BIM Interoperability and Data Exchange Support for As-Built Facility Management

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Abstract. Nowadays, the increasing complexity of buildings highlights the need for the architecture, engineering, construction, and operation (AECO) sector to manage a large amount of data. In this scenario, the building digitisation process offers the opportunity to create virtual databases to collect data from different disciplines efficiently. At this point, Building Information Modelling represents the innovative methodology able to manage a building in its entire life cycle.

Its application has been studied and documented in the design phase to construction, but it is important to underline its relevance in the Facility Management (FM) sector. While the literature highlights the many potentials, it also draws attention to the criticalities of using BIM for FM, such as inconsistent and organic asset data acquisition guidelines, inadequate knowledge integration due to different schemas, syntaxes and semantics, and lack of systematic cataloguing of different sources.

The contribution of this study is the identification of a generic set of information requirements for FM systems, which should be included in BIM As-Built models for efficient facility operations and maintenance using an open standard format such as Construction-Operations Building Information Exchange (COBie). To this aim, the process is structured in three steps starting with Data Acquisition with digital survey techniques to obtain a 3D point cloud. Then, Data Integration in a Revit platform, and finally, defining what information from the BIM model could be useful, Data Management to transfer the identified specific information requirements into FM systems.

Keywords: Digital survey · Scan-to-BIM · COBie · Information hierarchy

1 Introduction

1.1 State of the Art in Facility Management for Cultural Heritage

The spread of the BIM methodology is contributing substantially to revolutionising the way in which data relating to structures is managed and exchanged between all the actors involved in the processes of the Architecture, Engineering, Construction, and

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Operations (AECO) sector. In addition to gaining greater consistency between all the deliverables produced by the central model, professionals have been able to benefit from numerous functionalities such as object clash detection, cost analysis, quality take-off, energy analysis, optimised construction sequencing, all of which can be traced back to the so-called seven 'dimensions' of BIM [1–3]. The fast pace at which the methodology is being disseminated, especially for the design and construction phases, is stimulating interest in its use also during the stages following the commissioning of the building, such as facility management (FM), renovation, control of installations [4, 5].

In this way, it is possible to ensure the extension of BIM to the entire building lifecycle, resulting in reduced operating costs, access to structured information, the presence of a central database and less dependence on the workforce for data extraction [6].

While the literature highlights the many potentials, it also draws attention to the criticalities of using BIM for FM, such as inconsistent and organic asset data acquisition guidelines, inadequate knowledge integration due to different schemas, syntaxes and semantics, and lack of systematic cataloguing of different sources.

Most of these problems could be mitigated, if not completely solved, by using a standard for information management and exchange. Industry Foundation Class (IFC), a vendor-independent data model, is developed as a standardised digital description of assets for collaboration and information sharing throughout the project lifecycle.

Being designed to accommodate many different configurations and Levels of Development, the IFC is often too generic and complex [7]. The solution comes from the Model View Definition (MVD), a purpose-built subset of the IFC itself that filters the information required for a particular workflow. Some examples of such configurations contain the data required for clash detection, costing, fire risk management. The Construction Operations Building Information Exchange (COBie) is an MVD designed for FM and asset management [8] and collecting the minimum data required for such operations. This emphasises the need to collect and organise data already at the design stage to be used at later stages.

COBie is gaining the attention not only of the academic world and software houses but also of government bodies, as technicians have understood that the real innovation of BIM lies in the information component, which makes the final model something more than a simple three-dimensional visualization of the project. Such a change in perception should ensure awareness that there is no point in pushing for virtualisations that are overly rich in geometric detail (Level of Geometry - LOG) but instead, seek a balance between this and information content (Level of Information - LOI). To facilitate data acquisition for COBie, the guide and responsibility matrix help identify what information is needed, at what stages and from which stakeholders, highlighting a significant reliance on practitioners to ascertain that the data collected is in the right format and verified for consistency.

Some contributions point out that data management for FM is unfortunately disconnected from the design phases. This results in the loss of much information that could be useful in the operational phases, as it is not systematised properly [9]. An immediate consequence is that while the Level of Geometry increases along the life cycle (at least for new constructions requiring a direct engineering methodology), the LOI remains in the background and undergoes a strong growth only before the delivery of the building. A possible solution, proposed in some writings, foresees that the COBie datasheet is

drafted in stages preceding the operational one, using the implementation of the guidelines and the responsibility matrix. The implementation of this solution is however costly and requires considerable effort in terms of human resources.

Implementing new information along the supply chain is understood as an evolution of the information and not as simple addition and therefore requires a consistency check. This operation is made even more complex by the fragmentation of data and their correlation [10].

1.2 Aims of the Contribution and Case Study

The present work aims to highlight the potentialities of BIM implementation for FM and operations, starting from the identification of a series of operative protocols that enrich the BIM content through the development of appropriate guidelines compatible with different case studies with the same model uses [11].

The results achieved may contribute to the creation of an operational background, composed of examples able to overcome the actual lack of standards and interoperability, making the proposed method more effective since the field of facility management and BIM are beginning to formulate just what one means to the other [12].

To investigate the proposed standardisation, the definition of a data pipeline of the BIM model used connected to the FM field becomes essential.

The main steps are three: the 3D point cloud obtained from laser scanner survey; the implementation of an As-Built Model for FM [13]; the integration with a COBie platform. These could be reached through the operational declination of the corresponding objectives of Data Acquisition, Data Integration and Data Management. In these final steps, it will be essential to filter the information content to optimise the exchange process and identify the data that would be useful to maintain the data structure.

The research case study, represented by *La Usina del Arte*, is a multidisciplinary cultural centre located in *La Boca* neighbourhood, in the city of Buenos Aires (Fig. 1). Built in 1916, the building was used as a power plant by the Italian-Argentine Electricity Company for many years. It was opened as a cultural centre in 2012 following an ambitious regeneration project, taking inspiration from international projects such as Park Avenue Armory in New York and Radial System in Berlin. The centre has a 1,200-capacity symphony hall with state-of-the-art acoustics and multiple spaces dedicated to dance and art exhibitions.

As already stated, the developed BIM guidelines for FM contain the investigated methodology standardisation defined as a set of activities related to the acquisition, integration, and management of models. The subsequent sections of the document are specifically aimed at proving the adopted procedure. Section 2 presents data acquisition methods with a Scan to BIM approach and management information in a FM environment, defining a procedural pipeline. Section 3 reports the results obtained and, finally, Sect. 4 closes this paper with the necessary reflections and conclusions.

2 Methods

2.1 Our Scan-to-BIM Approach

The creation of a BIM model for existing buildings is a reverse engineering methodology. Unlike new construction processes, where starting from a high level of abstraction and logical design rules, we arrive at the production of a physical object, the documentation of existing structures aims to analyse their functioning in detail, reconstructing their underlying logic, and deriving useful information for subsequent management phases. Regarding the reproduction of geometries, the literature offers interesting applications [14], but a holistic treatment is still lacking.

The technique opted for is Scan-to-BIM, a reverse modelling technique that uses digital sensing technologies to obtain point clouds that become the basis for BIM modelling. In detail, a four-stage workflow is applied: purpose identification, data acquisition, analysis, redesign.

Starting from the decision-making aspect, it is important to remember that the development of this BIM model is linked to a precise purpose, i.e., its connection to an information database that can correctly systematise the data and exchange it between the figures involved in the operational phase of the life cycle. Therefore, the goal is the production of a BIM model that can become the access tool to all the heterogeneous information gathered so far.

At this point, a Level of Development (LOD) for the virtual objects should be defined [15]. However, the first difficulties arise. Standard levels are conceived with reference to a forward engineering methodology, where geometric and informative contents increase as one moves from the idea to the real system.

Based on these observations, referring to an existing building surveyed and then modelled, one could be led to attribute the product to a LOD 500 (built structure), where the digital objects express the verified virtualisation of the single building elements (As-Built situation), containing the trace of the management, maintenance, repairs, replacements carried out during the whole life cycle.

If this direct correspondence can be valid for the geometrical aspect (we will see that the problem is more complex than it seems), the same is not true for the information content, which depends on the cognitive process. A solution to the problem could be to decouple the two aspects, identified as Level of Geometry (LOG) and Level of Information (LOI) which, however, cannot be treated separately. A major problem concerns geometry. Just think of the detailed knowledge of the stratigraphy that must be achieved to ensure a LOD 500. This is certainly a simple but revealing example.

Returning to the case study, based on the above considerations, we could indicatively attribute it a LOD 350, while reiterating the need to specifically define the contents necessary to describe the heritage and differentiating the geometric and material characterisation of the surfaces, attributable to a LOD 500.

Turning to the analysis, automatic data segmentation is not employed in the proposed application. The structure investigated required manual cataloguing of information, relying on the skills of qualified personnel capable of differentiating the elements studied by interweaving numerous parameters, which are difficult to manage simultaneously by an algorithm.



Fig. 1. Main entrance of *La Usina del Arte* in the city of Buenos Aires.

The final stage of the workflow involves redesign (Fig. 2). Whenever measured data undergo transformation into a digital object, a method of representation must be chosen. In our case study, we do not opt for a well-defined one, but we prefer to start by assuming a level of Represented Accuracy to be respected, corresponding to USIBD LOA 20 (1.5 cm–5 cm). In the first instance, the elements are modelled with a simple fit. Where the deviations between model and measured data exceeded this LOA, a detailed fit is applied (Fig. 3).

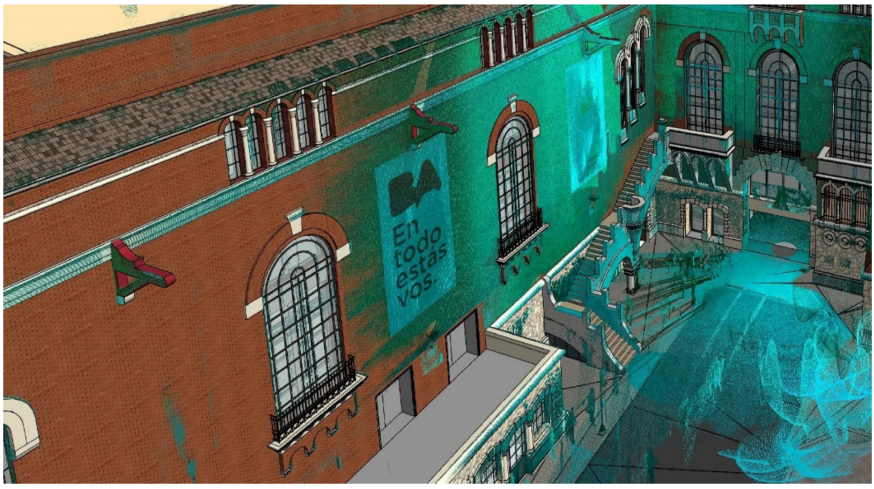


Fig. 2. Detail of the main entrance model with cloud overlay (Voyansi).

2.2 Information Management in a BIM Environment

One of the key issues for the proposed methodology is to define what information from the BIM model could be useful for FM [12]. In this regard, this procedure was considered. In the first instance, we proceeded studying the literature, standards, and best practice guidelines to define a set of information content. The second phase involved the use of a survey questionnaire based on the results of the first phase to prioritize the information content of BIM models to support FM systems specifically. The questionnaire was submitted to the client, asking them to rank the importance of the information requirements provided, with opportunities to add more.

As a result of the prioritisation phase, the following requirements needed to be registered to identifying objects: Manufacturer, Product model name and Product model number, included in Revit as type parameters, Unique equipment tag and an Uniformat code, which were instead included as instance parameters.

These information requirements were identified and ranked according to their potential to support FM systems, as suggested by the client. Based on these results, the next phase involved the development of a generic list of BIM model information contents to boost processes for identifying and exchanging data between BIM models and FM systems using an open data format. From a practical point of view, a plugin of Autodesk Revit, the platform used for parametric geometric modelling of the structure, was employed to export the predetermined information content in the form of COBIe spreadsheetML file [16, 17].

Using COBie categories, the information provided in the Revit Parameters was linked to the common language of the COBie Spreadsheet using a properly written COBie.Type tab. The choice in the file format was tied up also to the fact that, in practice, the modelling teams do not coincide with those of information management, and these last ones often do not possess abilities of programming. Formatting as a spreadsheet allows this potential barrier to be overcome, while preserving the ability to interface with the IFC model. After creating the COBie spreadsheet based on the linked information from the BIM model, this was then imported into YouBIM, the FM management platform.

3 Results

For this project, the end goal is leveraging technology with the aim of creating an As-Built model and drawings that could be used for future reference in remodels or maintenance [18]. As for the acquisition campaign, a FARO Focus^{3D} X330 scanner is employed. To ensure complete coverage of the site, avoiding shaded areas, 300 stations are planned, with scans acquired at a resolution of about 6 mm at 10 m. In total it took three days of work for a team of 2 operators.

The single clouds are characterized by a high degree of overlap and for this reason are registered employing a global bundle adjustment procedure, accomplished after a top-view-based pre-registration. Given the set of scans, the first step involves the selection of a reference scan, those that will be considered fixed and those that can be moved. The algorithm searches for all the possible connections between the pairs of point clouds with overlap. For each connection, a pairwise ICP is performed defining a maximum search distance, the dimension of the sample on the cloud to register (number of control points)

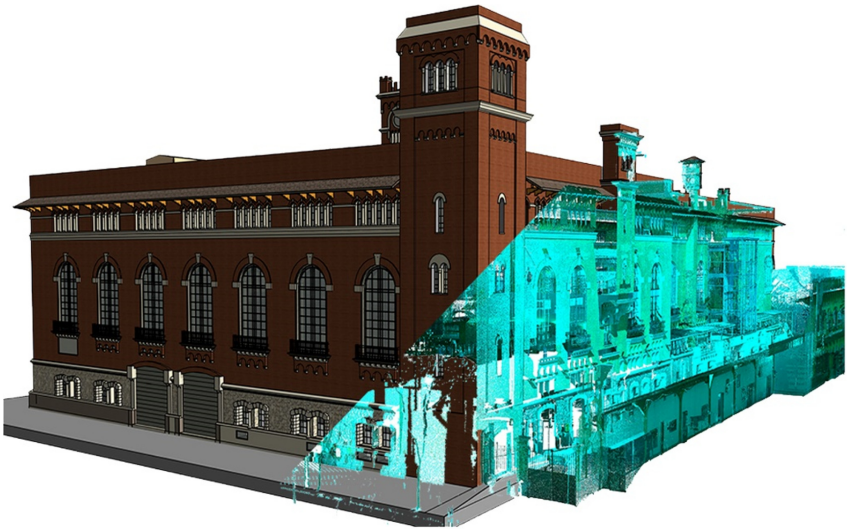
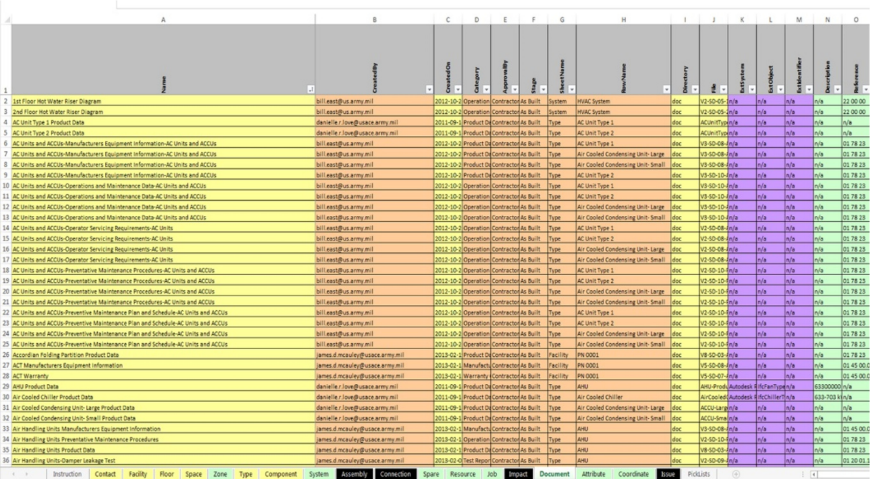


Fig. 3. Overlay of the BIM model with the laser scanner point cloud (Voyansi).

and the number of iterations. The best matching control point pairs between the two scans are saved. A final non-linear minimisation is run only among these matching point pairs of all the connections with the least square method. The global registration error of these point pairs is minimized, having as unknown variables the scan poses. The maximum value of the RMSE on the individual registration pairs is about 1.26 cm. Even the original versions of the scans are preserved to conduct more checks. The overall cloud consists of about 500 million points. For this reason, it has been divided into multiple regions to be imported smoothly into the software used for modelling. The team spent approximately 200 h to create an As-built BIM model using tools like Trimble and Edgewise to improve accuracy and speed. Based on the model, the team also created As-Built 2D drawings, including information related to room names, dimensions, gridlines, etc.

After this stage, the team had the challenge of starting from scratch with the asset data entry and development. All existing information was received in PDFs or images, so the team had to load them into the models through specific parameters, export the data as COBIe (Fig. 4) and finally upload contents to a FM Management software called YouBIM to manage the data.

As previously mentioned, one of our key tasks was to filter this content to streamline the interchange process and identify the data that would be useful when maintaining the structure. From the results of the analysis, it emerged that the most relevant data concerns the asset location, description and specification, room tags, system/equipment performances, maintenance history and other general information.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Name	CreatedBy	CreatedOn	Category	ApprovedBy	Stage	SheetName	RowName	Directory	File	ExtSystem	ExtObject	ExtIdentifier	Description	Reference
2	1st Floor Hot Water Riser Diagram	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	System	HVAC System	doc	V2-SD-05-	n/a	n/a	n/a	n/a	22 00 00
3	2nd Floor Hot Water Riser Diagram	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	System	HVAC System	doc	V2-SD-05-	n/a	n/a	n/a	n/a	22 00 00
4	AC Unit Type 1 Product Data	danielle.r.love@usace.army.mil	2011-09-1	Product Da	Contracted	As Built	Type	AC Unit Type 1	doc	ACUnitTypen/a		n/a	n/a	n/a	n/a
5	AC Unit Type 2 Product Data	danielle.r.love@usace.army.mil	2011-09-1	Product Da	Contracted	As Built	Type	AC Unit Type 2	doc	ACUnitTypen/a		n/a	n/a	n/a	n/a
6	AC Units and ACCUs-Manufacturers Equipment Information-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Product Da	Contracted	As Built	Type	AC Unit Type 1	doc	V3-SD-08-	n/a	n/a	n/a	n/a	01 78 23
7	AC Units and ACCUs-Manufacturers Equipment Information-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Product Da	Contracted	As Built	Type	Air Cooled Condensing Unit- Large	doc	V3-SD-08-	n/a	n/a	n/a	n/a	01 78 23
8	AC Units and ACCUs-Manufacturers Equipment Information-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Product Da	Contracted	As Built	Type	Air Cooled Condensing Unit- Small	doc	V3-SD-08-	n/a	n/a	n/a	n/a	01 78 23
9	AC Units and ACCUs-Manufacturers Equipment Information-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Product Da	Contracted	As Built	Type	AC Unit Type 2	doc	V3-SD-10-n/a		n/a	n/a	n/a	01 78 23
10	AC Units and ACCUs-Operations and Maintenance Data-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	Type	AC Unit Type 1	doc	V3-SD-10-n/a		n/a	n/a	n/a	01 78 23
11	AC Units and ACCUs-Operations and Maintenance Data-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	Type	AC Unit Type 2	doc	V3-SD-10-n/a		n/a	n/a	n/a	01 78 23
12	AC Units and ACCUs-Operations and Maintenance Data-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	Type	Air Cooled Condensing Unit- Large	doc	V3-SD-10-n/a		n/a	n/a	n/a	01 78 23
13	AC Units and ACCUs-Operations and Maintenance Data-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	Type	Air Cooled Condensing Unit- Small	doc	V3-SD-10-n/a		n/a	n/a	n/a	01 78 23
14	AC Units and ACCUs-Operator Servicing Requirements-AC Units	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	Type	AC Unit Type 1	doc	V2-SD-08-n/a		n/a	n/a	n/a	01 78 23
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22	AC Units and ACCUs-Preventive Maintenance Plan and Schedule-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	Type	AC Unit Type 1	doc	V2-SD-10-n/a		n/a	n/a	n/a	01 78 23
23	AC Units and ACCUs-Preventive Maintenance Plan and Schedule-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	Type	AC Unit Type 2	doc	V2-SD-10-n/a		n/a	n/a	n/a	01 78 23
24	AC Units and ACCUs-Preventive Maintenance Plan and Schedule-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	Type	Air Cooled Condensing Unit- Large	doc	V2-SD-10-n/a		n/a	n/a	n/a	01 78 23
25	AC Units and ACCUs-Preventive Maintenance Plan and Schedule-AC Units and ACCUs	bill.east@us.army.mil	2012-10-2	Operation	Contracted	As Built	Type	Air Cooled Condensing Unit- Small	doc	V2-SD-10-n/a		n/a	n/a	n/a	01 78 23
26	Accordian Folding Partition Product Data	james.d.mcauley@usace.army.mil	2012-02-2	Product Da	Contracted	As Built	Facility	PN 0001	doc	V8-SD-03-n/a		n/a	n/a	n/a	01 78 23
27	ACT Manufacturers Equipment Information	james.d.mcauley@usace.army.mil	2013-02-1	Manufacti	Contracted	As Built	Facility	PN 0001	doc	V5-SD-08-n/a		n/a	n/a	n/a	01 45 00.0
28	ACT Warranty	james.d.mcauley@usace.army.mil	2013-02-1	Warranty	Contracted	As Built	Facility	PN 0001	doc	V5-SD-07-n/a		n/a	n/a	n/a	01 45 00.0
29	AHU Product Data	danielle.r.love@usace.army.mil	2011-09-1	Product Da	Contracted	As Built	Type	AHU	doc	AHU-ProdcAutodesk.R	RefFanType	n/a	n/a	63300000	n/a
30	Air Cooled Chiller Product Data	danielle.r.love@usace.army.mil	2011-09-1	Product Da	Contracted	As Built	Type	Air Cooled Chiller	doc	AirCooledCAutodesk.R	RefChillerTy	n/a	n/a	633-703	n/a
31	Air Cooled Condensing Unit- Large Product Data	danielle.r.love@usace.army.mil	2011-09-1	Product Da	Contracted	As Built	Type	Air Cooled Condensing Unit- Large	doc	ACCU-Largen/a		n/a	n/a	n/a	n/a
32	Air Cooled Condensing Unit- Small Product Data	danielle.r.love@usace.army.mil	2011-09-1	Product Da	Contracted	As Built	Type	Air Cooled Condensing Unit- Small	doc	ACCU-Sma n/a		n/a	n/a	n/a	n/a
33	Air Handling Units Manufacturers Equipment Information	james.d.mcauley@usace.army.mil	2013-02-1	Manufacti	Contracted	As Built	Type	AHU	doc	V3-SD-08-n/a		n/a	n/a	n/a	01 45 00.0
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36	Air Handling Units-Damper Leakage Test	james.d.mcauley@usace.army.mil	2013-02-0	Test Repor	Contracted	As Built	Type	AHU	doc	V2-SD-09-n/a		n/a	n/a	n/a	01 20 01.1

Instruction | Contact | Facility | Floor | Space | Zone | Type | Component | System | Assembly | Connection | Spare | Resource | Job | Impact | Document | Attribute | Coordinate | Issue | PickLists

Fig. 4. Example of COBIe spreadsheetML file exported from the BIM model (Voyansi).

4 Conclusions

This study aims to propose a combined BIM-FM methodology to manage the information content of a building during its life cycle. One of the goals is to identify a general set of BIM information requirements to support FM systems, which could be used as a basis for developing an automated information exchange process. Information is gathered and identified through a literature review of similar studies, existing standards, and best practices. These results are then organised into a survey questionnaire that includes information items, according to feedback from the client interviewed. The results identify some relevant information: asset content, room labels, system performance, and maintenance history.

Most of them are related to maintenance and asset management, all factors perceived as a priority by customers to ensure maximum utilisation of both facility and equipment assets. The investigation also developed the proposed process of data identification and exchange using an open standard format such as COBie to develop facility information requirements at an early stage, to check for compliance to these requirements and, finally, to transfer the identified specific information requirements into FM systems.

The distinctive element of the methodology is that the information is filtered already at an early stage, streamlining the output file from the model. This will reduce the redundant efforts of sorting and organising the COBie spreadsheet to extract the required data.

Another contribution is the identification of a generic set of information requirements for FM systems, which should be included in BIM As-Built models for efficient facility operations and maintenance. The study findings provide the basis of the integration of BIM with FM systems. Such integration will enable automated data exchange, which will support efficient operations and reduce costs.

Some future developments will be addressed to expand the catalogue of transferred information content, building for them reference categories useful for a better systematisation of data. A further step forward will be the automation of data export process from the model and the consequent correlation to these categories.

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