A CASE STUDY INVESTIGATION OF INDUSTRY TEMPLATES AND INFORMATION QUALITY METHODOLOGIES FOR THE DEFINITION AND ASSESSMENT OF ASSET INFORMATION REQUIREMENTS

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Abstract

A case study of a social housing organisation's approach to the adoption of a Building Information Modelling (BIM) methodology for the definition and capture of asset information is presented. The use of information derived from BIM processes has long been recognised as beneficial to the effective management of the operation and maintenance of buildings, and large portfolios of buildings in particular. The application of tools and standards and their relevance in an empirical setting are explored. Information templates provided within guidelines such as the NBS BIM Toolkit, BIM Forum LOD and COBie offer guidance on the asset information to be captured and transferred during each phase of the building lifecycle. This study demonstrates that existing templates require amendment (both addition and removal of information requirements) in order to deliver the custom requirements of clients that manage large asset portfolios. Such customisation is not common practice in the industry at present. Existing guidelines also fail to provide methodologies for assessing the quality of information that is handed over. This paper builds on and extends the current literature to address how the quality of information and data can both be specified and validated to ensure that the data received within a BIM meets the needs of the operation and maintenance phases of the business. Management Information Sciences (MIS) research offer methodologies for measuring Information Quality (IQ). The contribution to knowledge is an approach which combines MIS research for IQ assessment with BIM methodologies to provide a new approach to developing asset information requirements.

Key words

BIM, Asset Maintenance, Facilities Management, Information Quality, Information Requirements

Résumé

Une étude de cas de l'approche d'une organisation de logement social à l'adoption d'un bâtiment Méthodologie de modélisation de l'information (BIM) pour la définition et la saisie de l'actif l'information est présentée. L'utilisation d'informations dérivées des processus BIM a

longtemps été reconnu comme bénéfique pour la gestion efficace de l'exploitation et de la maintenance bâtiments, et de grands portefeuilles de bâtiments en particulier. . L'application d'outils et les normes et leur pertinence dans un cadre empirique sont explorées. Modèles d'information fournies dans le cadre de lignes directrices telles que la boîte à outils BIM NBS, BIM Forum LOD et COBie offrent des conseils sur les informations sur les actifs à saisir et à transférer au cours de chaque phase du cycle de vie du bâtiment. Cette étude démontre que les modèles existants doivent être modifiés (ajout et suppression des exigences d'information) afin de livrer les exigences des clients qui gèrent de grands portefeuilles d'actifs. Une telle personnalisation n'est pas pratique courante dans l'industrie à l'heure actuelle. Les directives existantes échouent également à fournir des méthodologies pour évaluer la qualité de l'information transmise. Ce document s'appuie sur et étend la littérature actuelle pour déterminer comment la qualité de l'information et des données peut être spécifiée et validée pour s'assurer que les données reçues dans un BIM répondent aux besoins de l'opération et phases de maintenance de l'entreprise. Recherche de Management Information Sciences (MIS) offre des méthodologies pour mesurer la qualité de l'information (QI). La contribution à la connaissance est un approche qui combine la recherche MIS pour l'évaluation de QI avec les méthodologies BIM pour fournir une nouvelle approche pour développer les exigences d'information sur les actifs.

Mots clefs

BIM, Maintenance des Actifs, Gestion des Installations, Qualité de l'Information, Conditions d'information

1. Introduction

Large estate holders use digital asset information systems to capture business data that can offer insight into both scheduled and reactive maintenance routines. Building Information Models (BIMs) are intended to provide detailed information about assets as designed and constructed. Asset information such as manufacturer details, material, parts and warranty information can support the efficient and cost-effective repair, replacement and maintenance of assets. Often gaining access to this information through traditional data capture processes is slow and comes with the associated cost of obtaining this data and attaching it to asset maintenance registers. Much of the data handed over during a traditional site build is contained in un-editable PDF format meaning that the information within the document has to be manually copied and pasted into digital asset information systems (Kassem, et al., 2015). Often the handover of data happens when products are outside of their warranty making it difficult to maintain assets as required within the warranty period.

Importing highly detailed asset data from BIMs into digital asset information systems will reduce the cost and time associated with collecting this data and adding it to digital asset registers (Teicholz, 2013). Furthermore having access to asset data defined at the as-built stage will ensure that the data is accurately recorded, which is of particular importance when retrieving installation and warranty data. A well-defined set of Asset Information Requirements (AIR) that not only provide detail of the required data but also address aspects of information quality at the outset of a project can reduce costs associated with acquiring data for use during the Operational and Maintenance (O&M) phases of a building.

A case study of the social housing organisation Your Homes Newcastle (YHN) is used as an empirical study to explore existing approaches to AIR development. An enhanced

methodology is presented for supporting clients in developing AIRs more accurately to meet their needs for the O&M of built assets. Current guidelines for the development of an AIR are provided in the UK government level 2 suite of documents (British Standards Institution, 2007; British Standards Institution, 2013; British Standards Institution, 2013a; British Standards Institution, 2014; British Standards Institution, 2014a; British Standards Institution, 2015; buildingSMART, 2016). Additionally tools exist that offer guidance on the development of the AIR and validation of the data within BIMs (National Building Specification, 2017; buildingSmart, 2017). The industry currently lacks a comprehensive and structured approach to assessing the quality of information BIM models deliver for facility management and that this requires formalization of owner information needs.

Management Information Systems (MIS) research offer methodologies for measuring Information Quality (IQ). The Assessment Information Management Quality (AIMQ) methodology provides a framework for assessing and measuring IQ and is a well-established tool in MIS research (Lee, et al., 2002). This paper documents the process of combining AIMQ elements with BIM processes to establish a set of information requirements for measuring and validating the quality of information procured in a digital asset information register.

An empirical study of YHN's adoption of a level-2 BIM approach to procuring asset data for a digital information system is described. YHN's traditional procurement models and manual approaches to capturing digital asset information are documented. Current asset information processes, the scope and quality of information captured and the gaps in current information are discussed. Data likely to be procured using the 'standard' level 2 BIM processes and currently available tools are examined and gaps in the data specification identified. New BIM processes were developed to support YHN staff, who are not expert in BIM information, to develop their AIR documentation so that the required data would be procured through the new processes. The process of understanding YHN asset data requirements and a method for defining an accurate AIR that supports future information requirements is presented. The contribution to knowledge is an approach which combines MIS research for IQ assessment with BIM methodologies to provide a new approach to developing AIRs.

2. Background

YHN are a social housing organisation with a portfolio of over 26000 council owned properties. The YHN portfolio consists of a range of different property types and occupants. YHN are responsible for the management and maintenance of the properties and all their constituent assets. Additionally, YHN are responsible under the Care Act 2014, for identifying vulnerable tenants and where possible intercepting when issues arise relating to the use of the property that could potentially harm the occupant's welfare. YHN currently manages asset information in an APEX database system (APEX Industrial Technologies, 2018). Whilst YHN manage the council stock, the repair work is carried out by the Newcastle City Council, this means that any repair work must be reported via the council's new Works Management System (WMS). In addition to managing data across two existing systems, YHN are looking to adopt BIM processes which add a new layer of complexity to the capturing and transfer of data across the building lifecycle.

Operational handover specifications for describing the digital data requirements for the operational phases of a building are prescribed in the UK Level 2 BIM framework. Despite the government mandating the use of Level 2 BIM for centrally procured works, the adoption of BIM for the Facilities Management (FM) phase is still in its infancy. A number of case studies observe the adoption of BIM processes (Wang, et al., 2013; Arayici, et al., 2012;

Kassem, et al., 2015). Kassem et al. (2015) identify data accuracy, accessibility and efficiencies in work order execution as some of the values that BIM for FM can bring over traditional manual processes for collecting and handing over data. Love et al. (2015) demonstrate that having appropriate and reliable asset information such as product data and warranties, is pivotal for planning and carrying out O&M activities. Detailed data about an asset's condition, parts requirements, location, warranty and contractual information can be spread out across documents and systems (GCR, 2004). The time spent locating and verifying asset information after handover can add significant costs to FM processes. Abdirad (2017) attempts to identify a set of metrics for assessing BIM implementation. Recommended metrics for assessing the processing of BIM throughout the lifecycle phases of a building include assessing the number of times information is required to be revised and level of information to be shared during each transaction. What the literature lacks is a method for assessing the quality of the shared information.

It is claimed that BIM can reduce the time taken entering and exporting data into and across systems (Kassem, et al., 2015). PAS1192-3 (British Standards Institution, 2014) specifies how an Asset Information Model (AIM) should be created and how the model should be used and maintained throughout the asset lifecycle. A number of tools and guidelines exist to support the development of an AIR specification. The NBS BIM Toolkit, developed in response to the 'Digitising the Construction Sector' funding call, sent out by the Technology Strategy Board, in March 2014, to support the construction supply chain in the adoption of BIM (Technology Strategy Board, 2014; National Building Specification, 2017). The toolkit sought to develop a tool that allowed users to specify the information required, at each stage of a plan of work and to provide tools to validate whether or not the information required had been provided. The three key components that enable this are:

i) the digital plan of work,

ii) a unified classification system, and

iii) a platform that supports levels of definition for information requirements. The Levels of Definition (LOD) describe what information is needed at which stage in the digital plan of work.

Finally the BIM Forum Levels of Development Specification (BIM Forum LOD) also contains guidelines on the information requirements for different assets at different stages in the asset lifecycle (buildingSmart, 2017). The BIM guidelines and literature offer detail for defining asset information requirements and tools such as the NBS BIM Toolkit offer validation tools for checking data exists. International standardisation methods exist to support the quality and structure of data specifications for information handover (British Standards Institution, 2014a; National Building Specification, 2017; buildingSmart, 2017). The issues around the implementation and use of BIM and the need to standardise the process and agree a best practice are well documented (Jeong, et al., 2009; Azhar, 2011; Venugopal, et al., 2012). The importance of formalising owner information requirements is well established (Zadeh et al 2017, Patacas et al. 2016, Cavka et al. 2017) and as Cavka et al. (2017) notes, generalized definition of owner requirements are likely to fall short of meeting the highly contextual needs of a particular project or owner organisation. Several approaches have been proposed for definition of owner information requirements. Cavka et al. (2017) identify the computable information requirements from analysis of owner requirements gathered from analysis of documentation (codes, master specifications, technical guides etc.) and interviews with personnel in different functions who have differing information needs. Patacas et al. (2016) propose the structured definition of Asset Information Requirements (AIR) using business process modelling notation (BPMN) to specify the flows of activities

and supporting information. Very few of the published real-world case studies discuss the information required in BIM for the purposes of FM. Pishdad-Bozorgi et al. (2018) reviewed 15 case studies, demonstrating a gap in analysis in this area. A comparative evaluation of BIM standards for specifying data requirements for the use of Facilities Managers managing data for a large portfolio of building assets is lacking in the literature.

There is limited current literature that considers methods for defining and validating the quality of the information received in BIMs (Zadeh et al 2017). Methodologies for developing information and data quality requirements are well established in information sciences. Information quality relates to having data that is fit for purpose and available at the time it is required. MIS literature provides methodological approaches for specifying and assessing data and information quality. Hazen et al. (2014) demonstrate the value of using an interdisciplinary approach using data science to provide methods for addressing the quality and control of data in supply chain management. Woodall et al. (2013) recommend criteria for assessing the validity, completeness, comprehension, understandability, test coverage, practical utility and future resilience of data. Methods for assessing data quality from a subject, object and process perspective are proposed by Naumann and Rolker (2005). The AIMQ is a well-established tool for assessing and measuring data quality in MIS research (Lee, et al., 2002). The use of MIS approaches for specifying data requirements and for handover processes is largely underutilised within the BIM literature.

3. Methodology

A mixed method approach combining interviews, observation, desktop research and data analysis was taken for this case-study. Open ended interviews were held with the YHN asset information manager and facilities manager to understand the current asset information capture tools and processes. A range of scenarios demonstrating routine scheduled maintenance and responsive repair activities were identified and used to describe information capture and usage for O&M activities. Gaps in data arising through current processes were identified by the interviewees. Researchers took notes throughout the interview documenting the processes and systems described.

A small working group at YHN developed proposals for adopting a BIM approach to procurement and the organisation subsequently agreed to fund a pilot BIM project to investigate the organisational, project and legal requirements and the associated benefits of BIM through implementation on a live project. The pilot project looked at developing BIM processes that could be implemented on a new portfolio of properties from building design through to the O&M phases. YHN employed an independent BIM consultant to help them identify the organisational requirements to support a BIM-enabled approach. The external consultant assisted YHN with the development of their Employers Information Requirements (EIR). Whilst the process of developing the EIR was outside the scope of this study, the development of the EIR was observed to gain a better understanding of the organisation's information requirements for asset maintenance.

Both researchers attended five workshops held by YHN and the BIM consultant to develop the EIR. The researchers observed these workshops and took notes about the process and the information requirements highlighted during the workshops. The process for the definition of YHN information requirements focussed on generating the documented outputs of PAS 1192. Initial workshops identified high-level Organisational Information Requirements (OIR). These informed the development of an employer's BIM Execution Plan (BEP) and Employer's Information Requirements (EIR). Both documents were developed using generic templates. The EIR contained a Model Production and Delivery Table listing building

elements, identifying those that were maintainable assets and setting out the Level of Detail (LOD) and Level of Information (LOI) required for these at each stage of the plan of work. The detailed information requirements for FM purposes were defined by invoking the LOD/LOI information for each maintainable asset from either the BIM Forum or NBS BIM Toolkit templates. This adoption of standard templates differs significantly from requirements-based definition proposed by Cavka et al. (2017) and business process modelling as proposed by Patacas et al. (2016) and risks adopting generic information requirements that do not fully suit the owner or particular project.

The researchers worked with a sub-group of the YHN BIM working group to assess the NBS BIM Toolkit and BIM Forum LOD product templates for defining the YHN information requirements for the BIM project. The sub-group included YHN's Asset Information Manager, an Asset Information Officer and the Facilities Manager. The sub-group are responsible for the capture and processing of data for supporting asset installation, repair and maintenance activities. Three scenarios were selected for testing YHN's requirements against the two templates, the scenarios included replacing or repairing a window restrictor, an Energy Performance Certificate (EPC) and a sprinkler system. These scenarios are typical of the information that YHN captures and uses to support repair, maintenance and other processes on a regular basis. The window restrictor relates to a single component whereas the sprinkler system relates to a system comprising multiple products and the EPC relates to a whole building. The scenarios were selected in agreement with YHN who identified them as common scenarios.

The researchers developed an information requirements capture model for capturing YHNs current and future asset information requirements. The model was built on the five IQ assessment criteria recommended by Woodall et al. (2013). These criteria include validity, completeness, comprehension, understandability, test coverage, practical utility and future resilience of the data. By contrast, the IQ model for FM suggested by Zadeh et al (2017) identifies five IQ criteria from issues observed via case study; incompleteness, inaccuracy, redundancy, well-formedness and understandability. The Woodall model specifies information that is required about the asset data to ensure the data can be evaluated against the five IQ assessment criteria. Table 1 provides the information required by the framework and identifies the assessment criteria each element relates to. The information requirements were also tested with YHN staff from several departments, through discussion around the various scenarios in which the asset information would be used, the purpose, expected outcomes and who the information would need to be shared with.

For each scenario the researchers asked the YHN sub-group what information they needed at the building handover stage to operate the asset in question. Each item of information was listed in the 'Information Item' column of table 1. Then the sub-group were asked what type of information they would need for each item, the type of information is listed in the Value column of table 2. Then the researchers prompted the sub-group for future scenarios of data use such as what information would be required if to repair or replace an asset or to respond to a change in regulations relating to the asset. The items in the Information Item column were extended to include the data required to perform these actions. Finally, the sub-group were asked who might need access to the information, in what format and how would they access that information, this led to further items being added to the Information Item and Value columns of table 1.

Table 1 Information Requirements Capture

Information Item	Value	IQ Assessment Criteria

Object	Name of asset	
Data required	e.g. size, manufacturer, product ref etc	Completeness, comprehension, validity, understandability
Preferred format	PDF, CSV, ENUM, etc.	Practical utility
Current data	PDF etc	Comprehension
Where captured	APEX, WMS, Health and Safety Manual etc.	Future resilience
Process and format	e.g. manually taken from contractor PDF	Practical utility
Additional Data	Any additional data required	Completeness
Data importance	Essential, Desirable	Validity
Classification	e.g. Uniclass, Omniclass, NBS etc.	Completeness, comprehension, validity, understandability
Required for Replacement	True/False	Test coverage, future resilience
Stage required for Replacement	RIBA Plan of Work	Test coverage, future resilience
Required for Repair	True/False	Test coverage, future resilience
Stage required for Repair	DPoW	Test coverage, future resilience
Required for Maintanence	True/False	Test coverage, future resilience
Stage required for Maintenance	DPoW	Test coverage, future resilience
Required for regulation	Regulation name	Test coverage, future resilience
Stage required for Regulation	NBS Toolkit LOD stage	Test coverage, future resilience
Shared with	Tenants, repair staff, building manager, care staff, enforcing authorities, other-specify	Test coverage, practical utility, future resilience
Other information		
Current data validation method		Validity

The researchers compared the identified YHN information requirements for a scenario against the information defined in the BIM Toolkit LOD, BIM Forum LOD and COBie. This comparison highlighted which information properties were defined, what the required format was and whether they were specified at the stage at which YHN would require them to facilitate the scenario usage. Gaps in current YHN information processes were identified along with gaps between the product templates provided by the standards and the identified YHN requirements.

4. Findings

The first asset assessed was that of a windows restrictor, a safety mechanism specifying how far a window may be opened. The YHN sub-group developed a set of information requirements for the windows restrictor asset using the information capture framework in table 1. This provided a list of information requirements for the asset, along with the preferred data values and formats. Table 2 provides an example of a sub-set of information requirements for the window restrictor example.

Table 2: Window Restrictor Information Requirements

	Required Data Values	**Preferred Format**
Manufacturer Information		PDF
Operating Manual		PDF
Warranty Information		PDF
restrictors required	true/false	XML
Restrictors fitted	true/false	XML
reason not fitted if required	tenant refused; unable to gain access; technical problem; etc.	XML

The researchers then identified which of the required asset information requirements were available in the COBie specification. Then the same process was carried out for the BIM Forum LOD and the NBS BIM Toolkit. Table 3 shows the information requirements that were specified by the standards and guidelines and which requirements were missing. As table 3 demonstrates, none of the guidelines cover all of the information requirements required for the window restrictor asset. COBie has a facility to link documents to assets which was able to accommodate any asset information requirements that required a document as their preferred data format. The BIM Forum LOD had no specification for windows restrictors. The NBS BIM Toolkit lacked definitions for the operating manual, specifying if restrictors were required, fitted and for supplying any reasons for not having them fitted. Further to this the NBS BIM Toolkit offered additional information requirements such as ‘windows restrictor stays’ and ‘description’ which could potentially lead to the creation of unnecessary additional data. Out of the 23 information requirements identified for a window restrictor, 12 were available within the COBie specification, none were available in the BIM Forum LOD, 13 were available within the NBS BIM Toolkit, with the latter specifying 2 additional information requirements.

Table 3: Window Restrictor Information Requirements

	Required Data Values	**Preferred Format**	**COBie**	**BIM Forum**	**NBS Toolkit**
Manufacturer Information		PDF	COBie "Document"		Manufacturer
Operating Manual		PDF	COBie "Document"		
Warranty Information		PDF	COBie "Document"		Warranty guarantor (parts),Warranty duration(parts), Warranty guarantor (labour),Warranty duration(labour), Warranty

					duration unit, Warranty description, Warranty start date
restrictors required	true/false	XML			
Restrictors fitted	true/false	XML			
reason not fitted if required	tenant refused; unable to gain access; technical problem; etc.	XML			

There are three types of repair work, i) planned or preventative maintenance such as annual boiler service ii) reactive/responsive maintenance, where a tenant reports a problem, and iii) pre-tenancy maintenance (when a property becomes vacant and has to be prepared for new tenants). In the latter there is no way of knowing what the extent of the repair work will be as there are no details about the current state of the property. Asset data is used to support repair and maintenance tasks within properties (for example to ensure that maintenance operatives have the correct spare parts and instructions when they attend a property). Data can also be used to highlight problems with certain types of assets or to identify occupant behaviour that requires further

Data is supplied by contractors during the handover phase of the building. Often data is incomplete or out of the warranty phase by the time it gets to YHN information officer's and added to the APEX system. Data is exported from the APEX system and imported into the WMS, the import process requires a member of the council to manually import the data as a Comma Separated Values (CSV) file. YHN are reliant on someone at the council to import the data into the WMS system. Managing data across the two databases is viewed by YHN as inefficient and currently incurs costs associated with the time taken by YHN information managers to identify and collect data from consultants, contractors, suppliers and partner organisations, enter data into the internal database and export data to the council database. Historical data is inconsistent and incomplete in places making it difficult to get accurate asset information required for repair and maintenance tasks. This results in low levels of trust in the quality of data held and information managers tend to rely on their own knowledge and that of colleagues, gained from previous tasks or gathered during the lifecycle of other properties within the portfolio.

The information requirements capture model identified what information is currently required and at what stage in the DPoW. The AIR product templates provided by the NBS BIM Toolkit, the BIM Forum LOD and COBie did not fully meet the YHN information requirements for the three scenarios investigated. Furthermore the stages that YHN required information differed from those stages specified within the standards. Out of the three standards evaluated the NBS BIM Toolkit contained the most attributes required for the O&M phases of YHN assets and includes within it the COBie 'Type' properties intended to capture asset information. Despite being the most relevant out of the three standards, YHN specific information requirements were still not catered for within the NBS BIM Toolkit LOD. Asset information at a whole building level such as the information required for an Energy Performance Certificate were observed as important to YHN, but are poorly supported in existing product template data.

5. Discussion

A definition of the asset information requirements that is specific to the asset-owning organisation will obviously be of benefit in ensuring that all of the information required is

obtained at the right stage of the project. This would be best achieved through the adaptation and customisation of the standard templates rather than attempting to develop the information requirements completely. For this case study the NBS BIM toolkit template was found to be a more complete match to the organisation information requirements for YHN and would therefore present the logical starting point for customisation.

The approach adopted for the three concepts and scenarios was found to be beneficial in identifying information requirements and gaps in the standard templates, but is likely to be prohibitively time-consuming to undertake for every component, system, space and building for a project. It is suggested that an approach might be to:

- Identify the most critical/valuable information the asset owning organisation requires and undertake the exercise only for the most significant. This would ensure that no critical data is missing for these areas. The standard templates are likely to provide the majority of information required elsewhere and a significant improvement over current practice for many organisations.
- Organisations that procure construction projects on a regular basis have the opportunity to develop and manage their asset information requirements over time. They may adopt processes to review specific asset information by applying processes such as those developed for this project and addressing gaps and shortcomings identified. By adopting this strategy, the AIR becomes a dynamic document that captures knowledge and lessons from projects and ongoing management processes and is subject to continuous improvement.
- A managed AIR such as this should also capture why information is required, which processes it is required to support, which stakeholders or systems it is shared with and for what purpose in order to capture the relative importance of the information and understand the implications of any changes to systems that use the information.
- Asset-owning organisations will also need to define and implement processes to check the data delivered during BIM projects against the requirements set out in their AIR documentation. This is likely to be a combination of manual, semi and fully-automated processes, and resource needs to be made available for this if levels of trust in the data-assets are to be improved.

6. Conclusions

The benefits BIM can bring in terms of cost savings and improved information capture are well established in the literature. Even with the availability of tools, standards and frameworks, capturing and transferring data that is complete, relevant and usable at the O&M stages is a challenge. MIS research offers methodologies for defining and assessing information within projects.

- Templates for AIR such as BIM forum and NBS BIM toolkit should ensure that significantly higher quality information is delivered in the AIM than using non-BIM current practice. This was clearly evident in the case study for component examples investigated (window restrictors and sprinklers). These findings support those within the literature that demonstrate the requirement for a formalised approach to developing owner information requirements (Zadeh et al 2017, Patacas et al. 2016, Cavka et al. 2017)
- There is a tendency to accept the NBS or BIM forum templates without adapting them to the particular information requirements of the asset owner. As Cavka et al. (2017) suggest, this may be due to inexperience on the part of the asset owner, the processes

for AIR/EIR development or the resource required to fully define information requirements and then customise the templates to suit. From the investigation of this YHN case study, such adoption of the standard templates would result in some information requirements not being fulfilled by the BIM procurement, potentially resulting in the organisation not realising the full benefits of BIM.

- The client organisation (in this case YHN) is best-placed to identify their information requirements and undertaking this work for a small sample of specific examples (window restrictors, sprinkler systems and EPCs) was a relatively straightforward process, especially when supported with structured questioning and documentation. The standard templates provide a valuable data-source against which to test information requirements as they are being developed and this is beneficial to identification of information gaps.

A standardised questioning processe can be adopted to assist in identification of information requirements across concepts (products/components, systems and whole building). The information requirements capture framework offers an approach to formalising this process enabling non-BIM experts a tool with which to begin identifying and defining their information requirements. The researchers have identified a number of areas of further work resulting from this case study. The structured questioning template should be tested against a wider set of concepts and scenarios (e.g for information relating to specific spaces or different building types). Further case studies with other asset owners would be beneficial, in order to test and refine the methodologies against different building and organisation types. A framework for a managed AIR can be developed, along with processes for checking information obtained during a BIM project against the requirements set out in the AIR. This should adopt AIMQ to assess the quality of information captured i.e. after the data has been captured and used to carry out maintenance activities. Follow-on work is planned to extend the current case study through to completion of the construction and into maintenance cycles.

7. Bibliography

Abdirad, H., 2017. Metric-based BIM implementation assessment: a review of research and practice. Architectural Engineering and Design Management, 13(1), pp. 52-78.

APEX Industrial Technologies, 2018. APEX Supply Chain Technologies. [Online]

Available at: http://www.apexsupplychain.com [Accessed February 2018].

Arayici, Y., Onyenobi, T. C. & Egbu, C. O., 2012. Building information modelling (BIM) for facilities management (FM): The MediaCity case study approach. International Journal of 3D Information Modelling, 1(1), pp. 55-73.

Azhar, S., 2011. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and Management in Engineering, 11(3), pp. 241-252.

British Standards Institution, 2007. BS1192:2007: Collaborative production of architectural, engineering and construction information. Code of practice. , London: British Standards Institution.

British Standards Institution, 2013a. B/555 Roadmap (June 2013 Update): Design, Construction & Operational Data & Process Management for the Built Environment, s.l.: British Standards Institution.

British Standards Institution, 2013. PAS1192-2:2013 Specification for information management for the capital/delivery phase of construction projects using building information modelling, London: British Standards Institution.

British Standards Institution, 2014a. BS 1192-4:2014 Collaborative production of information. Fulfilling employer's information exchange requirements using COBie. Code of practice, London: British Standards Institution.

British Standards Institution, 2014. PAS1192-3:2014 Specification for information management for the operational phase of assets using building information modelling (BIM), London: British Standards Institution.

British Standards Institution, 2015. PAS 1192-5:2015 Specification for security-minded building information modelling, digital built environments and smart asset management , London: British Standards Institution.

buildingSMART, 2016. IfcBuildingElementProxy. [Online] Available at: http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/ifcproductextension/lexical/ifcbuildingelementproxy.htm

[Accessed February 2018].

buildingSMART, 2017. LOD. [Online] Available at: http://bimforum.org/lod/ [Accessed February 2018].

Care Act, 2., 2014. [Online] Available at: http://www.legislation.gov.uk/ukpga/2014/23/introduction/enacted [Accessed February 2018].

Cavka, H. B., Staub-French, S., Poirier, A., (2017) Developing owner information requirements for BIM-enabled project delivery and asset management, Automation in Construction, Volume 83, pp169-183.

GCR, N., 2004. Cost analysis of inadequate interoperability in the US capital facilities industry, s.l.: National Institute of Standards and Technology (NIST).

Hazen, B. T., Boone, C. A., Ezell, J. D. & Jones-Farmer, L. A., 2014. Data quality for data science, predictive analytics, and big data in supply chain management: An introduction to the problem and suggestions for research and applications. International Journal of Production Economics, Volume 154, pp. 72-80.

Jeong, Y., Eastman, C., Sacks, R. & Kaner, I., 2009. Benchmark tests for BIM data exchanges of precast concrete. Automation in construction, 18(4), pp. 469-484.

Kassem, M. et al., 2015. BIM in facilities management applications: a case study of a large university complex. Built Environment Project and Asset Management, 5(3), pp. 261-277.

Lee, Y., Strong, D., Kahn, B. & Wang, R., 2002. AIMQ: a methodology for information quality assessment. Information & management. 40(2), pp. 133-146..

Love, P. E. et al., 2015. A systems information model for managing electrical, control, and instrumentation assets. Built Environment Project and Asset Management, 5(3), pp. 278-289.

National Building Specification, 2017. NBS BIM Toolkit. [Online] Available at: https://toolkit.thenbs.com [Accessed February 2018].

Naumann, F. & Rolker, C., 2005. Assessment methods for information quality criteria. Berlin: Humboldt-Universität zu Berlin, Mathematisch-Naturwissenschaftliche Fakultät II, Institut für Informatik.

Patacas, J., Dawood, N., Greenwood, D, and Kassem, M., (2016) Supporting building owners and facility managers in the validation and visualisation of asset information models (AIM) through open standards and open technologies. Journal of Information Technology in Construction, Volume 21. pp. 434-455. ISSN 1874-4753

Pishdad-Bozorgi, P., Gao, X., Eastman, C., Self, A. P., 2018 Planning and developing facility management-enabled building information model (FM-enabled BIM), Automation in Construction, 87(7), pp. 22-38, https://doi.org/10.1016/j.autcon.2017.12.004.

Technology Strategy Board, 2014. Digitising The Construction Sector. [Online]

Available at:
https://connect.innovateuk.org/documents/22430844/0/Digitising%20the%20construction%20sector%20-%20competition%20brief [Accessed February 2018].

Teicholz, P., 2013. BIM for Facility Managers. New Jersey, NJ. : John Wiley & Sons.

Venugopal, M., Eastman, C., Sacks, R. & Teizer, J., 2012. Semantics of model views for information exchanges using the industry foundation class schema. Advanced Engineering Informatics, 26(2), pp. 411-428.

Wang, Y. et al., 2013. Engagement of facilities management in design stage through BIM: framework and a case study. Advances in Civil Engineering.

Woodall, P., Borek, A. & Parlikad, A. K., 2013. Data quality assessment: the hybrid approach. Information and Management, 50(7), pp. 369-382.

Zadeh, P. A., Wang, G., Cavka, H. B., Staub-French, S., Pottinger, R., (2017) Information Quality Assessment for Facility Management, Advanced Engineering Informatics, Volume 33, pp. 181-205