Chapter

The 7D BIM Model Used in the Estimation of the Useful Life of Façade Materials

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Abstract

The Building Information Modelling (BIM) methodology is supported on the concept of centralizing, in a parametric virtual model, all information related with the project, the construction and the overall lifecycle of a building. The building maintenance and management activities, requires the development of working facilities planned in an early project phase. The maintenance planning has been improved supported in BIM, as it allows professionals to easily retrieve, add and update the database of the BIM model. The definition of adequate maintenance strategies requires knowledge regarding the durability of the materials, mainly the degradation perdition of the materials. The present work is focused on the estimation of the useful lifetime of materials usually applied on the finishing of traditional building facades and terraces. Based on the knowledge of durability of the selected materials a Dynamo script was created allowing to obtain an estimation value concerning the degradation perdition of the materials. Other Dynamo script was developed oriented to the visualization of the degradation level of the materials. This innovative approach intends to support the maintenance engineers to make assertive decisions concerning the maintenance activity. In this study Dynamo programming improved BIM-FM systems integration, providing a positive contribution in construction maintenance context.

Keywords: BIM, 7D model, management planning, degradation prediction, wall's finishing, dynamo script

1. Introduction

Building Information Modelling (BIM) methodology offers a rigorous and complete representation of the building and presents a great potential to support the design, construction and occupation phases. However, the implementation of BIM requires an initial effort to train human resources, in order to acquire the skills mandatory in the use of the available tools, and a financial investment in the acquisition of new technologies and equipment.

The construction industry has been progressively incorporating the implementation of BIM methodology, supported by the permanent dissemination of its benefits recognised in reports and in recent technologic advances [1]. This methodology reveals a new and different way of working in the construction sector when compared to traditional methods based on two-dimensional (2D) technical documents. The BIM work transmits more transparency, better communication and a greater level of collaboration between all partners involved in the development of building projects [2]. When developing a project, using BIM platforms, a digital three-dimensional (3D) model of the physical and functional characteristics of the building in analyses is created. The model brings together the information produced in the various phases of the building life cycle forming a complete database supporting decision-makers [3].

The Facility Management (FM) activity, in a building, covers several disciplines in ensuring the functionality of the built environment integrating people, places, processes and technologies. The principal advantage that BIM can bring to this discipline is mainly related to the great capacity of storing a large volume of information, which normally is required in the maintenance activity [4]. The capacity to archive a great volume of data and allowing its accessibility with the connection to several FM systems make BIM strategies a very interesting perspective. During the occupation of a building, BIM implementation within the management and maintenance phases is not yet a recurrent concept, despite the benefits that have been reported. The research in this area, although it is currently growing, is still at an early stage [5].

The maintenance of a building starts immediately after its construction and ends with its demolition. It creates an accurate depiction of the physical conditions, environment, and assets of a facility. Currently, BIM-FM integration is still unusual. However, retrieving data from the model requires experience and relevant waste of time [6]. The FM professional is the 'expert in charge of a building whose concern covers operational issues of maintenance, cleanliness and safety of tenants'. The growing complexity of buildings and the significant cost of their administration has led to the need to introduce 'strategic and tactically based management functions', associated with other support activities such as the control of the human resources involved and the use of adequate and integrated software.

The present study intends to contribute to the reuse the information created and stored in the database of the model and its application in the maintenance activity in an integrated way [7]. The text introduces the current practices in BIM-FM and the main advantages and limitations in using BIM platforms, in the maintenance context. The study considers the development of two Dynamo scripts created to improve the integration of BIM models to FM functionalities. This innovative approach intends to support the management professionals to define adequate maintenance planning with the use of the created Dynamo scripts, to estimate service life of some frequent materials applied as finishing of exterior walls and roofs.

2. BIM-FM integration

The concept of Facility Management (FM) is understood as an interdisciplinary practice related to the management of buildings and facilities organised by the experts involved. The distinct applicability of BIM is referred to in the literature as the 'n' dimensions of BIM. Each dimension is associated with a set of distinct information, added to the 3D model, complementing it with the activities that can be elaborated, based on a selective retrieving and extraction from the 3D BIM model database [8]: the time factor (4D); the quantity and costs estimation (5D), simulation of energetic consume (6D) and the operation process (7D). So, the seventh dimension comprises the application of BIM methodology in the Facility Management activity. This activity supported in BIM platforms can be improved with recognised benefits. It can enable procedures like archiving, retrieving and reusing a great volume of data that is normally required in the context of the activity [9].

The 7D model gathers the information regarding each component and space, the applied materials, their quantification and costs and the specific information required to support maintenance actions. These data englobes data relate to material enterprises, to technical documents the products, to warranties and to guide manuals [10]. The 7D model supports the professional to take on the management phase of every achieved and retrieved data. By combining the quality of the facilities with the active control of costs, the FM allows to increase the efficiency of the organisation that uses the building and improves the quality of the employees' work [11].

The FM concept is still relatively recent in the construction industry. The International Facility Management Association (IFMA) was created in the United States of America in 1978 and was integrated in 1984 into the European entity by the European Facility Management Network (EuroFM), in order to implement FM in the practice of construction, education and research. Since then, its importance has been increasing and recognised as necessary in the management of a building, along with its occupation [12]. Based on the usual requirements and practices used in FM, IFMA has identified the 11 main competencies related to FM activity [13]:

- Communication: definition of plans and processes within the internal and external stakeholders;
- Quality: best practices, process improvements, and audits must be applied;
- Occupation and human factor: healthy and safe work environment for users;
- Finance and business: strategic plans, budgets, financial analysis and acquisitions;
- Emergency and business continuity plan: emergency and risk management plans and procedures;
- Leadership and strategy: strategic planning, organisation, team and leaders;
- Project management: supervision and management of all related projects and contracts;
- Environmental management and sustainability: sustainable management of natural and built environments;
- Real estate and property management: planning and acquisition of real estate;
- Operation and maintenance: operation and maintenance of buildings, services to occupants;
- Technology: FM technology, workplace management systems.

As the generation of a BIM model is based on the use of parametric objects, each component of a building includes a large amount of data such as the type of the applied materials and its related proprieties. In BIM-FM integration, the degree of interoperability performed between different software is the main limitation in applying BIM in the operational phase of the building [14]. However, using the native data format of the modelling system, the transfer process of information from BIM model to FM systems can be effectuated without loss of relevant information. Additionally, the model can be permanently updated, allowing the facility manager to update the building's operation services [15]. Therefore, it is possible to contribute to the reduction of investment costs and better facilities management services in a building [16].

Technological advances in BIM software and integration capacity aimed to improve the efficiency in supporting FM practices. BIM-FM integration allowed the development of a more comprehensive and reliable computational solution related to the collection, categorisation, visualisation and updating of information about the operation and maintenance of a building. This information must be complete, organised, accurate and accessible. The main challenge is to integrate the gathered information with the data acquired in the design and construction phases and the storage of this data in the BIM model, using adequate building management and operation systems [17].

The life cycle of a building involves several stages: The design of the project; the construction process; the building occupation; the demolition procedure. The phase of longest duration corresponds to the occupation of the building. To maintain the quality of the building, throughout this phase, it is necessary to carry out maintenance, conservation or renovation actions applied to the components of the building, in order to ensure the service conditions and to prolong the useful life of the building.

3. Estimation of the service life of materials

The service life period considers the definition of a minimum acceptable level for the performance of a building, depending not only on the evaluation criteria of the expert but also on the safety aspects, functionality for a given time or the environmental or regulatory context in which the assessment carried out is inserted. Considering this great diversity of influences, the prediction of the useful life of a building is difficult to estimate with accuracy. The value of the predate service life is estimated based on simple and linear mathematic models. In addition, a building does not age in a homogeneous way and its surroundings are subject to a high number of aggressive agents, resulting in a faster ageing rate when compared to the interior components [18].

The ageing process of the building encompasses a chain of events, directly conditioned, by the decisions implemented in the design phase and by the use or occurrences developed during the occupation period. The ageing mode also depends on the functional changes and constructive changes imposed, resulting from the technical evolution of aesthetic and comfort requirements, according to the users' needs. The components of the building are subjected to a diversity of deterioration processes, contributing to the ageing phenomenon [19]. The following prediction methods can be considered deterministic, probabilistic (or stochastic) and engineering methods [20].

The method considered in the study is the factor deterministic procedure. This method is a simplified approach that allows to calculate the estimated service life (ESL) value for the construction materials. This value is obtained by the product of the reference service life (RSL) value by several values related with a set of deterministic factors (**Table 1**).

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

Table 1.
The factors that interfere with estimation of the service life value.

Factor	Description		Value
Factor A	A1	Declaration of Conformity and Quality Certificate	
		With EC Declaration of Conformity and Quality Certificate	1.2
		With EC declaration of conformity or Quality Certificate	1.0
	A2	Characteristics of thermal insulation of the cover	
		With ISOLE rating higher than recommended for coverage type	1.2
		With the recommended ISOLE rating for the coverage type	1.0
		With ISOLE rating lower than recommended for coverage type	0.8
	A4	Type of bituminous membrane armour	
		Polyester felt of 250 g/m^2 or armed with polyester and fibreglass felt	1.2
		With polyester felt of at least 150 g/m^2	1.0
		With polyester felt less than 150 g/m^2 or with fibreglass felt	0.8

Table 2.
Factor A of the durability matrix of cladding applied on terrace roofs.

- The RSL value is data delivered by the construction company or homologated documentation, and by the set of data confirmed in analogous construction and behind similar exterior conditions of occupation;

- The factors from A to G can present values between 0.8 and 1.2. The unit value is considered when the factor has no weight for the material, a higher value increases the ESL; a lower value decreases the estimated service life.

In order to obtain a correlative database, the bibliographical references of Raposo [21], Lopes [22], and Matos [23] were checked. In it, three cases of application of the factor method according to the guidelines of the ISO 15686-1 standard were analysed [24]. The preliminary bibliographic research was conducted to define the durability matrix of the database. The retrieved data concerns the required factors and are related to the materials analysed in the present study, namely, cladding applied on the flat roof (**Table 2**), adherent ceramic tiling finishing one façade and the ventilated façade tiling type. In the aim of the study, the developed Dynamo script uses the factor values listed in independent tables concerning each material.

4. Visual programming in dynamo

Deterministic methods are based on the analysis of the factors and mechanisms that affect the degradation of the constructive elements, under the normal conditions of use, allowing for quantifying the level of degradation of the material. The present study proposes to include the factor method for estimating the service life of elements in construction. It involves the development of two scripts, using the visual programming tool Dynamo [25]: the 'Estimate Service Life' script and the 'ESL Analysis'. The scripts were applied over a case study allowing verifying its efficiency.

4.1 Dynamo script 'Estimate Service Life'

The tables of durability matrices previously created were used to support the development of the script 'Estimate Service Life'. The tables were integrated into the script so that the options of each factor can be selected according to the element and material used in order to estimate the respective service life value. The script can run over projects modelled in Revit and applied over the considered constructive elements: roof waterproofing membranes; adherent ceramic tiling on facades; ventilated facade claddings.

After obtaining the ESL value, for each of the elements under study, it is possible to make a prediction of the state of degradation of the elements for the horizon of a given year. The degradation process follows an incremental and uniform evolution. A set of colours was assigned according to the range in which the calculated % of useful life is. The script 'Estimate Service Life' was created using Dynamo visual programming whose main structure is represented in **Figure 1**.

In the development of the script 'Estimate Service Life (ESL)', it required the installation of the package Data-Shapes, which allows the programmer to collect

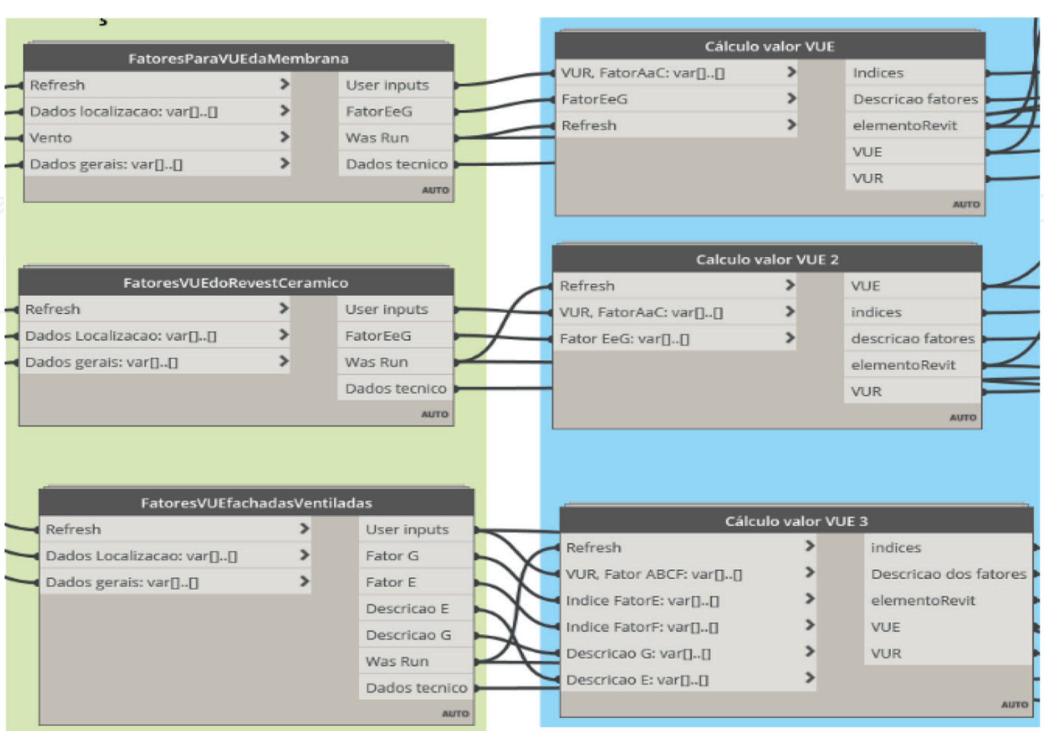

Figure 1.
Dynamo script 'Estimate Service Life'.

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various types of user inputs depending on the type of data to be inserted. This package is very flexible, allowing an easy control of the type and order of input data to be considered. The Code Block node, available in Dynamo standard library, is responsible for the insertion of various types of data. The connection to each entry in the master node is made through the use of lists. Due to the high volume of information to be presented in the interfaces, it was decided to use the Python Script node for the creation of the lists, simplifying the programming in the Dynamo interface.

To connect the tables inserted in the database to Dynamo it was necessary to instal the Slingshot package. This package presents a collection of nodes used in the database management system. They allow the connection and communication to the databases created in MySQL and SQLite formats, using the SQL language.

The inputs of the Dynamo script can be easily adapted to the needs of the user. The scripts can be configured to request input data prior to triggering the script. To perform this the Boolean node, selected as an input command, accessed in Dynamo menu, was set as input data for Dynamo Player. The Boolean (True or False) node displays the false option and deletes the data recorded in the last use of the script; the true option allows you to run the program and display the interface for a new use.

The selection of the project site allows us to suggest filling options for the factor E (to be addressed later) related to the characteristics of the outdoor environment. As an example of localization, the Lisbon, Porto and Algarve options were incorporated, chosen because they are associated with the examples used in the script programming. The interface also allows you to enter the type of fixation of the coating, variable according to the support structure chosen for the ventilated façade, and the data for identification of the technician. In this case, the fastening system chosen is a sight fastening system using clips.

4.2 Generation of the 'ESL analysis' script

The 'ESL Analysis' script was developed in association with the 'Estimate Service Life' script and allows:

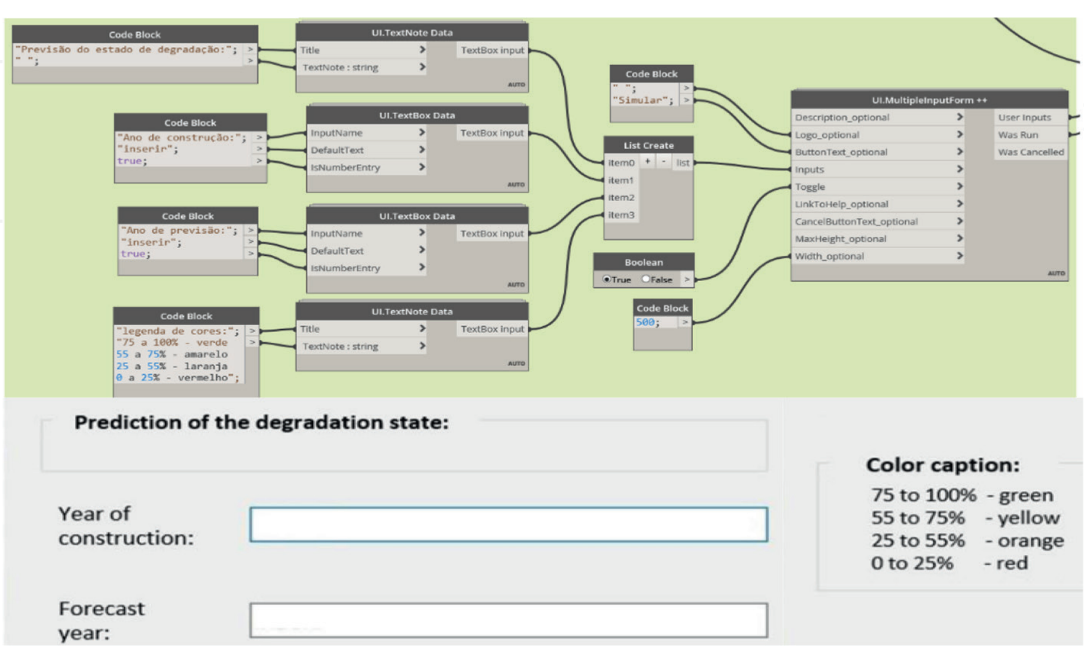

Figure 2.
Dynamo script 'ESL analyses' and the assignment of colours.

- Calculate the % lifetime for a given year, based on the value calculated for the ESL parameter;

- Assign a colour scheme to elements based on the % lifetime.

For each model component associated with the ESL parameter, the obtained ESL value is assigned. Based on it is possible to make an evaluation of the degradation state of the material for a given year. According to the value of ESL, the related percentage is considered, and the component presented the colour assigned to the respective interval of values. An initial degradation state corresponds to the green colour and an advanced degradation state is related to the red colour. In the second script, a set of colours was allocated according to the level of the achieved deterioration, in which the *% of lifespan* is established (**Figure 2**).

5. Application of the scripts

The selected building case, located in Lisbon, is composed of eight floors and a terrace. Using the Revit software (Autodesk), the architectural BIM model was created, having been modelled with a great detail, namely, the coatings applied to the facades and the roof (**Figure 3**).

- The north façade is composed of a double wall in brick masonry and presents a finishing material of porcelain tiles;

- The southeast façade presents a construction solution in ventilated clad with fibre cement plates;

- The roof terrace presents a finishing material composed of a waterproofing membrane in polymer bitumen.

For the representation of the walls, new parametric objects were created. A first selection of a wall is made from the available elements of the library of the system in use. The adaptation of objects related to walls is made based on the addition of successive layers in their composition, being assigned the type of material appropriate to each layer and indicating the respective thickness. The materials defined as membranes do not assume any thickness. Materials can be selected from the library of predefined materials, characterised with parameters related to graphic appearance and thermal and physical properties, controlled through the interfaces.

a *b* *c*

Figure 3.
Main façade with tiles (a), rear façade with fibre cement (b) and flat roof (c).

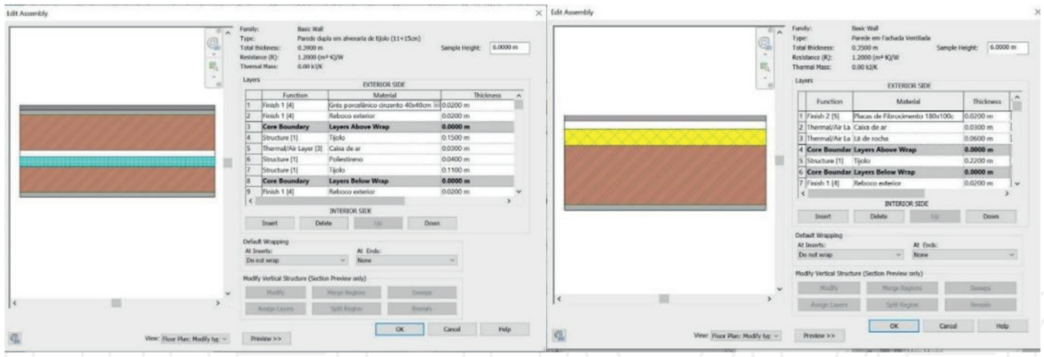

Figure 4.
Double wall in brick masonry (11 + 15 cm) with porcelain stoneware coating and wall in ventilated façade with fibre-cement plates.

The materials available in the system can be adapted to the graphic characteristics and properties required in each specific case. In the present case, there were selected materials close to those required, and later carried out the modelling of the outer cladding layers of the walls, adapted to the intended solutions. The layers of the coating materials applied to the facades were porcelain stoneware and fibre-cement boards (**Figure 4**).

The parametric objects used in the modelling process of the building were incremented with the necessary parameters related to the ESL of the components under analysis. The mentioned parameters, ESL and % lifespan, were assigned to the materials applied in both facades and the terrace roof. This allows the user to calculate the respective values obtained from the generated Dynamo scripts:

- The parameter ESL accepts the value estimated by the 'Estimate Service Life' script;
- The Excel file Maintenance records the location of the generated Excel file by the some script;
- The parameter % lifespan accepted the variable calculated based on the ESL parameter and the forecast year, obtained by the script 'ESL Analysis'.

5.1 Execution of the 'Estimate service life' script

The execution of the script is running through Dynamo Player option included in the upper menu of Revit. The script was successfully executed to estimate the service life of each of the materials identified and the result is visualised in **Figure 5**.

A table with the numerical results can be accessed and the aspect of the deterioration is illustrated by the colour assumed by each element. A period of ten years, from year 2020 and 2030, was tested. These years were referred to as the construction stage and a life forecast year.

5.2 Execution of the 'ESL analysis' script

Like the 'Estimate Service Lifetime' script, the 'ESL Analysis' script can be triggered through the Dynamo Player window. Having been configured as inputs of this script the selection of the elements in the created view and the Boolean node, it is

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 [m²]:	219
Replacement cost [€/m²]:	96
Clean cost [€/m²]:	19,49
Inspection cost [€]:	70

Figure 5.
Visualisation of the degree of deterioration and respective values.

possible to proceed to the selection of all the elements present in the view 'Analysis of useful life' where the two facades and the roof under analysis are inserted. Next, the 'VUE Analysis' script requires the indication of the year of construction and the year for which the user wants to make the prediction of the state of degradation of the element under analysis. In the lower area of the interface, it is displayed the colour legend that has been assigned according to different intervals of the % lifetime value. The execution of each of the scripts over the case study went smoothly and no errors were reported by Dynamo. After, an Excel table is obtained and exported supporting professionals to define or verify maintenance actions or plans.

This script considers the prediction of the useful life, in a global way. In the second script, an adequate colour is associated to a complete element (façade or terrace), and, as so, it not possible to define distinct zones or areas of an element with different level of deterioration. It allows to make a general comparison between the elements of the building and can even lead to rethinking the choice of some materials so that they are closer to the life of the project. However, in a more realistic situation, a more fragmented modelling of each of the elements could be applied.

6. Results and discussion

In the occupation-building phase, the BIM methodology can be implemented in order to improve the maintenance activity, namely, in the support of retrieving the required information within the database of the model and in the capacity of promoting an agile handling of data used for maintenance propose. The principal aim of the study was to incorporate into the BIM model, which must be created for each building in analyses, the degradation perdition value concerning some of the components of the building, with an important role in the exterior protection of the building, the facades and roofs.

Using the perdition value, a new strategy of visual impact was introduced supporting experts to improve their studies and easily present results to other partners and building owners, as it is possible to observe with distinct colours applied over the model, the level of degradation of the components for a horizontal period of time. In it, two Dynamo scripts were developed.

The application of the scripts developed for the case study allowed to achieve the objectives intended for the study, allowing to make an analysis of the durability of the elements to be applied in the building under study, in the design phase where the solution changes have less impact at the global costs. However, the BIM objects did not have the necessary parameters for the application of the factor method. It needs to include the reference useful life (RUL) found in the digital catalogue of each material, in order to evaluate the durability of the constructive elements in the project to which they are applied, taking into account all the factors to be filled in by the maintenance expert.

However, for the application of these scripts to a BIM model, it is necessary to create the design parameters: ESL, Excel Maintenance, % Useful life and the parameters related to costs, such as mentioned, because that's what they were called when programming was done in Dynamo. At this point, it was necessary to include, in the definition of each script, the creation of these parameters, using the node Parameter. Whenever the script was executed, the parameters were created and in the next execution, there was duplication of parameters. It would be more efficient if these new parameters were added directly and previously in Revit. Alternatively, one could proceed to the programming of independent scripts to create the necessary parameters, but the goal was to be all integrated into the same script.

The export of all the information to Excel was successful, and Dynamo proved to be a good programming software to collect and manage information from the initial model for the maintenance phase such as the composition of the elements, the corresponding area and the associated costs that served as the basis for the proposed maintenance plan. The file is also available from the BIM model, which can be accessed by selecting the Excel Maintenance parameter of the respective element and can be updated throughout its useful life.

7. Conclusion

Programing in Dynamo improved BIM performance concerning the maintenance activity, namely, concerning the estimation of the service live values of the selected materials, frequently applied in facades and terraces as finishing elements. The developed scripts allowed an analysis of the durability of the elements in the design phase where the change of solutions has less impact on overall costs. These scripts, elaborated for the presented study case, can be easily adapted to other components of the building and to other buildings. Two new parameters must be added to parametric objects representative of other components, of the present model, or of other building cases, and then the described procedure can be applied.

The application of the scripts developed for the case study allowed to achieve the objectives intended for the study, allowing to make an analysis of the durability of the elements to be applied in the building under study in the design phase where the change of solutions has less impact on the level of general costs. In it, it was necessary to assign new parameters for the application of the factorial method. Highlighting the need to include the reference useful life (ESL) in the digital catalogue of each object in order to evaluate the durability of the constructive elements in the project to which they are applied, taking into account all the factors to be filled in by the technician.

The execution of each of the scripts for the case study went smoothly and no errors were reported by Dynamo.

In addition, an architectural BIM model was developed, where only the essential steps for the modelling of the analysed elements were described, also illustrating the insertion of some types of data and additional parameters in order to enrich the BIM model with relevant information for this analysis. It is also notorious for a computer aspect in the skills of a civil engineer that increasingly tends to be necessary to explore more complex scenarios. This led to the learning of visual programming in Dynamo, and the textual syntax language in Python was also used to achieve the desired objectives through a self-learning process using tutorials available online that allowed us to explore the capabilities of this tool. Since the use of the BIM methodology is increasingly evident and the curricular plan attended does not guarantee appetite in the field of this application, this work allowed to acquire knowledge of its use.

The proposed approach supports the maintenance engineers as decision-makers concerning the maintenance activity. The developed Dynamo scripts improved the BIM-FM activity, providing the maintenance engineer with a prediction of the service life of the materials analysed, and bringing a positive contribution in the context of the building maintenance.

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