Universidade do Minho
Escola de Engenharia

Diogo Ferronato

BIM-based cost estimation at early stages
based on historical data

BIM A+
European Master in
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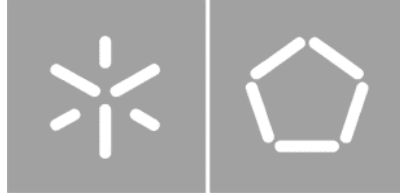
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European Master in
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Master Dissertation
European Master in Building Information Modelling

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Diogo Ferronato

RESUMO

A metodologia BIM está revolucionando a forma de trabalho do mercado de construção, levando à desejada digitalização e automatização ao longo de todo o ciclo de vida de um projeto. Ela consiste na combinação de três campos: tecnologias, políticas e processos. Juntos, funcionam como um recurso de conhecimento compartilhado para a informação, permitindo gerenciá-la, formando uma fonte confiável de dados para a tomada de decisões e possibilitando a todos os *stakeholders* colaborarem em todos os processos desde a primeira etapa do projeto. Além disso, o BIM também engloba quais dados são gerenciados em termos de criação, uso, reutilização e aplicação em modelos digitais visando o desenvolvimento e aprimoramento do projeto, construção e operação de um ou vários projetos. Dentre todos os usos possíveis para a metodologia BIM, está o suporte para a gestão de custos, vinculando as informações de custos ao modelo 3D. Esse uso é comumente conhecido como 5D BIM.

Gerenciamento de custos de projetos são os processos envolvidos no planejamento, estimativa, orçamento, financiamento, gerenciamento e controle de custos, buscando finalizar o projeto dentro do orçamento aprovado e desejado do cliente ou investidor. A estimativa de custo está entre os processos preliminares mais críticos em qualquer projeto de construção. Uma estimativa de custo inicial elevada pode levar a um processo desestimulante para o cliente prosseguir com o projeto. Alternativamente, uma estimativa de custo muito baixa pode levar a problemas financeiros durante o estágio subsequente. O método da área superficial é o método mais usado para estimativas preliminares de custos. No entanto, é uma previsão e não deve ser considerada como o custo final. Durante as fases iniciais do projeto, a qualidade e a quantidade de dados disponibilizados sobre o projeto são frequentemente baixas ou não definidas, levando a várias suposições. O uso de dados históricos pode preencher a lacuna deixada pela falta de informação. No entanto, a abordagem de estimativa de custo detalhada tradicional demanda uma alta carga de trabalho.

Esta dissertação propõe uma estimativa de custo baseada em BIM para os estágios iniciais do projeto com base em dados de custo históricos fornecidos por projetos anteriores e seu subsequente armazenamento em um banco de dados de custos. Por meio de pesquisas em artigos acadêmicos, dissertação de mestrado, teses de PhD, livros e diretrizes de custos e BIM, foram identificados desafios para o gerenciamento de custos durante os estágios iniciais do ciclo de vida do projeto. Entre os objetivos estavam a estimativa de custo facilmente atualizada de acordo com as mudanças de layout e possibilitar a atualização da estimativa de custo conforme o modelo BIM evolui. Para tanto, foi desenvolvido um *workflow* utilizando uma adaptação do método de área superficial, dividindo o valor do custo total em um sistema de classificação e classificando as áreas conforme seu uso. Um projeto hipotético foi usado para a demonstração inicial. Posteriormente, foi realizado um estudo de caso real em colaboração com uma construtora portuguesa. Como resultado, foi possível gerar uma estimativa de custo dentro de um ambiente BIM para os estágios iniciais utilizando banco de dados histórico de custos como fonte de informação. Foram feitas considerações sobre as escolhas de modelagem do projeto anterior e do amplo uso e benefícios possíveis decorrentes da aplicação do trabalho proposto.

Palavras chave: (5D BIM, Estimativa de Custo, Estágios Iniciais, Informações Históricas, Modelagem da Informação da Construção)

ABSTRACT

The BIM methodology is revolutionising the way the construction market works, leading to the desired digitalisation and automatization throughout the whole life cycle of a project. It consists of the combination of three fields: technologies, policies and processes. Together, they work as a shared knowledge resource for information, allowing to manage it, forming a trustful source of data for decision making and also making it possible for all the stakeholders to collaborate along all the processes beginning from the very first step of the project. Besides, BIM also covers which data is managed in terms of creation, use, reuse and application into digital models aiming the development and improvement of the design, construction and operation of one or several projects. Among all the possible uses for the BIM methodology, there is support for cost management linking the cost information with the 3D Model. This use is commonly known as the 5D BIM.

Project cost management is the process involved in planning, estimating, budgeting, financing, funding, managing and controlling costs, seeking to finish a specific project within the approved and desired budget from the client or sponsor. The cost estimation is among the most critical preliminary processes in any construction project. A high initial cost estimate can lead to a discouraging process for the client to proceed with the project. Alternatively, a too low-cost estimation could lead to financial problems during the subsequent stage. The floor area method is the most used method for preliminary cost estimates. However, it is a prediction and should not be considered as the final cost. During the early stages of the project, the quality and amount of data made available regarding the project are frequently low or not defined, leading to several assumptions. The use of historical data could fill the gap left by the lack of information. However, the traditional detailed cost estimation approach is a high demanding workload and time-consuming task.

This dissertation proposes a BIM-based cost estimation for early stages of the project based on historical cost data provided by prior projects and its subsequent storage into a cost database. Through research in academic articles, master dissertation, PhD thesis, cost and BIM books and guidelines, challenges for cost management during the early stages of the project lifecycle were identified. Among the objectives were the easily updatable cost estimation according to layout changes and to provide the possibility of updating the cost estimate as the BIM model evolved. Therefore, a workflow was developed using an adaptation of the floor plan area method, dividing the total cost value in a classification system and classifying the areas according to their use. A hypothetical project was used for the initial demonstration. Afterwards, a real case study was also performed in collaboration with a construction company from Portugal. As a result, it was possible to generate a cost estimation within a BIM environment for early stages using a cost historical database as a source of cost information. Considerations were made regarding the modelling choices of the previous project and the wide possible use and benefits arising from the application of the proposed work.

Keywords: (5D BIM, Building Information Modelling, Cost Estimation, Early Stages, Historical Data).

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1. INTRODUCTION

The construction industry is the second-least digitalized industry in the world, only behind agriculture (Agarwal et al., 2016). However, it is notable that the construction industry across the globe is driving towards digitalization and the Building information modelling (BIM) methodology is a powerful tool to reach this goal. In order to achieve its diffusion, there are three main diffusions dynamics (Figure 1) and its differentiation is essentially made by who occupies the role of the main actor and recipient: (1) The Top-Down diffusion, with the government or national regulatory body (e.g. applied in the UK), (2) Middle-Out, with large organizations or industry association (e.g. applied in Brazil, Canada, Finland, and Italy) and (3) Bottom-Up with the small organizations (e.g. applied in Spain and New Zealand) (Kassem and Succar, 2017).

Diffusion DYNAMIC	ACTOR Transmitter	Pressure MECHANISM	RECIPIENT Adopter	Pressure TYPE
Top-Down	Government or regulatory body	Downwards	All stakeholders falling within the circle of influence of the authority exerting pressure	Coercive; normative
		Horizontal	Governments and authorities in other markets	mimetic
Middle-Out	Large organization or industry association	Downwards	Smaller organizations further down the supply chain; members of industry associations	Coercive; normative; mimetic
		Upwards	Governments and regulatory bodies within the market	Normative
		Horizontal	Other large organizations and industry bodies within or outside the market	Mimetic; normative
Bottom-Up	Small organization	Upwards	Larger organizations and industry bodies	Normative
		Horizontal	Other small organizations	Mimetic; Normative

Figure 1 - BIM diffusion Dynamics (Succar, 2019).

According to NBIMS Committe, 2007, "a basic premise of BIM is the collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder". Inward the whole phases of the life cycle, it is necessary to segregate the tasks into BIM Uses to have better control and a clear goal to achieve. The Computer Integrated Construction Research Program from Penn State University created twenty-five BIM uses, divided among four stages of the project lifecycle – Plan, Design, Construct and Operate. Meanwhile, within the BIM Uses, there are Phase Planning - 4D Modelling and Cost Estimation – Quantity take-off and 5D Modelling (Messner et al., 2019).

The phase planning, or 4D modelling, is a process where the used model consists on the 3D model combined with the time dimension, as to plan actions such as the occupancy in case of renovation or to show the scheduled construction evolution and occupation of the construction site. It also works as a visual and communication tool to drive all stakeholders for a better understanding of the project

milestones and construction plans (Messner et al., 2019). Moreover, it also contributes to more intelligent allocation management of materials, time, resources (Agostinelli et al., 2019) and considering the constructability methods to develop each activity (Elghaish and Abrishami, 2020). On the other hand, the cost estimation, or 5D modelling, is a process which shall occur during the whole life cycle of a project, from the very early stages of the project until the facility management stage. This process seeks to generate better quantity take-offs and cost estimations using the BIM model as a source of information (Messner et al., 2019). Besides, develop a more precise, faster and integrated cash flow with the construction planned sequence and its actualization over time (Liu et al., 2014).

Commonly in the construction sector, the project data related to the planning and costs are usually analysed in a non-integrated form, often carrying little meaning and precision and requiring a high work-demand to manually integrate this information (Cho et al., 2010). However, the BIM methodology is allowing the development of integrated workflows to pursue a better framework and conditions to all the stakeholders regarding the project, information management and decision making.

With this dissertation, it is intended to obtain a deeper understanding of the use of BIM for the cost estimation at early stages, its application, and challenges to its implementation. The general objective of this dissertation is to apply the BIM methodology into the early stages of the project, enabling the generation of cost estimation based on historical data gathered by previous projects. It will be achieved by defining some real challenges faced by the construction industry related to cost and planning management. Besides, translating it to specific objects for the 4D and 5D BIM Uses and developing a workflow located at the early stage of the project, which also allows the use of the generated information on further stages.

The methodology proposed for this MSc dissertation is based on the assessment of a company current workflow, construction industry and academia challenges for cost estimation and will mainly tackle this by: (i) a systematic literature review; (ii) development and specification of a workflow by a hypothetical project, (iii) application of the workflow into a real case study and (iv) analysis of the results.

Firstly, meetings with the company were set to understand the actual workflow and the needs of the company regarding the process of cost estimation and the application of the BIM Uses 4D and 5D. Afterwards, a scientific literature review was made in cost estimation, budgeting and controlling where the BIM methodology has been used, for understanding the current practices applied in this field and how the data is utilized. With a better understanding of the literature review, a workflow was developed and applied, which allows a fast cost estimation at the early stages using historical data and presented in an organized classification system.

Considering that the cost estimation is performed at the pre-tender stage, the company may not know in advance if it will be selected to construct the project, and since it does not have that guarantee, it is desirable not to dedicate a large number of work hours in the project. Due to it, a suitable approach is to use a company's historical data built into a database aiming to generate estimations of costs. Besides, integrating this database within the BIM environment decreased the needed work hours to create and assess multiple alternatives, supporting better decision making during early stages of the

project. Moreover, this initial estimation was organized in a way that continues to be useful on the following steps of the design and construction management.

With the finalization of the cycle, the entire workflow was analysed, and considerations were made regarding the positive and negatives parts of the proposed dissertation, listing some potential future works related to the presented workflow or the following stages.

This master dissertation was structured on five chapters, namely: introduction, review of the state of art, BIM-based cost estimation, case study and conclusions. On the review of the state of the art were researched about the BIM methodology itself, showing its concepts, interoperability and dimensions. Besides, were classified cost management and the most used methods for cost estimation. The last part of this chapter was related to the link between cost management and BIM, also called 5D BIM.

On the chapter BIM-based cost estimation the proposed work was introduced, the criteria for the software selection were defined, challenges and objectives related to cost and planning management were presented. Besides, the workflow was demonstrated been applied to a hypothetical project.

On the case study was applied an application of the proposed work, gathering information from a real project and using it on a future project under development. The results and considerations regarding the of the workflow were also presented.

On the last chapter were made final comments about the proposed dissertation work, what were the perceived benefits of its application and suggestion for future developments.

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2. REVIEW OF THE STATE OF ART

2.1. Building Information Modelling – BIM

2.1.1. BIM Definition

BIM methodology is gaining position inside the AECO (Architecture, Engineering, Construction and Operation) sector and is one of the technologies trending in the construction industry (Kulasekara et al., 2013). However, the definition of this methodology is commonly misunderstood by the user and professionals of the sector. Even if the term BIM is well accepted and widespread, its meaning and the exact words that form it are not a consensus between the academia and industry. BIM could be the acronym for Building Information: Model (Kim et al., 2013), Modeling (Sacks et al., 2018) or Management (McArthur, 2015). Figure 2 shows some common connotations for the multiple BIM Term.
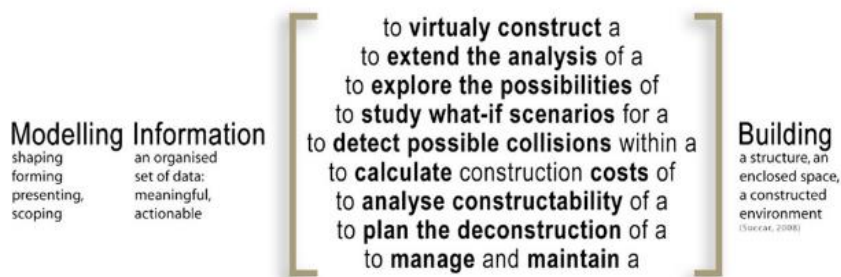
Figure 2 - Common connotations for several BIM terms (Succar, 2009)

Besides, many professionals link the BIM methodology as the use of software capable of designing their projects in a 3D form. This fact may be attributed to the fight between the software developers in the 2000s. The big software developers at that time tried to be the first one to develop software containing the rising new future of the design and construction data management (Chuck et al., 2008). Another possible reason is related to the benefits of the adoption of the BIM methodology which can only be felt when its processes, premises and concepts are interpreted by software, processing and filtering the information according to the desire of the user (Lino et al., 2012).

However, this understanding is not complete. This definition could be considered as part of the entire BIM. The functional definition of BIM is a combination of the three fields: technologies, policies, and processes (Succar, 2009). It works as a shared knowledge resource for information, allowing to manage it, forming a trustful source of data for decision making and also make possible to all the stakeholder to collaborate during its life cycle from inception onward (BuildingSMART, 2015). Beyond this, the pragmatic definition is that BIM works as a common language with many dialects for the entire construction industry, allowing to discuss and learn about the construction industry innovation all around the world (Succar, 2009).

Likewise, BIM is a digital representation of physical and functional characteristics of a facility (BuildingSMART, 2015) and process which data is managed, in terms of creation, use, reuse and application into digital models with the purpose of development and improvement of the design, construction and operation of one or several projects (Sacks et al., 2018). It is an intelligent simulation of the project and its characteristics. To enable the achievement of the integrated project delivery, are necessary to achieve, at least six key elements: digital, spatial, measurable, comprehensive, accessible, and durable. Clustering it allows to quantify, query, communicate, assess constructability, sequential and financial aspects of the project, interoperable between different tools and stakeholders and maintain the track and integrity of the data during all the phases of a facility's life (Campbell, 2006).
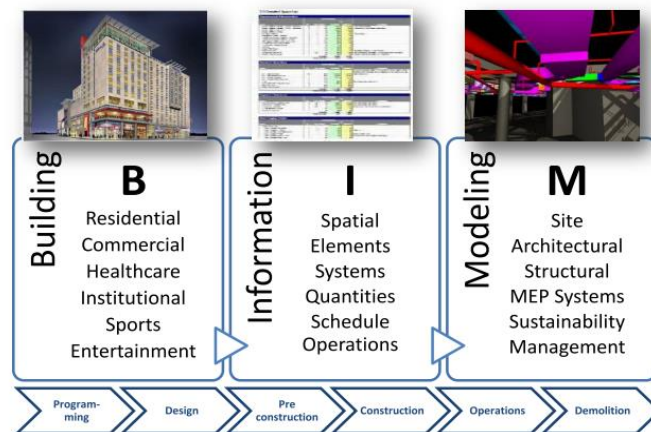
Figure 3 - Some explanations of each BIM acronyms letter (Azhar et al., 2015)

According to the definitions above, it is a consensus that BIM is much more than just software, and with the BIM implementation comes significant changes regarding the workflow and the project delivery processes inside the company/project (Hardin and McCool, 2015). Another possible change which came together with the BIM implementation is the Integrated Project Delivery (IPD), which is a project delivery approach to improve the collaboration between all the stakeholders integrating people, systems, business structures and best practices. Together, they optimize the process to reduce waste during the whole lifecycle of the project, anticipating decisions and spreading valuable information thought at the early stages of the project (Glick and Guggemos, 2009).

2.1.2. BIM Concepts related to models and elements.

Although the project desires to keep all the information in the same place to avoid redundancy and inconsistences, the sources of information are often from different stakeholders. To achieve this goal, inside the BIM methodology has mainly two different characterizations for the models of a project, the federated and coordinated models. A federated model is characterized as a distinct individual BIM model, which does not affect automatically other federated models, nor is affected by. The several federated models are linked and interact exchanging data among them, even though a change into one model impact the others, does not change automatically other federated models, reinforcing the distinction among them and the ownership of data. Usually, each discipline has it own federated model (e.g. architectural, structural), with the exception in big projects when is necessary to create several federated models within the same discipline, due to the better management. In this case, they are called volumisation model. On the other hand, the coordinated model is characterized by the merge of

several federated models, with the purpose to gather all the information and perform an integrated analysis of the status of the project, such as clash detection and constructability assessment (Cerovšek, 2019).

In terms of modelling, while the computer-aided design (CAD) approach is to design the object made by several lines, forms and text, the BIM methodology consists of the object-oriented approach. This method consists in model the object in an identical organization as the object exists in the real world, imputing information, classes, relationships, and characteristics of the object into a data structure database. It allows the interaction with other elements, enabling the use and filter of this information by demand of the user activity. Besides, with this approach, the user is possible to input not only geometrical information about the object but also information regarding developer, fabricant, clearance areas, costs, properties and other information required by the user (Sousa et al., 2011).

The oriented-object approach also reduces inconsistency and rework during the process. Once the object is created, this data is stored and allow reusing the same information inside the same or other projects and software. One sample is when you design an object "wall", and after it is generated a floor plan, 3D view and a quantity take-off, the software gets this information from the database. Therefore, when a change is performed on its parameters (e.g. length or height), it is automatically updated in all the floor plans, views, and quantity take-offs (Azhar et al., 2015).
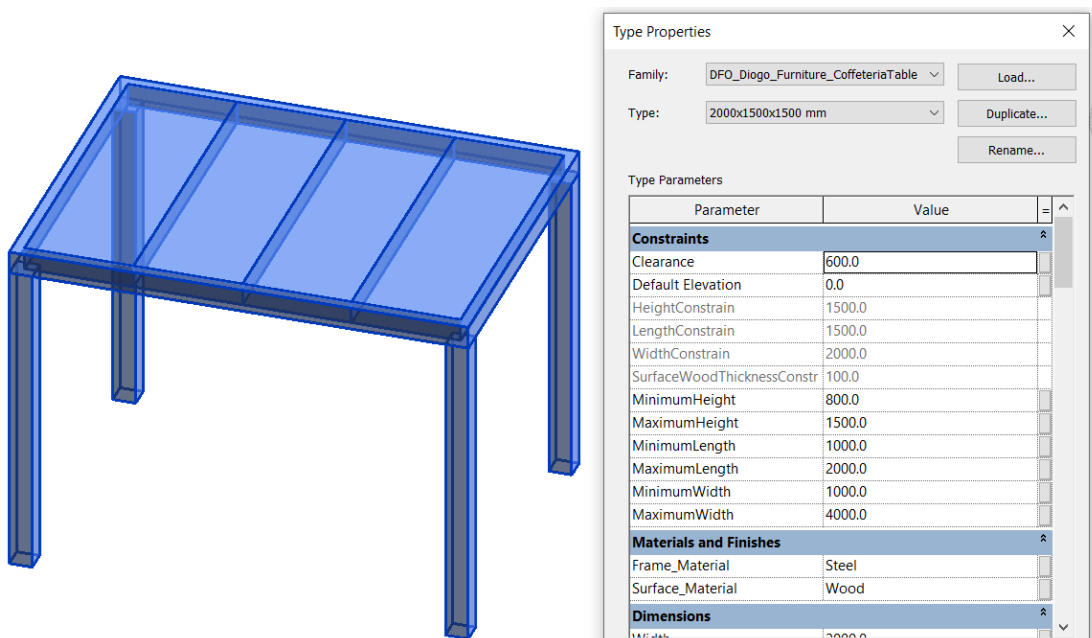
Figure 4 - Type properties and constraints of a cupboard modelled in Revit.

The introduction of the parametric design and relations is also one of the benefits of the BIM methodology, changing from the documentation that was only understandable by humans for new data representations which computer can also interpret (Jeong et al., 2009). As a consequence of the parametric design and relations, now each element from the model has internal and external pre-defined rules to follow, establishing connections and behaviours for the interaction between elements and classes of the model (Sousa et al., 2011). Internal are the ones defined within a class of object (e.g. the minimum or maximum length of a cupboard, as shown in Figure 4). The external is the relations

between two objects or classes (e.g. during the structural design, the column and beams are smart enough to do not create an overlap between the elements, avoiding an error for the quantity take-off or properties of the elements). This object-oriented design is shown in Figure 5.
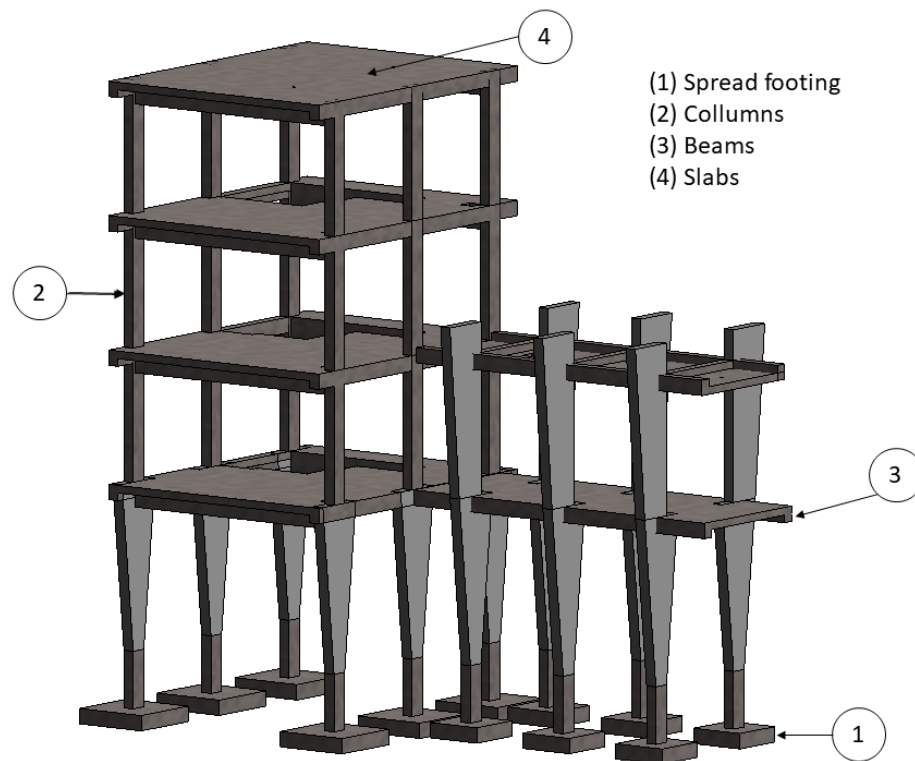
Figure 5 - Sample of a structural model designed in an object-oriented software (Adapted from Sandoval et al., 2019)

The result of these rules is that the computer now can analyse the relations between several and different objects while the user is doing the changes. If any rule is broken, the software does not finish the changing process. In case of a change that impacts other objects, the model adapts automatically according to pre-established rules between the elements, avoiding systematic errors and a very time-consuming checking of the model (Poças, 2015).

2.1.3. Dimensions

Besides the BIM Uses, there is also the definition of BIM according to dimensions. The dimension 2D and 3D are the more familiar use of BIM and usually the first benefits of the use of the BIM methodology. The dimension 2D consists of bi-dimensional drawings, such as floor plans, elevations and sections (Poças, 2015). The 3D dimension consists in the three-dimensional model expressing the design concepts, the parametric modelling, collision detection and model walkthroughs visually. (Charef et al., 2018). However, the BIM adoption allows to go further than only the 2D and 3D geometrical representation, as shown in Figure 6. It also allows performing other analysis regarding essential procedures and stages of the project, which was elaborated in a non-connected way before (Poças, 2015). To enhance the use of the three-dimensional structure of BIM, new ways of approaching the tool have been implemented over time (Gledson and Greenwood, 2016).

The visualisation and benefits brought by the 3D BIM started to be not enough to the industry, and better uses began to be defined by new dimensions of the BIM application. The responsible that are dictating these dimensions are mainly the researchers and the users of the methodology. The dimensions 4D and 5D, have a well spread and accepted definition for 3D model + time and 3D model + cost, respectively. However, the dimension 6D and 7D present some contradictions in academia and practitioners (Charef et al., 2018). The National Building Specification (NBS) defines the dimension 6D as a dimension where information regarding facility management and operation activities are included into the model (McPartland, 2017), nevertheless within the academia some articles and for some practitioners using the 6D dimension is also defined as sustainability (Charef et al., 2018) (Yung and Wang, 2014).
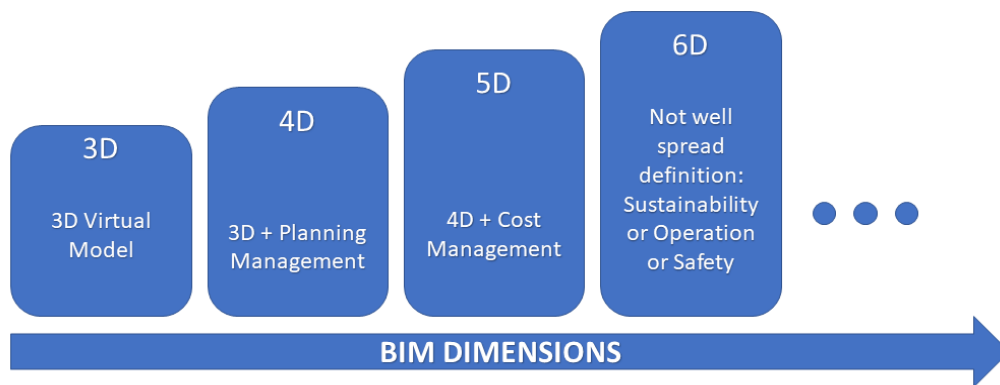
Figure 6 - BIM Dimensions

Due to their importance within the present work, the BIM 5D definition will be covered and explained in more detail in the following sub-chapters.

2.2. BIM and Cost Management

2.2.1. Cost management

The Project cost management is the processes involved in planning, estimating, budgeting, financing, funding, managing and controlling costs seeking to finish a specific project within the approved budget from the client or sponsor (PMI, 2017). Among these processes are:

1. Plan Cost Management – In this process are defined how the project cost will be estimated, budget, managed, monitored and controlled.

2. Estimate costs – The process of forecasting the approximate amount of cost needed to complete a specific task or project work.

3. Determine Budget – The process of cluster all the costs of all individual tasks/project work to generate a cost baseline.

4. Control costs – The process of monitoring the cost of the project, analysing the forecast cost and updating it if needed (PMI, 2017).

Cost management within the construction industry also relates to all cost-related activities since the start of the project until a successful building occupation, operation and maintenance (Ashworth and Perera, 2013). The cost management has several steps according to which stage of the project. It is undertaken in almost all the phases of a project, even considering that the activities can significantly vary. The cost management lifecycle starts together with the cost estimation during the preparation phase and least until the construction project complete. (Lu, 2018). Figure 7 demonstrates some of the tasks and responsibilities according to the stages defined by the RIBA Plan of Work.
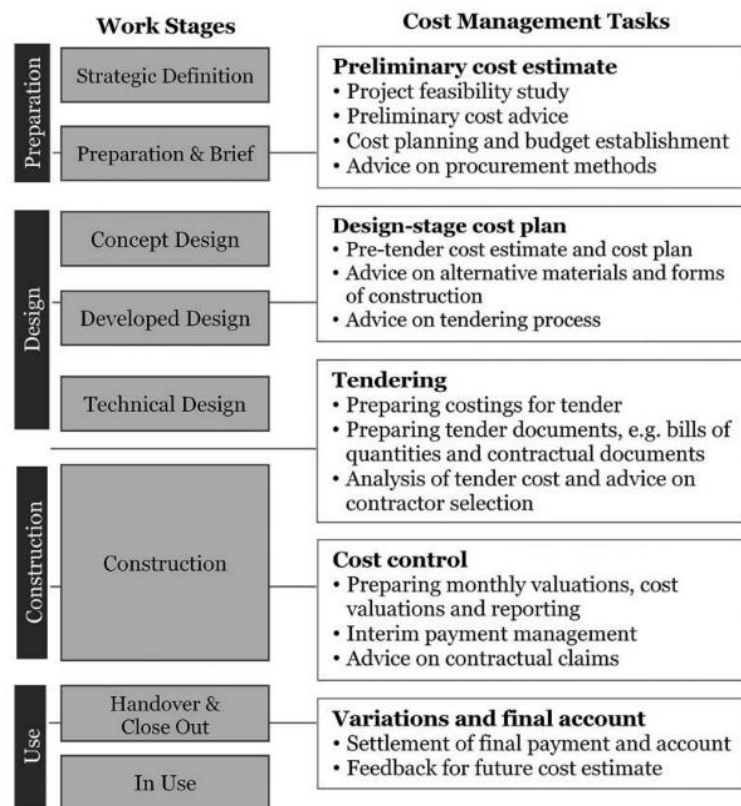
Figure 7 - Cost management tasks in the context of the RIBA Plan of Work (Lu, 2018)

The process of cost estimating is prepared and started as early as the company requires and should be revised and updated at many stages throughout the project. Considering it is a prediction, it should not be considered as a final cost, and it has the characteristic not to be 100% accurate (Potts, 2008). The most essential criteria for acceptance for cost estimation is accuracy. During the early stages of the project, the quality and amount of data made available regarding the project are frequently poor or not defined, leading to the assumptions and considering characteristics of similar previous projects. The impact of misunderstanding these characteristics could bring considerable effects on the stakeholder's perceptions of the project and sometimes even derail the project in economic terms. A high initial cost estimate can lead to a discouraging process for the client to proceed with the project. Alternatively, if the estimation is too low, it could lead to financial problems during furthers stage. Considering that the cost estimation of a construction is a probabilistic activity, is preferable to show a range of estimated sum or an explicit value margin rather than a fixed amount (Ashworth and Perera, 2013). Figure 8 shows a base for the acceptable estimate accuracy according to the stage of the project.

Project Stage	Feasibility	Concept Design	Preliminary front-end design	Detailed design
Estimate Accuracy	-25% to +50%	-15% to +25%	-10% to +15%	-5% to +10%

Figure 8 - Estimate accuracy according to the project stage (adapted from (Potts, 2008)).

The cost estimate under preliminary and feasibility stages usually prove to be less accurate but quicker than in the other. This process also relies on the experience and expertise from the professional who is performing the task, the historical cost data gathered in the company from similar and previous projects (Lu, 2018). Besides, the preliminary cost estimation should also consider the work term, the location of the project and which is the use and standard of the project (Potts, 2008).

In order to perform the cost estimation, a starting point is to define which method will be applied in the process. Several methods are widely used in the construction and other industries around the world. Thus, more than only accuracy other parameters should also be considered during this decision, such as how the information is related to the project, what is the time available to the estimation and how is the historical data stored (Ashworth and Perera, 2013). Figure 9 shows some methods generally used for initial cost estimates. Among the techniques shown in Figure 9, the most commonly used are the superficial method, unit method and approximate quantities method.

The superficial method, also known as "Floor area method", is the most used method for preliminary cost estimates. This method is fast to calculate, and also it is shown in a very perceivable way for all involved stakeholders. It consists of measuring a total area of all floors of the project in case and multiply by a historical unitary cost appropriate from similar previous projects. In order to have a comparison and a benchmark line among the projects, the floor area is calculated from the internal dimensions of the building. The historical unitary cost could be provided by former projects from a client, within the historical database from a company or from official data for unitary building cost provided by local institutions (Ashworth and Perera, 2013; Lu, 2018).

The unit method, also known as "Cost according to building function", consists in the selection of a standardise function unit for the project and multiply it by a historical base cost per unit. Usually is selected the best function to describe the use of this project. This method considers a close relationship between the cost of construction and the functionalities provided by the project. Some samples for the standard units are: (1) Beds, in case of a hospital project, (2) Car spaces, in case of Car Parking Project and (3) student, in case of a School project. This method is useful for estimating public and national buildings programs, in which it is necessary to have some comparability in the unit cost. (Ashworth and Perera, 2013; Lu, 2018)

The approximate quantities method consists of cost composition items which are measured combining or grouping specific bill-measure items. Even though this method has the characteristic to provide a more detailed cost estimation than the others, it is a very time and effort-demanding method. The

composition or grouping are performed according to the experience of the surveyor and require more information from the project. This method suits better to a more advanced stage of the project rather than at an initial phase. Thus, this method is more effective and used in practice when there is the possibility to analyse the complete project documentation at first, mainly in public tenders or big projects tendered with the design stage finished (Ashworth and Perera, 2013; Lu, 2018).

Method	Notes
Conference	Based on a consensus viewpoint
Financial methods	Used to determine cost limits or the building costs in a developer's budgets
Unit	Applicable to projects having standard units of accommodation. Often used to fix cost limits for public sector building projects
Superficial	Still widely used, and the most popular method of approximate estimating. Can be applied to virtually all types of buildings
Superficial perimeter	Never used in practice
Cube	Used to be a popular method amongst architects, but now in disuse
Storey-enclosure	Largely unused in practice
Approximate quantities	Still a popular method on difficult and awkward contracts and where time permits
Elemental estimating	Not strictly a method of approximate estimating, but more associated with cost planning; used widely in both the public and private sectors for controlling costs
Resource analysis	Used mainly by contractors for contract estimating and tendering purposes
Cost engineering	Mainly used for petrochemical engineering projects
Cost models	These methods are still in the course of development.

Figure 9 - Methods of initial cost estimating (Ashworth and Perera, 2013).

2.2.2. 5D BIM

The importance of the cost estimation during all the stages of a project has been widely recognized and performed. However, the traditional cost estimation approach is a very workload and time-consuming task, leading to results with low accuracy and reliability, which may cause disastrous costs overrun and project delay. In order to help this problem, one of the existing solutions is the application of the 5D BIM. It consists of the 3D model with the addition of the cost information (Cho et al., 2010). This BIM use leads to more precise cost estimations since the early stages and together with the automatic quantity take-offs allows a better understanding of the impact of changes and decision making during all the stages (Sacks et al., 2018). Using 5D Models also provides a better evaluation of alternatives scenarios and different approaches for the same project, allowing better decision making

during all the project lifecycle. Figure 10 shown a sample of 5D BIM software while performing the cost management together with the 3D visualisation of the project. Furthermore, (Wang et al., 2016) developed a model that utilises BIM to create a project budgeting curve, namely, an S curve. This model generates an optimised cost budget curve based on multi-criteria, making it more reliable in implementation and giving a realistic indication concerning cost/schedule cases.
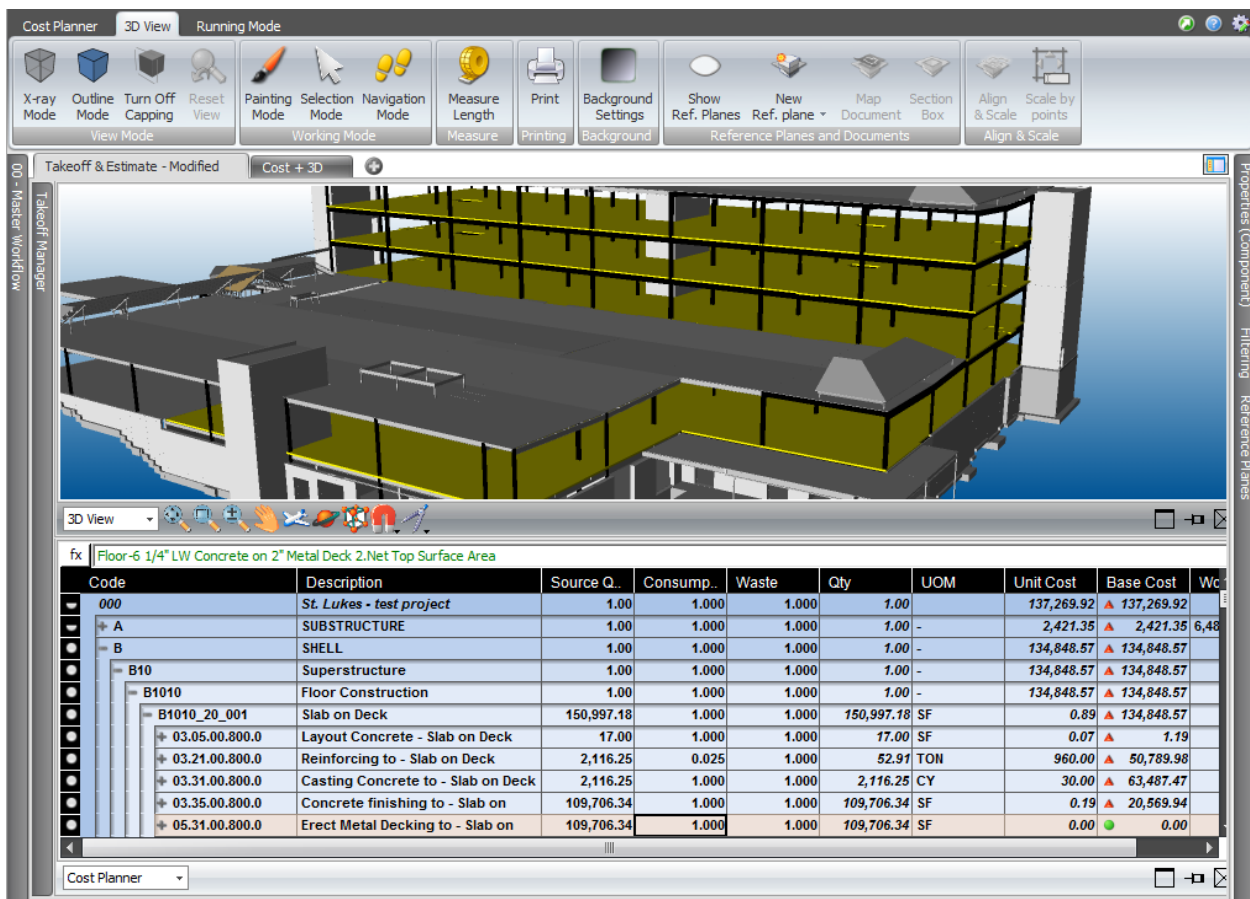
Figure 10 - **Sample of BIM 5D software (Trimble, 2019)**

Among the main advantages and uses of the 5D BIM Uses and stages are the quantity take-off, cost estimating, cost budgeting, cost control, life cycle cost analysis and claims (Vigneault et al., 2019). The use of BIM models allows for faster and more efficient quantity take-off reports and material needs schedules. Besides, the combination between the bill of quantities extracted from the model and the visual analysis of those same quantities result in an optimized report, carrying fewer errors and improving the overall visualization of the project. However, BIM models hardly contain all the necessary information to enable a complete and correct quantity take-off automatically (Nadeem et al., 2015). Some quantities of the project cannot be extracted from the model for several different reasons, such as current tools capabilities, how the information was structured in the model or due to lack of modelling some objects (Monteiro and Martins, 2013). Thus, during the quantity take-off process will still be needed to the use of indicators for some quantities, modelling of missing information or experience to validate the generated report (Chuck et al., 2008)

Utilizing the quantity take-off provided by the selected BIM solution, it usually allows the user to register the unitary cost to each resource/activity, generating the cost estimation (Azhar et al., 2015) It

usually also contain features allowing the user to link the quantity take-off to an external database to implicate in a less manual and faster task (Sacks et al., 2018). This link between the model and an external cost database also enables the possibility to generate alternatives in terms of cost and resources, demonstrating a more realist expectation of the project. Moreover, it improves the client and all stakeholders understanding of the project and the impact of their decisions related to cost (Olatunji et al., 2010). Further in the project, it is also an important step to consider real prices from subcontractor's quotes to the model, generating the Cost Budgeting.

Cost control should be performed regularly, updating the cost data, and analysing different economic indicators and generating reports. Automated cash flows analysis developed with the use of 5D BIM allows faster and more precise cash flow forecasts at early stage of the project. Besides, the current cost data can then be compared to the previously modelled cash flow to evaluate the variance between the actual costs and the budget, identify the most cost impacting elements and assess the probable final cost of the project (Sacks et al., 2018)

Procurement purchasing 5D BIM tools capabilities now allow the purchasing of elements directly from the model, since the objects modelled represent what needs to be acquired. Users are then able to use models developed by product manufacturers containing all the necessary specifications for quantity take-off, material schedules and cost estimating (Chuck et al., 2008)

5D BIM also allows the user to select a particular period to verify the completed task and select its elements, the related cost and validate the information regarding the subcontractor progress and compare its progress with the paid amount (Olatunji et al., 2010).

3. BIM-BASED COST ESTIMATION

3.1. Introduction

On this chapter, all the steps performed and considerations will be explained. Firstly, it was defined the software to be used during the entire process proposed by the workflow. Soon after, the main challenges detected in the field of cost and plan management were grouped during the pre-tender, design and construction stages. These challenges were researched through academic documents and interviews with a large construction company in Portugal. Next, the work stage and objectives for the proposed workflow were defined. With the goals defined, the workflow was developed and applied based on a hypothetical project to test it before the case study. The main steps to generate the cost estimation and plan validation purpose were summarized and demonstrated by Figure 11. The entire workflow will be explained in the following sub-chapters.
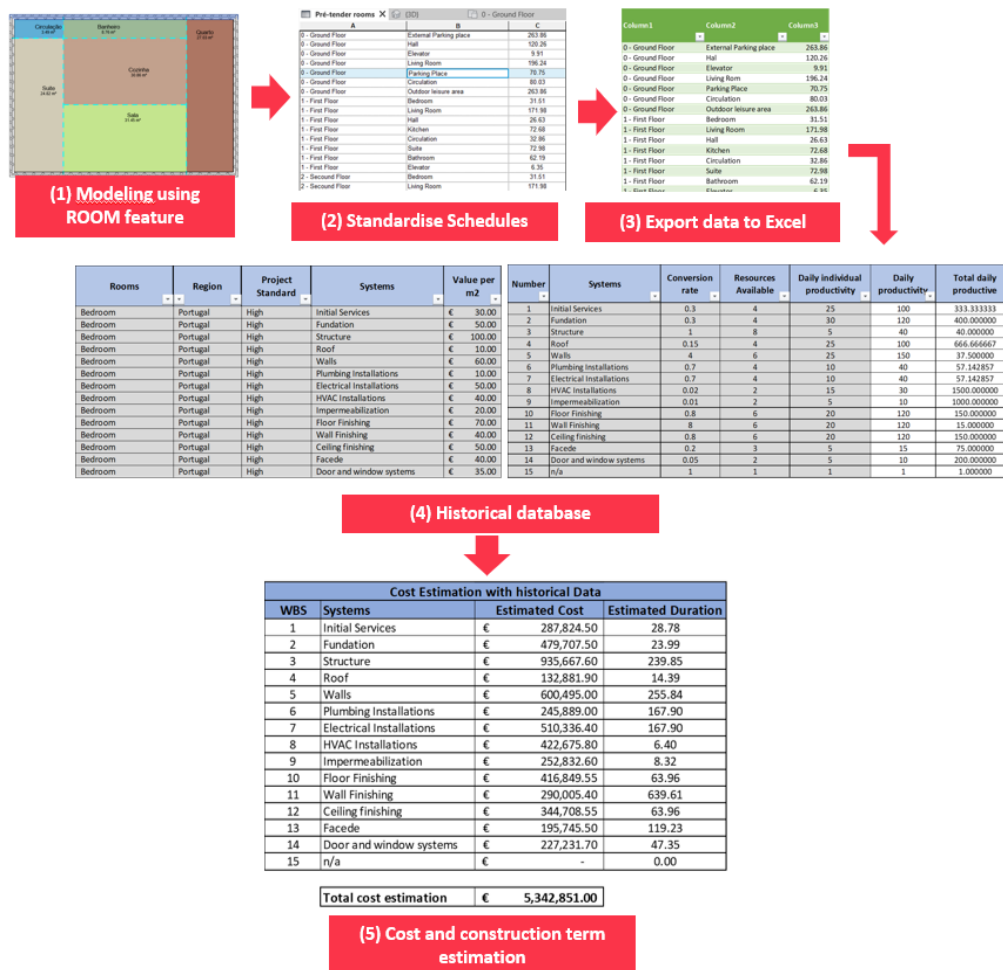
Figure 11 - **Steps for generating the cost and construction term estimation.**

3.2. Selection of software and its application

For the development of the workflow, the main filter for the software selection was to work in a BIM work environment in terms of modelling and extracting the information and a database application with good interoperability with the selected BIM tool. Then, several software were studied and analysed according to its characteristics and the use by the construction industry. The selected BIM authoring tool software was Autodesk Revit 2020 for modelling purposes and Microsoft Excel for the database creation and computing the cost estimation. The use of these software are directly linked with the following benefits and characteristics:

I.   Both software is well spread among the construction industry.

II.   Autodesk and Microsoft have academic licenses for Revit and Excel.

III. Availability of information to self-learn the software with tutorials online. The content provided by the software developers are enough to use the workflow developed.

IV. Previous knowledge and extensive use by the author in both software.

V.   Select software support to work in a BIM environment at further stages.

3.2.1. Autodesk Revit

The software Autodesk Revit is one of the most commonly used within the BIM environment. The original software was developed by Charles River Software, in 1997 and was acquired by Autodesk in 2002. This software is focused on the construction industry and was designed directed by the Building Information Modelling (BIM) methodology. Most of the concepts mentioned in chapter 2 above are present in Autodesk Revit.

As a software designed to the construction industry and within the BIM methodology, Revit allows importing information by several files extension apart from the RVT (native Revit file format), such as IFC, DWG, gbXML. Besides, the software allows extracting the required data in different forms. The user has the possibility to export the data from the BIM model as 2D documents and drawings, images, animations, OBDC database and tables/schedules in the TXT format. This last is the one applied to extract the data from the model within this workflow, linking the project model information with the excel database.

3.2.2. Microsoft Excel

Microsoft Excel is a powerful electronic spreadsheet application release in 1985 by Microsoft which permit to create and edit tables automatically, calculate, analyse, manipulate and display data into several different ways. Besides, the software accepts to manipulate the data using formulas, graphing tools, pivot tables, and to program automatically macros using the Visual Basic for Applications (VBA) language. Besides, excel has excellent interoperability with other software, allowing to import and export information in a wide range of formats and software. Even though Excel is not a specific tool to design and operate relational databases, it allows simulating a database, extracting data from pivot tables, queries and use of logics and formulas to achieve the information needed. Also, the

export feature from Revit saves the file as a delimited text, with extension .txt. This format is easily opened and configured in the Microsoft Excel application.

In the context of the proposed workflow, the Excel application will be used as the database, containing the historical data related to the cost and productivity, the location where information about the project will be processed and crossed with this database and generating the cost and construction term estimation related to each pre-defined group of activity in a fast and automatized way.

3.3. Challenges detected within the construction industry

In order to achieve a useful contribution for both academia and professional application, theoretical research and meetings with a big construction company from Portugal, where the new workflow was applied and tested, were performed. The goal was to understand some gaps and needs related to the cost and planning management and, through these gaps, establish objectives to a new workflow supporting the implementation of BIM 4D and 5D. Even though this master dissertation is not going to develop a complete workflow for cost and planning management through all stages, it also contributes to the stages following the initial stages. To organise the challenges, they were divided into three different construction stages: Pre-tender stage, design stage and construction stage. This division was performed due to the different needs, goals, inputs and outputs according to each stage. The points brought by the company and interpreted during this work are shown in Figure 12.
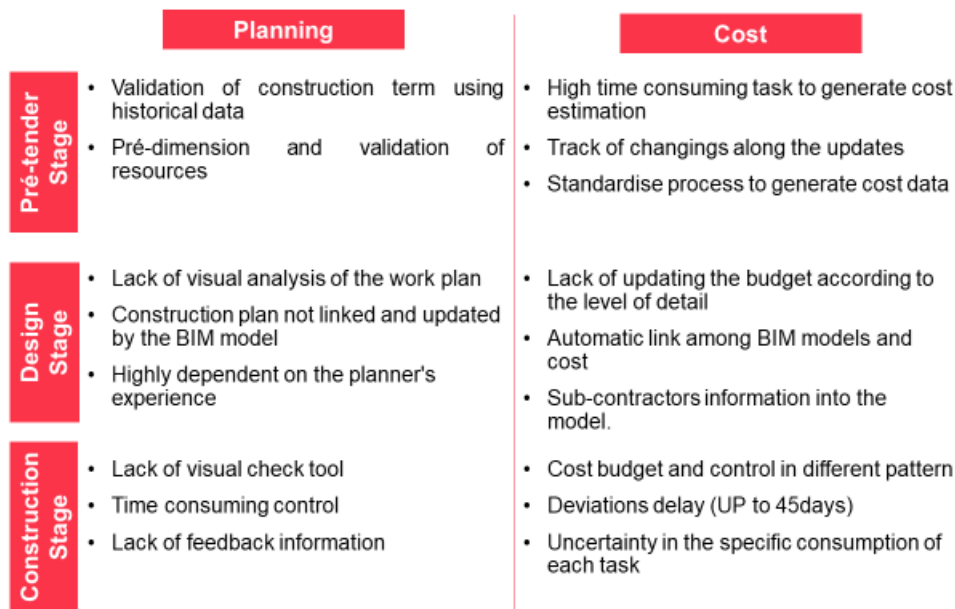
Figure 12 - **Planning and cost challenges through the defined stages.**

The first stage is the pre-tender stage. This stage starts as soon as the project itself start is initiated. During this stage, the information related to the project needs are usually not well defined, the construction company and sub-contractors usually are not yet been hired, and the technical preconstruction information is under assessment and development. Due to these premises, this phase has a high chance to incur significant variations and changes in the project, impacting to the cost and generated planning. Considering it all, the information generated among this stage should be performed with a low time consuming, the capability to be easily updated, flexible, not necessarily

high a rate of specificity and preferably use of automatic generation for the greatest number of tasks. To achieve these goals, the implementation of historical data from previous projects is highly recommended.

The second stage is the design stage, where during this period, the information received by the pre-tender stage is detailed in a more specific way, according to the project requirements. The cost and planning information received is based on historical data from previous projects, adapted and proportionally distributed by floor areas to the current project. The historical information is replaced by specific project cost and planning information according to the increase detailing of the model. Among the challenges during this stage are the visual analysis of the information generated, lack of automatic update of cost according to the model and a direct link among cost, plan and BIM model. At the end of this stage, the design information required for manufacturing and constructing the project needs to be completed.

The last considered stage is the construction stage. This stage starts together with the works on the construction site. The pre-tender and design stage are responsible for generating cost and planning forecast information. Meanwhile, the construction stage will make use of it, control and report feedbacks. All the needed information to perform the tasks related to cost and planning must have already been completed in the two previous stages. This information will be used as the basis for the tasks, reports and decision making in the construction stage. Also, this stage is responsible for assessing and controlling this information during the task, comparing what was performed with the planned one. This comparison could lead to the need for updates and reschedules. At the end of each task and the construction stage, the information generated by this stage should be used as an input of historical data for the pre-tender stage.

The output of each stage related to cost and planning works as an input for the following stage, as shown in Figure 13. The output of the pre-tender stages is the estimation, which is the topic of this dissertation. The output of the design stage is detailed information supporting the construction stage. After the handover of the project, the validated data should be used as input for future works as historical data. This approach allows reusing of the information generated.
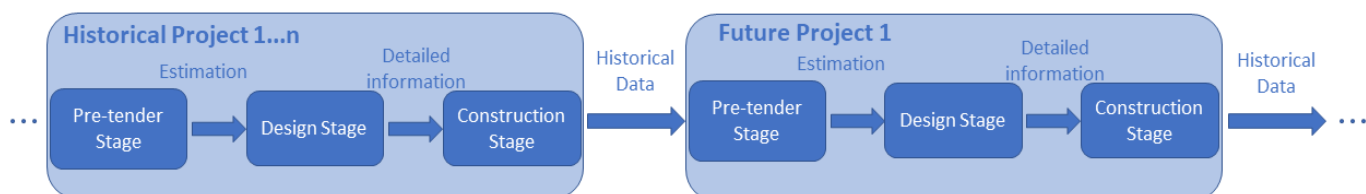
Figure 13 - Generating, storing and reusing cost information.

3.4. Objectives of the workflow

The objectives of the workflow can be divided into two different groups, namely the objectives of the workflow as a whole and the specific objectives to reach for the cost and planning estimation. Some of these objectives directly impacted on the software selection, as mentioned on the sub-chapter 3.2. The objectives of the workflow as a full application are the following:

- Perform cost estimation in a BIM environment at early stages based on historical data.

- Easy use and application by the construction industry.

- The workflow is performed in a BIM solution and database which is deeply in use by the construction industry and with easy access for educational licenses.

- Do not need big tutorials to apply the workflow.

- The user has the power to define the level of information generated by the workflow.

- Make it possible to use the same workflow for several different quality standards and typologies projects.

- Flexible to validate and update the information at the end of the project cycle.

- Reduce drastically the time needed to generate the information at the initial stages.

- The information generated could be used in the following stages.

- Enable to check the accuracy of the generated data on the following stages.

On the other hand, the main objectives related to cost and planning estimation are shown in Figure 14. Even though this dissertation workflow is focused on the pre-tender stage, were defined as possible cost and planning objective according to the stages and challenges mentioned on the sub-chapter 3.3.

BIM 4D	BIM 5D
Pré-tender Stage • Validate the estimate construction term • Apply the company's productivity rates for construction term estimations. • Estimate according to available resources.	• Faster cost estimation at early stages • Use of historical data • Standardise process and output
Design Stage • Visual validation for the construction planning • Virtual simulation of the project. • Modelling guideline for construction stage.	• Cost estimation and budged update according to the Model. • Cost mile-stones established. • Integrated cash-flow and BIM model.
Construction Stage • Visual controlling of forecast x performed • Visual critical path of the project. • Highlight unnecessary GAPS among activities due to rescheduling	• Cost budget and controlling in the same pattern. • Cost comparison forecast x performed on-time. • Order control and measurement.

Figure 14 - Objectives according to each stage.

On the field of cost estimating, the workflow aims to make possible the cost estimating at early stages of the project, where the amount of information is still limited. The workflow should provide information to support the decision making by the stakeholders, such as that needed to change layout or floor area size of the project, the systems with the most significant impact on the cost and modelling sequence of the most critical systems for cost management.

The objectives of the workflow for cost estimation are:

- Cost estimating at early stages of the project

- Easily updatable cost estimation in case of a layout change.

- Use of historical data grouped and organized for projects of the same typology

- Personalised cost estimation.

- Independent of the project, the input and output are shown in the same organized way.

- Easy to change, upgrade or update the information

- The user defines the level of detail of the cost estimation.

For the planning estimation purpose, the complexity inherent in the process is higher compared with the cost estimation process made in an automatic. There are a lot of internal relations and decisions on how to process with the construction plan. There are different correct ways to proceed with a construction plan, and the decisions are made according to specific needs of each project and team, not only related the construction technics adopted but also to other resources. As a consequence of it, the objectives of the workflow related to planning estimation are more focus in a sense for validation the expected term using historical data and available resources than automatic generating a schedule or sequences of activities. The objectives of the workflow for planning estimation are:

- Validate the construction term desired by the client

- Validate the amount of resources needed for the time and task

- Estimate the construction term according to the teams available for each period.

- Use historical productivity rate for the estimated term

3.5. Workflow

Figure 15 shows the proposed workflow developed for the entire cycle of the cost estimation at early stages. The cost estimation will be based on data available from previous projects developed by the user. Even though all historical information should be within a BIM methodology, this does not preclude the use of the workflow. It was developed to accept information generated by other work methodologies, as long as they are in the specific format required. However, this may imply more significant difficulties in data collection, more manual work or estimations. This cost information must

be organized and filled or exported to an external cost database. In this database, the information will be stored and ready to be used by future projects. As many previous projects as possible should be imported into this database, in order to provide a more solid basis for future estimates.

With the database filled, the next step is to generate the project information to provide the estimated cost. At this time, it is necessary to use the BIM methodology for the workflow to work. The information must be exported from the selected BIM authoring tool to the database containing information from the project rooms. After that, the database will correlate the historical costs of the old projects with the rooms of the new project and will generate the desired cost estimate.

All of these steps will be explained in detail and demonstrated through the hypothetical case study developed in the next sub-chapters.
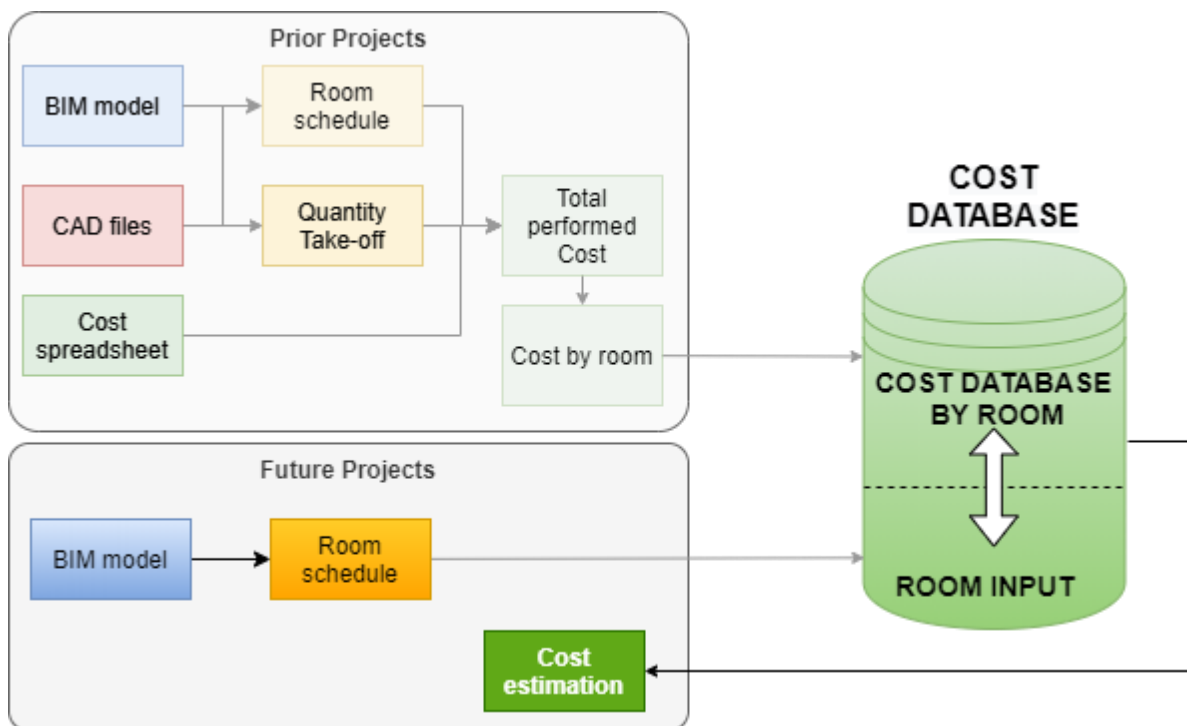
Figure 15 - **Workflow developed**

3.5.1. Calculation method

Several different approaches were analysed and were decided to apply the Floor Plan Area method for the estimation methods. According to (Ashworth and Perera, 2013), this is the most used and spread method for cost estimations among the construction industry. Usually, this method consists in sum the total floor plan area of the project and multiply it by a fixed average cost for the building use or purpose. The most significant benefits of this method are that it is fast to generate a cost estimation and easy for understanding the source of information. However, this method applied conventionally does not consider any other project information rather than the use and the total floor area. Besides, this average cost data is usually provided by market analysis or the average of construction costs from the project's local area and not the specific historical data from the company performing the cost estimation. Equation 1 presents how the cost is estimated applying the conventional floor plan area method

$$CE = FPA \times UAC \qquad \textbf{(1)}$$

Where:

CE = Cost estimation; FPA = Floor plan area and UAC = Unitary Area Cost.

To consider more project information, the method was adapted to consider more information during the cost estimation process. The idea of sum the area and multiplying it by an average value will be maintained. Still, the information will no longer be unique and general for the entire building, but a sum of values considering the internal layout of the project and the cost composition of each room. Instead of just two values multiplied, the FPA and UAC were now defined according to the internal use of the project. For example, in the case of a residential building, the systems contained in a bedroom and a bathroom are different, leading to different costs. For the proposed workflow, the bedroom and the bathroom have different values for the FPA and UAC, resulting in a cost estimation by each internal area. The total cost estimation is the sum of all the cost estimation of each internal area of the building, as shown in Equation 2. Considering these differences in the calculation method allows a more specific estimate for each project. Besides, as in the conventional method is also necessary to sum up all areas of the building, it is possible to generate a more specific cost estimate than the conventional method with the same time dedicated to this activity. Moreover, it is now also possible to carry out the estimation of several different scenarios of internal layouts for a project, even if the total value of the floor plan area does not change. This feature is of great value to support decisions making during the proposed stage for this workflow.

During the initial stages, it is very common to made changes in the internal layout of the projects due to several factors, for example, requirements of public bodies during approvals, problems with the terrain, optimization of internal areas, decisions on construction techniques, changes in the needs of the client, financing and funding difficulties, among others. With this new approach, it is possible to demonstrate the consequences of the cost of the changes made more quickly. With this, the decision has more support to be performed in a more agile way.

$$CE = \sum_{i=0}^{n} FPA_i \times UAC_i \qquad \textbf{(2)}$$

Even though the information generated has an excellent value for layout analysis at early stages, it is still not sufficient to achieve the objective of generating useful information for the next stages of the project. Although it allows the analysis of several different scenarios, it still does not allow its continuous updating as the project's modelling process advances. For this, the format of the unit cost of each area was adapted. Instead of applying a fixed value for each area, this value was segregated according to the systems needed to build the specific area. For example, in the case of a room, the conventional method would only use the cost information per square meter of the room. However, the actual information generated is a total value, not showing how each system impacts the cost. Thus, it is not possible to update this information when only one system is detailed, only after the entire project

has been completed. In the proposed workflow, the value of each system contained in the room is considered. After this breakdown, it is possible to generate the project cost estimate not only as a final value but also as a sum of the cost of the construction systems. In this way, it is possible to generate a forecast of which systems will have the most significant weight on the cost of the project. This information support different decision-making by different project stakeholders, such as which will be the first systems to be modelled and detailed.

The user's specific historical database provides all information related to the organization of the project areas, costs and how the project systems will be characterized. This is a crucial step in the process, as the amount of effort required to prepare historical information is proportional to the level of detail and complexity desired for the estimate. Thus, the organization of the areas and the classification system defined will be used for both cost estimation and planning validation. Although there are classification systems for civil construction, the information generated using them would not be used efficiently if the user has all his historical information and cost management defined in his own system. Also, it would be against the objective of allowing the user to have flexibility in generating and updating their cost estimates if a specific area and classification system is determined.

As mentioned by (Cho et al., 2010), the cost and planning information is usually generated in a non-integrated form, leading to time-consuming updates. To solve this constraint, the workflow was developed considering that the specific information about the project for the cost estimation and validation of construction planning is the same. Therefore, for planning validation, the floor plan area method was also applied and adapted. The same area classification applied for the cost estimate will be used. As described above, the objective related to the planning is not to generate a sequence of tasks automatically, but rather to validate whether the desired construction term is consistent or not with the historical basis of productivity and available resources. This validation is done in the same classification system used in the cost estimate. However, historical productivity data is usually measured at its main unit and not by floor plan area. For example, the measured productivity of the masonry service is measured by the square meter of masonry performed per day, and not by the daily square meter of masonry per floor plan. To solve this problem, a conversion rate was applied to bring the productivity of all systems to the same unit of the method. This information is often not available and requires a more in-depth analysis of previous similar projects. After obtaining a conversion rate for each system, the available amount of resources and the average productivity, it is possible to estimate the duration of execution of each system and validate if the construction term is executable or not.

The activities to perform the estimation and validation were divided into four different significant steps: organizing the historical data, modelling the information, the calculation of the cost estimation and the planning validation. A hypothetical project and historical data were used to elaborate and pre-validate the workflow before the study case.

3.5.2. Historical Data

The workflow started with the preparation of the historical basis to be used in the following steps. Some considerations were made before starting to fill in historical data:

- It is necessary to know the desired level of detail for the cost estimate. How the historical base will be clustered is directly linked to this. When higher accuracy is aimed at, more detailed clustering of the data is required. In addition, the quality of the output of the workflow is dependent on the quality of the historical basis. A large amount of poorly analysed and poorly accurate data will lead to an estimate with low reliability.

- Caution to highly detailed estimates at such an early stage was taken. Although it is possible to have a great degree of detail through this workflow, it was not developed to generate a bill of quantities, but cost estimation according to the construction system based on the specific layout of the project.

- The time required for organizing and filling in the historical base is exponentially linked to the determined estimate level of detail. Non-useful information desired in excess, which will not be used in future stages, leads to wasting time and efficiency during the workflow.

- When deciding which areas to register, it is worth remembering that the output is a cost estimate at an incredibly early stage of the project, so areas with small differences characteristics do not necessarily need to be separated.

- The workflow was developed allowing the evaluation, correction, updating and addition of new systems and areas in an organized, direct and straightforward way. Therefore, do not stick to several specificities at the beginning of the process.

After these considerations, it will be demonstrated with the hypothetical project how the workflow was developed by means of which are the necessary historical data inputs and how the information is handled automatically.

Having as starting point the historical data inputs, two more variables were selected besides the room and classification system mentioned above. This information is related to the region in which the project will be carried out and its quality level. The database was designed in such a way that each region and quality level contain its relative cost. Although it does not lead directly to a more accurate cost estimate, it allows the use of the same historical database to projects in different countries and from different standards. Moreover, it supports also to compare the estimations for the same project in different countries. This is of great value for multinational companies and the ones with a wide range of products.

The separation of the areas was done through 11 different types of areas corresponding to common uses, namely: bedroom, suite, kitchen, bathroom, hall, living room, circulation, elevator, parking place, external parking and outdoor leisure area. The classification system adopted was divided into 14 different systems, namely: initial services, foundation, structure, roof, walls, plumbing installations, electrical installations, HVAC installations, floor finishing, wall finishing, ceiling finishing, façade and door and window systems. Considering it is a hypothetical project, the area and system classification were based on the background experience of the author within cost management. For the example purposes, the regions were divided into two: Portugal and Spain, Finally, the project standard into High and Medium. Figure 16 shows how the initial information was organized in the Microsoft

Excel sheets. In order to organize the information, all the inputs cells needed to be typed by the user were filled with grey colour. All the cells with values and filled with white colour are calculated automatically.

Rooms	Number	Systems	Region	Project Standard
Bedroom	1	Initial Services	Portugal	High
Suite	2	Fundation	Spain	Medium
Kitchen	3	Structure	n/a	n/a
Bathroom	4	Roof	n/a	n/a
Hall	5	Walls	n/a	n/a
Living room	6	Plumbing Installations	n/a	n/a
Circulation	7	Electrical Installations	n/a	n/a
Elevator	8	HVAC Installations	n/a	n/a
Parking place	9	Impermeabilization	n/a	n/a
External Parking place	10	Floor Finishing	n/a	n/a
Outdoor leisure area	11	Wall Finishing	n/a	n/a
n/a	12	Ceiling finishing	n/a	n/a
n/a	13	Facede	n/a	n/a
n/a	14	Door and window systems	n/a	n/a
n/a	15	n/a	n/a	n/a
n/a	16	n/a	n/a	n/a
n/a	17	n/a	n/a	n/a
n/a	18	n/a	n/a	n/a
n/a	19	n/a	n/a	n/a
n/a	20	n/a	n/a	n/a

Figure 16 - Historical data organization in Microsoft Excel

After defining all the variables to be considered in the workflow, the historical data was filled out, relating all these characteristics. As mentioned above, the number of values to be filled is proportional to the variables. The defined way led to 616 different cost information. Figure 17 exemplifies how the historical cost data for a bedroom was filled, for Portugal and considering a High construction standard. Note that the information provided is the cost according to each system. The spreadsheet will consider the values in this way to perform the cost estimation calculation, but this way makes it difficult to assess whether the values are correct or not. To solve this, the values of all systems were grouped, in order to show the final unit costs of each area. To achieve this, conditional values search, sum and logic formulas were used in the historical cost database. The final form of these grouped values is shown in Figure 18.

Rooms	Region	Project Standard	Systems	Value per m2
Bedroom	Portugal	High	Initial Services	€ 30.00
Bedroom	Portugal	High	Fundation	€ 50.00
Bedroom	Portugal	High	Structure	€ 100.00
Bedroom	Portugal	High	Roof	€ 10.00
Bedroom	Portugal	High	Walls	€ 60.00
Bedroom	Portugal	High	Plumbing Installations	€ 10.00
Bedroom	Portugal	High	Electrical Installations	€ 50.00
Bedroom	Portugal	High	HVAC Installations	€ 40.00
Bedroom	Portugal	High	Impermeabilization	€ 20.00
Bedroom	Portugal	High	Floor Finishing	€ 70.00
Bedroom	Portugal	High	Wall Finishing	€ 40.00
Bedroom	Portugal	High	Ceiling finishing	€ 50.00
Bedroom	Portugal	High	Facede	€ 40.00
Bedroom	Portugal	High	Door and window systems	€ 35.00

Figure 17 - **Filling bedroom information for Portugal and High standard**

Rooms	Region	Project Standard	Cost by m2
Bedroom	Portugal	High	€ 605.00
Suite	Portugal	High	€ 660.00
Kitchen	Portugal	High	€ 680.00
Bathroom	Portugal	High	€ 680.00
Hall	Portugal	High	€ 525.00
Living room	Portugal	High	€ 640.00
Circulation	Portugal	High	€ 515.00
Elevator	Portugal	High	€ 910.00
Parking place	Portugal	High	€ 640.00
External Parking place	Portugal	High	€ 465.00
Outdoor leisure area	Portugal	High	€ 465.00
Bedroom	Portugal	Medium	€ 515.00
Suite	Portugal	Medium	€ 560.00
Kitchen	Portugal	Medium	€ 605.00
Bathroom	Portugal	Medium	€ 640.00
Hall	Portugal	Medium	€ 455.00
Living room	Portugal	Medium	€ 560.00
Circulation	Portugal	Medium	€ 455.00
Elevator	Portugal	Medium	€ 910.00
Parking place	Portugal	Medium	€ 605.00
External Parking place	Portugal	Medium	€ 445.00
Outdoor leisure area	Portugal	Medium	€ 425.00

Figure 18 - **Cost values according to each room, region and project standard**

For the historical data related to planning was characterized in another format. As mentioned above, the information required for the planning validation is the conversion rate to transform the quantity of services from its original unit to square meters and daily productivity. The daily productivity was calculated by the daily individual productive multiplied by the number of available resources. The total daily production was calculated, applying the conversion rate to daily productivity. The available resources data is only required to calculate daily productivity data; however, they were filled together, considering that this is a theoretical validation. Figure 19 shows how the data was presented and organized.

Number	Systems	Conversion rate	Resources Available	Daily individual productivity	Daily productivity	Total daily productive
1	Initial Services	0.3	4	25	100	333.333333
2	Fundation	0.3	4	30	120	400.000000
3	Structure	1	8	5	40	40.000000
4	Roof	0.15	4	25	100	666.666667
5	Walls	4	6	25	150	37.500000
6	Plumbing Installations	0.7	4	10	40	57.142857
7	Electrical Installations	0.7	4	10	40	57.142857
8	HVAC Installations	0.02	2	15	30	1500.000000
9	Impermeabilization	0.01	2	5	10	1000.000000
10	Floor Finishing	0.8	6	20	120	150.000000
11	Wall Finishing	8	6	20	120	15.000000
12	Ceiling finishing	0.8	6	20	120	150.000000
13	Facede	0.2	3	5	15	75.000000
14	Door and window systems	0.05	2	5	10	200.000000
15	n/a	1	1	1	1	1.000000

Figure 19 - **Historical productivity data**

Now all the necessary historical data for the workflow has been filled. The way it will be automatically processed by the software according to the project information will be explained in the sub-chapter of cost estimation and planning validation. The next step of the workflow is generating the project data by the modelling process.

3.5.3. Modelling

The modelling process of the proposed workflow was performed in the software Revit 2020. It was developed so that it does not have several steps that are time-consuming and is focused on generating only useful information for the workflow. At this point, it is not necessary to focus on graphical and non-graphical information on the model, but on generating the information necessary for the application of the method. Although these are of great value, they will not be used and applied at this specific stage.

When starting the Revit 2020 software, the default Architectural template of the software was selected, as shown in Figure 20. As the method is based on the floor plan area, it is essential to check which are the project units considered in the software. An important step is to check if the project area unit and rounding considered in the project is the same than the used in the database, as shown in Figure 21. The entire database is organized using the mentioned unit. If the extraction of the information from the BIM model does not follow the same organization, it will lead to incorrect cost estimation.
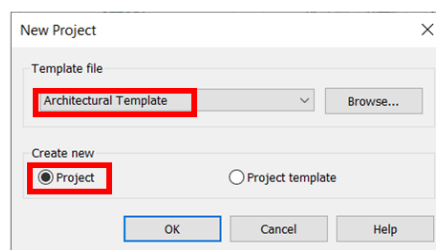
Figure 20 - **Architectural template selected on Revit**
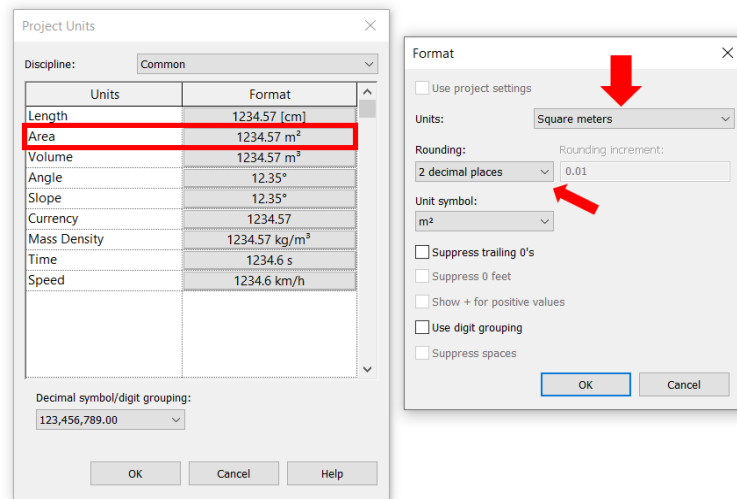
Figure 21 - Project units defined on Revit software

With the unit and format defined, the modelling process itself was started. The modelling process is impacted as the client initially generated the project layout. The Revit software allows the link and import of several different formats, for example, its native format RVT, IFC, CAD, XML, PDF and images, as shown in Figure 22. For this hypothetical project, it was considered that the modelling would start from the beginning, without any link or import.
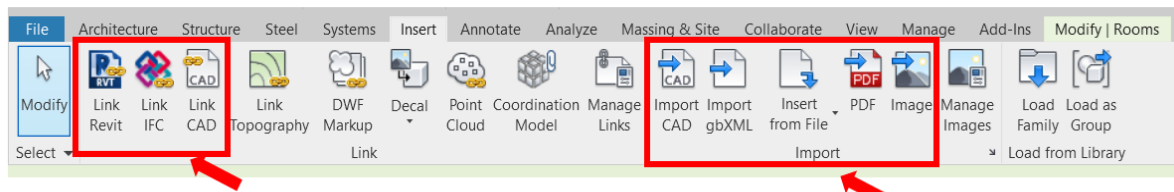
Figure 22 - Importing options of the source of information.

To define the project areas, the "Rooms" feature of the software was used. "Rooms" are considered a model element in Revit, like walls and door. In this way, it is possible to add the graphical and non-graphical information needed in this element. This feature allows you to create and detail reports which describe the areas defined in plan views. Revit considers a "room" to be a subdivision of a project area, based on boundaries elements, such as walls, floors and roofs. The software also allows the use of room separation lines to subdivide spaces where there is no physical division through border elements. The moment the border element is added, moved or deleted; the dimension of the "room" is updated automatically. It is also possible to pre-define room names in the software before placing the wall or other border elements in the model. In this way, the first step was to add the specific areas contained in the project. Afterwards, the rooms inside the software were created. As it is only allowed to place rooms in a plan view, the project levels and their respective floor plans were generated, as shown in Figure 23.
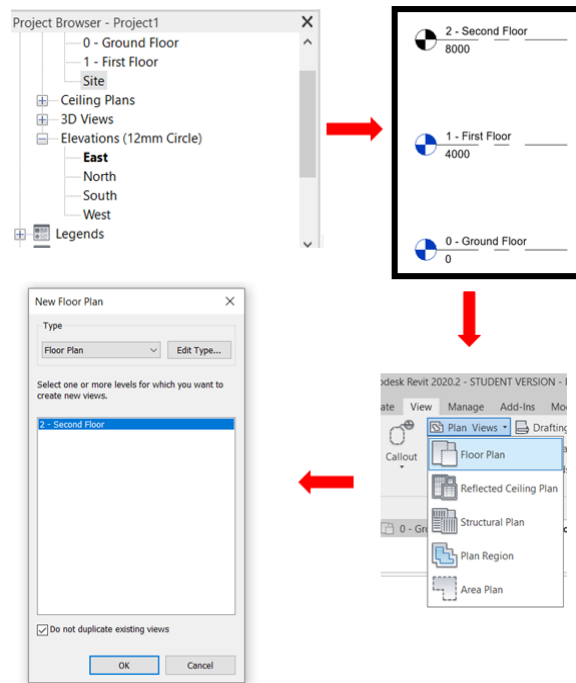
Figure 23 - Generating the floor plans

With the generated floor plans, the process of modelling room-bounding elements began. As a way to test the resources, it was decided to use both walls and room separation lines as delimiters. The external bounding was modelled as walls and all internal divisions with the room separation line. As this example is hypothetical, it was not considered a real layout of a project, but only areas for the continuity of the workflow. After modelling the elements walls and room separation lines, the command "Place rooms automatically" was used to generate all areas automatically. Afterwards, the names of each area were changed according to their use. A visual legend tool based on the name was added to make a visual check of areas were. These were divided into internal and external areas of the building on the ground floor. Figure 24 shows how the model looks after all these steps were performed.

The same process was carried out for the first floor, only differentiating the internal areas in order to generate a more realistic example.

At this moment, the necessary information about the project to estimate the cost and validate the execution time of the work has already been elaborated. The next step was to organize this information in a standardized way and export it. It was performed using the schedule/quantities feature and selected the category Rooms for the schedule, shown in Figure 26.
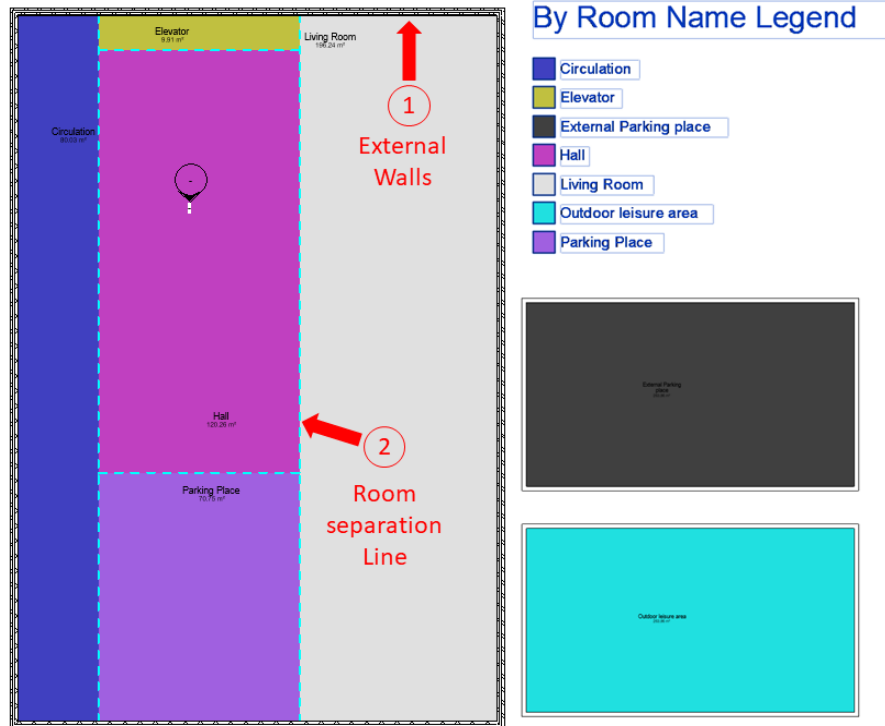
Figure 24 - Ground floor areas
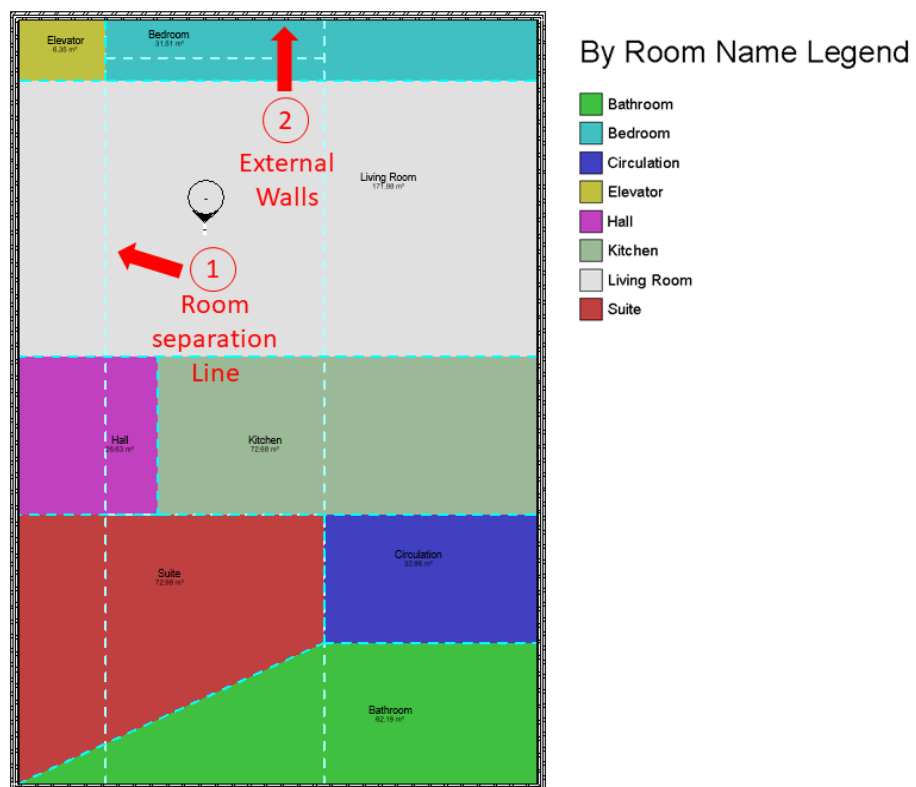
Figure 25 - First and following levels layout
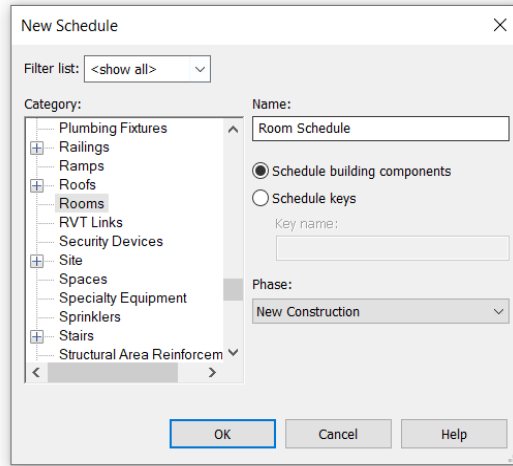
Figure 26 - Creating the schedule

The necessary information contained in the Revit room element are: (1) Level, (2) Room name and (3) its plan area. In order to organize this way, it was necessary to configure the fields, sorting/organizing and formatting configuration of the schedule. In the field configuration, were added the three related parameters from the room element. On the sorting configuration was decided to sort by Level. An essential step during this configuration is to check the box "Itemize every instance", otherwise it will be sorted only by level, and not by level and room. At the formatting area, was selected the field "Area" and selected to calculate the totals of each room. All these steps are shown in Figure 28. The final generated information is now organized the correct way, as shown in Figure 27

Figure 27 - Final schedule containing floor area data
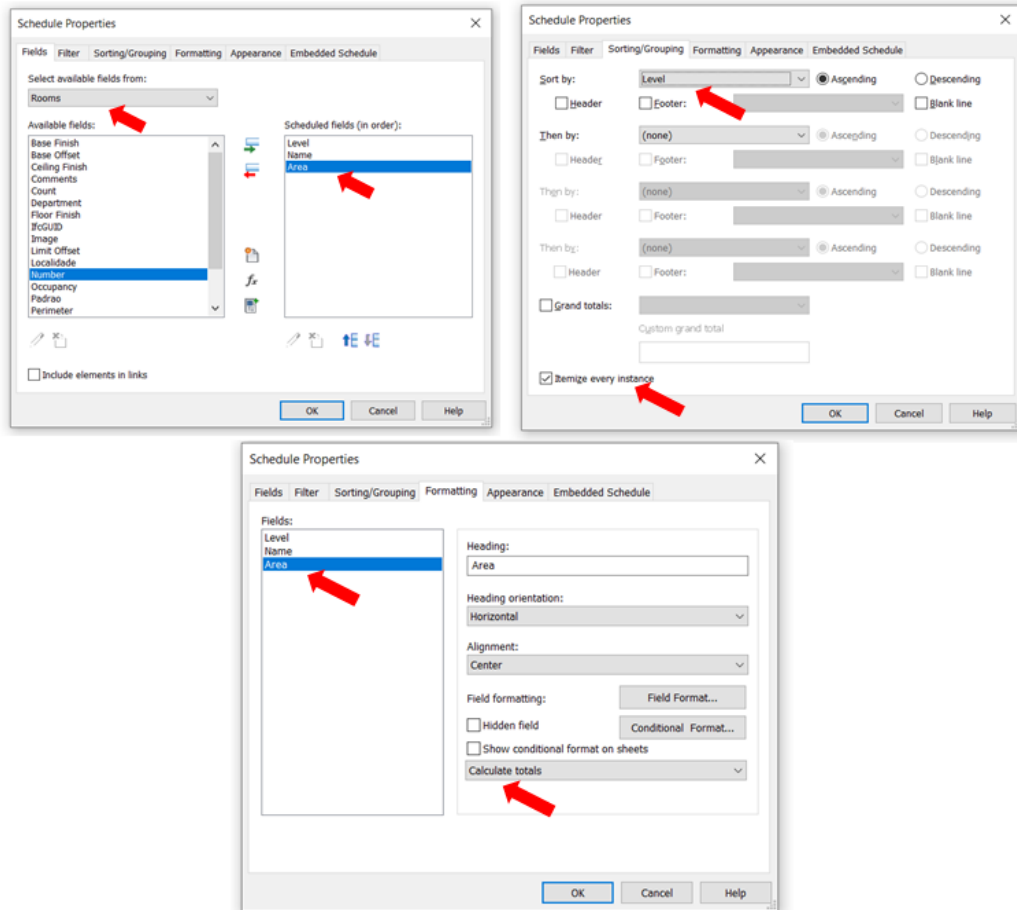
Figure 28 - Schedule configuration

The last step was to export this information. The software provides an exportation feature and was not needed to develop an API or script to perform this task. The file format extension of the export is delimited text file, which is easily read and manipulate by Microsoft Excel. To perform the export, while selected the generated schedule view, it was considered to export the schedule as a report. Considering that the schedule had already been configured, no major configuration was needed. Figure 29 shows the steps and configuration applied.

Now, all the data needed by the modelling part was already finished, and this delimited text data will be used and manipulated by the Microsoft Excel, where the cost estimation and planning validation were performed
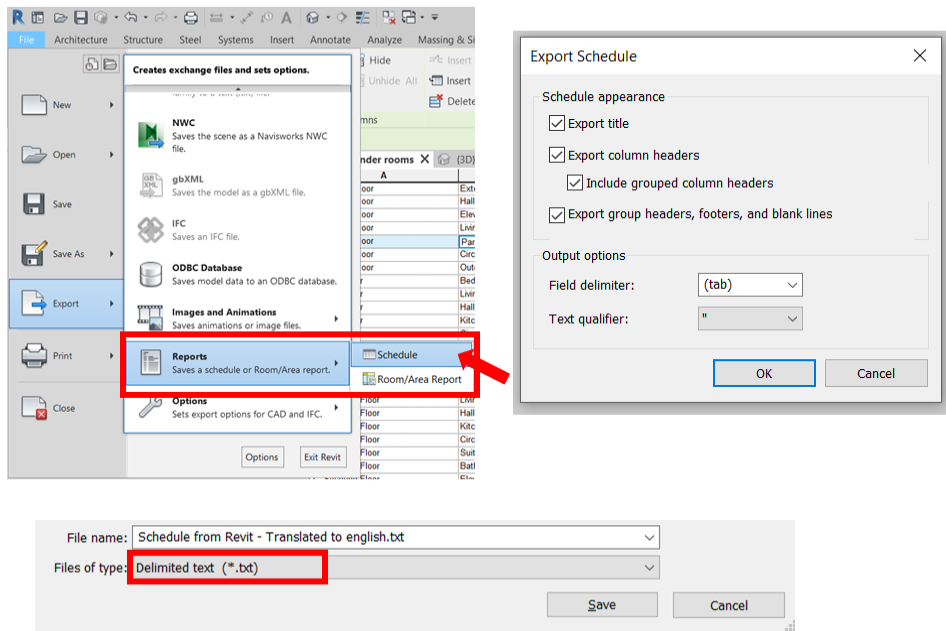
Figure 29 - Export process and configuration utilized

3.5.4. Cost estimation and Planning Validation

At this stage, the information related to the project to be analysed and the historical database are fully available. Now the integration of these two information points will be done, where the automatic analysis and the generation of the reports are made. The integration between the delimited text file and the Microsoft Excel was performed using the "Get Data From TXT/CSV File" from Microsoft Excel. The information imported from the TXT file will be stored and presented in the table format, as shown by Figure 30.

Column1	Column2	Column3
0 - Ground Floor	External Parking place	263.86
0 - Ground Floor	Hal	120.26
0 - Ground Floor	Elevator	9.91
0 - Ground Floor	Living Rom	196.24
0 - Ground Floor	Parking Place	70.75
0 - Ground Floor	Circulation	80.03
0 - Ground Floor	Outdoor leisure area	263.86
1 - First Floor	Bedroom	31.51
1 - First Floor	Living Room	171.98
1 - First Floor	Hall	26.63
1 - First Floor	Kitchen	72.68
1 - First Floor	Circulation	32.86
1 - First Floor	Suite	72.98
1 - First Floor	Bathroom	62.19
1 - First Floor	Elevator	6.35
2 - Secound Floor	Bedroom	31.51
2 - Secound Floor	Living Room	171.98
2 - Secound Floor	Hall	26.63
2 - Secound Floor	Kitchen	72.68
2 - Secound Floor	Circulation	32.86
2 - Secound Floor	Suite	72.98
2 - Secound Floor	Bathroom	62.19
2 - Secound Floor	Elevator	6.35

Figure 30 - Project information imported as a table in Excel

This table must be positioned at a specific position in the work area, allowing all analyses to be carried out automatically. For this reason, a link was created between a blank file and Excel. The file exported

by Revit should replace this blank file, keeping its location and file name. Another way of working is to enter the table settings and replace the data source where the exported Revit file is located.

It is necessary to check the exported data before continuing with the workflow. This verification step is of utmost importance for the expected result to be achieved. Without this verification, the workflow would not be considering areas containing error embedded in their name, such as a typo or rooms not registered in the database. It was programmed to verify if each of the values contained in column 2 of the table has an identical record with defined values. This verification was done comparing the data in the table with the defined rooms shown in Figure 16 of the sub-chapter 3.5.3. In order to show where is the error embedded, the Pivot Table feature was used. This feature analyses the compared data and shows the amount of obtained errors. Clicking on the total number of errors, it shows which are the incorrect rows. Figure 31 shows two typos made on purpose, located at the "0 – Ground Floor", where Hall and Living Room were misspelled. The same figure also evidences how the Pivot table showed the results in a dashboard and the specific error information by clicking on it

Before continuing, it is necessary to return to the Revit software, correct the typos and export again. Afterwards, it is only necessary to refresh the table information Microsoft Excel once is everything linked and calculate in an automatic form.
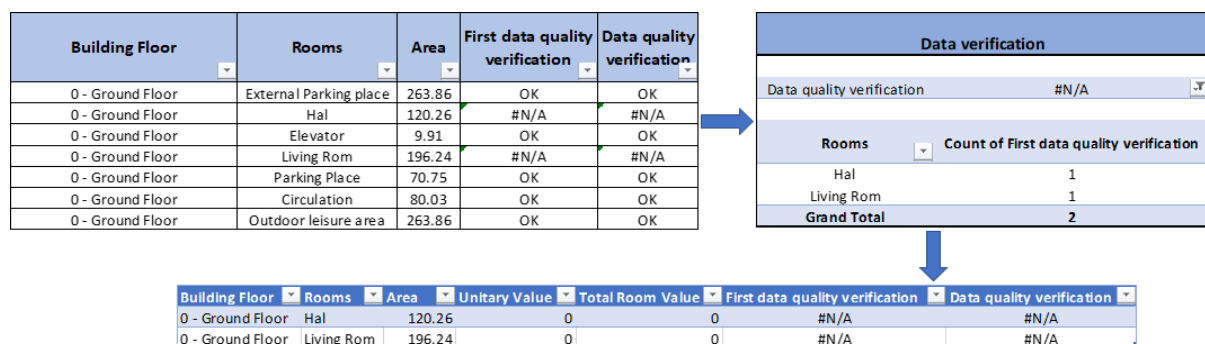
Figure 31 - Process of data quality check

After the data check and correction, starts to perform the cost estimation and the planning validation itself. Initially was necessary to inform the software which was the location and quality pattern to be considered. In order to avoid errors, the selection of the information is performed applying the "data validation by list" feature from Microsoft Excel (Figure 32). This way, instead of typing the information, it will be selected by a list and only accept values contained on this list. The source of data for this list was the same shown in Figure 16 of the sub-chapter 3.5.3. The cost estimation cannot be performed without the selection of this information.
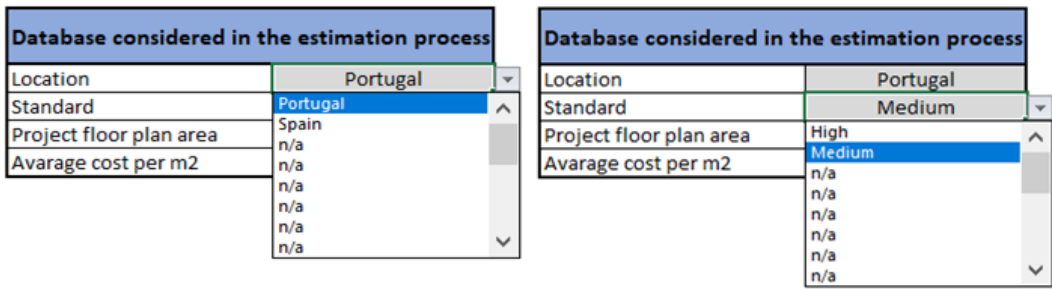
Figure 32 - Selection of the location and standard considered

All the room's area was summed and presented in a new table (Figure 33). These values were multiplied automatically by the software with their respective cost values, considering the region, the standard and the systems. Also, the software calculates the estimate duration of each system based on the historical productivity data.

Rooms	Imported Areas
Bedroom	567.18
Suite	1313.64
Kitchen	1308.24
Bathroom	1119.42
Hall	599.60
Living room	3291.88
Circulation	671.51
Elevator	124.21
Parking place	70.75
External Parking place	263.86
Outdoor leisure area	263.86

Figure 33 - Sum-up of the project areas

Now, the information and calculations necessary for the cost estimate and validation of the construction term have already been calculated and are contained in the database. A specific worksheet was set up to demonstrate the results simply and objectively. As at the beginning of this hypothetical case, historical data from two regions and two project quality patterns were included, with this data segregation made it possible to extract four different cost estimates. The cost estimates related to Portugal were shown in Figure 34 and Spain by Figure 35.

Considering that different cost values were assigned considering their location and quality standard, different cost estimations were generated. With the information shown in Figure 34 and Figure 35, it is possible to make a quick assessment of the difference between building the same project in different regions or for different target audiences. These differences have an excellent value for decision making in large companies, where usually they work in several countries, and it is often necessary to select where the project will be developed and constructed.

Database considered in the estimation process

Location	Portugal
Standard	Medium
Project floor plan area	9594.15
Avarage cost per m2	€ 556.89

Cost Estimation with historical Data			
WBS	Systems	Estimated Cost	Estimated Duration
1	Initial Services	€ 287,824.50	28.78
2	Fundation	€ 479,707.50	23.99
3	Structure	€ 935,667.60	239.85
4	Roof	€ 132,881.90	14.39
5	Walls	€ 600,495.00	255.84
6	Plumbing Installations	€ 245,889.00	167.90
7	Electrical Installations	€ 510,336.40	167.90
8	HVAC Installations	€ 422,675.80	6.40
9	Impermeabilization	€ 252,832.60	8.32
10	Floor Finishing	€ 416,849.55	63.96
11	Wall Finishing	€ 290,005.40	639.61
12	Ceiling finishing	€ 344,708.55	63.96
13	Facede	€ 195,745.50	119.23
14	Door and window systems	€ 227,231.70	47.35
15	n/a	€ -	0.00

Total cost estimation	€ 5,342,851.00

Database considered in the estimation process

Location	Portugal
Standard	High
Project floor plan area	9594.15
Avarage cost per m2	€ 628.72

Cost Estimation with historical Data			
WBS	Systems	Estimated Cost	Estimated Duration
1	Initial Services	€ 287,824.50	28.78
2	Fundation	€ 479,707.50	23.99
3	Structure	€ 935,667.60	239.85
4	Roof	€ 132,881.90	14.39
5	Walls	€ 600,495.00	255.84
6	Plumbing Installations	€ 245,889.00	167.90
7	Electrical Installations	€ 510,336.40	167.90
8	HVAC Installations	€ 422,675.80	6.40
9	Impermeabilization	€ 252,832.60	8.32
10	Floor Finishing	€ 636,967.90	63.96
11	Wall Finishing	€ 384,202.00	639.61
12	Ceiling finishing	€ 481,834.20	63.96
13	Facede	€ 317,500.00	119.23
14	Door and window systems	€ 343,262.45	47.35
15	n/a	€ -	0.00

Total cost estimation	€ 6,032,076.85

Figure 34 - Estimations for Portugal

Database considered in the estimation process

Location	Spain
Standard	Medium
Project floor plan area	9594.15
Avarage cost per m2	€ 633.23

Cost Estimation with historical Data			
WBS	Systems	Estimated Cost	Estimated Duration
1	Initial Services	€ 335,795.25	28.78
2	Fundation	€ 503,100.72	23.99
3	Structure	€ 1,065,348.00	239.85
4	Roof	€ 144,267.46	14.39
5	Walls	€ 603,021.46	255.84
6	Plumbing Installations	€ 254,741.32	167.90
7	Electrical Installations	€ 502,418.74	167.90
8	HVAC Installations	€ 448,460.52	6.40
9	Impermeabilization	€ 279,223.82	8.32
10	Floor Finishing	€ 503,177.93	63.96
11	Wall Finishing	€ 488,258.84	639.61
12	Ceiling finishing	€ 531,947.07	63.96
13	Facede	€ 231,861.50	119.23
14	Door and window systems	€ 183,704.00	47.35
15	n/a	€ -	0.00

Total cost estimation	€ 6,075,326.63

Database considered in the estimation process

Location	Spain
Standard	High
Project floor plan area	9594.15
Avarage cost per m2	€ 686.28

Cost Estimation with historical Data			
WBS	Systems	Estimated Cost	Estimated Duration
1	Initial Services	€ 335,795.25	28.78
2	Fundation	€ 483,857.04	23.99
3	Structure	€ 1,070,024.85	239.85
4	Roof	€ 153,653.36	14.39
5	Walls	€ 604,644.54	255.84
6	Plumbing Installations	€ 247,381.92	167.90
7	Electrical Installations	€ 524,607.16	167.90
8	HVAC Installations	€ 423,810.16	6.40
9	Impermeabilization	€ 253,966.96	8.32
10	Floor Finishing	€ 732,909.40	63.96
11	Wall Finishing	€ 486,711.70	639.61
12	Ceiling finishing	€ 577,775.70	63.96
13	Facede	€ 406,922.20	119.23
14	Door and window systems	€ 282,209.00	47.35
15	n/a	€ -	0.00

Total cost estimation	€ 6,584,269.24

Figure 35 - Estimations for Spain

4. CASE STUDY

4.1. Introduction

The caste study was performed in collaboration with a big construction company from Portugal. The company is one of the largest in the construction sector in Portugal, maintaining a family-owned enterprise characteristic. With a consolidate presence in the domestic market, the Group operates in 16 different countries around Europe, South America, Africa and Asia. The company is partners of the BIM A+ master and were since the beginning collaborating with the development of the proposed dissertation.

For the case study, two different projects with similar characteristics were used. The project for collecting and organizing historical cost data is related to the construction of a hotel with a capacity for 112 rooms, located in the south-central region of Portugal. The total project will be distributed over four floors, the first being underground. On the first two floors are located the areas of parking and technical areas, lobby, reception, breakfast areas, living areas, toilets and some bedrooms, while the last two were intended for the exclusive use of bedrooms and support areas to supply the customers. In addition, it contains an external area on the ground floor.

The company was responsible for the general construction and design of some disciplines of the project. Due to it, part of the systems was modelled and developed under the BIM methodology for, while others were developed using CAD-based solutions. Also, the company uses a specific software called Candy CCS for cost management. Information related to the design of the structure and architecture specialities was delivered in a BIM model, while the MEP and HVAC specialities were made available in CAD format. Information related to the total cost was delivered using Excel spreadsheets, directly exported from the CCS software.

The project to be carried out the cost estimation is for the same client as the previous project. Its use is also for the hotel and located in the same region in Portugal. This project is in the final stage of its architectural design, while the cost estimate and budgeting are in progress. The files for the project were provided in CAD format, containing their floor plans and sections. The design and modelling of the other systems related are under development.

The project selected to be applied to the workflow developed fits perfectly in the stage proposed by the dissertation. The project is at the early stage, with decisions related to layout and construction techniques still in progress. At this time, the information is still very susceptible to change. Still, a cost estimate is necessary to have a better understanding of the estimated budget needed to construct the project. With the historical cost base organized in the database, took less than one day to be prepared the information within the BIM tool, export to the database and generate the cost estimation by the dissertation author.

During the next sub-chapters, the steps and difficulties faced during all stages were demonstrated, since the selection and adaptation of the classification systems, adaptation of the current cost

spreadsheet to the database, modelling, exporting the layout data into the database and the generated cost estimation.

4.2.   Collecting and organizing the historical data.

The construction company provided the data related to the cost and design of the Project 1. The information was contained in BIM models in RVT format, spreadsheets with the total cost of the project in xls format and drawings in CAD format. To apply the proposed workflow, it was necessary to organize the project's data into structured floor plan areas and their relative costs separated into defined systems.

The first task was to define the classification system adopted for the workflow. The company has already developed and adopted its own classification system for cost management and, to produce useful information for the next stages, thus this was adopted as a basis and some adaptations were made. The classification consisted of 6 major groups, namely structure, architecture, hydraulic installations, electrical installations, mechanical installations and HVAC, as shown by Table 1. However, the architecture group contained 48% of the total costs of the project and was comprised of several different groups of activities. Therefore, it was decided to replace the architecture group with its subgroups, grouping them based on similar characteristics, so as not to have an excessive number of classifications. The classification system adopted contains 18 systems and is shown in Table 2.

Table 1 - Company classification system and its totals

Item	Systems	Amount	%
EST	Structure	€ 874,772.94	19.4%
ARQ	Architecture	€ 2,178,225.96	48.3%
HID	Hydraulic instalations	€ 392,980.11	8.7%
IETS	Electrical installations	€ 509,256.24	11.3%
IE	Mechanical installations	€ 40,521.64	0.9%
VC-GTC	HVAC	€ 518,189.98	11.5%
	Total:	€ 4,513,946.87	100%

Table 2 - Final classification system and its totals

Number	Systems	Cost		% total
1	Structure	€	874,772.94	19%
2	Preliminary Work	€	636,431.98	14%
3	Walls	€	242,052.97	5%
4	Impermeabilization and insulation	€	68,235.82	2%
5	Roof	€	28,908.36	1%
6	Floor covering	€	141,260.43	3%
7	Column and wall cladding	€	283,276.57	6%
8	Ceiling cladding	€	75,304.09	2%
9	Windows and steel structure	€	241,470.86	5%
10	Furniture and wood work	€	207,994.07	5%
11	Painting	€	75,970.01	2%
12	Sanitary wares and accessories	€	126,225.81	3%
13	Cleaning and handover preparation	€	26,440.65	1%
14	External areas finishing	€	24,654.34	1%
15	Hidraulic instalations	€	392,980.11	9%
16	Electrical instalations	€	509,256.24	11%
17	Mechanical instalations	€	40,521.64	1%
18	HVAC	€	518,189.98	11%
	Total:	€	4,513,946.87	100%

Afterwards, it was defined how the project areas would be classified. The company had already used the "Rooms" tool in the Revit software to classify areas in its design process. However, they were using it for the purpose of showing the name of the room in the 2D floor plans generated by the software. In contrast, within this workflow, it will use the "Name" parameter on the room element as a connection between the BIM model and the cost historical database. The BIM model received contained several different classifications of rooms, depending on their use and location. However, the names of this classification had some specific factors, such as floors and gender of the toiles, generating 36 different room classification. The current Classification System was maintained as a basis, and the areas with the same use were grouped. After grouping, the project areas were separated into 12 items, namely: Bathroom, breakfast area, elevator, external area, hall, hotel room, kitchen, lobby, parking place, roof, staircase and technical area. The initial classifications and the final grouping are shown in table Figure 36. Figure 37 and Figure 38 figure shows in a floor plan how the areas were organized after classifying each room element.

Key Name	Name
Antecamara da caixa de escada	Antecamara esc.
Antecamara elevador hóspedes	Antecamara elev.
Antecamara elevador serviço	Antecamara elev. serv.
Antecamara entrada	Antecamara
Armazém	Armazém
Armazém geral	Armazém geral
Bagagens	Bagagens
Caixa de escadas	Escadas
Caldeiras	Caldeiras
Central SCI	Central SCI
Copa limpa	Copas limpa e suja
Copa piso	Copa piso
Copa suja	Copa suja
Corredor acesso quartos	Corredor
Corredor interno serviço	Corredor interno de serviço
Elevadores	Elevadores
Escritório	Escritório
Estacionamento	Estacionamento
I.S. quarto	I.S.
IT	I.T.
Lobby	Lobby
Pequenos almoços	Pequenos Almoços
PT	P.T.
Quarto piso 0	Quarto
Quartos pios 1 2 e 3	Quarto
Receção	Receção
Receção produtos	Receção de produtos
Sala reuniões	Sala de reuniões
Sala segurança	Gab. Seg.
Vestiário feminino	Vestiário F.
Vestiário masculino	Vestiário M.
WC hóspedes feminino	I.S. F.
WC hóspedes masculino	I.S. Acessível
WC hóspedes mobilidade reduzida	I.S. M.
Zona de estar	Zona de estar
Zonas técnicas	Zonas técnicas

New Names
Bathroom
Breakfest Area
Elevator
External Area
Hall
Hotel Room
Kitchen
Lobby
Parking Place
Roof
Staircase
Technical Area

Figure 36 - Initial and final room classification
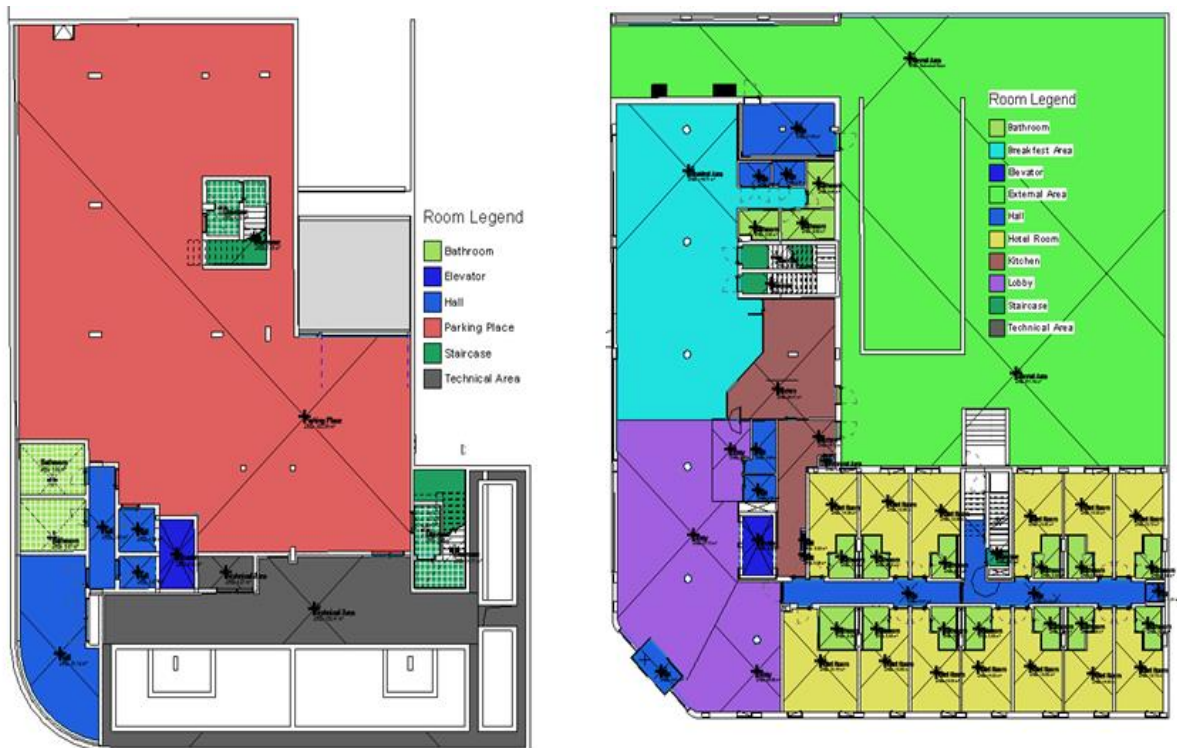
Figure 37 - The floor plans -1, and 0.
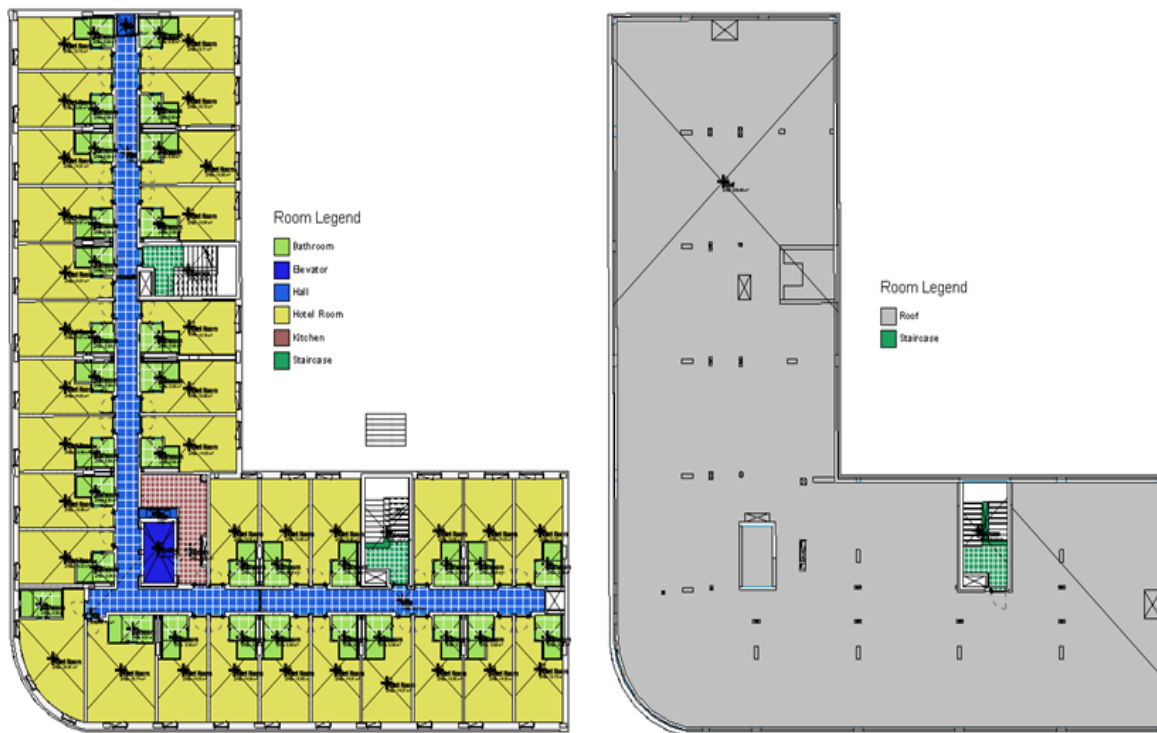
Figure 38 - The floor plans 1,2,3 (left) and roof (right)

Once the cost classification system and the project areas were defined, it was necessary to organize the information according to the areas and to divide it between the systems. Although the cost spreadsheet provided already contains the total values separated by the systems, it was not classified by areas. Their total values were calculated based on the unit price of the activity multiplied by the total quantity of the entire project. Thus, it was necessary to segregate the total amount by the classified areas. At this stage, the importance and difference in the reuse and sharing data between projects elaborated applying the BIM methodology and elaborated in CAD-based solutions was remarkable. Some of the systems were developed based on the BIM methodology, and the designers delivered others in CAD form, and this directly impacted the way the information was worked on. For the systems within the BIM methodology, the quantity take-off item was extracted by "schedules" in Revit, itemizing all the instance on the schedule and determined the related area classification by visual verification on the model, as shown in Figure 39. Besides, the company provided some floor plains as a support material for the quantity take-off. With this task, it was possible to define the impact percentage of each system into each area. These percentages were applied to the total value of the systems and after divided by the floor plan area of corresponding, generating the necessary information for the workflow.

For the systems developed on the CAD-based solution were not possible to extract information in such a way. The data contained on it was mainly designed applying lines and layers and was not possible to automatically extract any quantity-take off report. Due to it, the cost value of these systems was divided equally among the areas. Table 3 resumes the systems, methodologies applied in their development and the cost separation method.

Figure 39 - Hotel Room's windows selected in the schedule and highlighted on the floor plan

Figure 40 shows all the cost values per room and systems, while Figure 41 shows the gathered values per room. Subsequently, the content of Figure 40 was automatically manipulated and organized in the same template needed by the workflow and linked to the estimation file. Considering all these tasks, the process of collect and organize the historical data was finished. The following step was to collect the layout information from project 2.

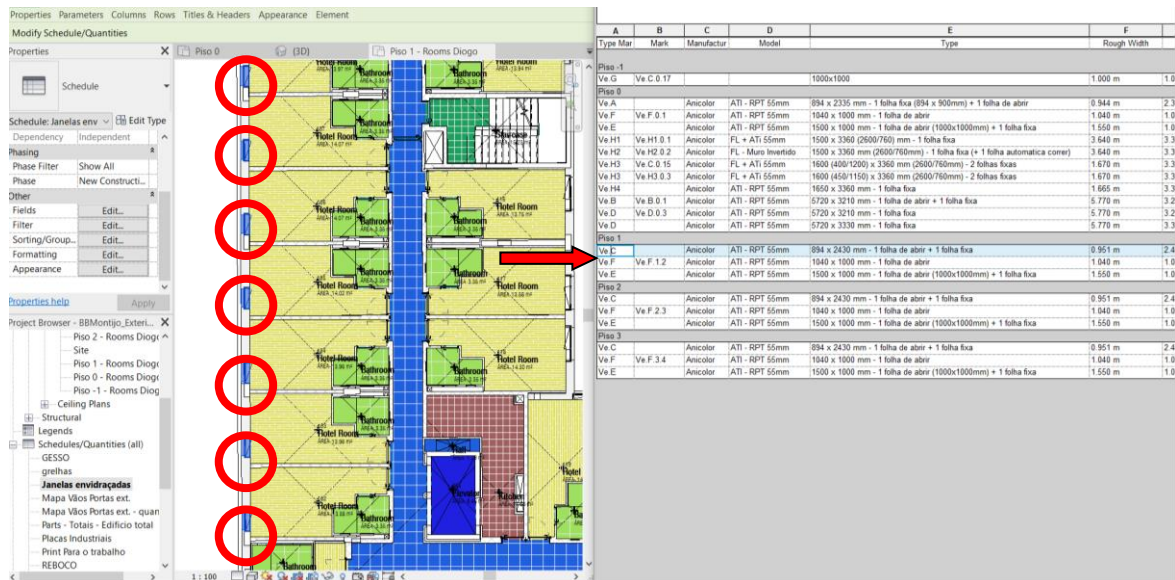| System	Rooms											
	Bathroom	Breakfest Area	Elevator	External Area	Hall	Hotel Room	Kitchen	Lobby	Parking Place	Roof	Staircase	Technical Area
Structure	€ 252.56	€ 252.56	€ 252.56	€ -	€ 252.56	€ 252.56	€ 252.56	€ 252.56	€ 252.56	€ -	€ 252.56	€ 252.56
Preliminary Work	€ 183.75	€ 183.75	€ 183.75	€ -	€ 183.75	€ 183.75	€ 183.75	€ 183.75	€ 183.75	€ -	€ 183.75	€ 183.75
Walls	€ 59.04	€ 68.97	€ -	€ -	€ 105.65	€ 71.24	€ 133.11	€ 122.06	€ 29.03	€ -	€ 42.51	€ 61.91
Impermeabilization and insulation	€ 66.07	€ -	€ 105.37	€ -	€ -	€ -	€ 136.25	€ -	€ 16.89	€ 12.38	€ -	€ 63.31
Roof	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ 34.97	€ -	€ -
Floor covering	€ 47.87	€ 60.82	€ -	€ -	€ 26.18	€ 41.57	€ 59.70	€ 62.42	€ 18.14	€ -	€ 81.70	€ 18.05
Column and wall cladding	€ 152.36	€ 26.61	€ -	€ -	€ 10.65	€ 112.78	€ 85.37	€ 29.13	€ 9.60	€ -	€ 70.94	€ 35.98
Ceiling cladding	€ 23.32	€ 21.78	€ -	€ -	€ 19.30	€ 24.80	€ 18.60	€ 28.78	€ 17.33	€ -	€ 9.32	€ 13.33
Windows and steel structure	€ -	€ 156.23	€ 50.89	€ -	€ -	€ 61.45	€ 82.73	€ 213.94	€ 35.47	€ 16.96	€ 334.81	€ 11.15
Furniture and wood work	€ 66.95	€ 51.43	€ -	€ -	€ 44.99	€ 84.64	€ 48.28	€ 89.53	€ 2.94	€ -	€ 7.67	€ 11.03
Painting	€ 18.39	€ 52.14	€ 117.31	€ -	€ 20.87	€ 18.89	€ 37.92	€ 28.53	€ 9.40	€ -	€ 24.50	€ 35.24
Sanitary wares and accessories	€ 305.56	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Cleaning and handover preparation	€ 7.63	€ 7.63	€ 7.63	€ -	€ 7.63	€ 7.63	€ 7.63	€ 7.63	€ 7.63	€ -	€ 7.63	€ 7.63
External areas finishing	€ -	€ -	€ -	€ 43.14	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Hidraulic instalations	€ 113.46	€ 113.46	€ 113.46	€ -	€ 113.46	€ 113.46	€ 113.46	€ 113.46	€ 113.46	€ -	€ 113.46	€ 113.46
Electrical instalations	€ 147.03	€ 147.03	€ 147.03	€ -	€ 147.03	€ 147.03	€ 147.03	€ 147.03	€ 147.03	€ -	€ 147.03	€ 147.03
Mechanical instalations	€ -	€ -	€ 1,251.44	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
HVAC	€ 149.61	€ 149.61	€ 149.61	€ -	€ 149.61	€ 149.61	€ 149.61	€ 149.61	€ 149.61	€ -	€ 149.61	€ 149.61

Figure 40 - Final cost historical data according to each system and room.

Rooms	Region	Project Standard	Cost by m2
Bathroom	Portugal	Medium	€ 1,593.60
Breakfest Area	Portugal	Medium	€ 1,292.02
Elevator	Portugal	Medium	€ 2,379.03
External Area	Portugal	Medium	€ 43.14
Hall	Portugal	Medium	€ 1,081.68
Hotel Room	Portugal	Medium	€ 1,269.41
Kitchen	Portugal	Medium	€ 1,455.99
Lobby	Portugal	Medium	€ 1,428.42
Parking Place	Portugal	Medium	€ 992.83
Roof	Portugal	Medium	€ 64.32
Staircase	Portugal	Medium	€ 1,425.47
Technical Area	Portugal	Medium	€ 1,104.04

Figure 41 - Final cost historical data by room.

Table 3 - Systems and its cost separation method.

Systems	Information received	Cost separation method
Structure	BIM Model	Equally divided
Preliminary Work	Only cost data	Equally divided
Walls	BIM Model	According to the quantities
Impermeabilization and insulation	BIM Model	According to the quantities
Roof	BIM Model	According to the quantities
Floor covering	BIM Model	According to the quantities
Column and wall cladding	BIM Model	According to the quantities
Ceiling cladding	BIM Model	According to the quantities
Windows and steel structure	BIM Model	According to the quantities
Furniture and woodwork	BIM Model	According to the quantities
Painting	BIM Model	According to the quantities
Sanitary wares and accessories	BIM Model	According to the quantities
Cleaning and handover preparation	Only cost data	Equally divided
External areas finishing	BIM Model	According to the quantities
Hidraulic instalations	CAD-based	Equally divided
Electrical installations	CAD-based	Equally divided
Mechanical installations	CAD-based	Equally divided
HVAC	CAD-based	Equally divided

4.3. Generating project information for cost estimation.

The layout information from Project 2 was developed using CAD-based software. The provided information was composed of the floor plans of each floor and some elevations. Considering that the work has been done within a BIM environment, this information was not complete and was necessary to adapt it. The design process for this case study followed almost all the steps described in Chapter 3. The difference is that in the case study utilized a CAD layout as a base for the design, while the hypothetical project was started from scratch in Revit.

After setting up the template in Revit, the floor plans were separated into separate CAD files and imported into their respective pre-configured levels. After that, the external and internal walls of the building were modelled to work as the room-boundaries. At this time, the basic wall by Revit was selected as a basis for modelling, and several type walls were created according to the thickness specified in the project. This step is significant, as the workflow uses the internal areas of the walls as the basis for calculation, and thickness differences between the modelled and designed information would impact the final result of the cost estimate. In addition, room separators were used in places where there was no physical separation of areas. Figure 42 shows layouts in the CAD format and the BIM Model.
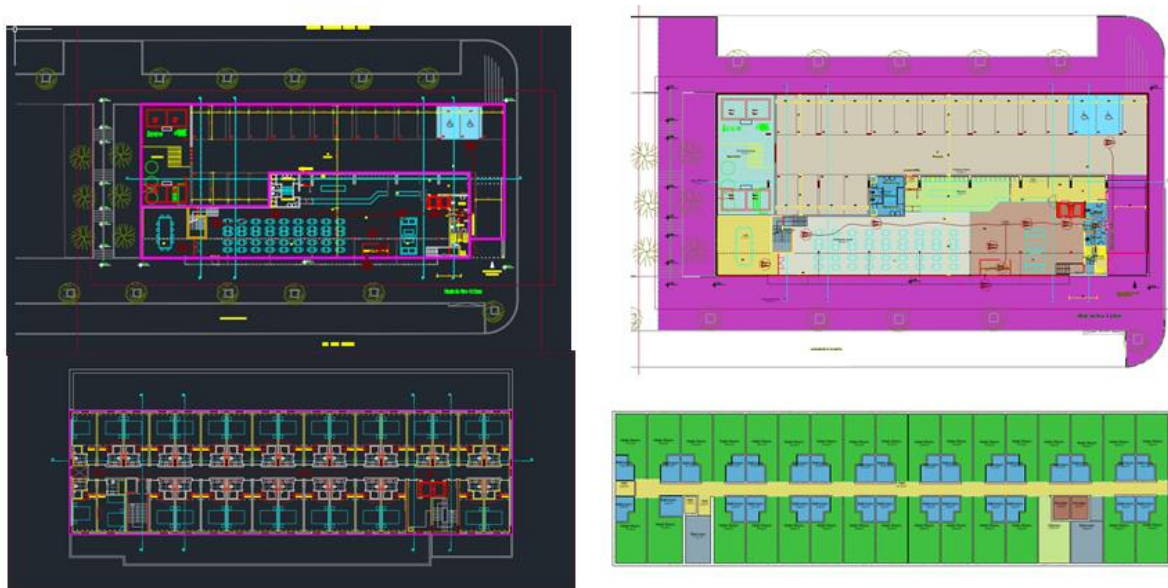
Figure 42 - CAD layout and the BIM model floor plan.

Once finished, the "rooms" feature was applied into all the spaces and filled with the correspondent room information by the classification mentioned above. The BIM software calculates automatically the total area related to each room. Lastly, were prepared the schedule and exported the information by the delimited text format and imported to the database containing the historical data. Table 4 shows the total areas according to each room calculate by the BIM software. The last step performed was to select the information regarding the location and the standard of the project on the database, which was Portugal and medium, respectively.

Table 4 - Total areas exported from the BIM Software

Piso -1	Bathroom	34.57
Piso -1	Breakfest Area	169.69
Piso -1	Elevator	6.63
Piso -1	External Area	1069.43
Piso -1	Hall	95.53
Piso -1	Kitchen	51.99
Piso -1	Lobby	119.45
Piso -1	Parking Place	520.93
Piso -1	Staircase	16.68
Piso -1	Technical Area	106.93
Piso 0	Bathroom	117.82
Piso 0	Elevator	7.33
Piso 0	Hall	80.97
Piso 0	Hotel Room	483.76
Piso 0	Kitchen	15.37
Piso 0	Staircase	26.81
Piso 1	Bathroom	122.19
Piso 1	Elevator	7.33
Piso 1	Hall	73.96
Piso 1	Hotel Room	486.07
Piso 1	Kitchen	15.37
Piso 1	Staircase	26.81
Piso 2	Bathroom	117.82
Piso 2	Elevator	7.33
Piso 2	Hall	80.97
Piso 2	Hotel Room	483.76
Piso 2	Kitchen	15.37
Piso 2	Staircase	26.81
Cobertura	Roof	778.28

4.4. Results

Once the historical cost data and the floor plan areas were filled into the database, the software automatically calculates and generate the cost estimation desired presents the total cost estimation generated and its values divided by the classification system adopted. Figure 44 shows the final cost estimation value for the case study layout. Besides, the workflow generated the average cost per square meter of the project (Figure 43), which allows comparing this estimation with the market values cost estimation. The validation system developed on the Excel application confirmed that no issues related to filling the historical data or the data imported from the BIM software were found.

Database considered in the estimation process		
Location	Portugal	
Standard	Medium	
Project floor plan area	3318.25	
Avarage cost per m2	€	1,295.77

Figure 43 - Data selected in the database and the average costs per square meter

Cost Estimation with historical Data		
Item	Systems	Estimated Cost
1	Structure	€ 838,048.57
2	Preliminary Work	€ 609,713.55
3	Walls	€ 226,950.40
4	Impermeabilization and insulation	€ 67,516.49
5	Roof	€ 27,219.80
6	Floor covering	€ 130,835.23
7	Column and wall cladding	€ 259,360.61
8	Ceiling cladding	€ 71,919.32
9	Windows and steel structure	€ 216,338.83
10	Furniture and wood work	€ 191,837.88
11	Painting	€ 71,976.07
12	Sanitary wares and accessories	€ 119,903.67
13	Cleaning and handover preparation	€ 25,330.63
14	External areas finishing	€ 46,140.54
15	Hidraulic instalations	€ 376,482.17
16	Electrical instalations	€ 487,876.85
17	Mechanical instalations	€ 35,816.22
18	HVAC	€ 496,435.53
19	n/a	€ -
	Total cost estimation:	€ 4,299,702.37

Figure 44 - Total cost estimation generated by the workflow

Even though was achieved the desired cost estimation, was also possible to demonstrate more useful information related to this cost estimation. Cost reports divided by floors (Figure 45), rooms (Figure 46) and correlating floor and rooms (Table 5) were generated. This information could support the decision making by the stakeholders related to which are the most impactful areas in a project in the case where reduce the project cost is needed.

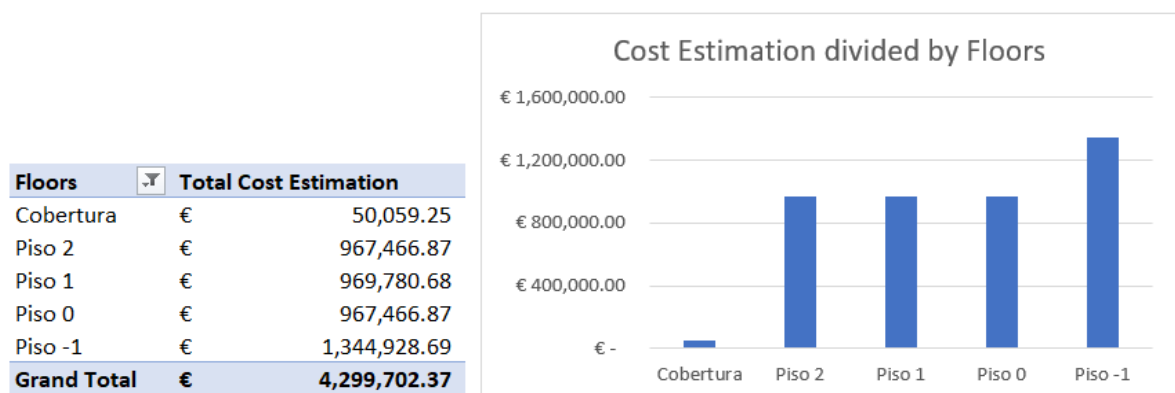| Floors	Total Cost Estimation
Cobertura	€ 50,059.25
Piso 2	€ 967,466.87
Piso 1	€ 969,780.68
Piso 0	€ 967,466.87
Piso -1	€ 1,344,928.69
Grand Total	€ 4,299,702.37

Figure 45 - Cost estimation divided by floors.

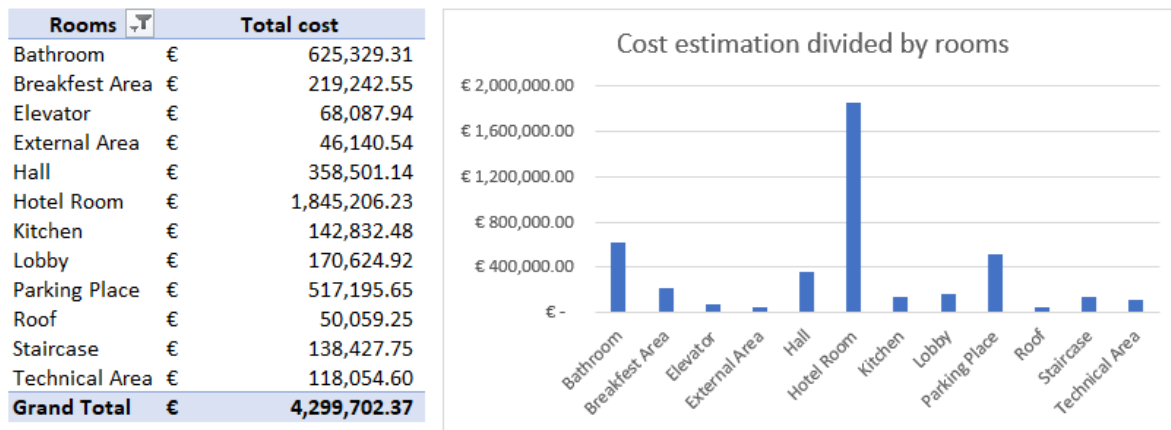| Rooms		Total cost
Bathroom	€	625,329.31
Breakfest Area	€	219,242.55
Elevator	€	68,087.94
External Area	€	46,140.54
Hall	€	358,501.14
Hotel Room	€	1,845,206.23
Kitchen	€	142,832.48
Lobby	€	170,624.92
Parking Place	€	517,195.65
Roof	€	50,059.25
Staircase	€	138,427.75
Technical Area	€	118,054.60
Grand Total	€	4,299,702.37

Figure 46 - Cost estimation divided by Rooms

Table 5 - Cost estimation divided by floors its rooms

Row Labels		Total Cost estimaton
⊟ Cobertura	€	**50,059.25**
Roof	€	50,059.25
⊟ Piso 2	€	**967,466.87**
Bathroom	€	187,758.15
Elevator	€	17,438.32
Hall	€	87,583.61
Hotel Room	€	614,091.30
Kitchen	€	22,378.55
Staircase	€	38,216.95
⊟ Piso 1	€	**969,780.68**
Bathroom	€	194,722.19
Elevator	€	17,438.32
Hall	€	80,001.04
Hotel Room	€	617,023.64
Kitchen	€	22,378.55
Staircase	€	38,216.95
⊟ Piso 0	€	**967,466.87**
Bathroom	€	187,758.15
Elevator	€	17,438.32
Hall	€	87,583.61
Hotel Room	€	614,091.30
Kitchen	€	22,378.55
Staircase	€	38,216.95
⊟ Piso -1	€	**1,344,928.69**
Bathroom	€	55,090.81
Breakfest Area	€	219,242.55
Elevator	€	15,772.99
External Area	€	46,140.54
Hall	€	103,332.87
Kitchen	€	75,696.85
Lobby	€	170,624.92
Parking Place	€	517,195.65
Staircase	€	23,776.90
Technical Area	€	118,054.60
Grand Total	€	**4,299,702.37**

4.5. Considerations

During the application of the workflow, several points impacted both positively and negatively according to what was planned. The importance of applying the BIM methodology has been dramatically reinforced during the organization of historical cost information. The BIM methodology allows to automatically quantify and handle the information according to the user's desire. In contrast, the information received in CAD-based solution demands to be done manually, leading to high execution time and prone to errors. Although a lot of information can be generated automatically, the way the BIM model is designed can make it difficult to manipulate information. Some systems had greater difficulty than others during the step of separating the total quantities in their respective areas due to the grouping of different systems in the same element.

An example of this was the walls and its coverings. The approach chosen was to design only one wall element as a whole, and within its structure to make the composition of materials and construction methods. Even if it brings greater agility and ease of change during the design stage, it brings difficulties to extract specific quantities and locations for each system.

For the time required to apply the workflow, the activity which demanded more time was to organize historical information related to cost. It occurred due to several factors but mainly linked to the fact that how the modelling was carried out and how cost management is organized are not entirely linked. As a consequence, it was necessary to separate their quantities and locations by selecting each element and making a visual check of its position. If there was a common parameter linking the two information, an automatic way of segregating the information could have been developed. Despite this factor, the historical information generated can be used by countless projects in a very fast way, making this initial effort be rewarded by providing fast and direct cost estimation processes for future projects.

For the modelling process, it was performed in a fast, efficient and objective way. The information required by the workflow is clear, and the feature offered by the chosen software does not demand a high degree of specificity. In addition, updating the cost estimate based on changes in the layout of the project occurs almost automatically, depending only to export the schedule and updating the database in excel.

In terms of interoperability, there was no problem between the selected software. It occurred because Microsoft Excel provided a specific feature for importing data in the same format as exported by Revit. Also, Excel allows managing the file information even before it is imported into the spreadsheet. This was important during the workflow due to the delimited text format adopted by Revit carries all information as text, and for the use of the workflow the areas must be characterized as a number. This adjustment was made using the Power query editor feature of Excel. In addition, if the user wishes to increase the level of automation of this information exchange, it is possible to link Revit and the database almost automatically using visual programming by the Dynamo feature.

The negative consideration of the workflow is related to the validation of the work planning. Even though the core of this dissertation was to perform the cost estimation, was also desired to generate useful information regarding planning at the early stages. Nevertheless, during the case study was

realised that the proposed workflow is not a good approach to do this task. Unlike cost, planning has many internal rules and to organize historical information and correlate with a layout automatically requires a high level of programming.

At the end of the workflow, the way the database was organized made it possible to extract extra reports based on the same data. In addition to the desired way of demonstrating the cost estimate, it was also possible to demonstrate the costs by correlating floors, areas and the systems adopted. All of these reports generated at such early stages of the project support the stakeholders to assess whether the project's objectives. In addition, if these are not being reached, the proposed workflow is also a quick way to assess which changes are necessary to fit the cost of project execution with the available resource.

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5. CONCLUSIONS

Cost estimation is one of the most important tasks performed at the initial stages of the project. Big mistakes at these estimates can lead to the discontinuity of the project or financial problems during the following stages. In addition, before the company wins the tendency to build the project, there is a need to make a general budget, where it is necessary to make a balance between the precision and the time required for this activity. One way to optimize this relationship is to use the company's historical data to prepare cost estimates.

The initial objective of using BIM work environment for the creation of cost estimates at the very early stage of the project was achieved. The concepts highlighted and used throughout this dissertation were based on the use of BIM to gather information in a defined classification system, the floor plan area method adapted for calculating the cost estimate and a database for gathering the information and ultimately to provide the cost estimation.

The presented dissertation allowed to understand the main methods to elaborate a cost estimation, its characteristics and usability for the construction industry. Besides, an adaptation of the most applied method was proposed in order to consider the layout of the project, its location and quality pattern in an organized, objective and straightforward way, within a BIM environment.

For the organization of the historical cost database, the information contained in BIM federated models, CAD files and cost spreadsheets provided by the company were used. During this stage, it was noticed in practice the difference in the reuse of information comparing the BIM methodology with projects delivered in CAD-based solutions. The concept of object-oriented and the use of non-graphic information applied to elements in BIM software helps to extract and classify the necessary information. However, it was noted the importance and difficulties produced by inconsistency between the elements modelling approach and the cost management system classification used. Due to the way in which the systems were designed within the previous BIM model, it was not possible to automatically extract data from some of them, requiring the visual checking and manual work. It was also perceived the importance of developing a BIM execution plan to provide guidelines for how the information will be produced and used throughout the life cycle of a project.

Regarding the layout modelling, this was a simple, fast and efficient process for estimating the cost, always taking into consideration a time optimization process. The BIM software chosen provides a specific room classification feature, just requiring to provide which are the boundaries of each specific room. Applying this feature into the proposed workflow, it was possible to estimate the cost of a project by modelling only the walls and its room-separations lines.

The Interoperability between the BIM software and the database software chosen occurred as planned, without any significant conflicts. In addition, the semi-automatic updating of the database allowed updating the cost estimation on an on-time basis as changes were made to the project layout, thus ensuring its usability for future projects, as well as the possibility of increasing the reliability and accuracy of the estimation by having new information.

The cost estimation obtained at the early stage was developed in the same classification as the company performs cost management during the next stages of the project. Therefore, the information produced through this proposed workflow, in addition to helping cost-related decision making at the very beginning of the project, also will not be lost in the middle of the process and are prepared to be used and updated during the evolution of the project steps. Besides, at the end of the project could be possible to check the accuracy of the cost estimation, updating the historical database for further projects.

Lastly, the BIM methodology proved to be an excellent ally for the evolution and digitalization of the construction industry. The use of BIM tools allows the generation, use, storage and reuse of information according to the user's demand and in an organized and flexible way throughout the life of the project.

Considering that the BIM methodology covers the different specialities and accompanies the project throughout its entire lifecycle, there are numerous possible future researches related to the field of cost estimation or management of the project as a whole. In addition, it is possible to optimize the current proposed work by developing automated processes and more specific guidelines for specific steps. Therefore, potential future research related to both cases mentioned above are presented:

• Development of guidelines for modelling purposes, enabling an automatic extraction and exporting the historical information based on the area of each room.

• Development of a structured database with automatic connection to the model for extracting information by parameters included in the model.

• Application of the proposed dissertation using a standardised classification system for the historical data, such as OmniClass or UniFormat.

• A framework contemplating the use and updating of the generated cost estimation on further processes of the 4D and 5D stages.

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	Two-dimension
3D	Three-dimension
4D	Four-dimension
5D	Five-dimension
6D	Six-dimension
7D	Seven-dimension
AECO	Architecture engineering construction and operation
API	Application programming interface
BIM	Building information modelling
CAD	Computer-aided design
CE	Cost estimation
CSV	Comma-separated values
e.g.	exempli gratia
FPA	Floor plan area
HVAC	Heating, ventilation, and air conditioning
IFC	Industry foundation class
IPD	Integrated project delivery
MEP	Mechanical electrical and plumbing
MSc	Master of science
NBIMS	National building information modelling standard
OBDC	Open database connectivity
PDF	Portable document format
PhD	Doctor of Philosophy
RIBA	Royal Institute of British Architects
TXT	Text
UAC	Unitary area cost
UK	United Kingdom
VBA	Visual basic for applications