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DATA TRANSFER BETWEEN DIGITAL MODELS OF BUILT ASSETS AND THEIR OPERATION & MAINTENANCE SYSTEMS

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ABSTRACT: *The operation and maintenance of built assets is crucial for optimising their whole life cost and efficiency. Historically, however, there has been a general failure in the transfer information between the design-and-construct (D&C) and operate-and-maintain (O&M) phases of the asset lifecycle. The recent steady uptake of digital technologies, such as Building Information Modelling (BIM) in the D&C phase has been accompanied by an expectation that this would enable better transfer of information to those responsible for O&M. Progress has been slow, with practitioners being unsure as to how to incorporate BIM into their working practices. Three types of challenge are identified, related to communication, experience and technology. In examining the last aspect, it appears that a major problem has been that of interoperability between building information models and the many computer-aided facilities management (CAFM) systems in use. The successful and automatic transfer of information from a building model to an FM tool is, in theory, achievable through the medium of the Industry Foundation Classes (IFC) schema. However, this relies upon the authoring of the model in terms of how well its structure permits the identification of relevant objects, their relationships and attributes. The testing of over 100 anonymised building models revealed that very few did; prohibiting their straightforward mapping to the maintenance database we had selected for the test. An alternative, hybrid approach was developed using an open-source software toolkit to identify objects by their geometry as well as their classification, thus enabling their automatic transfer. In some cases, manual transfer proved necessary. The implications are that while these problems can be overcome on a case-by-case basis, interoperability between D&C and O&M systems will not become standard until it is accommodated by appropriate and informed authoring of building models.*

KEYWORDS: *Asset information models; automatic data transfer; case study; facilities management; operation and maintenance; xBIM software toolkit.*

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1. INTRODUCTION

Operation and maintenance (O&M) activities are part of the wider functions of facilities management (FM) and (physical) asset management (AM). Whilst FM "integrates people, place and process" within a built asset (ISO, 2018) and AM is "the practice of managing the entire life cycle … of physical and infrastructure assets" (ISO, 2014), O&M is concerned with ensuring that a "building and its systems and equipment … perform their intended function" (Cavka, et al., 2015). Here we are primarily concerned with O&M; that is, activities that ensure the functional performance of an existing physical asset. Authors such as Lee et al. (2012) and Yalcinkaya and Singh (2014) have stressed the importance of O&M, with the former reporting that it can account for up to 80% of a building's lifecycle costs. However, there has historically been a disconnect between design-and-construction (D&C) and O&M phases of the built asset lifecycle, particularly in the handover of information, which is at best unstructured, and commonly deficient. Clayton et al. (1999: 2441) remarked that the "as-built" or "record" drawings that are commonly delivered "are not an adequate information base for operating a building"; and Owen (1987: 238) complained that "It is not sufficient for design, manufacturing and installation information to be handed over in bulk at the end of the construction contract". The uptake of Building Information Modelling (BIM) presents the opportunity for automated information exchange throughout the building lifecycle, including between the D&C and O&M phases. The relatively recent adoption of BIM by the construction sector has led to a growing expectation that the output of the construction procurement process would not simply be a physical entity (in the form of a building or infrastructure asset) but include sufficient information about the asset to enable its proper operation, management and maintenance. McGraw-Hill's 'SmartMarket Report' has highlighted that "owners are the greatest beneficiaries of BIM" and described BIM for O&M/FM as a "critical goal" (McGraw-Hill, 2014). The opportunities for O&M/FM that are inherent in BIM have been recognised by many authors: these include Aziz et al. (2016), Kassem et al. (2015), Pocock, et al. (2014), Volk et al, 2014. The ambition to maximise this value is evident in the UK Government's 'Specification for information management for the operational phase of assets using building information modelling' (published as PAS1192-3:2014 by the British Standards Institute, transitioning to BS EN ISO 19650-3 Part 3: 'Operational phase of assets'). The document assumes that BIM as a process will enable the creation of a useful Asset Information Model (AIM). It highlights the importance of asset management in optimising whole life cost and recognises that integrating information between construction and asset management promotes better results at reduced costs, through "automated transfer of accurate, complete and unambiguous information … from one service provider to another" (PAS 1192-3:2014: iv). It is widely accepted that the most important aspect of BIM is in its value to owners and users after the physical assets have been constructed (Becerik-Gerber et al. 2011; Patacas et al., 2016). The benefits of a 'BIM-based repository' that could accrue to the operation phase of an asset are summarised by Aziz et al. (2016) as: better documentation; [reduced] operational cost; quicker and more effective decision making; improved collaboration and work flexibility; and more effective updating of information. In their more activity-focused list Wong et al. (2018:315) cite commissioning, preventive maintenance planning, maintenance and service [activities], space making, quality control, energy performance, managing emergencies and deconstruction as activities that could benefit from BIM-based 'as-built information'. They also recognise the advantages of being able to visualise that information and to update it during the life of the asset.

1.1 From 'BIM' to 'AIM': theory and practice

The use of computer software and potential for computer-aided facilities management (CAFM) for FM and O&M activities was highlighted around 30 years ago by Teicholz (1991) and the use of standalone CAFM software in the sector has been commonplace for some years. There is now a wide range of proprietary CAFM systems in use, and even within a single building there may be many systems operating concurrently, each with a specific purpose thus posing a challenge to effective system integration (McArthur and Bortoluzzi, 2018: 679). However, these systems require "significant amounts of data to be entered manually" (Shen et al., 2010: 205) in a process of data entry that relies upon searching the electronic files or paper documents that are handed over at project completion. So, according to Becerik-Gerber et al. (2011: 47) "finding relevant information that is often disregarded by designers" typically consumes more than 80% of a facilities management team's time. The potential re-use of existing data, rather their re-creation or manual re-entry at each stage in the project lifecycle phase is a fundamental advantage of digitalisation. However, efficient reuse of BIM data for O&M and FM purposes relies on the completeness and correctness of those data at the point that they are required. As early as 2007, East identified the need for "non-proprietary, interoperable versions of the data … to effectively operate modern facilities", describing the prevailing systems as "boxes of papers filled with the technical descriptions of materials, products, equipment, and systems that are stored and never used…" (East, 2007: 5). Little had changed by the time that Lee et al. (2012) found most practitioners still using paper-based processes to manage O&M and FM activities. More recent evidence (for example Liu, 2012; Eadie et al., 2013; Liu and Issa, 2013; Volk et al, 2014; Patacas et al., 2015; Codhinoto et al., 2018; Hu et al., 2018) indicates that BIM is not being as widely adopted for the O&M phase as it is during the D&C stages. And even when handover information was presented in electronic format (for example, spreadsheets or databases) it has been commonly found to be incomplete, inaccurate and difficult for practitioners to access and utilise (Kassem et al., 2015). Proposals continue to appear as to how the growing use of BIM could support effective D&C-to-O&M information exchange. In contrast with the claim by Parn et al (2017: 45) of "a paucity of literature…[on]… building information modelling (BIM) for asset management…" Wong et al. (2018) identified and systematically reviewed well over one hundred journal articles, conference papers and technical notes, published between 2004 and 2017, that related to the use of digital technology in FM. Although the authors' definition of digital technology extended to GIS, reality capture tools and sensor network technologies, nevertheless, most - over 80% - of the articles they reviewed concerned the potential of BIM. Similarly, Matarneh et al. (2019) have undertaken a review of 113 journal articles published from 2008 to 2018; conclude that BIM-to-FM information transfer is "not a straightforward process"; and advocate work that develops a "seamless information exchange" between the two. Notwithstanding this flow of academic advice, professional practice in O&M/FM remains reticent to adopt it. In 2013 a UK FM survey reported "a high degree of indecision" over how to incorporate BIM into "future working practices" (BIM4FM Survey, 2013) causing the FM Leaders' Forum to conclude that "there is still a lack of understanding about how [BIM] can propel FM to a leading role in the design, commissioning and management of buildings…. ensuring that information needed for operational management is included in building models" (FM Leaders Forum, 2013). It is perhaps understandable therefore, that in their review of the literature Wong et al. (2018) found very few cases of actual application, and according to Codhinoto et al. (2018: 1) the actual adoption of BIM for FM has been "sparse, scarce, and extraneous". In the most recent NBS National BIM Report, although 75% of respondents had produced 3D digital models over the previous 12 months only 29% considered that they had passed on a model to "those who are responsible for the continued management of the building or other asset" (NBS, 2019: 29). Even then, it should be noted that simply 'passing on a model' does not necessarily mean that the model was used or even usable.

1.2 Barriers to progress

Despite the potential of BIM for FM there are currently a number of challenges to the efficient and effective transfer of appropriate information from the D&C to the O&M phases. Becerik-Gerber et al (2011: 438) group these into three categories: process-related, organizational, and technological. Here we adopt a different three-fold classification of challenges. The first relates to communication. As Patacas et al. (2015) point out, information required for asset information modelling should be created, collated and exchanged throughout the design stage and not left until the handover phase. They propose a process framework to support the proper definition, handover and validation of such information in a structured form. Similarly, Liu (2012) highlighted the need to improve the efficiency of communication between facility managers and BIM designers, and Liu and Issa (2013) noted a need to communicate maintenance requirements during the design phase. The second challenge, possibly the root cause of the first, is the lack of awareness and experience on the part of owners and facility managers. of what information is available and what they might require. According to Ku and Taiebat (2011: 176) facility owners are not sufficiently familiar with BIM to specify what they want from it. Giel and Issa (2014) identified around 60 critical factors of BIM competency for exploiting the use of BIM efficiently during the O&M phases and found these lacking in most facilities operators. However, it is likely that the awareness of asset owners and facility managers will increase over time and this will be assisted by work such as that of Farghaly et al. (2018) who have explored asset owners' requirements and developed a related asset information taxonomy for identifying data that could usefully pass from BIM to FM systems.

The third type of challenge, and the one that emerged in the present study, is technological. Overcoming the communication and awareness/experience issues are to a large extent beyond the immediate control of researchers, whereas technical challenges may be responsive to solutions developed under laboratory conditions. Becerik-Gerber et al (2011) identify several aspects to the technological challenges of which we would identify three as being the most critical. These are: (1) "diversity in BIM and FM software tools, and interoperability issues"; (2) [lack of] "accurate as-built models of all building components"; and (3) [lack of] "logical object tree organization to manage the various components within the model" (Becerik-Gerber et al, 2011: 438). It is worth noting that matters that are categorised as 'technological challenges' relate to both the availability of the requisite technology (item (1) above) its correct use (item (2), above) and its proper application (item (3), above). Some of these challenges have been addressed in recent studies. For example, Pishdad-Bozorgi, et al. (2018:35) advocate "1) a clear definition of what FM-enabled BIM constitutes, 2) a seamless and practical process of collecting the FM-enabled BIM data throughout project development phases, and 3) a well-executed interoperability plan for exchanging data between BIM tools and facility management systems.” They also recognise the importance of early identification of information requirements (preferably through the involvement of users at the outset) which are then continuously monitored throughout, and that sufficient resources and time is allocated to do this. They also recognise the inherent difficulties of information sharing on the multi-party projects (which are, of course, that are typical in the construction sector) and advocate an integrated project delivery (IPD) approach to overcome this. Zadeh, et al., (2017) defined dimensions of information quality such as accuracy, completeness, reliability, and level of detail derived from earlier conceptual work by Wang and Strong (1996) and Lee et al. (2002). Using these they proposed a framework which they operationalized through the development and evaluation of information quality tests using BIM model checking tools across three projects with different levels of detail and complexity.

Many of the technical problems of interoperability relate to the variety of available applications at either end of the transfer: i.e. in the (source) BIM modelling software and in the (target) O&M/FM tools. In the project upon which this study is based, and whose description follows, we sought to overcome the interoperability challenge in two ways. As our source, we used models in the Industry Foundation Classes (IFC) format (Laakso and Kiviniemi, 2012; Steel et al., 2012, buildingSMART, 2019). IFC is an information model exchange standard in a neutral data file format that has already been identified (e.g. by Schevers et al., 2007, Solihin et al, 2015, Parn, et al., 2017, Pishdad-Bozorgi, et al., 2018, Matarneh et al., 2019) as the most likely means of transferring BIM data into CAFM tools. Secondly, as it was outside our control to address the diversity of all existing FM software tools, we examined one – an industry-standard maintenance specification tool. Thus, the main objective of our work was to enable data transfer between working IFC models and a single OM/FM maintenance tool and this is described in the next section. However, having controlled the variable of technical interoperability, what emerged was the continued persistence of two remaining challenges: the accuracy of models and their logical organisation.

2. A PROJECT AIMED AT ENABLING BIM-TO-FM DATA TRANSFER

The project was designed to create a means of automatically exchanging data between two platforms, namely: (1) the native BIM models (BIMs) that are increasingly being created for new (and existing) buildings and (2) an existing web-based standard maintenance specification (SFG20) that allows the customisation and prioritisation of regulatory-compliant commissioning and maintenance regimes for the Mechanical, Electrical and Plumbing (MEP) systems of buildings. The focus on MEP is particularly important since these systems are critical to the operation of most buildings and their associated costs have been estimated to be up to 50% of the total investment in large-sized projects (Lee and Ahn, 2018: 3804). SFG20 is an industry-standard service originally developed by the UK Building Engineering Services Association (BESA) as a tool for facilities managers, building owners, contractors and consultants who are involved in the planned maintenance of MEP systems. It is a widely-used tool, currently supporting around 350 FM contractors, with an increasing number of owners and consultants, and provides a dynamic web-based service with standard updated maintenance specifications. Users can employ bespoke criticality ratings to model multiple prioritised service regimes. Data from SFG20 can be downloaded into CAFM software (in cases where the user intends to perform or commission maintenance direct) or tender/contract documentation (where the user wishes to contract-out the service).

2.1 Brief description of the project

The ultimate objective for the research team was to produce a technical solution for enabling the transfer from BIMs to SFG20 of data that are appropriate to its functionality. Evidence from the literature (as reported above) suggested that there were challenges to transferring structured BIM data in this way. This first stage involved the research team in developing an understanding of SFG20 and how it is used to schedule, manage and document maintenance tasks carried out on buildings.

The next stage was to explore how objects within models could be linked to associated maintenance schedules within SFG20. As noted earlier our approach involved the use of the IFC schema. IFC was developed to provide an open standard approach to capturing building model data. The IFC schema allows objects, their relationships and attributes to be defined and subsequently identified. Properly defined objects can be identified, and, once identified, reliably mapped from one application to another (in this case, from any BIM model to SFG20).

At the outset, therefore, there were two fundamental research questions. The first (RQ1) was how well the authoring of BIMs supported the subsequent identification of objects, relationships and attributes. The second

(RQ2) was to what extent this information could be automatically transferred from a BIM model to an FM tool such as SFG20.

- (For RQ1) Obj.1 Establish a data sample of BIM models
- (For RQ1) Obj.2 Develop a method for identifying classifications applied to objects within the models
- (For RQ2) Obj.3 Develop an approach for linking classified objects within a model to maintenance schedules within an FM tool such as SFG20

The first of these questions (RQ1) is explored in the next section, the results of the analysis are set out in Section 4 and, informed by these results, the second question (RQ2) is dealt with in Section 5.

3. RESEARCH METHODOLOGY

The research methodology consisted of three key stages as shown in Figure 1, which is followed by a description of each stage. The first stage relates to establishing the data set of BIM models; the second deals with identifying classifications applied to the models within the data set; and the final stage involves mapping objects from the models to maintenance schedules within SFG20.

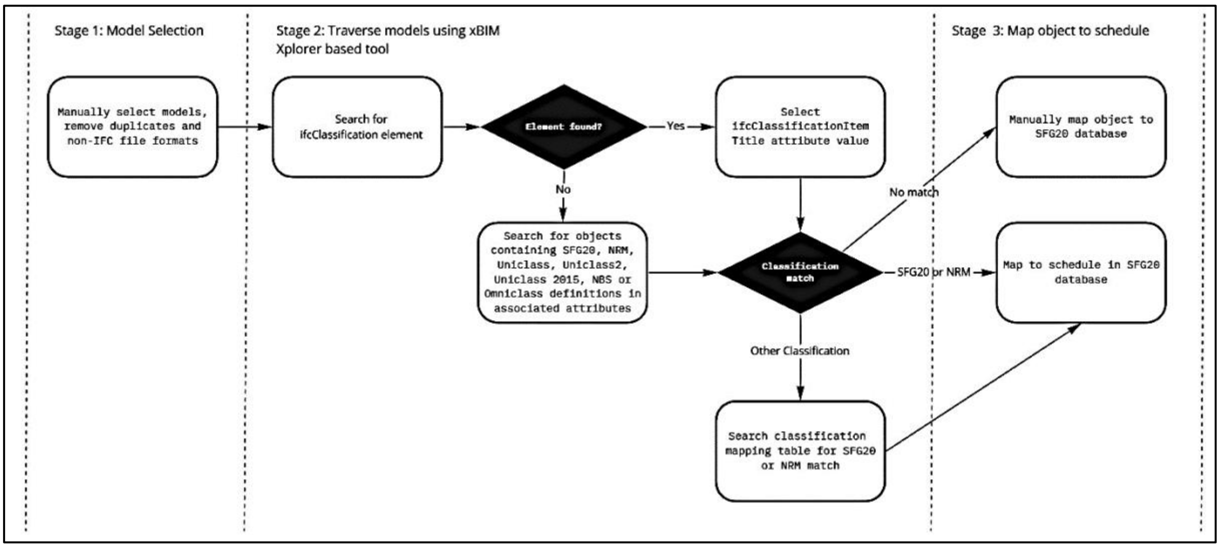

FIG. 1: Three-stage methodological approach

3.1 Establishing the data sample

An initial available sample of 221 files was inspected and screened for suitability; the main criteria being that they were in a pure IFC format, that they contained enough meaningful data, and that they were not duplicates of other files in the sample. Through this screening process 109 files were excluded: these included duplicates (e.g. work-in-progress files for which we had final versions), files in inappropriate formats (e.g. IfcXML and IfcZIP), and those with little or no significant data (e.g. a file with a single IfcBuildingElementProxy item representing a site entrance). The remaining 112 IFC files were retained for analysis.

The sample comprised 65 architectural, 2 electrical, 1 fabric, 1 furniture, 22 MEP, 1 plumbing only and 20 structural models from a range of industry organisations and relating to a variety of building types. The files were created between 2006 and 2016, as shown in Figure 2, below. All the files were in IFC 2x3 schema, which despite not being the most recent version (the latest being IFC 4.1) are nevertheless by far the most prevalent and offered a larger sample of models for testing purposes.

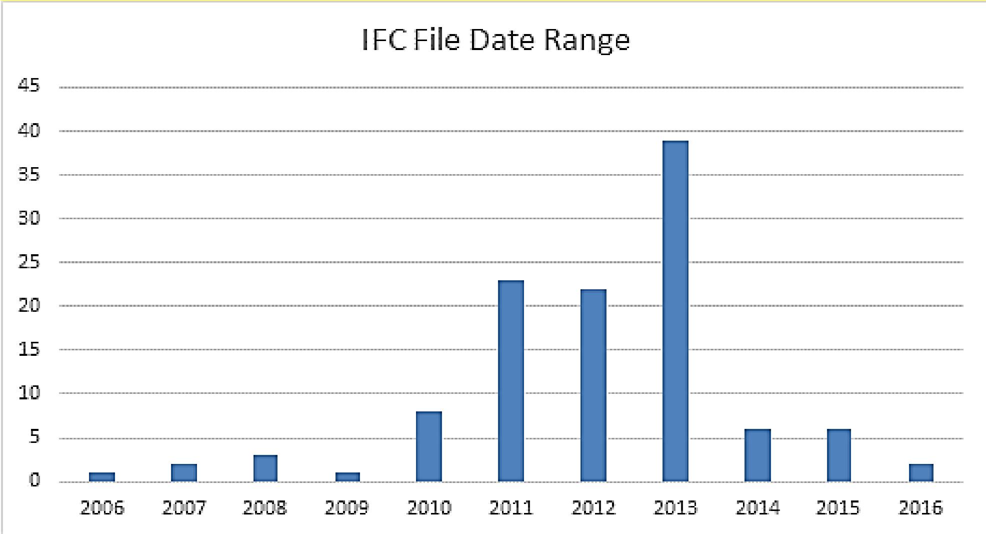

FIG. 2: Date range of IFC file creation.

3.2 Analysing object classification methods (Obj. 2)

The process of mapping the object information contained within a BIM model first requires its identification. Proper identification relies upon how well an object has been classified and meaning may be lost for example when a standardised format is not followed. A multiplicity of different classification systems exists for object-oriented information exchange (Lou and Goulding, 2008) resulting in a likelihood that those used by the source and destination files may differ. If the same classification system is shared by the source and destination of transfer, then elements from one can be automatically mapped onto the other. Where they differ, some classification systems offer a built-in ability to map to others: if they do not, this can be achieved using an ad hoc intermediary mapping table. However, as the research team was aware from its work on the earlier NBS BIM Toolkit (NBS, 2017) problems arise when a model has no clear classification system, or one that is partially or incorrectly applied; a situation confirmed by the literature (e.g. Solihin et al., 2015: 739).

The 112 anonymised IFC models were analysed for patterns of consistency in their asset information and semantic structure. Their use of BIM libraries, BIM authoring tools, and classification systems for producing semantic data were also identified and documented. For the analysis (and for subsequent data extraction) the open source software development toolkit, xBIM (Lockley et al., 2017a; Lockley et al., 2017b; xBIM, 2020) was utilised. xBIM Xplorer, an application within the toolkit, allows the reading and validation of an IFC schema and traversing the IFC structure, as well as the querying of syntax for data extraction. A bespoke software tool was built on the xBIM Xplorer functionality to load each source model into memory, traverse the model's IFC structure and analyse the semantic and descriptive data of its objects and their associated properties.

The IFC structural analysis sought evidence of the use of a standard classification system in two ways: first, by checking whether the IfcClassification element within the IFC schema had identified which (if any) standard classification system had been used. A more intricate method was then applied to interrogate each object within the model for a property reference or value that could be associated with a standard classification system. In view of the possible variations in classification that might be inherent in the sample, an approach to mapping was adopted, as shown in Table 1.

The importance of classification systems for object-oriented information exchange between source and destination files was outlined earlier, as were the problems surrounding the possible variations in classification that might be encountered. Here, our 'destination system' (the SFG20 tool) uses its own custom ('SFG20') classification alongside the Royal Institution of Chartered Surveyors' New Rules of Measurement (NRM) system (RICS, 2019). The situation regarding the source models was less straightforward.

Scenario	Solution
1. IFC Element uses SFG20 or NRM classification system	Element automatically mapped to SFG20 maintenance schedule
2. IFC Element contains SFG20 or NRM classification data within its property names or references	Element automatically mapped to SFG20 maintenance schedule
3. IFC Element uses the Uniclass, Uniclass2, Uniclass 2015, OmniClass or NBS classification system	Element automatically mapped to SFG20 and NRM classes via a mapping table
4. IFC Element uses the Uniclass, Uniclass2, Uniclass 2015, OmniClass or NBS classification data within its property names or references	Element automatically mapped to SFG20 and NRM classes via a mapping table
5. IFC Element contains no references to a classification system	Check IFC Element and compare Element name and associated property details with SFG20 and NRM classification and suggest mapping where likeness occurs
6. IFC Element contains no references to a classification system and the Scenario 5 check produces no recognised likeness	No match found thus an alternative solution involving hybrid, or manual mapping is the remaining option

TABLE. 2: IFC to Maintenance Schedule mapping functions.

4. RESULTS OF SUITABILITY ANALYSIS OF CURRENT BUILDING INFORMATION MODELS

4.1 Results of the analysis of 112 sample IFC models

The first stage in the analysis of the sample, i.e. examination of each model's *IfcClassification* element, revealed that the predominant classification system (representing just over half of the sample) was OmniClass (Construction Specifications Institute, 2019) with 59 occurrences. NBS/Uniclass (e.g. NBS, 2012) appeared in three IFC models, and was used together with OmniClass in a further six models. In an additional seven models these systems were supplemented with the aforementioned NRM system. In just over a third (37) of models no standard was used. A more detailed view of classification systems in the sample is given in Table 2, below.

Classification system	Instances
OmniClass	59
NBS/Uniclass	3
OmniClass and NBS/Uniclass	6
OmniClass, NBS/Uniclass, and NRM	7
No standard used	37
TOTAL	112

TABLE. 2: Standard classification systems in the sample.

The mere presence of a named standard classification system in *IfcClassification* does not guarantee its comprehensive coverage within an IFC model, nor its correct application. The generation of the IFC structure within building models often defaults to the preferences of the BIM authoring tool or proprietary and generic product family libraries that can be used to automate the generation of product data. There is a particular problem when a model author does not know how to apply an IFC classification system via the authoring tool they are using. An example is the *IfcBuildingElementProxy* definition. Current standard classification systems do not cater for every building object. The systems are constantly expanding to remedy this, but for objects without a predefined IFC type the general definition of *IfcBuildingElementProxy* (the IFC equivalent of a 'sundry' or 'miscellaneous' category) exists (buildingSMART, 2020c). Across the 112 sample files there were 588,107 objects had been defined and 44,902 were classed as *IfcBuildingElementProxy*.

Using xBIM, each of these objects was interrogated to see whether it had been correctly classified. Where an appropriate alternative IFC classification existed, but IfcBuildingElementProxy had been used instead, an instance of incorrect use was recorded. As illustrated in Table 3, just under 10% of all objects were classified as IfcBuildingElementProxy and in around 90% of cases its use was not appropriate.

Files (Nr)	Model View Definition	Model Type	Total Objects (Nr)	Total objects named as IfcBuildingElementProxy	Instances of incorrect use IfcBuildingElementProxy
58	Coordination	Architectural	237194	25907	21858
2	Coordination	Electrical	24522	7314	7314
1	Coordination	Ext. Fabric	18905	265	265
1	Coordination	Furniture	8227	0	0
20	Coordination	MEP	177084	8474	8474
1	Coordination	Plumbing	8443	488	488
18	Coordination	Structural	60449	482	419
2	QTO Add On	Architectural	13012	131	57
5	N/A	Architectural	29131	714	714
2	N/A	MEP	8476	1127	1127
2	N/A	Structural	2664	0	0
		Totals:	**588097**	**44902**	**40716**

TABLE. 3: Overview of analysis of 112 IFC files.

5. DEVELOPMENT OF A HYBRID APPROACH

The aim of the project was to effect the automated exchange and utilisation of data between native BIM models and the SFG20 tool for O&M regimes (primarily for the engineering services assets within buildings). The results of the tests described in the previous section posed a challenge to answering RQ2 and meeting Objective 3 (i.e. linking classified objects in a BIM model to maintenance schedules within SFG20). These tests, on a relatively large sample of asset models (n=120) had revealed a varied and piecemeal use of classification systems (Table 2) and indicated misuse of IFC naming conventions (Table 3). This exposed the unreliability of simply using classification systems or IFC definitions as a basis for information transfer between building models and SFG20 (or indeed, other asset management tools). Consequently, given that the overall objective of the project was the automatic transfer of relevant data from BIMs to SFG20, an alternative approach was required.

5.1 A hybrid system of data mapping

As illustrated above in Table 1 (Scenarios 5 and 6), where an IFC Element contained no reference to a classification system the next step is to compare the element name and associated property details for a recognisable likeness to one within the SFG20 and NRM classifications within the SFG20 tool. If no recognised likeness was found, then a hybrid approach, or (as a last resort) manual mapping would be the remaining option. In this case, the hybrid approach involved inspecting the geometry of objects in the source IFC models. BIM data can be represented both visually, through geometric models of buildings and assets, and semantically, through the data structure that defines the assets within the model and the associated data that describes an asset; for example, make, model or manufacturer information. 'Scenarios 1-5' of Table 1, and their corresponding solutions, relied on inspecting the semantic model data and its structure. A hybrid solution was necessitated by the discovery that 'Scenario 6' was the prevalent situation in the sample models.

5.2 A hybrid mapping methodology

The team then developed a solution that integrated the xBIM toolkit into the SFG20 software. This enabled SFG20 to use the *xBIM Essentials* tool (https://github.com/xBimTeam/XbimEssentials) to automatically read an IFC file, traverse the IFC structure, and interrogate the *IfcClassification* element and associated values. In cases where this proved acceptable, the automatic link was then made to the SFG20 schedules. Where this was not possible, a list of the relevant remaining building assets was generated for manual linking (and unlinking, if necessary) to the SFG20 schedules.

To do this, two further xBIM tools, *xBIM Geometry* (https://github.com/xBimTeam/XbimGeometry) and *xBIMwebUI* (https://github.com/xBimTeam/XbimWebUI) were used to load IFC geometry into a web browser facilitating visual identification of assets from this list and their location within each IFC model. The result was a software prototype that embedded the xBIM geometry engine and schedule-matching functionality into the SFG20 platform. Figure 3 shows a screenshot of the IFC geometric model within SFG20 simultaneously linked to the schedules for assets within the model.

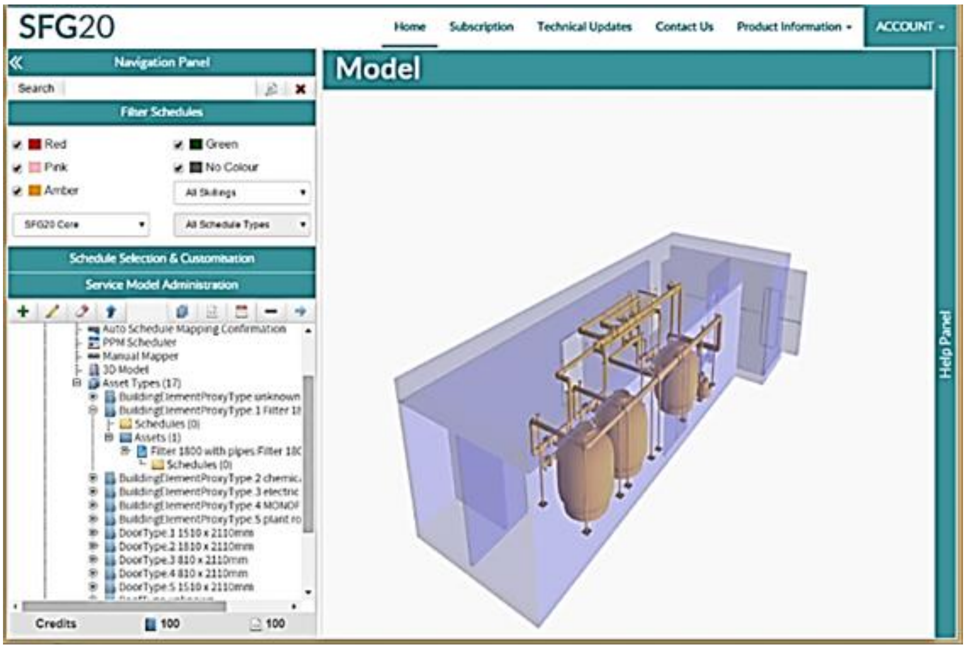

FIG. 2: SFG20 Prototype with IFC geometric viewer and mapping capabilities (screenshot).

6. SUMMARY AND DISCUSSION

There is a consensus in the literature over the disconnect between the D&C and O&M phases of the built asset lifecycle, and the ongoing failure to hand over of information effectively from one to the other. There are several reasons for this: one being insufficient communication between owners, facilities managers, designers and contractors. The growing adoption of digital technologies in the D&C phase of the lifecycle has raised expectations for the improved transfer of information to FM and O&M practitioners and asset users. However, there is also consensus over the current failure to exploit this potential, and information in digital building models is still predominantly focused on the D&C rather than the O&M phase; with the end purposes to which models can be put not properly considered at the outset.

In this project, we examined the feasibility of automatically identifying and transferring relevant data from BIMs in their most interoperable (i.e. IFC) form to an O&M tool (SFG20). Two research questions were posed: how well the authoring of BIMs supported the subsequent identification of objects, relationships and attributes (RQ1); and to what extent this information could be automatically transferred from a BIM model to an FM tool (RQ2). To answer the first of these questions we established a data sample of BIM models (Obj.1) as described above in Section 3.1. Based on this sample, and as described in Section 3.2, we developed and implemented a bespoke tool for identifying classifications applied to objects within the models (Obj. 2) using the xBIM Xplorer application to read and validate each IFC schema, traverse their structure, and query their syntax. The results of this exercise undermined the use of classification systems or IFC definitions for the information transfer sought by RQ2, and prompted an alternative approach in response to Obj.3, namely a hybrid solution for data transfer, on a case-by-case basis, between IFC models and an O&M tool. This allowed automated mapping where the IFC model quality permitted and facilitated manual mapping where it did not, and intervention was necessary.

The case study, supported the technical feasibility of creating a prototype using xBIM geometry engine and schedule-matching functionality to read IFC files, identify and view the relevant objects and their properties, and map them into the O&M tool. However, this process depends upon the quality of the semantic data and the naming conventions of objects within the source model. An examination of a large sample of existing IFC files revealed that such quality cannot currently be relied upon and the hybrid solution (Section 4) was needed. In their mapping of potential errors in the transmission of data between asset information models and FM systems, Pishdad-Bozorgi, *et al.* highlight the most common to be “the ones caused by human mistakes” and note the “necessity of BIM data quality control and assurance” (2018: 32). This finding is supported by the present study: the overall aim of project was a practical one, namely, to effect the automatic transfer of data between BIM models and O&M systems, but encountered a serious problem with the suitability of models in the first place. What we initially considered to be a technical challenge was overshadowed by human issues of accuracy and completeness. In our research sample there were persistent difficulties with the accuracy of models and their logical organisation: and these appeared to be due to modellers' inexperience, lack of time, incentive or realisation of what is required. Adherence to an 'Information Quality Assessment' framework, such as that proposed by Zadeh *et al.* (2017) might help overcome this.

This study, like any other, has limitations. As far as the 'receiving end' of the information transfer, we have concentrated on a single O&M product and generalised from that basis. More importantly, in terms of our conclusions, although the sample of BIM source data was relatively large, it was time-limited: models since 2016 may show improvements and an updated analysis may reveal this. Nor, unlike some authors, have we investigated the source of (i.e. the originator) or the reason for (e.g. ignorance or neglect) the models' deficiencies and this might be usefully explored by others. However, it is apparent that the methods used by BIM authors to develop models are subject to the capabilities, awareness, and habits of the author as well as the idiosyncrasies of the authoring tools they use. The results rarely follow the IFC schema guidelines. In order to ensure interoperability across systems, the elements of the data models need to be consistently and correctly authored so the linking of data can be automated. Until there are clear lines of communication between knowledgeable FM/O&M practitioners and model authors who are aware of what is required of them, such routine interoperability across systems is unlikely to be possible.

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