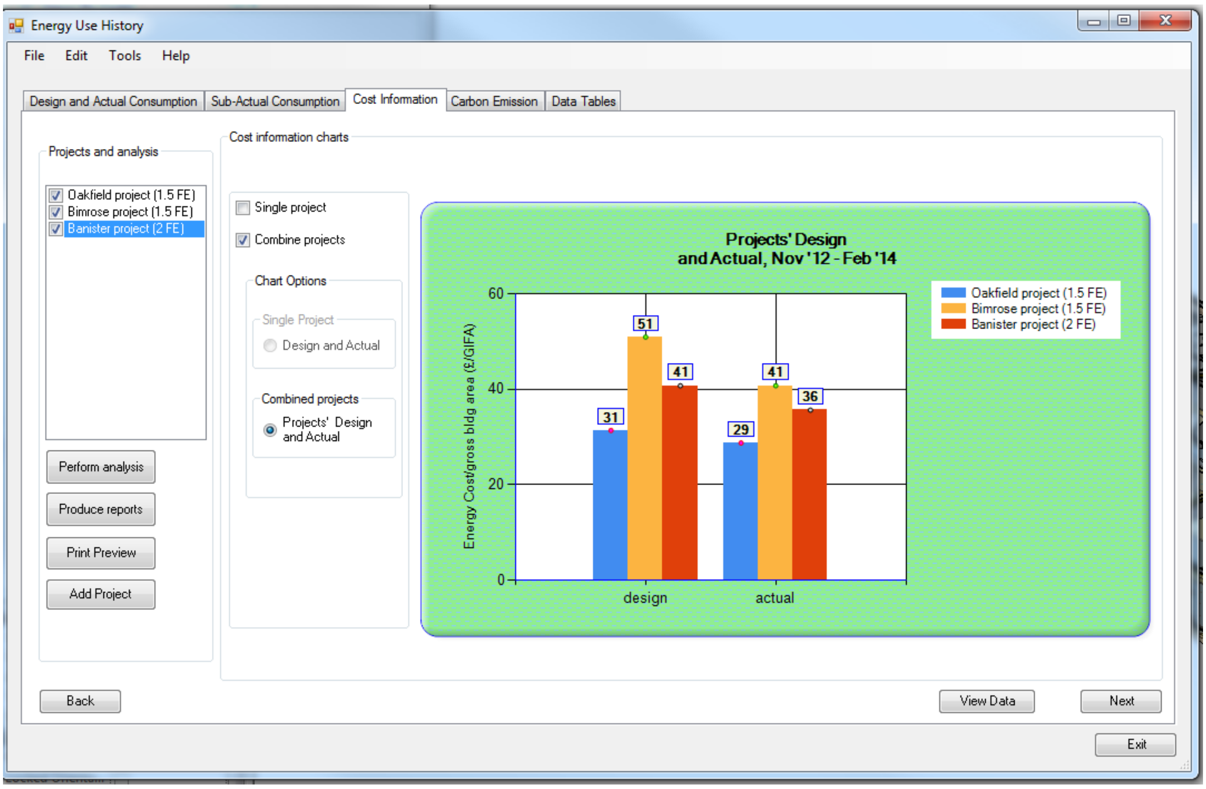

Figure 15: The comparison of projects' design and actual consumptions

6 Limitations and suggestions for future research

At present, the output of the implementation, in the form of a prototype, is tailored towards turnkey projects handled by the contracting partner of the consortium. However, we are of the opinion that the findings of this research will be useful to general integration efforts of building operation and the other phases in the building life cycle. The prototype will be most suited for turnkey project delivery arrangements and in particular where the same or similar designs are used for the construction of projects such as estates, campuses and schools. Another restraint is that BMS data of different projects need to be formatted to similar structure before loading into the prototype. The challenge is that the intervals at which BMS data is collected may vary. Some adjustments to data collection intervals may be necessary in such cases. A pre-defined and consistent data collection framework, which would ideally be undertaken at the same intervals, be automated and operationalised on the Cloud, could overcome this challenge.

In this paper, we suggest taking advantage of BIM technology to enable the feedback of BMS data to earlier project stages. However, there are issues relating to the willingness of clients/building users to allow employing such feedback processes to improve project delivery. A survey [32] of some south-east UK householders in the mid-90s suggests the public is interested in knowing and reducing potential or actual household energy use/impact. The declaration of such, as energy labels, in real estate and property managements circles have been reported to have some influence on the value placed on property [15-17]. As such property owners may be looking for means to be on the good scale of energy declarations on property. Despite this developing incentive, Clarke et al [33] is of the opinion that legislation and enforcements may become the key drivers in the UK energy economy to leverage energy stakeholders pursuing the deployment of sustainable energy efficient systems. The European mandate on the energy performance of buildings directive (EPBD) is relevant here. As an off-shoot of the Kyoto protocol, EPBD was adopted in 2002 as Directive 2002/91/EC which requires that an energy performance certificate is made available when buildings are constructed, sold or rented out [34]. This directive touches on all stakeholders in the property market and the extent to which it is implemented and adhered to needs to be comprehensively investigated and regularly updated [34, 35]. In any case, incorporating historical energy performance data from BMS in BIM (as planned and/or as built) will go a long way to contributing to realizing the EPBD.

While building energy consumption remains a very essential requirement for the functioning of individuals and the community, it is also important that the overall consumption levels of individuals and groups are not made up of a large proportion of consumption categories that can be avoided or reduced. The overall categories of energy consumption levels can be obtained via BMS data which can also be compared to anticipated performance at the design stage. However, such data do not provide any information on why consumption levels in certain categories are low or high, as the case may be, compared to design benchmarks. The challenge in learning from historical energy consumption data when fed back to the digitized building model in BIM environment is therefore in identifying the factors influencing consumption levels and improvising means to reduce their effects. At the moment, there is a tendency to attribute the difference between design and operation performances to user behaviour or low quality of construction resulting from problems such as low levels of air-tightness. It is not possible to verify such attributions with BMS data alone. Achieving certain energy performance standards, e.g. BREEAM, at the design stage does not necessarily guarantee lower energy consumption levels in the building. Further analysis of BMS data to identify areas exceeding design benchmarks and associated reasons is therefore necessary.

This constitutes an area for future investigation which is outside the scope of this paper. However, the framework developed in this research can assist in categorizing and streamlining factors contributing to possible performance levels of such identified areas as it manly allows for the comparison of energy performance of buildings built largely to the same pre-designed scheme.

7 Conclusion

One aspect of concern in emerging BIM applications is how to influence overall project costs and improve sustainable construction practices right from the planning and design stages. This requires integrating various aspects of existing work stages and processes into BIM. However, the incorporation of FM issues into BIM have seen the least patronage even though it is one of the key stages where all the outputs of the concerted efforts of planning, design and construction of the building is put to test by use. There is the existing gap of how outcomes from such tests are fed back to the planning, design and construction processes to contribute to improving the overall project delivery. In the construction sector, the 'big data syndrome' is prominent in the operation phase of the building as a result of the advent of sensing and automated data acquisition technologies such as BMS. There is also a perception that the sector is going to benefit from the availability of large amounts of data, especially if it is integrated into a BIM environment. Although it is true that data, such as that generated by BMS, has the potential to influence overall project costs and improve sustainable construction practices right from the beginning of the project life-cycle; its automated collection, analysis and integration are still problematic. We, however, suggest that these challenges can be tackled with the aid of the modelling approaches and integration capabilities provided by BIM applications as demonstrated in this paper.

The paper illustrated how building design-operation integration can be achieved by presenting a bespoke framework for incorporating BMS data in a BIM environment. It presented the concept of the framework implemented in .NET framework and interfaced with a BIM-enabled tool. Thus, it made a contribution to closing the feedback loop between operations and design stages of the building life-cycle, which has so far seen the least patronage in practice and in research on BIM. This was achieved in three key steps. First, potential tools for integrating BMS data to BIM and the available approaches to achieving such integration were identified. Then second, a bespoke framework, which incorporates process flow charts and information representations, was developed to utilise information on building energy consumption to inform and improve design and facility management. Third, aspects of the framework were implemented and tested in a software environment in the form of a plugin interfaced with a BIM-enabled tool. Two key challenges of integrating building operation data in a BIM environment, i.e. structuring and analysing the large and unstructured BMS data, and lack of flexibility in configuring off-the-shelf tools to stream data from existing BMS systems due to interoperability challenges, were thus overcome. The emergent plugin tool compares as-planned energy performance with actual energy performance in a single school and across a number of schools that are built using the same scheme. As a result, it establishes whether the delivered assets suffer from' the performance gap'. In the main, this work bridges some of the existing gaps in harnessing historical data from the building operation phase to assist in building information modelling and design. It becomes a possible first step in making better sense of building energy performance in use, which has the potential to incorporate other factors such as the Climate, building and use-related characteristics and occupant behaviour. Devising a framework for automatically collecting, analysing and integrating data on the last two categories of factors is identified as an area for future research.

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References

1. B. Becerik-Gerber, F. Jazizadeh, N. Li, G. Calis, Application areas and data requirements for BIM-enabled facilities management. *Journal of Construction Engineering and Management*, 2011. **138**(3): p. 431-442.
2. R. Codinhoto, A. Kiviniemi, S. Kemmer, C.G. da Rocha, BIM-FM Implementation: An Exploratory Invesigation. *International Journal of 3-D Information Modeling (IJ3DIM)*, 2013. **2**(2): p. 1-15.
3. G. Lee, R. Sacks, C.M. Eastman, Specifying parametric building object behavior (BOB) for a building information modeling system. *Automation in Construction*, 2006. **15**(6): p. 758-776.
4. C. Eastman, P. Teicholz, R. Sacks, BIM Handbook: A guide to Building Information Modelling for Owners, Manager, Designers, Engineers, and Contractors. 2008, USA: John Wiley & Sons, Inc.
5. Y. Arayici, T. Onyenobi, C. Egbu, Building information modelling (BIM) for facilities management (FM): The MediaCity case study approach. *International Journal of 3D Information Modelling*, 2012. **1**(1): p. 55-73.

6. Z. Alwan, B.J. Gledson, M. Kumaraswamy, P. Love, Towards green building performance evaluation using Asset Information Modelling. *Built Environment Project and Asset Management*, 2015. **5**(3).
7. N. Kohler, S. Moffatt, Life cycle analysis of the built environment, in *Industry and Environment*. 2003, UNEP. p. 17-21.
8. G.K.C. Ding, Sustainable construction-role of environmental assessment tools. *Environment and Management*, 2008. **86**: p. 451-464.
9. A.H. Oti, W. Tizani. A sustainability extension for building information modelling in *Proceedings of the CIB W78 2012: 29th International Conference –Beirut, Lebanon, 17-19 October*, 2012. R.R. Issa (Editor). Beirut, Lebanon: CIB MENA.
10. Y. Wang, X. Wang, J. Wang, P. Yung, G. Jun, Engagement of facilities management in design stage through BIM: framework and a case study. *Advances in Civil Engineering*, 2013. **2013**.
11. H. Doukas, K.D. Patlitzianas, K. Iatropoulos, J. Psarras, Intelligent building energy management system using rule sets. *Building and Environment*, 2007. **42**(10): p. 3562-3569.
12. S. Taneja, B. Akinci, J.H. Garrett, L. Soibelman, E. Ergen, A. Pradhan, P. Tang, M. Berges, G. Atasoy, X. Liu, Sensing and field data capture for construction and facility operations. *Journal of construction engineering and management*, 2010. **137**(10): p. 870-881.
13. Z. Ozturk, Y. Arayici, S. Coates. Post occupancy evaluation (POE) in residential buildings utilizing BIM and sensing devices: Salford energy house example. in *Proceedings of the Retrofit*, 2012. R. Aspin and S. Bowden (Editors). Greater Manchester.
14. N.O. Olsson, H. Bull-Berg, D. Walker, Use of big data in project evaluations. *International Journal of Managing Projects in Business*, 2015. **8**(3).
15. F. Fuerst, P. McAllister, The impact of Energy Performance Certificates on the rental and capital values of commercial property assets. *Energy policy*, 2011. **39**(10): p. 6608-6614.
16. N. Kok, M. Jennen, The impact of energy labels and accessibility on office rents. *Energy policy*, 2012. **46**(0): p. 489-497.
17. D. Popescu, S. Bienert, C. Schützenhofer, R. Boazu, Impact of energy efficiency measures on the economic value of buildings. *Applied Energy*, 2012. **89**(1): p. 454-463.
18. Z. Yu, B.C. Fung, F. Haghighat, H. Yoshino, E. Morofsky, A systematic procedure to study the influence of occupant behavior on building energy consumption. *Energy and Buildings*, 2011. **43**(6): p. 1409-1417.
19. V. Bazjanac. Improving building energy performance simulation with software interoperability. in *Eight International IBPSA Conference, August 11-14*, 2003. G. Augenbroe and J. Hensen (Editors). Eindhoven, Netherlands. p. 11-14.
20. V. Bazjanac, Building energy performance simulation as part of interoperable software environments. *Building and Environment*, 2004. **39**: p. 879-883.
21. J.W. Hand, D.B. Crawley, M. Donn, L.K. Lawrie, Improving non-geometric data available to simulation programs. *Building and Environment*, 2008. **43**(4): p. 674-685.
22. R. Attar, E. Hailemariam, M. Glueck, A. Tessier, J. McCrae, A. Khan, BIM-based building performance monitor, 2010: SimAUD 2010-Orlando, FL, USA.
23. A. Khan, K. Hornbæk. Big data from the built environment. in *Proceedings of the 2nd international workshop on Research in the large*, 2011. ACM.
24. W. Maner. Rapid application development using iterative protyping. 1997 [cited October 2012]. Available from: http://csweb.cs.bgsu.edu/maner/domains/RAD.gif
25. N. Hichri, C. Stefani, L. De Luca, P. Veron. Review of the “as-buit BIM” approaches. in *Proceedings of the 3D-ARCH International Conference, 25-26 February.*, 2013. J. Boehm (Editor). Trento, Italy.
26. L. Xuesong, M. Eybpoosh, B. Akinci. Developing as-built building information model using construction process history captured by a laser scanner and a camera. in *Construction Research Congress*, 2012.

27. P. Tang, D. Huber, B. Akinci, R. Lipman, A. Lytle, Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques. *Automation in Construction*, 2010. **19**(7): p. 829-843.
28. R.J. Mayer, C.P. Menzel, M.K. Painter, P.S. Dewitte, T. Blinn, B. Perakath, Information integration for concurrent engineering (IICE) IDEF3 process description capture method report, 1995, DTIC Document.
29. P. Hoes, J. Hensen, M. Loomans, B. De Vries, D. Bourgeois, User behavior in whole building simulation. *Energy and Buildings*, 2009. **41**(3): p. 295-302.
30. Z. Yu, F. Haghighat, B.C.M. Fung, E. Morofsky, H. Yoshino, A methodology for identifying and improving occupant behavior in residential buildings. *Energy*, 2011. **36**(11): p. 6596-6608.
31. A.H. Oti, W. Tizani, BIM extension for the sustainability appraisal of conceptual steel design. *Advanced Engineering Informatics*, 2015. **29**(1): p. 28-46.
32. D.E. Perry, N. Staudenmayer, L.G. Votta, People, organizations, and process improvement. *Software, IEEE*, 1994. **11**(4): p. 36-45.
33. R. Owen, R. Amor, M. Palmer, J. Dickinson, C.B. Tatum, A.S. Kazi, M. Prins, A. Kiviniemi, B. East, Challenges for integrated design and delivery solutions. *Architectural Engineering and Design Management*, 2010. **6**(4): p. 232-240.
34. A. Anderson, A. Marsters, C. Dossick, G. Neff. Construction to operations exchange: Challenges of implementing COBie and BIM in a large owner organization. in *Construction Research Congress*, 2012.
35. W. Wu, R. Issa, BIM-enabled building commissioning and handover. *Computing in civil engineering*, 2012. **2012**: p. 237-244.