Information management and construction systems for Maintenance and Operation Digital Transformation

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Abstract

Collaborative work requires mutual understanding and trust and a deeper level of standardized processes than what has become current practice in the Architecture, Engineering, Construction and Operation (AECO) sector, so that information is useful and made available in timely and consistent. The information requirements are a guarantee that the information passed between the different actors throughout the life cycle is coherent, representing the intended efficient way.
This paper intends to be a step to overcome challenges, identified in AECO sector, related to the future maintenance management including the concepts of information transmission and digital transformation. A link between information management systems, such as BIM (considering the requirements of ISO 19650), and Construction information systems, such as ProNIC, is explored.

Keywords: Maintenance; Asset Management; Facility Management; BIM and COBIe; buildings; collective use

1. Introduction

Nowadays, the Architecture, Engineering, Construction and Operation (AECO) sector has faced several problems, highlighting weak productivity, insufficient innovation, lack of consistent and rigorous processes, disconnected suppliers, and fragmentation (WEF, 2016). These problems are mainly due to the lack of standardized processes and the lack of monitoring of new technologies, namely information technologies (Campos, 2017).
The inevitable process of digital transformation of the AECO sector depends on several contributions. The design digitalization, including the respective work process, is essential so that, downstream, the different agents can contribute to a properly organized and structured digital object. The availability to the construction sector of solutions and components in BIM models, by manufacturers, will allow a faster transition to the desired digital landscape. However, BIM models should be able to incorporate structured and recognizable information in the European standardization environment (Lucas and Aguiar, 2018).
The BIM methodology and information technologies have been promoting the digital transformation in AECO sector, promoting the creation of digital environments that encourage the exchange of information and enhance the processes digitization (Eastman, Chuck et al., 2011). The observed changes require the objective definition of processes and digital models to support and manage this information (Azhar, 2011).

However, very considerable resources are still spent on correcting unstructured information, on incorrect information management, on solving problems arising from the lack of coordination of the various teams involved throughout the life cycle of built assets and solving problems related to reuse and reproduction of information (Nascimento and Santos, 2002). To take advantage of the information created, generated, and stored, it is necessary to adequately define its use. The ISO 19650 standard establishes requirements for information management throughout the entire life cycle of a built asset, using the same high-level BIM principles and requirements.

Portuguese information system - ProNIC (Protocol for the Standardization of Construction Technical Information) may be interconnected. It is a construction information system adapted to the current practices, following the assumptions of the international standards. ProNIC comprehend the entire life cycle projects and includes costs and technical information related to materials and work execution.

2. Conceptual Framework

2.1. Digital transformation

With the introduction of the World Wide Web, the scope, dimension, scale, speed and effects of digitization fundamentally changed, resulting in increased pressure on the societal transformation processes. In the last decade, digitization began to be used more widely as a concept and argument for an overall governmental introduction of IT. Digital transformation is defined as the integration of digital technology into all areas of a business, fundamentally changing how you operate and deliver value to customers. It's also a cultural change that requires organizations to continually challenge the status quo, experiment, and get comfortable with failure. It is the process of using digital technologies to create new (or modify existing) business processes, culture, and customer experiences to meet changing processes and requirements. As information moves from paper to spreadsheets to smart applications for managing processes, the chance to reimagine these processes with digital technology (Heinze, et al., 2018).

The AECO sector has a significant impact on the world economy (CT197, 2021). In the European Union market, this sector also represents a characteristic of the PIB, being responsible for several million jobs in several companies. However, a representativeness of the sector is marked by the lack of productivity that is reflected in an inefficient image of both the process and the service delivered to the final customer (EU Regulation n.305/2011). In global terms, the AECO sector presents a medium level of digitization, although with a strong probability of rising through the implementation because of the 4th Industrial Revolution already explained. Within the AECO sector, the construction sector is not the end of the list of sectors that implement digitization, as a process and methodology of use (coBuilder, 2021). The greatest difficulty to be overcome may be a transversal modernization of the sector which, as it represents the performance of different agents at different stages of the construction life cycle, implies using BIM as an integrated system for storing information (Lucas and Aguiar, 2018).

The AECO sector is due for a digital renovation. Faced with challenges around project efficiencies, ongoing safety concerns and flatlining labour productivity levels, the industry’s sluggish adoption of new technologies has reached an inflection point. Digital transformation requires changing processes and using new resources that harness the power of data to improve communication, efficiency, productivity, and safety. This can position stakeholders for profitable growth in a highly competitive sector, while also addressing workforce challenges. Transforming AECO sector means more than introducing modern

technologies. Once correctly incorporated has the effect of rippling through and improving interrelated processes. This requires assessing the current state of a business, strategizing for the future state, and then mapping a journey to that future (Shapiro et al., 2019).
Digital transformation goes far beyond digitizing analog functions. It enables a fundamental shift in how to operate so that it can compete in a digital world. Figure 1 presents the areas of transformation that are ultimately enabled by end-user adoption (Shapiro et al., 2019): i) Digital Business (to enable growth), ii) Digital Process (to improve efficiency and profitability); and iii) Digital Backbone (to facilitate usability for processes needs).

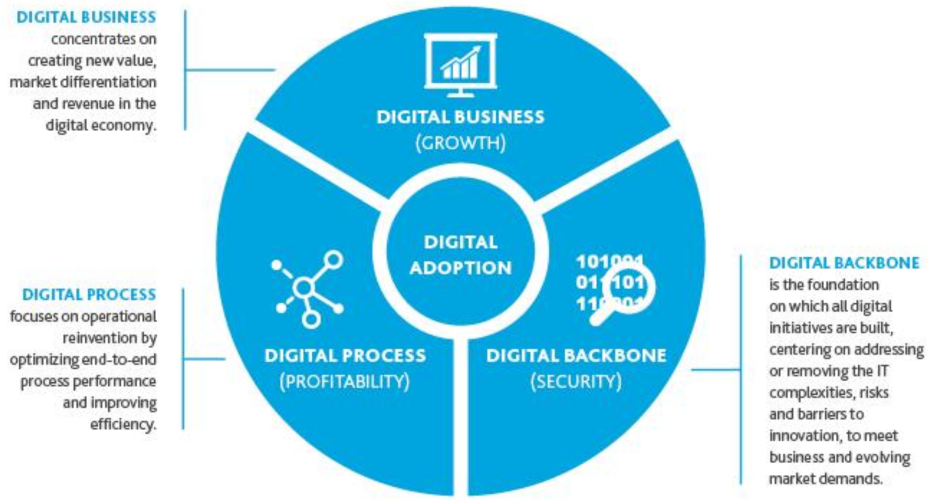


Figure 1: Digital transformation

2.2. Information management systems

From a conceptual point of view, BIM is a methodology of information production, integration and management between all stakeholders involved in the process and is transversal to all phases of the life cycle project (ISO 12006-2). BIM allows for a simpler and, at the same time, more detailed information exchange between all those involved from the engineer to the owner project, enabling everyone involved in the process to visualize the model of different possibilities, allowing modify or add information in real time, depending on each specialization (ISO 22274).
BIM is based on a manipulable digital model that allows you to virtually simulate, through software suited to your needs, the real environment (ISO16739) and makes it possible to work with specific objects, adapting them to the space and environment, through modelling and parametric relationships (C. E. d. N., 2017). Object modelling consists of choosing a pre-defined object from a library provided by the software. Any change in one of the parameters means that throughout the model there is a constant and real-time update of the modified information, ensuring that the model is always updated, regardless of the user's choices (ISO 12006-3 and ISO 29481-1).
The ISO 19650 series was prepared by the Technical Committee ISO / TC 59 “Buildings and civil engineering works” in collaboration with the Technical Committee CEN / TC 442 “Building Information Modelling (BIM). ISO 19650 can benefit from a formal asset management process (e.g. ISO 55000 series). The ISO

19650 can also benefit from a systematic approach to quality within an organization (e.g. ISO 9001, even though certification to ISO 9001 is not a requirement of the ISO 19650). ISO 19650 is applicable to build assets and construction projects of all sizes and levels of complexity. This includes large properties, infrastructure networks, individual buildings and pieces of infrastructure, and the projects or sets of projects that deliver them. ISO 19650-1 establishes the concepts and principles recommended for processes throughout the built environment, emerging to support the management and production of information during the lifecycle of the assets built using BIM. These processes can deliver beneficial business outcomes to asset owners/managers, customers and those involved in project financing, including increased opportunity, reduced risk and reduced costs through the production and use of project and asset information models. ISO 19650-2 defines the information management process, containing the activities through which the teams involved can collaboratively produce information, minimizing and avoiding unnecessary activities.

An information management process is initiated whenever a new assignment is made in the delivery phase or in the operational phase, regardless of whether this commitment is formal or informal. This process involves preparing information requirements, reviewing possible named parties in relation to information management, initial and detailed planning of how and when information will be delivered, and reviewing the information results against information requirements before to be integrated into operating systems. The information management process must be applied in proportion to the scale and complexity of project and/or asset management activities (Lucas and Aguiar, 2018).

Information requirements are distributed in a flow to the most relevant designated party within a delivery team. Information deliveries are grouped by the principal designated party before delivery to the designated party through an information exchange process. The information exchange process is also used to transfer information between the Leading Designated Parties when this is authorized by the Designated Party. The workflow is used to support the collaborative production, management, sharing and exchange of all information during the operation and delivery phases. Information models containing aggregated information deliverables are produced as a result of the workflow to address the stakeholders' perspective because information management process, the number and description of asset lifecycle subdivisions (embedded in solid rectangles), information exchange points (embedded in solid circles) and decision points for delivery teams, parts stakeholders or designee (incorporated in the form of "diamonds") should reflect practice locations, stakeholder and designee requirements, and any specific agreements or requirements for project delivery or asset management (Davis, 2016).

2.3. Construction information systems

ProNIC (Protocol for the Standardization of Construction Technical Information) is a research project developed by developed by a consortium of three Portuguese research, development, and innovation institutes (which integrate LNEC - National Laboratory for Civil Engineering). The main purpose is to develop an information management system to support the AECO sector that allows the simplification of proceedings related to contracts and make available both technical and economic information in a structured and standardized way (INESCTEC; 2008). Figure 2 shows general details about ProNIC.

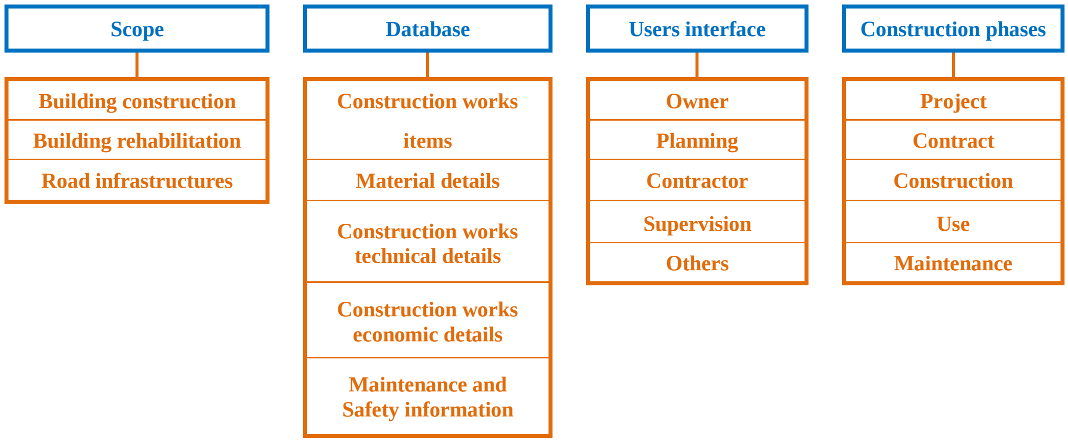


Figure 2: ProNIC details, adapted from (Salvado et. al., 2014)

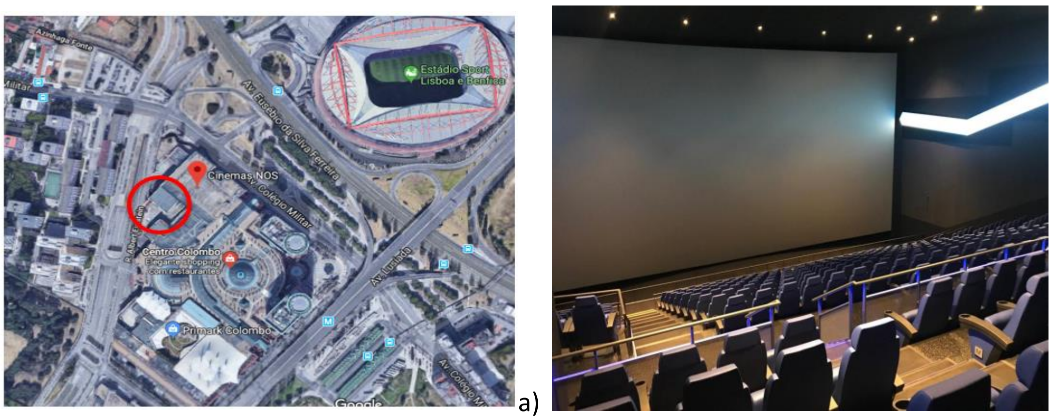
ProNIC intends to be a system adapted to the Portuguese reality and the current practices, following the assumptions of the international standards. Given the scope of the subject, the goals are necessarily achieved through a gradual process of adaptation and transformation of information, followed by tests, corrections, and validations. In his base, ProNIC is a breakdown structure, commonly referred in English literature as Work Breakdown Structure (WBS). This structure may be detailed in terms of associations or links established and dependent of the detailed degree desired. Contrarily to what occurs in other systems, ProNIC WBS, being the basis of all information produced, has been the object of a structured and comprehensive development to achieve a higher degree of detail. The task of defining the structure desegregation has been one of the main works. The ProNIC work classification criterion presents a division by chapters, subchapters and articles assigned to a particular code (the same code is always assigned to the same construction work). An article presents the description of the construction work, which will be edited and after integrated on the Work and Quantities Statement. After the definition of an article the designer can perform the measurements. The cost database philosophy is in accordance with the principles of cost and income data sheets developed by LNEC. Linked with the article there are files with work and material technical specifications. These files are individual and seek the principle that each type of work has a description of how it is performed (a work specification file), and files with specifications for each different used material. ProNIC comprehend the entire construction life cycle. From above, it is verifiable that it serves first the designer, and the work owner needs, mainly during the construction design and procurement. However, its structure contains features that are transversal to all the constructive process, as the work contract process (designer and contractor/sub-contractors), construction (contractor and technical supervision) and use (maintenance provisions). It is expected that, in Portugal, ProNIC will be mandatory for use in public works process (Salvado, et al., 2014).

3. Case study 1: BIM implementation

3.1. Case study characterization

The project in question concerns the IMAX room at Cinemas NOS at the Colombo Shopping Centre, located at Avenida Lusíada, 1500-392 Lisbon, Portugal (Figure 3). The Colombo Shopping Centre has an area of

115,000 m² and was built in 1997. In 2013 there was an expansion, with national repercussion, from an ordinary cinema room to an IMAX-type room. The IMAX room was built in a metallic structure, with a façade of prefabricated concrete panels. Sound insulation was designed for each wall, floor and false ceiling of the enclosure and auxiliary areas. The manager and owner of the asset made available for the development of this work the projects of the metallic structure, architecture, electrical installations, drainage, acoustics, the Atmospheric Discharge Protection System and the Earth Network. The Architectural, Electrical Installations, Drainage, Acoustics, Lightning Protection System and Earth Network Execution Projects were traditionally developed in AutoCAD 2D software. The design of the metallic structure was developed in IFC format, contains a graphic part in LOD 500, according to the BIM Forum 2018, but the non-graphic information is not very specific (Luedy et. al, 2020a).



a) b)

Figure 3: Case study 1: a) localization and b) inside detail (Luedy et. al, 2020a)

3.1. Information Requirements definition

Building Information Modelling (BIM) stands out as a vector of innovation encouraging a revolution in modern Civil Engineering. BIM implementation in buildings and infrastructures have been advantageous when compared to traditional process, allowing error and rework reducing as well improving costs previsions. One of BIM's biggest challenges is managing and sharing a large amount of information. Each building element needs to align the requirements for information and detail to be included in the models for design, construction, and operation. The case-study comprises modeling of a private leisure space located in Lisbon, being developed a model for each project phase and the corresponding information requirements planned in conformity. The standardization of BIM is in the initial stages and there is not, until the present moment, an international standard about the Level of Information Need. Therefore, it is necessary to analyze some BIM standard and relevant guides], such as ISO 12006-2 (2015), ISO 19650-1 (2018), ISO 19650-2 (2018), BS 1192-4 (2014), BIM Forum 2018, Caderno BIM de Santa Catarina (2014) to understand the information requirements to BIM Models (Luedy et. al, 2020b).

The disciplines adopted in this case of study are the main commons in the buildings and infrastructure project worldwide: Architecture and Structure. In addition, it was included the Installation to represent how the complementary projects are applied. The main list of non-graphic information was based in the BIM Notebook of Santa Catarina. The complement of this list was the ISO 12006-2 [16] that clarifies the concept of Category, a property essential to beginning phases. The concept of Level of Information Need is based in ISO 19650-1 and ISO 19650-2 publicized in 2018. In BIM models, it is important that the maintenance information's are used in the operational phase of the building. As some materials are chosen only in the construction stage and the maintain information due to the material, this property is suggested to be added only in the as built. The result of all this process is joined in a Table 2.

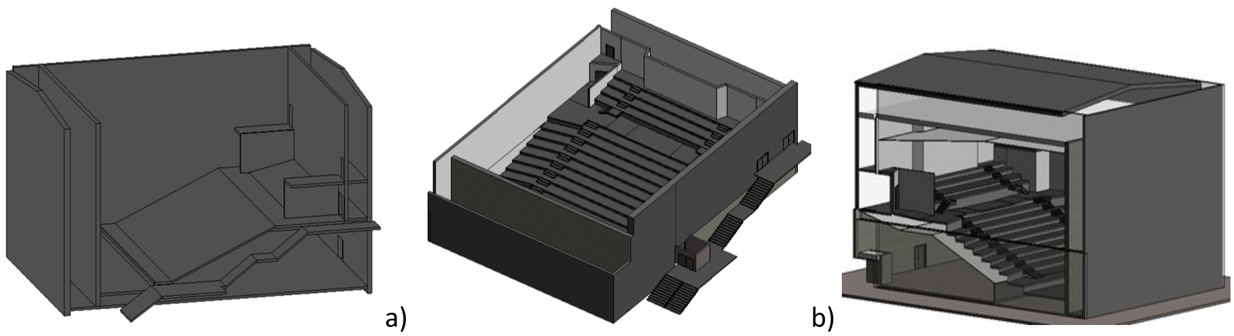
Table 2. Information Requirements to BIM models, adapted from (Luedy et. al, 2020a)

INFORMATION REQUIREMENTS FOR BIM MODELS				
	Project Phase			
Disciplines | Properties	Previous study	Pre-project	Execution Project	As built
Architecture				
Category	x	x	x	x
Type		x	x	x
Dimension	x	x	x	x
Insider material			x	x
Superficial material			x	x
Producer				x
Maintenance				x
Structures				
Category		x	x	x
Type		x	x	x
Dimension		x	x	x
Material			x	x
Producer				x
Conections			x	x
Maintenance				x
Complementaries Projects				
Category		x	x	x
Type		x	x	x
Dimension		x	x	x
Conections			x	x
Material			x	x
Producer				x
Maintenance				x

Afterwards, the applicability of Information Requirements to BIM Models is evaluated in three phases of the modelling of a cinema: i) previous project; ii) executive project; iii) maintenance. Maintenance does not correspond to a project phase in the Portugal Standard but was included to adapt to the cinema's real needs. It was necessary to insert one more subcategory in the worksheet to divide by category of element like wall, pipe, or column. The Disciplines that were worked on was Architecture, Acoustic, Structure and Sewage Facilities. Exceptionally, the Structural Project has an IFC file with all the geometric in 3D (Luedy et. al, 2020b).

3.3. BIM Modelling

The Information Requirements (Table 2) were highly useful to restrict which information is really needed for the project and avoid data and work waste. In the previous study phase was only necessary to model the volume and category of the architectural project (Figure 4a). All the elements have the same material, and the walls were named by the width as a strategy for facilitate the work in the next phases. The "Mass & Site" feature of Revit was useful to model the walls and roof. The stairs were modeled as a ramp to give the volume sense needed. In the Execution Project phase, all the projects were modeled and compatibilized using Revit and Navisworks, softwares from Autodesk (Figure 4b). During the modeling were found design errors, inconsistencies, and lack of information in the original project. Besides that, some information was difficult to be searched and interpreted. The operational phase important information was added as a new Property sheet (Navisworks). The last phase modeled was the Maintenance (as-built model). The main space focused in the Maintenance phase was under the bleachers (Figure 4c), an area that is used for stock and is managed by the company. All the information was added as a Property sheet (Navisworks) as in the Execution Project. Geometric and non-geometric information related with the construction phase was deleted for this phase to promote a reduction of the size of the model and an optimized workflow (Luedy et. al, 2020c).



a) b)

Figure 4: BIM modelling: a) previous study, b) execution project and c) as-built model, adapted from (Luedy et. al, 2020a)

3.4. Results analysis

During modelling, it was quite difficult to interpret information from traditional AutoCAD designs, especially in relation to the heights and details available in the drawings of the design cuts. Errors and incompatibilities were easily identified during the modelling using the BIM methodology, which validates the theory presented in Chapter 2 concerning BIM. Another important issue is that in the traditional project, information is spread across many different drawn and written pieces (blueprints and documents), which is solved when modelling in BIM. Element categories are, in most cases, working points from different steps in the methodology. The model in IFC format was easily coupled with the Execution Project model. The quality in the design elaboration, and especially in relation to the properties of the elements, allowed the essential interoperability in BIM to happen easily. The Exploration model was developed based on the Execution Project where the changes identified in the technical visit were updated (Luedy et. al, 2020a)

4. Case study 2: ProNIC implementation

4.1. Case study characterization

The case study chosen for the application of the LCCA methodology proposed to ProNIC was an Hospital Building, located in Portuguese territory, object of a public-private partnership and with a concession contract. The respective LCCA methodology was prepared following the following main assumptions: i) Concession period – 30 years; ii) Construction period – 2 years; iii) Life Cycle Maintenance Period –

28 years. In the preparation of the LCCA methodology, the assumptions indicated in Table 3 were also considered (Simões et. al, 2016).

Table 3. Assumptions considered for the preparation of LCCA methodology, adapted from (Simóes at. al, 2016)

Assumptions considered	Time horizon considered
Life cycle considered for the building	28 years
Shipyard and preparatory work	8,0 %
Studies and projects	5,0 %
Dump removal and preparation	5,0 %
Hits	3,0%
Construction repair costs	1,0 %
Extra hours	5,0 %
Safety and hygiene	0,5 %
Interest rate (annual percentage)	0,0 %
Inflation rate	0,0 %
Discount rate	0,0 %

In the modelling presented in 4.3, the following components were analysed: i) Structures and foundations (BC1); ii) Rough and Finishing (BC2); iii) Cold Water and Sewage Installations (BC3); iv) Installation of Medicinal Gases (BC4); v) Elevators (BC5); vi) Electrical, telecommunications and security installations and equipment (BC6); vii) HVAC (BC7); viii) Exterior arrangements (BC8); General Equipment (BC9). The application of the proposed LCCA methodology was made to items BC1 and BC2. The costs present in the MECCV were calculated based on the following assumptions: i) Guarantee of access to the areas to be renovated; ii) Contracts for the renewal of competitive components (in the spectrum of market offers); iii) Areas to be renovated with access prohibited to the general public and hospital staff; iv) Decontaminated areas delivered in safe conditions; v) Adequate hygiene and health; vi) Restrictions on working hours; vii) Correction of labour to activities; viii) Use and maintenance of the building and equipment in accordance with the recommendations of the respective manufacturers. Regarding the estimation of the maintenance costs of the building's components, within the scope of its life cycle, the LCC methodology was prepared based on the quantification of works and composition of the prices presented in the construction budget, proposed in the tender stage (Simóes, 2017).

4.2. Conceptualization of the LCCA methodology

It is important to find mechanisms that allow estimating the real costs at each stage (ISO 15686-5, 2008), (DIRECTIVE 2014/24/EU, 2014) and (Decree-Law no. 214-G/2015, 2015). Generically, for LCCA, the construction life cycle can be considered divided into four phases (Campos, 2014): i) In an initial phase, before the project is carried out: technical economic feasibility analysis, strategic option of LCCA in a given period versus full lifecycle cost; ii) Design and construction: life cycle cost assessment at different levels

(systems, components, works); iii) During the operational phase: LCC associated with maintenance, exploration and rehabilitation; iv) Demolition: life cycle cost at the end of the useful life / end of interest in the property.
The work developed intends to complement the information already existing in ProNIC through the implementation of the LCCA methodology in it. The main objective of this methodology is to insert into ProNIC all the elements of analysis necessary for its application, namely, information on the maintenance work to be carried out throughout the life cycle of a construction project, its frequency, and the respective costs. The application of the LCCA methodology contemplates an intervention in ProNIC at three levels: i) Change / Creation of articles related to the operation phase; ii) Change in the structure of the FET and FMAT items; iii) Restructuring of Cost Sheets. Based on the cost sheets existing in ProNIC, it is proposed to add to each of them the costs related to the operation of a building, throughout its life cycle, based on the necessary information on costs during the operation phase. (Replacement work), relating to each element that makes up the building. Since the structural component does not have such a significant intervention in the building's life cycle, and to complete and enrich the work developed, the existing information was analysed in the LCCA methodology, relating to building coatings and finishes. Thus, the information existing in ProNIC was analysed and compared with the information made available in the MECCV, with a view to integrating the information on life cycle work into ProNIC (Simões, 2017).
In a first phase, an analysis was made of the existing components of the LCCA methodology, designated as construction works and their respective replacement works, comparing this information with that existing in ProNIC at the level of articles, present in the subchapters Works of General Construction and Rehabilitation Works, respectively. In short, the objective of the analysis made to the building components, both in terms of construction work and replacement work, present in the LCCA methodology and comparison with the articles in ProNIC, was to verify whether there was a correspondence between them. Secondly, regarding FET and FMAT, the specifications for the execution of construction works and the material specifications present in ProNIC were adapted. From the analysis of the FET and FMAT, both for Construction Work in General and for Rehabilitation Work, it was found that at the level of some of the articles, the respective files are not presented and that the only information related to the operation (maintenance, operation, and rehabilitation), present in the FET maintenance item, is very scarce. In this sense, it was proposed to create a model text to be incorporated in each of the two types of records in ProNIC. The model texts to be incorporated in the respective sheets, for the application of the proposed methodology, present information on the number of cycles of each work, during the indicated period of analysis, and the respective percentage of replacement. Finally, the same information regarding the replacement percentage and the number of cycles is proposed to be incorporated in ProNIC's Cost Sheets (Simões et. al, 2017).

4.3. ProNIC modelling

Item BC1 presents works and LCC, in the following components of the LCCA methodology: i) Foundations - Direct Superficial Foundations; ii) Metallic Structures; iii) Lightweight Concrete Structures. Regarding item BC2, it presents works and LCC, in the following components of the LCCA methodology: i) Masonry; ii) Carpentry; iii) Locksmiths; iv) Insulation and Waterproofing; v) Wall Coatings and Finishing; vi) Coatings and Finishing of Floors, Baseboards and Stairs; vii) Ceiling Coatings and Finishing; viii) Covers. As an example of application, construction and replacement works are presented, the respective percentage of replacement and the number of cycles of each work for the Metallic Structures component. At ProNIC level, 43 articles, their technical specifications and cost sheets were analysed and intervened. Table 4 presents the description of the ProNIC article – 20.2.1.2.2: Repainting, with partial removal of pre-existing paint, of Metallic Structures, and the respective filling, according to the information available in the LCCA methodology.

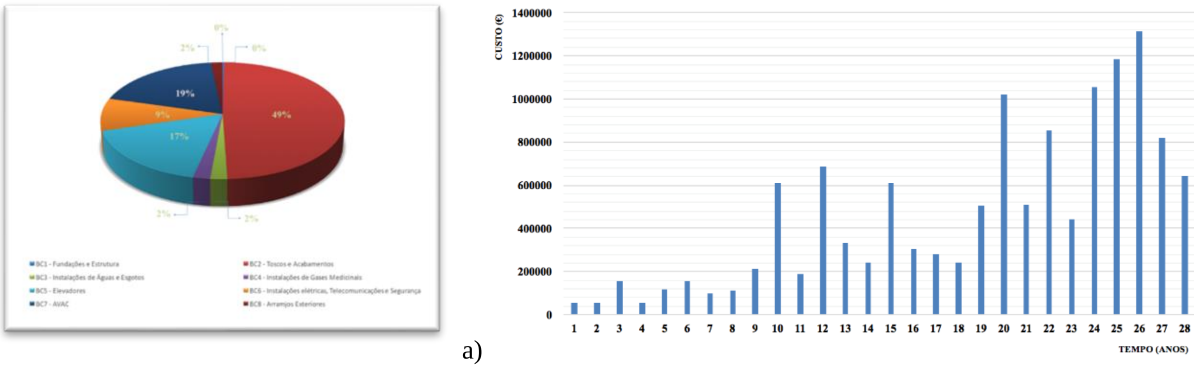
Table 4. Completion of article 20.2.1.2.2: Repainting, with partial removal of pre-existing paint, of Metallic Structures, adapted from (Simões, 2017)

Article description	Fields to Fill ($)	Unit
Pre-existing compatible paint scheme, for surfaces **$20**, for atmospheric corrosive environment **$2**, type **$1 $11**, with **$12** coats of paint, finish **$3 $4, $5, $6**, with durability level **$7** as per standard ISO 12944-5, **$8, $10**, including base preparation suitable for the proposed paint scheme, supply, loading, transport, unloading and application, all in accordance with the specifications.	**$20** - Indicate the nature of the metal and other information regarding the state of the surface to be painted (Optional Field) - **Nothing to put** **$2** - Specify atmospheric corrosivity category according to EN ISO 12944-2 - **Nothing to put** **$1** - Specify Layout Type - **Multilayer** **$11** - Indicate number of primer coats if it is a multilayer system - **N/A** **$12** - Indicate number of coats of paint (optional field) - **Nothing to Place** **$3** – Specify Finish Appearance – **Nothing to Put** **$4** – Specify RAL color e.g. in RAL color 9110 (Optional Field) – **Nothing to Put** **$5** - As an alternative to RAL, specify color - **N/A** **$6** - Specify Gloss Class - **Nothing to Put** **$7** - Specify durability level according to EN ISO 12944-5 - **M (average, or from 5 to 15 years)** **$8** - Specify Special Features (Optional Field) - **Nothing to Put** **$10** – Other Requirements (Optional Field) – **Nothing to Post**	m^2

At FET level, it is proposed in the Maintenance item to add the following information: i) Carry out the anti-corrosion painting according to the recommended frequency, every 10 years, starting in year 10, or when there is any damage to the painting that the justify. At FMAT level, in the new item created, put the following information: i) The paint with anti-corrosion properties must be replaced in its entirety (100%), according to the recommended frequency or when any damage justifies it. For both the repainting of metallic structures and metallic structures, the total unit price was based on an average price, taken directly from LNEC's income sheets (Manso, 2013), considering that there was no change in price until the days of today.

4.4. Results analysis

Figure 5a shows the LCC for each item present in the LCCA methodology, expressed as a percentage. Figure 5b indicates over the analysis period (28 years), for each year, the total annual cost to be considered of all LCCA methodology items, with the performance of the life cycle work. Any of the values represented in Figure 5b are indicators that can be very useful for assessing the economic performance of the building under study or for obtaining a value that can serve as a measure of comparison between buildings with similar characteristics. They may also be useful, in the investment planning stage, helping to prepare the strategic asset management plan and, consequently, the asset management plan (Simões, 2019).



a) b)

Figure 5: a) LCC for all items present in the LCCA methodology and b) Annual Life Cycle Costs of each item in the LCCA methodology, adapted from (Simões, 2017)

From the application of the proposed LCCA methodology, it was found that the greatest intervention in ProNIC will have to be made at the level of FET, FMAT and Cost Sheets. In the FETs, as these already present information on maintenance, from their analysis, it was found that the information presented is very scarce, hence, at this level, the application of the LCCA methodology was also very useful. In the FMAT, since ProNIC does not contain any information regarding the maintenance, operation, and rehabilitation of materials. At the level of the cost sheets existing in the Construction Works in General, the objective of the work developed is to include, in addition to the existing project and construction costs, the maintenance, operation and rehabilitation costs, through the addition of information related to the percentage of replacement and the number of times it is necessary to carry out the respective replacement, so that it is possible, at the level of any item consulted, present in the Construction Works in General, to have access to a life cycle cost analysis.

5. Conclusion

The generic structure of the proposed information requirements is based on different standards and guidelines, having required the comparison and simplification of the content of the original documentation. This framework aims to be the basis for architects and engineers, who are starting to implement BIM, to understand and apply the parameters in their projects. Later, it is necessary to use the customization aspects to adapt the overall structure to each project and company reality. From the application of the proposed structure to the case study, it is concluded that the structure is useful and applicable, guiding the entire modelling process. Another important result was that the design of structures, in IFC format, was verified through the proposed structure, which works as a checklist of parameters, ensuring the principle of interoperability of BIM.

ProNIC is easy to use and features numerous features that are a symbol of great benefit to the AECO sector. With the aim of making ProNIC a transversal platform for all phases of the construction process, from the project design phase to the end of its life, a case study for the application of the proposed ACCV methodology was presented. From the exercise carried out, which consisted of applying the developed methodology, it is recognized that ProNIC is a complete platform in terms of information on construction work (in the articles, in the information available in the FET and FMAT, and in the cost sheets) but only relating to the design and construction phases. Regarding the existing rehabilitation works at ProNIC, it was found that the technical specifications are largely scarce, and these are included in the construction works. Comparing the MECCV with the resources that already exist in ProNIC, it was found that in relation to: i) The construction work needs to be adapted so that an analysis can be carried out along the life cycle, for each work; ii) For rehabilitation works, there is a need to specify aspects that were not yet covered. It was also found that the biggest intervention in ProNIC, for maintenance and operation, was at the level of cost sheets and technical specifications.

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