Taxonomy for BIM and Asset Management Semantic Interoperability

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Abstract

At present, the capability to collect information from different sources (BIM, Sensors, Assets database) for Asset Management (AM) use has generated significant opportunities for asset owners and Facility Managers. Building Information Modeling (BIM) in particular, is considered as a potentially effective data pool for storing and managing project information during the building lifecycle, providing a common data environment for stakeholder data and guarantying information availability and credibility at the handover stage. However, this data integration in a BIM environment has come along with issues related to the establishment of an effective process to extract, store, manage, integrate and distribute data to ensure interoperability. Further to the interoperability issue, an important challenge is the identification of what data is relevant, reliable, useful and also can add value to the AM processes. This research explores the asset owner requirements from BIM in the operation and maintenance stage from an AM perspective. The research aim is twofold: first, to synthesize the non-geometric BIM data required for AM and develop a relevant taxonomy. And secondly, to develop an Application Programing Interface

(API) plug-in for Autodesk Revit in order to implement the proposed taxonomy. To achieve the aims of this study, a critical review of previous literature, face-to-face and focus group interviews with BIM and Facilities Management (FM) experts were conducted. The main output is a sixty-parameter Asset Consuming Energy Information Management (ACE-IM) taxonomy and the relevant API plug-in which can help BIM professionals to identify the required data to be submitted to Facility Managers in order to improve AM processes.

Keywords: Building Information Modeling, Asset Management, Interoperability, Revit Plug in

Introduction

Asset Management (AM) is a term measuring the capacity and ability of an asset to achieve its objectives (Riso 2012). An asset could be an item, equipment or space or any other entity that generates financial or non-financial value for the organization. AM capabilities embrace resources, processes and technologies aiming to improve and facilitate delivery of AM plans, asset activities and continual improvement (Riso 2012). AM also enables asset owners to examine the performance of their assets and related systems to achieve organizational requirements (Love et al. 2015) and also integrates all management systems to overwhelm operating in silos (Cooksey et al. 2010). Accordingly, AM transforms business objectives into asset-related decisions and assists in financial decision-making, short-term and long-term planning, and in generating scheduled work orders (Pocock et al. 2014). Appropriate and reliable assets information; such as asset location, specifications, warranties and maintenance schedules, in a well-structured form are essential for supporting effective decision making during asset operation and management stage (Love et al. 2015; Nicał and Wodyński 2016). A common database is required to collect and store all required asset information during all the different stages of Architecture, Engineering and Construction (AEC) and Operation and Maintenance (O&M) (Spilling 2016).

BIM is defined as 'a shared digital representation founded on open standards for interoperability' (NBIMS 2007 2012). BIM can enable information from all project phases to be stored in a single digital model (Love et al. 2015). A BIM model/database can be the ultimate platform for collecting, capturing and visualizing information using different technologies such as standardized barcodes and radio frequency identification devices (RFID) labels during the planning, design, construction and operation and maintenance phases of a facility. A BIM model works as a shared knowledge resource forming a reliable basis for decisions during the facility lifecycle. The UK Government Soft Landing (GSL) policy (2012) stated that BIM can provide a valuable dataset for Computer-Aided Facility Management (CAFM) systems; however, this dataset has to be maintained through the facility lifecycle. The required information for AM has to be extracted from the BIM model and linked to a relevant database that stores all information related to the built asset in order to form an Asset Information Model (AIM) (Kivits and Furneaux 2013). Asset Information Modelling provides the underlying foundation to AM improvement.

Despite BIM capabilities and promises for improving AM practice, the implementation of BIM in Facilities Management (FM) generally and in AM particularly is rare and filled with obstacles (Eadie et al. 2015). Love (2014) argues that interoperability solutions alone cannot deliver business outcomes and that the implementation process should be proactively managed to ensure the organization obtains the results it expects. Several works (Ashworth et al. 2016; Becerik-Gerber et al. 2012; Carbonari et al. 2015; Ibrahim et al. 2016) have criticized the lack of connection between BIM deliverables and the owners' goals and requirements for AM. Mayo and Essa (2015) and Gerrish et al. (2017) specify that the implementation of BIM in FM requires the owners and facility managers ,during the design stage, to provide more details of the required information deliverables and guarantee that the designers and the contractors have the skills to deliver these requirements. Love et al. (2015) argue that determining the required data and the appropriate workflows for delivering digital BIM models for the asset owner remains a challenge. The absence of that information has a negative impact on the building performance as it would be the reason of workflow variabilities (Arashpour and Arashpour 2015). Variability can be reduced by defining the owner’s requirements, illustrating the appropriate workflows and assigning the new jobs related to the BIM data in an early stage of the project (Arashpour and Arashpour 2015; Mayo and Issa 2015).

Based on the above discussion, the research presented in this paper aims to enhance the implementation of BIM in AM through improving the efficiency and effectiveness of data capturing and storage for asset building semantic data. To achieve this, the following objectives are identified: To conduct a critical synthesis of previous literature and identify key aspects of BIM-AM interoperability; to investigate state-of-the-art taxonomies of non-geometric BIM data for AM; to develop and validate ACE-IM taxonomy for the required non-geometric BIM data for AM; and to develop a ACE-IM application programming interface (API) plug-in Autodesk Revit that adds all the AM required parameters to the assets and validate it on an existing educational building - one of Oxford Brookes University buildings.

BIM-AM Interoperability

The integration of BIM-AM data can provide a good quality database for achieving the goals of AM plans. The integrated BIM-AM database for assets can provide several benefits including improving return on investment, reducing costs, enabling the organization to improve its decision making, reducing financial losses, improving health and safety and finally improving client satisfaction, stakeholder awareness and confidence (Spilling 2016). However, the implementation of BIM in FM and AM faces many challenges. The six main challenges are perception of BIM, fundamental difference between project and life-cycle management, contractual and legal frameworks, training, roles and responsibilities, cost and interoperability (Ibrahim et al. 2016). The interoperability challenge is the a key barrier to overcome first as the entire theoretical framework of BIM data being used for FM is predicated on the assumption that data can be exchanged between software programs (Kensek 2015). Interoperability is defined as the ability to exchange data between applications to facilitate automation and avoidance of data re-entry.

Conceptual interoperability consists of six levels namely technical, syntactic, semantic, pragmatic, dynamic and conceptual (Wang et al. 2009). Syntactic interoperability identifies an agreed exchange format to exchange the right forms of data in the right order, but the meaning of data elements is not established. Love et al. (2014) criticized that emerging handover standards such as model view definitions (MVD) for FM provide only the structure of how information can be extracted and collected over the facility lifecycle; however, they do not support the owner with a list of the required information for FM. Most of the works conducted by software vendors and researchers can be classified as level 2 syntactic interoperability as the focus is on technology rather than developing computable information requirements (Cavka et al. 2017). These efforts have provided different approaches to link easily and smoothly between BIM and AM data through a common data format. These approaches include the Industry Foundation Classes (IFC), Construction Operation Building Information Exchange (COBie) and proprietary middleware (for example, Ecodomus) (Ibrahim et al. 2016). IFC is an open, vendor-neutral BIM data repository, specified and developed by buildingSMART, for the semantic information of building objects (Thein 2011), IFCs models have been used as the standard file format for importing BIM models into CAFM platforms to overcome the lack of interoperability between existing CAFM tools and the growing number of commercially available BIM packages (Becerik-Gerber et al. 2012). COBie is a neutral file format defined by the MVD of IFC 'subset of IFC for asset management' (Kang and Choi 2015). The COBie approach suggests entering the structured data as it is created during the design, construction and commissioning phases (Messner and Kreider 2013) facilitating the process of transferring information from BIM platforms to CAFM platforms at the handover stage. Proprietary middleware is a computer software designed by a single company and offering services to software applications beyond those available from the operating systems. The approach identifies a, usually bi-directional, link between the BM and AM systems using programing languages and API, design patterns, web services and BIM-based neutral file format such as open data standard (IFC) and data structure specifications (COBie).

Despite all these approaches, syntactic interoperability solutions alone cannot ensure that the integration of BIM-AM could achieve the required expected benefits and results. Lee et al. (2013) observed that the technology quality variable for BIM acceptance has to achieve compatibility (syntactic interoperability) and output quality (semantic interoperability). Ozorhon and Karahan (2016) added that the availability of the required information and technology is one of the most important factors in BIM implementation. Pärn et al. (2017) critiqued that level 3 'semantic interoperability' is the single most important interoperability challenge to overcome in the integration of BIM data with other systems such as AM platforms. The slow implementation of BIM by owners and facility managers is, to an extent, due to the complex nature of the assets information (Love et al. 2014) and complicated taxonomies (Sheriff et al. 2011). A case study of an educational institution (Thabet et al. 2016) illustrated that the most common obstacle in BIM-AM integration is that asset data is scattered and unstructured while the components' data are not integrated or even referenced with other related data/information. Bercerik-Gerber et al. (2012) emphasized the heterogeneity of data by observing that more than 80% of AM teams' time is consumed finding relevant information which is often disregarded by designers in earlier stages. Teicholz (2013) summarized a list of issues associated with interoperability and BIM-AM data integration. These include: inconsistent naming conventions, a myriad of bespoke FM information requirements, inadequate data categorization in BIM and CAFM systems, poor information synchronization and lack of a methodology capturing data related to existing facilities and assets. McArthur (2015) proposed four main tasks required to develop efficient AIM; identifying the critical required information for operations and maintenance, managing data transfer between BIM models and AM tools, managing the level of effort to create the model and handling uncertainty where building documentation is incomplete for existing buildings.

Due to the heterogeneity of the assets and buildings, the required information cannot be generalized for all assets or even by the asset system (Cavka et al. 2017). However, a required information taxonomy can be developed for assets based on their functionality in certain building type. The research concentrates on a case study for a university. The selection of university, education buildings in general, because the total energy use within the educational building in UK in 2017 exceeds 11% of the UK's energy use. Meanwhile, as the need of providing sustainable performance during the building lifecycle has been emphasized, the research concentrates on assets consume energy. Asset management frameworks should be in place to improve the energy performance of buildings (Ruparathna et al. 2016). Zadeh et al. (2017) stated three different AM aspects can improve the building energy performance and reduce energy consumption i.e. early decision making for sustainability, timely maintenance and accurate occupant operations. Cavka et al. (2017) stated that developing a conceptual framework that identify the owner requirements and link them with the digital and physical products can improve the asset management performance in general and sustainability in particular.

The considerations and suggestions above provide the basis for the development of a new Asset Consuming Energy Information Management (ACE-IM) framework. The framework can still be updated and adapted to cover all the building assets required maintenance and operation. The four main key aspects can be classified according to two dimensions (see Figure 1). The first dimension (y-axis) is referred to as endogenous/exogenous dimension. This dimension concerns aspects related and/or inclined in the BIM environment or not. The second dimension (x-axis) is referred to as theoretical/practical dimension. This dimension concerns aspects which are more theoretical and the development of conceptual constructs or more practical and the development of prototype and add-ins. Using the above-mentioned two dimensions classification, the ACE-IM framework consists of four main aspects. A new classification of assets that consume energy based on the discipline of energy consumption, a taxonomy for the required data for each asset, a model for extracting the required data with appropriate classification for each asset and a database for storing and integrating BIM data with assets that consume energy data.

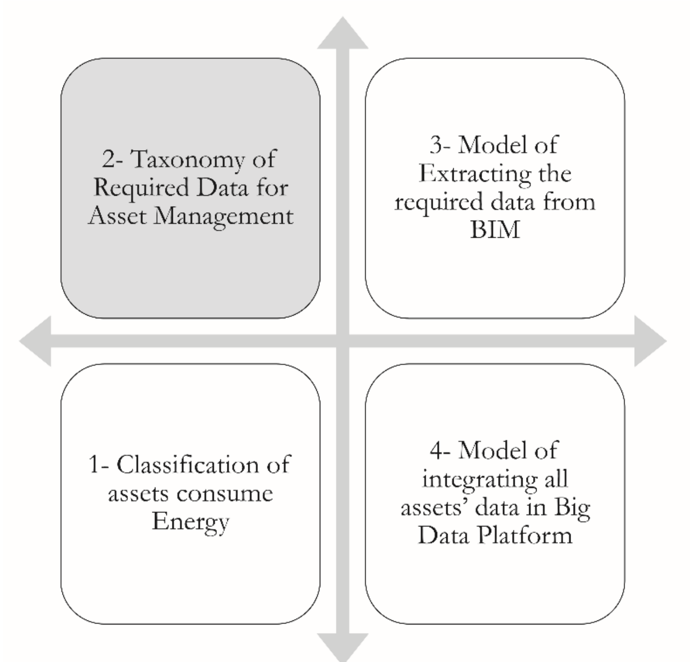

Figure 1: ACE-IM Framework for BIM-AM interoperability aspects

The ACE-IM framework has a wide range of aspects related to integrating BIM and AM data that need to be considered. This paper, as highlighted in Figure 1, focuses on the development and implementation of a taxonomy for the non-geometric data required for assets that consume energy. The proposed taxonomy can be utilized by field researchers to advance and develop further aspects for implementation of BIM in AM and by industry developers to improve their systems.

Methodology

The research presented in this paper explores and illustrates the non-geometric asset data required to support successful implementation of BIM in AM practice. The research design employs participatory action research (PAR) (Whyte 1991) to develop a taxonomy for the required data for AM and produce an API plug-in. PAR has some key components which are particularly suitable for developing the required taxonomy based on AEC industry expert views such as: context-specific, a cyclical process, emphasis on collaboration between participants and researcher and generation of knowledge through participants' collective efforts and actions (Greenwood et al. 1993). The two stages of the PAR approach proposed by Azhar et al. (2011) have been adjusted and adopted for data collection, analysis and validation in accordance with the research aim. The first stage concentrates on the aim of developing the taxonomy for the required data and its three related objectives, the second stage focuses on the aim of developing an API Revit plug-in for the developed taxonomy. The research design is illustrated in Figure 2.

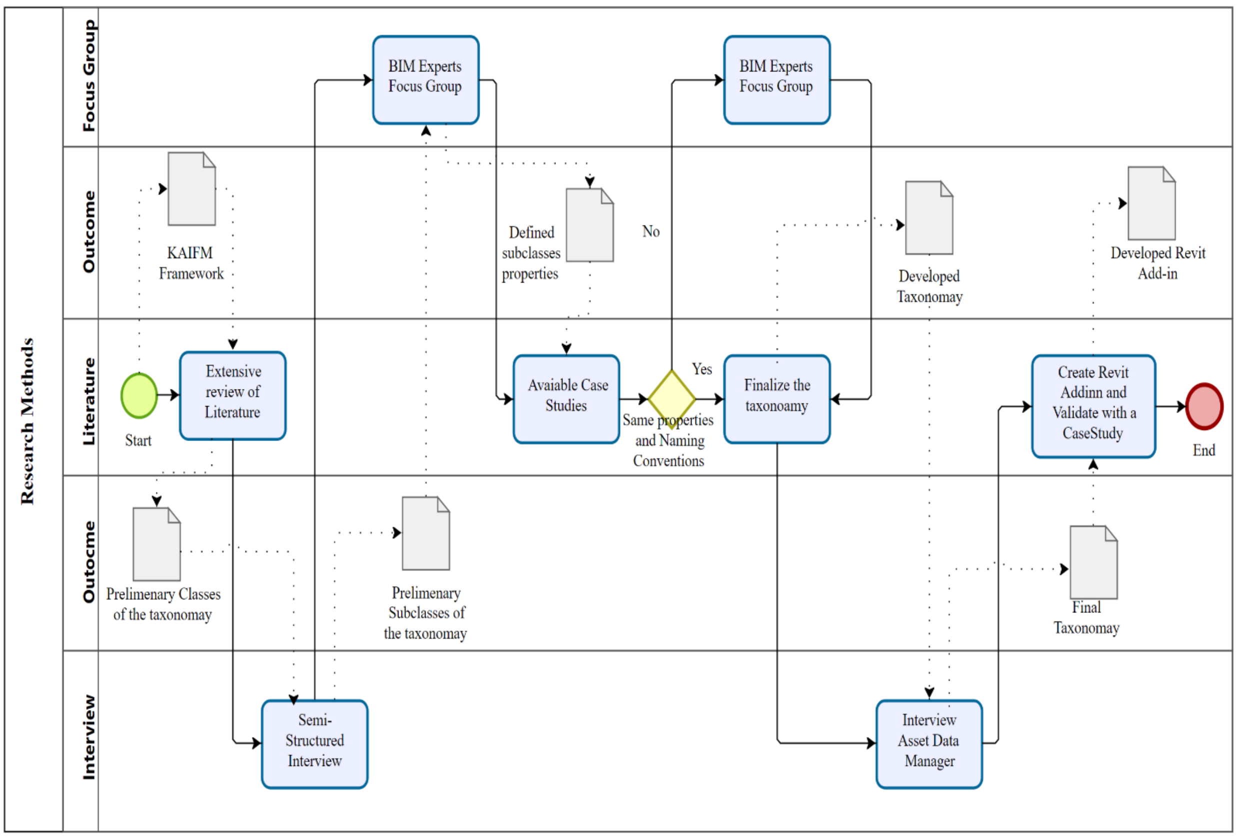

Figure 2: Research Design and Methods

Development and validation of the ACE-IM taxonomy.

The taxonomy has been developed by utilizing and synthesizing different research methods including a literature review, semi-structured interviews and a focus group. An iterative approach of four main steps proposed by Cavka et al. (2017), to understand the owner requirements, identify the required information and how they relate to BIM, has been adapted in this stage. First, an extensive review of the current academic, project documents, international reports and practice guidelines and standards was carried out focusing on the recommended/proposed non-geometric asset data extracted from BIM models for AM. Also, a set of existent case studies were used as exemplars for showing which BIM information is utilized for AM. The case studies were purposely selected in order to assure industry engagement in the reviewed literature.

Subsequently, three semi structured interviews were conducted with a facility manager, an asset data manager and an information manager who were involved in the decision to adopt BIM for FM in their companies. Semi structured interviews are chosen for this research as they can provide understandable relationship between different aspects in explanatory study (Saunders et al. 2011). The number of interviewees doesn't represent the actual sampling as each interviewee's input is based on participating in several projects. Meanwhile Jette et al. (2003) suggested that expertise in the chosen topic can reduce the number of participants needed in a study. The selected interviewees have more than 20 years of experience in construction and/or asset management industry and delivered at least five BIM projects. The interviewees were asked to comment on the research main questions; however they were free to elaborate on AM challenges as they experienced these in their projects. The interviews were aimed at confirming and clarifying the required asset data from BIM identified by the literature review. Based on the findings from the literature and the semi structured interviews, a thematic analysis was carried out using an appropriate coding scheme in order to develop and classify the taxonomy of the BIM parameters required. After the third interview, it has been found that the taxonomy has reached redundancy. To interview to saturation, Fusch and Ness (2015) suggested that a focus group is one way to provoke a number of perspectives on a given topic to reach data saturation. They added that focus group is an appropriate approach after interviews with a small number of participants for validation. Consequently, a focus group with eight BIM experts was conducted to evaluate and validate the developed taxonomy, and link the developed taxonomy to Revit, one of the most popular BIM platforms, taxonomies/structures. The expertise for eligibility to participate in the focus group was determined based on different criteria namely; five years' experience in BIM projects, expert in BIM applications such as Revit platform and mechanical or electrical engineer. All the participants have worked in world class project all around the Middle East, most of the projects are educational buildings such as King Abdullah Petroleum Studies and Research Center (KAPSARC), Qatar University and different schools.

Development of the API plug-in Autodesk Revit

This stage focuses on demonstrating the ACE-IM taxonomy by developing an API plug-in Autodesk Revit that adds all the required parameters for AM to the assets and scrutinizing the plug-in via a case study. It has to be noted that this stage is not aimed at validating the developed taxonomy since this would be validated by the focus group. The aim of developing the API plug-in is mainly to assure that the required parameters for AM defined in the taxonomy can be easily, correctly and automatically added to the selected Revit elements. The API development consists of two stages which include creating a shared parameter file that contains all the required parameters proposed in the ACE-IM taxonomy, and automatically adding the new parameters while reading from the existing parameters. The project selected as a case study is the Abercrombie building, Oxford Brookes University campus, U.K (Figure 3). The model was created by using information including available floor maps, 3D sketch up models, modifying the models using plans and mechanical specifications provided by the FM team and/or inspecting the existing facilities. The model was completed with filling the ACE-IM required parameters in approximately 160 hours for one storey level, with an average of 10 m^2 completed every hour.

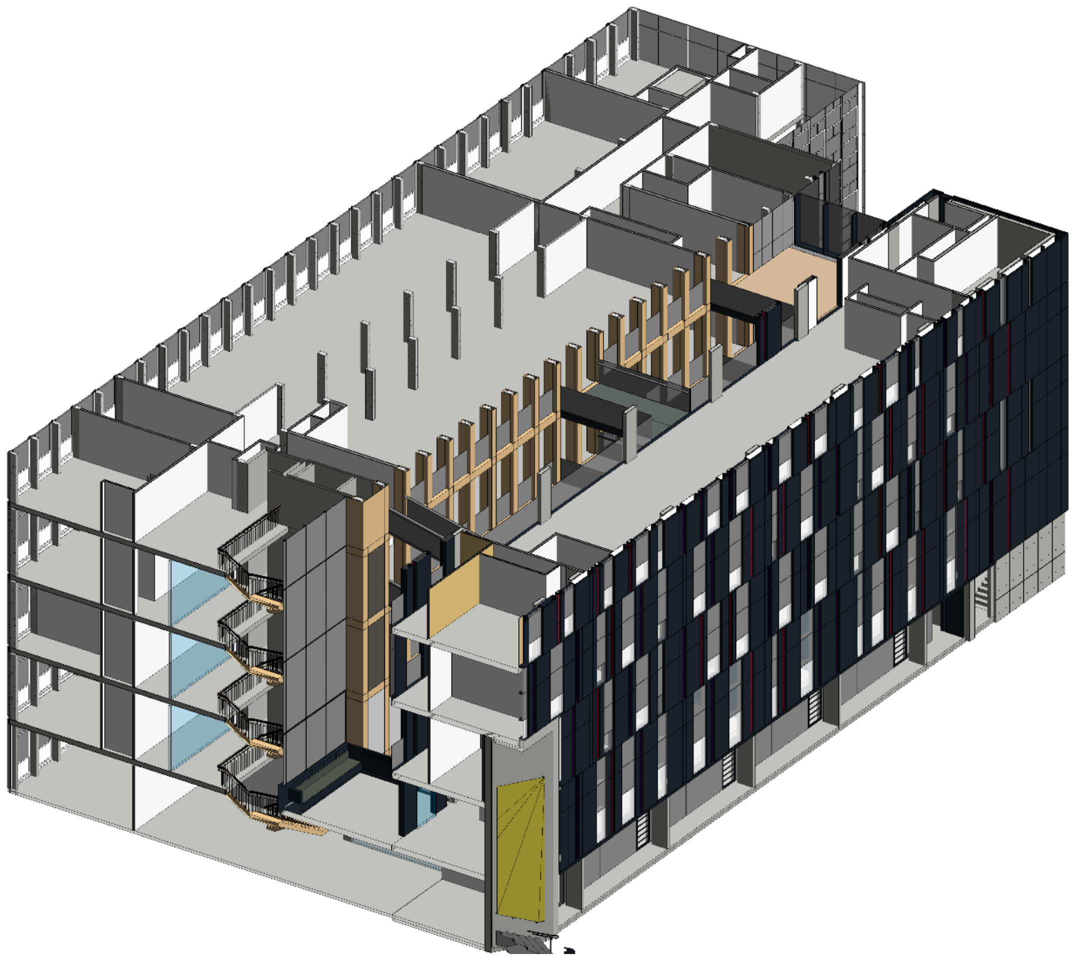

Figure 3: 3D BIM Model for the Abercrombie Building, Oxford Brookes University

Related Taxonomies

Most studies in BIM implementation in FM have largely focused on geometric data requirements., However, there is an urgent need to concentrate on identifying the non-geometric requirements as well in order to support successful implementation (Becerik-Gerber et al. 2012). Becerik-Gerber et al. (2012) identified the required data in a pyramidal classification from the early stages down to the operation and maintenance data which can be captured during building usage. Wang et al. (2013) proposed the structure of a BIM database for FM in the early engagement of AM in the design stage. This database of equipment and systems was divided in two categories namely; attributes and data which includes information related to vendor, location, etc. and portfolios and documents which includes information related to specifications, manuals, certificates, etc. Hunt (2011) proposed another hierarchical classification in the closeout and handover stage with two main levels. First, description system level with sublevels related to location, manufacture information, vendor, ID name and number and second, technical content level with sublevels related to warranties, maintenance instructions, etc. Mayo and Issa (2015) refined these taxonomies further through conducting a Delphi survey with 21 FM experts. They classified the required data based on FM applications. For example, they proposed four main types of data required for building AM namely; asset location, asset purchase information, bar code information and asset identifier.

COBie can also be considered as a taxonomy of information required for AM. COBie is a data standard that was developed by the US Corps of Engineering to manage the non-graphical data received from BIM models, particularly for the handover of Operation and Maintenance (O&M) manual information (East 2013; Spilling 2016). COBie classified the data into ten main categories: facility (project, site and building/structure information), floor (the mandatory spatial structure), space (the spatial locations where inspection, maintenance and operation jobs occur), zone (additional functional groupings of locations), type (mandatory grouping of components as types or products, used to organize maintenance tasks), component (the physical assets), system (additional functional groupings of components), spare (the physical objects), job (the processes and tasks used to maintain and operate the assets) and resources (support the processes and the tasks). COBie UK 2012 was extended with two more categories: cost and carbon (Spilling 2016).

COBie is a repetitive process with four defined ‘data drops’” taking place at crucial stages of the project lifecycle to capture the available and required data for AM (East and Carrasquillo-Mangual 2013). In a £185m new build prison project in the UK, the Ministry of Justice has created a set of Plain Language Questions (PLQs) to be combined with COBie data for handing over a series of asset schedules at the end of the project. These include lists of building services equipment such as plant, air handling units, pumps, fans and fixtures and fittings, all of which are asset tagged within the model (Cousins 2015).

At the same time, several industry projects and guidelines recommend different required data. The Sydney Opera House (SOH) is one of the first projects implementing BIM for FM. Due to the long design life of the SOH and its complexity, the engagement of BIM was mandatory in order to provide open interoperability and serve as a data management pool (Schevers et al. 2007). In the SOH Model Management Plan (MMP) document, thirty-six parameters were identified as the required data from BIM models for AM. According to the building information manager of the SOH, the MMP is a live document which is revised and updated from time to time to achieve successful AM. The identified required data are classified into six main categories: 1) BIM4FM including the capex data related to the assets from the design and construction stage, 2) element details suggesting the location and unique details for each asset, 3) element specification, 4) warranty, 5) certifications and 6) asset control. The Manchester City Hall (MCH) is another project where BIM has been implemented for AM. Before BIM implementation, the asset information in the CAFM system was inadequate and inaccurate and thus, was highly inefficient in terms of creating an onward maintenance plan. Therefore, BIM was implemented to create an AIM and New Rules of Measurement (NRM3) was selected as guidance for the asset taxonomy (Oluteye and Marjanovic-Halburd 2015). NRM3 is an asset classification standard for structuring the cost data of assets relevant to the operation and maintenance phase of a facility. (Green 2014). NRM3 information requirements for order of cost estimates and the purpose of BIM implementation influenced and formatted the collected/required asset data. The collected asset data included information related to asset location, maintenance history, operation history and costs. The Doha Metro is a project in the capital of Qatar consisting of four lines and 37 stations. Qatar Rail, the owner of the project, published a document to stipulate asset information requirement for maintenance management system (MMS). Seven mandatory sets of information were identified as asset information requirements (AIR) namely; item name and number, location, manufacture details, vendor details, price, installation date and warranty.

Further to the specific project developments described above, the consultancy Microdesk has also published a white paper named "Transitioning BIM Data to Asset Management" (Broadbent 2016). The paper identifies 72 critical parameters to be captured for asset and maintenance management. It also highlights that 62 of these parameters can be captured from the BIM model and can be categorized in 7 main classifications namely; purchase information, facility information, asset specification, system specifications, maintenance procedures, manufacturer, vendor and extended warranty. Generally, in the current on-going BIM projects, the required information is identified based on PLQs, educated experience and, sometimes on assumptions of data that might be needed for better AM (Tune 2017).

Meanwhile, in the last couple years, three leading construction bodies in the UK; the Building Engineering Services Association (BESA), the Construction Products Association (CPA) and the Chartered Institution of Building Services Engineers (CIBSE) have been developing standardized product information for successful implementation of BIM in all the phases of AEC and O&M (Caplehorn 2017). CIBSE formed a working group and engaged industry experts to make standardized Product Data Templates (PDTs) under a project called BIMHawk. Meanwhile, CPA in cooperation with the BIM Task Group and the UK BIM Alliance are leading the development and implementation of LEXiCON, the plain language approach to product data definition and exchange in the UK. As part of this development, the key source of product information requirements comes from the Harmonized European Standards (hENs), standards requirements, industry recognized requirements, and client requirements (Thompson et al. 2016). The concept of LEXiCON is to create so-called Product DNA, i.e. information that stays with a product throughout its lifecycle. LEXiCON provides the governance to ensure the defined properties are the correct ones and are aligned with the buildingSMART Data Dictionary (Caplehorn 2017). In other words, LEXiCON will guarantee that the AEC and O&M industries have one common fixed PDT for each product type, including agreed parameters and their standardized naming convention, which is managed by the CPA and relevant trade associations (Small 2017). BESA, CIBSE, and CPA have agreed on the respective roles of the 'LEXiCON' and 'BIMHawk' to avoid any confusion or even competition (Caplehorn 2017). The PDT is meant to be a standardized way through which manufacturer product attributes/parameters can be made available in machine-readable format during all the phases of the facility. Parallel efforts have been exerted by CIBSE, National Building Specification (NBS) and Norway coBuilder to create their own PDTs. CIBSE's PDT is an Excel spreadsheet with five columns. The first column defines the information category which is divided to three sub-categories, i.e. specification, suitability and asset management. The columns two, three and four represent the parameter required to be defined, the value of the parameter, and the value unit respectively. Finally, the fifth column is for guide notes. It has to be noted that only the third (value) column needs to be completed as all other are fixed for each asset. Once this data is added, the PDT becomes a Product Data Sheet (PDS). The total number of fields/parameters varies from PDT to PDT depending on the asset functions and its manufacturer (Thompson et al. 2016). NBS produced its own PDTs as part of its BIM toolkit which contains more than 5700 consistently structured templates covering buildings and infrastructure that state the minimum product data requirements for Level 2 BIM. Norway coBuilder developed more than 700 PDTs based on IFC where the PDT parameters are aligned with the Construction Product Regulations (CPR) (Tune 2017). Tune (2017), the CEO of coBuilder in the UK, suggested that coBuilder PDTSs are the only PDTs created based on European standards such as CEN/CENELEC standards and Environment Product Declaration (EPD), National standards such as classifications and object naming conventions and market requirements. Based on the literature review, different classifications and long lists of diverse required information were formed. On the basis of the available lists, a preliminary taxonomy was developed to collate and consolidate results of these previous studies. This also served as the groundwork for conducting the semi-structured interviews. In the next section of this paper, a taxonomy for the required information for management of assets that consume energy is presented and discussed.

Taxonomy Development

According to the Oxford English Dictionary, a taxonomy is a scheme of classification where the description of terms and their relationships in the context of a knowledge area are identified. While Van Rees (2003) defines taxonomy as 'a hierarchy created according to data internal to the items in that hierarchy'. Developing a taxonomy of the objects of a knowledge field can provide a common terminology which eases the sharing of knowledge, helps in identifying the knowledge gaps in the field and supports decision making (Usman et al. 2017). There are four main approaches to structure a classification schema including hierarchy, tree, paradigm and faceted analysis (Kwasnik 1999). Hierarchy leads to taxonomies with a single top class and its subclasses, i.e. a hierarchical relationship with inheritance. The tree approach is similar to the hierarchy; however, there is no inheritance relationship between the classes of tree-based taxonomies. Kwasnik (1999) added that there is another type of the tree approach in which the entities are related by the partitive relationship. This means that each class is divided into its components (part/whole relationship). The paradigm methodology leads to taxonomies with two-way hierarchical relationships between classes and the faceted analysis leads to taxonomies whose subject matters are classified using multiple perspectives (facets). The characteristics of the tree structure approach are the most suitable for developing the required taxonomy. After the interviews, the preliminary taxonomy was modified and updated. The taxonomy was developed taking in consideration the revised developing taxonomy method of Bayona-Oré et al. (2014) proposed by Usman et al. (2017) and also the guide of creating ontology by Noy and McGuinness (2001). Usman et al. (2017) approach consists of four main stages; planning, identification and extraction, design and construction and validation, as well as thirteen different activities. While the Noy and McGuinness (2001) method consists of four iterative steps namely to; determine the domain and the scope of the taxonomy, consider reusing existing ontologies, define the class and the class hierarchy and finally, define the properties and slots of classes.

Figure 4 is a diagrammatic representation of the proposed taxonomy of the required data for successful implementation of BIM in AM. The taxonomy adopts a two-level tree structure with a top-down development process. The top level is classified into six main branches/classes namely; location/space, classifications, specifications, warranty, assets capex and maintenance. At the second level sixty subclasses are representing the required BIM data/parameters for AM at the handover stage. These parameters can be collected in any of the following stages; planning and design, construction, commissioning, handover and closeout and finally, operation and maintenance. Further properties and slots are identified for these parameters in Table 1. The six top categories/classes are discussed below with their required parameters.

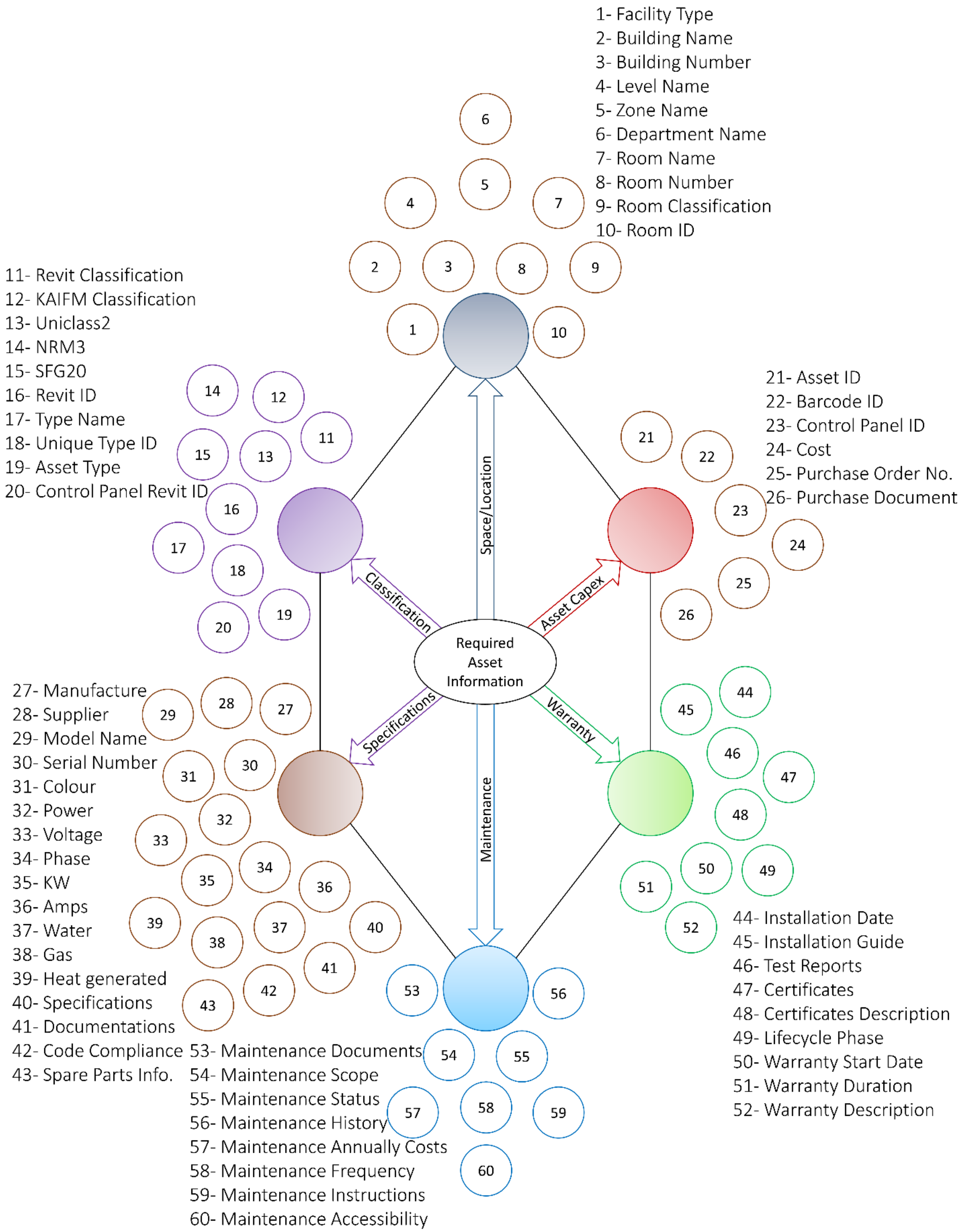

Figure 4: ACE-IM Taxonomy for the required information for AM

Space/Location category includes eight parameters: facility type, building name, building number, level name, zone name, department number, room name, room number, room classification and room ID. All of these parameters are related to the spatial location of the asset and they can be identified and captured from the architectural models during the design stage. All of the space/location parameters are instance parameters which differ for the same type of asset depending on location. However, the parameters facility type, building name and building number are related to the building and are required when the assets of clusters of buildings are managed and operated together. Some of these parameters and parameters in the other categories (such as NRM3, specifications and maintenance duration) have to be added to the Revit model as a shared parameter as they are not available by default in the Revit platform.

Classification category includes the following parameters: Revit classification, ACE-IM Classification, Uniclass2, NRM3, SFG20, Revit ID, Type Name, Asset Type and Control Panel Revit ID. This category provides a common data classification from different perspectives. All of these parameters can also be collected during the design stage; however, some of them, such as NRM3 and SFG20, are usually collected in the operation stage. Revit Classification is the default classification for the mechanical and electrical Revit elements and is called system classification for mechanical objects. The ACE-IM classification parameter is developed based on the proposed classification of the assets that consume energy (Aspect 1 - ACE-IM framework). Figure 5 illustrates the different elements classification based on the classification of energy consumption (Pérez-Lombard et al. 2008; Sadeghifam et al. 2013). This classification of elements that consume energy has been developed through the focus group work in collaboration with the BIM experts. Uniclass2 is the new UK implementation of the international framework for construction information. Uniclass2 classification is not identified in the Revit Database;

however, it can be easily implemented. The NRM3 provides the data structure to integrate construction with operation and maintenance. Unfortunately, the NRM3 has been only published as a hard copy and therefore, the data has to be added manually to the Revit platform. In PAS 1192, uniclass2 is classified as the relevant BIM data classification for design and construction stage, while NRM3 is classified for the operation and maintenance. SFG20 is another well-known standard for maintenance specifications in the UK. SFG20 is a web-based online application where the different tasks of maintenance can be assigned to project assets. The SFG20 core library offers users more than 400 industry-standard maintenance specifications covering all principal types of heating, cooling and ventilation, installation, plant and electrical services, complete with regular technical updates. Although SFG20 is not specified in PAS 1192, it can be easily figured out as it is aligned with NRM3. Revit ID and Control Panel Revit ID are unique identification information generated by Revit for the objects that need to be maintained and operated and for the control panel responsible for the objects that consume energy respectively. Type Name is the name assigned for the asset in the design stage, while asset type defines whether the asset is fixed or movable. Revit ID and Control Panel Revit ID are instance parameters while the remaining ones are type parameters.

Asset Capex category includes six parameters namely, Asset ID, Bar Code ID, Control Panel ID, cost, purchase order number and purchase documents. The Asset ID is the identification assigned to an asset that enables its differentiation from other assets. The Bar Code ID parameter identifies the bar code, or RFID, given to an occurrence of the product (per instance). The control panel ID is the identification assigned to a control panel by the asset managers enabling its differentiation from other control panels to control, manage and evaluate each control panel separately. The cost parameter indicates the purchase cost of the asset and its replacement cost.

Purchase order number and purchase documents are two parameters related to the procurement of assets. Purchase order number is a unique number for each purchase for easier classification while the purchase documents parameter is a URL path for the document.

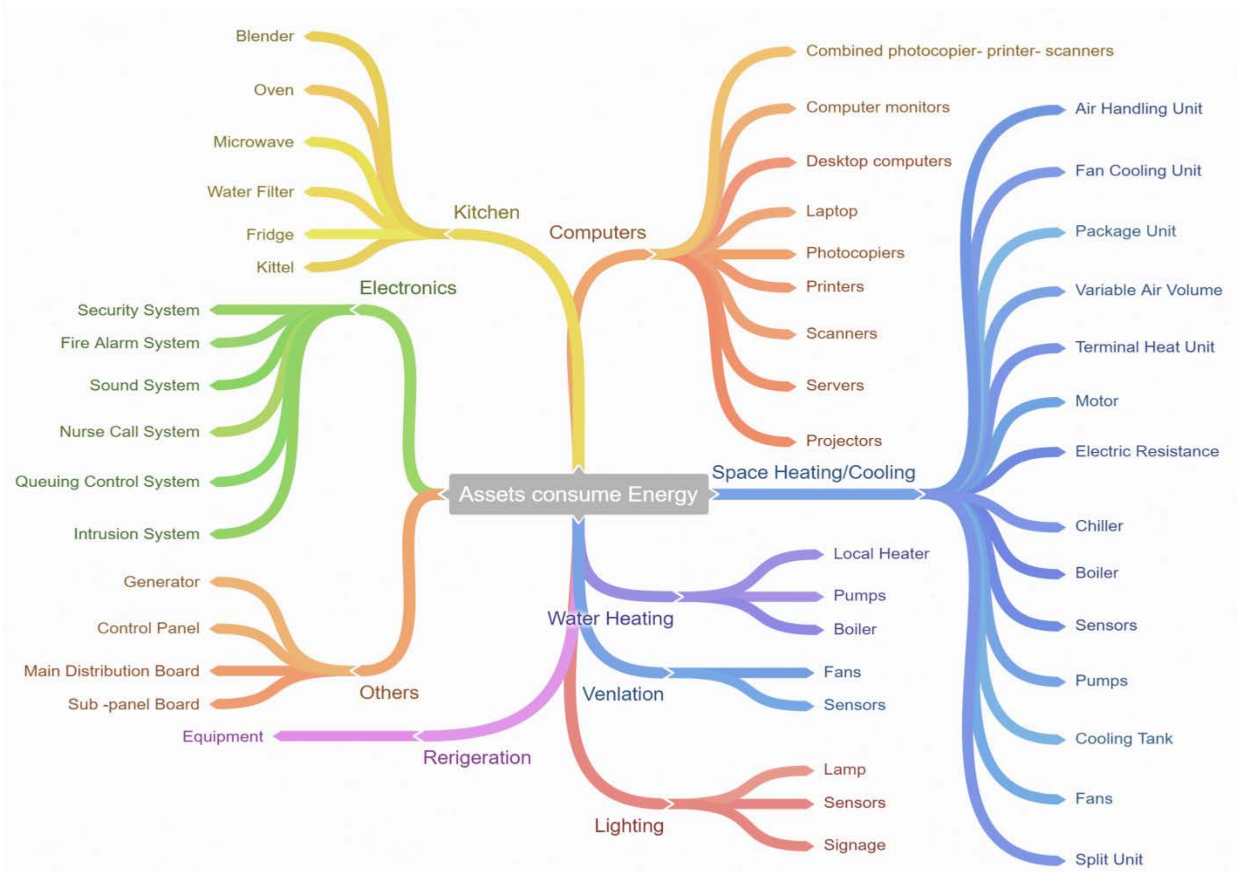

Figure 5: ACE-IM classification of the assets consume energy

Specification category includes seventeen parameters namely, manufacture, supplier, model name, serial name, color, power, voltage, phase, KW, Amps, water, gas, heat generated, specification, documentation, code compliance and spare parts document. These parameters are related to the specifications of the assets and all are type parameters except the parameter serial name. These data can be collected during the commissioning and handover stage. The manufacture parameter includes the email address or the name for the organization responsible for manufacturing the asset. The supplier parameter identifies the organization responsible for delivering the asset. The model name is a label of the asset assigned by the manufacturer and usually, its value is the same with the type name parameter. The serial name is the product, item or unit number assigned by the manufacturer of the asset. Color is the characteristic or primary color of product/asset, while the insulation class provides basic protection information against electric shock. Voltage, phase, power (KW), current (Amps), water, gas, heat generated parameters state the energy properties for the asset. Specification, documentation and spare parts are URL value parameters for the documents stating the specification of the asset, any relative documentation and the spare parts specifications respectively. Code compliance is a parameter where the object performance towards its compliance is defined.

Warranty category includes nine parameters namely, installation date, installation guide, test reports, certificates, certificates description, lifecycle phase, warranty start date, warranty duration and warranty description. Installation data is the time that the manufactured item was installed and this parameter is an instance parameter. Installation guide is the documentation describing the installation procedures and techniques. Installation guide, test reports and certificates are URL value parameters for the installation and certification documents. Certificates description and warranty description are parameters summarizing the available certificates and warranties for the asset respectively. Lifecycle phase states the expected life duration of an asset. Warranty start date is the date the warranty commences for an asset and usually, has the same value as the installation date, while the warranty duration is the duration of warranties for individual asset parts. When some assets include different parts with different warranty durations, a new parameter is added which includes the URL for the document of the different warranty durations for the parts.

Finally, maintenance category includes eight parameters namely, maintenance documents, maintenance scope, maintenance status, maintenance history, maintenance and operation annually costs, maintenance frequency, maintenance instructions and maintenance accessibility.

Table 1 illustrates and summarizes the sixty parameters, their category, their unit and type or instance and the phase where the data can be collected. The parameter unit is the named 'parameter type' in the Revit platform and is responsible for identifying the nature of the parameter (alphanumeric, numeric, URL, integer, material or yes/no question). The non-graphical parameters in Revit can be divided in two kinds of predefined parameters: Type Parameter and Instance Parameter. Type parameters of an asset are the same for all occurrences of that asset. Parameters that have their own properties and are unique to its installation are categorized under the Instance Parameter type. However, as already mentioned, the predefined parameters do not include all the required parameters for the ACE-IM taxonomy and as a result, new parameters are identified as such. Finally, the ACE-IM required information is extracted and collected at different stages of the building lifecycle as the COBie data drops. The four ACE-IM data drops are akin to the Royal Institute of British Architects (RIBA) Stages 4, 5, 6 and 7. Once these parameters and their corresponding properties are identified, they are arranged to be used in developing a Revit Plug-in. In the next section of this paper, a Revit Plug-in is presented where the ACE-IM taxonomy for the required information can be identified and added to the Revit elements.

Table 1: ACE-IM Parameters for the required information for AM

Category	Parameter Name	Unit	Type/Instance	Defined/New	Phase
Space/Location	Facility Type	Alphanumeric	Project	New/Write	1
	Building Name	Alphanumeric	Project	Available	1
	Building Number	Alphanumeric	Project	Available	1
	Level Name	Alphanumeric	Instance	New/Read	1
	Zone Name	Alphanumeric	Instance	New/Write	1/3
	Department Number	Alphanumeric	Instance	New/Write	1/3
	Room Name	Numeric	Instance	New/Read	1

	Room Number	Numeric	Instance	New/Read	1
	Room Classification	Alphanumeric	Instance	New/Write	1
	Room ID	Numeric	Instance	New/Read	1
Classification	Revit category	Alphanumeric	Type	Available	1
	KAFIM Classification	Alphanumeric	Type	New/Write	1
	Uniclass2	Alphanumeric	Type	New/Write	1
	NRM3	Alphanumeric	Type	New/Write	1/3
	SFG20	Alphanumeric	Type	New/Write	1/3
	Revit ID	Numeric	Instance	Available	1
	Type Name	Alphanumeric	Type	Available	1
	Unique Type ID	Alphanumeric	Type	New/Write	1
	Asset Type	Alphanumeric	Type	New/Write	1/3
	Control Panel Revit ID	Numeric	Instance	New/Read	1/2
Assets Capex	Asset ID	Alphanumeric	Instance	New/Write	3
	Barcode ID	Alphanumeric	Instance	New/Write	3
	Control Panel ID	Alphanumeric	Instance	New/Write	3
	Cost	Numeric	Type	Available	2/3
	Purchase Order No.	Alphanumeric	Instance	New/Write	2/3
	Purchase Documents	URL	Instance	New/Write	2/3
Specifications	Manufacture	Alphanumeric	Type	Available	2/3
	Supplier	Alphanumeric	Type	New/Write	2/3
	Model Name	Alphanumeric	Type	Available	2/3
	Serial Number	Alphanumeric	Instance	New/Write	2/3
	Color	Alphanumeric	Type	New/Write	2/3
	Insulation class	Alphanumeric	Type	New/Write	2/3
	Voltage	Numeric	Type	New/Write	2/3
	Phase	Numeric	Type	New/Write	2/3
	Power - KW	Numeric	Type	New/Write	2/3
	Current - Amps	Numeric	Type	New/Write	2/3
	Water	Numeric	Type	New/Write	2/3
	Gas	Numeric	Type	New/Write	2/3
	Heat Generated	Numeric	Type	New/Write	2/3
	Specifications	URL	Type	New/Write	2/3
	Documentations	URL	Type	Available	2/3
	Code Compliance	Alphanumeric	Type	New/Write	2/3
	Spare Parts Info.	URL	Type	New/Write	2/3
Warranty	Installation Date	Numeric	Instance	New/Write	2
	Installation Guide	URL	Type	New/Write	2
	Test Reports	URL	Type	New/Write	2
	Certificates	URL	Type	New/Write	2
	Certificates description	Alphanumeric	Type	New/Write	2
	Lifecycle phase	Numeric	Type	New/Write	2
	Warranty Start Date	Numeric	Instance	New/Write	2
	Warranty Duration	Numeric	Type	New/Write	2
	Warranty Description	Alphanumeric	Type	New/Write	2
Maintenance	Documents	URL	Type	New/Write	2/3
	Scope	Alphanumeric	Type	New/Write	2/3
	Frequency	Numeric	Type	New/Write	2/3
	Annual Cost	Numeric	Instance	New/Write	4
	Instructions	Alphanumeric	Type	New/Write	2/3
	Status	Alphanumeric	Instance	New/Write	4
	History	Alphanumeric	Instance	New/Write	4
	Accessibly	Alphanumeric	Instance	New/Write	2/3

Taxonomy Implementation

The completion of the study requires the development of a platform which has a dedicated building modeling section (Mechanical and Electrical section), supports object extraction and accommodates interaction with external plug-in object-oriented interface. The Revit platform was found to be suitable with rich SDK documentations and also, available to researchers at subscribing institutions. A Revit model consists of objects geometry, i.e. graphical information, associated with its predefined properties/parameters, i.e. non-graphical information. However, these existing predefined parameters are not sufficient to cover the required information for AM and therefore, further parameters have to be added. Revit provides the functionality for adding user-defined parameters through C# object-oriented programming (OOP) within the .NET Framework environment. This functionality was used to add the required parameters to each Revit object which can be defined as an asset. To create the new model parameters, various parameter properties were considered; including discipline, type of parameter, group parameter under ‘value’ and categories, based on the Revit Parameter Properties Dialogue Box. The type of parameter (e.g. text, integer, URL) depends on the required information listed in Table 1. All the additional parameters are added in Group parameter under ‘Other’. The required parameters are added under specific categories the selection of which will be defined in the end-user interface as they may differ from one project to another. In order to add user-defined parameters, first, a shared parameter file must be created (Figure 6). The shared parameter file stores the definitions and properties of the shared parameters. A shared parameter is an attribute for information that can be used in multiple Revit families or projects. Shared, instead of project, parameters were used in the creation of the new parameters as a shared parameter can be scheduled and made available for multiple projects. The different properties of each parameter were included in the shared parameters text file for standardization and automation. The first step in the prototyping is creating this shared parameter file. Overall, 8 common existing parameters and 39 new parameters (22 type parameters and 17 instance parameters) were identified. Details of the existing and new parameters are illustrated in Table 1. Once the default shared parameter file is created, the second step is adding the new parameters and reading from the existing parameters.

```
# This is a Revit shared parameter file.
# Do not edit manually.
*META	VERSION	MINVERSION
META	2	1
*GROUP	ID	NAME
GROUP	1	01. Location
GROUP	2	02. Classifications
GROUP	3	03. Specifications
GROUP	4	04. Warranty
GROUP	5	05. Asset Capex
GROUP	6	06. Maintenance
*PARAM	GUID	NAME	DATATYPE	DATACATEGORY	GROUP	VISIBLE	Parameter	Parmeter Group
PARAM	27e9fa04-e94d-4293-acae-f4d6ef1bbc92	Room ID	TEXT	1	1	Instance	Data
PARAM	b8a0ff12-e631-475f-84ed-d5b34f46b5df	Certificates Description	TEXT	4	1	Type	Data
PARAM	bfa6021b-ff83-4644-b425-8e778530b2c1	Room Classification	TEXT	1	1	Instance	Data
PARAM	43faf927-e783-4437-aecc-26979184c23f	Power	TEXT	3	1	Type	Data
PARAM	ea934c2c-bed2-4b35-8ad6-78e945284a70	Installation Guide	URL	4	1	Type	Data
PARAM	3a943031-6d49-4ad5-ae70-fbd64fb60184	Purchase Order Documents	URL	5	1	Instance
PARAM	97bc5d32-a99b-41db-84fa-d39ee7593a9d	Installation Date	TEXT	4	1	Instance	Data
PARAM	fd202034-19be-4746-95e4-4f59cb9f2565	Lifecycle Phase	NUMBER	4	1	Type	Data
PARAM	3ff2e134-d200-48a1-8f42-964a66d23438	Room Name	TEXT	1	1	Instance	Data
PARAM	d2bb5d3a-e22d-4d2a-95ca-ad77dab789c4	Room Zone	TEXT	1	1	Instance	Data
PARAM	c2e43346-9186-477e-baf5-c644c1d576ba	Warranty Description	TEXT	4	1	Type	Data
PARAM	0e39054e-797b-4fba-bf6e-803eb7a88dd3	Facility Type	TEXT	1	1	Type	Data
PARAM	3abe1950-fac6-4dd8-9bea-24c05a6548f4	Puchase Order No.	TEXT	5	1	Instance	Data
PARAM	07f1ff51-b6ed-4c58-b961-ccc0aff755ab	KAIFM	TEXT	2	1	Type	Data
PARAM	b56ea556-62c0-4fb0-9e2a-1c5fca5122af	Barcode ID	TEXT	5	1	Instance	Data
PARAM	ea52c757-eb6c-4253-a10e-27ed668573cc	Warranty Duration	NUMBER	4	1	Type	Data
PARAM	44cb515f-02dd-40e3-a69f-ecb6fc709934	Specification	URL	3	1	Type	Data
PARAM	734c2867-4166-402a-9120-627b8ba68904	Maintenance History	TEXT	6	1	Instance	Data
PARAM	88363375-f0ae-4bd6-8e72-c48960e447c0	Maintenance Instructions	TEXT	6	1	Type	Data
```

Figure 6: Developed Shared Parameter File for ACE-IM Taxonomy

Figure 7 shows a screenshot for the developed ACE-IM Plug-in. The sequence (a-g) shows the steps to execute the Plug-in to add the required data for the required assets. Firstly, select the tab assets' parameters. A new window will appear containing all the features for the Plug-in. secondly, browse the computer file system and select the shared parameter created previously. Press on the group drop box where the different categories of the ACE-IM taxonomy appear and their corresponding parameters. Subsequently, select the Revit category required to add the parameters in its properties. For example, select lighting fixtures to add the parameters for all the elements defined under this category. In the defined shared parameter, various parameter properties were considered and predefined for each parameter, including discipline, type of parameter, group parameter under ‘value’ and categories. An option was added in the Plug-in where the user can either use the properties assigned in the shared parameter or assign customized properties for each parameter. Finally, select ‘Add parameter(s)’. Once all the steps are performed, the selected Revit elements will contain the blank parameters required to be filled for AM. For the developed Plug-in a validation study was conducted. The results of the validation showed that the ACE-IM parameters are added to the elements correctly based on the predefined properties in the shared file.

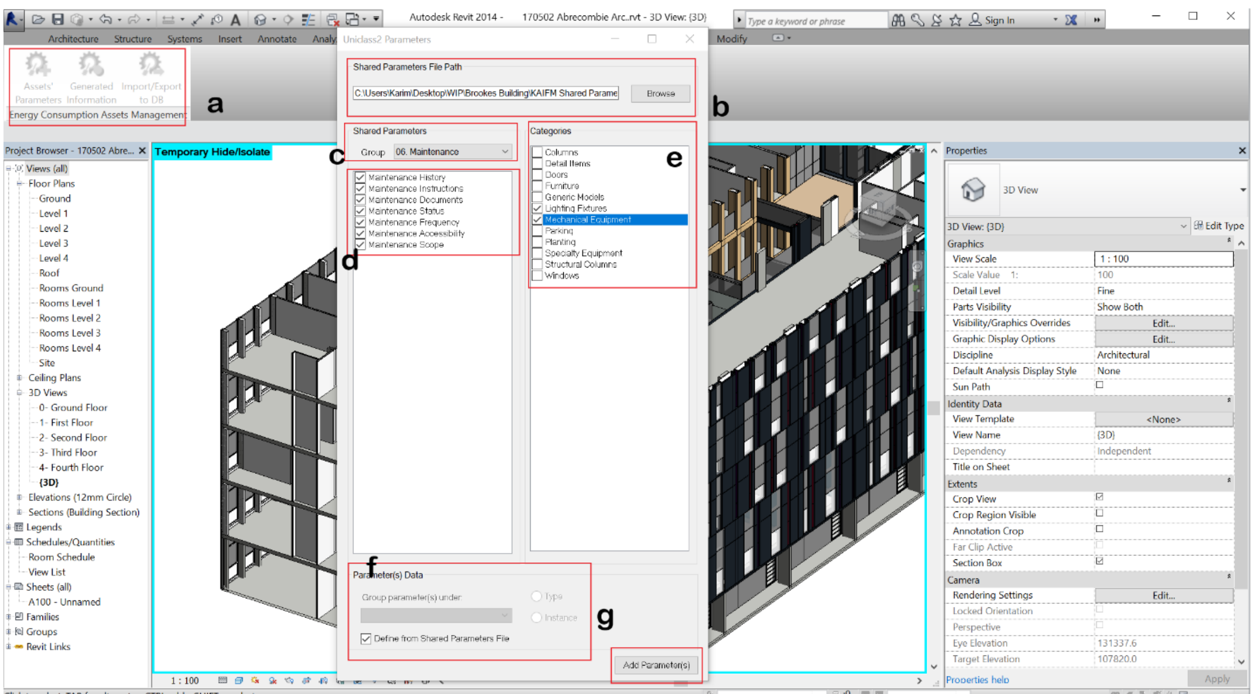

Figure 7: Launching ACE-IM Plug-in

Conclusions and Recommendations

The effective management of asset data is crucial for the delivery, operation and maintenance of any built facility. The identification of BIM data which can be linked to AM is subject to both academic and professional investigation. In the UK alone, there are currently two major projects aiming to develop standard product data parameters and structures. In an attempt to cover the knowledge gap, this paper presented a domain taxonomy which has been created in order to facilitate the successful implementation of BIM in AM. The research was based on a literature review, semi-structured interviews and a focus group. The taxonomy was drawn to benchmark the best practice from other domains while abiding to existing standards and model view definitions.

The developed taxonomy consists of sixty parameters categorized in six main categories; Space/Location, Classifications, Specifications, Warranty, Asset Capex and Maintenance. Each category contains various parameters which can be instance or type parameters. The paper also presented the development of an appropriate Revit Plug-in which was developed to enable the creation of the required parameters. The developed taxonomy represents the required data for the effective application of BIM for AM. The taxonomy, which is based on international data, could facilitate further academic research, contribute to the relevant on-going works by the AEC and O&M industry and provide the underlying foundation for establishing the owner's Asset Information Requirements. Due to heterogeneity of assets' characteristics, the proposed taxonomy focuses only on the assets consuming energy in educational building, further research is required for the other assets. Also further work will involve developing an ontology and MVD based on the proposed taxonomy containing a set of relationships between the subclasses of the ACE-IM taxonomy.

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