Maintenance and Asset Management Integration in Buildings for Collective Use

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Abstract - The Maintenance and Asset Management activities are important tools in the Architecture, Engineering, Construction, and Operation (AECO) sector. These activities promote proper management of the resources involved and increase competitiveness. These issues are in constant evolution along with the widespread adoption of information systems and new technologies. The use stage is a relevant one in the building life cycle because it covers an extended range of time with several economic variables with associated uncertainty. Accurate cost estimation, during this stage, thus contributes to improving the economic performance throughout the building life cycle. This paper presents a framework of Maintenance and Asset Management and highlights its origin and evolution over the last decades, including the scientific developments as well as applicable specifications and standards. It also presents case studies related to buildings for collective use, to demonstrate the benefits of Maintenance and Asset Management activities integration, to improve economic performance.

Keywords: Maintenance; Asset Management; Facility Management; BIM; COBie; Buildings; Collective Use

1. Introduction

The importance of Asset Management has been under development and discussion, for several decades, connected with the life-cycle concept. This is not a recent discipline. Asset Management activities, in an organization, integrate several fields including engineering; financial management; risk management; logistics and support; relationship with customers; environmental management and legislation; and finally, asset life cycle requirements [1].

Although this evolution is only thought of as a change in semantics, it is more certain that its functions and responsibilities evolve alongside changes in nomenclature. Asset Management is a terminology that has been used in organizations and can present different meanings, depending on the country or sector where it is used [2]. Research studies, all over the world, demonstrate the importance of Asset Management in different areas, levels, and applications. It is verified that this concept is used more in the financial area and is less used in the area of engineering and Maintenance [3,4]. Over time, Asset Management activities acquired growing importance in organizations. It corresponds to the natural evolution of the organization's operation and monitoring of its assets in order to achieve resource optimization. It also achieves the evolution of the AECO sector requirements, the increasing need for reliability, and the assurance of quality in the products' supply and services. The need for optimization in Asset Management activities is visible in the progressive increase of the regulatory entities' requirements in different service areas [5].

Until recently, the attention of stakeholders was mainly directed toward the reduction of construction costs, and only a few paid attentions to the reduction of the maintenance and operation costs of buildings. While architects and planners can refer to several tools for the planning and calculation of construction costs, calculation methods for use costs are scarce and not very accurate. It has been reported that between 70% and 85% of the building Maintenance and Operation costs can be influenced during the design stage, which is a significant part of the total building life cycle costs [6].

The publication of the Institute of Asset Management [7] emerged with the purpose of providing a broader view of the Asset Management discipline. It is based on an integration of all groups of activities and emphasizes the importance that Asset Management has in fulfilling organizational objectives.

In Australia, under a scenario of reduced service levels, cost increases, and low-quality planning, a restructuring was carried out in the public sector, in order to establish strategies for planning, prioritizing, and assessing the cost/benefit ratio of assets [7]. In this context, the Asset Management Council published a compilation of definitions and models related to this discipline. It systematizes an Asset Management conceptual model, where risk management allows "all organizations to understand and develop an appropriate balance between the cost of doing something, the risk resulting from the expense of those resources, and the expected result of the performance of the asset and the organization" [8]. In order to reduce the costs associated with assets, without compromising the performance of other requirements, a critical and holistic view of the entire life cycle is required. However, this task faces new challenges when applied, not only to the built asset, but to the entire project that encompasses it, and even more when it comes to the management of a program or portfolio simultaneously by an organization [9].

2. Conceptual Framework

2.1. Buildings for collective use

Buildings for public use are those managed by entities of the public administration, direct and indirect, or by companies providing public services and intended for the general public, while buildings for collective use are those intended for commercial, hotel, cultural, sports, financial, tourism, recreational, social, religious, educational, industrial and health activities, including buildings of the same nature activities.

2.2. Maintenance

The concept of Maintenance has several definitions, depending on the author. Building maintenance is currently difficult to define and precise, covering various activities such as building inspection, service execution, and small repairs and replacements, providing functional elements to maintain their quality [10].

The term Maintenance is defined in ISO 15686-1, as a combination of technical and administrative actions that allow the building and its constituent elements to perform, during their useful life, the functions for which they were designed [11]. In Brazil, the NBR 5674 standard defines Maintenance as a set of activities to be carried out to conserve or recover the functional capacity of the building and its constituent parts, in order to meet the needs and safety of its users [12]. According to British Standard 3811, Maintenance is the combination of all actions taken to maintain the building or to restore it to a reasonable state, clarifying that the maintenance of a building includes tasks such as inspection, cleaning, repair, and replacement of various systems or elements [13]. In Portugal, there is no norm or legislation that defines the concept of building maintenance. The standard NP EN 13306: 2007 defines the term of Maintenance, as the combination of all technical, administrative, and management actions, during the life cycle of an asset, aimed to keep it in a state in which it can perform the function required [14]. All Maintenance concepts defined above, meet common objectives, such as [15]: i) give better performance to the building and its elements, trying to restore its initial quality; ii) improve the useful life of buildings and their elements; iii) avoid high costs with major repairs, and iv) ensure the performance requirements established in the project.

2.3. Facility Management

Facility Management (FM) emerged in the late 1960s, in the United States of America, in order to describe the growing practice followed by outsourcing banks in the responsibility of processing credit card transactions for specialized suppliers [16]. This activity has been growing a lot since there is a greater concern with the phase of exploration and operation of the facilities. Currently, in a building with a useful life of 50 years, it is estimated that its operating costs can exceed 80% of the total costs and only 20% of the costs are applied to its design and construction. In Portugal, the first steps at the FM level were taken in 2006, and the Portuguese Facility Management Association (APFM) was formed with the objective of disseminating and developing the FM "as the integrated management of workplaces and environments", with the purpose of optimizing spaces, processes, and technologies [17]. Although there are several definitions for FM, all of them converge in the main idea [18]: FM is a concept that aggregates resources such as people, properties, and experience in process management, in order to provide vital support services for the organization [19].

2.4. Asset Management

An asset is something capable of generating potential or effective, tangible or intangible, financial or nonfinancial value, considering its useful life from conception/acquisition to its end-of-life phase. According to ISO 55000, Asset Management (AM) comprises a coordinated set of activities from an organization to obtain value through its assets, being formulated comprehensively to adapt to specific asset needs, changing contexts, and differences of the organizations. In this sense, AM is the set of coordinated activities that an organization uses to see its assets generate value. The benefits of AM may include: i) improved financial performance; ii) informed decisions on asset investment; iii) risk management; iv) improvement of services and results; v) demonstration of social responsibility; vi) demonstration of conformity; vii) improving reputation; viii) improving the organization's sustainability; and ix) improving efficiency and effectiveness [19, 20].

2.5. BIM and COBie

Building Information Modelling (BIM) allows you to manage installations by visualizing them, based on accurate and precise information about systems and equipment, their locations, and technical specifications, among others. From the outset, this information in a three-dimensional digital model appears to be a huge advantage over traditional (2D) drawings. Since the BIM model contains all the necessary information for an installation, it is possible to carry out its strict management, including maintenance and operation. In fact, this will be one of the great advantages of BIM since, by controlling all the elements of an installation, it facilitates any type of intervention. BIM, in Facility Management, goes through the specification of the necessary information during the entire design and construction phase, so that this information can later be used in the operation phase. By doing automation through BIM, the possibility of generating equipment inventories, such as a Computerized Maintenance Management System (CMMS), is also created. The advantages are not only visible in terms of cost reduction but also in quality gains in the response to customers [21]. The BIM Project Execution Planning Guide [22, 23] provides guidelines for the implementation of FM in BIM methodology. The possibility of using BIM for FM is the use of features presented by the BIM model to the Facility Manager. Through this model, you can collect geometric or non-geometric information and manage the building in an efficient and organized way [24].

Construction Operations Building information exchange (COBie) [25] is an international standard that relates to the exchange of building information and is mostly used in product data handover, from the construction team to the operation team. It is, in addition to other proprietary formats of commercial applications, an information-sharing format for the cycle of a given installation, which allows for the organization of all information, from the initial process to its exploitation. COBie was created in the USA by building SMART, which corresponds to a format that intends to "manage the exchange of information about assets" despite "not adding new requirements to contracts, it only changes the way documents are delivered in a standardized way" and aims to describe spaces and equipment. The exchange of information occurs in the first instance at the end of the construction, however, the maximum efficiency exponent of COBie will be obtained during the life cycle of an installation, when there is a need to share information regarding spaces or equipment [26].

2.6. Standards and Regulations

Long-term economic sustainability represents an important factor in the AECO sector. To assess the building economic sustainability, the Life-Cycle Cost (LCC) approach can be used. LCC is defined as the cost of a building

throughout the consecutive and interlinked stages of its life while fulfilling the technical and functional requirements [27].
In the sustainability context, several standards related to the LCC concept have been published, such as EN 15643-4 [27] and EN 16627 [28]. On the other hand, EN 16646 [29] related to maintenance within physical asset management, highlights the importance of the use stage throughout the building life cycle. Following the need to unify FM in the European space, CEN adopted the following standards EN 15221: i) Part 1: Terms and Definitions; ii) Part 2: Guidelines for the elaboration of FM agreements; iii) Part 3: Guide57 lines for quality in FM; iv) Part 4: Taxonomy, classification and FM structures; v) Part 5: Guidelines for FM processes; vi) Part 6: Measurement of FM areas and spaces; and vii) Part 7: Benchmarking [19]. The Institute of Asset Management (IAM), in partnership with the British Standard Institute (BSI), developed PAS 55 specification [30], which defines Asset Management as the systematic and coordinated activities and practices, that an organization uses to manage its assets and systems in an optimal and sustainable way.
The international standards series, ISO 55000 [20], defines the requirements for an appropriate Asset Management system throughout the asset's life cycle and considers that the value realization requires a balance between the cost, risk, and benefits of the asset over different time periods.
This series of norms establish principles, requirements, and guidelines for the implementation of Asset Management. International cooperation confirmed that the common practices identified can be applied to an ample range of assets in diversified organizations and cultures. Adherence to these standard procedures provides the expected benefits: predictability and consistency.
EN 16646 introduces Asset Management as a framework for Maintenance activities. It also introduces the relationship between organizational strategic planning and maintenance management systems and describes the interrelations between the maintenance process and all the other physical asset management processes. It addresses the role and importance of Maintenance within the Asset Management system during the whole life cycle of an item.
It is important to structure the data related to the economic information of buildings during the use stage. According to EN 15643-4, the building life cycle economic information is divided into three groups: i) before the use stage; ii) use stage, and iii) after the use stage. Table 1 shows the organization and the types of costs to be included, for structuring economic data during the use stage of buildings.

Table 1: Structure for economic data

Use Stage	Typical scope of costs
Operation	Building-related facility management costs; Cyclical regulatory costs; Building-related insurance costs; Subsidies and incentives; Professional fees.
Maintenance	Costs related to all components and products used in maintenance activities; Cleaning; Land and garden maintenance costs, consistent with the environmental assessment; Costs related to processes to ensure functional and technical building performance; Redecoration; Disposal inspections at end of the lease period; End of the lease; Taxes on goods and services; Subsidies and incentives; Professional fees.
Repair	Repair of minor components / small areas; Repair of major systems and components; Costs related to repair waste management; Taxes on goods and services; Subsidies and incentives; Professional fees.
Replacement	Replacement of minor components / small areas; Replacement of major systems and components; Costs related to replacement waste management; Revenue from sale goods, elements or components; Taxes on goods and services; Subsidies and incentives; Professional fees.

Refurbishment	Costs related to new building components; Costs related to planned refurbishment; Costs related to building adaptations; Costs related to refurbishment; waste management; Revenue from sale goods, elements, or components; Taxes on goods and services; Subsidies and incentives; Professional fees.
Operational energy use	Energy costs related to fuel and electricity for heating, domestic hot water, cooling, ventilation, lighting, power, and other systems; Taxes; Subsidies and incentives.
Operational water use	Costs related to water for consumption, sewerage, hot water, irrigation, roofs or green facades, heating, cooling, and ventilation, specific systems; Taxes; Subsidies, and incentives.

3. Case Studies

3.1. Public school buildings

This case study covers a portfolio of 166 public school buildings (buildings for collective use constructed in Portugal). Costs related to operation (B1), maintenance (B2), repair (B3), replacement (B4), rehabilitation (B5), energy consumption (B6), and water consumption (B7) over their use stage were collected. The time period begins in the 1940s, with the original construction, and ends after the rehabilitation interventions that were held between 2007 and 2011. The building portfolio has a total constructed area of 2,404,500 m^2 and an estimated use stage net costs of 5,12 billion euros [31]. This portfolio is heterogeneous, both in terms of the morphological buildings type and their architectural and constructive quality. Although mainly composed of standard solutions resulting from the application of standard project designs, it comprises buildings with a recognized heritage value, as well as others in which innovative solutions were tested (at the time of construction) in spatial and constructive terms [32]. Historical data collection involved dealing with economic data dispersed in different public entities with different information organization formats. Some of the main contributors to the information included the following public entities: i) Portuguese Ministry of Education (data from 1942 to 1989), and Portuguese General Services of School Facilities and secretariat of school buildings (data from 1989 to 2008), with information in paper format; and ii) information management systems (data from 2007 to 2009), with information in informatic files format, consulted in the Portuguese public entity that is currently responsible for the building management activities. The costs were collected as real costs (cost expressed as a value at the base data, including estimated changes in price due to forecast changes in efficiency and technology but excluding general inflation or deflation). Nominal costs (an expected price that will be paid when a cost is due to be paid, including estimated changes in price) were obtained using a multiplication factor that considers the annual inflation/deflation rate during the period of analysis [31].

Figures 1 and 2 represent examples of economic performance indicators (time series) obtained with the historical data obtained and structured in a standardized way (see Table 1).

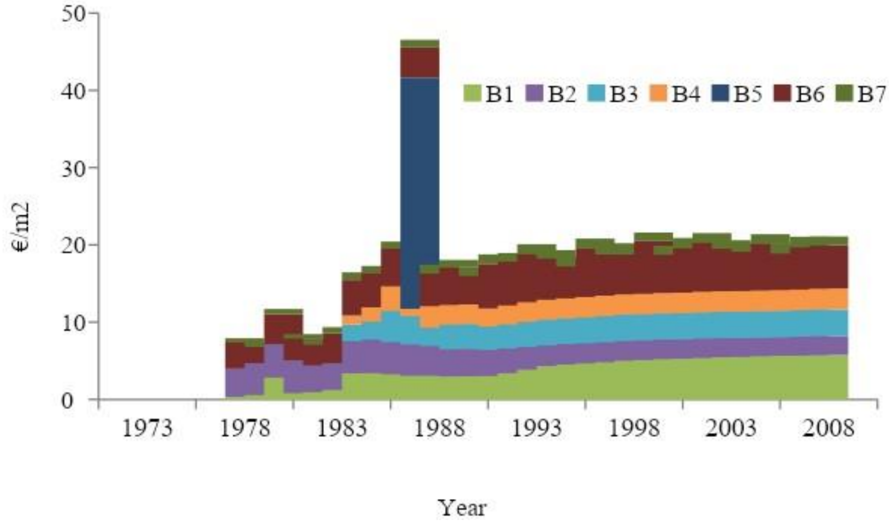


Figure 1: Example of cost/m^2 of one building (time series)

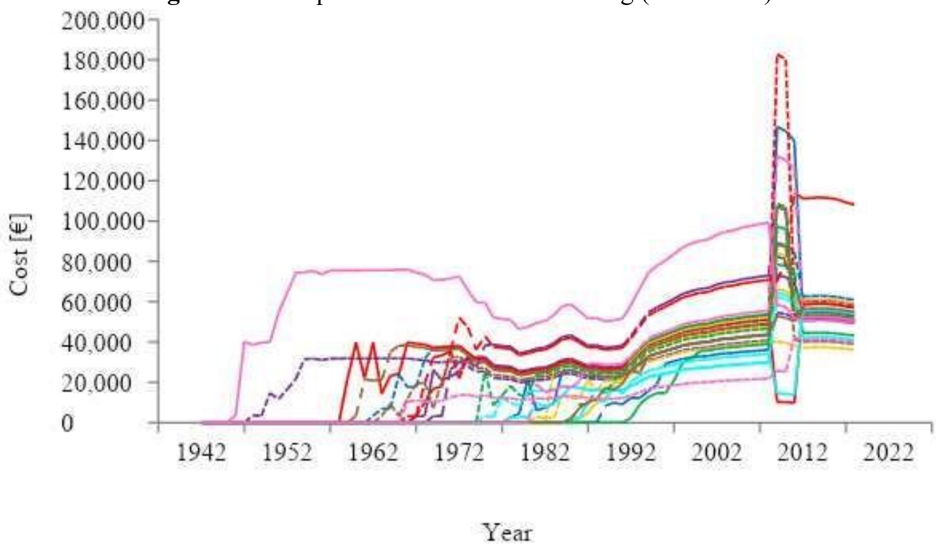


Figure 2: Example of maintenance costs (B2) for some buildings (time series)

3.2. Commercial buildings

This case study corresponds to a portion of the Colombo Shopping Centre car park and arises from a partnership between the National Civil Engineering Laboratory (LNEC) and SONAE-Sierra Portugal. To support FM activities, the BIM methodology and the COBie standard were used.

To model the building for FM purposes (Figure 3 to Figure 5), over 6,000 PDF files of the different design specialties, made available by SONAE-Sierra Portugal, were used. However, much of the information was irrelevant to the BIM modeling. After a careful analysis of all available files, the following specialties were modeled: i) Architecture; ii) Structure; iii) Electric network; and iv) Fire Network. It should be noted that the modeling of architectural and structural specialties was much easier than the modeling of the electrical network and the fire network because there were plants in AutoCAD of the first two specialties and these presented a very acceptable degree of updating.

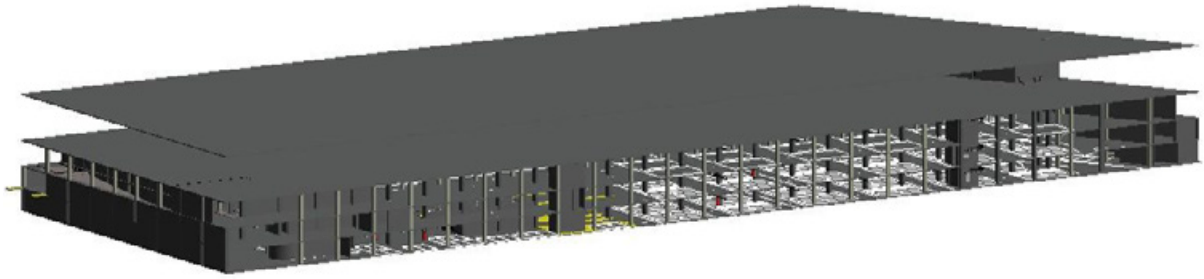


Figure 3: BIM final model of the car park of commercial building for Maintenance and FM purpose

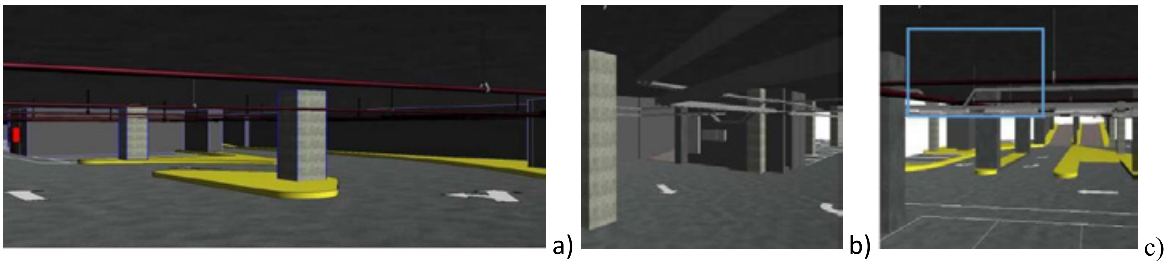


Figure 4: Interaction between design specialties in different zones

Figure 5: Model of different elements for Maintenance and FM purposes: a) reel; b) pipes; c) valves

One way to export information from a BIM model project to COBie data sheets is through the plug-in that is made available by Autodesk, called COBie Toolkit. For the present case study, this was the one used, presenting itself as the most advantageous solution, because there was a lot of information about how the plug-in worked and the basic steps to familiarize yourself with COBie. The great advantage of using COBie associated with a BIM model is the fact that it generates data sheets, with all the information available in the organized model, and serves these data sheets (Figure 6) for the manager to carry out the maintenance and operation processes, in the most efficient way possible. From these sheets, it is possible to trace plans that guarantee the correct management of the facilities.

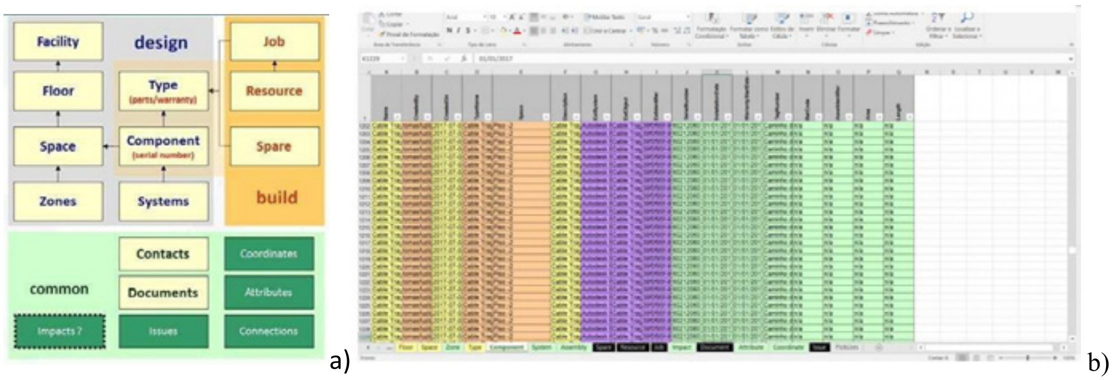


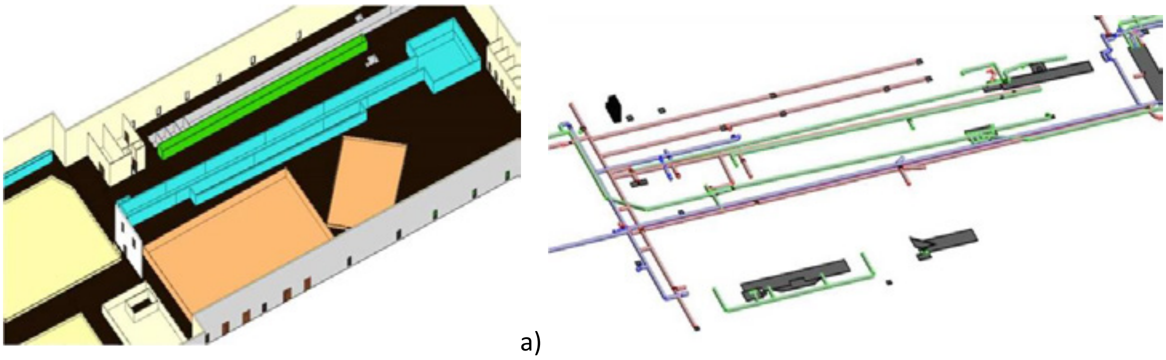
Figure 6: COBie sheets, used for integration with the BIM model of the commercial building, generated for FM [33]: a) general structure; b) example of the sheet for the electric network.

Since all the information is in the BIM model, it is possible to create alerts when there is a need to repair or replace a certain element. For these alerts to be created, it is up to the facility manager to provide information on when a particular element should undergo changes or not. Thus, since previous work has been done on the various elements, the right time to carry out interventions will be known. With the adoption of these methodologies, it is possible to have planned maintenance, which leads to fewer failures. After the BIM modelling of the facilities under study and after it was proposed to carry out its management using FM software, a survey of the necessary steps was taken to follow, with a view for structuring a method for altering COBie: i) analysis of the documents provided, verifying which are relevant to the BIM model; ii) evaluation of the design final drawings, to verify that they are identical to the existing reality; iii) if they are out of date, outline a method for updating them, in order to facilitate BIM modelling (in situ survey, laser scanning, etc.); iv) survey of equipment and elements present in the facilities, through documents or visits in situ; v) after collecting all the information about the equipment and elements, search the manufacturers' websites and BIM websites for availability in a compatible format; vi) analysis of the information provided by the manufacturers and websites of BIM objects and identify the need for more information for the FM objectives; vii) in case of lack of information on the objects, place it manually right at an initial stage, so that all elements have the necessary information for a later efficient management of the facilities; viii) after placing the information on the BIM objects, make the modeling of the various specialties, based on the design final drawings provided or on the final drawings updated by the manager, or through the survey by laser scanning, if available; ix) create a BIM file for each specialty, to do not make the model too heavy; x) after the modeling is finished, the errors of the different specialties must be corrected; xi) installation of the COBie extension in Revit; xii) filling in the COBie parameters automatically, by exporting the data present in the families of elements; xiii) verification of parameters filled in automatically; xiv) if some parameters are missing, manually fill them in the various elements; xv) through the extension, choose which parameters are intended to be exported to COBie sheets; xvi) export the parameters to the data sheets; xvii) check on the COBie sheets if all the information necessary for the correct management of the facilities is placed, and xviii) control the COBie sheets so that everything is in accordance with what is intended, checking the need for interventions through the information placed on the sheets and, whenever necessary, updating the various elements present in the model. It is only necessary to update what is missing, there is no need to create new sheets, as COBie allows updates [33].

When using BIM and COBie together, it is essential that all the information contained in the model is available in a succinct and organized manner so that the model is constantly updated in order to provide correct management of a facility. With the growth of BIM, new opportunities are available in the architecture, engineering, construction, and operation sectors, because the concept facilitates communication between all stakeholders. The association of Maintenance and FM with this concept will have enormous advantages, as there will be only one working environment, allowing professionals to work more effectively and keep themselves updated throughout the various process phases. Choosing the COBie extension to solve the problem of how and when information for installation management should be collected further, improves the efficiency of FM.

3.3. Laboratory buildings

In this case study, and for Asset Management purposes, the Architecture and Facilities Networks (MEP) design specialties of an Operative Laboratory Unit for Hydraulic Tests (OLUHT) in scientific research use, were modeled. The structure specialty was excluded because, in this case, its components do not need frequent maintenance, being just objects of regular inspections. For the application of the BIM methodology in OLUHT Asset Management, a commercial BIM software was chosen and the plug-in for connection with Asset Management used was COBie. First, the BIM model of Architecture and MEP was created (Figure 7), then all the necessary information was added, such as equipment, types, location, and characteristics, among others. Afterward, all the information was exported to the data sheets (COBie). This way, Asset Management of the OLUHT installation takes place in an easier way.



a) b)

Figure 7: Model of different specialties for Asset Management purposes: a) Architecture; b) MEP, adapted from [35]

For the development of asset management in the facilities under study, a set of duly identified processes was prepared, in accordance with ISO 55000 standards and the PDCA management cycle (Plan, Do, Check, Act / Action).

The first stage (Plan) corresponds to the definition of OLUHT asset management strategy and requirements. In this stage, strategic objectives, that correspond to what is intended to be achieved with UOLEH's asset management activities, were defined. The implementation of strategic asset management objectives was triggered by the following situations: i) aging of facilities; ii) increased service requirements; iii) increased economic and environmental requirements, and iv) analysis of the cost/efficiency ratio.

In this second stage (Do), a set of information was grouped for the implementation of the Asset Management Plan centered on the Comprehensive and Integrated Model of Industrial Asset Management (MAIGAI model) [34] and on the maintenance activities. This MAIGAI model aims to apply the ISO 55001 standard and proposes a methodology applicable to hydraulic testing facilities. The main elements considered for the asset management system at the OLUHT facilities are: i) business management (a clear view of the laboratory and its activities, good leadership, good communication skills, etc.); ii) engineering (concept of environmental impact, concept of risk/reliability); iii) operation and maintenance (continuous improvement, teamwork, reliability, etc.); and iv) asset manager (person responsible for verifying that asset management plans and regulatory legislation are being met).

In the third stage (Check), the efficiency of the asset management system and the performance of this activity at UOLEH is monitored. This way they can identify themselves, through a detailed process of a SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) and a definition of the Maturity Degree of asset management, the need for improvements, and/or the necessity of errors correction and subsequently implement them (in the Action Plan). For the assessment of the degree of maturity, 29 questions were asked for each of the 27 requirements of ISO 55001, prepared by IAM in 2014. The degree of maturity obtained was level “2” (Development).

In the final stage (Act or Action), efforts should be made so that, when occurs the event of nonconformity or an incident in the assets, asset management, or asset management system, certain actions are carried out, such as i) taking measures to control and correct; ii) dealing with the consequences; iii) assess the need for action to eliminate the causes of incidents, so that it does not recur or does not occur; iv) determine the causes of the non-compliance or incident, and v) determine the existence of similar nonconformities or the susceptibility of occurring.

4. Conclusion

Buildings for collective use represent an investment effort that mobilizes significant financial resources from public or private budgets, which are restricted. However, while it is increasingly important to justify investments and subsequently associated expenditure over several decades or even centuries, information relating to the economic performance over the use stage of those buildings is practically unknown.

The Maintenance and Asset Management activities do not directly address overarching issues such as policy and strategy for organizations but can be used to support decision-making processes in building projects or in managing building asset portfolios. It is also a driver for engaging stakeholders with noneconomic aspects of sustainability and encouraging environmentally sound building design, namely by highlighting the economic relevance of energy efficiency or water savings throughout the lifecycle of a building. It contributes to more accurate cost estimates over the life cycle of a building while optimizing maintenance and operation costs.

The demands for the AECO sector include the need to gather standardized information on the use stage and the creation of economic databases. This paper addresses these concerns and describes case studies to demonstrate the generation of data on buildings for collective use constructed in Portugal.

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References

[1] IBM. *The evolution of Asset Management* - Finding the Right Best Practice is Not All Theory. 2007, United States of America.

[2] Davies, R., Register, L. PAS 55 - *Why do we need a standard and how does it help*?. Water Event, 6th Institution of Engineering and Technology, 2008, 22, p. 1-33.

[3] El-Akruti, K., Dwight, R. *Research methodologies for Engineering Asset Management*. Proceedings of ACSPRI Social Science Methodology Conference, 2010, Sydney, Australia.

[4] Henderson, K., Pahlenkemper, G., Kraska, O. Integrated Asset Management – An Investment in Sustainability, Procedia Engineering, 2014, 83, p. 448-454.

[5] Abdelhamid, M.; Beshara, I.; Ghoneim, M. Strategic asset management: Assessment tool for educational building in Egypt. HBRC Journal, 2015, 11:1, p. 98-106.

[6] Biondini, F. & Frangopol, D.M.: Proceedings of the first international symposium on life-cycle civil engineering. The first international symposium on life-cycle civil engineering. 2008. Varrena, Lake Como, Italy: Taylor & Francis Group, London, UK.

[7] IAM. (2012). Asset Management - an anatomy. Institute of Asset Management, Bristol, UK.

[8] AMBOK. (2014). Asset Management Body of Knowledge. Framework for Asset Management (2nd ed.). Melbourne, AU: Asset Management Council, UK.

[9] Salvado, F.; Almeida, N.; Azevedo, A. (2018). Towards improved LCC-informed decisions in building management. *Journal of Built Environment Project and Asset Management*, Vol. 8:2, pp.114-133. https://doi.org/10.1080/09613218.2019.1612730.

[10] Raposo, S. (2011). A gestão da manutenção em edifícios públicos, modelo e definição de estratégias para uma intervenção sustentável. Tese de Doutoramento, Instituto Superior Técnico.

[11] International Organization for Standardization. (2000). ISO 15686-1 -Buildings and constructed assets -Service life planning -Part 1: General principles. Geneva, Switzerland, Suiça: Internacional Organization for Standardization.

[12] Associação Brasileira de Normas Técnicas. (1999). NBR 5674 -Manutenção de edificações Procedimento. Rio de Janeiro

[13] British Standard Institution. (1984). British Standard 3811-glossary of maintenance management terms in terotechnology. London.

[14] Salvaterra, L. (2009). Processos de manutenção técnica de edifícios em revestimentos de piso. Faculdade de Engenharia da Universidade do Porto.

[15] Plácido, R (2013), Proposta de Modelo de Avaliação do Estado de Conservação de Equipamentos Escolares, Dissertação de Mestrado, Instituto Superior de Engenharia de Lisboa.

[16] Price, I (2012) The selfish signifier: Meaning, virulence and transmissibility in a management fashion. International Journal of Organizational Analysis, 20(3), 337–348. https://doi.org/10.1108/19348831211243848

[17] Nik-Mat, N., Kamaruzzaman, S., Pitt, M. (2011) Assessing the maintenance aspect of Facili205 ties Management through a Performance Measurement System: A Malaysian case study. Procedia Engineering, 20, 329–338. Kuala Lumpur: International Building Control Conference. Disponível em: https://doi.org/10.1016/j.proeng.2011.11.174

[18] EN15221: 2016. Facility Management: Integration of processes within an organization to maintain and develop the agreed services which support and improve the effectiveness of its primary activities. CEN Comité Européen de Normalisation.

[19] Falcão Silva, M.J., Couto, P. (2019), Facility and asset management on BIM methodology, CIAC2019 - Conference on Automation Innovation in Construction 2019. Instituto Politécnico de Leiria, Leiria, 7 e 8 de novembro,

[20] International Organization for Standardization. (2014) ISO 55000: 2014. Asset management - Overview, principles and terminology. Geneva, Switzerland, Suiça: Internacional Organization for Standardization.

[21] GSA. BIM Guide for Facility Management, General Services Administration 1–5 (2011). Washington: U.S. General Services Administration, GSA Building Information Modeling Guide Series: 08.

[22] CIC (2011a) - BIM Planning Guide for Facility Owners, Version 2.0. Pennsylvania: Manual para Facility Management. The Pennsylvania State University, University Park, PA, USA.

[23] CIC (2011b) - Computer Integrated Construction Research Program. BIM Project Execution Planning Guide, Version 2.1. Pennsylvania: Manual para Facility Management, The Pennsylvania State University, University Park, PA, USA

[24] Rodas, I. (2015). Aplicação da Metodologia BIM a Gestão de Edifícios. Porto: Faculdade de Engenharia da Universidade do Porto, Dissertação de mestrado.

[25] Sousa, F. (2013). A evolução de um modelo BIM de construção para gestão de empreendimentos. Porto: Instituto Superior de Engenharia do Porto, Dissertação de Mestrado.

[26] Silva, J. (2013). Princípios para o Desenvolvimento de Projeto com Recurso a Ferramentas BIM. Porto: Faculdade de Engenharia da Universidade do Porto, Dissertação de Mestrado.

[27] EN 15643-4:2012 Sustainability of construction works. Assessment of buildings - Part 4: Framework for the assessment of economic performance. European Committee for Standardization (CEN).

[28] EN 16627:2015 Sustainability of construction works. Assessment of economic performance of buildings – Calculation method. European Committee for Standardization (CEN).

[29] EN 16646:2014 Maintenance - Maintenance within physical asset management. European Committee for Standardization (CEN).

[30] PAS 55:2008. Specification for the optimized management of physical assets. British Standard Institute (BSI).

[31] Salvado, F.; Almeida, N.; Azevedo, A. (2019). Historical analysis of the economic lifecycle performance of public school buildings. *Building Research and Information*. Vol.47:7, pp. 813-832. https://doi.org./10.1080/09613218.2019.1612730.

[32] PE. (2011). Parque Escolar 2007-2011. Intervenção em 106 escolas. Lisboa: Parque Escolar EPE, Direção-Geral de Projeto - Área de Edificações. [In Portuguese].

[33] Fuzil, T. (2017). Facility Management no Building Information Modelling, Dissertação de Mestrado, Instituto Superior de Engenharia de Lisboa.

[34] Martins, J (2015). O papel da engenharia na gestão de ativos de uma unidade industrial. Instituto Superior de Engenharia de Lisboa. Lisboa, Portugal.

[35] João, S. (2019). Metodologia BIM aplicada à gestão de ativos, Dissertação de Mestrado, Instituto Superior de Engenharia de Lisboa.