7D Building Information Model (7D BIM) used in building maintenance

Inês Margarida Seixas Domingos

Instituto Superior Técnico, Universidade de Lisboa

November 2020

ABSTRACT

The use of the Building Information Modelling (BIM) methodology has become increasingly evident in the various phases of a project. The virtual model created admits a high capacity in the registration of all the information produced throughout the life cycle of the building, showing a relevant potential in the use of its database to support the maintenance activity. It is, however, in the design phase that the feasibility of the options taken has a major impact in reducing the costs related to the maintenance activity. The choice of design options with a sustained knowledge of the durability of materials and the costs involved throughout their life cycle are aspects to be considered by the owners and facility managers responsible for the maintenance of the building.

In this context, the aim of this paper consists in the evaluation of a method for service life prediction, applied to certain construction components as a basis for the elaboration of a specific schedule for the sustainable maintenance of each construction element.

In this study, the available BIM-based technology Revit as the modelling system and the visual programming plug-in Dynamo, were used to create two scripts to support service life estimation. The developed scripts allow the user to estimate the service life of the selected components, applied to case studies, and additionally predict their degradation state for a given year. Thus, still in the design phase it is possible to: prepare a planning of maintenance actions, supported by knowledge of the conditions to which the elements will be subject throughout the life of the building; compare the feasibility of constructive solutions to apply, supported by the information gathered in the BIM model and compiled in an Excel file, easily accessed for consultation.

This work contributes positively to the implementation of BIM in the maintenance activity, with relevance in demonstrating the high potential of the Dynamo tool in the information management of the BIM model, a perspective still slightly explored in the scope of maintenance.

Keywords: Service life prediction, Maintenance, BIM, Dynamo.

1. Introduction

In the last decades, the Architecture, Engineering, Construction and Operation (AECO) industry has evolved to progressively incorporate the implementation of the BIM methodology, enabled by constant technological advances and several incentives for its use. This methodology reveals a new and different way of working and thinking in the construction sector, compared to traditional methods, where transparency, communication and collaboration between those involved are determinant factors [1]. The BIM model represents a digital representation of the physical and functional characteristics of a building, which brings together the information produced in the various phases of the life cycle

forming a reliable basis for decision making. In the operation phase, the integration of BIM is not so frequent despite the benefits associated with it. Research in this area, although growing, is still in an initial phase [2]. In the activity called Facility Management (FM), which covers several disciplines in ensuring the functionality of the built environment integrating people, places, processes and technologies, BIM integration is still unusual. However, it is recognized by several authors, who emphasize the ability to gather continuously during the various phases of design and construction, all the information necessary for FM, which allows improving the efficiency and productivity for the application of management processes [2]. The ability to store large amounts of information and keep it accessible for consultation allied to the fact that currently several FM systems, which are not BIM solutions, already support the connection with BIM models, enhances their use. For a facility manager, how to use information from a BIM model to support FM activities is the question [3]. This paper introduces the current practices in BIM-FM as well as the main obstacles to its use. With main emphasis on the study of the service life of construction components as a basis for planning maintenance tasks, an integral function in FM skills.

2. BIM for FM: an overview

Although available for a few decades, it was only in recent years that BIM and its concepts began to spark more interest in the construction industry, extending their application to the entire life cycle of buildings. The types of building information that might be required in a model to manage the design, construction and operation of built assets can be described as dimensions [4]. BIM dimensions refers to levels of information and data entered into a 3D model using BIM software, and includes 3D model data (3D), time data (4D), costs (5D), sustainability (6D), facility management (7D), safety and accident prevention (8D). Each dimension can be applied independently and there is no need to consider other dimensions of the model simultaneously.

The seventh dimension comprises its application to Facility Management which presents a greater detail in this study. In a general concept, this dimension intends to gather all the information that has been developed and updated throughout the project, representing the as-built model of the building [5]. Besides gathering information on the elements and spaces that represent the asset, such as constituent materials and their quantities and costs created throughout the project, it also has specific information to support maintenance actions. This information ranges from manufacturer data, technical information on the products, warranties, user manuals and expectable service life among others necessary to support these activities [6].

The evolution of digital tools and technologies applied in FM practice is oriented to the use of management systems such as Computer Aided Facilities Management (CAFM) and Computerized Maintenance Management Systems (CMMS). Facility managers seek solutions that allow the accumulation, categorization, visualization and updating of information about the operation and maintenance of a building, which must be complete, organized and accurate. The main challenge is to integrate the accumulated information with the data acquired during the design and construction phases and provide the building management systems with relevant information at the time of operation [7].

For current users of the FM methodology, the transition to BIM-FM does not require a sudden change in the way it is applied, but rather represents an evolution. Where the flow of information from the BIM model to the FM system has the potential to be more efficient instead of manually filling in information in management systems [7]. The interoperability between different software is one of the key factors for the application of BIM in the operational phase of the building. The process of information transfer from the BIM model to the FM system can essentially be guaranteed through direct integration between the BIM model and the FM systems based on the native data format, ensuring a high interoperability between systems where the transfer occurs without loss of information. There is no need to validate the transferred data, promotes a realistic view and allows access to the BIM

model database. Additionally, the model can be permanently updated, allowing the facility manager to update the building's operation services. In this way the owner has a precise record as a basis for future refurbishments and expansions, and to support the FM activity [8]. When direct integration between the BIM model and the FM system is not available it is still possible to use other methods. Another method is supported by data structure specifications (e.g. Construction Operations Building information Exchange - COBie). This provides a structure to record the data needed for the main management systems, constituting a way to collect information in a structured way of the BIM model. Its most common representation is in spreadsheet format [9]. Several companies responsible for BIM and FM software have developed interfaces to import and export COBie data. However, users should be aware that the data needs to be validated after import, since the source system is not integrated in the target system [8].

The growing number of researches that address the BIM-FM topic are an indication of the industry's interest in its application, however they still highlight some barriers for its adoption [2,10]. Mostly due to: a lack of guidance, protocols and standards for BIM FM; Technical expertise needed for the maintenance and updating of the BIM; Limited software interoperability [11]; Unclear BIM FM requirements at early project stages [12] which reflects the fragmented nature of the construction industry. Emphasizing the need for the inclusion of the facility manager, mainly in coordination with the owner and the project team, in order to allow them to define, as part of the project premises [13], the requirements at the level of information required as well as the desired level of detail for that information [2]. This way it is possible to contribute to the reduction of investment costs and better facilities management services for the users of the building.

3. Service life prediction

Over time, buildings and their components tend to deteriorate, naturally, and lose some of their original properties.

The useful life or period of service of a building corresponds to the period of time during which its properties respond to or exceed the minimum acceptable levels for its operation - of intrinsic order to the element, normative or subjective - in a situation of current maintenance [14,15].

The degradation of a component is a consequence of the natural aging process, associated with exposure to adverse environmental conditions. The evaluation of the degradation level is based on mathematical models, which consider several types of variables, and when properly adjusted, allow estimating the remaining lifetime of the element under analysis. The methodology for predicting the service life of construction components should be integrated by design technicians as a design criterion [16]. This allows to compare different constructive solutions regarding their durability and to verify if the performance of the applied products remains acceptable throughout the estimated service life. The models also allow to evaluate the environmental and economic costs associated with their life cycle, optimizing the adoption of effective maintenance plans developed by facility managers [17].

The awareness of the relevance of buildings' durability for a more sustainable construction led to the establishment of several methodologies for the prediction of a building's service life. According to Moser and Hovde [18] the following prediction methods can be considered: deterministic, probabilistic (or stochastic) and engineering methods.

3.1. The factor method

The factor method fits into the deterministic methods as a simplified approach to support the prediction of the service life of construction components [18]. The main purpose of the method, proposed by ISO 15686-1 [15], consists in the prediction of a value for the estimated service life (ESL) of a given construction element, through the product of the reference service life value (RSL), under standard conditions, by seven deterministic factors:

ESL = RSL x factor A x factor B x factor C x factor D x factor E x factor F x factor G

Where:

    factor A – quality of components
    factor B – design level
    factor C – work execution level
    factor D – indoor environment
    factor E – outdoor environment
    factor F – in-use conditions
    factor G – maintenance level

The standard [15] suggests a rigorous methodology for determining the RSL, which can also be influenced by data provided by the manufacturer, homologated documentation or thematic bibliography, and also by the collection of information verified in similar cases under identical conditions of use.

The assignment of values to each of the deterministic factors must follow this standard, considering the deviation of the characteristics of the element under analysis from the reference conditions. The standard suggests that the factors should have values between 0.8 and 1.2 where: the unit value is assigned when the factor has no weight for the element under study; a higher value corresponds to an increase of the ESL; a lower value is reflected in a decrease of the estimated service life.

The factor method provides only an empirical estimate based on the available information but is an expeditious way of gathering the influence of each of the variables that can affect the useful life of the element. Emphasizing the facility of understanding and application of this method. However, they are subject to several criticisms as to the simplicity with which they address the complexity of degradation processes [19].

In the present study the bibliographical references of Raposo [20], Lopes [21] and Matos [22] were consulted, where three cases of application of the factor method according to the guidelines of the ISO 15686-1 standard are described [15]. In each case a durability matrix is presented, developed by each author listed in tables, containing the factors applicable to a set of construction elements. Thus, each table analyses a type of component: cladding applied on flat roofs [20]; adherent ceramic tiling on

façades [21]; ventilated façade tiling [22]. The tables are composed by the description of the factors and their index, so that they can be applied as variables of the factor method. These tables served as a basis for the practical development of this paper, and it was possible to estimate the service life for the selected elements in each case of study and to develop a maintenance plan based on the ESL values obtained.

4. Visual programming in Dynamo

4.1. Methodology

The performance of buildings is becoming more and more an aspect desired by those involved in the construction process, concerned both in the short and long term, both in terms of costs and durability, with the implicit need for the maintenance process to be thought about and discussed at an early stage of the construction process. In this context, it is proposed to include the factor method for estimating the service life of elements in construction and its application to a case study using the visual programming tool Dynamo, recognized for its potential to manage and manipulate information in a BIM model.

Dynamo allows to work in a visual programming environment, in which it is possible to connect elements for the establishment of relations and define the sequences of actions that make up the algorithms [23]. Information handling is done through nodes and wires in Dynamo's work environment that constitute a script. The study involved the development of two scripts, defined in the Dynamo system: the "Estimate Service Life" script and the "ESL Analysis", presented below. The mentioned scripts consist of nodes present in the Dynamo standard library, as well as nodes inserted in two installed packages: Data|Shapes, which allows collecting various types of user inputs depending on the type of data to be collected; Slingshot! For Dynamo, which presents a collection of nodes for use with database management systems.
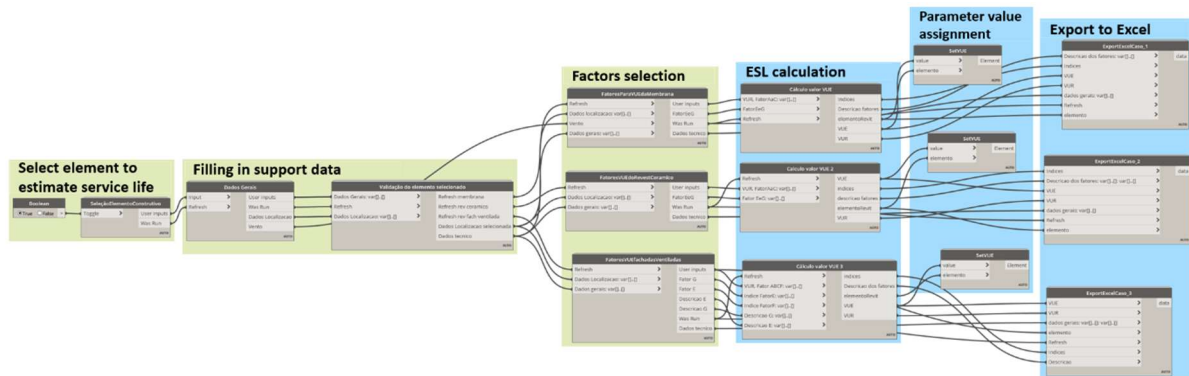
4.2. Dynamo script "Estimate Service Life"

At the basis of the development of this script are the durability matrices mentioned. These were

integrated in the script so that, in a dynamic way, the options of each factor can be selected according to the element of the project that is intended to estimate the service life. It can be executed in projects modelled in Revit and applied to the elements studied by the authors (roof waterproofing membranes, adherent ceramic tiling on facades and ventilated facade claddings). To achieve these purposes, it was created the script "Estimate Service Life" which is represented in **Figure 1**. In this figure it is possible to see several groups of nodes that distinguish the phases of the script according to their function. The groups of nodes in green were programmed to receive the data selected by the technician through user interfaces. For the programming of interfaces were used mostly the nodes present in the DataShapes package in order to ask the user: the selection of the object in the model; the selection of the indexes to be assigned to the factors present in each durability matrix; and the selection of the Excel file to export model information. In order to assist the filling of certain factors, detailed in the master thesis [24] a database was created in the DataBase Browser software and the nodes present in the Slignshot package were used to link the database to Dynamo. The communication to the database is done

SQL language. Depending on certain parameters, such as the location of the project, the connection to the database provides data relating to the characteristics of the outdoor environment (such as summer and winter climate zone, rainfall zone, average annual number of days with frost and solar radiation index) essential to characterize the factor E.

The groups of nodes in blue have been programmed to calculate the service life according to the factor method (depending on the indexes selected in each interface); assign the calculated value to the project parameter in Revit; and export information to the selected Excel file. For each Excel file, previously formatted, essential information is exported for the planning of maintenance activities such as the composition of the element selected in Revit, the ESL, area and associated maintenance costs. The Excel file is also associated to the respective element of the model, being always accessible for consultation. In the script, the information flow is transmitted from left to right, executing each node sequentially when receiving information from the previous node. The detailed programming of each of the nodes present in **Figure 1**, is explained in the master thesis [24].

automatically through commands and queries in

Figure 1 – Dynamo script "Estimate service life".

4.3. Dynamo script "ESL Analysis"

The "ESL Analysis" script was created as a complement to the previous script, and its use requires that the first script has already been executed. Thus, for the elements of the model to which the ESL is assigned it is possible to make a prognosis of their degradation state for a given year. For this, a linear degradation of

the elements was assumed, where a set of colours was assigned according to the range in which the % of lifespan is. This is calculated by the expression:

$$\% \, lifespan = \frac{ELS - (forecast\ year - year\ of\ construction)}{ELS} \times 100$$

In **Figure 2** it is possible to see the dynamo script developed where the green groups allow

to collect the variables of the referred expression. These have been programmed to collect the value of the ESL parameter by selecting the elements in the model. The programming of the lower green group results in the interface represented in **Figure 3** that allows to record the value of the remaining variables of the equation. In the lower zone of the same interface is displayed the colour legend that was assigned according to different periods of the value of % of lifespan. In the custom node of the group identified in blue is calculated the % of lifespan of the selected elements, according to the variables introduced. Depending on the interval in which the calculated percentage is inserted, the element displays the colour assigned to the interval. The green colour corresponds to an initial degradation state, while the red colour is assigned to an advanced degradation state.
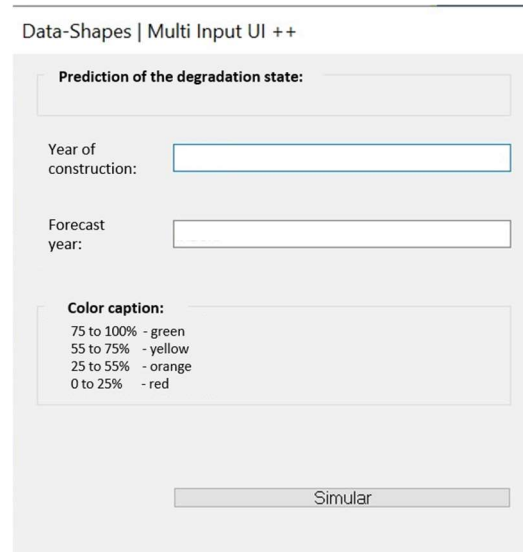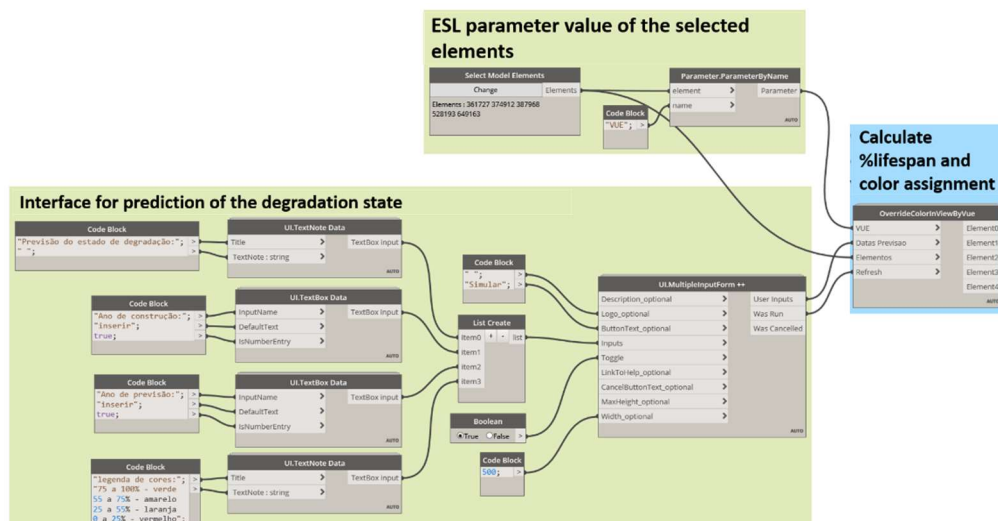

Figure 3 – Interface.

Figure 2 – Dynamo script "ESL Analysis".

5. Case study

The selected case study corresponds to a building integrated in a private complex, located in the Lisbon area, with 5 elevated floors, 3 floors in semi-basement and roof terrace. It presents two blind warps oriented to West and Northeast. The BIM architectural model was created using the Revit software. The building envelope was modelled in greater detail, which is the target of analysis in the present work, in particular, the cladding applied to the facades and the roof:

- The main façade, facing north, consists of a double wall in brick masonry (11cm+15cm), and is covered with adherent tiles in porcelain stoneware; (**Figure 4**, left)
- The Southeast oriented façade, a solution in ventilated façade clad with fiber cement plates; (**Figure 4**, right)
- On the roof terrace was applied, as a finishing material, the waterproofing membrane in APP polymer bitumen self-protected with mineral granulate. (**Figure 5**)

Figure 4 – Main facade with adherent tiles in porcelain stoneware, left and rear facade with fiber cement plates, right.
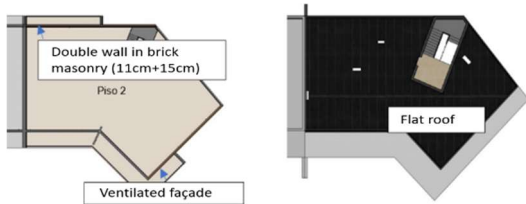

Figure 5 – Floor plan, with the identification of the facades, and flat roof.

5.1. Added project parameters

The objects used in this work do not contain the necessary parameters related to the ESL of the components under analysis, which made necessary to add them. New parameters were created, associated to the referred materials, in order to be able to admit, in a dynamic way, the values to be calculated through the two Dynamo scripts presented. The new parameters were designated as:

- *ESL*, receives the service life value estimated by the "Estimate Service Life" script;
- *Maintenance Excel*, registers the directory of the Excel file that when selected opens the file;
- *% lifespan*, variable calculated based on the ESL parameter and the forecast year, controlled in the script "ESL Analysis".

Parameters that understand the costs related to the planning of maintenance actions were also created. Its value was manually filled in Revit.

5.2. Application of "Estimate service life" script in the case study

The execution of the created script can be triggered easily through Dynamo Player that allows running the scripts developed in Dynamo, in the Revit environment. For this purpose, the necessary inputs have been configured in Dynamo.

The script was successfully executed to estimate the service life of each of the materials identified (facade cladding and roofing), with all the steps detailed in the master thesis [24]. As a result of the application of the script, the filled parameters, ESL and Maintenance Excel, associated to the respective element in the model, can be seen in **Figure 7**. Additionally, part of the information transposed from Revit to Excel and organized according to the selected template is presented in **Table 1**, corresponding to the fiber cement plate cladding. In this table, the necessary information for the planning of maintenance activities throughout the period in service of the components can be found. In each Excel template are also gathered generic maintenance actions for each type of cladding to be maintained [24].

With the data in Excel it is possible to explore scenarios of maintenance actions, combined with the element's costs, areas to intervene and periodicity of actions to be performed. The ESL is the main parameter involved in all economic considerations such as the return on capital invested and investment planning for maintenance and subsequent demolition [18]. A financial chronogram of the actions to be performed has been developed for each constructive element studied, from which it was concluded that the porcelain stoneware cladding is not only more durable but has lower maintenance costs than the fiber cement plate solution. According to the parameter values obtained in **Figure 7** the waterproofing membrane presents a much lower durability, therefore should be subject to periodic inspections in order to analyse it condition over time and plan maintenance actions in line with its actual state in order to extend its service life. Even so the planning of the activities must be readjusted to what is necessary according to the state of degradation of the elements during the period in service. Depending on the maintenance actions performed, the useful life values can be exceeded. The execution of the script to the case study occurred without errors, allowing to compare the durability and costs of each constructive solution studied.

Table 1 – Data exported from Revit to Excel.

Technician's name:	Inês Domingos
Date:	2020

Element category:	Wall
Element type:	Ventilated wall
Fixing system:	At sight
Maintenance target element:	Fiber cement plates 180x100cm

Year of construction:	2020
Reference service life (RSL):	30
Estimate service life (ESL):	34,6

Total facade area [m^2]:	219
Replacement cost [€/m^2]:	96
Clean cost [€/m^2]:	19,49
Inspection cost [€]:	70

5.3. Application of "ESL Analysis" script in the case study

To simplify the use of this script, the 3D view of the model was duplicated with an associated filter so that only the objects that contain the ESL parameter are visible. The new view was called "Life Analysis", and in this way the assignment of colours to the objects of the model do not overlap with the colours of the original model. This view is selected to run the script in order to see the life effects in a certain period.

When the script is executed, all the elements present in the mentioned view are selected, which include the two facades and the roof under analysis. Next, the interface of **Figure 3** appears, where the year 2020 and 2030 were filled as an example to simulate the year of construction and the year for life forecast respectively. When the script is completed it is possible to observe the elements with a distinct colouring, represented in the view created. The result of the inserted values is the parameter *% lifespan* (automatically field) calculated for each element in **Figure 7**. The colours shown in **Figure 6** correspond to the state of conservation of the building for the entered year.

Figure 6 – Script execution to the case study.

It can be observed that the wall in porcelain stoneware (coloured in green) presents a greater durability for the year 2030 than the other wall (coloured in yellow) and the waterproofing membrane (coloured in orange) which will be near the replacement year in 2030 if they do not receive maintenance actions. It is relevant since it can compromise the whole viability of the roof with possible infiltrations, which becomes more expensive to solve.

As mentioned, this script considers in a global way the forecast of the service life of each element, which allows to have a chronological picture of their degradation. However, it presents some limitations because it considers a linear degradation of the materials which have been applied equally to the totality of each element surface under analysis, not making any differentiation between sections of the element that are more susceptible to present anomalies and therefore could present a different colour. Additionally, it does not foresee maintenance actions that are being carried out throughout the O&M phase that may contribute to an increase of the service life of the element in relation to what is foreseen. However, it allows a general comparison between the building elements which may lead to rethinking the choice of some materials so that they come closer to the project life. However, in a more realistic situation, extrapolating this academic study, a more fragmented modelling of each of the elements could be applied.

Figure 7 – Final properties of the analysed elements.

6. Conclusion

The use of Dynamo allowed to show the tool's potential in the way it can explore, manipulate and export the data of the BIM model. However, considering that the Dynamo integration with Revit is used with greater incidence for the development and manipulation of model geometry, it presented several difficulties regarding the chaining of the interfaces used in the first script. A problem that Dynamo users have highly reported and that was felt in this master thesis was the little flexibility that the software allows in the manipulation of the algorithm flow. For example, the recurring difficulty that existed in preventing certain nodes from being executed to the benefit of others when the user is allowed the option of three different paths that in this case represent the 3 elements for which the service life was estimated (inserted in the same script). This problem has been circumvented through several validations in Python Script (to prevent the nodes from not being executed), not making the software very effective in this sense. After this development it was concluded that it would have been easier to develop a script to estimate the useful life of each constructive element separately.

Revit also provides the functionality to develop macros that allows a better manipulation of the algorithm flow which for the developments made within this paper could have been more appropriate. Moreover, in terms of performance, in Dynamo when a node is activated 100% of its

processing is used, while for the objectives of the algorithm that is being developed all this capacity may not be necessary, which in terms of performance is not the most favourable because it uses the processing and internal memory of the computer even when is not necessary.

The scripts execution to the case study allowed the achievement of the purposes intended for this paper. It allowed an analysis of the durability of the elements in the design phase where the change of solutions have less impact on overall costs. However, the BIM objects did not have the necessary parameters for the application of the factor method, highlighting the need to include in the digital catalog of each object the RSL to be able to evaluate the durability of the constructive elements in the project to which they are applied, taking into account all the factors to be fulfilled by the technician. The execution of each of the scripts occurred without problems and no errors were reported by Dynamo. However, to apply these scripts to a BIM model it is necessary to create the project parameters: *ESL, Maintenance Excel, % lifespan* and all the cost's parameters, mentioned in [24] as they were named when in Dynamo. To get through this point it was necessary to include in the script the creation of each parameter. At first the *Parameter.CreateProjectParameter* node was included, but every time the script was executed the parameters were created and in the next execution there was duplication of the created parameters, not having been able to avoid this

situation was decided that it would be more effective to add it from Revit.

The perspective of the study was directed towards the occupation phase of the building, which since it is the phase of longer duration and where the maintenance activity increases costs that sometimes exceed the initial investment, the use of BIM has the potential to gather all the information to support this phase and reduce the associated costs. Its implementation is not yet recurrent at a business level, particularly in the national context, although as demonstrated in this study, the tools exist to allow it.

7. References

[1] Antunes, C. (2019). *BIM: the turning point in the construction sector*. Available in: https://pontosdevista.pt/2019/05/26/bim-ponto-viragem-no-setor-da-construcao/, consulted in June 2020.

[2] Pishdad-Bozorgi, P., et al. (2018). *Planning and developing facility management-enabled building information model (FM-enabled BIM).* Automation in Construction 87, pp. 22-38. Available in: https://doi.org/10.1016/j.autcon.2017.12.004.

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

[4] Kamardeen, I. (2010). *8D BIM modelling tool for accident prevention through design.* Association of Researchers in Construction Management, ARCOM 2010 - Proceedings of the 26th Annual Conference, (September), pp. 281–289.

[5] Jamil, G., et al. (2019). *Handbook of Research on Emerging Technologies for Effective Project Management.* IGI Global, 2019 Edition. United States of America. ISBN 1522599940.

[6] The B1M. (2015). *What is 6D BIM?* Available in: https://www.theb1m.com/video/what-is-6d-bim, consulted in January 2020.

[7] Araszkiewicz, K. (2017). *Digital Technologies in Facility Management - The state of Practice and Research Challenges.*
Procedia Engineering 196, pp. 1034–1042. Available in: https://doi.org/10.1016/j.proeng.2017.08.059

[8] Schley, M., et al. (2016). *BIM for Facility Management.* BIM-FM Consortium. Version 2.1.

[9] Yalcinkaya, M., et al. (2014) *Building Information Modelling (BIM) for Facility Manager – Literature Review and Future Needs.*

[10] Ilter, D., & Ergen, E. (2015). *BIM for building refurbishment and maintenance: current status and research directions.* In Structural Survey (Vol. 33). Available in: https://doi.org/10.1108/SS-02-2015-0008.

[11] Gouda Mohamed, A., et al. (2020). *BIM and semantic web-based maintenance information for existing buildings.* Automation in Construction, *116*, 103209. Available in: https://doi.org/10.1016/j.autcon.2020.103209.

[12] Codinhoto, R., & Kiviniemi, A. (2014). *BIM for FM: A Case Support for Business Life Cycle.* IFIP Advances in Information and Communication Technology, 442, pp. 63–74. Available in: https://doi.org/10.1007/978-3-662-45937-9_7.

[13] Potkany, M., et al. (2015). *Facility Management and Its Importance in the Analysis of Building Life Cycle*. Procedia Economics and Finance 26, pp. 202–208. Available in: https://doi.org/10.1016/s2212-5671(15)00814-x

[14] Gaspar, P., & Brito, J. (2003). O Ciclo de vida das Construções.

[15] ISO 15686-1. (2000). *Buildings and constructed assets - Service life planning - Part 1: General Principles.* International Organization for Standardization, Geneva.

[16] Silva, J. (2011). *Vidas úteis em elementos da construção em edifícios habitacionais - sistemas envelope e interior*. Master Thesis. Instituto Superior Técnico, Universidade de Lisboa.

[17] Souza, J., et al. (2018). *Service life prediction of ceramic tiling systems in Brasília-Brazil using the factor method*. Construction and Building Materials, *192*, pp. 38–49. Available in: https://doi.org/10.1016/j.conbuildmat.2018.10.084.

[18] Hovde, P. J., & Moser, K. (2004). *Performance based methods for service life*

prediction. In State of the art reports, CIB Report: Publication (Vol. 294).

[19] Chai, C. (2011). *Previsão da vida útil de revestimentos de superfícies pintadas em paredes exteriores.* Master Thesis. Instituto Superior Técnico, Universidade de Lisboa.

[20] Raposo, T. (2009). *Durabilidade da Construção. Estimativa da vida útil de revestimentos de coberturas planas.* Master thesis. Faculdade de Engenharia da Universidade do Porto.

[21] Lopes, C. (2009). *Durabilidade na Construção. Estimativa da vida útil de revestimentos cerâmicos de fachadas.* Master thesis. Faculdade de Engenharia da Universidade do Porto.

[22] Matos, M. (2007). *Durabilidade como critério de projecto. O Método Factorial no contexto português*. Faculdade de Engenharia da Universidade do Porto.

[23] The Dynamo Primer. Available in: https://primer.dynamobim.org/. Consulted in March 2020

[24] Domingos, I. (2020). *O modelo 7D/BIM utilizado na manutenção de edifícios.* Master Thesis. Instituto Superior Técnico, Universidade de Lisboa