Towards green building performance evaluation using Asset Information Modelling

Anonymous Author 1
Engineering and Environment, Northumbria University, Newcastle upon Tyne, UK

Anonymous Author 2
Engineering and Environment, Northumbria University, Newcastle upon Tyne, UK

Structured abstract

Purpose – This paper provides a conceptual framework for an integrated asset management strategy making use of available facility environmental assessment methods and tools and proposes areas of commonality between these and the matured as-built Building Information Model (BIM), that becomes the Asset Information Model (AIM). This framework considers emerging requirements for the capture of Building Performance Attribute Data (BPAD), and describes how these can be managed in order to assist with effective post-construction building performance evaluation.

Design/methodology/approach – A review of the current process relevant to the development of as-built BIMs and AIMs was undertaken which included a discussion of BIM standards and of the COBie process. This review combined with data provided by industry practitioners, led to the identification of the requirement of BPADs which can be used within existing green building tools, such as BREEAM In-Use, LEED and integrated with COBIE and FM /Asset management methods. In turn these methodologies were used to identify possible synergies and areas of integration in AIM-enabled environments.

Findings - Recognising the cyclical nature of asset management and BIM, a conceptual model was generated. It was found that BPADs could be aggregated within an AIM model which could influence the delivery of effective facilities and asset management. The model considers the use of existing Building Management Systems (BMS) and Computer Aided Facility Management Systems (CAFMs) and identifies issues associated with the overall sustainability strategy.

Originality value - A conceptual framework is generated that proposes the use of effective information management and aggregation of building performance attribute data within an Asset Information Model.

***Keywords* -** Asset Information Management (AIM); As-built BIM; Building Information Modelling (BIM); Building Performance Attribute Data (BPAD), Facilities Management (FM).

Introduction

The aim of this paper is to address the disconnect between design aspiration and operational performance of facilities through proposed developments in the use of Building Information Modelling (BIM). Although improved understanding of the business value of BIM has begun to permeate into the knowledge base and practices of many international governments and construction industry organisations and practitioners (Becerik-Gerber and Rice, 2010), it is generally accepted that current maturity rates across different national and international sub-cultures vary. The main focus of this work will be in considering efforts in this area in the United Kingdom, where government reports and white papers since 2010 have sent a consistent and clear message that BIM is a key enabler in the transformation to the low carbon economy (HM Government, 2013; 2012; 2011; BIM Industry Working Group, 2011; IGT, 2010). Within academia, research efforts into addressing the use of BIM within the operational stages of the life cycle (LC) of the asset is in its infancy (Codinhoto *et al*, 2013), however, there is now a global movement towards understanding and leveraging the benefits that the post-completion re-use of information generated during the design and construction stages of an asset can provide, through the production of an asset information model (AIM) used to assist in portfolio management activities. Green and sustainable building construction is expected to grow by an average annual rate of 22.8% up until 2017, and a 50% reduction in greenhouse gases by 2025 against the 1990 baseline has been set as a strategic UK government target (HM Government, 2013). A proportion of these improvements will come through the construction of new buildings and efficient management of these assets, by making good use of BIM early in the delivery process in order to respond to these challenges, but improvements in the management and energy performance of existing building stock through the use of astute facilities information management can also help meet these targets. International requirements for improved sustainability reporting and better approaches to maintenance management over the LC of a building have resulted in new standards of global green assessment being introduced, such as the Leadership in Energy and Environmental Design (LEED) and Green Start approaches, as produced by the Green Building Councils (GBC) of the United States and Australia respectively, as well as the widely-used European assessment scheme for existing buildings in Europe, as produced by the Building Research Establishment (BRE) - BREEAM in-use. Whichever method is used, practitioners may make use of BIM-based sustainability analyses and performance measurement assessment methods at the planning and design stages of an asset, with the aim of these tools being to provide instantaneous results on anticipated building performance, and identify any areas of weakness where improvements could be made. The early use of such tools and the data that they generate is disconnected and therefore separated from their ultimate downstream use by the Facilities Management (FM) systems, in areas such as building energy efficiency, energy management, and refurbishment of facilities (see Fig. 1). To combat this, the UK Government BIM task force has drawn specific attention to the idea that: "*the effective transfer of structured information between the asset lifecycle stages delivers significant value*" (BSI, 2013), and the importance of the post-construction uses of building product data through the re-use of information within the process of Asset Information Modelling (AIM). These ideals have been documented in a series of publicly available specifications (PAS), such as PAS1192-2:2013, which focuses upon collaboration and the information exchanges specific to BIM in the delivery phases of construction projects, and the follow-up document, PAS 1192-3:2014, where guidance on the use of management of BIM data at asset level is provided .

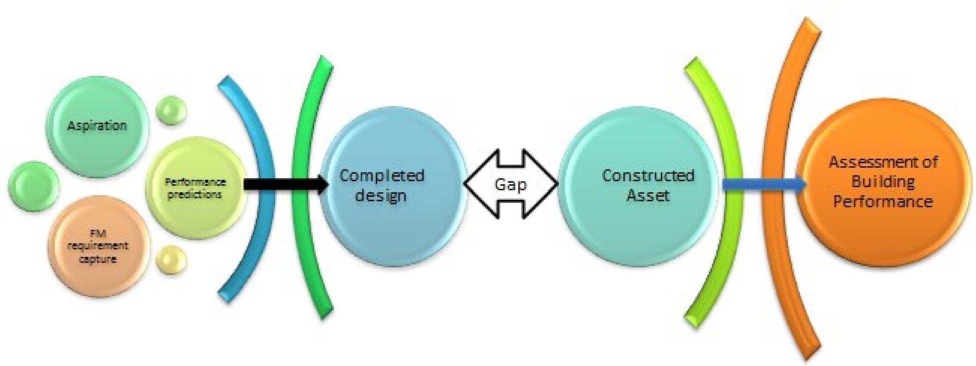

Figure 1: Disconnect between design aspirations/predicted performance and actual operational performance of facilities.

Information transfer for asset management purposes

Before considering detailed AIM requirements, it is worth revisiting the premise of one of the underlying aims of the current BIM agenda - the need to eliminate instances of '*data leakage*' that occur in the traditional information transfer processes between key parties to a construction project, such as architect to engineer, design team to contractor and contractor to client (Rekola *et al*, 2010; Tizani, 2007; Anumba *et al*, 2002). In addition to *data leakage* occurring as a result of traditional paper based or non-intelligent CAD transactions (see Fig. 2), several researchers have also been investigating the data leakage that occurs from within BIM-based transactions (Stapleton *et al,* 2014; Venugopal *et al*, 2012; Sacks *et al*, 2010; Grilo and Jardim-Goncalves 2010) and have recorded observations of sub-optimal technological interoperability during information transfer whilst also advocating the use of the BuildingSMART IFC schema as the most feasible presently available solution to minimise these occurrences.

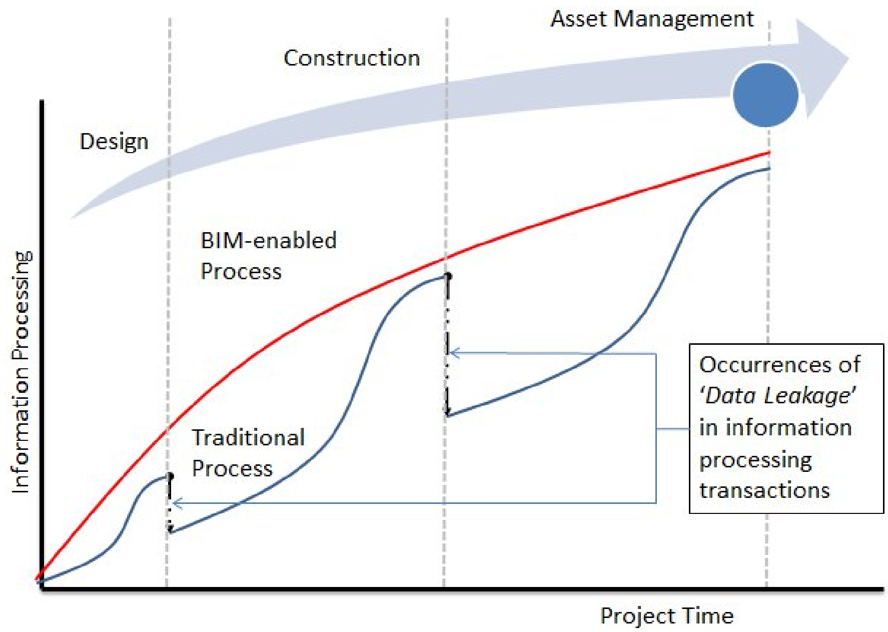

Figure 2: Data leakage in information processing over project time (Adapted from Gledson & Greenwood, 2013)

The rest of the construction industry is experimenting with the re-use of electronic data for production purposes as a solution to this problem, the handover of all relevant as-built information between a construction client and the owner/operator of a facility and then onward to facility management professionals who have responsibility for the operation and maintenance of an asset is still largely done using traditional methods of information transfer, usually in a paper-based format, which is a sizeable effort (Eastman *et al*, 2011). This is largely because traditionally there has been limited participation of asset owners, in the design and FM decisions Therefore if key decisions regarding the operation and management of the facility are not managed effectively during the production stage of a project, asset owners cannot extract maximum value from any investment. If one of the strongest arguments for the use of BIM is that data produced by the initial designers can be further reused downstream by a range of persons including engineers, quantity surveyors, contractors and finally as the basis for a facilities management handover, then one solution would be the development of an as-built BIM model developed throughout the construction process that could be ultimately transformed into the Asset Information Model. Love *et al*, (2014, citing Huber *et al* 2012) provided details of a three-stream approach for creating as-built BIM's for both new and existing buildings. First is where designers update the as-planned BIM for new buildings, the second approach, is where constructors leverage the benefits of BIM and produce their own construction only BIMs from 2D production information – which again need to be updated with as-built information. The third approach would only be applicable to existing buildings, where object data has to be captured, processed from as-surveyed facilities and converted into a BIM model. Volk *et al* (2014) provided an extensive literature review into BIM for existing buildings and found low levels of BIM implementation within existing buildings due to problems associated with data capture and management, remodelling of the existing physical building structure into a new BIM. With reference to the first two approaches, however it should be noted that as the design is developed, much additional work to the model should to be expected, through the development of the Project Information Model (PIM) such as the updating or replacement of generic content placeholder objects during initial design stages for objects that contain constructability information and then again with product supplier information. Thus the final as-built model may end up being made up of many different objects than the initial concept model (See Table 1).

AEC (UK)	**AIA (US)**	**Name**	**Comments**
Grade 0	LOD 100	Schematic	Massing model suitable for building shape and form. Areas and volumes extractable.
Grade 1	LOD 200	Concept	Generic modelling components introduced including wall, floor, column and beam objects.
Grade 2	LOD 300	Defined	Generic components substituted for manufacturer specific objects.
Grade 3	N/A	Rendered	Improvements in rendering and aesthetical purposes particularly 3D representations.
Grade 4	LOD 400	Fabrication	Fabrication and assemble information incorporated
Grade 5	LOD 500	Facility Management	As-built digital information suitable for operation and maintenance purposes

Table 1: Model development Grade / LOD terminology.

In model development, objects within a Grade 0 model/LOD 100 model may end up being swapped over multiple times over the project lifecycle, with generic placeholder objects replaced with detailed objects suitable for an Asset Information Model (Grade 5 / LOD 500). This is good practice in terms of efficient use and re-use of data ,as first efforts at concept stage should be focussed on the extracting and responding to employers requirements rather than producing artistic building objects, as the size of the model will grow substantially and become more unwieldy because of issues of over production - adding data and detail in the over-modelling of objects or the over-production of model views.

Role of COBie in Asset Information Management

Alongside as-built model development full compliance is also needed with the requirements for the Construction Operations Building Information Exchange (COBie), data schema that defines what data should be present and how it should be organised and exchanged at stages in the lifespan of a model. COBie is defined within PAS 1192-2:2013 as being the "*structured facility information for the commissioning, operation and maintenance of a project often in a neutral spreadsheet format that will be used to supply data to the employer or operator to populate decision-making tools, facilities management and asset management systems*" (BSI, 2013). In a COBie process, a series of predetermined information exchanges or 'data drops' are required. Current COBie-UK-2012 requirements call for 5 data drops 1, 2a, 2b, 3 and 4 to be performed at key stages of the project LC. The final data drop enables hand-over of a useful and comprehensive asset register that helps organise facility information. FM professionals can upload data entered from the final COBie drop into existing Computer Aided Facilities Management (CAFM) systems employed. Contractors assist by incorporating information during model development about the physical aspects of a facility into the data drops including spaces, floors and zones and by organizing components into product types. Objects representing building components should include COBie ready data which has been provided either directly by the suppliers and material manufacturers who model their own components and make these available for use by designers, or who have outsourced this task to service providers who model libraries of building objects. The COBie spreadsheet consists of a series of distinct tabs where details can be entered pertaining to the facility, floors, levels, spaces, zones, type, component, attributes, and content is required to be structured into the necessary spatial, object and FM process hierarchies.

Standards for the electronic capture of asset information requirements

One key challenge in delivering asset information models is in understanding facilities management requirements early in the design stage of a project. The British Standards Institute advocates following the information delivery cycle processes described within PAS 1192-2:2013 for capturing FM requirements. In this process a BIM execution plan (BEP) detailing roles, responsibilities, standards, methods and procedures is developed during the procurement stage of a project as a response to the original employers information requirements (EIR's), before incorporating these details into the Master Information Delivery Plan (MIDP) at the contract award stage, with model development then progressing through PIM and AIM phases (See Fig.

3). This approach complies with official UK Government Construction Strategy (HM Government, 2011) that mandated the minimum requirement for Level 2 BIM on all centrally procured public projects and compliance with the Government Soft Landings (GSL) policy by 2016. GSL requires the *“graduated handover of a built asset from the design and construction team to the operation and maintenance team to allowed structured familiarization of systems and components and fine tuning of controls and other building management systems”* (BSI, 2013).

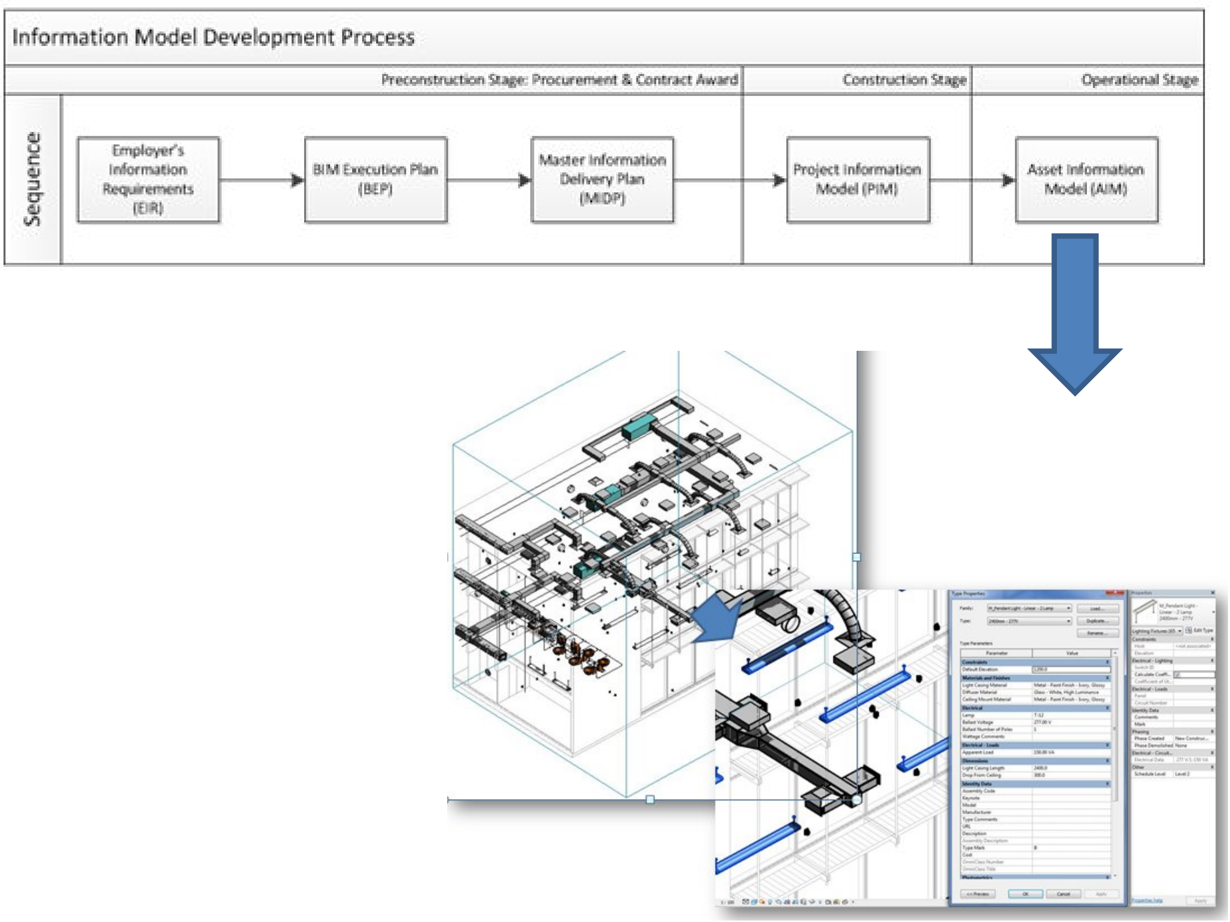

Figure 3 – The information model development process (adapted from PAS 1192-2:2013, p-viii, and effective tracking in AIM

This process enables fully populated asset data captured during project delivery using COBie to be imported directly into the CAFM systems, thus providing reductions in the post construction time that would be required to source and enter this data, and also provides additional benefits in the way that data can be re-used during the asset management stages. One such scenario would be where there is owner dissatisfaction in the performance and/or cost of an existing FM provider, and who would prefer not to continue using that provider, can make available facility data to any newer and potentially more competitive FM providers, thus avoiding any initial and prohibitive costs involved in a full scale re-survey of the facility by the subsequent FM provider. As this process of provider review may be something that may occur at semi regular intervals throughout the LC of an asset then the opportunity to reuse AIM data could prove to be of substantial benefit. Figure 3 illustrates benefits of AIM in component tracking, however, these system are usually disconnected from other building performance indicators such as BMS. It is important to note that despite the use made of metadata such as timestamps and Global Unique ID's (GUID's) that allow object identification and tracking, present capabilities of the AIM only allow physical geometry of components to be managed and located, for purposes of planned preventative maintenance (PPM). Whilst this provides certainty in the sizing of replacement components, as well as rapid retrieval of specification information, without having to physically gather this information on site, the current gap remains in aspects of the predicted building performance using BIM tools and the measurement of building performance either through the use of Building Management Systems (BMS) or through post use evaluations methods.

Environmental assessment methods and the gap in building performance.

Over the past 20 years there has been an increasing demand to evaluate and measure sustainability aspects of buildings primarily using the Building Research Establishment Environmental Assessment Method (BREEAM). Prominent criticisms over the use of such methods focus on concerns that efforts are largely concentrated on new build developments and many successes and green certificates are achieved solely at design stage, with no real method of ensuring the as-designed building performance will be realised beyond the handover stage. There is an ever expanding disconnect between design aspiration and operational performance, with new and refurbished buildings being measured and rated on a host of aspects to get through the planning permission stages of a project or making them attractive as assets. In the UK, where the built environment is responsible for 40% of energy use, Ashurst and Doherty (2008) argue that there are growing demands from facilities and asset owners to consider the overall sustainability strategy including aspects of operational energy, carbon footprint of refurbishment, fuel and material saving fuel and material savings. For most green building tools there is a post occupancy evaluation (POE), to be undertaken and while this is effective as a mechanism for ensuring design stage commitments are met to achieve the rating, it does not extend to continued use in asset management and for purpose of long term performance benchmarking.

Increasing pressures on sustainability reporting and maintenance over the LC of existing buildings, have resulted in the promotion of green building tools, which measure the LC environmental performance of a facility. These tools can provide instantaneous results on predicted building performance, and identify areas of weakness to focus improvement efforts on. Whilst green benchmarking tools do play important role in measuring performance, appropriate data for metrics such as energy use, waste, and predicted maintenance, are currently not adequately captured for purposes of effective asset management or for use in existing CAFM systems, nor are they currently considered within BIM tools and processes. Three main components of the BREEAM In-Use system - the *Asset*, *Organisational* and *Building Management* ratings systems - are all closely related and there is potential for considerable overlap in these areas. Consideration of how to do this, whilst also strategizing how best to capture and aggregate performance data could play a vital role in terms of the overall building environmental performance management in an effective AIM. Whilst assessment methods give a good indications of asset performance, building management policies, and occupier management, its current links to AIM in terms of the incorporation and use of BMS and COBIE data has not yet been advocated.

The BREEAM In-Use standard is aimed at owners to monitor and produce action plans to manage and improve the sustainability of facilities. One BREEAM case study reported on a real estate services organisation with a large property portfolio who applied the BREEAM In-Use assessment scheme to over 250 of its built assets Because of the use of the method on one of its multi-occupied offices of 115,000 ft^2, benefits were reported of enhanced energy monitoring driving reductions in energy use; Reduced water consumption, and greater engagement with tenants. The BREEAM In-Use method uses initial pre-assessment questionnaires, coupled with later responses verified by an independent assessor. A rating is obtained that assesses the overall performance of an asset against the BREEAM In-Use criteria, which ranges from *Unclassified, Acceptable, Pass, Good, Very Good, Excellent* and *Outstanding*.

Application of BIM-based green building tools at design stage

There has been a sharp increase in the use of Green BIM at pre-design stage of a project (McGraw Hill, 2010) with BIM being used for both new and retrofit projects and monitoring building performance. BIM use can give a significant technological advantage towards conventional methods in terms of environmental improvements at design stage, with findings by Kriegel & Nies (2008) indicating that BIM can assist in the design of building massing, daylight analysis, energy modelling and the specification of sustainable materials. Hope and Alwan (2012) investigated the integration of BIM & BREEAM at design stage and discussed the use of Environmental Assessment Methods (EAM's) as a basis for measuring sustainability in buildings but concluded that that BIM as-built models were not being effectively used for intelligent asset management, and due to the method of data handling, vital information could be lost during assessment processes throughout design and construction. It is worth noting the use of alternative systems such as LEED®certification process and their place within this field. Case studies by Azhar *et al* (2011) and Alwan *et al (2014)* indicated that BIM can use LEED to facilitate the complex processes of sustainable design such as day-lighting and solar access assessments, as well as automate activities like material take-offs, cost estimation and construction schedules. Azhar, *et al* (2012) also signalled that any integration of green building tools with BIM has limited use for FM management personnel, however this was largely due to their focus on design stage assessment tools and BIM data, in this work a more comprehensive model is presented based on specific analysis of existing systems and possible data linkage.

Building Performance Attribute Data (BPAD)

Current use of BIM to define the exact components that more greatly influence building performance is particularly challenging for those professionals involved in the operation and management of the asset. "*Typical BIM workflow that is often adopted by asset owners, is deemed to be inefficient and ineffective for the purposes of FM*" (Love *et al*, 2014). This was demonstrated in a case study by Burg and Mealy (2014), which concluded that owners have changing requirements over the levels of graphical and semantic data over the building LC, with initial greater levels of graphical data and lower levels of attribute data required at design stage, decreasing to lower levels of graphical data being required at the operational stages, supplemented by increasing levels of attribute data. Currently, little research exists on how to populate the necessary attribute data for owners and to determine which information makes the biggest difference to overall asset performance.

Greater articulation of the level of appropriate building performance detail required within component attributes could make a significant difference in terms of measurement of the overall performance of a facility or asset. The research team suggest that the term Building Performance Attribute Data (BPAD) is introduced into the BIM terminology lexicon used by the research community, and is employed for all data pertaining to the assessment of building performance using AIM methods. Articulation of BPAD's would enable the measurement of energy use, energy efficiency, materials recycling, carbon footprint, and green building materials and allow the necessary data to be incorporated into the development of the PIM and ultimately the AIM. A clear strategy for the collation of BPAD would allow more effective and efficient management of the realised asset post completion of the construction phase. The realisation of these post completion benefits would also include improvements in commissioning and handover documentation, improved integration of AIM and existing CAFM systems and could be greatly facilitated by providing appropriate links directly into objects within the AIM that direct the FM personnel to product suppliers technical documentation allowing for ease of operation and maintenance of building components. Currently there is little integration of data linked to building performance over the lifetime of the building, and the performance appraisal of assets have been traditionally associated with accounting and the financial success of FM, on the basis of operational efficiency and financial success (Madritsch and Ebinger, 2011). It is proposed that a focus on BPAD's could offer other possible benefits in improving the assets management process, particularly where the focus of various efforts from green benchmarking tools have targeted achieving reductions in carbon and operational energy levels, both in building materials and in onsite processes. These aspects require greater adoption of integrated BIM approaches, with a specific shift toward performance measurement metrics. Substantial efforts should be made to incorporate any agreed BPAD by the project design, construction and asset management team in order to fully optimise the project matured PIM/AIM. This model would then assist in the management of the asset through various means such as providing basic information on space data or from active monitoring of employee activity that could be directly linked with reporting upon facility lighting and energy needs, which is ultimately linked to the asset operational energy requirements and overall carbon monitoring activities.

Research Method

Exploratory research was undertaken capturing data through a series unstructured interviews with 20 industry practitioners via individual and small group discussions with participants involved in two separate BIM storm events facilitated by The BIM Academy, an independent BIM industry / academic joint venture consultancy based in the North East of England. The disciplines involved in these events included Architects; Quantity Surveyors; Mechanical Engineers, and Construction management practitioners. Workshop 1 (November 2013) captured data relating to the integration of BREEAM within BIM and possibilities for sharing of performance data and environmental benchmarking. Workshop 2 (March 2014) captured data focusing on the possibilities of long term asset data management. Additional quantitative data was also captured from this sample, using questionnaires with ranking type questions.

Whilst no claims can be made over statistical inference, interesting data was generated using these methods. The primary aim of collecting this data was to inform the development of the conceptual model by collating views on the relative importance and potential for building performance evaluation using BIM methods. To collect qualitative data, participants were asked a series of questions to determine their evaluation of the importance of BIM in FM and LC analysis. Participants were asked about the role of BIM when considering FM as part of the early design process of buildings and facilities; about their level of understanding of where BREEAM and other Green benchmarking tools as part of the operational aspects of the Facility; whether they considered Facilities Management to be high on the agenda of BIM implementation of projects; thoughts on Building Performance, particularly carbon reduction and its part of the long term building and facilities management strategy; and finally their thoughts on using BIM for FM to address the disconnect between design and build aspirations. Quantitative data was also collected using short questionnaires containing ranking type questions - a series of statements were provided and the respondents selected from a range of responses spanning from ‘strong disagreement’ to ‘strong agreement’ type responses.

Results

While the ultimate aim of the data collection was to develop the conceptual framework the data yielded from the participants greatly assisted in the realisation of the importance that sector professionals place on specific performance gaps.

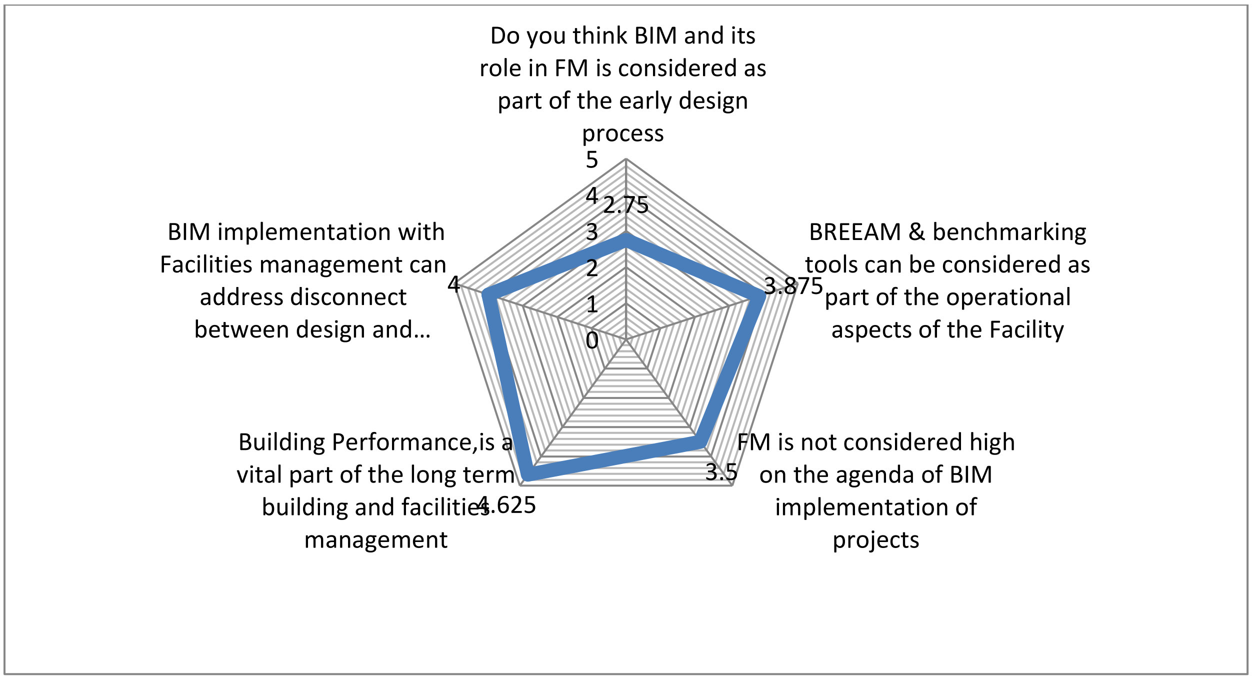

Figure 4 – Radar graph providing results of collected quantitative data on asset management and BIM

Results from the quantitative research questions have been presented using the form of a radar chart where the centre point (0) is equivalent to a 'strong disagreement' response and a 5 is equivalent to 'strong agreement'. Interpreting these responses show that there are high levels of agreement from the majority of respondents that Building performance, and Green building tools should be given greater emphasis during the operational aspects of buildings, and that there is potential for overall BIM in FM, whilst a more moderate range of responses are in agreement that FM is not considered as part of the early process of project delivery, and is not high enough in the current BIM agenda.

Notable qualitative comments included the following responses. Against the question: 'Can you make a suggestion on how BIM can be used to address the disconnect between design and operational performance of buildings?' Delegates commented upon the need for early and greater involvement of the client and FM professionals from the start of the process: *"Facilities management companies/personnel have to be more involved in the design process"*, and *"the client has to embrace it. If the client desires or as required to achieve a certain standard then BIM tools at early stages is a no-brainer"*. There were also practical suggestions on how to impact product and process in order to address this gap: *"Provide models with energy performance indicators. Provide method statements equivalent to how design currently has to consider buildability"*. In response to a separate question 'Please list the areas you consider important in terms of using BIM to address facilities management', Delegates focussed on the role of software vendors: *"Depending on the situation, BIM could provide many different possibilities. There are plenty of software vendors selling the answers, the problem is getting the end users investing in the early implementation of work to enable FM to come out of the BIM model. There is rarely the business case let alone having the necessary stakeholders on board at the early stages"*, and on addressing inefficiencies in process *"Process has to be iterative - start with the data - then move onto understanding the tangible benefits"*

Conceptual Model

Analysis of the data confirms the importance placed by industry professional of potential integration of asset management within the BIM process, and how a mind-set change is needed to address the barriers of better AIM, and use of BPAD. Figure 5 shows the importance of integrating COBie and BREEAM in-use to identify areas of commonality to develop and fill the attribute data with the correct information for effective AIM. Burg and Mealy (2014) identified the importance of attribute data but did not make the link between these requirements and how these can assist in effective building performance.

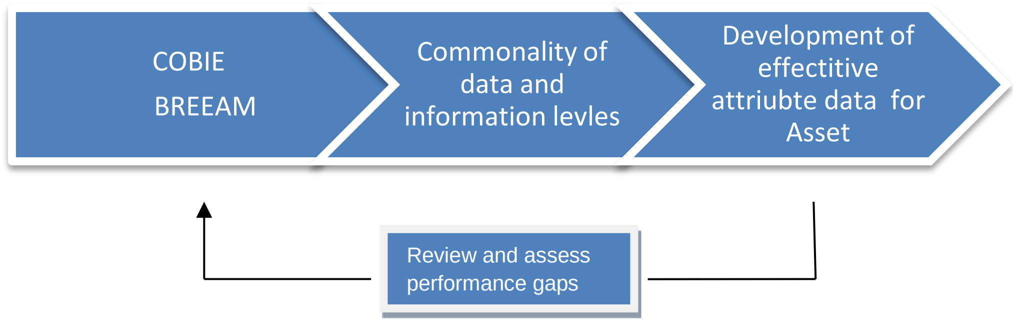

Figure 5 – Requirements for the development of Building Performance Atribute data (BPAD)

Once BPADs has been addressed as part of an asset they can be further integrated into a more comprehensive framework (See Fig. 6). This model is crucial in addressing gaps in peformance and seeing BPAD taking a more active role in evaluation and continuous improvement of the asset. They can play a role in informing how changes made within the asset can be addresed over the life cycle which is a crucial requirement under PAS1192. In addition it could tied to requirements of the Buildng Management System (BMS) and Computer Aided Facility Management Systems (CAFM) as demonstrated below.

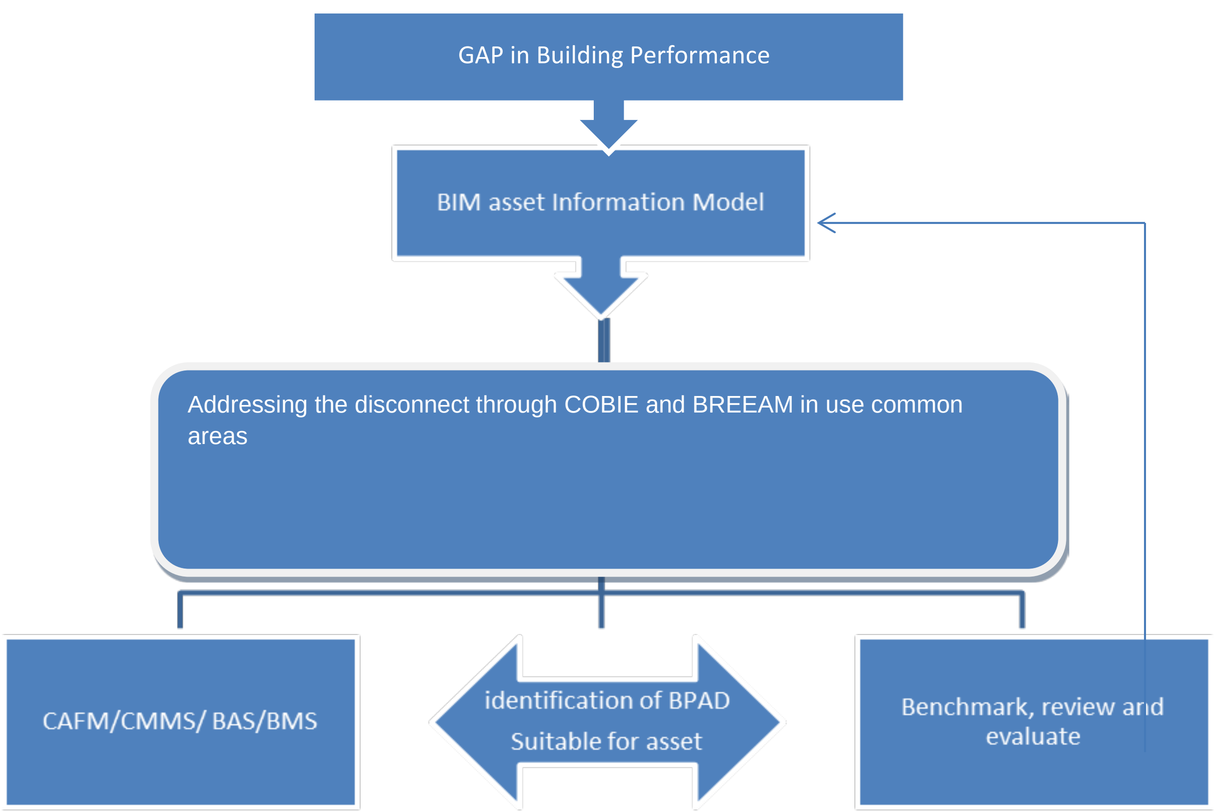

Figure 6 – proposed model for fitting the disconnect between design and operational performance

Conclusions and Recommendations

While the aim of the research was to develop the conceptual framework, the data yielded from the participants greatly assisted in the realisation of the importance that sector professionals place on specific performance gaps, amongst the many responses it was indicated by the participants that whilst design firms often take responsibility for driving adoption of BIM for green projects, an increase in owner demand would be even more effective in stimulating this market.

Through the development of the conceptual model, the research team have come to realise the importance of Building Performance Attribute Data in the process and advocate the focus on the development of BPADs' within the research community. A key question in this area is, '*to what level can BPAD's be articulated and managed within the BIM asset management system from the design stage?* Asset information requirements which have primarily focused on floor areas, space usage O&M operations, can host more relevant building performance data such as Carbon outputs, energy rating, classification (Uniclass), systems types and classification. The team also recommend that more academic effort is now focussed on aspects of BIM based facilities management in such areas and BIM assisted LC building performance evaluation. Findings in this area could be of great interest to asset owners and managers who are currently struggle with conflicting asset demands and incompatible building management systems, green buildings tools requirements for management of assets and clients demands.

References

Alwan, Z., Greenwood, D. and Gledson, B.J. (2015). Rapid LEED evaluation performed with BIM based sustainability analysis on a virtual construction project. *Construction Innovation: Information, Process, Management*, Vol. 15 No. 2. (In Press)

Anumba, C.J., Baugh, C. and Khalfan, M.M. (2002). Organisational structures to support concurrent engineering in construction. *Industrial Management & Data Systems*, Vol. 102 No. 5. pp. 260–270.

Ashurst, C., Doherty, N. F. and Peppard, J. (2008). Improving the impact of IT development projects: the benefits realization capability model. *European Journal of Information Systems*, Vol. 17 No. 4, pp. 352-370.

Azhar, S., Carlton, W. A., Olsen, D. and Ahmad, I. (2011). Building information modeling for sustainable design and LEED ® rating analysis. *Automation in construction*, Vol. 20 No. 2, pp, 217-224.

Azhar, S., Khalfan, M. and Maqsood, T. (2012) Building information modelling (BIM): now and beyond, *Australasian Journal of Construction Economics and Building*, Vol. 12 No. 4, pp.15-28

Becerik-Gerber, B. and Rice, S. (2010). The perceived value of building information modeling in the US building industry. *Journal of Information Technology in Construction*, Vol. 15 (February), pp.185–201.

BIM Industry Working Group (2011). *A report for the Government Construction Client Group*, London.

BRE. (2012), "Why BREEAM In-Use", available at http://www.breeam.org (accessed 12 March 2014)

BRE. (2012), "BREEAM in use: Cushman & Wakefield", available at http://www.breeam.org/filelibrary/Case%20studies/BREEAM_In-Use_Case_Study_-_C__W.pdf (accessed 20 January 2014)

BSI. (2013) PAS 1192-2:2013. Specification for information management for the capital / delivery phase of construction projects using building information modelling.

BSI. (2014). PAS 1192-3:2014 Specification for information management for the operational phase of assets using building information modelling.

Burg, B. and Mealy, C. (2012) Xavier University Facility Management BIM Integration- a case study, available at https://bimforum.org/fall-2012-bimforum-agenda/xavier-universitys-facility-management-bim-integration-a-case-study/ (accessed 25 February 2014)

Codinhoto, R., Kiviniemi, A., Kemmer, S. and Gravina da Rocha, C. (2013). BIM-FM Implementation: An Exploratory Invesigation. *International Journal of 3-D Information Modeling (IJ3DIM),* Vol. 2 No. 2, pp. 1-15.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2011). *BIM handbook, A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers, and Contractors*, *2nd Ed*. L. Khelmani, Ed. Wiley, New Jersey.

Gledson, B. and Greenwood, D. (2013) BIM for optimising the planning and control of construction projects. *Industry BIM Workshops presentation*, Asta Development plc

Grillo, A. and Jardim-Goncalves, R. (2010), Value proposition on interoperability of BIM and collaborative working environments, *Automation in Construction*, Vol. 19 No. 5, pp. 522-530

HM Government. (2012) *Building Information Modelling. Industrial strategy: government and industry in partnership*, London.

HM Government. (2013) *Construction 2025. Industrial Strategy: government and industry in partnership*, London.

HM Government. (2011). *Government Construction Strategy*, London.

Hope, A. and Alwan, Z. (2012) "Building the future: integrating building information management and environmental assessment methodologies". In: *First UK Academic Conference on BIM,* Conference Proceedings, 5 -9 September 2012, Northumbria University, Newcastle Upon Tyne pp. 87-95

IGT. (2010) *Low Carbon Construction*, Department for Business, Innovation and Skills.

Kriegel, E. and Nies, B. (2008). Green BIM. *Indianalolis: Wiley Publishing,*

Love, P. E. D., Matthews, J., Simpson, I., Hill, A. and Olatunji, O. (2014) A benefits realization management building information modeling framework for asset owners. *Automation in Construction*, Vol. 37, pp. 1–10.

Madritsch, T., & Ebinger, M. (2011). A management framework for the built environment: BEM2/BEM3. *Built Environment Project and Asset Management*,*1*(2), 111-121.

McGraw Hill Construction. (2010) *Green BIM: How Building Information Modeling is Contributing to Green Design and Construction*. Smart Market Report, McGraw Hill Construction Research & Analytics MA USA.

Rekola, M., Kojima, J. and Mäkeläinen, T. (2010) Towards Integrated Design and Delivery Solutions: Pinpointed Challenges of Process Change. *Architectural Engineering and Design Management*, Vol. 6 No. 4, pp. 264–278.

Sacks, R., Kaner, I., Eastman, C., M. Jeong, Y.S. (2010) The Rosewood experiment — Building information modeling and interoperability for architectural precast facades. *Automation in Construction*, Vol. 19, No. 4, pp. 419–432.

Stapleton, K.A.J., Gledson, B.J. and Alwan, Z. (2014) Understanding technological interoperability through observations of data leakage in Building Information Modelling (BIM) based transactions. In E. Thompson, ed. Proceedings of the 32nd eCAADe Conference. Newcastle Upon Tyne, England, UK, 10-12 September 2014 pp. 515–524.

Tizani, W. (2007). “Engineering Design”, in Aound, G., Lee, A., and Wu, S. (Ed.), *Constructing the future: 3D modelling*. New York: Taylor & Francis, pp. 14–39.

Venugopal, M., Eastman, C., Sacks, R. and Teizer, J.. (2012) Semantics of model views for information exchanges using the industry foundation class schema. *Advanced Engineering Informatics*, Vol. 26 No. 2, pp. 411–428.

Volk, R., Stengel, J. and Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings — Literature review and future needs. *Automation in Construction*, Vol. 38, pp.109–127.