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BIM MODEL TO SUPPORT O&M TASKS

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SUMMARY: *Technological evolution and BIM have changed the design development process in the construction industry. The operation and maintenance (O&M) phase requires building information throughout its service life, which was previously paper based, making it difficult to carry out maintenance activities. BIM assists in the management, storage, and digital sharing of information generated. However, only part of the information generated is required for the maintenance phase of the building. Although a subset of the IFC schema already exists to describe the data exchange between the BIM model and maintenance software, the data are generic and not well defined according to each the element source of maintenance (ESM). Therefore, through a literature review of existing studies on the use of BIM to support O&M processes, this paper aims to design an information flow to integrate maintenance information into the BIM model. The information is based on six main maintenance acts (inspection, cleaning, proactive measure, correction, replacement, and terms of use) and organized in an external sheet. The building will be divided into ESM according to its function in the building to facilitate the maintenance information flow between sheets and the BIM model.*

KEYWORDS: *Maintenance information; BIM model; Information; Interoperability*

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1. INTRODUCTION

Facility Management (FM) is the process of integration that involves two major areas: (i) spaces and infrastructure (technology), (ii) people (users, owners, and employees) and the organization. It aims to keep and ensure the built environment functionality, comfort, security, etc., through improved support for agreed services (NP EN 15221-1, 2016). The International Facility Management Association (IFMA) (IFMA, n.d.) establishes various core competencies for facility managers (FMs) that contribute to building efficiency, among them the operation and maintenance (O&M) area has some relevance. O&M activities performed by the FM team require considerable time and effort in collecting and accessing data arising from paper and/or electronic documentation. However, this traditional process leads to data loss, redundancies, additional data search expenses, and manual data re-entry, among others (Matarneh et al., 2019).

As a new paradigm, BIM emerges as a technology that allows the generation and centralization of the required information for the management of a building in service, supporting O&M activities. Then, it is possible to obtain improved and standardized planning of each O&M proceedings for each building (Eastman, C., Teicholz, P., Sacks, R. and Liston, 2011; Volk et al., 2014). In recent, the dissemination of BIM has enabled new opportunities for professionals in the AEC-FM (Architecture, Engineering, Construction, and Facility Management) industries to improve the building quality at a reduction in cost and shorter designer duration (Gao & Pishdad-Bozorgi, 2019). The use of BIM in the O&M phase changes the traditional methods of documentation, maintenance, control, analysis (Naghshbandi, 2016), generating information, and information exchange management (Cavka et al., 2017). BIM model simulates a real building, digitally, which contains the information regarding the element source of maintenance (ESM) in service. The digital BIM model facilitates access, management, and systematization of building information throughout the constructive phases of the building. Thus, maintenance professionals use BIM to reduce operations maintenance costs, improve ESM control systems, and perform more planned maintenance operations (Naghshbandi, 2016). Despite several possibilities arising from BIM for FM adoption, the professionals face difficulties in the information exchange process between the BIM model and FM software to support O&M proceedings, due to the undefined data transfer process, omitting O&M data required, interoperability, among others (Matarneh et al., 2019).

The definition of the information required in the O&M phase is still a challenge because the BIM models must be developed with the data collected over the building life cycle (Naghshbandi, 2016; Pishdad-Bozorgi et al., 2018) and this depends mainly on the early involvement of maintenance managers and of the owner. Several studies have been developed on this topic. Cavka et al. (2017) report that in many cases maintenance information, when documented, is spread out in numerous documents and does not have a formalized structure with BIM requirements. In addition, there is the difficulty in addressing and structuring the data included in the BIM model according to the FM needs (Cavka et al., 2017). Becerik-Gerber et al. (2012) approached in their study that each FM application area covers different types of data, for example, in the maintenance phase, the information involves semantic data and some geometric data. The data exchange between BIM tools is standardized by the IFC schema, however, for FM activities a Model View Definition (MVD) is used, e.g., COBie, being an international standard for data exchange in the facility management area (Lee et al., 2021). In their study, Lee et al. (2021) developed requirements and defined robust rules for data validation in the BIM information exchange process, aimed to automate and improve reliability in the system interoperability. KIM et al. (2018) affirm that despite the existence of the IFC coding system and the COBie standard, FM professionals rarely use facility management systems in the workplace through the traditional approach without IFC objects or COBie data, due to these systems are not standardized to link COBie data or IFC objects with a public data model. For this, construction information, generated with different data schema throughout the building life cycle, must be semantically integrated in order to deliver FM data based on objects that support BIM-FM integration, such as management and maintenance work review and 3D view (Kim et al., 2018).

Even with the IFC coding system and the COBie standard, the vast amount of information generated in the BIM model must be structured according to the FM area and the purpose of data use. During this study, a clear definition of the information required to support O&M activities from the perspective of an advisor was not found. Therefore, this research aimed to identify existing studies about BIM used to support O&M proceedings. An analysis of the existing literature was conducted to understand the knowledge gap between the definition and extraction of data based on six main maintenance activities. The literature review shows that maintenance information is not well specified according to defined maintenance activities. Thus, this paper proposes an information flow to integrate maintenance information from an external database to the BIM model. Maintenance information will be based on the six main procedures carried out in maintenance activities and organized in a sheet. The building will be divided into elements source of maintenance according to the function that the element performs in the building (Rodrigues, 2001; Rocha, 2014) .

2. REVIEW

2.1 BIM for O&M

The technological growth in the industry has changed the development of the building construction process, from conception to the demolition and disposal phase. The adoption of BIM technology enables the integration of building lifecycle stages, resulting in a dynamic and collaborative environment. A single integrated BIM model can be developed, and information can be entered as the project progresses (Pärn et al., 2017). That information is valuable for FM activities and when gathered in a single data source significantly reduces the effort and time to capture it.

FM activities cover several skills that involve people, spaces, and tools and require facility managers' wide strategic and tactical knowledge to better manage facilities (IFMA, 2021; Naghshbandi, 2016). However, the BIM-FM integration has been more used in O&M field due to automation in data transfer and update, data management through the integration between BIM and Computer-Aided Facilities Management (CAFM), BIM and Computerized Maintenance Management System (CMMS) integration assists in space management, maintenance, and preventive maintenance planning based on historical trends, among others (Naghshbandi, 2016). In their study, Becerik-Gerber et al. (2012) describe FM areas in which BIM can be implemented and present benefits for professionals and people involved in the process. In the O&M field, these authors highlight that BIM can facilitate the following tasks: building components location to perform maintenance or commissioning; access to real-time data; checking maintainability of elements source of maintenance (ESM's), and generation and updating of assets in a digital model. However, the data must be modified as the tasks are performed, aiming to provide updated information.

Despite the increasing dissemination of technology in construction, the adoption of BIM in O&M is still very low (Lu et al., 2018; Heaton et al., 2019; Hu et al., 2018) and limited due to some factors, e.g., workflow changes, maintenance professionals' training plan, organizational issues, availability, and accessibility of building information (Lu et al., 2018). Besides that, data integration between BIM and maintenance information management systems is still not performed satisfactorily (Heaton et al., 2019). Some studies have been developed to demonstrate the BIM uses in O&M from different perspectives. Lu et al. (2018) established a model based on activity theory to comprehensively analyse the BIM use process in O&M for existing buildings aiming for owners to understand the BIM implementation procedure. Heaton et al. (2019) proposed a methodology for extracting BIM-related data from a database to integrate with existing asset management systems.

From another perspective, other authors like Hu et al. (2018) and Liu & Issa (2012), analysed the management of maintenance information related to the MEP (Mechanical, Electrical, and Plumbing) system. Liu & Issa (2012) propose a model in which information generated throughout the design and construction phases is available in a database and can be transferred bidirectionally between modelling software and existing facility management software. Hu et al. (2018) describe a chain of solutions to integrate and digitize the information related to MEP in the as-built model to assist in the O&M management system. These authors highlight that in addition to the information created during the design and construction phases, the information generated only in the O&M phase, such as operation, repair, and maintenance status, must also be integrated into BIM for maintenance management.

The FM industry involves a variety of data that are often organized and managed in information systems, such as CMMS and CAFM that assists in managing and storing data. The data collected by BIM during the activities is valuable for different FM areas, therefore a single software cannot cover all FM areas (Wong et al., 2018). The software available for the O&M area can be divided into four large groups according to the purpose of use as (i) facilities manager (e.g., ARCHIBUS and Onuma), (ii) user information manual, (iii) condominium manager, and (iv) provider (e.g., CMMS).

2.2 Maintenance types

Maintenance requires a set of strategies to improve the quality of the built environment and the functions for which the building was built. These strategies involve the activities, processes, and procedures that lead to maintenance interventions during the building life (NP EN 13306, 2021). The information generated during the building life must be stored and transmitted to the maintenance manager so that the maintenance plan can be developed. Maintenance can be divided into two large groups, namely: (i) corrective maintenance that results from action after the detection of anomalies in the ESM and aims to restore the element to a state similar to the initial one; (ii) preventive maintenance that values the execution of maintenance operations before the appearance of anomalies, that is, before the EMS presents any pathological manifestation (NP EN 13306, 2021). Among the groups, the first should be used as a last option and in exceptional cases, despite being a quick resolution to the anomaly, it is economically less advantageous when compared to preventive interventions.

2.3 Data Exchange

The data exchange between BIM software encompasses integration and interoperability, however, it can present difficulties when different systems must communicate among themselves (Ozturk, 2020). Interoperability is the ability to exchange data between different systems, allowing different specialties to contribute to building development (Eastman, C., Teicholz, P., Sacks, R. and Liston, 2018). For this, the Industry Foundation Classes (IFC) (information exchange between BIM software) was developed as an open and neutral international standard data model that codifies the semantic information of entities and their characteristics (Ozturk, 2020; *Building Smart*, 2021), so that files from different software can exchange this information. During the building life cycle stages, several information is generated and can be stored in the BIM model, however, some information is unnecessary for the O&M phase. The Construction Operation Building Information Exchange (COBie) (information exchange between people/subcontractors) data schema is a subset of IFC that filters the information required for FM activities, thus it is the most suitable and used for FM phase (Volk et al., 2014; Ozturk, 2020). Ideally, this interoperability between BIM and FM should be automatic and easily performed using the IFC schema or a specific model view definition (MVD), such as COBie. However, even if the data exchange is performed well, BIM does not provide all the information required by FM. This is due to the IFC schema provides geometric (such as width and height) and semantic (such as building costs and schedules) information of the model, while COBie provides information beyond the aforementioned, such as asset details and graphical information (Chen, Chen, & Cheng, 2018). Therefore, this integration requires various guidelines and definitions related to information.

Some researchers seek to improve the interoperability between BIM (IFC) and FM (COBie) systems. Rogage & Greenwood (2020) developed a model to automate data exchange between the BIM model and FM tool used, but the semantic data quality and the naming convection influenced the data recognition by the FM tool, and it prevented an automatic data exchange. Kim et al. (2018) propose advanced data management to integrate IFC objects, COBie data, and facility management system (FMS) database through the semantic web, and they point out that each FMS requires a specific database for data exchange with the BIM model. Venugopal et al. (2015) defined and documented the ambiguities of the information generated by IFC, in addition, to refine the IFC schema to facilitate model views. Lee et al. (2021) propose a framework for automatic data validation from two MVDs analysed. However, the data mapping from IFC entities and their relationships are not yet clear and there are ambiguities in the information generated (Lee et al., 2021; Suyama & Miyazaki, 2015). In addition, there are still problems such as the unclear definition of the MDV used and human errors limiting the information exchange between BIM (IFC data format) and FM tools (Lee et al., 2021). Pishdad-Bozorgi et al. (2018) affirm that the automatic data exchange between BIM and CMMS depends on the early definition of the required data that is compatible with the CMMS used. Chen et al. (2018) proposed an ontology-based data mapping framework between IFC and COBie to improve data exchange between BIM and FM systems. Although, importing COBie data to the FM systems was performed by filling in the information manually, and sometimes can have data loss.

2.4 Required information

The BIM-FM implementation process is complex, requires effort, and involves an amount of data. According to Cavka et al. (2017), the information contained in the BIM model should be identified by the facility owners at the early stages for the model to be useful for FM activities. This information varies by building, FM area, and O&M team needs (Becerik-Gerber et al., 2012). Usually, the FM teams need more non-geometric information than geometric information (Cavka et al., 2017). Becerik-Gerber et al. (2012) reported that the development of FM-enabled BIM models focuses mainly on geometric data requirements, e.g., the accuracy of BIM model data including several design disciplines, accurate as-built model, and labeled division of spaces of the building according to FM guidelines. On the other hand, semantic data cannot all be extracted from the BIM model, but they also need to be identified to support BIM-FM integration, according to the FM area (Becerik-Gerber et al., 2012). The information of an asset involves a graphical model, semantic data, and documentation, only some of which are originated, managed or exchanged in the BIM model (Eastman, C., Teicholz, P., Sacks, R. and Liston, 2018). That is, the geometric model and part of the semantic information are obtained from the BIM model, while the rest of this information and the documentation are stored in other types of tools, such as CMMS (Chen, Chen, Cheng, et al., 2018). The COBie format also provides a standard for capturing and storing various data, but it is still necessary to define and identify the BIM information required by maintenance activities (Pishdad-Bozorgi et al., 2018). Pishdad-Bozorgi (2018) developed a pilot project to analyze obtaining FM data from the BIM model developed before the design and construction phases. To define this information, the maintenance team were involved in the early stages of the process that defined main assets that needed to be tracked for maintenance. Chen et al. (2018) proposed an extension of the IFC schema so that maintenance information is stored within the BIM model with Level of Detail (LOD) 500, in order to automate the scheduling of work orders. This process included the identification of maintenance information based on routine maintenance, data mapping in the IFC standard and mapping and integration of BIM-FM data.

3. PROPOSAL APPROACH

3.1 Maintenance activities

Maintenance includes technical, administrative, and management actions, which together aim to maintain or replace an asset so that it can perform the function for which it was built, throughout its life cycle (NP EN 13306, 2021). Activities can range from simple visual inspections to function check-out. Among them, the most relevant ones will be used in the maintenance sheets, Table 1, proposed by the authors, namely: (i) inspection: procedures that aim to identify indicators of the building's behaviour (Rodrigues, 2001); (ii) cleaning: ensuring the hygiene of the environment and the aesthetics of the building; preventive measures: aim to assess and/or mitigate the degradation of the building; (iii) proactivity: aimed at reducing the deterioration of the ESM through periodic interventions; (iv) corrective measures: aimed at correcting and eliminating pathologies that are in a more advanced stage of degradation (NP EN 13306, 2021); (v) replacement: it consists of replacing the element or part of it that presents irreparable anomalies in order to resume its initial functionality; and (vi) terms of use that defines how to use an asset to maintain its function and good condition. Among the maintenance procedures shown in Table 1, only two are well described in the literature.

TABLE 1: Maintenance sheet

<table>
<tr><th colspan="6">Maintenance sheet</th></tr>
<tr><td>Name (instance)</td><td colspan="3"></td><td colspan="2" rowspan="3">ESM picture</td></tr>
<tr><td>Family</td><td colspan="3"></td></tr>
<tr><td>Type</td><td colspan="3"></td></tr>
<tr><td>Location</td><td colspan="5"></td></tr>
<tr><td>Dimension</td><td colspan="5"></td></tr>
<tr><td>Material</td><td colspan="5"></td></tr>
<tr><td>Element ID</td><td colspan="5"></td></tr>
<tr><td>Installation date</td><td colspan="5"></td></tr>
<tr><td>Warranty end date</td><td colspan="5"></td></tr>
<tr><th>Operation</th><th>Procedures</th><th>Execution</th><th>Associated entity</th><th>Schedule</th><th>Cost</th></tr>
<tr><td>Inspection</td><td>----</td><td>----</td><td>----</td><td>----</td><td>----</td></tr>
<tr><td>Cleaning</td><td>----</td><td>----</td><td>----</td><td>----</td><td>----</td></tr>
<tr><td>Proactivity</td><td>----</td><td>----</td><td>----</td><td>----</td><td>----</td></tr>
<tr><td>Correction</td><td>----</td><td>----</td><td>----</td><td>----</td><td>----</td></tr>
<tr><td>Substitution</td><td>----</td><td>----</td><td>----</td><td>----</td><td>----</td></tr>
<tr><td>Terms of use</td><td>----</td><td>----</td><td>----</td><td>----</td><td>----</td></tr>
</table>

However, these maintenance procedures must be included in a maintenance manual, including the definition and description of the activities that will be developed (NP EN 4483, 2009). Therefore, this study considers an integrated maintenance approach and proposes the inclusion of six procedures, based on standard NP EN 4483 and our professional experience, to compose the maintenance sheets. This structuring of maintenance information proposed is limited to residential and office buildings. Other building types are more complex due to the number of ESM involved in the construction, thus it is not included in this study. Figure 2 shows how the activities of the maintenance sheet can be related according to maintenance types (Rodrigues, 2001).

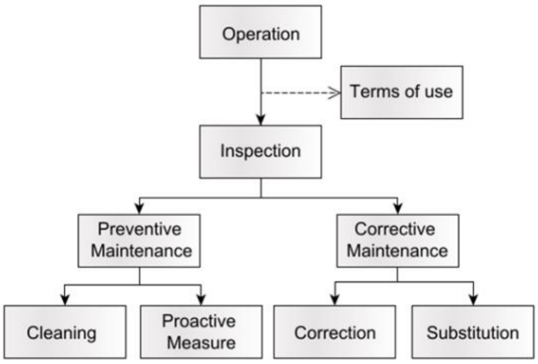

FIG. 2: Maintenance types and activities

3.2 BIM information about element source of maintenance (ESM)

In maintenance, the constructive elements of a building can be divided into sets according to their functionality. The element source of maintenance is a part of a building corresponding to the association of components or elements with unique degradation mechanisms (Rodrigues, 2001). In Autodesk Revit software, this division is made by the following hierarchy: families are defined as a set of elements that have parameters in common, types that are the variations within the families, and an instance that is the element inserted in the model (*Autodesk Knowledge Network*, 2021). This organization allows the software to support multiple objects in the model that have the same function and different characteristics, e.g., hot and cold water pipes. The similarity between the division of ESMs in a building and the hierarchy in Revit can be easily noticed, both make this division based on element functionality levels. Moreover, the Revit approach facilitates the visualization of ESM due to the visual "isolation" of the family or element selected. Figure 2 shows how the information in the proposed table is arranged within the BIM model. Some of this information can be identified within the software used (right side of Figure 2) and others can be identified by plugins or other software intended for reading and analysing IFC files (left side of Figure 2). Figure 3 shows the native BIM information and external information according to Table 1.

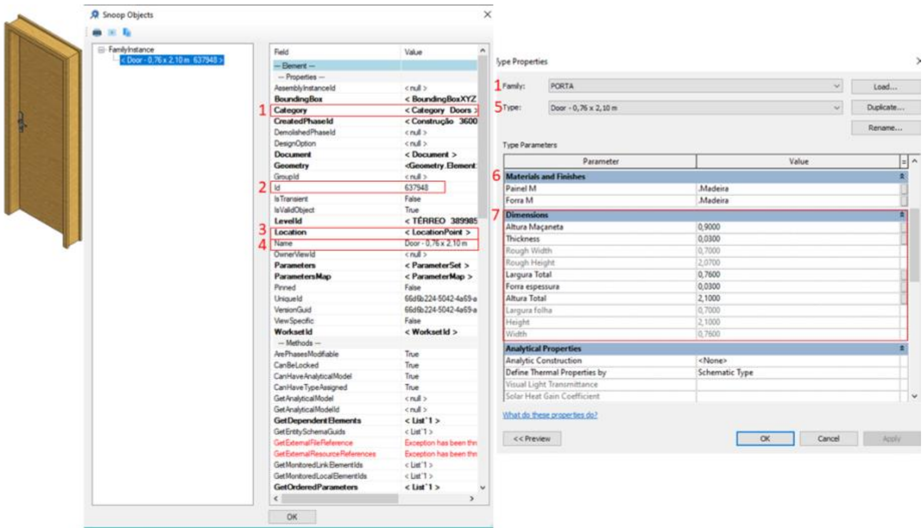

FIG. 2: BIM information FIG. 2: BIM information

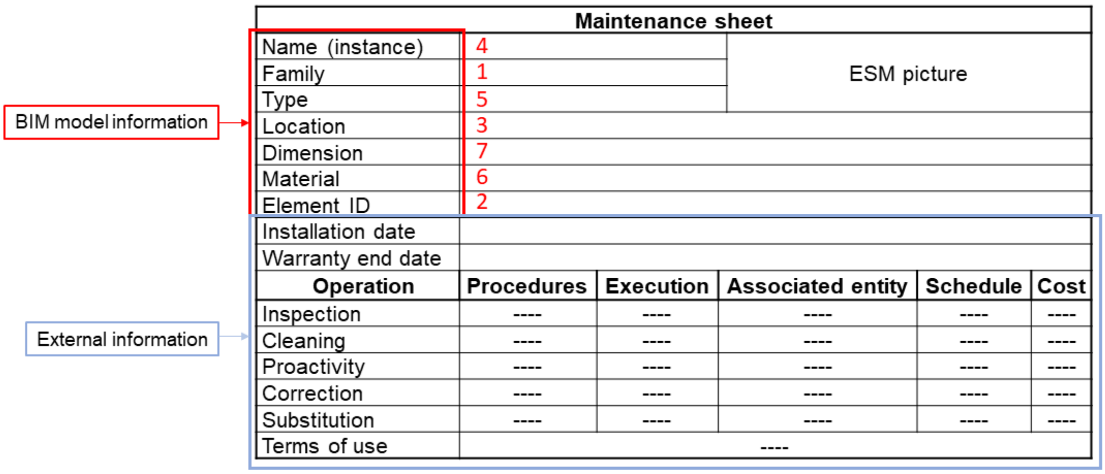

FIG. 3: External and BIM model information

Processes involving data handling are more efficient when done outside of the Revit software due to the program's architecture. Therefore, information regarding maintenance activities will be stored in an external database to the BIM model, in Excel spreadsheets. The information can be accessed through a link, Figure 4, and each ESM has its own link and, therefore, its own maintenance worksheet. For this, it will be necessary to create a new parameter, namely Maintenance Sheet, in each ESM. The interoperability between the external database and the BIM model will be done through the development of codes in visual programming.

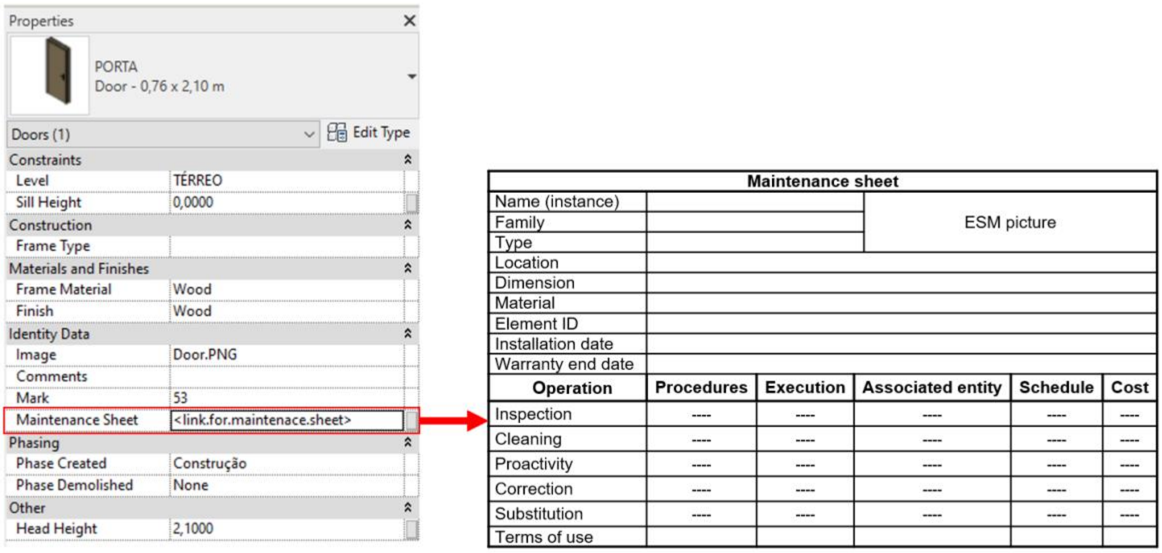

FIG. 4: Link to access the maintenance sheet

3.3 Maintenance sheet access

The model developed in BIM will not be the database to be used by the maintenance manager. BIM software has a high capacity to organize and store information throughout the building's life phases without significant loss of information. However, the size and complexity of the building directly influence the amount of data stored within the BIM software, i.e., the greater the number of ESMs, the more information will be part of the model, resulting in data overload in the software. Therefore, maintenance managers or end-users will be able to access the maintenance sheet in an external database, even if it is linked to the model developed in BIM. The link between the BIM model and the sheets allows real-time access to maintenance information in the model itself by selecting the desired ESM. Figure 5 shows access to the maintenance sheet and the information flow.

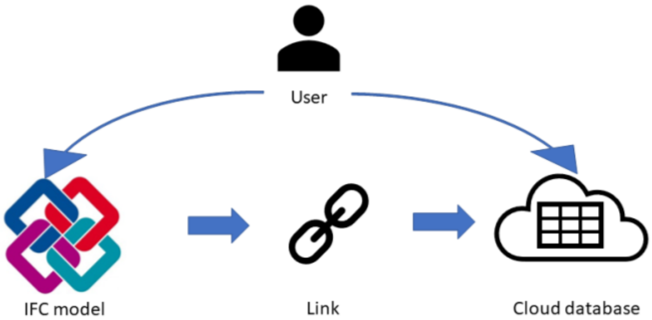

FIG. 5: Maintenance sheet access and information flow

4. CONCLUSION AND FUTURE RESEARCH

Maintenance activities involve a large amount of information that must be structured to facilitate building maintenance management. The building model developed in BIM can facilitate access to information stored during the construction process, from design to disposal. Despite the existence of the COBie format for extracting maintenance data from the BIM model, there is still some difficulty in using it and defining the required data. Therefore, this research outlines an information flow to integrate maintenance information into the BIM model. That aims to simplify and facilitate the process of extracting and filling out those sheets. As mentioned above, the maintenance information is based on the six main maintenance acts, and wil be integrated in the BIM model throght a link created.

Future work might be needed to develop in four stages, namely: (i) preparation of the BIM model with an adequate level of development for the O&M phases; (ii) identification and definition of the information required according to the proposed maintenance form, some of which are native to the BIM model and others can be stored in an external database; (iii) development of links, which can be through an API, to access information from the maintenance sheet of each ESM within the BIM model; and (iv) automatic extraction of the maintenance form from the BIM model.

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REFERENCES

Autodesk Knowledge Network. (n.d.). Retrieved December 12, 2021, from https://knowledge.autodesk.com/

Becerik-Gerber, B., Jazizadeh, F., Li, N., & Calis, G. (2012). Application Areas and Data Requirements for BIM-Enabled Facilities Management. *Journal of Construction Engineering and Management*, *138*(3), 431–442. https://doi.org/10.1061/(asce)co.1943-7862.0000433

Building Smart. (n.d.). Retrieved December 12, 2021, from https://technical.buildingsmart.org/standards/ifc

Cavka, H. B., Staub-French, S., & Poirier, E. A. (2017). Developing owner information requirements for BIM-enabled project delivery and asset management. *Automation in Construction*, *83*(September 2016), 169–183. https://doi.org/10.1016/j.autcon.2017.08.006

Chen, W., Chen, K., & Cheng, J. C. P. (2018). Towards an ontology-based approach for information interoperability between BIM and facility management. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 10864 LNCS* (Issue January). Springer International Publishing. https://doi.org/10.1007/978-3-319-91638-5_25

Chen, W., Chen, K., Cheng, J. C. P., Wang, Q., & Gan, V. J. L. (2018). BIM-based framework for automatic scheduling of facility maintenance work orders. *Automation in Construction*, *91*(March), 15–30. https://doi.org/10.1016/j.autcon.2018.03.007

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2018). *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors* (3rd ed.). Hoboken: Wiley. IBSN: 978-1-119-28753-7.

Gao, X., & Pishdad-Bozorgi, P. (2019). BIM-enabled facilities operation and maintenance: A review. *Advanced Engineering Informatics*, *39*(November 2018), 227–247. https://doi.org/10.1016/j.aei.2019.01.005

Heaton, J., Parlikad, A. K., & Schooling, J. (2019). Design and development of BIM models to support operations and maintenance. *Computers in Industry*, *111*, 172–186. https://doi.org/10.1016/j.compind.2019.08.001

Hu, Z. Z., Tian, P. L., Li, S. W., & Zhang, J. P. (2018). BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase. *Advances in Engineering Software*, *115*, 1–16. https://doi.org/10.1016/j.advengsoft.2017.08.007

IFMA. (n.d.). *International Facility Management Association*. Retrieved December 8, 2021, from https://www.ifma.org/about/what-is-facility-management

Kim, K., Kim, H., Kim, W., Kim, C., Kim, J., & Yu, J. (2018). Integration of ifc objects and facility management work information using Semantic Web. *Automation in Construction*, *87*(January), 173–187. https://doi.org/10.1016/j.autcon.2017.12.019

Lee, Y. C., Eastman, C. M., & Solihin, W. (2021). Rules and validation processes for interoperable BIM data exchange. *Journal of Computational Design and Engineering*, *8*(1), 97–114. https://doi.org/10.1093/jcde/qwaa064

Liu, R., & Issa, R. R. A. (2012). Automatically updating maintenance information from a BIM Database. *Congress on Computing in Civil Engineering, Proceedings*, *June*, 373–380. https://doi.org/10.1061/9780784412343.0047

Lu, Q., Chen, L., Lee, S., & Zhao, X. (2018). Activity theory-based analysis of BIM implementation in building O&M and first response. *Automation in Construction*, *85*(March 2017), 317–332. https://doi.org/10.1016/j.autcon.2017.10.017

Matarneh, S. T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M., & Matarneh, R. (2019). Building information modeling for facilities management: A literature review and future research directions. *Journal of Building Engineering*, *24*(October 2018), 100755. https://doi.org/10.1016/j.jobe.2019.100755

Naghshbandi, S. N. (2016). BIM for Facility Management: Challenges and Research Gaps. *Civil Engineering Journal*, *2*(12), 679–684. https://doi.org/10.28991/cej-2016-00000067

Ozturk, G. B. (2020). Interoperability in building information modeling for AECO/FM industry. *Automation in Construction*, *113*(February), 103122. https://doi.org/10.1016/j.autcon.2020.103122

Pärn, E. A., Edwards, D. J., & Sing, M. C. P. (2017). The building information modelling trajectory in facilities management: A review. *Automation in Construction*, *75*, 45–55. https://doi.org/10.1016/j.autcon.2016.12.003

Pishdad-Bozorgi, P., Gao, X., Eastman, C., & Self, A. P. (2018). Planning and developing facility management-enabled building information model (FM-enabled BIM). *Automation in Construction*, *87*(December 2017), 22–38. https://doi.org/10.1016/j.autcon.2017.12.004

Portugal. (2009). *Instituto Português de Qualidade - Guia para a implementação do sistema de gestão da manutenção: NP EN 4483 : 2009*.

Portugal. (2016). *Instituto Português da Qualidade - Facility Management Parte 1: Termos e definições. NP EN 15221-1*. 1–19.

Portugal. (2021). *Instituto Português de Qualidade - Terminologia da Manutenção : NP EN 13306 : 2021*.

Rocha, P. F. (2014). *Building Maintenance in the design process. Decision Support System.* PhD Thesis. Porto: Faculty of Engineering of University of Porto.

Rodrigues, R. M. G. C. (2001). *Gestão de edifícios : Modelo de Simulação Técnico-económica.* PhD Thesis. Porto:

Faculty of Engineering of University of Porto.

Rogage, K., & Greenwood, D. (2020). Data transfer between digital models of built assets and their operation & maintenance systems. *Journal of Information Technology in Construction*, *25*(February), 469–481. https://doi.org/10.36680/J.ITCON.2020.027

Suyama, Y., & Miyazaki, T. (2015). *An Ontology-based Analysis of the Industry Foundation Class Schema for Building Information Model Exchanges Manu*. *Mvd*, 292–293.

Venugopal, M., Eastman, C. M., & Teizer, J. (2015). An ontology-based analysis of the industry foundation class schema for building information model exchanges. *Advanced Engineering Informatics*, *29*(4), 940–957. https://doi.org/10.1016/j.aei.2015.09.006

Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings - Literature review and future needs. *Automation in Construction*, *38*(March), 109–127. https://doi.org/10.1016/j.autcon.2013.10.023

Wong, J. K. W., Ge, J., & He, S. X. (2018). Digitisation in facilities management: A literature review and future research directions. *Automation in Construction*, *92*(March), 312–326. https://doi.org/10.1016/j.autcon.2018.04.006