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# BIM FOR FACILITIES MANAGEMENT: EVALUATING BIM STANDARDS IN ASSET REGISTER CREATION AND SERVICE LIFE PLANNING

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**SUMMARY:** *Operation and Maintenance (O&M) costs in buildings represent a significant part of the total building life cycle cost. However, project delivery methods in the Architectural, Engineering and Construction (AEC) industry are often focused on the capital delivery stage and associated costs ranging from planning, through design, to construction and handover. Open data standards such as the Industry Foundation Classes (IFC) and specifications such as the Construction Operations Building information exchange (COBie) provide the capability to capture Facilities Management (FM) data requirements in a structured manner from the early stages of project development. We aim to investigate how and whether IFC and COBie can deliver the data and information about assets required by facility managers within a whole life cycle perspective. We focus on specific use cases including the creation of asset registers and service life planning. However, the methodology adopted can be generalised and applied to any other FM use case. The results show that IFC, COBie and the tested supporting tools exhibited some shortcomings in delivering some of the data entities, types and parameters required for the selected FM use cases. We discuss these shortcomings and propose them as areas for improvement to domain researchers, standardisation bodies and technology providers. Finally, we instigate domain researchers to adopt the proposed methodology and conduct further FM use cases.*

**KEYWORDS:** *BIM, Facilities Management, Operation and Maintenance, Asset Register, IFC, COBie, IDM, Service life planning*

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# 1. INTRODUCTION

O&M costs are often overlooked at the design phase by owners and project stakeholders although they could amount to over half of the total building life cycle costs (Becerik-Gerber et al. 2012). Data and information handover to the FM phase is left until the completion of the construction phase and information is typically handed over in manual or non-digital formats. With this late delivery of unstructured data, it becomes very challenging for owners and facility managers to assess whether the information they need is included in the handover data. In addition, the transfer of such data and information to FM systems is a cost and time consuming process, resulting in prolonged periods before optimal building performance can be reached, as optimisation decisions (e.g. maintenance, energy, safety) at the FM phase are delayed.

The emergence of Building Information Modelling (BIM) open standards such as IFC and data structure specifications such as COBie enable the handing over of digital data and information to the FM phase in a gradual and structured way. Several countries such the United Kingdom and the Scandinavian countries and some large clients in the U.S. (i.e. General Services Administration) have prescribed open standards and data specifications as data sources and information exchange formats between the project delivery phases and the use phase of the building (Kassem et al, 2013 and Kassem et al., 2015).

In the United Kingdom (UK), the HM Government's BIM Programme has mandated level 2 BIM (file-based collaboration and library management) on all centrally-procured Government projects by 2016. Within this policy, the need for the provision of structured data for asset information models is recognised in the UK PAS1192-3:2014, which specifies an information management methodology for the operational phase of assets based on open BIM standards and data specifications – (COBie) (BSI 2014a). Also, emerging standardisation efforts for service life planning such as ISO 15686-4:2014 (ISO 2014) and life cycle costing during the maintenance phase of buildings such as BS 8544:2013 (BSI 2013a) are proposing the use of open BIM standards (i.e. IFC) and COBie as data sources and data handover information exchanges for the operational phase of building assets.

Building maintenance activities are multidisciplinary efforts with extensive information requirements. Maintenance can be defined, according to ISO15686-1 as the "Combination of all technical and associated administrative actions during service life to retain a building or its parts in a state in which it can perform its required functions." (ISO 2011, p.2). To maximize the use of buildings and minimize risk and operational costs, maintenance efforts for the occupancy and post-occupancy stages of a building life cycle should be considered from project inception and checked throughout the life cycle phases (BSRIA 2009).

BIM concepts, tools and workflows and their underpinning open standards (i.e. IFC) and data structure specifications (i.e. COBie) aim to provide means to support the exchange of information throughout the life cycle of buildings. In a whole life cycle context, BIM can provide the required information for asset maintenance planning and execution, provided that information is kept in an organized management system (CIC 2012). BIM can contribute to facilities management both as an information source and as a repository to support the planning and management of building maintenance activities in both new and existing buildings (Volk et al. 2014). However, studies that investigate how and whether IFC and COBie support specific FM use cases are still lacking as concluded from the literature review.

In the remainder of the paper, we first present the problem statement and outline the research methodology. Second, we illustrate the literature review covering current research on FM and BIM for FM. At this stage, we also introduce key terms and definitions. In this context, the literature review is employed as a means to provide a comprehensive summary and synthesis of a defined field (Maxwell, 2005) which is '*BIM for FM*'. Third, we perform the use cases for testing IFC and COBie in asset creation and service life planning applications. Finally, we discuss the results and present the conclusions.

# 2. PROBLEM STATEMENT

The unstructured and late delivery of data and information to the FM phase of buildings is a recognised issue among research and communities of practice alike. BIM technologies, workflows and standards are providing new possibilities to address this challenge. Recent studies have identified the general BIM requirements to support building maintenance tasks (Becerik-Gerber et al. 2012, CIC 2012, Motamedi et al. 2014). However, detailed and systematic evaluations of the BIM open standards (IFC and COBie) in specific FM use cases are still lacking and deserve noteworthy attention. This research proposes a methodology for the definition and checking of owner's requirements throughout the life cycle of buildings by focusing on total expenditure costs (i.e. capital and operational costs). This evaluation also needs to consider the role of construction clients and stakeholders such as designers and facility managers in the definition and continuous checking of detailed operational requirements (BSRIA 2009). Within this holistic life cycle methodology, this paper conducts specific FM use cases to: 1. Evaluate IFC and COBie support in fulfilling the information requirements for asset register creation and service life planning, and 2. Propose workflows for embedding and extracting client maintenance requirements into and from BIM, respectively. The overarching implication of this research is to help owners and facility managers with the decision making process regarding the operation phase of buildings through the delivery of an Asset Information Modelling (AIM) based on open BIM standards (IFC) and data structure specifications (COBie).

# 3. THE IDM AND USE CASE DRIVEN METHODOLOGY

This research aims to support construction project stakeholders (i.e. architects, engineers, contractors, client, owners and facility managers) with the process of defining and transferring their data and information requirements for the FM phase using open BIM standards and technologies. This aim is investigated within a whole life cycle perspective utilising open BIM standards (IFC) and data structure specifications (COBie). To achieve this aim, a *use case* driven methodology based on the *Information Delivery Manual* (IDM) methodology (ISO, 2010) is proposed. IDM was selected due to its capabilities for the specification of the business processes undertaken during the development and delivery of built facilities, along with the specification of information that is required by these processes, hence, providing a way to map and describe information processes across the life cycle of a constructed facility. Indeed, it enables this research to focus on specific FM use cases without losing the links with the building whole life cycle stages where information is generated, exchanged, checked and utilised. The use case is a system 'usage scenario' characteristic of a specific 'actor' – users or external systems communicating with the system being tested (Regnell et al., 1995). In our case, the system usage scenario is the 'evaluation of IFC4 and COBie 2.4 and some of their enabling technologies as a source of information for service life planning' and the actors are all stakeholders involved in delivering a construction project across its whole life cycle. The use case is designed to deliver the two-fold goal of assessing IFC, COBie, and their supporting technologies, and showcasing the workflows that can be used to deliver specific owner requirements (e.g. service life planning). The use of the IDM methodology as the basis for the use case driven approach proposed in this research is part of a global methodology for FM requirement-based testing. Relevant established standards for the definition of FM requirements are selected and used within this methodology.

# 4. LITERATURE REVIEW

## 4.1 Service life planning

The service life of buildings and civil infrastructure is typically in the range of decades. These built assets are made of many different components with different service lives. Service life information of building components should be taken into account from the early design stages of building development. Careful considerations are necessary when selecting components with different service life spans as this can impact on the ease and feasibility of maintenance and replacement at the O&M phase (Hovde and Moser 2004, Marteinsson 2005). Service life data and information is required by the owner during the O&M phase to effectively support decision making processes in the development and execution of maintenance strategies (Marteinsson 2005).

According to the ISO 15686-1 (ISO 2011), the activity of service life planning primarily aims to demonstrate that the service life of a proposed building (i.e. the period of time after construction during which a building or its component parts meet or exceed the performance requirements) will exceed its design life. Several methods are proposed to support the task of service life planning (Hovde and Moser 2004). These methods can be categorised into deterministic and probabilistic approaches. A method which supports both approaches is the factor method (ISO 2008). The factor method is used to obtain the Estimated Service Life (ESL) of components by modifying a Reference Service Life (RSL)[1] and considering the differences between the object-specific and reference in-use

[1] Service life data that has been generated under a set of reference conditions. Sources for service life of components and

conditions, under which the RSL is valid. These differences are classified into several factor categories (ISO 2008). To account for uncertainty and variability in building components, the factor method supports the use of probability distributions or probability functions for any of the factors and the RSL. While the factor method does not constitute a time-dependent degradation model, it takes the effect of degradation in service life into account through the use of environmental factors.

Life Cycle Costing (LCC) is one of the methodologies used in service life planning to predict and assess the cost performance of constructed assets (ISO 2011). The results from LCC assessments can be used as an input into decision-making and evaluation processes. LCC assessments are performed over an agreed period of analysis which is a fraction of the total life cycle of the asset. The quantification of life cycle costs varies in levels of detail according to building life cycle stages (ISO 2008).

Life cycle costs can be split into construction, operation and end-of-life costs such as decommissioning and demolition. During the use phase of the building, LCC assessment can contribute to the O&M decision making processes. For example, outcomes of LCC enable facility managers to evaluate the acceptable level of performance of the assets. The results from LCC assessments can also be used as an input for annualised maintenance plans, Life Cycle Renewal (LCR) plans, and evaluation of asset depreciation/sinking fund requirements (BSI 2013a).

BIM can be used as an information source to perform LCC. The emergence of nD BIM based modelling tools is providing the ability of performing LCC assessments at the early design phases using IFC files (Fu et al. 2007). Hallberg and Tarandi (2011) proposed a life cycle management system for construction works which is based on the IFC standard and 4D visualization. According to the authors' findings, IFC models (IFC 2x3) constitute a clearer and more efficient source of information when compared to traditional database solutions. However, these are still inadequate for life cycle management during the maintenance phase and need further development in this area. Recently, ISO proposed the standard ISO 15686-4 for service life planning information using the IFC4 standard and the COBie data specification. Data requirements are specified, including the support for uncertainty through the representation of probability distributions in IFC and COBie (ISO 2014). This is particularly important since data for service life planning is frequently provided in the form of uncertain values, which can be represented using probability distributions. The standard also proposes IFC Property Sets to support service life planning in IFC4, including information about service life, service life factors (to support the factor method for service life prediction), and environmental impacts.

## 4.2 BIM and FM

Facilities management (FM) can be defined as an integrated approach to operating, maintaining, improving and adapting building and infrastructure assets in order to support the primary objectives of the occupants, owners and facility managers (Atkin and Brooks 2009). FM constitutes an extensive field encompassing multidisciplinary and independent disciplines whose overall purpose is to maximize building functions while ensuring occupants wellbeing (Atkin and Brooks 2009, Becerik-Gerber et al. 2012). FM functions require extensive data and information from various fields and disciplines in order to fulfil their purpose. Traditionally, FM data and information are organised and maintained in dispersed information systems such as Computerised Maintenance Management Systems (CMMS), Electronic Document Management Systems (EDMS), Building Automation Systems (BAS), etc. The information and data required for such systems comes from different sources, is created and manipulated several times during the asset life cycle, and is not synchronised between systems, resulting in error-prone processes (Becerik-Gerber et al. 2012). The limited use of open standards that define the information requirements for specific FM tasks is also considered a key barrier for improving the information handover to the FM phase. There is a need for open systems and standardised data libraries that can be utilised by any FM system (BIFM 2012). The availability of such open standards and data specification will represent a significant opportunity if they are successfully adopted by the industry on new and existing assets. For existing assets, built before the emergence of BIM, the challenge is even greater as their FM legacy systems do not support open BIM standards. They require a robust business case to migrate their existing systems to new open standards compliant FM systems (Kassem et al. 2015).

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buildings can include but are not limited to papers in scientific journals, manufacturers' literature and publications from construction research organizations (ISO, 2011).

BIM technologies and open standards are providing opportunities for integrating the FM phase with the upstream project delivery phases. BIM technologies and processes allow the management and integration of the information needed for FM through the asset life cycle phases using open standards. If it is implemented and managed properly, it can provide a single source of accurate and up-to-date information. The potential use of BIM in FM applications was realised since the early years of the development of the IFC schema. Studies proposing open BIM data models to enable information sharing among computer applications can be traced back to about 15 years ago. For example, Yu et al. (2000) proposed a data model for FM – Facilities management core model (FMC) – along with mapping between IFC and FMC. The use of the open standards to bridge between disparate applications is persisting and applications could be identified in different project phases. Recently, Zhang et al. (2014) developed an IFC based approach to achieve bidirectional conversion of structural models between different structural analysis technologies. The conversion was based on a unified IFC information model and a number of algorithms that help overcome the differences between the data structures and representation logics of different structural analysis technologies.

Currently, open BIM standards such as IFC – registered with ISO as ISO16739 (buildingSMART 2014a) – and COBie are continuously being developed by buildingSMART with input from the architectural, engineering, construction and operation industry. The overarching aim of these initiatives is to enable information exchange throughout the construction industry business processes and asset life cycle phases. These standards allow models to be structured in a universal way enabling product data to be exchanged between designers, suppliers, constructors and operators (Atkin and Brooks 2009).

COBie is a subset of the IFC model, based on the Facilities Handover model view definition, which can be used to define the owner/client's requirements and provide support for the realization of FM tasks (East 2014b). To evaluate the compliance of AEC software applications with COBie data exchange, a series of COBie challenge events are carried out on a yearly basis by buildingSMART and are focused on various lifecycle stages: Planning, Design, Construction and Facilities Management (East 2013). Results from the COBie challenge for Facility Management 2013 trials highlighted the fact that with the exception of Archibus and IBM Maximo, software applications did not support the whole of the COBie schema contents used in buildingSMART's evaluation procedure.

The transfer of structured information, between project parties, about buildings and infrastructure based on COBie has resulted in industry standards such as the BS 1192-4: 2014 in the UK. The definition of COBie data drops, introduced in the UK, helps capturing and checking client's requirements throughout the life cycle of buildings (Cabinet Office 2012). Data drops specify data requirements for key stages of building life cycle development and are aligned with RIBA Plan of Work stages (RIBA 2013). The BS 1192-4:2014 supports asset and facility managers in specifying their information needs in the form of an 'Asset Information Model' (AIM) - a data model that contains all digital data required to operate an asset (BSI 2014b). The AIM can then be communicated to lead designers and contractors. To meet the information needs of owners and facility managers, information has to be produced, collected and exchanged throughout the asset life cycle delivery phases, and not left to be dealt with only at the handover phase. To achieve this, the PAS 1192-2: 2013 and the PAS 1192-3: 2014 respectively specify the information delivery processes and the information exchange during and between the capital project delivery phases (i.e. planning, design and construction) and the operational phase. In particular, the PAS 1192-3: 2013 proposes the use of open standards and data specifications (e.g. IFC, COBie) for the definition of Asset Information Models (AIMs) and for the interface between AIMs and existing enterprise systems (BSI 2014a).

## 4.3 BIM and FM case studies

BIM can support FM functions for both new and existing buildings (Volk et al. 2014). Several case studies aimed to showcase and discuss BIM applications in FM in these two types of assets. One of the earliest attempts at using BIM for FM was in the 'ifc-model based Operations and Maintenance of Building' (ifc-mbOMB) project (Nisbet 2008). This project recreated the design process of a college building using BIM workflows and deliverables which included room-briefing, layout, detailing, environmental analysis, mechanical and electrical equipment requirements, product selection and substitution. During this process, the IFC schema and a model server were used to capture the information needed for asset management. Asset management information was then translated into Maximo facility management format through the mapping of the IFC model to the Maximo data structure (Nisbet 2008). Outcomes from this project provided the bases for the development of COBie.

A notable BIM for FM case study is the Sydney Opera House (CRC 2007). In this project, the Sydney Opera House was modelled specifically for FM purposes using the IFC standard. This project demonstrated the different applications of BIM in FM and highlighted the need for changing current workflows and processes. The project identified the lack of support of the IFC standard by FM tools as a key barrier. A recent application of BIM for FM in Manchester Town Hall Complex report (Codinhoto et al. 2013) identified the lack of awareness of the potential of BIM in the FM phase and the need for clear guidelines for its implementation in FM as key challenges.

Another case study by Kelly et al. (2013), using BIM for managing existing university campus buildings, identified the improved accuracy of records of geometric information and the increased workforce and process efficiencies as two key benefits. The authors also concluded that the lack of: clear requirements for the implementation of BIM in FM; quantifiable key performance indicators; interoperability; clear roles and responsibilities, and contract and liability framework are the main challenges facing BIM in FM applications.

Motawa and Almarshawad (2013) proposed a methodology which combines the use of BIM and case-based reasoning to capture and manage knowledge in building information models to inform maintenance teams about the history of the building and its components. Shen et al. (2012) presented an information integration framework that supports software and hardware applications, using agent-based web-services, in providing decision support for facility management and maintenance.

The visualisation capabilities of BIM and their role in decision making for O&M tasks are receiving an increased attention. Motamedi et al. (2014) integrated Computerised Maintenance Management Systems (CMMS) data with BIM visualisation capabilities to enhance the detection of failure root causes in FM. In this study, IFC model relationships were used to capture failure mechanisms and fault tree analysis was used to model and capture knowledge about building system failures.

Rasys et al. (2013) proposed an information integration framework for the management of civil and oil & gas facilities in which Web3D technology is used for integrating and visualising assets' 3D components and their linked FM data using class libraries. The use of BIM spatial relationships for visualisation and analyses of facilities data were also applied in the planning of maintenance activities and repair works in buildings (Akcamete et al. 2010).

This review, which included a non-exhaustive illustration of BIM for FM studies, is just an evidence of the increased proliferation of studies in this area and the increased role of BIM technologies and open standards in FM. This increased attention towards BIM for FM studies is also accompanied by remarkable industry wide initiatives in terms of standardisation (IFC and COBie) and mandating BIM uses and standards in FM. Yet studies that systematically investigate such standards as sources of data for FM applications are missing in literature. Also studies on the workflows required to gradually produce the information needed for FM along the project life cycle phases are still limited. This paper contributes to both gaps by investigating the applicability of IFC and COBie as sources of information for specific FM uses (i.e. asset register creation and service life planning) while considering the asset life cycle phase as such information becomes available.

## 5. EVALUATION OF IFC/COBIE SUPPORT FOR ASSET REGISTERS

The first part of this analysis evaluates IFC and COBie as data sources for creating asset registers while considering the project phase at which such data becomes available. The FM data and information requirements of asset registers are based on established standards and were extracted from Section 9.7.4 of BS 8210 (BSI, 2012). The entities utilised for IFC4 and COBie 2.4 were adopted from the building SMART IFC 4 specifications (buildingSMART 2014b). The project phases, at which such data and information requirements become available, are adopted from the definition of COBie Data Drops of the UK Cabinet Office's COBie Data Drops document (Cabinet Office 2012). The results from this analysis are presented in Table 1. These results are discussed in Section 7 (Discussion) together with outcomes of the use case application presented in section 6.

*TABLE 1: Evaluation of IFC and COBie support for asset register requirements as defined in BS 8210 (BSI, 2012, buildingSMART 2014b)*

| **Asset register information requirements (BSI, 2012)** | **IFC 4** | **COBie 2.4 (Spreadsheet xml)** | **COBie Data drop** |
|---|---|---|---|
| **a) identification number or unique reference for the asset;** | SerialNumber (Pset_ManufacturerOccurrence) | Component sheet - SerialNumber | 4 – as-built |
| | BarCode (Pset_ManufacturerOccurrence) | Component sheet - BarCode | 4 – as-built |
| | | Component sheet - TagNumber | 4 – as-built |
| | | Component sheet - AssetIdentifier | 4 – as-built |
| **b) make and/or model;** | ModelReference (Pset_ManufacturerTypeInformation) | Type sheet - ModelReference | 4 – as-built |
| **c) manufacturer;** | Manufacturer (Pset_ManufacturerTypeInformation) | Type sheet - Manufacturer | 4 – as-built |
| **d) vendor, if different to manufacturer;** | Manufacturer (Pset_ManufacturerTypeInformation) | Type sheet - Manufacturer | 4 – as-built |
| **e) date of manufacture;** | ProductionYear (Pset_ManufacturerTypeInformation) | | 4 – as-built |
| **f) date of acquisition, installation or completion of construction;** | AcquisitionDate (Pset_ManufacturerOccurrence) | Component sheet - InstallationDate | 4 – as-built |
| | WarrantyStartDate (Pset_Warranty) | Component sheet - WarrantyStartDate | 4 – as-built |
| **g) location of asset;** | IfcSpace | Component sheet - Space | 4 – as-built |
| **h) whether or not access equipment is required;** | IfcTask | Job sheet | 5 – O&M |
| **i) whether or not the asset is subject to a permit-to-work requirement** | IfcTask | Job sheet | 5 – O&M |
| **j) initial cost;** | IfcCostValue | | 4 – as-built |
| **k) predicted lifetime;** | ExpectedLife (Pset_ServiceLife) | Type sheet - Expected Life | 4 – as-built |
| **l) specification;** | | Type sheet - all | 4 – as-built |
| **m) replacement cycle;** | IfcTask | Job sheet | 5 – O&M |
| **n) cost breakdown;** | | | 5 – O&M |
| **o) servicing requirements, including type and frequency of service;** | IfcTask | Job sheet | 5 – O&M |
| **p) other maintenance required;** | IfcTask | Job sheet | 5 – O&M |
| **q) maintenance costs;** | ReplacementCost | Type sheet - ReplacementCost | 5 – O&M |
| **r) accumulated depreciation;** | | | 5 – O&M |
| **s) written-down value;** | | | 5 – O&M |
| **t) source of components and spare parts, where applicable** | | Type sheet - Manufacturer | 5 – O&M |
| **u) energy consumption and, where applicable, energy-efficiency rating;** | SustainabilityPerformanceDescription / Environmental (IfcTypeObjectProperty) | Type sheet - SustainabilityPerformance | 4 – as-built |
| **v) identification of hazardous or other risks to people or property.** | Pset_Risk | | 4 – as-built |

## 6. IFC & COBie SUPPORT FOR SERVICE LIFE PLANNING

The broader context of this research is to develop methodologies and tools for supporting building life cycle management using IFC and COBie in a whole life cycle approach. Within this context, a specific use case on service life planning is presented in this section. The use case aims to show the process of the definition of data requirements by the building owner – denoted in the remainder of the paper as ‘employer’ - and the fulfilment of such requirements by the project stakeholders or suppliers. The development of the use case was based on the Information Delivery Manual (IDM) methodology and the definition of Employer’s Information Requirements (EIR). The IDM methodology aims to document processes and support information exchanges between AEC industry stakeholders. IDMs can be used to support specific use cases in the AEC industry in the form of general guidance for the involved stakeholders, as well as for the development of software specifications (ISO 2010, Volk et al. 2014). IDMs can be bound to specific data types and software applications, or remain independent from these (ISO 2010). The EIR specifies the supplier’s requirements throughout the life cycle of the building, and can be supported by COBie data (BSI 2014b).

The goal of the developed use case is to evaluate how and whether employer requirements can be satisfied through the production of COBie data drops for a specific operational purpose. The employer specific requirements in this use case are the data requirements and specifications for service life planning of mechanical components according to ISO 15686-4 (ISO 2014), which should be supplied at handover – COBie data drop 4. The definition of the overall process, the relationships between actors, and exchange requirements which support the defined tasks were all set according to the IDM methodology. The selected tools, data models, standards and data exchanges were defined according to the EIR (BSI 2014b). Process maps are defined using the Business Process Modelling Notation (BPMN), specifying the flow of activities and supporting data and information requirements that need to be fulfilled to carry them out. Exchange requirements are defined by specifying data and information requirements to support the defined processes. Functional Parts, which are reusable units of information that specify IFC Entities, Property sets and other Functional parts, are grouped together to support Exchange requirements in the form of Exchange requirement models (ISO 2010).

According to ISO 15686-4 (ISO 2014), service life planning requirements should be defined by the owner at the early stages of building project development and should be checked throughout the design, construction, maintenance and operation stages of the building lifecycle. During the early stages of design development, service life data determination is limited to the design life of products (ISO 2014). At later design stages and during construction, when information about specific building products becomes available, it is possible to analyse the service life of products according to their in use conditions. These conditions can be estimated using the factor method (ISO 2008), which was considered in this use case and specified in the EIR. Figure 1 illustrates the process map which outlines the method of service life data requirements’ checking at the handover stage, and supports the development of the use case, depicting the sequence of tasks and data interactions in the form of information production and exchange to meet the employer requirements.

The process starts with the definition of EIR by the Owner (Task 1.1 EIR definition, Figure 1). EIRs are used to control BIM-based information exchanges that support various tasks during the design, construction, maintenance operations, and demolition throughout the lifecycle of a building. A minimum set of information requirements for EIR is specified in PAS 1192-2 (BSI 2013b). EIR definition often constitutes a challenge to the owner since this document specifies requirements for all the disciplines involved in the development of the project and the management of the building throughout its lifecycle. Therefore, the definition of EIR should take into account the input from designers and facility managers, which is detailed in Process Map 1.1 – EIR Definition (Figure 2). A legend outlining the used BPMN elements is provided in Figure 3.

During the construction stage, service life data of building components is provided by the manufacturer and should be supplied to the Design-Build Team or Contractor according to the EIR defined by the owner. The Design-Build Team or Contractor update service life data in the building model and produce the as-built COBie (data drop 4) according to the employer’s requirements. Upon receiving the COBie data drops, the owner can accept or reject them (Decision Point 2. Requirements Validated). In case of rejection, the owner communicates the missing requirements in the defined EIR format. If the data drops are according to the EIR, they can be imported to the owner’s FM application and become part of the owner’s Asset Information Model (AIM). Table 2 outlines the employer’s information requirements for service life planning, which are defined according to the ISO 15686-4 (Buildings and constructed assets — Service life planning — Part 8: Reference service life and service life estimation) and also includes specific software requirements.

Central to the depicted process (Figure 1) is the Design-Build Team/Contractor use case for the provision of Service Life data in COBie data drops according to the EIR. The use case consists of tasks 6.1 to 6.4 and is detailed in Figure 4 in IDEF0 notation including the various inputs, outputs and supporting tools, according to the EIR (Table 2). In the following sections (6.1 to 6.4), each of the individual tasks in the use case (task 6.1 to task 6.4) is explained in detail. Table 3 provides the Exchange Requirement Model, specifying the exchange objects, in this case a custom property set and properties, that support the EIR defined in Table 2.

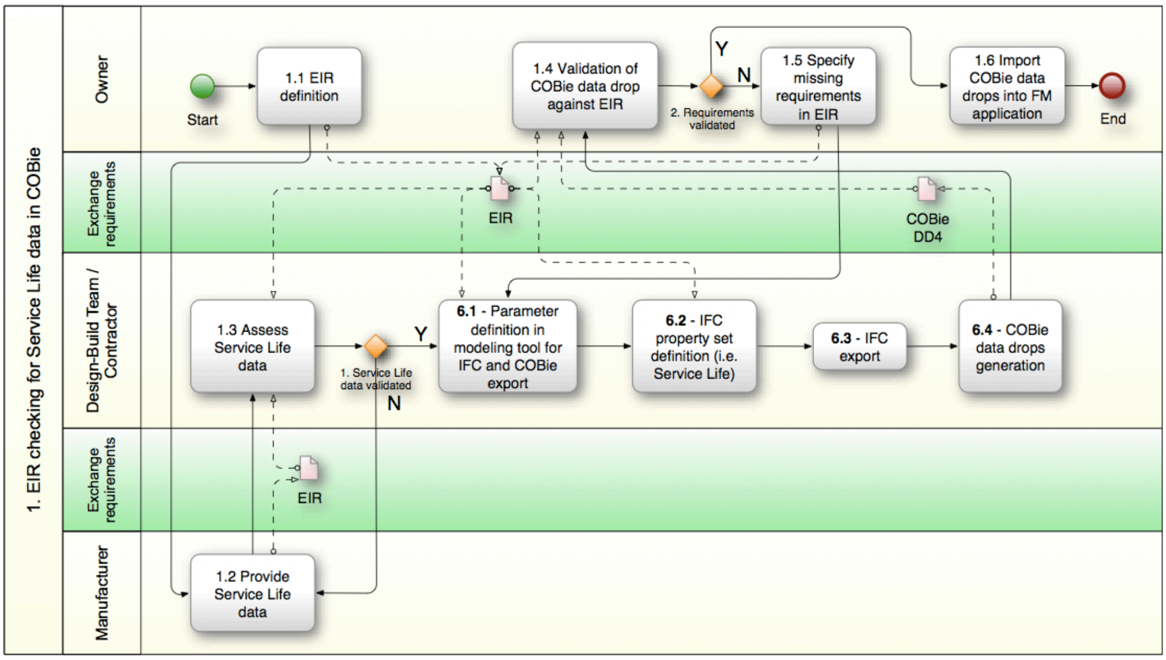


*FIG. 1: Overall process supporting the development of the use case*

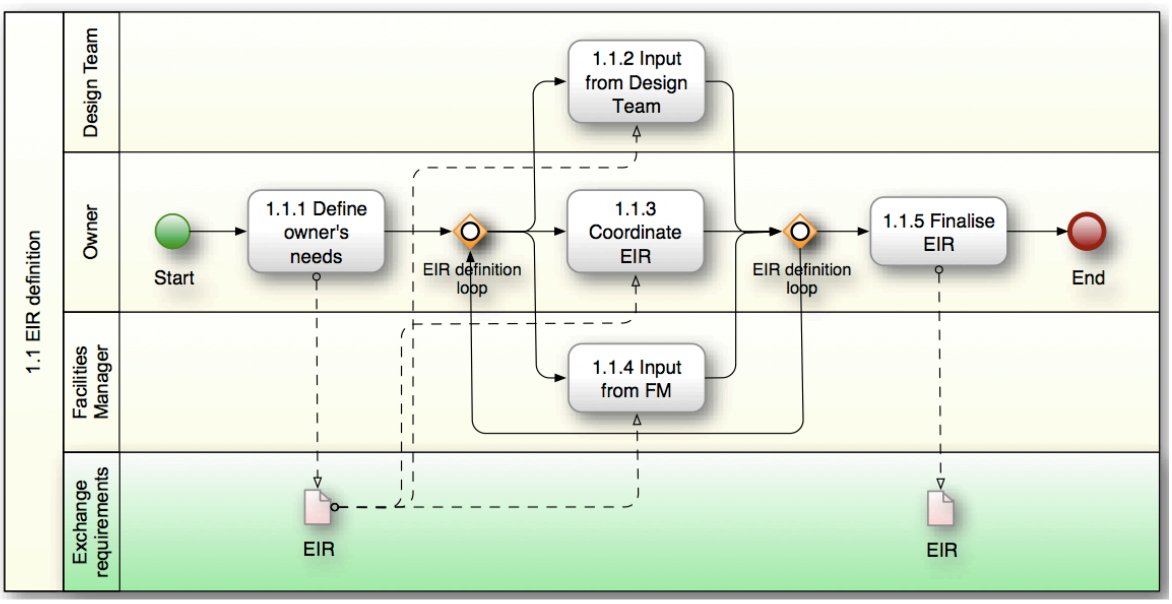


*FIG. 2: Process map detailing Task 1.1- EIR definition (Figure 1): supporting the definition of the owner's EIR using the input from the Design Team and FM*

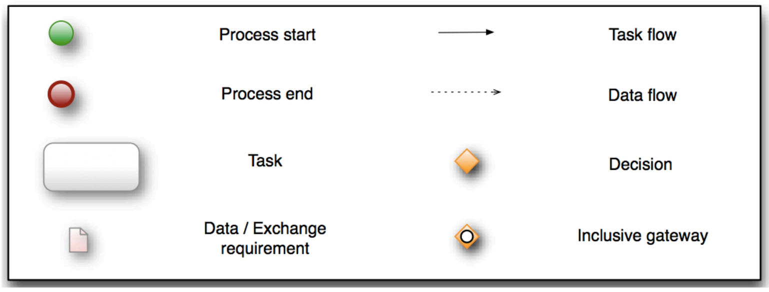


*FIG. 3: Legend of used BPMN elements in process maps (Figures 1 and 2)*

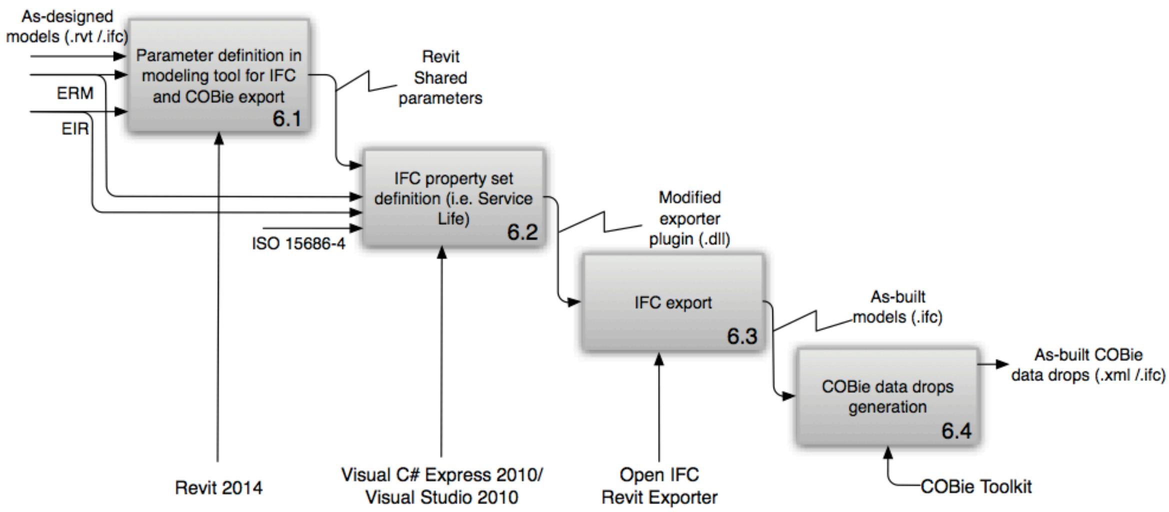


*FIG. 4: IDEF diagram detailing the Design-Build Team/Contractor use case*

*TABLE 2: Employer's Information Requirements (EIR) definition*

| Task | Name | Software requirements | Supporting standards | Exchange objects |
|---|---|---|---|---|
| **6.1** | Parameter definition for IFC and COBie export | Autodesk Revit 2014 | | Pset_ServiceLife |
| **6.2** | IFC property set definition | Visual C# Express 2010/ Visual Studio 2010 | ISO 15686-4 | Pset_ServiceLife |
| **6.3** | IFC export | Open IFC Revit Exporter | | |
| **6.4** | COBie data drops generation | COBie Toolkit | | Pset_ServiceLife |

*TABLE 3: Exchange requirement model*

| Exchange requirements | | | Functional Parts |
|---|---|---|---|
| **Required information** | **Supplying actor** | **Data type** | **Entity/ Property set/ Functional Part** |
| Service Life Type | Manufacturer | String | Pset_ServiceLife.ServiceLifeType→IfcPropertySingleValue::IfcText |
| Service Life Duration | | Real | Pset_ServiceLife.ServiceLifeDuration→ IfcPropertySingleValue::IfcReal |
| Quality of Components | | Real | Pset_ServiceLife.QualityOfComponents→ IfcPropertySingleValue:: IfcPositiveRatioMeasure |
| Design Level | | Real | Pset_ServiceLife.DesignLevel→IfcPropertySingleValue:: IfcPositiveRatioMeasure |
| Work Execution Level | | Real | Pset_ServiceLife.WorkExecutionLevel→ IfcPropertySingleValue:: IfcPositiveRatioMeasure |
| Indoor Environment | | Real | Pset_ServiceLife.IndoorEnvironment→ IfcPropertySingleValue:: IfcPositiveRatioMeasure |
| Outdoor Environment | | Real | Pset_ServiceLife.OutdoorEnvironment→ IfcPropertySingleValue:: IfcPositiveRatioMeasure |
| In Use Conditions | | Real | Pset_ServiceLife.InUseConditions→ IfcPropertySingleValue:: IfcPositiveRatioMeasure |
| Maintenance Level | | Real | Pset_ServiceLife.MaintenanceLevel→ IfcPropertySingleValue:: IfcPositiveRatioMeasure |
| Utilization | | Real | Pset_ServiceLife.Utilization→ IfcPropertySingleValue:: IfcPositiveRatioMeasure |

## 6.1 Revit Parameter definition for IFC and COBie export

An existing building model 'Project 1 Duplex Apartment' (East 2014a) was used in the development of this use case. Autodesk Revit 2014 was the utilised version in which IFC 2x3 Coordination View 2.0 is implemented and certified. Hence, IFC 2x3 is the IFC version referred to in this use case. Since COBie is a subset of IFC, COBie files will be generated from IFC files. Revit allows the mapping of specific objects to IFC entity types through their definition in the IFC Export Classes dialog box (Autodesk 2014b). Since Revit object categories are defined more broadly than the corresponding IFC entities, when exporting IFC from Autodesk Revit using the default settings, some components will not be correctly mapped (USACE 2011). Two additional parameters were added to the Revit project template as shared project parameters.

- IfcExportAs: This parameter should be filled in with a valid IFC entity type.
- IfcExportType: This parameter should be filled in with the IFC Predefined Type setting.

These parameters become available to every object type and override an individual family's IFC export category (Autodesk 2014a). The mapping of these parameters to IFC types and instances can be accomplished using the IFC 2x3 final release documentation (buildingSMART 2014c). These parameters were already defined in the utilised building model for the selected M&E components.

The Open IFC export for Revit plugin allows the definition of custom property sets in a text file providing a correct mapping of COBie parameters from the IFC files generated in Autodesk Revit 2014. COBie parameters were defined as shared project parameters in Revit and their specification was defined based on the template file from the IFC for Revit project 'IFC2x3 Extended FM Handover View.txt' (Autodesk 2014b). To automate the creation of shared parameters, the Revit API was used to define shared type parameters for the Type sheet and to automatically assign the Category field from the NBS Uniclass 2 Keynote file for Revit (Hamil 2012).

## 6.2 IFC Property Set definition

To deliver the employer's requirements specified in the EIR (Table 2) according to the ISO 15686-4 2014 (ISO 2014), the property set 'Pset_ServiceLife' has to be added to the exporter as a common property set. This was achieved by editing the source code from the IFC for Revit project, which relies on the Revit API (Autodesk 2014b).

The source code consists of a C# Solution including 3 projects: Install, BIM.IFC.Common and Revit.IFC.Export. The top level code resides in the Exporter class, within the Revit.IFC.Export project. The Exporter class includes three main *methods*: BeginExport, InitializeElementExporters, and EndExport. BeginExport initialises the export, which includes initializing the IFCFile based on schema, initializing property and quantity sets and creating unique and top-level IFC entities such as IfcProject and IfcBuilding. The InitializeElementExporters method creates a set of delegates that order the element traversal of the document. The EndExport method creates element relations and writes out the resulting IFC file (Autodesk 2014b).

In order to add the 'Pset_ServiceLife' property set to the exporter, a *method* was added to the ExporterInitializer class from the Revit.IFC.Export project to include the property set definitions. The Revit.IFC.Export project was then compiled and the resulting Revit.IFC.Export.dll file was used to replace the default class library from the Open source IFC Exporter. Figure 5 outlines a class diagram showing the relations between the Exporter, ExporterInitializer and Object (the main .NET class) classes.

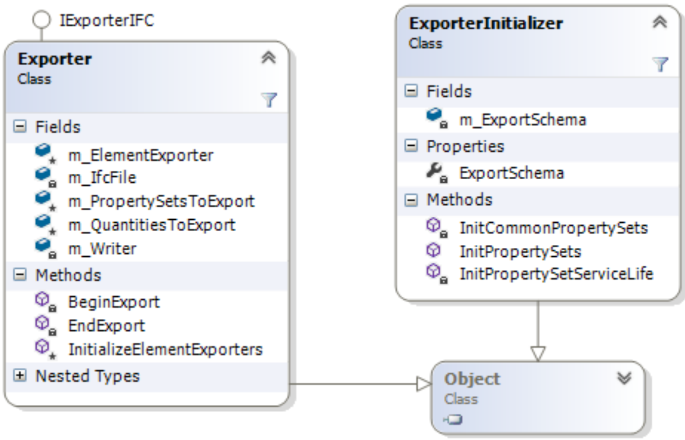


*FIG. 5 – Class diagram specifying relations between Exporter, ExporterInitializer and Object classes; Custom methods can be defined in the ExporterInitializer class (e.g. InitPropertySetServiceLife)*

An excerpt from the method `InitPropertySetServiceLife` from the ExporterInitializer class for the definition of properties from the Pset_ServiceLife proposed in ISO 15686-4 is the following - not all properties are included:

```
private static void InitPropertySetServiceLife(IList<PropertySetDescription> commonPropertySets)
{
//property set description
PropertySetDescription propertySetServiceLife = new PropertySetDescription();
propertySetServiceLife.Name = "Pset_ServiceLife";
//sub-type of ifcelement
propertySetServiceLife.EntityTypes.Add(IFCEntityType.IfcElement);
PropertySetEntry ifcPSE = PropertySetEntry.CreateText("ServiceLifeType");
propertySetServiceLife.AddEntry(ifcPSE);
ifcPSE = PropertySetEntry.CreateRatio("Utilization");
propertySetServiceLife.AddEntry(ifcPSE);

commonPropertySets.Add(propertySetServiceLife);
}
```

Finally, Service Life parameters were defined as shared type parameters in Revit, and added to M&E components to enable export to IFC and COBie.

Table 4 outlines the service life planning information requirements proposed in the ISO 15686-4 2014; the ways they are supported in the defined Exchange Requirement Model (ERM – Table 3), and the corresponding shared parameters that were defined in Autodesk Revit 2014 to support the ERM.

*TABLE 4: Parameters from the Service Life property set defined in ISO 15686-4 2014 and in the proposed ERM, and Revit shared parameter names and data types used for IFC export*

| ISO 15686-4 2014 (Service life planning standard) | | Exchange Requirement Model | Revit | |
|---|---|---|---|---|
| **Name** | **Data type** | **Entity/ Property set/ Functional Part** | **Shared parameter name** | **Revit data type** |
| **Service Life Type** | Enumeration | Pset_ServiceLife.ServiceLifeType | ServiceLifeType | Text |
| **Service Life Duration** | Duration | Pset_ServiceLife.ServiceLifeDuration | ServiceLifeDuration | Real |
| **Quality of Components** | Positive Ratio | Pset_ServiceLife.QualityOfComponents | QualityOfComponents | Real |
| **Design Level** | Positive Ratio | Pset_ServiceLife.DesignLevel | DesignLevel | Real |
| **Work Execution Level** | Positive Ratio | Pset_ServiceLife.WorkExecutionLevel | WorkExecutionLevel | Real |
| **Indoor Environment** | Positive Ratio | Pset_ServiceLife.IndoorEnvironment | IndoorEnvironment | Real |
| **Outdoor Environment** | Positive Ratio | Pset_ServiceLife.OutdoorEnvironment | OutdoorEnvironment | Real |
| **In Use Conditions** | Positive Ratio | Pset_ServiceLife.InUseConditions | InUseConditions | Real |
| **Maintenance Level** | Positive Ratio | Pset_ServiceLife.MaintenanceLevel | MaintenanceLevel | Real |
| **Utilization** | Positive Ratio | Pset_ServiceLife.Utilization | Utilization | Real |

## 6.3 IFC Export

Following the definition of shared project parameters for IFC and COBie, an IFC 2x3 model is exported. This model was then used to generate the COBie Data Drops required by the employer for Service life planning. A specific export setup was defined in the open source IFC exporter for Revit to support the definition of custom property sets in a text file. Specific COBie parameters defined in the text file are accounted for by selecting the 'Export user defined property sets' option. To export the Service Life Property set, 'Export IFC common property sets' was selected. To support the use of Uniclass 2 classification in COBie, shared project parameters defined for classification fields were indicated in the IFC assignments panel of the open IFC exporter. Prior to the export of the COBie Data Drops, the employer's requirements in terms of Service Life Planning were checked using 'Solibri Model Viewer'. For a specific component (i.e. the Boiler), Figure 6 shows that the mapping of all Pset_ServiceLife attributes and the Uniclass 2 Classification attributes were all successfully achieved.

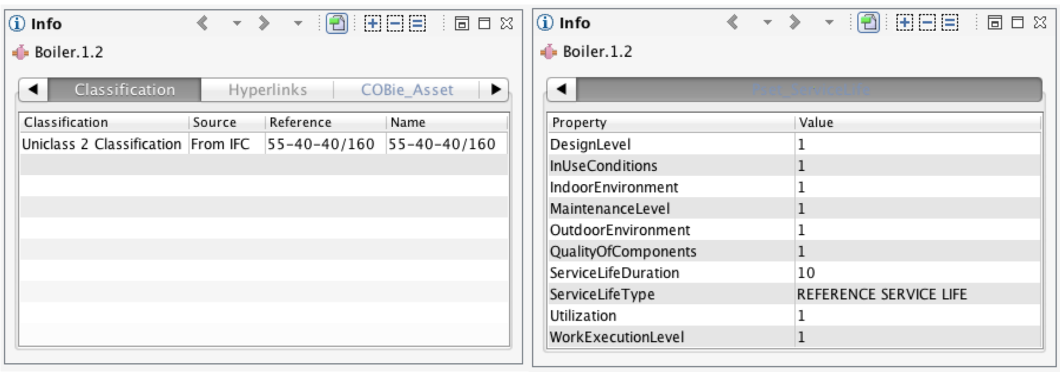


*FIG. 6: Uniclass 2 Classification attributes and Pset_ServiceLife attributes for a Boiler element in the IFC model in Solibri Model Viewer*

## 6.4 Generation of COBie Data Drops from IFC files

To generate the COBie Data Drops from the exported IFC model, the COBie Toolkit for Autodesk Revit 2014 was used. This COBie Toolkit allows the export of certain IFC entities based on ObjectIDM plugins. These can be used to manage the contents of COBie Data Drops, e.g. through the exclusion of information about products which are not tracked as assets by facility operators (ERDC 2013). In this experiment, the default COBieIDMPlugin was used. The IFC model file is loaded into the COBie Toolkit and it is converted to COBie internally. It is then possible to export the file in the preferred COBie format. In this experiment the file was exported as a COBie spreadsheet (COBie version 2.4). Figure 7 shows the representation of several attributes in the Type sheet for Heat Exchanger and Boiler elements, including: Uniclass 2 Classification, Asset Type, Manufacturer, Model Number, Warranty parameters and reference to the element's IFC Type. Figure 8 shows the representation of the property set Pset_ServiceLife in the Attribute sheet. The two Figures show the successful classification and production of the employer's requirements in terms of COBie Data Drops for Service life planning and the allocation of the appropriate Uniclass 2 code.

| 1 | Name | atedBy | CreatedOn | Category | Description | AssetType | Manufacturer | delNumber | WarrantyGuarantorParts | WarrantyDurationParts | WarrantyGuarantorLabor | rrantyDurationLabor | WarrantyDurationUnit | ExtSystem | ExtObject |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 147 kW | Joaou | 2014-07-3 | 55-40-40/160 | 147 kW | Fixed | Vokera | 36HE | 1 | 5 | n/a | n/a | Year | Autodesk | IfcBoilerType |
| 3 | Radiator - | Joaou | 2014-07-3 | 60-45-35/120 | Radiator - | Fixed | Stelrad | K1 | 1 | 5 | n/a | n/a | Year | Autodesk | IfcHeatExchangerType |

*FIG. 7: Uniclass 2 (CPIC 2014) Category in Type sheet - COBie spreadsheet*

| 1 | Name | atedBy | CreatedOn | Category | SheetName | RowName | Value | t | ExtSystem | ExtObject |
|---|---|---|---|---|---|---|---|---|---|---|
| 44 | DesignLevel | Joaou | 2014-07-3 | Requirement | Component | M_Hot Water Boiler - 59-440 kW:147 kW:530072 | 1.0 | n/a | Autodesk | Pset_ServiceLife |
| 45 | OutdoorEnvironment | Joaou | 2014-07-3 | Requirement | Component | M_Hot Water Boiler - 59-440 kW:147 kW:530072 | 1.0 | n/a | Autodesk | Pset_ServiceLife |
| 46 | QualityOfComponents | Joaou | 2014-07-3 | Requirement | Component | M_Hot Water Boiler - 59-440 kW:147 kW:530072 | 1.0 | n/a | Autodesk | Pset_ServiceLife |
| 47 | IndoorEnvironment | Joaou | 2014-07-3 | Requirement | Component | M_Hot Water Boiler - 59-440 kW:147 kW:530072 | 1.0 | n/a | Autodesk | Pset_ServiceLife |
| 48 | Utilization | Joaou | 2014-07-3 | Requirement | Component | M_Hot Water Boiler - 59-440 kW:147 kW:530072 | 1.0 | n/a | Autodesk | Pset_ServiceLife |
| 49 | InUseConditions | Joaou | 2014-07-3 | Requirement | Component | M_Hot Water Boiler - 59-440 kW:147 kW:530072 | 1.0 | n/a | Autodesk | Pset_ServiceLife |
| 50 | WorkExecutionLevel | Joaou | 2014-07-3 | Requirement | Component | M_Hot Water Boiler - 59-440 kW:147 kW:530072 | 1.0 | n/a | Autodesk | Pset_ServiceLife |
| 51 | ServiceLifeType | Joaou | 2014-07-3 | Requirement | Component | M_Hot Water Boiler - 59-440 kW:147 kW:530072 | REFERENCE SERVICE LIFE | n/a | Autodesk | Pset_ServiceLife |
| 52 | ServiceLifeDuration | Joaou | 2014-07-3 | Requirement | Component | M_Hot Water Boiler - 59-440 kW:147 kW:530072 | 10.0 | n/a | Autodesk | Pset_ServiceLife |
| 53 | MaintenanceLevel | Joaou | 2014-07-3 | Requirement | Component | M_Hot Water Boiler - 59-440 kW:147 kW:530072 | 1.0 | n/a | Autodesk | Pset_ServiceLife |

*FIG. 8: Pset_servicelife: Property definitions for a Revit Family in Attribute sheet – COBie spreadsheet*

## 7. DISCUSSION

Asset registers and service life factors are key elements for the assessment of life cycle costs in the operational phase of buildings (ISO 2011). They are also important inputs for the decision-making processes that support design for maintainability as proposed in the Soft Landings methodology (BSRIA 2009). In several countries, open BIM standards and data specifications were prescribed as data structures and information exchange formats for the handover of information and data to the operational phase of buildings. Yet, there is a lack of studies investigating the suitability of, and processes for producing, information and data complying to open standards during the operational phase. This research aimed to assess the suitability of open BIM standards (IFC 2x3, IFC 4, COBie 2.4) to capture, integrate and deliver employer requirements in terms of Asset register creation (IFC 4 and COBie 2.4) and service life planning (IFC 2x3[2]). The results obtained are discussed in the subsequent sections.

## 7.1 IFC and COBie support for Asset Register data

The support of IFC4 and COBie 2.4 in satisfying the information requirements of asset registers was tested by setting a benchmark test against an established standard. The information content of IFC4 and COBie 2.4 was benchmarked against the asset register requirements as defined in BS 8210 (BSI, 2012). Table 1 listed the details of how asset register requirements can be captured in IFC4 and COBie 2.4 entities. Table 1 shows that several of these

[2] Autodesk Revit 2014 is certified IFC 2x3 hence, IFC4 was not used for the testing of service life planning.

requirements are not directly supported in IFC 4 (5 out of 22) and COBie 2.4 (6 out of 22). Most of the non-supported fields are part of data drops generated during for O&M phase of buildings. Gaps that were identified in this analysis include capital information such as costs breakdown, written down value of assets, accumulated depreciation, and sources of components and spare parts (Table 1). On the other hand, some of the information requirements for O&M can be represented in the COBie.Job worksheet (COBie 2.4), which identifies O&M tasks that need to be carried out to run the facility efficiently, or in IFC 4 through the corresponding IFC entity IfcTask (buildingSMART, 2014b). Such information includes: requirements for access equipment, permit-to-work requirements, replacement cycle, servicing requirements and other maintenance requirements.

Gaps identified in this analysis are consistent with the results of other studies in which shortcomings in IFC 4 in terms of supporting the properties and relationships for O&M phase were found (Motamedi et al. 2014). However, it should be noted that in the case of IFC, and due to the flexibility of its schema, FM software providers might be able to indirectly support the non-supported information requirements through ad-hoc software functionalities. Also, the possibility of including additional information in IFC and COBie files, using custom property sets or extensions to the model schemas, is a remedy and can strengthen the role of such schemas in fulfilling O&M information requirements.

## 7.2 Generation of COBie data drops for the O&M phase

Following the benchmarking of IFC4 and COBie 2.4 against the information requirements of asset registers, a practical use case was conducted to test the processes of fulfilling Employer Information Requirements (EIR) for O&M using open standards (IFC 2x3) and data specification (COBie 2.4). A use case focused on service life planning was conducted. The service life planning requirements were established from the ISO 15686-4 standard (ISO 2014).

To generate the COBie Data Drop including service life planning data at the handover stage, an IFC model was first produced from Autodesk Revit 2014, including the definition of specific parameters to support IFC types and instances for a number of a selected M&E components. While the undertaken use case focused on the delivery of service life data at the handover stage, the adopted approach using the Autodesk Revit 2014 design tool could also be used at earlier lifecycle stages to support the service life planning process during the design. By specifying dedicated shared parameters in Autodesk Revit 2014 for the mapping of COBie entities and using IfcExportAs and IfcExportType shared project parameters, well defined IFC model and COBie data drops were obtained (Figures 6, 7 and 8).

However, it should be noted that the application of this process in real projects can be time consuming: the design team has to first identify which components are not correctly exported to IFC, and then define the correct IFC types and entities for each of these components. Also, COBie shared parameters must be defined for each COBie entity and they must be edited for each component and/or type. For this latter challenge, it was demonstrated that Revit API can automate this task through the definition of shared type parameters for the COBie Type sheet and through the automated assignment of the category field based on the NBS Uniclass 2 Keynote file. To support specific requirements from the employer and facility managers, the definition of COBie parameters and the content of the COBie Attribute tab – which includes IFC property sets – should be agreed upon in advance. The management of information for the COBie Data Drops can also be supported by the ObjectIDM plug-ins of the COBie Toolkit which can specify what elements are included in the COBie Data Drops.

It is also important to highlight that with the technologies (i.e. Autodesk Revit 2014) used in the use case to support the employer requirements in terms of Service life planning, it was necessary to edit open IFC Revit exporter source code as these were not supported in IFC 2x3. This property set has now been proposed by buildingSMART for IFC4 (buildingSMART 2014b) and by ISO 15686-4 (ISO, 2014), but is still not supported in the open source IFC Revit exporter.

## 7.3 IFC property set definition

To achieve the EIR in terms of service life planning with IFC 2x3 and COBie 2.4 in this use case, it was necessary to define custom property sets in IFC. However, some limitations were found in this process: upon examination of the official IFC4 documentation (buildingSMART 2014b) against the list of supported IFC Entity Types by the open source exporter (defined in IFCEntityType.cs file), it was found that not all IFC Entity Types are supported in

Revit using shared parameters. Important examples include IfcPropertyBoundedValue and IfcPropertyTableValue. The IfcPropertyBoundedValue is a property object which has a maximum of two numeric or descriptive values assigned, the first value specifying the upper bound and the second value specifying the lower bound. The IfcPropertyTableValue is a property with a value range defined by two lists of numeric or descriptive values assigned to specify a table with two columns (buildingSMART 2014b). The ISO 15686-4 recommends the use of IfcPropertyBoundedValue and IfcPropertyTableValue entity types for the service life property and factors to support the definition of uncertain values based on probability distributions or probability functions. While the IFC exporter can support complex data types through entities such as IfcPropertyBoundedValue and IfcPropertyTableValue, Revit can only support parameters with simple types (integer, real, Boolean, string). For this reason, while the official IFC4 documentation recommends the use of IfcPropertyBoundedValue and IfcPropertyTableValue entity types for the representation of service life parameters, only the type 'Real' is implemented and supported in commercial software. This represents a limitation for the tested use case as data for Service life planning often comes from expert opinions using the Delphi method, which usually provides median, minimum and maximum values for each factor (ISO 2008). While it is possible to represent such data in the IFC model, it is not possible to represent it in Autodesk Revit 2014 using the proposed method.

## 7.4 Generation and checking of EIR

The process for the generation and checking of EIR is central to the development of the use case performed in this study (Figure 2). The explicit definition of owners' requirements is fundamental to support the owner's decision making processes within a whole lifecycle perspective. The input from stakeholders such as designers and FM enable the owner to define maintenance requirements from the early stages of project development. Such requirements include the support of asset's functions, compliance with building standards and other legislation, and data and information requirements for the owner's AIM. In the developed use case, which focuses on service life planning data requirements at the handover stage, the owner uses the EIR to validate the Design-Build Team/Contractor's submission (Task 1.4, Figure 1). As the EIR includes the definition of the ERM, which specifies which IFC Entities, Types and Properties should be included in the submitted COBie data drops, it is possible for the owner to check if the information specified in the EIR is included in the data drops. This way, using an IFC/COBie compliant FM software for the import of COBie data drops, the process for the elaboration of the owner's AIM can be streamlined, and the owner can ensure that the AIM is in accordance to the EIR.

# 8. CONCLUSIONS

Open BIM standards and data specifications are increasingly being prescribed in several countries and by large clients as the source, structure and exchange formats for handing over information to the operational phase of built assets. To date, initiatives have been mainly focussed on certifying software and benchmarking software outputs in terms of e.g. accuracy and completeness of COBie outputs. There is still lack of investigations that endeavour to benchmark such outputs against the actual need or information requirements of the FM industry. With this study, we set the scene for this new discussion aimed at assessing and investigating whether and how such open standards and data specifications can meet the actual and specific data and information requirements of the FM industry. In particular, we focussed on the requirements of asset register creation and service life planning. While we contribute to knowledge in this specific area of FM, we also instigate domain researchers to develop additional use cases and contribute to improve the applicability of such open standards for FM purposes.

The results from this research showed that while IFC and COBie do not satisfy all information requirements of asset register and service life planning by default, they allow users to add some of the unsupported information in the form of property sets using Revit shared parameters. However, not all IFC Entity Types can be supported using shared parameters. Some of the identified entities which are not supported include IfcPropertyBoundedValue and IfcPropertyTableValue. Even when such entity types are implemented in BIM commercial applications, their application in certain FM applications such as Service life planning will still have some limitations. To support the use of probability distributions and functions for Service life planning data, standards such as ISO 15686-4 prescribe the use of such entity types. However, current BIM technologies only support parameters with simple data types. These are areas of improvement identified by this research and proposed for future investigations by researchers, standardisation bodies and technology providers.

The proposed methodology represents a guide for domain researchers and FM professionals to experiment and evaluate open standards and data specifications in fulfilling specific FM requirements. Even though the performed use cases were based on UK-specific documents such as EIR and AIM, the adopted methodology is generic and can be replicated across countries. While data requirements were specifically defined and bound to the IFC schema using Exchange Requirement Models to allow data exchanges to be validated, the same approach could be undertaken to bind data requirements to a different schema. Therefore, the approach proposed in this study can also contribute to support processes in countries where different standards and data specifications have been mandated. In the specific context of the UK, the adoption of the proposed approach will enable the automated checking of suppliers' requirements against the COBie deliverables produced according the BS 1192-4:2014 – Collaborative production of information Part 4: Fulfilling employer's information exchange requirements using COBie – Code of practice (BSI 2014b). The ultimate benefit from replicating the proposed approach would be to guarantee that supplier's requirements are fulfilled throughout the building life cycle, and to allow for a smoother transition between the capital delivery phases (e.g. design and construction) and the operational phase. The results from such analyses can also contribute to improve current BIM standards and software applications and their support for various stakeholders in the construction industry.

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