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BIM Analytics for QTO and Planning Management during the Construction Phase

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Master Dissertation
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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.

RESUMO

Analíticas BIM aplicadas à Gestão de Medições e Planeamento durante a fase de Construção

Durante o ciclo de vida de um projeto de construção, são tomadas decisões pelas partes interessadas que definirão o caminho para o desenvolvimento desse ativo. Devido à ausência de informação controlada e centralizada acessível a esses processos de decisão, muitas destas decisões não são apoiadas com dados, mas antes baseadas na experiência dos decisores e líderes, sem um fundamento tangível que apoie esse processo de decisão. Com base na informação quantitativa obtida através de processos de digitalização e BIM, é possível gerar bases de dados estruturadas para criar análises automatizadas a serem implementadas para uma melhor avaliação das variáveis envolvidas numa decisão e ser capaz de tomar decisões orientadas por dados para otimizar o resultado destas resoluções.

A informação quantitativa pode ser a ligação entre a solução técnica e a estratégia de construção e os custos de produção associados. Este estudo centra-se na estrutura de informação necessária para implementar uma tomada de decisão quantitativa completa baseada em BIM que pode ser utilizada para consultar dados relevantes e aplicar a Análise BIM baseada em informação quantitativa, para apoiar as partes interessadas na tomada de decisões orientadas por dados. Os principais desafios, as iniciativas de normalização existentes e as soluções oferecidas pelo software enquadram um estado da arte apresentado neste documento que pretende dar uma noção do nível de implementação das Medições e Quantidades baseadas em BIM nos dias de hoje. Cinco profissionais envolvidos em processos de tomada de decisão para a indústria AECO apoiaram este estudo com os seus conhecimentos profissionais para identificar como a informação quantitativa pode ser utilizada para apoiar decisões orientadas por dados e com propostas para ultrapassar os principais desafios na geração da informação estruturada. A aplicação de quatro estudos de caso explica o processo para ligar as Medições e Quantidades e o BIM com base em modelos baseados em informação quantitativa centrada em quatro tipos de processos de tomada de decisão: Acompanhamento do progresso, Engenharia de Valor, Gestão da Mudança e Contratação Eletrónica. Os requisitos de informação, os níveis de necessidade de informação, a classificação necessária dos dados e as principais considerações foram enquadrados com base na revisão bibliográfica, na implementação de estudos de caso e no conhecimento dos profissionais participantes para orientar os interessados na necessária estruturação da informação, geração de bases de dados e BIM Analytics para apoiar a tomada de decisões e tomar decisões com base em dados.

Durante esta dissertação, foi desenvolvida uma ferramenta de avaliação. Esta ferramenta centraliza a informação mais relevante em modelos de painel de instrumentos controlados e interativos, personalizados para cada um dos processos de tomada de decisão abordados. Através da implementação desta ferramenta de formato aberto e de fácil utilização, os interessados podem avaliar as variáveis que influenciam uma decisão, a fim de tomar resoluções orientadas por dados que justifiquem as escolhas feitas e otimizem os resultados. Além disso, esta ferramenta é capaz de criar registos e estatísticas das decisões tomadas num projeto e da informação contida no mesmo para ser utilizada em projetos futuros. Além disso, esta implementação serve como base para continuar este tipo de desenvolvimentos a favor da melhoria da Gestão de Projetos e Business Intelligence para a Indústria AECO.

Palavras Chave: (BIM-based QTO, BIM Analytics, Business Intelligence, Gestão de Projectos, Tomada de decisões)

ABSTRACT

During the lifecycle of a construction project, decisions are made by stakeholders in all project stages that will define the path for the development of the building asset. Due to the absence of controlled and centralised information to be accessible for decision-making processes, many of these decisions are not supported with data, but based on the experience and intuition of leaders without a tangible fundament that supports the decisions process. Based on quantity information obtained through digitalization and BIM processes, it is possible to generate structured databases to create automatised analytics to be implemented for a better assessment of the variables involved in a decision and be able to make data-driven decisions to optimise the outcome of these resolutions.

Quantity information can be the link between the technical solution and the construction strategy and associated production costs. This study is focused on the required structure of information needed to implement a complete BIM-based Quantity Take-off (QTO) that can be used to query relevant data and apply BIM Analytics based on quantity information, to support stakeholders to make data-driven decisions. Main challenges, existing standardisation initiatives and solutions offered by software frame a State of the Art presented in this document that intends to give a notion on the level of implementation BIM-based QTO nowadays. Five professionals involved in decision-making processes for the AECO Industry supported this study with their professional knowledge to identify how quantity information can be used to support data-driven decisions and with proposals to overcome the main challenges in the generation of the structured information. The application of four case studies explains the process to link modelled-based QTO and BIM Analytics based on quantity information focused on four types of decision-making processes: Progress Tracking, Value Engineering, Change Management and E-Procurement. Information requirements, levels of information need, required classification of data and main considerations were framed based on literature review, on the implementation of case studies and on the knowledge of participant professionals to guide stakeholders for the required structurization of information, generation of databases and BIM Analytics to support decision-making and make data-driven decisions.

During this dissertation, the development of an assessment tool was achieved. This tool centralises the most relevant information into controlled and interactive dashboard templates customized for each one of the addressed decision-making processes. By the implementation of this user-friendly and open format tool, stakeholders can assess the variables that influence a decision, in order to make data-driven resolutions that justifies the choices done and optimises results. Moreover, this tool is able to create records and statistics of the decisions done in a project and the information contained in it to be used in future projects. Furthermore, this implementation serves as a basis to continue these kinds of developments in favour of the improvement of Project Management and Business Intelligence for the AECO Industry.

Keywords: (BIM-based QTO, Decision-making, Business Intelligence, Project Management, BIM Analytics)

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1. INTRODUCTION

BIM implementation in the AECO (Architecture, Engineering, Construction and Operation) industry has had a tendency of continuous growth during the last two decades. According to a study developed by McGraw-Hill Construction (Mcgraw-Hill Construction, 2014), between 2% and 8% of contractors in countries with an important economy worldwide, such as United States, Canada, Japan, South Korea, Australia, Germany, United Kingdom, France and Brazil were implementing BIM in the early 2000s, whilst approximately 75% registered some BIM implementation between 2007 and 2010. This study shows that 75% of the surveyed contractors reported a positive Return of Investment (ROI) in BIM, and in some countries like Japan, Germany, and France, 97% of the contractors reported a positive ROI for BIM implementation.

Nevertheless, when comparing the AECO industry with other industries such as aeronautical and automotive industry, the digitalization of process and overall performance registers a significant less growth for the past decades. Construction, which involves real estate, infrastructure and industrial structure is the largest industry in the global economy, representing 13% of the world´s Gross Domestic Product (GDP), but its annual productivity growth over the past 20 years was only one third part of other economy average growth (Mckinsey Global Institute, 2020). Since 2000, this industry has registered only 1 percent average growth per year, which is low in comparison with the average growth of the world economy that has been 2.8 percent (Mckinsey Global Institute, 2017). The construction industry is characterized to be exposed to rapid, unexpected changes, and dependent of many variables, which makes it challenging to manage. This constant changes during the development of a project, have created a tendency in which stakeholders make a profit from claims rather than from a successful delivery (Mckinsey Global Institute, 2020). In addition to this, nowadays customers and owners of construction assets are becoming more sophisticated, resulting in more complex Project Information Requirements (PIR) and on an increase in the complexity and volume of information managed during the lifecycle of a project (Mckinsey Global Institute, 2020). Supported by these McKinsey Reports, even though the BIM implementation has grown in the last decade, the maturity level needs to be further enhanced to overcome the new construction, seeking for sustainability of the industry and continuous improvement in the efficiency on the execution of projects through digitalization and implementation of technology.

An approach that can lead to an improvement in the control of information and management of the construction projects, is BIM-based Quantity Take-off. A correct and controlled estimation of quantities of a project can allow to generate analytics for cost estimation and cash-flow management, improvement in the construction schedule, delay analysis, resource control, among other aspects. The opportunity to develop a construction model that contains the quantity information, which contains a structure that allows information to be linked to the analytics mentioned before, permitting a controlled query of information and an automatic update when including modifications during the construction phase, can result in a better project management by reducing estimation errors and allowing to make decisions based on data and statistics. Furthermore, an information structuration that allows a controlled connection between the quantities and the technical solution of a project will represent a bidirectional link between the design engineering and the economic management of a project. Digitalization through

BIM implementation can allow the link between these two fundamental aspects through the lifecycle of a project: the technical solution and the cost of execution. This connection will impact positively the process in which data is assessed via analytics, leading to an optimization of the technical, economical, and political decisions taken among the AECO Industry. Thereafter, this structure of information will exponentiate the collaboration among stakeholders, generating integrated work processes in terms of design development, construction management and project control aiming on an optimal business intelligence for the industry.

In the past few years, many companies had been extracting quantities from BIM models and using this information for analysis of their projects, but many challenges appear and there is limited standardization to perform this kind of procedures (EUBIM Task Group, 2021). The structure of data contained in information models and databases used nowadays do not fulfil the requirements to accomplish a complete connection between the design engineering and cost management with automatized generation and update of Key Performance Indicators to support data-driven decisions. This study aims to contribute to the comprehension of required structuration and information requirements needed to achieve this connection and improve decision-making processes by allowing more efficient and data-driven decisions based on quantity information.

1.1. Objectives

In order to improve the decision-making during the construction phase, it is necessary to present accurate, standardised, complete and secured information that allows construction leaders and stakeholders to make more data-driven decisions digitally integrated with de technical design, construction strategy and costs. In this manner, this study will focus on the study of BIM-based Quantity Take-off, the required level of information and necessary structure to develop an accurate, standardised, and controlled process of quantity estimation. Moreover, delve into the applications and analytics based on quantity information, namely cost estimation, automatised construction scheduling and 4D/5D analysis, to frame important considerations and requirements needed to perform these tasks in a complete and controlled manner. Finally, this study will seek to create assessment tools that allow to gather and present controlled and transparent information, to assist stakeholders to make more data-driven decisions based on centralized information and simulations of different scenarios, through the engaged connection of technical design and the construction strategy associated with production costs, specifically for four types of concurrent decisions in the construction phase: Progress Tracking, Value Engineering, Change Management, and E-Procurement.

1.2. Partnership for the dissertation

This project was developed in collaboration with BIMMS – BIM Management Solutions, an international BIM Consulting company that provides digital solutions to main contractors of large-scaled projects. The collaboration of BIMMS was necessary for the development of this investigation, providing constant guidance and support from its team throughout the process, as well as required information for the case studies, contacts to perform relevant interviews and surveys and a place to develop the dissertation, with optimal conditions to work.

1.3. Structure of the dissertation

This dissertation is organized in six chapters. The first chapter is the introduction, which aims to establish the importance of this study, its main objectives, an explanation of the partnership involved in this project, and a brief description of the structure of the document.

Then, the second chapter is the state of the art. This chapter focuses on understanding the process of BIM-based Quantity Take-off and the different variables involved in the execution of the process nowadays. This chapter is divided in three parts. The first part contains a literature review that compiles important definitions, main challenges, existing regulations, and standards. The second part is a study of relevant BIM-based QTO software. This part studies characteristics of software available in the market, organizing the information according to defined criteria considered to be important in this kind of software. Also, this part includes a development of a tool that allows to evaluate different software based on the previously defined criteria and can be suitable to the priorities that a company or a team could have when choosing a BIM-based QTO software. The third part involves an interview with experienced leaders of the AECO industry, to understand how the quantity take-off is performed currently, its main purposes, and how this information is supporting decision-making nowadays for the construction phase, in order to know how to improve this challenging task. Also, the interview has the objective to identify which relevant information should be considered for each type of decision-making that will be approached in the next chapters.

The third chapter is developed in the use of four relevant case studies, each case focused on the four types of decision-making addressed in this study. The purpose of this chapter is to execute the process of QTO and BIM analytics for each case, to identify important requirements and considerations before the quantity estimation, during the quantity estimation and for the generation of the BIM analytics. Consequently, the chapter is divided in four parts, one for each case study. Every part contains a description of the case study, explanation of the executed process, and presentation of obtained results.

The fourth chapter is a framework that aims to compile requirements and considerations for the development of BIM-based QTO and BIM Analytics using quantity information, based on the information and processes obtained in the previous chapters. This chapter is divided in three parts. The first part focuses on the considerations and requirements needed before the execution of quantity estimation. The second part compiles the information and recommendations during the quantity estimation, and the third part frames the information for the generation of the different BIM Analytics executed in the previous chapter.

The fifth chapter presents the development of assessment tools that allows to present the generated information in a complete, controlled, and user-friendly manner, aiming to assist stakeholders to make more data-driven decisions. This tool is composed by information templates with one set of templates customed for each type of decision-making addressed in the previous chapter. For each set of templates, there is a description of the process to create the template, and a presentation of the results.

Finally, the last chapter presents the conclusions of this work and suggestions for potential future developments. Figure 1 presents the workflows used on the dissertation´s development, from second to the fifth one, representing its methodology. A larger image is presented in Appendix 1.

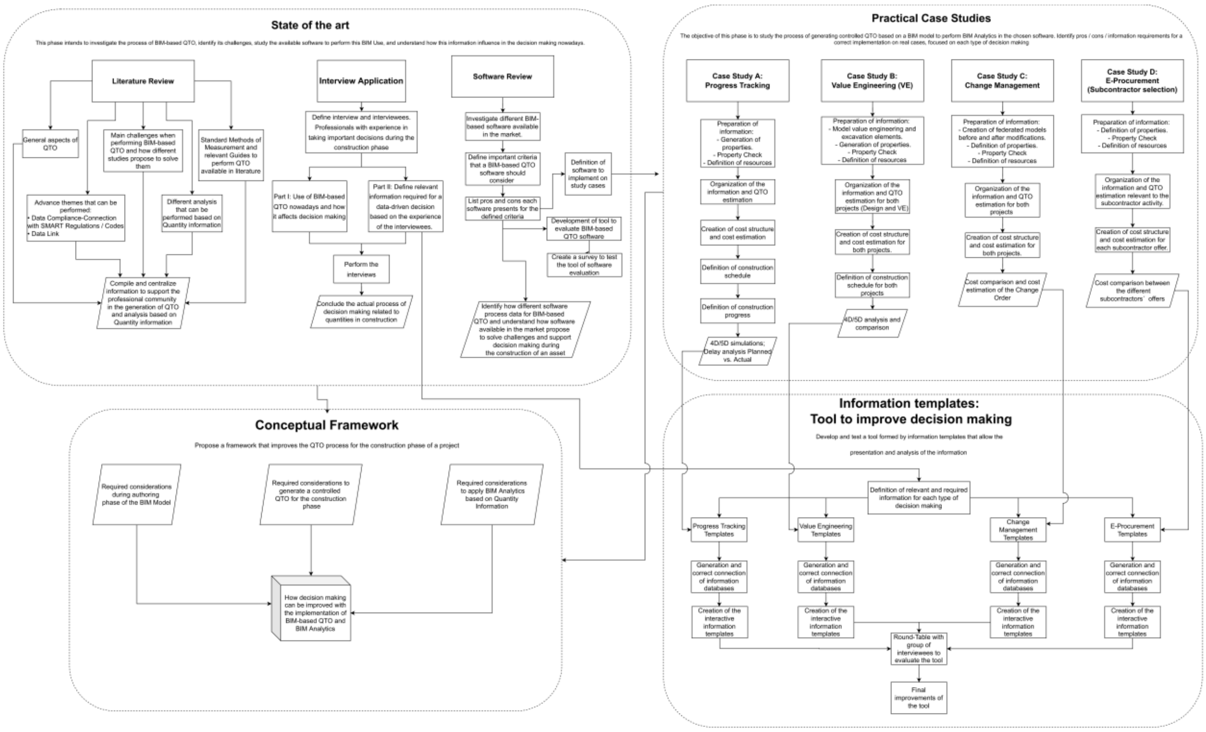

Figure 1. Workflow of Dissertation´s development - Methodology

2. STATE OF THE ART

This chapter aims to understand the current state of BIM-based Quantity Take-off. First, a literature review presents main definitions, challenges pointed out in other research, and existing guides, regulations, and standards, as well as some relevant definitions for BIM analytics and types of decision-making that will be further addressed. Thereafter, this chapter contains a study of the existing BIM-based software available in the market. Finally, using interviews to experts, it presents how QTO influences decision-making nowadays, and how this process can be improved based on the criteria of experienced professionals in the industry.

2.1. Literature Review

2.1.1. BIM-based quantity take-off

The cost estimation is key for the planification and viability of any construction process, and the estimation of quantities is the foundation for this estimation. Quantity Take-off (QTO), which is a process to measure and count building elements and components (Khosakitchalert et al., 2019b), is implemented in many phases of the lifecycle of a project. In the early stages, it is performed to estimate preliminary costs to support the decision on whether a project is viable or not. In the tender, QTO is applied by the main contractors in more accurate estimation as a basis for the election of the contractor. During the construction phase, this information is used for Planning Management, the definition of the construction strategy and supply change, scheduling, progress tracking, and many more. Also, for the Asset and Maintenance phase, it is necessary to determine possible reconstructions (Bečvarovská & Matějka, 2014). As the project evolves from the design phase to the construction phase, the level of detail for QTO increases as well as the applications that use this information (Ersen Firat et al., 2010). Figure 2 shows the flow of QTO during the design and construction stages of a project.

QTO estimations were initially done through a manual process, where the general contractor used the physical drawings provided by the design team to measure and quantify the project. Then, the digitalization of plans originated the development of software to assist the quantity surveyors in their estimations, enabling them to measure areas of elements or zones from scaled drawings and keep count of selected components. This approach started the automatization of the QTO, seeking to improve an error-prone manual process. Jadid & Idrees (2007) developed a concept to estimate material quantities of structural elements by linking the AutoCAD drawings with the Bill of Quantities (BoQ). The algorithm they created extracts and recognizes the layers and objects from a two-dimensional DXF drawing, along with the information of the coordinates, and calculates the areas and volumes of different elements. These computation techniques reduce the mistakes usually done when estimating quantities manually.

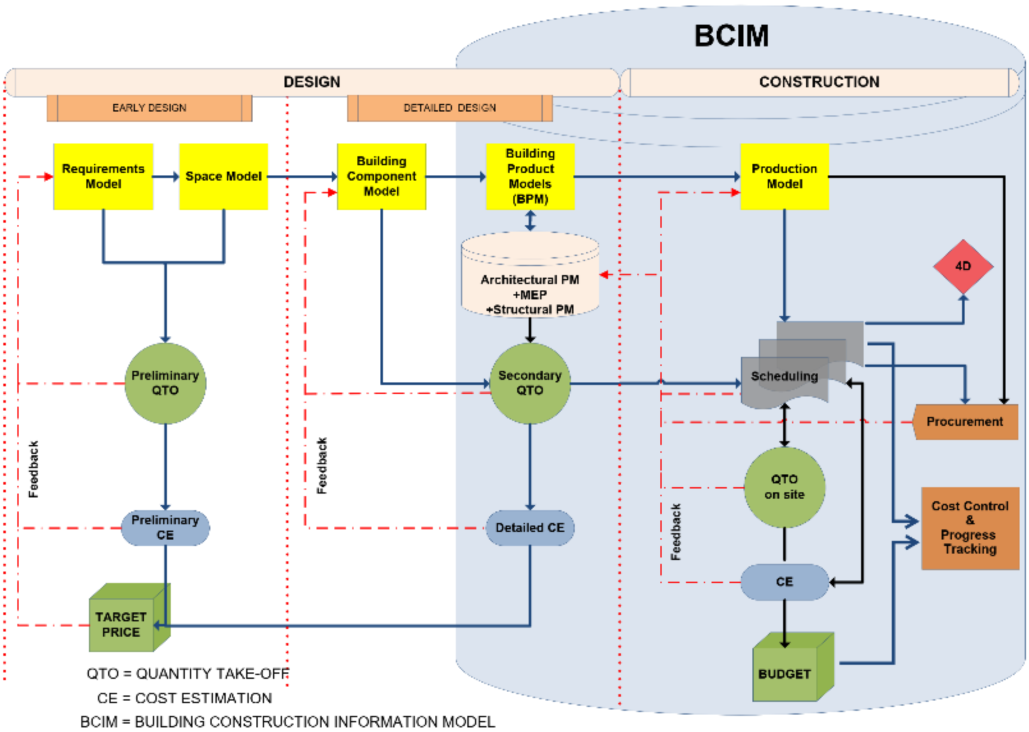

Figure 2. Process flow for quantity take-off during design and construction.
(Adapted from Ersen Firat et al., 2010)

Manual processes of estimating quantities present different risks in comparison to the ones engaged through a model-based digital quantity extraction. Traditionally, quantity surveyors have been using 2D drawings for a manual count and measurement of material quantities, also depending on their interpretation of the project based on the drawings. This process is time-consuming and error-prone, exposed to human errors of duplication and omission of elements (Liu et al., 2022). On the other hand, BIM-based QTO can only extract the information that is in the model, which in some scenarios can require further time to author systems that were not initially included in the BIM model for its quantity extraction. Also, this digital extraction will depend in the metadata included on the model and requires a proper structure of information for a complete mapping of the Bill of Quantities and the information model. Nevertheless, the associated risk on the manual extractions becomes exponentially higher when considering design changes, because BIM-based QTO allows an automatised update of quantities if it is done properly (Khosakitchalert et al., 2019b).

Nowadays, with BIM technology and its implementation, it is possible to automatically measure quantities based on the information models, improving substantially the time invested in this task and reducing errors in the estimations, accomplishing a BIM-based Quantity Take-off. Bečvarovská et al. (2014) did a comparative analysis of QTO using a manual approach and implementing a BIM tool aiming to determine if the use of BIM is more expedient, if the results obtained using BIM are correct, and if not what causes the mistakes; and how much time is saved in comparison with a manual method. By estimating quantities in a case study, they obtain a reduction of 80% of the time spent calculating quantities using the BIM model, and even though they faced deviations mainly caused by errors in the authoring process of the model, they categorized the deviations as negligible, concluding that the results were correct (Bečvarovská & Matějka, 2014).

This BIM-based implementation has been more adopted by construction companies and quantity surveyors in recent years. In the United States, a study was made (Olsen & Taylor, 2017) by surveying general contractors with a virtual construction department to identify factors that limit the ability to extract quantity data from the model, and 100% of the respondents used BIM for quantity take-off. Nevertheless, this BIM-based methodology is not flawless, and the generation of reliable and accurate information will depend on the completeness of metadata and the correctness of authoring processes used in the BIM models. The process of QTO is not an end in itself, but a methodology that precedes important tasks such as cost estimation, construction planning, or tendering (Monteiro & Poças Martins, 2013). Therefore, it is as important as having a reliable and accurate estimation of quantities as having an adequate information management process, for further analysis and aiming to support decision-making during the Design Development and Construction Management stages.

2.1.2. Challenges and issues in BIM-based QTO

2.1.2.1. Estimating quantities from compound objects

The challenges to perform a reliable model-based estimation of quantities are plenty, and several studies are done to identify problems and seek for solutions. An issue found regarding the geometrical information involves compound elements that are modelled as single objects but contain several layers with different data of materials in each layer, so they cannot be analysed as a single element. Khosakitchalert et al., (2019) created a study that explains the variations and inaccuracies obtained when estimating quantities of compound elements in relation with modelling issues and software limitations. Then, proposes a methodology to improve the accuracy of calculated quantities from compound elements, which was named “BIM-based compound element quantity take-off improvement (BCEQTI) method”. Afterwards, in a subsequent study (Khosakitchalert et al., 2020), he developed an automatic compound element modification (ACEM) method that modifies wall and floor objects that were modelled as multi-layered objects, to obtain independent objects for each layer so they can be quantified and analysed independently. At the end of the process, the semantic objects are joined, solving overlapping problems that could affect quantity estimations.

The use of multi-layered elements may also cause inaccuracies in the measurements, not only because of the need of having different properties for each layer (e.g., material), but also because the geometry of all layers fixed to a common boundary can result in inaccurate quantities. Considering a multi-layered internal wall, for example, composed of inside plaster, insulation, and structural material, because the wall is modelled as a single block, the height of each layer is the same, which is not aligned with the physical wall where only the plaster reaches the ceiling level. Similar inaccuracies appear in practically all multi-layered elements such as walls, floor slabs, slab-on-grade floors, etc. (Zima, 2017). Kim et al. (2019) did a study to evaluate the quantity discrepancies that can be obtained in interior components when modelling these elements as compositely modelled objects (CMO) or individually modelled objects (IMO), where CMOs are multi-layered objects and IMOs are modelled each part independently. In this research, two residential buildings in Korea were used as case studies, and for each project, the interior components were modelled as CMOs or IMOs, then quantities were calculated and compared to analyse the differences. Quantity discrepancies reached values of 15% in cement plaster and 10% in insulation materials, laminated floors, paper covering, and suspended ceilings, to name the major discrepancies. These results show how the quantities are directly affected depending on the authoring process implemented to model this kind of objects, where individually modelled objects allow a more accurate estimation of quantities. Also, it is important to consider that modelling each layer as a single element is a more complicated methodology, that can result in an increase in time and cost of the authoring process (Kim et al., 2019)

2.1.2.2. QTO based on geometrical properties and metadata

Most model-based QTO software relies on geometrical properties to estimate quantities. When the authoring protocols used are not correct or do not comply with the measurement standards, the quantity estimations are affected. For example, the connection of a slab and a beam will generate different quantities whether the slab was modelled over the beam until its external, or aside from the beam until the internal face of the beam, as shown in Figure 3. Liu et al., (2022) developed an algorithm that analyses the geometry of objects to automatically determine their border and the intersection planes with other elements. Based on this border, quantities of area, volume, height, and width can be calculated without depending on the geometrical properties of the objects. The algorithm extracts the vertical surfaces and scales along the z-axis with small distances to detect points where the border is thickened to identify other solids and adjust the border of the element by introducing cutting planes.

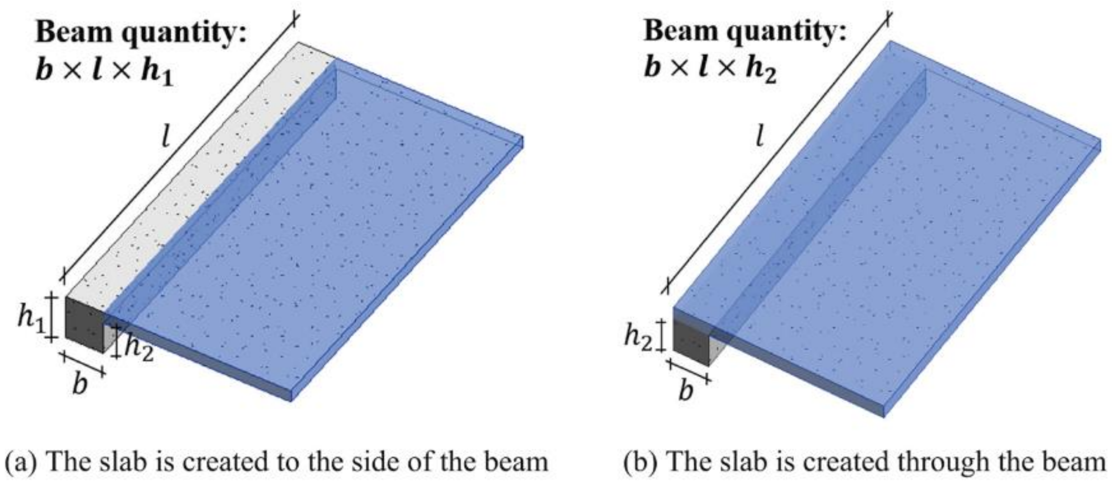

Figure 3. Different BIM model creation methods for a joint between a slab and a beam (Liu et al., 2022)

Intersecting objects also causes discrepancies when estimating quantities. A clear example, shown in Figure 4, is when non-structural walls clash with structural framing (e.g., columns and beams). This issue might be avoided when joined elements are properly defined, but in scenarios where this procedure is not correctly done, especially in early design stages where these elements are a work in progress, the manual correction to join these elements can be time-consuming and error-prone. Khosakitchalert et al. (2018) proposed a method to estimate the quantities of materials from the core and finished wall layers without relying on the join elements, and even considering the areas where structural framing is exposed and must be summed for the external finish quantification. The methodology uses Revit and a Dynamo script to identify the different elements and obtain the relevant surfaces. Then, based on a clash detection through Dynamo, identifies the intersected surfaces and estimates net areas in each layer. A graphical representation of the quantification of internal and external finish area might be seen in Figure 5. Because the procedure estimates independently core and finish layers, and this last one is also divided between internal and external finishing layers, it is possible to classify each quantity and accurately estimate the area aligned with the construction process (e.g., internal finishing layers delimited by the ceiling height)

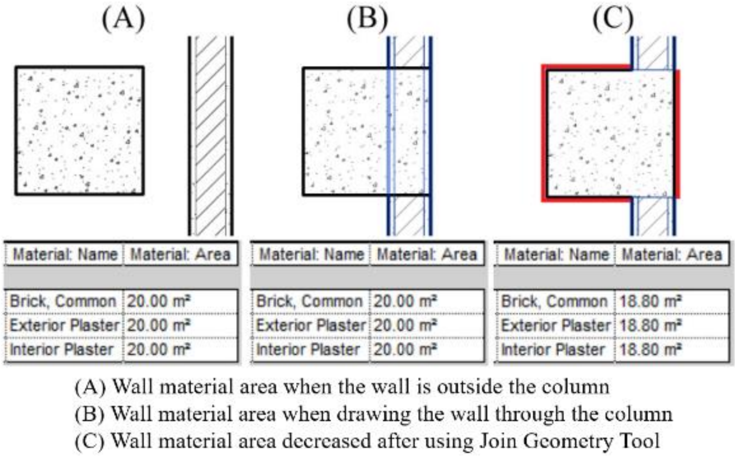

Figure 4. Different quantity estimations of materials in a wall according to the intersection and join element configuration. (Khosakitchalert et al., 2018)

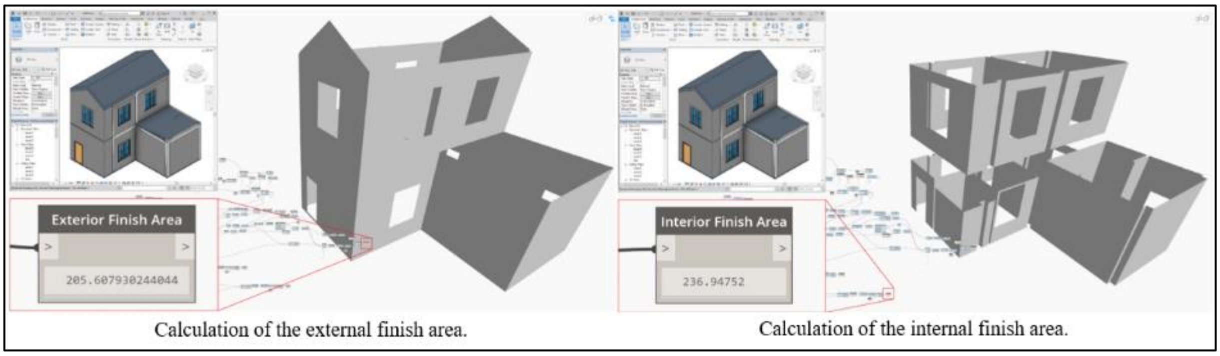

Figure 5. Graphical representation of the quantification of internal and external finish area. (Khosakitchalert et al., 2018)

2.1.2.3. Information exchange and property check

Workflows implemented to generate model-based quantity take-off and BIM analytics usually involve different software for the authoring process, estimation of quantities, and further analysis. This originates the necessity to exchange information between software. This interoperability is commonly performed using IFC (Khosakitchalert et al., 2019b). The IFC schema is constantly under development, and the results of exporting an information model from a native format to IFC may vary depending on the software used and the setup configuration for the export process, causing in some scenarios the loss of metadata and misinterpretation of geometrical properties. This problem affects the automated model-based estimation of quantities since the software relies on the object properties for information. Therefore, the revision of the information and property checking processes are indispensable before any calculation. Choi et al. (2015) proposed a system for schematic quantity estimations of a building frame using Open BIM tools, namely IFC models. The research is developed in four steps. The first step studies the LOD and IFC property requirements to improve the accuracy of the model. Then, proposes a physical quality checking of the model using Solibri Model Checker, which is a rule-based software to verify minimum requirements for shape representation and intersections among elements aiming to increase the accuracy of the quantity estimations. The next step explores the verification of data quality by implementing an *InSightBIM-QTO Pre-check* to check whether or not required data is introduced and to detect errors in input data. The final step refers to the quantity take-off process estimating the quantities of a building frame on the used case study.

In continuance with the importance of model review and property check, in the study previously mentioned, Liu et al., (2022) developed a semantic auditing approach to identify missing information and unintended textual errors before running the algorithm for the automatic quantity measurement. This auditing process is very valuable because not only identifies missing information, but also data that has input errors, whether it is related to typos or incorrect use of naming conventions. In model-based QTO, sorting and grouping is a key process to organize the information correctly and obtaining accurate results. This type of error causes inaccuracies in the prediction of resource quantities and is not easy to detect.

2.1.2.4. Quantities of unmodeled elements

The estimation of unmodeled elements is a challenge since the BIM-based quantity take-off depends on the information included in the model, but still, this calculation is required for a complete cost estimation. A common example is the formwork of cast-in-place reinforced concrete elements. The formwork is not commonly included in a model because it is a temporary element, though in many cases represents an important material and labour cost. Monteiro et al., (2013) approached the estimation of the formwork and indicated that the only solution to systematically carry out a QTO of formwork through a BIM-based methodology is to explicitly model the formwork. He explored the possibility of creating an add-on for the authoring software ArchiCAD for the generation of the formwork. This approach apart from being time-consuming may also cause problems interpreting properties when an exchange of models is done using IFC because the official IFC schema (IFC 4 ADD2 TC1) does not include an element type for formwork (buildingSMART International Ltd, 2020).

On the other hand, Khosakitchalert et al., (2019a) developed an automatic model-based methodology to calculate formwork area without modelling formwork elements. The method focuses on cast-in-place reinforced concrete, and it is divided into two parts: finding the formwork surface area and classifying formworks by element categories to calculate the correct formwork area based on the element's surface. In the first part, all non-structural, non-concrete elements are discarded from the model. The remaining elements are integrated into a single geometry to eliminate areas where elements intersect, then exploded to obtain all surface of elements. Previous to the breakdown of objects into surfaces, these are classified as to whether they require only lateral formwork (walls, columns, foundations) or lateral and soffit formwork (slabs, beams, stairs). In the second part, the surfaces are converted into geometries to calculate the surface areas organized according to the object type. To test this method, first, a simple prototype was created using Revit and Dynamo, and then the method was implemented in a case study where formwork quantity was manually calculated. The results were remarkable, obtaining a 0% deviation in comparison with the original calculation for each object type.

Unmodeled objects can also be a result of omissions in the model, due undefined information requirements. Rajabi et al. (2015) did a study focused on the optimization of the QTO process for MEP elements in the tender estimation phase, which is characterized to have a short time for estimations and a low Level of Development (LOD) in the BIM objects. The research focused on a case study where lamps and radiators were not modelled in some spaces but were still required, so the quantities must be considered for cost estimation. The estimation is done through variable wizards contained in RIB iTWO software. In the case of the lamps, based on the properties of the desired lamp and the required illumination intensity (Lux) for the space according to its function, the software estimates the number of lamps required to fulfil the illumination requirements. A similar logic is applied for the estimation of radiators, using the capacity of the desired radiator and the volume of the spaces, it is possible to obtain an estimated quantity of the number of elements to be installed in each room (Rajabi et al., 2015). Even though the information obtained cannot be assumed as highly accurate, the proposed methodology is an alternative solution when there is no information and the time available for the cost estimation is limited.

2.1.3. Measurement Rules and Official Guidelines for model-based QTO

The estimation of quantities and construction costs is one of the processes that lack standardization in the AEC Industry, due to the different practices adopted to perform a Quantity Take-off, which also vary depending on the region. There have been efforts to create standards that can be used worldwide for the quantity estimation and correct generation of the Bill of Quantities. One of the most known guidance has been developed by the Royal Institute of Chartered Surveyors (RICS). The globally recognized professional body has been providing quantity surveyors and construction cost managers with rules of measurement for building construction works since 1922 (Benge & Davidson, 2012) when the first Standard Method of Measurement (SMM) was published. Through time, significant improvements were required to address the problems associated with quantity estimations and construction measurements, leading to new editions of the standard until the publication of the SMM7 was reached, with the latest revision in 1998. Later, due to the evolution of the industry and the lack of adequate measurement rules that could be applied in the new constructions, RICS developed a new guide, entitled RICS New Rules of Measurement. Seeking to be applied throughout the lifecycle of the project, NRM is divided into 3 volumes:

- NRM 1: Order of cost estimating and cost planning for capital building works
- NRM 2: Detailed measurement of building works
- NRM 3: Order of cost estimating and cost planning for building maintenance works

Another Standard development intended to be used at an international level is the Civil Engineering Standard Method of Measurement (CESMM), which is elaborated by the Institution of Civil Engineers (ICE). Its first edition was published in 1976, mainly based on British Standards and working practices registered in the United Kingdom. The fourth and latest version was published in 2012 with the last revision in 2019, in which the British Standards were removed seeking to be applicable worldwide (MCGILL, 2012).

Also, some institutions have documented guidelines to be applied at a national level like the Hong Kong Institute of Surveyors (HKIS) with the development of the Hong Kong Standard Method of Measurement (HKSMM). The first edition of this document was published in 1962 and has been improved throughout the years to reach the current 4th edition (HKSSM4) published in 2005 (The Hong

Kong Institute of Surveyors, 2021). According to the HKIS, vast change in the construction industry in the last decade considering the adoption of new materials, the advanced construction technologies particularly in prefabrication, and the use of innovative BIM technologies, it was necessary the development of the 5th edition that is currently a draft and has not been officially published, though it has free access for the compilation of suggestions and comments.

According to Monteiro et al. (2013), in Portugal, there are no official standards for quantity take-off, but a publication entitled "Curso sobre REGRAS DE MEDIÇAO NA CONSTRUÇAO" (Santos Fonseca, 2003) from *Laboratório Nacional de Engenharia Civil (LNEC)* is often used as a reference for this process. This document has the purpose to provide the different stakeholders with a set of definitions and measurement rules to be used as a guideline during a construction measurement, whether it is from a design or on-site. Even though the document was not redacted to be used for BIM-based QTO processes, it contains information like units of measurement, classification (e.g., direct, and indirect foundations), and calculation examples that can be a basis for information requirements needed for a model-based estimation.

Other countries like Malaysia, have done great efforts to produce their own Standard Measurement Methods. According to the Construction Industry Development Board (CIBD) of Malaysia, the first edition of the Malaysia Civil Engineering Standard Method of Measurement (MYCESMM) was first published in 2013, evolved from the CESMM (*Malaysia Civil Engineering Standard Method of Measurement 2 (MyCESMM2) | Construction Industry Development Board*, n.d.). Akbar et al. (2015) developed a study through literature review and an interview approach to identify all current issues related to the Malaysian SMM, aiming to improve the standard and its application. The current version of the Standard is the second edition (MYCESMM2) which was evolved in accordance with the development of new versions of the Institution of Civil Engineer´s Standards (CESMM3 and CESMM4) and based on current local practices (*Malaysia Civil Engineering Standard Method of Measurement 2 (MyCESMM2) | Construction Industry Development Board*, n.d.).

With the constant increase in BIM implementation for construction projects and the exponential development of BIM technology, documentation has been generated to adapt quantity and cost estimations using model-based quantity take-off. One example is the RICS guidance note entitled BIM for cost managers: requirements from the BIM model. This document has the objectives to assist the quantity surveyors and cost managers in delivering cost consultancy services by using model-based data and to inform the needs of the quantity surveys and cost management in performing the measurement role in a BIM environment (RICS et al., 2015).

The software employed to perform model-based quantity take-off and cost estimations use different measurement rules (Abanda et al., 2017). Navisworks for example has integrated Construction Divisions (CSI-16, CSI-48) from MasterFormat standard for information organization. Other software like iTWO CostX gives the user the option to use different libraries containing New Rules of Measurement (NRM 1, NRM 2) and Standard Measurement Methods (SMM7, HKSMM, ASMM5). Vico Office contains a Work Breakdown Structure based on Uniformat. In the end, these classification systems and standards are developed in Extensible Markup Language (XML) format, which much software also can incorporate these libraries to be applied by the user.

2.1.4. Uses and Applications from QTO information

2.1.4.1. Automatic scheduling and 4D analysis

The integration of a BIM-based 3D model with a construction schedule that represents the variable of time and the sequence in which the activities are going to be done results in a 4D model, and has been highlighted as one of the great uses of BIM for planning and construction management (Wang et al., 2014). Nonetheless, in scenarios where the construction schedule is developed independently from the information model and using this technology only as visualization or animation of the construction process, does not reach the full capacity of this BIM implementation. Wang et al., (2014) developed an interface system that applies the quantity take-off information to provide a site-level operations simulation, and consequently generate a construction schedule for the reinforced concrete elements of a relevant case study. He accomplished evaluating task durations according to the material quantities and to plan resource allocations based on the simulation of the operation.

2.1.4.2. Cost estimation and 5D analysis

The cost estimation process in BIM is derived from the quantity take-off. A well-prepared QTO can reduce time and effort in cost estimation and also becomes less prone to omissions in comparison with a manual process (Gołaszewska & Salamak, 2017).

Cash flow management is a central feature for construction projects, being the construction industry considered one of the industries with a higher financial risk. Amin Ranjbar et al., (2021) proposed a framework to estimate the cash flow on construction projects based on cost estimation and construction schedule generated with BIM. Then, assess the identified risks of the project to generate a probabilistic cash flow using Monte-Carlo Simulation to support decision-making in the project management. The framework was then tested in a 5-storey building project in Iran. As shown in the workflow of Figure 6, all the proposed analysis starts from Quantity Take-off, justifying once again the importance of an accurate and reliable QTO.

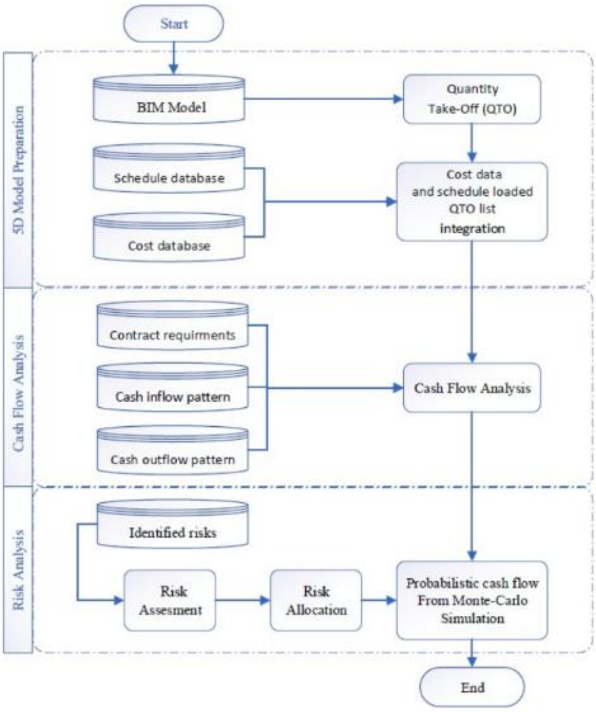

Figure 6. Workflow for the generation of a probabilistic cash flow on a construction project. proposed by Amin Ranjbar et al., (2021).

2.1.5. Types of decision-making present in the Construction Phase

2.1.5.1. Progress Tracking

Project progress tracking and controlling is one of the most critical responsibilities during a construction project (Greeshma & Edayadiyil, 2022). According to the Project Management Body of Knowledge guide (PMBOK Guide), progress tracking "is the process of tracking, reviewing, and reporting the progress to meet the performance objectives defined in the project management plan (Project Management Institute, 2013). For this process, it is essential to compare the actual project performance against the project management plan. Therefore, it is required to previously have a correctly structure project plan that allows a proper update.

Among the most complex challenges that the progress tracking encounters, is the great amount of information that is related to a vast number of variables like scheduling, activity performance, quality control and change orders, to name a few. Also, in many cases the information from the construction site is provided by diverse sources which not always match in structure and classification. In addition, it is a great challenge to correctly record deviations caused by unconscious decisions like an unperformed workmanship for example (Omar & Nehdi, 2016).

2.1.5.2. Value Engineering

The concept of Value Engineering was first introduced in the construction industry in the early 1960´s, and has been employed worldwide since then (Chen et al., 2010). According to the PMBOK Guide, Value Engineering (VE) is “an approach used to optimize project life cycle costs, save time, increase profits, improve quality, expand market share, solve problems, and/or use resources more effectively” (Project Management Institute, 2013). In this manner, to in depth analyse if a proposal could result in a positive safe without losing functionality, it is required to consider many variables that influence the cost, construction time, quality, resource management and construction logistics. As well as other decisions, to analyse a proposed optimisation of the project by this VE approach it is also required to have a complete and structure estimation management plan, in order to make a complete comparison. Even in the case of a VE proposal that considers all relevant information, if the previous planning lacks equal detail, the effort becomes worthless, and it is not possible to correctly address a data-driven decision.

One of the main challenges of the traditional VE studies, is that it comes from free-thinking techniques such as brainstorming, which lack of a structure that guaranties the coverage of all necessary information, and limits the possibility of finding innovative solutions because options are based only on the experience of the team addressing the issue (Zhang et al., 2009). Throughout BIM implementation, it would be possible to interconnect the relevant information based on quantities to create a complete estimation of a VE approach.

2.1.5.3. Change Management

It is inevitable that changes in the design appear throughout the lifecycle of a project, meaning the management of change orders are one of the most, if not the most, concurrent decision-making during a construction project. In this manner, change management becomes necessary to reduce as much as possible the impact of changes on a project (Hwang & Low, 2012). It is important to address modifications in the early stages of the project´s lifecycle. As explained in the MacLeamy Curve shown in Figure 7, the earlier a change is identified and addressed, the less impact on the cost and the ability to impact cost and functional capabilities are higher.

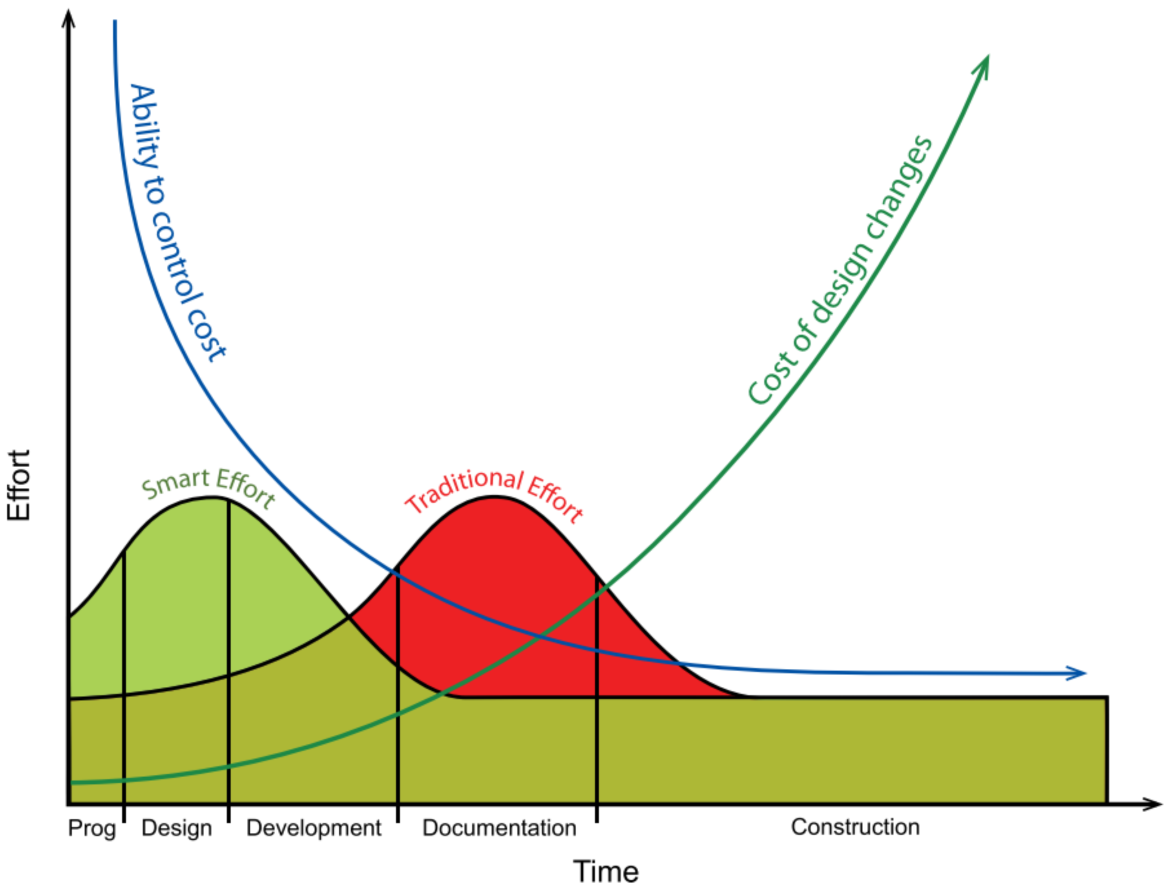

Figure 7. MacLeamy Curve (MacLeamy, 2020)

Even though the importance of change management is well known, many are the projects that still do not have a proper change management system. Mohamed M. Anees (et al., 2013) developed a study through the implementation of surveys to evaluate the efficiency of change management in construction contractors in Egypt. Among other findings, he identified that 43% of all participants in the study did not use a well-defined change order management system to approach this kind of decisions. He also identified the importance of collaboration and proper communication of the information among the stakeholders, being the owners the main source of modifications, but not always the ones who dominate the complete details and variables involved in every change.

2.1.5.4. E-Procurement

Electronic procurement, commonly known as e-procurement is the transformation of conventional manual processes into digital procurement systems, allowing to order and purchase resources or goods in online services (Yevu et al., 2022). For the construction industry, the implementation of E-Procurement Systems (EPS) allows the digitalization of the supply chain system and its connection with the design information. It is directly linked with quantity information through the negotiation, quotation, purchase and overall management of suppliers and subcontractors that conform the supply chain system for a construction company on specific projects.

The digitalization of the procurement and connection with the supply chain has gained popularity in the construction industry due to the significant added value and benefits in the information management and in the time and cost spent on this area. Hashim et al., (2013) developed a study to explore the value of e-procurement in construction companies, throughout a survey of 120 main contractor companies in Malaysia. His study confirmed the positive impact, pointing less error-prone processes to manage the supply chain, the reduction of time and cost, and the improvement in the communication with the characters involved in the supply chain.

One of the most important participants in a construction project supply chain are the subcontractors. The approach of subcontracting specialized tasks for the construction process has gain popularity in the project management planification. Thus, drafting subcontracts has become a challenging decision for the main contractor, which involves many variables regarding the time and cost of the subcontracted activity, as well as contract conditions which play an important role throughout the process (Hassan & Le, 2021). Therefore, it becomes important to apply approaches that allow a complete analysis of the bidding of subcontracts to make data-driven and less error prone decisions when defining a subcontractor.

According to the McKinsey report (Mckinsey Global Institute, 2020) that predicts what will be considered as the new normal for the construction industry, its ecosystem will represent a more standardised, product-based industry. Due to the digitalization, several projects will be able to identify common products within the different designs, in which suppliers will become more expert in detailed products or services. In comparison with the environment nowadays, which involves independent designs and for each design specific products and services are manufactured without connection within different projects. For the new environment, E-Procurement Systems will be key for a proper operation, where it will be possible to map the information requirements stipulated on the design database to the supply chain. Figure 8 shows illustrated diagrams of today´s construction ecosystem and the ecosystem in the future, explaining the product-based approach that the industry will manage, according to the prediction in the study.

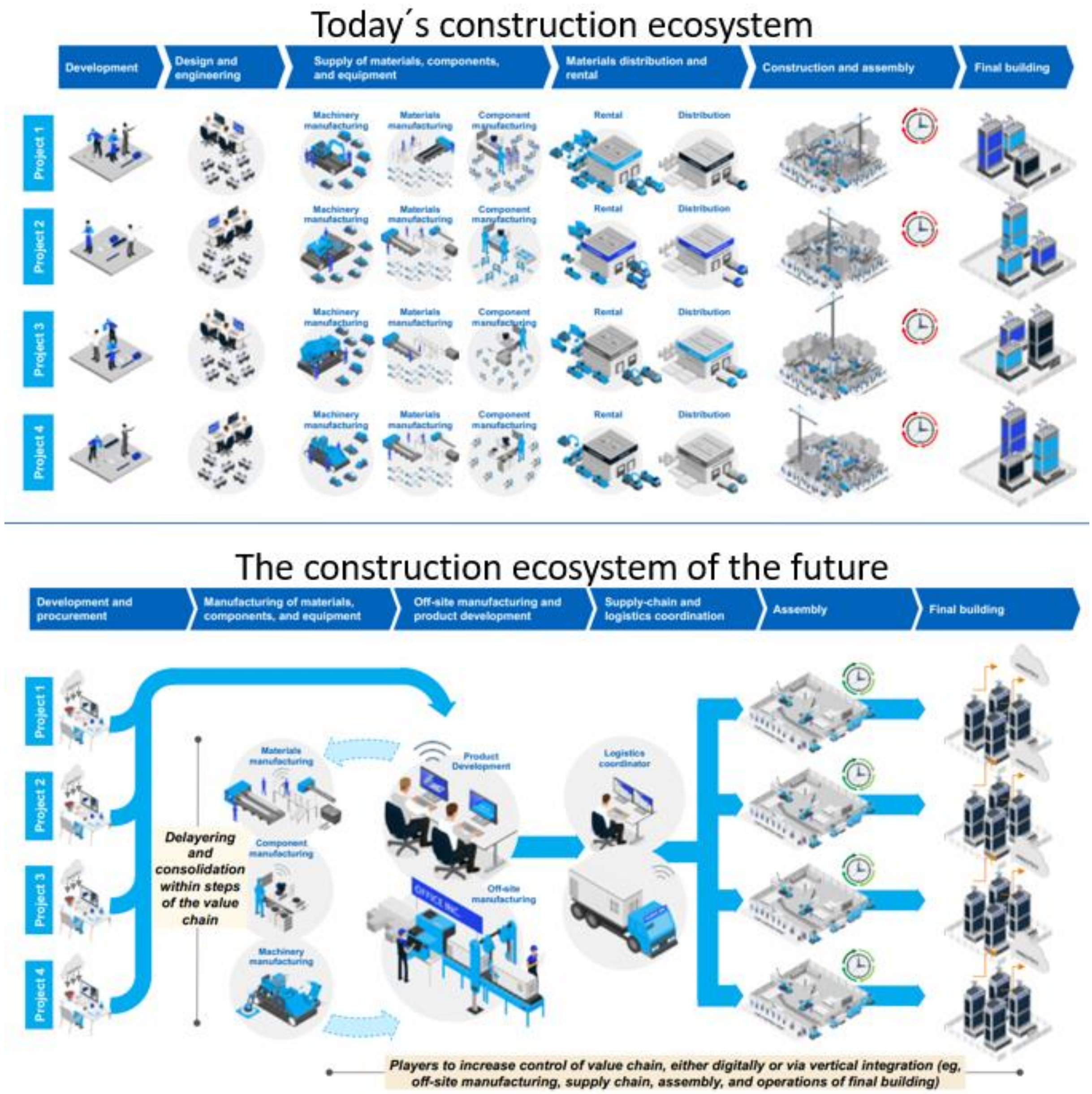

Figure 8. Ilustrated diagrams comparing today´s construction ecosystem with the future of the industry (Source: Ribeirinho et al., 2020)

2.2. BIM-based QTO Software Review

In this chapter, a study was done to assess offered solutions, pros, and cons of software dedicated to BIM-based QTO, to study how information is generated and to understand how the main issues faced for this estimation process are addressed by distinct software available in the market. For this evaluation, tutorials were studied for each software, as well as user guides and in some cases small tests were directly performed on the available software. The objective is not to conclude which software is the best, but to comprehend how different tools available in the market process and analyse quantity information. For that, it was possible to access seven different software were entitled Software A to Software G. For some cases, a single software was studied but on other cases each analysis includes several software, since the process of Quantity Take-off and BIM Analytics is done through different software from the same software package. The assessment of each software was done maintaining impartial criteria to obtain objective comparisons and free of bias.

2.2.1. Software comparison schema

For the evaluation of each software, five categories were defined: information management, usability, BIM analytics, collaboration, and visualization of the information. Each category is then divided into criteria, and each criterion is meant to answer certain questions or compile with some features or capabilities. Figure 9 shows a graphical explanation of the structure about the considered criteria.

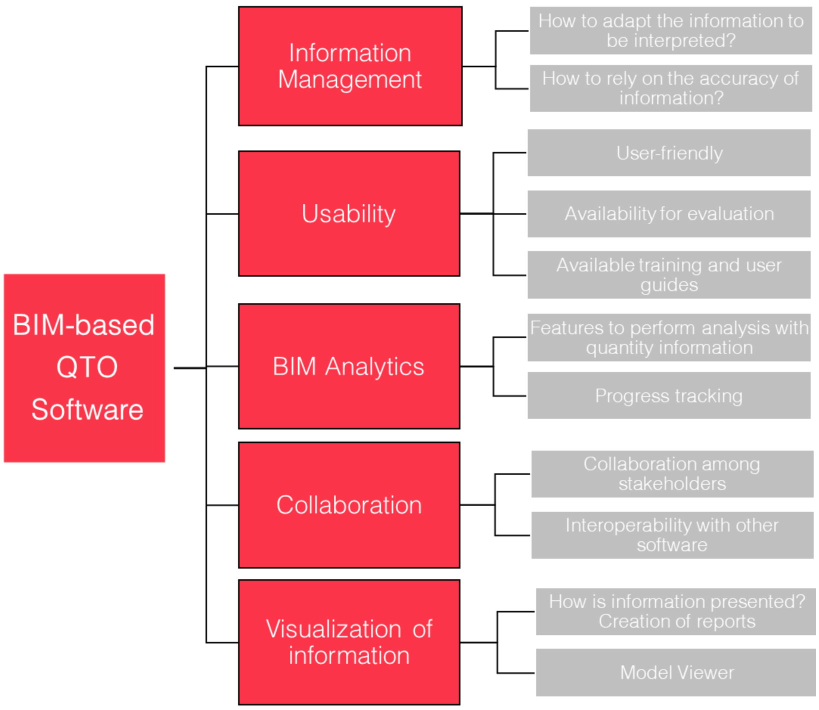

Figure 9. Structure for the criteria considered for software evaluation

2.2.1.1. Information Management

The category of Information Management is divided into two criteria. The first criterion refers to the ability of the software to organize, add or modify the input information so the quantity extraction will be correct, without excluding any relevant information. The second criterion focuses on the capabilities or processes a software might contain to evaluate if the information received is complete and accurate. Table 1 presents the characteristics of each software regarding the mentioned criteria.

Table 1. Results of the software evaluation for the Information Management category.

	How to adapt information to be interpreted?	How to rely on the accuracy of information?
Software A	- The software gives the user the possibility to add, modify and delete element properties. – It also allows an intelligent creation of selection sets and breakdown structures to group elements and information.	– Elements are automatically populated with calculated geometrical properties such as volume, surface area, largest projected area, bounding box height, width, and length. These properties cannot be modified. – The software counts with add-ins to check the model such as property checker and IFC model checker. – Registers every version of the model, but the versions are not comparable. – Through the clash detection feature it can detect repeated or clashing elements. – It can automatically eliminate non geometrical elements.
Software B	– It is possible to divide elements to count and analyse each part independently, for a better adaption to the construction strategy. – The software allows the assignation of tags to identify and group cost items. – It can group elements among levels without relying on the level properties but using locations: spatial division that can be customized. These locations can also group elements horizontally. – The software allows the user to add or hide properties for a better organization of the information. Adding properties can only be done derived from existing properties of the object.	– For the main geometrical properties such as volume and area, it measures these quantities for main elements such as walls, columns, and slabs, without depending on native properties of the object. – Allows to create manual quantities by measuring the model. – Includes a Painting Mode, that adds colours to the objects to visually verify which Take-off Quantities and Take-off Items are included in the estimations. – Has a very complete tool to compare model sources by version and by discipline.
Software C	– Allows to include calculated properties. – It is possible to create customized zones to group elements horizontally and vertically according to its spatial location.	– Estimations depend completely on the object´s properties, with the particularity that for models imported directly from Revit or Mudshark, it uses a template to identify and group properties for quantities. – Allows to manually calculate areas from the BIM model, which can be useful to check metadata included in the model.

	How to adapt information to be interpreted?	How to rely on the accuracy of information?
Software D	– Useful creation of selection sets and querying price lists by browsing words. – Includes a feature to add tags to certain objects for grouping and querying using tags. – Allows to include calculated properties.	– Estimations depend on the object´s properties and the authoring protocols used. – When updating an IFC model, it automatically creates a selection group with the new elements, allowing to understand the changes and additions in the model. – Includes a tool that allows to compare versions of documents with the actual documents.
Software E	– Includes an algorithm that can group similar elements that are not categorized equally by issues regarding naming convention, classification, etc. – Straight forward and effective organization of the data that is required to show or the one that is considered relevant. – Useful colouring tool that allows an easy manipulation of the level of granularity of data, with a visualization of 3D and 2D views simultaneously.	– Estimations depend on the object properties and the authoring protocols used. – Includes a comparison model feature that highlights changes, identifying whether they were added, modified, or deleted by using a colour code.
Software F	– Allows users to split objects and assign cost codes accordingly, permitting them to be better aligned with the construction strategy, resulting in a better analysis of data. – Uses Advance Work Packages (AWP) for a complete grouping of elements and linking with relevant documentation for a complete organization of the information.	– Calculates geometrical properties of volume and area which cannot be modified, and this estimation applies to every object without distinction. – Creates a report with changes when updating a model.
Software G	– It is possible to create calculated quantities but only based on other existing properties. – Objects are grouped depending on the IfcType property. – Object properties cannot be modified.	– Estimations are obtained from IFC properties. – Possible to visually check which elements are assigned to the quantity estimation and which are not.

2.2.1.2. Usability

The category of Usability aims to study the complexity to use the software. This category is divided into three criteria: user-friendly, availability for evaluation, and available training and user guides. The first criterion compiles characteristics to determine how easy to manipulate the information and understand how the software works, from the point of view of a non-experienced user. The second criterion refers to the possibility to learn to use the software through free trials, trainings or similar. The third criterion evaluate the accessibility of sources like tutorials, user guides, or similar, to learn how to use the software. Table 2 presents the results of the software evaluation for this category.

Table 2. Results of the software evaluation for the Usability category.

	User-friendly	Availability for evaluation	Available training and user guides
Software A	- Considered a complex software, due to the number of commands, the different layouts it includes, and the specific processes to work.	- 1 year student license with complete features. - 30-day trial with a full version of the software.	- Plenty of tutorials and support. The user guide is easy to follow with samples to learn the software.
Software B	- Considered a complex software, due to the number of commands, the different layouts it includes, and the specific processes to work.	30 day-trial & student version application available.	- User guide available but very limited tutorials. The user guide includes explanations of different features but not step-by-step procedures.
Software C	- Not very complex to use in comparison with other software.	- Student version available that requires a payment a small amount. The student license is very limited and lacks many features - There is no free trial available.	- Plenty of video tutorials available online.

	User-friendly	Availability for evaluation	Available training and user guides
Software D	- The processes are more intuitive like in the case of grouping semantic data.	- Available a 30-day trial and student license available.	- Good instructional information available including a user guide and instructional video tutorials uploaded by the developer.
Software E	- User-friendly in comparison with other software, with intuitive procedures.	- Some weeks free trial available. - Does not have a student license available.	- Plenty of training supplied by the developer, as well as sample projects available
Software F	- Moderate user-friendly. - Email costumer support is helpful and with a good time answer rate and tracking of problems.	- Student license available, but with limitations in creation of project: only 30-day project trial creation. - The software package includes different platforms, but not every platform is available upon student license or free trial.	- Accessible user guides and training at the developer's webpage, with a previous creation of a user. - Plenty of video tutorials online, but not very complete in comparison with other tutorials for other software.
Software G	- Element mapping for QTO seems an intuitive yet very manual process. Also, it is possible to create rules for estimation according to properties of certain element types. These rules can be saved and used in future projects.	- Evaluation version available.	- Video tutorials available. - There is no user guide with step-by-step procedures but there is a document with the explanation of the features that the software includes.

2.2.1.3. BIM Analytics

The category of BIM Analytics explores the ability of the software to generate systematic analysis based on the quantity data. This category is divided in two criteria, as shown in Table 3. The first criterion relates to the features for analysis of the project a software might include such as cost estimation, construction scheduling, 4D/5D simulations, etc. The second criterion refers to the possibility to record progress tracking to compare planned vs. actual statistics of a project.

Table 3. Results of the software evaluation for the BIM Analytics category

	Features to perform analysis with quantity information	Progress Tracking
Software A	- The software can create a cost estimation through the assignation of resources, organized into cost items. - Construction schedule can be imported, as well as created using methodologies and zones. - Activity durations can be automatically calculated according to daily outputs. -Complete generation of 4D/5D simulations and analysis. - Includes an API console integrated for programming tailored processes.	- Complete record of progress tracking feature that can be used to compare actual quantities, costs, activity durations and overall schedule. - The process to register the progress into the software is complex, and does not have mobile app.
Software B	- Very complete tool to compare source models, as well as quantity and cost date between different disciplines or different versions. - Complete cost estimation. Also, costs can be imported from an excel sheet. It does not require a specific template structure to import the data because each column can be manually mapped. - Possible to create construction schedule for 4D/5D analysis. It can be created using methodologies for an easier creation of the dependencies of the activities. - Includes a Bid manager feature that allows bidding comparison for subcontractors for example.	- Allows to track the construction progress and compare it with the planned schedule and quantities.

	Features to perform analysis with quantity information	Progress Tracking
Software C	- Comprehensive comparison subcontractor tool that supports decision-making to choose subcontractors in Planning Management. At the end is an intelligent excel spreadsheet that allows to include calculated quantities for comparison, as well as autofill missing information of quantities from the subcontractors offer to allow a more equivalent comparison. - Combines the 3D model views with the 2D drawings when making a calculation. Also allows to do visual revision of the quantities and identification of changes when updating, but still is very focused on 2D estimations	- Progress tracking is not supported. The software house has another software focused on construction project management, but it cannot be connected with the QTO software.
Software D	- Includes a database of pricelists from different locations as well as customized in-house pricelists and allows to open more than one pricelist at a time for comparison. - The software package includes several software, and the one focused on QTO includes features only for estimating quantities but does not go further with the calculated information like other software. It has another software focused on construction scheduling an another intended for cost estimation.	- Progress tracking is not supported. The software developer company has another software intended for construction management but does not connect with the information of the addressed software package.
Software E	- Allows a connection with Oracle Primavera (construction scheduling software) to incorporate a construction schedule and link resources to the schedule. Also, it is able to create 4D simulation and analysis based on the imported schedule.	- Complete progress tracking feature connecting in real-time with the mobile app and easily report progress.

	Features to perform analysis with quantity information	Progress Tracking
Software F	- Complete scheduling tool allowing to create schedule from resources and automatically create a 4D simulation. Is also possible to automatically set duration of tasks depending on the capacity per time to create a certain task. Also, it has the possibility to import different schedules from different sources (subcontractors for example) to link into the same schedule and perform a coordinated 4D analysis.	- Allows a complete progress tracking using two software. The progress is registered in the software intended to manage the construction site, then directly synchronized to the scheduling software for planned vs. actual comparison and analysis. - It is possible not only to estimate progress per task, but also to indicate resource status (e.g., formed, reinforced, or poured for concrete elements; or equipment ordered, shipped, received, late for procurement management). This registration is configured in the scheduling software, can be reported in the construction site management software and then analysed back into the scheduling software, with the possibility to create coloured coded visualization depending on the defined status and updating progress schedule.
Software G	- Is possible to do a comparison of models and estimates from updated versions. - Includes a cost estimation feature. The user can store and access different pricelists from different companies. - Includes a construction scheduling feature. It is possible to set duration of activities according to the quantities and input daily values. - It is possible to perform 4D and 5D simulations using the cost and schedule information.	- The software does not have a progress tracking feature but has a feature to register and analyse accounting through the input of received payments.

2.2.1.4. Collaboration

The next category evaluates the possibility to perform collaborative work. It considers two criteria for its evaluation: the first one studying the collaboration among stakeholders and the second one the interoperability with other software. The results of the software evaluation for this category are presented in Table 4.

Table 4. Results of software evaluation for the Collaboration category

	Collaboration among stakeholders	Interoperability with other software
Software A	- Online projects allow the software to function as a CDE allowing different users to Collaborate on the same project, and with defined roles for users for access control. - Resource templates, selection sets, cost structure templates can be exported and imported in future projects. - Communication and tracking of issues, as well as progress reports can be exported and imported using BIM Collaboration Format (BCF) OpenBIM format.	- Can export models in IFC format, including the added or modified properties. Includes an export configuration that allows to define: IFC2x3 or IFC4 schema; all elements, selected elements, or visible elements; schedules, QTOs, linked documents, 3D scene colours and export sources as different files. - Issues can be created in. BCF Open BIM format. Includes a direct export to a BIMCollab project to automatically communicate issues in BCF format. - Includes a connection with Power BI to export reports about clash detection, project information and data, QTO and cost estimation, and progress tracking. - Exports reports and templates (custom breakdown sets, cost classification sets, etc.) and can also import these templates to be used and modified in the software. As expected, these templates have a defined structure. - Able to import and export schedules with Primavera and MS Project, using XML format. - There is a publisher plugin for Revit and Navisworks to export directly from this software to the software format. Does not require a license for this export. The plugin for Navisworks allows the integration of files that cannot be exported to IFC in their authoring software but are compatible with Navisworks. After testing the export from Navisworks it was not an optimal export, since all elements are exported as generic models. - There is also a plugin for Revit to import properties into this authoring software, allowing to add, populate and modify properties to be imported into Revit.

	Collaboration among stakeholders	Interoperability with other software
Software B	- Through a connection using Trimble Connect, it is possible to connect data with models so that quantity information will appear as properties in Trimble Connect. Also, possible to share models for updates. - It is not possible to work collaboratively in the same project.	- Possibility to import, create, modify, and export issues in BCF Open BIM format.
Software C	- It is possible do connect the projects to be used through a network setup, but it depends on an external database configuration.	- The software supports many formats to import models like IFC, and models authored in Revit, ArchiCAD, MicroStation, Tekla, Mudshark, and SketchUp. It also has full support for CPIXML files. - It is possible to import BoQ from CSV files to edit in the software and to export in CSV as well.
Software D	- The software package has an online platform that allows sharing info in the web-based app, but still maintaining an access control. It also has great integration with the model viewer software developed from the same software house. - The software can save and load BoQ templates and models to be used for future projects.	The model can be imported and exported to IFC. - Price lists and BoQs can be imported and exported to/from Excel and Word. It can be done through the Import/Export tool or by drag and dropping selected info (for export).
Software E	- The software is web based, allowing great collaboration in which the user license allows unlimited users to access, but still managing permissions for access control and modification permissibility. - Calculated properties can be used in future projects without the need to reconfigure.	- Only supports Revit and Navisworks model formats. To import IFC, it must be done through Revit, which is not optimal because Revit does not interpret correctly IFC files. - Selection sets created in the software can be imported into Navisworks. - Sharing data with other software or users can only be done by exporting into Excel spreadsheets. - Views can be imported or exported to be used in other projects.

	Collaboration among stakeholders	Interoperability with other software
Software F	- All the information is held in in a web-based software from the software package, which allows access to external users (e.g., Subcontractors) to view published information, tasks assigned to them and related documents.	- Supports a great number of formats to import 3D models, including IFC. This process can be done through a is a direct import for supported formats, or by using a plugin for some authoring software like Revit. - Information like resource cost can be imported using an excel template. - Schedules can be imported to the scheduling software from MS Project, Primavera P6, Safran, Asta and IfcWorkSchedule.
Software G	- Projects can be stored in a cloud developed by the software house, with the possibility to create users and roles for access control.	- The software can import and export the cost of resources using an Excel template. - It can also import and export schedules to Primavera, MS Project, and Synchro Pro, maintaining the mapping of elements.

2.2.1.5. Visualization of information

This category evaluates how the information is shown to the users, especially assisted with a model viewer, as well as the generation of reports to present results. Therefore, this category is assessed in two criteria: creation of reports and model viewer. Table 5 presents the results of the software evaluation for each criterion of this category.

Table 5. Results of software evaluation for the Visualization of Information category

	How is information presented? Creation of reports	Model Viewer
Software A	- The software has an add-in to automatically create interactive reports in Power BI. - It also automatically generates graphics to compare and analyse resource quantities and costs. - It is possible to export the Quantity Take-off, the Cost Breakdown Structure, and the schedule information into Excel spreadsheets, in structured reports. The report creation for the QTO has a styled report that shows the location of the estimated element using a viewpoint from the model viewer	- The software includes a complete 3D model Viewer with multiple features like distance measurement, spot elevation, wireframe to shaded, selection modes, walking mode, as well as types of views like 3D view, Schedule view, assigned/unassigned elements and colour coded from the WBS defined in the QTO. - When positioning over an object in the model viewer, it automatically displays predefined info of the object like cost and properties like volume, area, depending on the type of element. - Is it also possible to create bounding boxes and section planes. The section planes can be aligned automatically with predefined levels or wit floor levels that the software identifies from the input data. - The user can change the view styles into wire framed, opaque or shadowed. - The model viewer includes a very complete property viewer for the selected elements.
Software B	- The software includes a very complete tool to create graphical reports of cost estimation, progress report, resource quantities, and schedule information.	- This software includes a model viewer that allows a geometrical comparison of models from different versions or disciplines. The user can create a division plane that can be moved to divide the compared models to check for difference in position of the models or geometry and quantity of the elements. - The view styles can be applied to each model source independently. - Elements are highlighted automatically when selecting a line in the QTO sheet, allowing a better comprehension of the location and geometrical representation of the information. - It is also possible to do manual measurements directly in the model, which highlight to understand and review the boundaries of the measurement. - The model viewer allows to create bounding box and section planes that are easy to manipulate.

	How is information presented? Creation of reports	Model Viewer
Software C	- This software incorporates an excel plugin that allows the user to easily create spreadsheets from data in the software, and this data will be linked to the software so it can be automatically updated when changes happen in the spreadsheet. - Estimated quantities from the QTO can be presented in 2D layouts.	- The model viewer included in the software allows to create cut planes by scrolling into the model, which makes these planes easy to manipulate. Also, the view can be saved as a viewpoint. - It includes different view styles like wireframe, shaded, transparent and ghost view. - Easy to handle hide/unhide elements tool according to selections or classifications. Also, by using layers or the model tree. - Accessible object properties view only by right-clicking on an object.
Software D	- The software allows to export BoQ in .docx or xlsx format in a presentable template. Also, this information can be exported in the software´s file format to be used in other projects.	- The viewer includes a property view for the selected element. - It is possible to show or hide certain elements using assigned group tags. - It is possible to make linear measurements on the model. - View styles (wireframe, shaded, shaded with lines, on/off bounding box and 2D geometry) can be defined.
Software E	- The software has a direct connection with Power BI to create graphical interactive reports of quantities, costs, and progress.	- Selecting objects in the model tree also highlights the elements in the model viewer and in the inventory, as well as selecting in the inventory, permitting a better understanding of the information. - It is possible to create views based on custom rules that use properties (e.g., show only columns with material concrete or hide all walls with family type drywall).
Software F	-The software to perform QTO has a limited creation of reports, where it is only available to export to an Excel spreadsheet without any configuration - The software for construction scheduling has a tool to generate different reports, including the possibility of automatically generate graphics to compare data from the planned and progress tracking input information.	- Both the software for QTO and the one for scheduling have model viewer included. The one in the QTO software allows more options like section planes and element property view. The one in the scheduling software only contains a hierarchical element grouping tree and a property viewer.

	How is information presented? Creation of reports	Model Viewer
Software G	- The tool to compare models and quantity estimations from updated versions automatically generate dashboards and graphics. - Analyses of prices and costs can be exported to Excel using customizable templates	- The software includes a simple model viewer with few features like cut planes. - It is possible to visualize element properties and filter elements through property query.

2.2.2. Software evaluation tool

After studying the assessed BIM-based QTO software and listing its main characteristics depending on different criteria, it was intended to quantify each software´s performance for each defined criterion. The objective was to be able to provide a tool that could be used for a team looking for a BIM-based QTO software that suited them best. Therefore, a matrix was created configured with calculations that use weights to set a range of importance to each criterion, allowing the tester to rank each criterion based on their own studies and previous knowledge of a software, and get an overall score that would provide a guidance to the team on which software could be better suited for their work.

To be able to rank each criterion, several sub-criteria were defined, based on the software evaluation and its features. The diagram shown in Figure 10 presents the defined sub-criteria organized according to which criteria they are meant to qualify. A larger visualization of this image is presented in Appendix 2. Then, a specific number of points were set for each sub criterion, so that the sum of each group of sub criteria will give a maximum of 5 points to the criterion it is evaluating. The number of points defined for each sub criterion can also be defined by the user based on their needs. Finally, using the input of the user where he or she qualifies the performance for each sub criteria in a range from 0 to 10, the score for each criterion is estimated through the following formulas:

$$S_T = \sum P \times S_{max} \qquad (1)$$

$$C = S_T \times W \qquad (2)$$

Where,
S_{max} equals to the number of points assigned to each sub criterion, in which the sum of these numbers must be 5 for each criterion.
P equals to the points input by the user to rate the performance of the software in each specific sub criterion, which goes in a range from 0 to 10.
S_T equals to the score obtained for each sub criterion
W equals to the defined percentage weight for each criterion. The sum of all weights must be 100%
C equals to the score obtained for each criterion

Figure 10. Organization of sub-criteria for each criterion for the software tool evaluation

Once the matrix was set, it was tested setting the weights and points for each sub criterion according to the needs considered most important to develop the case studies of this project. According to the needs to develop the case studies, both criteria from the Information Management category were considered important to properly adapt the information from the design and ensure accuracy on the extracted quantities. Also, available training and user guides had a higher weight to facilitate the learning process of the software to be used. BIM Analytics were also considered important aligned with the objectives of the development of the case studies, where the automatization of cost estimations and construction schedules were main goals in several case studies, and the incorporation of progress reports was indispensable for the case study focused on this subject. In this case, the Collaboration category was not highly weighted because a single user was developing the case studies. Moreover, the creation of reports was considered important to enhance the incorporation of the produced information within Powe BI dashboards. The maximum points for each sub criterion are shown in Table 6 to Table 10. The final score of the evaluation, including the defined percentage weights for each criterion are presented in Table 11. A larger visual for this table is presented in Appendix 3.

Table 6. Maximum points defined for the sub criteria evaluating the category of Information Management

INFORMATION MANAGEMENT			
How to adapt information to be interpreted?		How to rely on the accuracy of information?	
How is information grouped?	1.333	Automatically calculated properties	1.5
Can elements be divided?	1.333	Versioning control	1
Adding/modifying/deleting properties	1.333	Model revision by discipline	1
Calculated properties	1	Automatized property check	0.75
TOTAL	**5.0**	Revision through manual measurement	0.75
		TOTAL	**5.0**

Table 7. Maximum points defined for the sub criteria evaluating the category Usability

USABILITY					
User-friendly		Availability for evaluation		Available training and user guides	
All in one software	2.5	Free-trial version	3.5	Video tutorials	2.5
Complexity to understand how to input data	2.5	Sandbox projects	1.5	User manual	2.5
TOTAL	**5.0**	**TOTAL**	**5.0**	**TOTAL**	**5.0**

Table 8. Maximum points defined for the sub-criteria evaluating the category BIM Analytics

BIM ANALYTICS							
Scheduling and 4D analysis		Cost estimation and 5D analysis		Progress tracking		Other features	
Automatic task duration	2	Cost estimation	2	Progress tracking feature	3.5	Specify each feature	1
Scheduling based on methodologies	2	5D simulation	2	Mobile app for progress registration	1.5	Specify each feature	1
Possibility to import schedules	1	Use of templates for resource assignment	1	**TOTAL**	**5.0**	Specify each feature	1
TOTAL	**5.0**	**TOTAL**	**5.0**			Specify each feature	1
						Specify each feature	1
						TOTAL	**5.0**

Table 9. Maximum points defined for the sub criteria evaluating the category Collaboration

COLLABORATION			
Collaboration among stakeholders		Interoperability with other software	
Collaborative work	2.5	Import IFC	1.25
Access control	2.5	Export IFC	0.5
TOTAL	**5.0**	Connection with Power BI	0.75
		Import plugins for authoring software	1
		BCF creation for issues	1
		Other interoperability	0.5
		TOTAL	**5.0**

Table 10. Maximum points defined for the sub criteria evaluating the category Visualization of Information

VISUALIZATION OF INFORMATION			
How is information presented? Creation of reports		Model Viewer	
Export reports to excel	1.5	Hide/unhide according to selection sets	2
Graphical report	3	Property view	1.5
Other report feature	0.5	Cut/section plane	1
TOTAL	**5.0**	Other viewer features	0.5
		TOTAL	**5.0**

Table 11. Results of the evaluation software tool test

Criteria / Software	Weight	SOFTWARE A		SOFTWARE B		SOFTWARE C		SOFTWARE D		SOFTWARE E		SOFTWARE F		SOFTWARE G	
		Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
How to adapt information to be interpreted?	10%	3.67	0.37	3.87	0.39	2.00	0.20	3.33	0.33	2.33	0.23	4.33	0.43	1.08	0.11
How to rely on the accuracy of information?	10%	2.88	0.29	4.25	0.43	0.75	0.08	1.75	0.18	2.75	0.28	2.09	0.21	1.75	0.18
User-friendly	5%	3.75	0.19	3.75	0.19	4.38	0.22	3.13	0.16	4.38	0.22	1.25	0.06	4.38	0.22
Availability for evaluation	5%	5.00	0.25	3.50	0.18	0.00	0.00	3.50	0.18	4.13	0.21	2.50	0.13	3.50	0.18
Available training and user guides	10%	5.00	0.50	3.13	0.31	2.50	0.25	4.38	0.44	3.75	0.38	4.38	0.44	3.13	0.31
Scheduling and 4D analysis	10%	5.00	0.50	4.00	0.40	0.00	0.00	1.75	0.18	2.50	0.25	5.00	0.50	3.00	0.30
Cost estimation and 5D analysis	10%	5.00	0.50	5.00	0.50	3.00	0.30	5.00	0.50	2.50	0.25	5.00	0.50	5.00	0.50
Progress tracking	10%	3.50	0.35	3.50	0.35	0.53	0.05	0.88	0.09	5.00	0.50	5.00	0.50	0.88	0.09
Other features	5%	3.00	0.15	2.00	0.10	1.25	0.06	2.00	0.10	2.00	0.10	0.75	0.04	1.25	0.06
Collaboration among stakeholders	5%	4.63	0.23	3.25	0.16	3.75	0.19	4.38	0.22	5.00	0.25	5.00	0.25	5.00	0.25
Interoperability with other software	5%	4.75	0.24	3.25	0.16	2.25	0.11	2.25	0.11	1.63	0.08	2.75	0.14	1.75	0.09
Creation of reports	10%	5.00	0.50	4.50	0.45	2.25	0.23	2.25	0.23	4.25	0.43	3.25	0.33	1.50	0.15
Model Viewer	5%	5.00	0.25	5.00	0.25	3.75	0.19	4.00	0.20	3.38	0.17	3.50	0.18	3.50	0.18
TOTAL	**100%**	**56.17**	**4.31**	**48.99**	**3.86**	**26.40**	**1.87**	**38.58**	**2.90**	**43.58**	**3.33**	**44.80**	**3.69**	**35.71**	**2.60**
OVERALL SCORE			**86%**		**77%**		**37%**		**58%**		**67%**		**74%**		**52%**

Once the tool was developed, it was sent to selected professionals to be tested and a survey was done. The objective was to ensure that the tool would work correctly compiling the different range of values for each sub-criterion and calculating the score for each criterion automatically considering the weights. The 17 selected professionals that participated in the survey were mainly collaborators from BIMMS – BIM Management Solutions, considered expert users of BIM software. From the responses received, it was possible to conclude that the framework worked correctly and was able to automatically calculate scores from the input of the users. Although, more than 50% of the sent surveys were returned with no answers, with the indication of the participants that they were not able to answer the survey, because they did not have detailed holistic expertise in certain specific evaluated software, which is understandable. These results denote that it is necessary to do a previous study of the selected software to be assessed and collect all possible data to understand how each software performs regarding each criterion.

2.3. Understanding decision-making for the construction phase: interviews with experienced professionals

To have a better understanding on the impact that quantity information has on decision-making processes during the construction phase of projects nowadays, different conferences were carried out with experienced professionals.

The first conference was a round table done at the main headquarters of BIMMS – BIM Management Solutions, were 12 collaborators of the company gathered to discuss the importance of BIM-based Quantity Take-off and its main challenges nowadays.

Subsequently, a set of interviews with five different professionals were conducted. The interviewees were chosen based on the expertise of the collaborators, choosing professionals in contact with the process of extracting and analysing quantities, but most important with experience participating in making decisions with a high impact on the performance of construction projects. The interviewees were chosen with the objective to cover different areas, and which participation varies among the lifecycle of a project. In this manner the following positions were covered with the chosen interviewees:

- Design Manager
- Preconstruction Manager
- Information Manager
- Construction Manager
- Industry Regulation Expert

2.3.1. Round Table Workshop

During the round table performed with collaborators of *BIMMS – BIM Management Solutions* it was discussed how the AEC Industry has been left behind in the evolution and technological implementation in comparison with other industries, together with the losses this has caused; and how BIM-based Quantity Take-off can contribute on the improvement of the execution of projects and reduce this breach between the manual, traditional process and the technological implementation for the AEC Industry.

Regarding the importance of quantity information and the main purposes to perform Quantity take-off processes, there was a common agreement that quantities are the base for multiple procedures done during the development of a project, ergo it has a great impact feasibility and success of a construction project.

2.3.2. Interviewees experience

This section describes the experience of each professional that was interviewed, justifying why they were considered to participate.

2.3.2.1. Pablo Murillo

Pablo Murillo is a Civil Engineer graduated from the University of Costa Rica, with a Master's degree in BIM Management from Zigurat Global Institute of Technology. Eng. Murillo has been involved in the planification and construction of important large-scale projects, on positions with high impact on decision-making such as Project Manager, BIM Manager, Quality & Productivity Manager and Director of Pre-Construction, role in which he is currently working nowadays at one of the top construction companies in Costa Rica and Central America.

2.3.2.2. Tiago Novais

Tiago Novais is a Civil Engineer graduated from *Instituto Superior de Engenharia de Lisboa*, with a Master´s degree in Civil Engineering with emphasis on Structural Engineering from the same institution. With more than 7 years of working experience, Novais has gained a lot of experience in Digital Construction and Information Management for the AEC industry, mainly in complex and multidisciplinary projects such as Enterprise Data Centres for several European countries. Currently he is working as a BIM Leader in BIMMS - BIM Management Solutions, leading the team that supports main contractors in the BIM implementation and Information Management of large-scale and complex projects by the application of Digital Solutions for the construction phase.

2.3.2.3. José Carlos Lino

José Carlos Lino is a Civil Engineer with vast experience in the Digitalization and Technology Implementation for the AEC Industry, mainly through Building Information Modelling. With a Master´s degree in Structural Design from the *Universidade do Porto*, Lino has been actively participating in both labour and academic spheres. He is founder and board member of several companies from different countries specialized in Structural Design and Information Management, such as *NEWTON – C*, and *BIMMS – BIM Management Solutions* in Portugal; *NossoBIM* in Spain, USA, and Brazil; IBERD Architecture and Engineering Services in South Africa; and *Consultores BIM* in Brazil. He has also been a Researcher and Invited Lecturer for the *Universidade do Minho* for more than 14 years and has been supervisor of more than 20 Master´s dissertations for several institutions such as the *Universidade do Minho* and *Faculdade de Engenharia da Universidade do Porto*. He has also been an active member of buildingSMART Portugal, where he currently collaborates on the role of Chairman.

2.3.2.4. Eloy Morúa

Eloy Morúa is a Civil Engineer with more than 35 years of experience leading the construction process of large-scaled projects in Costa Rica. For his highest level of education, he obtained a Ph.D. in Civil Engineering from the University of Michigan, and has collaborated as a Professor, reaching the position of Director of the Construction Department at the university *Instituto Tecnológico de Costa Rica*. Eng. Morúa has been a Construction Manager for more than 300 000 m^2, for many projects with different uses such as hospitals, shopping malls and residential buildings. Throughout his experience he has gain a great knowledge on the impact and importance of decision-making for the construction phase, and a great understanding on how these decisions are done nowadays.

2.3.2.5. Bruno Caires

Bruno Caires is a Civil Engineer and a Design Manager who has dedicated his career to the Digital Design and Construction in the AEC Industry. Caires holds a Master´s degree in Civil Engineering with a major in Structural and Geotechnical Engineering from the *Universidade do Minho* and is an active participant as a lecturer for several BIM Master programmes. For the last 8 years he has been working in *BIMMS – BIM Management Solutions*, in which he is Co-Founder and Board Member, and currently performing as Director of Operations in the company. During this experience, Bruno has participated in the Coordination and Information Management of design and construction process on large-scale and complex projects, having the opportunity to get involved in important decision-making processes, giving him a great comprehension of the main challenges encountered and the opportunities of improvement that can be achieved with a correct Information Management.

2.3.3. Interview Qualitative Data

The interviews with these five professionals had two main purposes and consequently the questions were grouped in two parts. The first purpose was to understand the use of QTO in construction projects, its importance, main challenges, and types of decisions that were influenced by the quantity information. The second objective was focused on determine, according to the expertise of the interviewees, the information required to perform a data-driven decision, aligned with the four types of decisions studied in this research: Progress Tracking, Value Engineering, Change Management and E-Procurement. The set of questions can be consulted in the Appendix 4.

2.3.3.1. 1st Part – Understanding the use of QTO

QTO information is a required input for information management and its impact over the lifecycle

Pablo Murillo noted that quantity information is an input required for most of the decisions done during the planification and execution of construction projects and specified that it is not about the quantity itself, but the analysis done using this information. Tiago Novais stated that, under the role of main contractor, the information obtained from a correct estimation of quantities is a key factor to produce reliable information to provide to different stakeholders, such as clients and subcontractors. Also, he spoke about the positive impact this information has regarding sustainability by producing less waste and enabling work activities to be more efficient. Murillo mentioned that QTO has a direct connection with the cost estimation at different stages of the project. It is used to study the viability of a project in its early stages of development, the definition of the construction budget at the planification phase and the basis of information for cost control during the construction execution. He also mentioned the importance of a correct structure and mapping of the information to estimate the impact of change management at the level of construction scheduling and resource control. Jose Carlos Lino indicated that QTO is often mistaken as a minor role when it actually has a major impact on important tasks such as payment and contract processes. Nevertheless, in sonic markets, namely in United Kingdom, for several years the quantity estimation process has been performed by quantity surveyors, which in many cases are experienced professionals with the responsibility to estimate the information that will be the basis for the payment control and completion checklist demanded by the Appointing Party during the development of an asset. Lino explained that QTO becomes a powerful tool that can be used to define three major aspects during the construction phase: quantities, construction time, and quality assurance. Bruno Caires spoke about the great opportunity of improvement that is offered in terms of procurement, value engineering, delay analysis and change management, by having a construction model linked to quantities and the level of control on a project that can be achieved by applying these methodologies. He also emphasised the fact that these methodologies are not new, and have been used by other industries to optimize production, but the challenge comes when applying these technologies for the construction industry, in which there is a need to generate a standard method of delivery in terms of information management and decision-making metrics.

The exchange of viable and structured information between Designers and Contractors is key

Covering the main challenges faced when performing a controlled and reliable BIM-based QTO, many of the interviewees agreed on the lack of collaboration between the Design team and the main contractor, were the information produced during the design stage does not consider the use of quantity extraction aligned with the construction strategy to produce helpful analytics with this information. Pablo Murillo stated that in his experience, BIM-based QTO has been performed for the Planification and Construction Phase and brings a lot of benefits, but there is an important risk to perform the extraction with information models developed by third parties that do not fulfil required standards and authoring protocols that guarantee the veracity of the information and lacks a structure that allows a correct estimation of quantities. On the other hand, he stood up for the benefits accomplished in his experience when performing BIM-based QTO with controlled information, where there has been an outstanding improvement on the invested time to perform the process and the accuracy of the estimations, in comparison with traditional methods based on 2D estimations. Furthermore, this controlled information has generated great benefit for different means the information was used, namely change orders, definition of contracts and resource management.

A unified way to classify and structure information is a must for a successful QTO

Additionally, Jose Carlos Lino pointed out the importance of classification of the objects that conform an information model. For Quantity Take-off, it is indispensable to classify the components, and in recent years, the industry has been relying on different standardized classification systems, which intend to unify the information. The challenge using these standardized systems is that classifying every single component present in the industry becomes a never-ending task, especially because the industry is on a continuous evolution. Also, there is a great difference on how a computer interprets an object in virtual construction and how it is really managed in real-time construction, because construction is a flow that involves not only objects, which in many cases are temporary, but also activities. Consequently, the tendency towards the future is to classify components using dynamic systems based on the semantic and taxonomy of these objects, where standardization is implemented on higher levels of classification, but for the most detail classification it should be classified by the user.

The structure of the information and commitment of the stakeholders should exist from early stages

Bruno Caires explained that one of the biggest challenges nowadays encountered to execute a complete and controlled BIM-based Quantity Take-off is to have the commitment of all stakeholders involved to generate structured information that allows a proper execution of this BIM use. This requires considering the digital construction strategy since early stages of a project, and designers must align with the population of specific data on the information model that would allow a proper organization of the information according to the Work Breakdown Structure which represents the construction strategy that is going to be implemented. This also involves the implementation of a correct classification system, together with transparency information. Tiago Novais referred to this challenge as well, indicating that these methodologies represent a drastic change in the way of thinking of how managers have been controlling their projects during the past decades. He also mentioned the importance of transparency of the information that is required for a complete collaboration among stakeholders. Pablo Murillo mentioned as well that the required level of transparency of information is a main challenge because it changes the manner of how business have been traditionally done for the AEC Industry. Also, the incorporation of the construction strategy in early stages of development of a project is a main challenge, that in the most recent times, it has been leveraged by collaborative contractual methodologies for the execution of projects, namely Integrated Project Delivery. Tiago Novais also agreed that initiatives like Integrated Project Delivery can bring great benefits to the industry and allow the correct structuration of information for a controlled BIM-based QTO and BIM analytics, but again it requires a high level of transparency of information to achieve full collaboration during the process. Bruno also agreed with IPD being the main collaboration strategy to incorporate the construction strategy into early stages of development of a project. He also spoke about Design-Build methodologies, where quantities set in early stages are very general but when the design is reaching a Stage 4 according to the RIBA Plan of Work which corresponds to a technical design, a detailed quantity extraction must be done by the main contractor for the construction plan. This way, it is important to develop the structure of information that allows a general quantification on the early stages, but also evolve to a more detailed quantification maintaining the same structure on the higher levels of hierarchy of the breakdown structure. At the end, all participants agreed for IPD to be the most efficient collaborative methodology for the addressed BIM use and BIM analytics, being the most efficient methodology but also one of the less adopted, and this is the challenge to overcome together with the open book concept of information that is needed to reach the transparency level required for a full collaboration.

Not always one´s need to model everything to get a sufficient QTO

Another major issue discussed when performing QTO based on a BIM model is to quantify systems or activities that are not modelled. Bruno Caires mentioned three options to solve this issue. The first would be to model everything that is missing, which is time consuming and depending on the scenario can be very complicated. The next option is to calculate indirectly based on metadata and measurements of other elements. He gave the example of the estimation of reinforcement for concrete structures, which can be estimated using a ratio of kilograms of reinforcement per volume of concrete. Pablo Murillo also referred to this possibility, stating that the activity to model reinforcement is one of the most time-consuming activities for authoring models, so depending on the use of the quantities it can be viable to obtain the quantity of reinforcement depending on the volume of concrete. He emphasized that it is very important to consider the accuracy of these estimations which is not exact and can be used to estimate daily outputs and general quantities but depending on the project and the objectives of the QTO, it would be necessary to apply a more precise quantity extraction. He also mentioned that the ratios should be defined by the structural designer specifically for the project intended, and to avoid using ratios from statistics or different projects because they are much less representative and would increase the deviation of the estimation. The third option mentioned by Caires is adding a digital reference and manually inserting the missed item using concepts of ratios based on Business Intelligence systems or experience. However, this last option should not be done to significant quantities of the BoQ.

When the facts are not clear, decisions become less data-driven and more based in personal experience.

During the discussion to determine which types of decisions nowadays are less based on data driven and more on the experience of the professionals, there was a common agreement that the harder variables to measure are the ones that support the decisions that are less data-driven. Tiago Novais gave examples about decisions depending on quantities of materials are more based on data, but when incorporating variable that are harder to measure like the weather, times of transportation, duration of installations, among others, the professionals base their decisions more on previous experiences. Pablo Murillo on a similar approach, mentioned the complexity of measuring labour resources because of their variability, and how the different conditions a project can have directly affects the performance of this kind of resource, making the statistics recorded less representative for projects with different conditions. Therefore, stakeholders base their decisions on their experience for the execution of the activities based on their experience, without being able to properly justify the decisions with data.

Data-driven decision is an important way of limiting responsibility

On the other hand, Bruno Caires spoke about the importance of justifying decisions with data regarding the responsibility acquired when taking a decision. When a stakeholder defines a solution to proceed without data that backs it up, the responsibility he or she gets is enormous. When taking a decision justified by data, the professional still assumes the responsibility but he or she can properly defend the solution proposed, especially in legal terms when the solution does not reach the objective, or even worse when it causes a major issue. He also referred to the improvement in the efficiency of the process when tools are used to generate data to support decisions. In more traditional approaches, managers spend approximately 70% of their time calculating data and looking for the relevant information, leaving a short time to assess the decisions. Instead, with digitalization and automation of processes, a manager can focus the majority of his or her time assessing the generated data and concentrating on the decisions.

Big data could be the future for data-driven decisions

Jose Carlos Lino spoke about the current level of generation of information to make data-driven decisions nowadays for design construction and operation of the projects. He mentioned that still many decisions are based on the intuition of the leaders, not only for private projects but regarding politics that involve the AEC Industry, which still in many cases are not technical decisions based on data but political decision based on human relationships. He mentioned the necessity to generate big data base models able to contain important amount of data to consider all the variables involved in a decision, which the models generated nowadays do not reach that level. Even so, with the proper evolution in the future it can be possible to register statistics from decisions taken in many projects, with the objective to base the decisions on precedents incorporating risk management to accomplish data driven predictions and exponentiate the efficiency of the process. In Lino´s professional opinion, he thinks that nowadays the structure and robust level of information generated in the AEC Industry only supports around 50% of decisions to be completely data driven, highlighting the importance in studies like the one exposed in the present document to improve the quality of information. Nevertheless, he was clear that even in a promising future where database models can totally support all decisions considering all possible variables, human management will always be required to assess and confirm the data, being a person who will always take the decision.

2.3.3.2. 2nd Part – Information required for data driven decision making

For a second part of the interview, specific cases were discussed focused on the types of decisions addressed in this study, to register from the professional point of view of the interviewees, which information is most relevant to be generated and included for each decision-making process. On a general matter, Bruno Caires pointed to the importance of the dashboard which incorporates the model viewer to present the information and analytics performed to support the decisions. More than a 3D model used for general visualization, it must be linked to the quantities to help the stakeholder who is assessing the situation to understand better the location and function of each quantity incorporated, being a 3D model viewer the best visual aid for this aspect. Pablo Murillo also mentioned that during his experience, the presentation of information, for example change orders or value engineer options, are always accompanied with as built drawings to clarify the modifications presented, and he agreed that a model viewer linked to the presented data will take a further step to aid the professional to comprehend the information and make faster, more transparent decisions. Nevertheless, he stated the importance to keep this tool user-friendly and easy to handle, since many of the stakeholders and managers are not used to manipulate complex model viewers.

Progress Tracking

Speaking about progress tracking, Lino mentioned the importance to implement Key Performance Indicators to evaluate a project. He also stated the automatization to generate the information to feed the KPIs, to avoid biased inputs intended to manipulate the results in favour of an interested party. On the other hand, Pablo Murillo, and Eloy Morúa agreed that based on their experience, the most used KPI to evaluate progress and perform delay analysis is Earned Value. Also, Eloy Morúa spoke about the importance to have a planned methodology to register the progress on a construction site, so it can be properly mapped in the construction model. He emphasized that this is not an easy task, especially in large-scale projects with high daily consumption of resources. A correct report structure is key for a data driven progress tracking.

Value Engineering

In the case of value engineering, there was a common agreement that to evaluate the viability of a value engineering, it is important to estimate the complete impact in cost, duration, and quality the modification would have. Therefore, it becomes very useful to count with a construction model which has cost, and duration analytics linked to it, where it can automatically change the values when incorporating the modification, then compare both scenarios and evaluate if the proposal could be considered as value engineering. José Carlos Lino pointed out that before performing a detailed design with the proposal, the general costs must be evaluated to consider the added cost that the design of the proposal will have. Once this first estimation is done, if the result is still positive then the team can proceed with the detail design.

Change Management

For change management, it was discussed for the specific scenario of the case study, which is exposed in detail in Chapter 3, the methodology to measure cable trays and cable tray fittings for the estimation of a change order. Both Pablo Murillo and Tiago Novais agreed that even though the cable trays are produced in pieces of specific length, the estimation for its cost is always done based on the linear meters of the cable trays. Tiago Novais also stated that the cable tray fittings on a traditional methodology are not detailly counted but estimated adding a percentage to the cost of the cable tray fittings. This approach is very unprecise specially for cost estimation because some of the units of cable tray fittings can be very expensive depending on the type and size. With a proper BIM-based QTO, the exact quantities of all fittings should be estimated. Also, he explained that the breakdown structure of the information for the estimation should consider the type of cable trays and its fittings, and then the size for each type because unit costs may vary considerably within one another. This generates a lot of unit costs that must be defined, so it is important to have a controlled organization of the information to avoid errors and omission when mapping unit costs with the elements.

E-Procurement

Regarding the decision to choose a subcontract for a specific activity, as part of the e-procurement system of a project, a discussion took place to understand which information should be given to the subcontracts, which information should be analysed for the election and what information should be requested to each possible appointed party. Pablo Murillo indicated that in terms of duration of activities, the construction schedule should be optimized by the main contractor and the subcontractor must agree and adapt to the established durations. He explained that is not convenient to request the most optimal durations each subcontractor could give, because this can cause that if a subcontract reduces too much the duration of an activity, other activities that are related might not be able to adapt to these durations, causing the subcontract activity to stuck resulting in a resource waste. This concept under the Lean theory is known as waste for overproduction. The construction schedule must be optimized considering the most efficient durations of the activities as a whole system, and not optimizing an activity independently. Eng. Lino also spoke about the excess of information and the issue this causes. He emphasised that every generation of information has an associated cost to be produced and this must always be under consideration. He referred to the Pareto´s law, stating that efforts must be focused on the 20% of developments that will produce 80% of the results. Also, all data creation has an energetical consumption with an environmental impact associated. In this manner, the focus should be not for an exponential growth, but to seek for a balance, both economical and environmental.

2.3.4. Major Outcomes

Based on the results of the interviews and the round table performed, main ideas are pointed out as followed:

- Quantity information is base for multiple procedures executed during the evolution of a project, and its proper calculation has a great impact in the feasibility and success of a construction project.
- The collaboration between designers and main contractors is very important to define the information requirements needed to perform a structured and controlled BIM-based QTO.
- The required structure for a complete QTO extraction must be defined since early stages of development of the project, increasing the detail as the project development advances yet maintaining a constant structure.
- Information must be classified to enable a correct organization and structuration of information. The classification system implemented must be revised to compile with the structure defined in the construction strategy, reflected on the Work Breakdown Structure.
- It is possible to extract indirectly the quantities of unmodelled elements or systems, always considering the level of accuracy and the source of the ratios implemented for an indirect quantity extraction.
- Decisions that involve humanistic and qualitative variables are the hardest to be measured, resulting in the less data driven resolutions.
- The importance of data driven decisions rely on the support and justification of the choice made, with a direct impact in the responsibility acquired by the decision-maker.
- Proper structuration and record of statistics will allow the generation of big databases to be implemented in the support of data driven decisions for future projects.

- For the comprehension of quantity information linked to a construction model, the most complete visual aid is a 3D model viewer that interacts properly with the quantities linked to a model.
- For Progress Tracking, the implementation of KPIs is fundamental for the evaluation of the project, being the Earned Value Analysis one of the most common KPIs used for this purpose.
- BIM-based QTO offers a better detail of the extracted quantities in systems composed by many elements, namely cable trays and cable tray fittings, which by traditional methodologies of quantity extraction, a detailed and accurate count of all elements is very hard to accomplish.
- The election of a subcontractor is a fundamental decision to define the E-Procurement System of a project. It is important to evaluate the quantity information that will be shared with the subcontractors and the information that will be requested, to enable a complete and controlled comparison of options.

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3. DEVELOPMENT OF QUANTITY TAKE-OFF AND BIM ANALYTICS: PRACTICAL CASE STUDIES

This chapter presents the case studies implemented during this investigation, including a description for each scenario, the preparations to estimate quantities through BIM-based QTO, the procedure to create analytics based on the quantity information and a presentation of the results. The use of case studies had the main objective to undergo through the generation of BIM-based QTO and BIM analytics focused on the four types of decisions approached, to deeply understand the different procedures, identify important requirements and considerations throughout the process. Therefore, there were four different case studies implemented, one for each type of decision-making.

The main software used for the estimation of quantities and creation of BIM analytics was BEXEL Manager, based on the availability of the student license and considering the results obtained during the software evaluation presented in the previous chapter. Other software was used for specific tasks and are described as they appear in the body of this chapter. The BIM models used as an input in each case study were provided by BIMMS – BIM Management Solutions. These models were authored in Autodesk Revit, and then exported to IFC format to be analysed in BEXEL Manager. It is important to clarify that all unit costs and resource performances for the estimation of activity durations were simulated and do not correspond to any existing information from any existing project.

3.1. Case Study A: Progress Tracking

3.1.1. Description of the case study

Case Study A had the objective to register a simulated progress for the construction process based on estimated quantity information. Moreover, the current performance of the project management and execution was determined, together with future predictions of the results of the construction by different analytics generated, namely cost estimation and construction schedule to create 4D and 5D simulations and analysis. The built asset is a 6-level reinforced concrete building to be an office and commercial building, with a footprint of 1208 m^2 and a total of 5190 m^2 of construction area. For the purpose of this study, only the structural discipline was considered, including foundations, concrete columns, concrete walls, beams, slabs and concrete stairs. Figure 11 to Figure 13 shows an isometric view, a floorplan view, and an elevation view of the project.

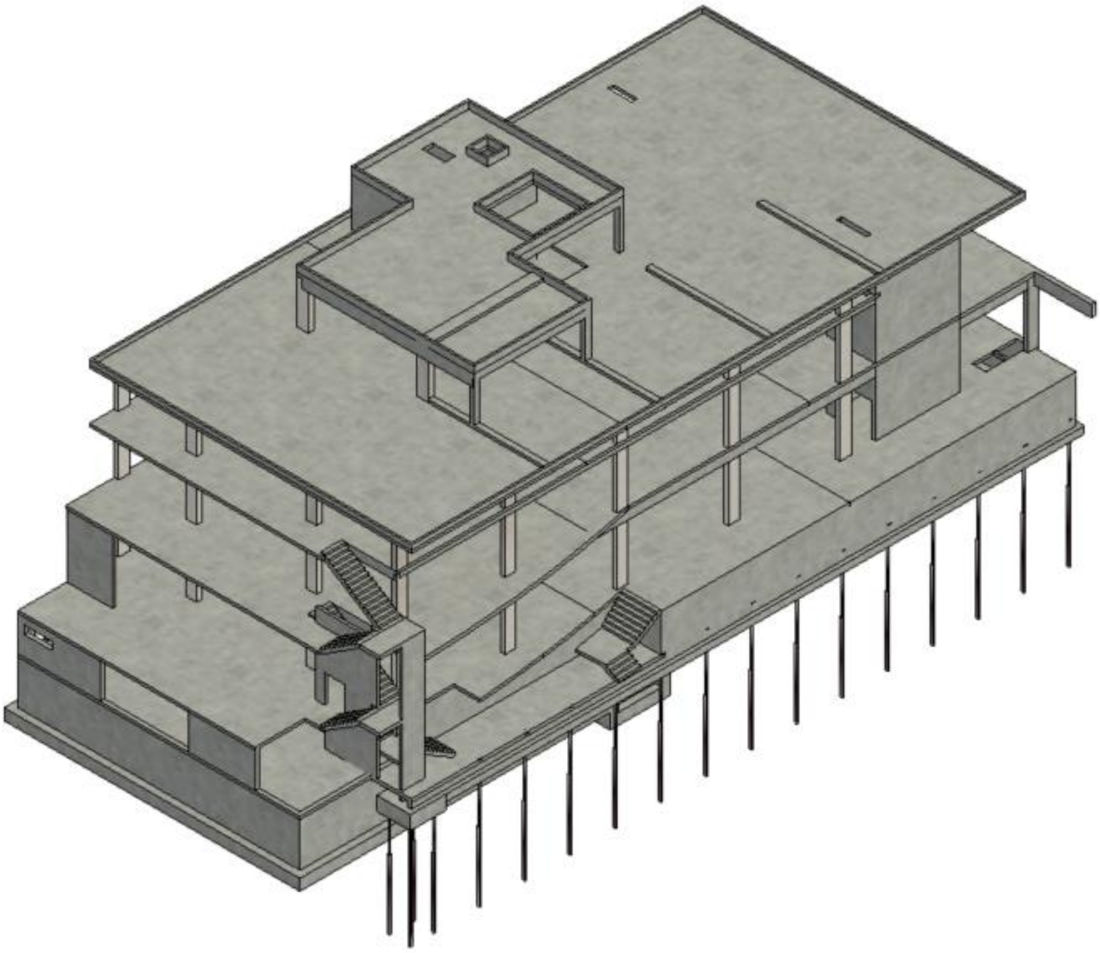


Figure 11. Isometric view of Case Study A project.

Figure 12. Floor plan view of the main floor of Case Study A project.

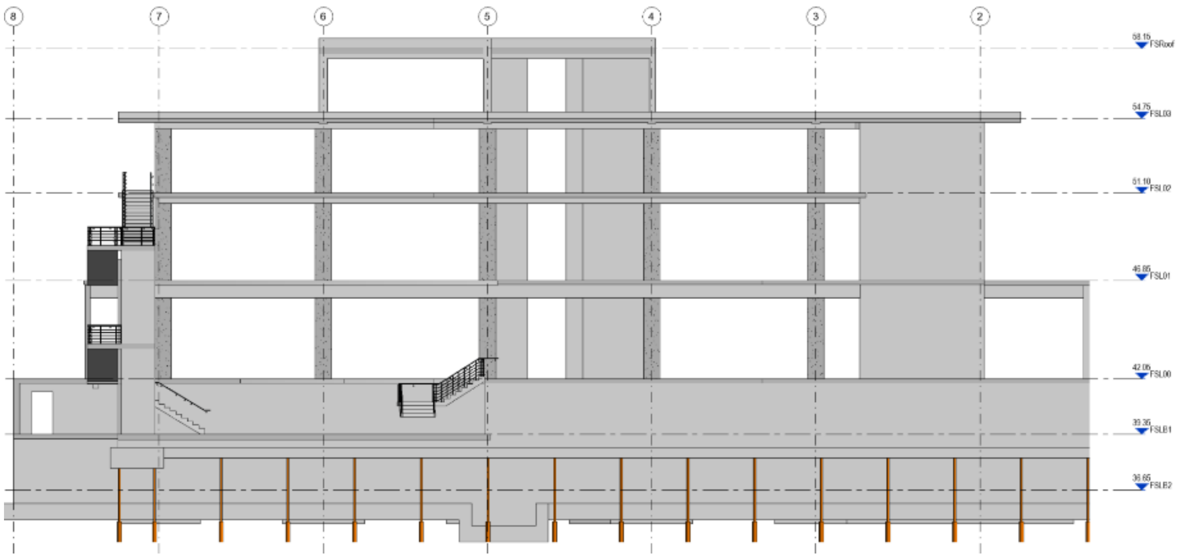


Figure 13. Elevation view of the Case Study A project.

3.1.2. Quantity Take-off preparation and results

For the analysis of the performance of the construction progress, four main activities were considered: reinforcement placement, formwork placement, concrete casting, and formwork removal. For each activity labour and material resources were measured. Also, as shown in Figure 11, part of the foundations includes micropiles. For these elements, an installation resource per length was estimated.

Before starting to analyse the information model in the BIM-based QTO software, it was necessary to do some modifications in the authoring software to guarantee that the generated information and analytics will be aligned with the work breakdown structure and construction strategy. The first correction was regarding the concrete columns, which originally were modelled as single elements throughout all the levels of the buildings. This would preclude to obtain quantities of the columns broken down by elements, which furthermore will cause major problems when creating a construction schedule aligned with the construction strategy and linked to the information model. To perform the division of columns in Autodesk Revit, first a group containing all the columns was created. Then, this group of elements was saved into an independent .rvt file, and then inserted back in the original model as a link. This link model was then monitored using the copy and monitor option, and under its configuration setup, choosing the option to split columns by levels. Next the monitored elements were copied into the original model, creating new columns divided by levels. Finally, the linked model was removed leaving only the new created columns. A visual revision was done to guarantee the correct position of the columns in each level.

For this scenario, three construction phases were defined to divide horizontally the construction progress. The division of the building in its phases is shown in the isometric and floorplan views with a colour code applied in Figure 14. Similar to the division of levels, elements must also be divided according to the phase division to structure the quantity information correctly. In this case, concrete slabs and beams were divided aligned with the defined division between phases.

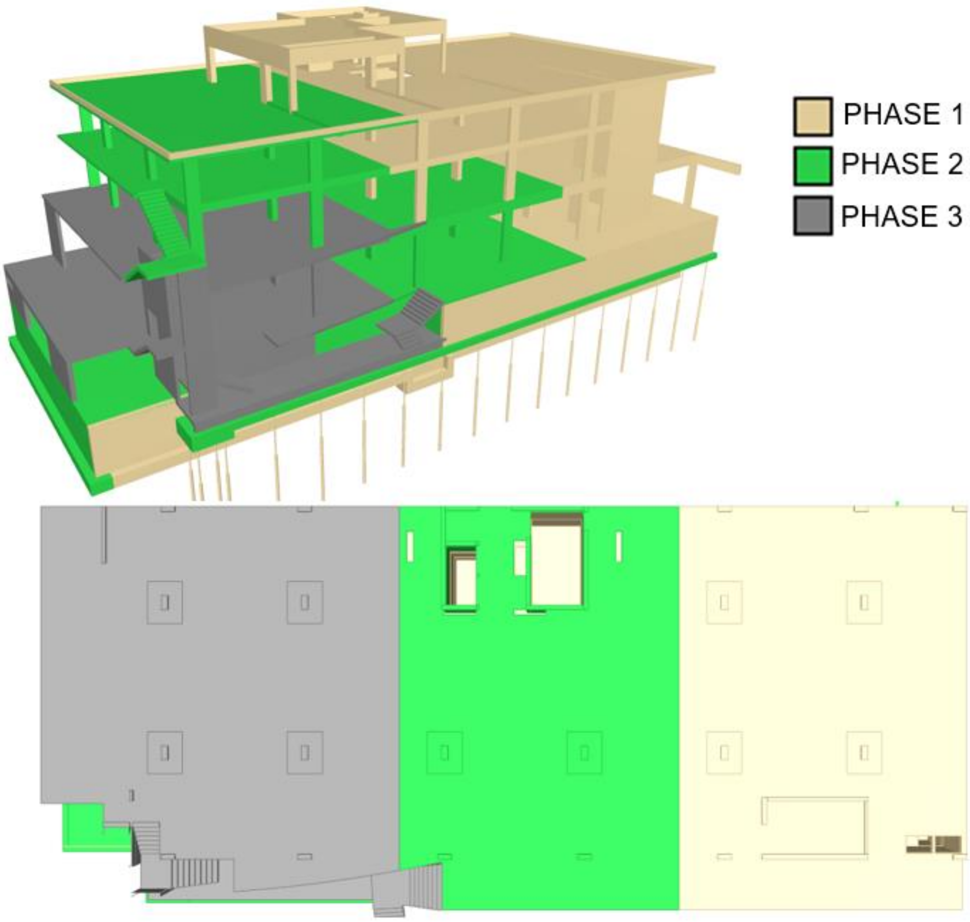


Figure 14. Division of construction phases according to the defined construction strategy.

Once all the elements were correctly divided according to levels and phases, there was a process of checking the correct union between concrete elements, to ensure that connected elements are correctly joined instead of clashing, to avoid repetition of quantities of area and volume. As shown previously in Figure 3, it is necessary to correctly define the joints of concrete elements to obtain accurate quantities for each element. Also, an incorrect definition of joints between concrete elements in a BIM model could generate empty spaces that do not represent the reality of the building, therefore causing inaccuracies in the estimation of quantities.

The next modification performed in the authoring software was the creation of a property to estimate the formwork area of elements. To estimate the formwork area on a model of a concrete building, if the user uses the quantities of surface area, it may induce into errors of the faces of elements joined to other elements. Therefore, for this estimation, a plugin tool for Autodesk Revit was implemented, which is called “Formwork Areas BIM TOOL” developed by SOFiSTiK. This tool creates two properties that determines the formwork area of selected elements: “SOFiSTiK_FormworkArea_Side” that estimates the side formwork area, and “SOFiSTiK_FormworkArea_Bottom” which indicates the bottom formwork area of the elements. The tool is configured to indicate relevant quantities depending on the category of the element, e.g., it does not calculate bottom formwork area for walls nor columns. It is also important to define the joints of concrete elements beforehand, because if an element suffers modifications in its joints, this will delete the data from the formwork properties. To ensure that the calculations of the formwork area were correct, a simple test was performed creating a small model which contained a wall, a column, a beam, and a slab and estimating the formwork area using the tool, and then comparing it to manual estimations.

The next step was to export the model into IFC format to be analysed in BEXEL Manager. IFC 2x3 version of the schema was selected, based on previous experience of the author, to avoid graphical issues for certain family types detected when exporting using IFC 4 version of the schema. Once working in this software, a set of properties were created for the estimation of the total amount of reinforcement and formwork for each element. For the formwork, a calculated property was created to sum the formwork bottom and side area to obtain the total formwork area for each element. In the case of reinforcement, since the provided information did not contain any data regarding the configuration of reinforcement, a quantity of reinforcement weight per cubic meter of volume was introduced as a property, depending on the category of the element. The defined quantities of reinforcement are shown in Table 12. These quantities were calculated based on literature review (One Click LCA, 2021) and also on the personal experience of the author of this dissertation and the team from BIMMS – BIM Management Solutions. These properties should be provided by the structural designer to reduce the error margin for the calculation. Once these properties were defined, a calculated property was added to multiply the reinforcement weight per unit of volume with the volume of the element resulting in the total reinforcement weight for each element.

Table 12. Amount of reinforcement weight per unit of volume for each element category.

Element Category	Reinforcement weight per unit of volume (kg/m^3)
Beams	300
Columns	325
Ground Concrete Slab	65
Concrete Slab	110
Concrete Walls	120
Foundation Isolated Slab	85
Foundation Beam	280
Foundation Floating Slab	20

Once the properties were defined for the elements of the model, different selection sets were created in BEXEL Manager to organize the information according to these sets and to perform some property checks before executing the quantity take-off. First, considering that the creation of construction schedule based on zones and methodologies was aimed in this case study, the elements were grouped in categories aligned to the construction strategy, which not necessarily match with the element category from the authoring process. According to the construction strategy, the construction process will start with foundations, then columns and walls, followed by beams and then concrete slabs, repeating this pattern for each level in order and proceeding horizontally in the order of the defined phase. Consequently, elements considered as foundations have multiple categories according to the information obtained from the original model, such as slabs and beams element types that together structural foundation types constitute the foundations of the building. Therefore, a selection set was created determining the category of each element ensuring the alignment with the work breakdown structure and the construction strategy.

On a similar procedure, selection sets were created to group elements according to the different levels and the three construction phases showed before. The selection set for the building elements were used as well as a metadata check, to ensure that each element is located in the correct level without relying on the metadata that indicates the level assigned to an element. This is useful because not every element has the same properties to define the level. For example, walls and columns contain properties for top base and bottom base levels, but beams and slabs contain in most cases a single property to determine the level. Therefore, creating selection sets allows to isolate each level and visually check that all the elements are correctly organized using the model viewer included in the software. For this case study, the information requirements were not properly established during the authoring process of the information models. It is important to define the metadata that will contain the information regarding the associated level of each element, using Product Data Templates defined in the Exchange Information Requirements, to avoid discrepancies among the definition of data within the model. Nevertheless, these processes of Quality Check and Quality Assurance of the information model are important to ensure the completeness and compliance of metadata included for each element.

Other selection sets were generated to be used as property checks for the created properties used to estimate quantities of formwork and reinforcement. These selection sets were created by grouping the elements that contained the properties of total reinforcement and total formwork. Then, in combination with the model viewer of the software, it was possible to hide selected elements from the selection set to ensure that none of the remaining elements visible in the viewer should contain this property. Also, in the case of formwork, the elements were grouped in selection sets according to the property value, to ensure that elements with null amount of bottom formwork area correspond to walls or columns for example, and that this type of elements would not register a bottom formwork area as well, that would result in estimation errors. Similarly, a selection set was created grouping elements with a null value for the total formwork area property, to find elements that did contain the formwork properties, but registering null amounts of area. As mentioned before, when using the SOFiSTiK/Revit tool to estimate the formwork area, if an element that had the estimation of the formwork area suffers a modification, the values on the formwork properties reset, resulting in null values. This caused that some elements had the formwork properties assigned but with incorrect values, requiring corrections to avoid quantity errors.

Once all the properties and selection sets are created and revised, the next step was to generate the QTO structure and the automatized quantity estimation. First, the work breakdown structure was defined, considering that the cost breakdown structure generated afterwards will have the same organization and this as well will be used as structure for the construction schedule. The defined structure had on the first level the categories defined for the schedule methodology, namely foundations, columns, walls, beams, slabs, stairs and ground slab. The second level of the structure was the element category for the foundations and ground slab, and the building storey for the other elements. Continuously, the 3rd level was the family type of each element and the fourth level the defined activities: formwork, reinforcement, concrete, and formwork removal. This structure was defined based on the experience of the author and the team present in BIMMS -BIM Management Solutions, together with the metadata available in the design model which did not contain any standard classification system. This definition is also explained in Table 13.

Table 13. Definition of the Work Breakdown Structure

1st LEVEL	2nd LEVEL	3rd LEVEL	4th LEVEL
Foundations	Element category	Element family type	Activity
Columns	Building Storey	Element family type	Activity
Walls	Building Storey	Element family type	Activity
Beams	Building Storey	Element family type	Activity
Slabs	Building Storey	Element family type	Activity
Stairs	Building Storey	Element family type	Activity
Ground Slab	Element family type	Activity	

After defining the structure, the properties used for estimating each quantity were selected. For the estimation of formwork and reinforcement, the selected properties were the calculated properties previously defined. In the case of concrete, the selected property was the calculated volume, which is a property that BEXEL Manager has by default under the property set of Calculated Quantities. The volume reported in this property is estimated by an algorithm included in the software that estimates the volume of each element according to its geometry. An advantage to use this property is that it cannot be modified, avoiding a mistaken manual manipulation of the quantity. This property was manually tested to check the accuracy of the calculation, and to ensure that it considered openings. Once defined the metadata used for calculation, the quantities were automatically calculated using the quantity take-off software tool. This software does not allow to create more than one breakdown rule under the same level, and the quantities cannot be assigned independently for each breakdown rule, so each quantity type will be equally applied to the lowest breakdown rule in the hierarchical level defined. Therefore, it was required to create a QTO for each activity and for each defined category, resulting in 27 different QTO estimations that were later manually organized in the Cost Breakdown structure to have a single structure. The organization of the different QTOs are shown in Figure 15, while Figure 16 shows as an example the values obtained for the quantity estimation of formwork for the slabs, with the defined structure in the format that the information appears on the software. At this point, the property check previously done becomes very important because if at some point an element does not have the property selected for calculation, the sum on the breakdown rule will not appear.

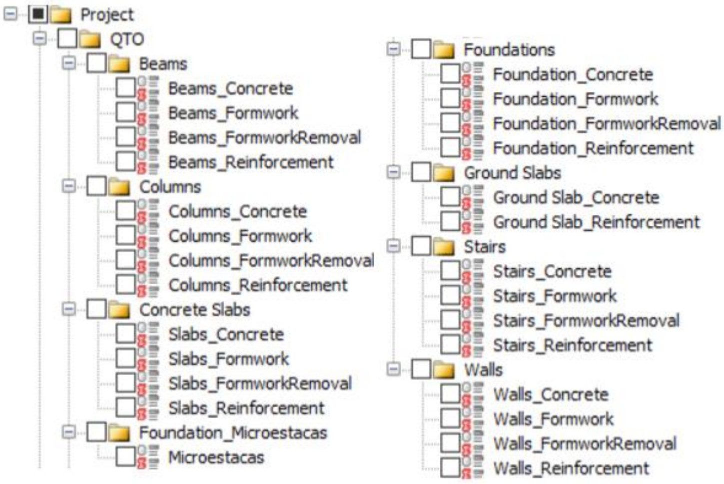


Figure 15. Organization of the different quantity take-off processes performed

02. Slabs_Formwork

Structure - All elements (56 Elements)	Count	SOFiSTiK_FormworkArea_Bottom (Sum)	SOFiSTiK_FormworkArea_Side (Sum)	SOFiSTiK_FormworkArea_Total (Sum)
BEXEL_Level = 01. FSLB2	16	1,042.617 m²	130.450 m²	1,173.066 m²
Floor:Drop Panel 50cm	10	48.000 m²	42.240 m²	90.240 m²
Floor:Laje Esp. 200mm	2	906.524 m²	74.147 m²	980.671 m²
Floor:Slab 25cm	4	88.093 m²	14.063 m²	102.155 m²
BEXEL_Level = 02. FSLB1	14	1,175.445 m²	96.846 m²	1,272.292 m²
Floor:Drop Panel 50cm	10	48.000 m²	26.400 m²	74.400 m²
Floor:Laje Esp. 200mm	3	1,074.810 m²	59.921 m²	1,134.732 m²
Floor:Slab 25cm	1	52.635 m²	10.525 m²	63.160 m²
BEXEL_Level = 03. FSL00	11	965.931 m²	80.690 m²	1,046.621 m²
Floor:Drop Panel 50cm	6	27.520 m²	15.840 m²	43.360 m²
Floor:Laje Esp. 200mm	3	802.411 m²	47.064 m²	849.475 m²
Floor:Slab 25cm	2	136.000 m²	17.786 m²	153.785 m²
BEXEL_Level = 04. FSL01	7	797.242 m²	82.740 m²	879.982 m²
Floor:Drop Panel 50cm	5	94.400 m²	34.920 m²	129.320 m²
Floor:Laje Esp. 200mm	2	702.842 m²	47.820 m²	750.662 m²
BEXEL_Level = 05. FSL02	7	1,054.982 m²	93.023 m²	1,148.006 m²
Floor:Drop Panel 50cm	5	94.398 m²	31.580 m²	125.978 m²
Floor:Laje Esp. 200mm	2	960.585 m²	61.443 m²	1,022.028 m²
BEXEL_Level = 06. FSL03	1	151.129 m²	22.695 m²	173.824 m²
Floor:Slab 25cm	1	151.129 m²	22.695 m²	173.824 m²

Figure 16. Results of the quantity take-off performed for the formwork of the slabs

3.1.3. BIM Analytics procedure and results

When the quantity information is generated in the desired structure and correctly mapped with each element, the information was used for analytics. First, the cost estimation was created. Correspondent to the Work Breakdown Structure, a Cost Breakdown Structure (CBS) is defined maintaining the hierarchy presented in Table 13. To maintain the mapping of elements created in the QTO, the CBS was generated using the creation wizard tool from BEXEL Manager, that automatically creates the structure based on the data from the QTO. As mentioned before, since there were several QTOs generated as shown in Figure 15, the creation wizard was used for each QTO, and then manually organized into the established hierarchy to reach the desired CBS.

Once the CBS was created, different resources were defined to be used to calculate the cost. For this case study, resources were defined for material and labour cost estimation. For the material resources, it was assumed that all elements have the same type of concrete, to simplify the process. On a real case, it is important to create independent resources to different materials, because they will have different conditions, so it becomes necessary to analyse them independently. For the labour work, according to de construction strategy, two types of labour were defined: reinforcement labour and inhouse workforce labour. The definition obeys to the strategy planning to have an independent subcontract for the reinforcement labour, and a contracted labour for the other tasks such as concrete casting, placement, and removal of formwork, considering that the same category of workforce is capable to perform for these three tasks. This definition becomes very useful when creating the construction schedule, to be able to level labour resources and avoid having sudden peaks of required amount of labour at certain periods of time, which do not represent a real case of a construction project. The defined resources on the BIM-based QTO software are shown in Figure 17.

Code	Type	Quantity Type	Quantity Unit	Unit Cost	Color
Enter text to search					
Concrete_Material	Material	Volume	m^3	100,00 €	
Formwork_Material	Material	Area	m^2	10,00 €	
Reinforcement_Material	Material	Mass	kg	1,00 €	
Micropiles_Installation	Material	Length	m	50,00 €	
Reinforcement_Labor	Labor	Time	h	10,00 €	
InhouseWorkforce_Labor	Labor	Time	h	10,00 €	

Figure 17. Definition of resources for Case Study A

Next, resources were assigned to the correspondent cost items set in the CBS, using smart selection and multiple assignment at once to make a faster and less error prone process. In this case, the cost items correspond to the activities, since they are the items positioned at the lowest hierarchy level at the CBS. When assigning resources, the daily outputs for each cost item were also established, which define the performance of each resource depending on the type of cost item, meaning the amount of units of element can be completed in a workday, and the amount of material and/or labour required to accomplish that daily output. This definition will estimate the total labour cost for each element, and it is further used to define the duration of tasks when creating the construction schedule. For the purpose of this study, due to the confidentiality of the project, the daily outputs and resource requirements to fulfil these daily outputs were fixed on standard figures. In real case projects, this data should come from statistics from previous experiences. This references to the importance of Business Intelligence, and how it can be integrated with BIM-based QTO for the generation of statistics to be implemented in projects with similar conditions. During the assignment of resources, the quantity of waste to be considered per resource is also defined. In this case, the waste was defined as 5% for the material resources, namely concrete, reinforcement and formwork. Again, these values should be defined based on statistics in real projects, considering the different values such as type of resource, element to be applied, projects conditions, along with other considered relevant. The defined values for this case study are presented in Table 14. Once the CBS is completed with the desired structure, all elements correctly mapped and all resources assigned, the costs were assigned to each element using the auto-assignment tool from BEXEL Manager cost editor to generate a Bill of Quantities for the project. This will use the defined mappings to assign correspondent costs to all possible elements. This procedure presents advantages in comparison with manual assignments, being much faster process and less error prone. Additionally, the software will notify if by any reason, a cost was not correctly assigned to an element, usually related to a mapping error. Once costs are assigned, it is important to use the model viewer to show and hide assigned elements, to ensure that every cost was correctly assigned to each item. The complete BoQ for Case Study A is presented in Appendix 6.

Table 14. Daily outputs and daily resource quantities required defined for the cost estimation.

Category		Activity	Daily output	Material daily quantity	Labour daily quantity (working hours)
Foundations	Beams	Formwork (m^2)	70	70	24
		Reinforcement (kg)	3950	3950	48
		Concrete (m^3)	100	100	32
		Formwork Removal (m^2)	60	N.A.	16
	Isolated footings	Formwork (m^2)	70	70	24
		Reinforcement (kg)	3950	3950	48
		Concrete (m^3)	100	100	32
		Formwork Removal (m^2)	60	N.A.	16
	Wall Foundations	Formwork (m^2)	70	70	24
		Reinforcement (kg)	3950	3950	48
		Concrete (m^3)	100	100	32
		Formwork Removal (m^2)	60	N.A.	16
	Micropiles	Installation (m)	12	12	N.A.
Columns		Formwork (m^2)	35	35	48
		Reinforcement (kg)	1000	1000	64
		Concrete (m^3)	10	10	48
		Formwork Removal (m^2)	70	N.A.	24
Walls		Formwork (m^2)	160	160	48
		Reinforcement (kg)	2600	2600	96
		Concrete (m^3)	80	80	48
		Formwork Removal (m^2)	160	N.A.	24
Beams		Formwork (m^2)	25	25	32
		Reinforcement (kg)	625	625	48
		Concrete (m^3)	15	15	32
		Formwork Removal (m^2)	25	N.A.	16
Slabs		Formwork (m^2)	120	120	80
		Reinforcement (kg)	3200	3200	96
		Concrete (m^3)	120	120	64
		Formwork Removal (m^2)	120	N.A.	32
Stairs		Formwork (m^2)	30	30	32
		Reinforcement (kg)	750	750	32
		Concrete (m^3)	10	10	32
		Formwork Removal (m^2)	30	N.A.	16
Ground Slab		Formwork (m^2)	120	120	80
		Reinforcement (kg)	3200	3200	96
		Concrete (m^3)	120	120	64
		Formwork Removal (m^2)	120	N.A.	32

The next performed analytics was based on the automatic generation of the construction schedule using the quantity information and the structure of this data. It is categorized as an automated process because, rather than traditional procedures on creating a construction schedule, here, every task is not manually created but automatically generated based on organization of zones and methodologies for the creation of scheduling tasks and their relationships between one another. For this project, two zones were defined: order according to phases, and order according to levels. The organizational order of the zones created is presented in Figure 18.

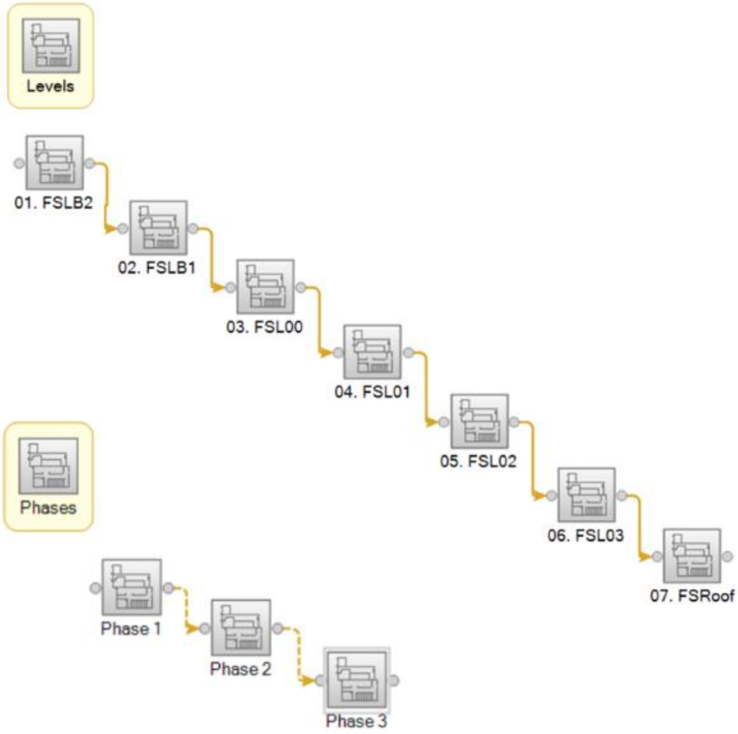


Figure 18. Definition of zones for the construction schedule for Case Study A

On a similar procedure, methodologies were defined to determine the sequence in which different types of elements will be built. These methodologies are created using the Cost Breakdown Structure previously defined to ensure the correct mapping of elements. Because of this reason it is necessary to consider the organization that will be required on the construction schedule when creating the CBS, because at the end all this data is linked. Aligned the WBS and CBS, the methodologies have levels of hierarchy, and together with the zones define the structure of the construction schedule, being the zones in the highest hierarchical levels, followed by the levels of the methodologies reaching to the activities in the most detailed level. As an example, Figure 19 presents the levels of methodology defined for a type of isolated footing. As shown in the image, this definition of methodologies is very graphical, which helps comprehend the relations that are being defined between each group of items.

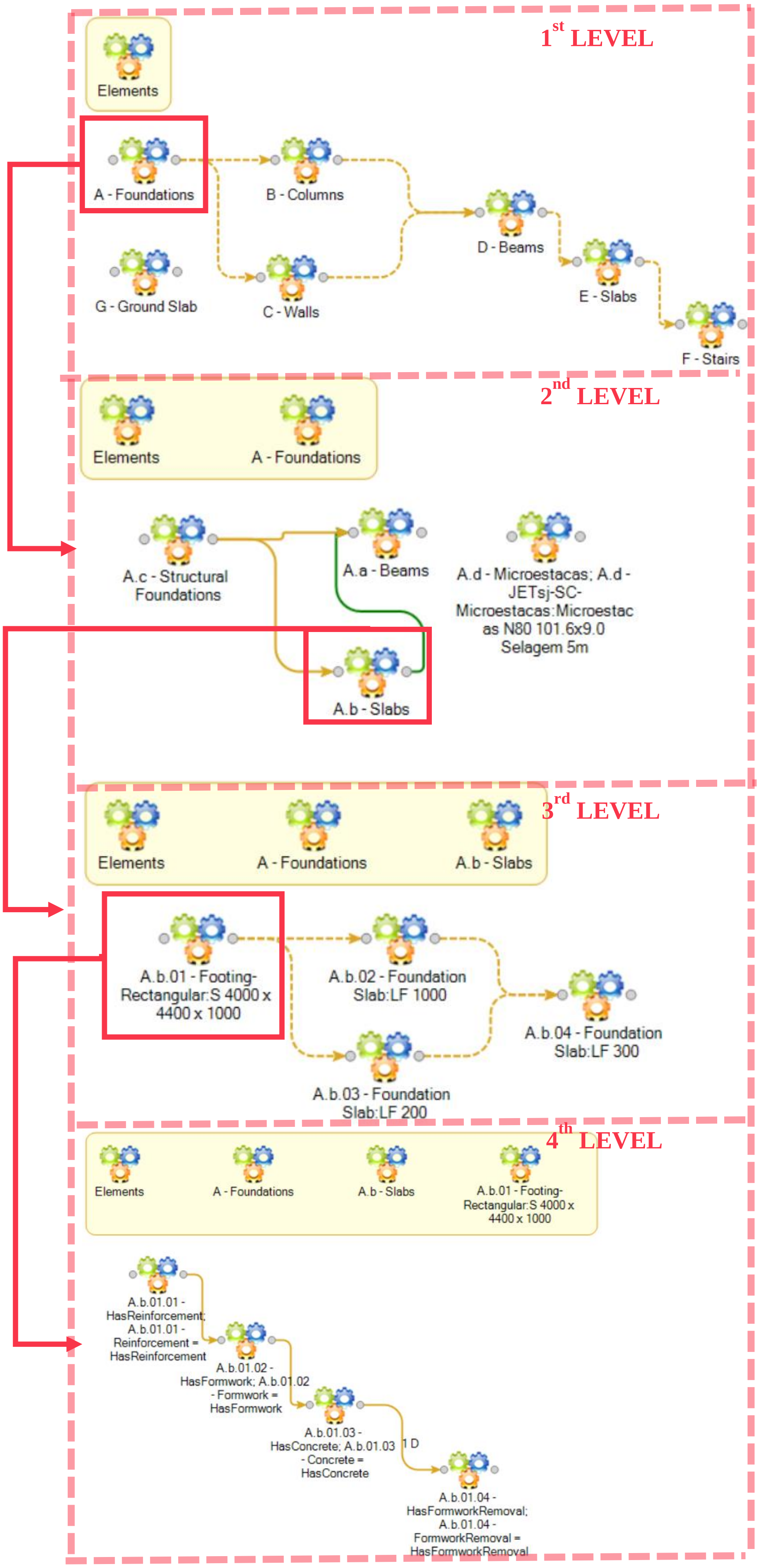


Figure 19. Definition of levels of hierarchy of the methodologies for foundations.

When zones and methodologies are set, the schedule was created using this organization. The result is the automatized generation of all tasks and task relations required to execute all assigned elements according to the sequence defined. At first, these tasks appear with a default duration of 40 working hours, but since the CBS contains information to determine the performance of resources for each element, it is possible to modify these durations based on this data by simply updating task durations on the schedule editor of BEXEL Manager. Figure 20 shows a section of the Gantt chart of the schedule for the detail of the isolated footings, showing the structure according to the levels of hierarchy defined by the zones and methodologies, as well as the relations for the different tasks and the updated duration of the activities according to the defined daily outputs and resource performance.

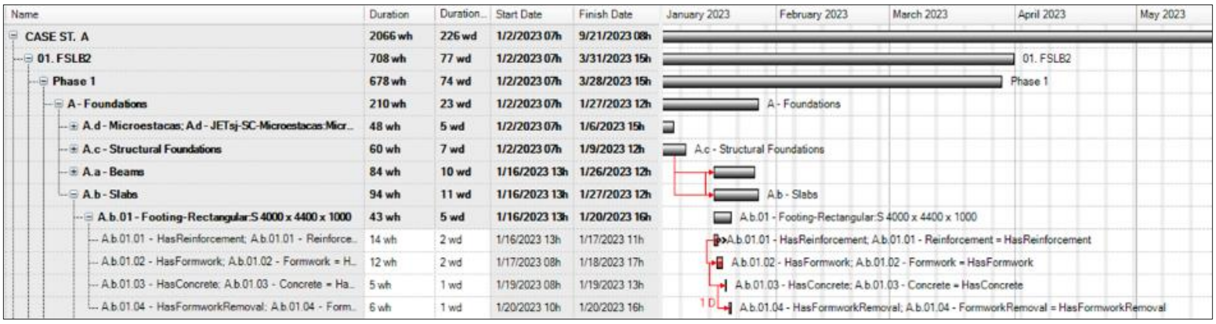


Figure 20. Extract of the construction schedule showing the structure of the Gantt chart for an isolated footing.

A great advantage to have all the information of CBS and construction schedule link to the BIM model in a software like BEXEL Manager, is the automatically generated 4D and 5D simulations which allows a better comprehension of the planned construction sequence and cashflow resulted from this schedule. It is also important to revise the schedule when it is automatically created, to ensure that all the relations are correctly established. With the use of the 4D simulation, the schedule can be reviewed through a graphical method. For this case study, once the schedule was created, the 4D simulation was analysed and additional relations between tasks were manually created for a more accurate planification of the construction. BEXEL Manager allows to pause at any moment the 4D simulation and identify all the tasks that are being executed in that instance, then automatically find the desired tasks in the Gantt chart to create additional relationships when required. One example of this kind of correction done using this procedure was the concrete cast of the slab elements that conform each level. These elements have a greater width in the connections with columns to avoid punching share failure on the slabs, and these segments are represented on the BIM model with an independent element from the main slab. Since the volume of these elements is less in comparison with the main slab, when defining the task duration automatically based on daily outputs, these elements appear to be built first than the slab, but in the real construction, the concrete cast is a single activity for all the slab of the level, delimited by the construction phase, to have monolithic concrete elements. Therefore, start-to-start relations were manually to ensure the correct execution of these elements. Figure 21 presents a comparison of the results from the 4D/5D simulations for the planned scenario and the actual one adapted from the progress report. A larger visual for this image is presented in Appendix 5.

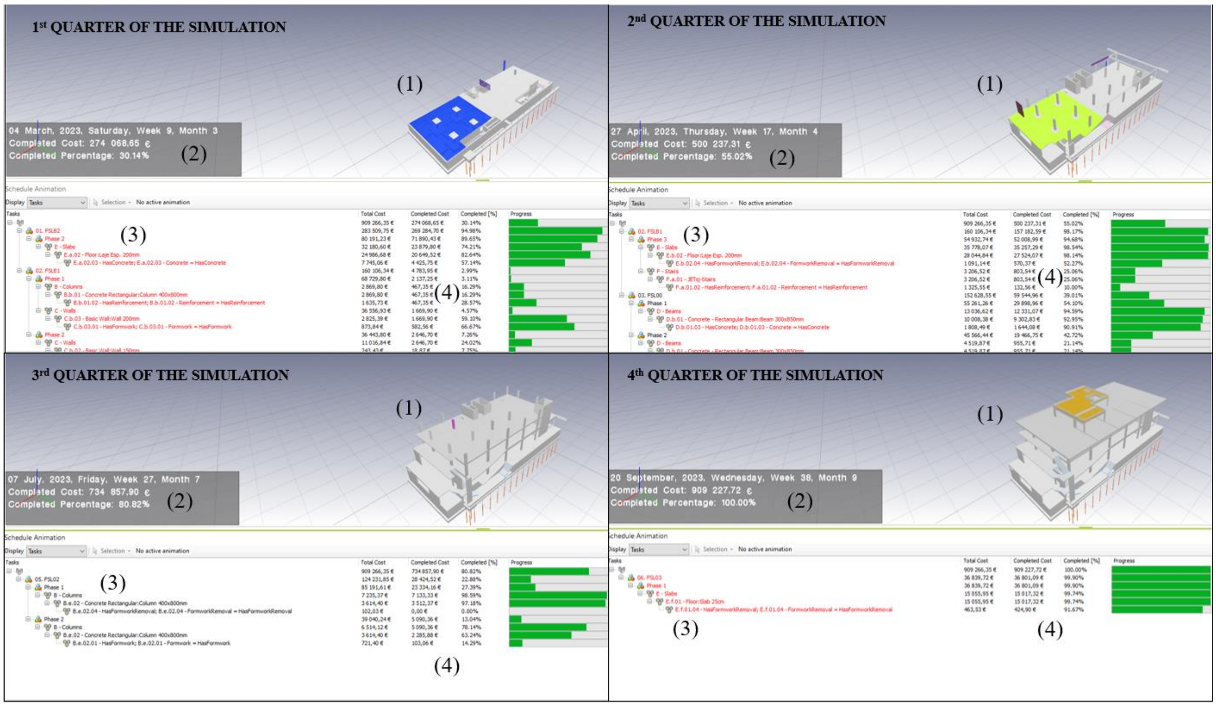


Figure 21. 4D/5D simulation for Case Study A.

(1) 4D simulation showing completed and in (2) Detail of current date, total completed cost and

(3) Tasks that are been executed at the (4) Detail of total cost, completed cost and

Once the schedule is revised and all the relations are correctly set, it is possible to level the use of labour resources to avoid radical changes throughout time because it is not feasible to increase and decrease the number of workers constantly, which will result then either in a waste of resource or an insufficiency of it. When using the levelling tool, the software will modify the start dates of tasks that are not part of the critical path, to have a more constant use of the resource without drastically affect the finish date of the project. For this case study, limits for labour resources were set in 3 periods: first month, next six months, and last two months. Figure 22 shows the average amount of workers per day during every month, for each labour resource after levelling, where the reinforcement labour presents an approximate of 6 workers for the first two months, 6 to 7 workers for the next 6 months, and 4 workers for the last month, while the inhouse workforce has an approximate amount of 3 workers for the first month, 7 to 8 workers for the next 6 months and 4 workers for the last two months.

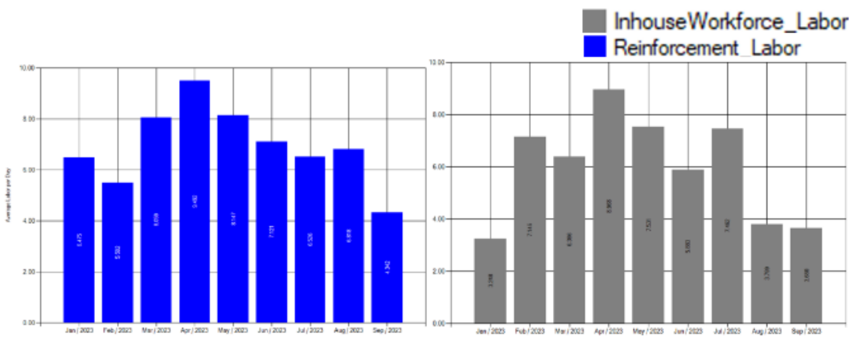


Figure 22. Average amount of workers per day for each month

After finishing the planning management described, a simulation of construction progress was done, to compare the planned information with the actual reported as progress. The report of the progress was simulated until the 12th of May, which according to the planification done it should reach 60% of completion. To define the elements that were completed to this period, a selection set was created including the elements that were completed according to the simulated progress reported, which is shown in Figure 23 in comparison with the elements that were planned to be completed according to the 4D simulation previously described.

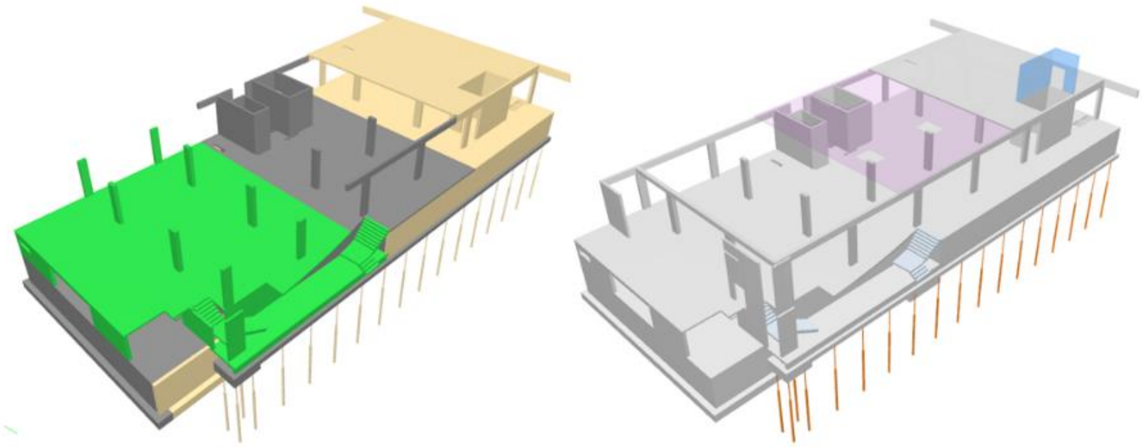


Figure 23. Completed elements according to the reported progress in comparison with the elements that should be completed according to the planned schedule

To include the reported progress in the schedule, the planned schedule was duplicated to save a frozen copy of the planned version to be able to compare it with the actual schedule. Then, using the progress report tool on the schedule editor of BEXEL Manager, the amount of consumed material resources as well as the working hours required were set, creating some differences in comparison to the planned version to be able to compare both situations. Specifically with the amount of consumed material resources, round amounts were introduced, since the required amount was automatically calculated, the values are decimal numbers, but usually the quantities on progress reports are round numbers because values come from measurements from the construction site.

Once the progress report is complete, is possible to make comparisons between the actual schedule and the planned schedule. One of the possible comparisons is to compare planned vs. actual schedules and identify differences in duration, start date and finish date of activities. Figure 24 shows part of the Gantt chart containing the tasks to execute some wall elements, where it is possible to compare the bars of the Gantt chart for each activity, were in several activities it is possible to note differences in duration, as well in the dates the activity was executed. Another possible comparison is between accumulative costs, as shown in Figure 25, where a comparative graph presents the difference between the S-curves that represent the accumulated costs for planned and actual situations. In this case, the data regarding the reported progress is being projected to predict the result of the accumulative costs of the project, according to the expenses reported.

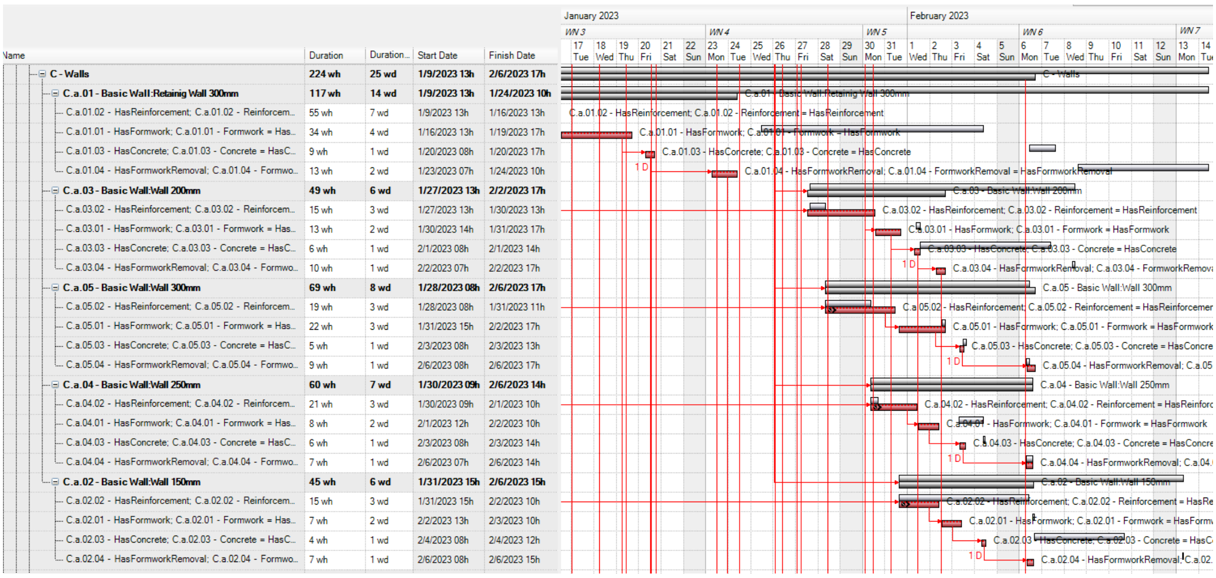


Figure 24. Extract of Gantt chart comparing the actual schedule with the planned schedule.

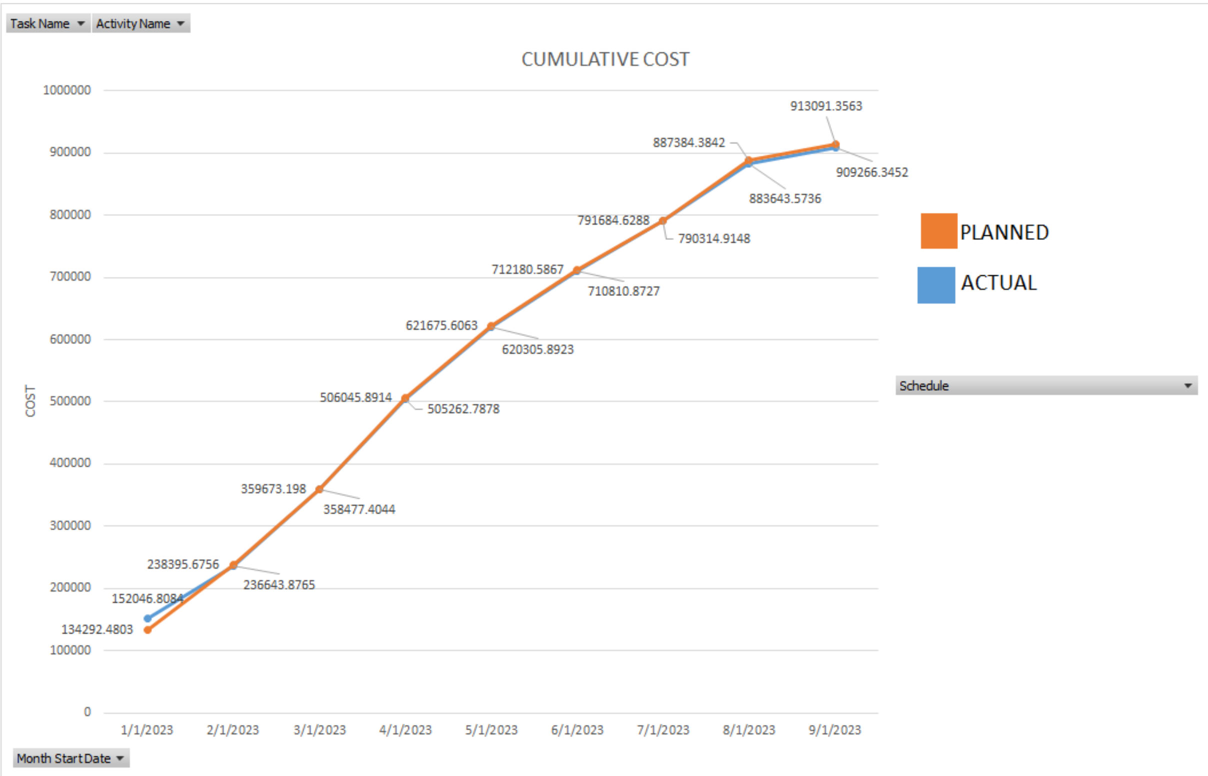


Figure 25. Comparative graph of accumulative costs between planned vs. actual

3.2. Case Study B: Value Engineering (VE)

3.2.1. Description of the case study

This case study was done using the same building as Case Study A. A modification on the design of the foundations was proposed as a potential value engineering solution and then evaluated to determine if it has a positive impact in the construction time and cost of the project. The foundations on the original design are composed by isolated footings connected with beams. The new proposal presents the option of substituting these foundations with a floating slab of 1,2 m of thickness, with its upper surface aligned with the finished floor level of the original ground slab, therefore substituting this element as well. At first, it appears that the increase in the amount of concrete for the foundations will result in a higher construction cost, but the objective is to calculate the quantities of all the different variables, then use BIM analytics to do a complete comparison between the two options and make a data driven decision. For the purpose of this case study, it is assumed that the structural design of the proposed foundation is correct and the definition of its geometry, together with its reinforcement came from a structural design. On a real situation, the structural validation must be the first step before analysing its economic feasibility.

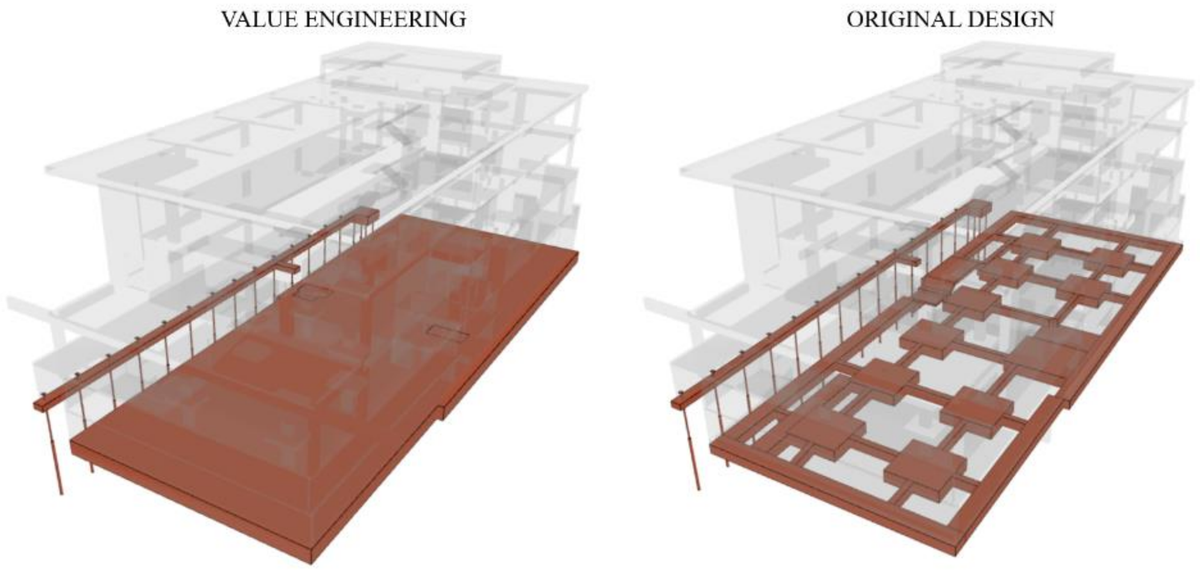


Figure 26. 3D view of the foundations for each design option.

3.2.2. Quantity Take-off preparation and results

To analyse all the quantities that could impact the time and cost, it is necessary first to have all the elements that will be measured. Consequently, the first step was the duplication of the BIM model and modification of the foundation on the authoring software Autodesk Revit to create the VE design option. To model the foundation floating slab, the family type of isolated footings was copied and modified, to maintain properties such as material because the proposed foundation maintains the same type of concrete. Next, the floating slab was modelled, matching its boarders with the ones on the wall foundations from the original model, then aligning the top surface of the floating slab with the upper surface of the ground slab. Next, modifications to the slab were made for the elevator shaft. Once the modelling of the floating slab was complete and elements correctly located, the original foundations were eliminated, and walls and columns bottom constraints were corrected to match the new height of the foundation. Then, the order of joins between the floating slab with columns and walls was revised, to proceed then with the creation of parameters to calculate the formwork of the foundation, as well as the modified columns and walls using the same tool described for the preparation of Case Study A.

An important variable considered in this analysis was the excavation and backfill required to build the foundations on both designs. Therefore, it is necessary to have elements that represented both excavation and backfill to be able to quantify these volumes. Thereby, mass elements were modelled representing the volumes of excavation and backfill for the foundations of both designs. Although in some cases mass-in-place elements are not convenient because of the lack of metadata they have, for this approach they fulfil the requirement to report the exact volume of its geometry, and have a versatile process to model volumes, facilitating the modelling of all the foundations matching their geometry, especially for the original design. Also, since the excavation and backfill share a common space, it is required to have different modelled elements for backfill and excavation, which is not possible to accomplish with elements like topography for example. Additionally, it is possible to cut the mass components when intersecting with other elements and report the corrected volume, like in the case of columns that intersect with backfill volumes, as shown in the detail of these elements for the original design in Figure 27. Since the differences in excavation volume between the two designs are from the lower surface of the ground slab down, both excavation and backfill were modelled from this level. Therefore, the value engineering design does not require backfill elements, only excavation.

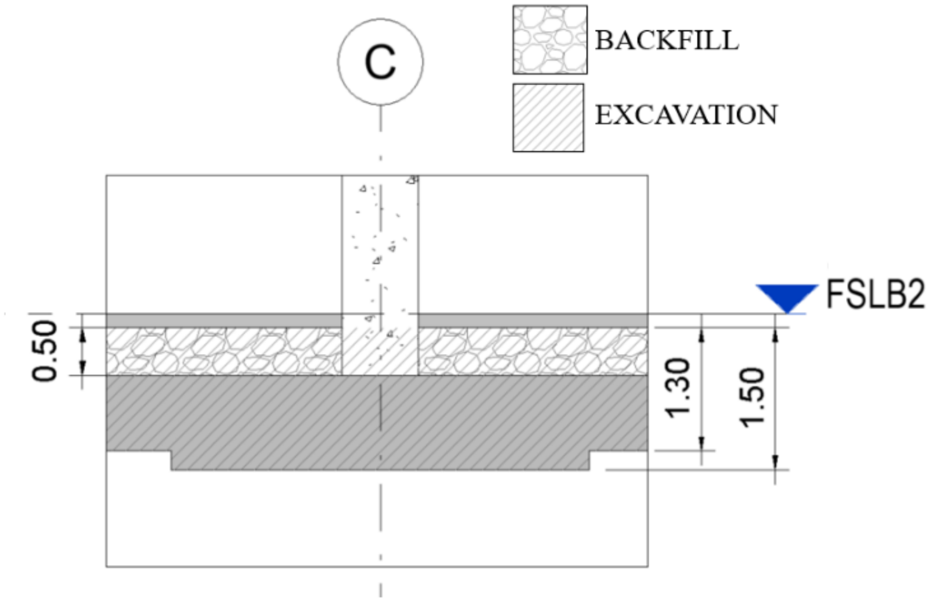


Figure 27. Detail of modelled backfill and excavation for an isolated footing and conecting beam from the original design.

When all the modifications on the authoring software are complete, the models are exported to IFC format to be analysed in BEXEL Manager. In this case study separate projects were created in the BIM-based QTO software for each model. First, selection sets were imported from the project of Case Study A, and the new elements were included in the correspondent selection sets of levels and phases. Also, two new selection sets were required for grouping the excavation and the backfill elements, that will be also used for the definition of methodologies for the construction schedule. Then, for the VE design, properties to estimate the quantity of reinforcement were created for the new elements conforming the floating slab, according to the values presented in Table 12.

Once the information is organized within the selection sets and containing all required properties, property checks were done similar to the process described for Case Study A, particularly for the formwork properties, to ensure that all elements contain the correct metadata to calculate these areas after the modifications done in the authoring software. Then, the procedure of automatized quantity take-off was performed, maintaining the same structure of the WBS defined in Case Study A. In the case of the excavation and backfill estimations, the QTOs were organized under the foundation activities, and the quantities on the QTOs were structured using the naming convention implemented for the authoring of the mass elements, which reference the foundation element correspondent to the activity. This structure can be observed in Figure 28.

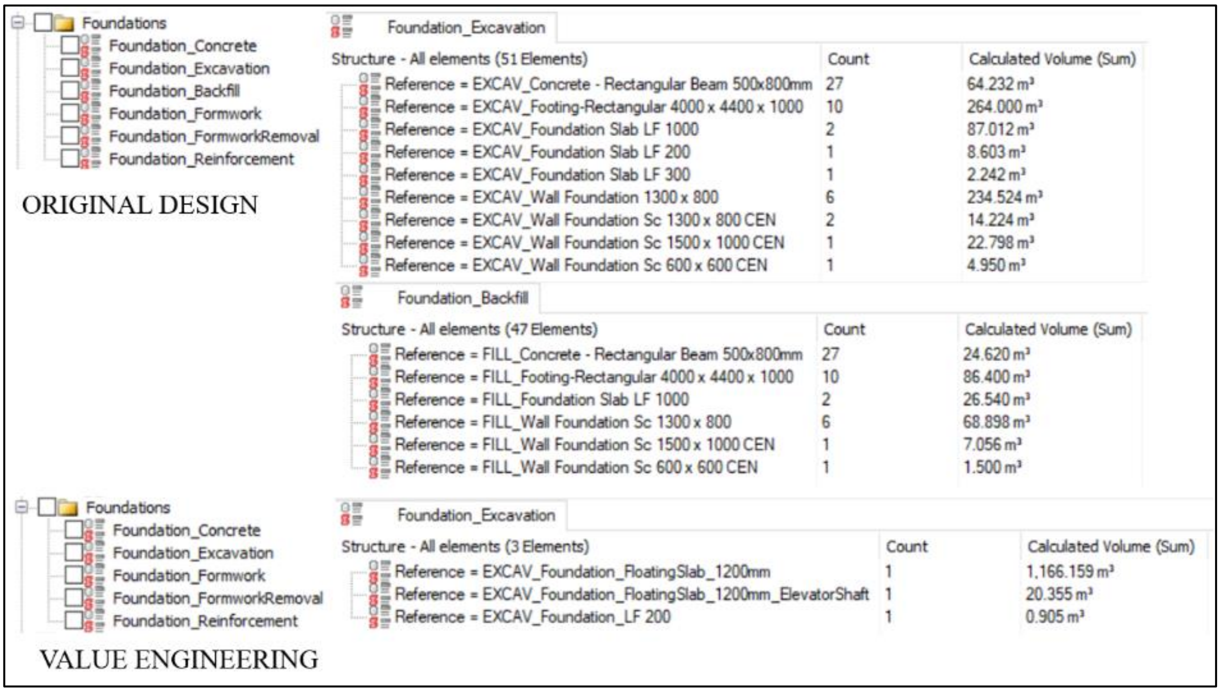


Figure 28. Quantity Take-off results for excavation and backfill volumes for original and VE designs.

3.2.3. BIM Analytics procedure and results

As performed for Case Study A, a Cost Breakdown Structure was defined for both projects integrated in this case study, where excavation and backfill was included on the second level of hierarchy for the foundation group. For the calculation of the quantities for these two activities, the volumes obtained represent exactly the projected area of the foundations as shown in Figure 27, but this do not represent accurately the volume of earth movement on the construction site, because excavations extend from the projected area. First, additional space is required for the installation of the side formwork, then the walls of the excavations are inclined, and its slope will depend on the properties of the ground. Therefore, it was estimated an additional of 40cm on the bottom of the excavation, and assuming a ground with good conditions for stability, a slope on the walls that would produce an additional of 50 cm on the top of the excavation as shown on Figure 29.

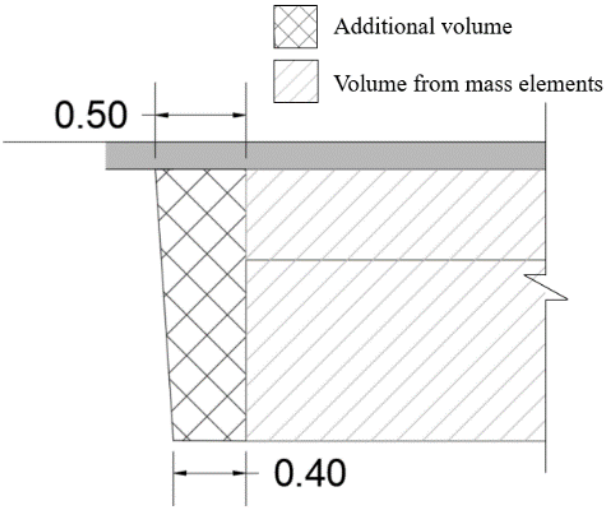


Figure 29. Detail for the estimation of additional excavation

To estimate this additional volume, a factor was calculated that could be applied for all the foundations. Since the height of the excavation is not being modified, the area of the vertical section of the excavation was used to determine this factor. First, the incremented section area was calculated, using an equivalent area that increases each side of the excavation 45cm. Then, dividing the increased area and the original area, an increasement factor is calculated for each type of excavation, equivalent to the foundation element type it represents. Next, using the total volume per type of foundation calculated previously, it was determined the weight that each type of foundation has on the total volume. Multiplying each weight with each factor, a weighted factor was obtained. The sum of all the weighted factors gives the total factor that was used to project the additional excavation and backfill volume. For the VE design, it was not necessary to weight the factor since the floating slab element represents 98% of the total volume, and the rest corresponds to the elevator shaft, which was not considered representative. The values and results for these calculations are presented in Table 15 for the original design Table 16 for the VE design. As expected, the factor for the original design is considerably larger, because the foundation system for this design option results in more excavation borders in comparison with the VE design.

Table 15. Estimation of the volume increase factor for the excavation and backfill for the original design

Mass element volume						Additional volume projection				
	b (m)	h (m)	Area (m^2)	Total Volume (m^3)	Volume weight	b (m)	h (m)	Area (m^2)	Increasement factor	Weighted value
EXCAV_Footing-Rectangular 4000 x 4400 x 1000	4.00	4.40	17.60	264.00	40.63%	4.90	5.30	25.97	1.48	0.60
EXCAV_Concrete - Rectangular Beam 500x800mm	0.50	4.00	2.00	64.23	9.89%	1.40	4.00	5.6	2.80	0.28
EXCAV_Foundation Slab LF 1000_1766621	4.84	5.75	27.83	41.74	6.42%	5.74	6.20	35.588	1.28	0.08
EXCAV_Foundation Slab LF 1000_1767109	3.35	5.75	19.26	45.27	6.97%	4.25	6.20	26.35	1.37	0.10
EXCAV_Wall Foundation 1300 x 800	1.30	21.20	27.56	234.52	36.09%	2.20	21.65	47.63	1.73	0.62
						TOTAL FACTOR				**1.68**

Table 16. Estimation of the volume increase factor for the excavation for the VE design

Mass element volume				Additional volume projection			
	b (m)	h (m)	Area (m^2)	b (m)	h (m)	Area (m^2)	Increasement factor
EXCAV_Foundation_FloatingSlab_1200mm	53.45	21.20	1133.14	54.35	22.10	1201.14	**1.06**

Since new activities were incorporated, namely excavation and backfill, the definition of new resources is required. Labour resources were created independently for these activities, to be able to analyse and make comparisons of these data. Therefore, in addition to the resources defined for Case Study A, the following resources were defined:

- Excavation_material: The excavated material must be disposed somewhere, and this has a cost. This resource includes the cost of transporting the extracted material to its destination.
- Excavation_Labour: The workforce required for the excavation. Since most of the work is done using machinery, it only represents workforce to mark the excavations and assisting the operator of the machinery.
- Excavation_equipment: Considers the machinery for the excavation, including all its associated costs (operator, transportation in and out the construction site, maintenance, etc.) For the original design, the resource cost is less than an excavator used in the VE case, but its performance is slower because it is an equipment with less capacity and a more detailed excavation. The resource representing the equipment for the VE option has a unit price almost 4 times bigger, because it represents a bigger, more expensive equipment, but it also has more capacity, and since the excavation is very regular, it has a larger daily output.
- Backfill_material: Represents the ballast material used to fill the excavations for the construction of the ground floor slab. It considers the transportation of the material per unit of volume.

- Backfill_Labour: Includes the workforce needed to place and compact the backfill material.
- Backfill_Equipment_compaction: Considers the tamping rammers for the compaction of the ballast.
- Backfill_Equipment_backhoe: Considers a backhoe to place the material to be compacted.

Code	Type	Quantity Type	Quantity Unit	Unit Cost	Color
Enter text to search					×
Backfill_Equipment_backhoe	Equipment	Time	d	80,00 €	
Backfill_Equipment_compaction	Equipment	Time	d	40,00 €	
Backfill_Labor	Labor	Time	h	10,00 €	
Backfill_Material	Material	Volume	m^3	20,00 €	
Concrete_Material	Material	Volume	m^3	100,00 €	
Excavation_Equipment	Equipment	Time	d	80,00 €	
Excavation_Labor	Labor	Time	h	10,00 €	
Excavation_material	Material	Volume	m^3	12,00 €	
Formwork_Material	Material	Area	m^2	10,00 €	
InhouseWorkforce_Labor	Labor	Time	h	10,00 €	
Micropiles_Installation	Material	Length	m	50,00 €	
Reinforcement_Labor	Labor	Time	h	10,00 €	
Reinforcement_Material	Material	Mass	kg	1,00 €	

Figure 30. Definition of resources for the original design option

Code	Type	Quantity Type	Quantity Unit	Unit Cost	Color
Enter text to search					×
Concrete_Material	Material	Volume	m^3	100,00 €	
Excavation_Equipment	Equipment	Time	d	300,00 €	
Excavation_Labor	Labor	Time	h	10,00 €	
Excavation_Material	Material	Volume	m^3	12,00 €	
Formwork_Material	Material	Area	m^2	10,00 €	
InhouseWorkforce_Labor	Labor	Time	h	10,00 €	
Micropiles_Installation	Material	Length	m	50,00 €	
Reinforcement_Labor	Labor	Time	h	10,00 €	
Reinforcement_Material	Material	Mass	kg	1,00 €	

Figure 31. Definition of resources for the VE design option.

Once the resources are defined, they are assigned to the cost items on the CBS, with the same procedure described for Case Study A. An important consideration is the percentage of expansion that the ground has when is extracted, as well as for the backfill material when is compacted. When a compacted material is excavated, the resultant material has approximately 20% more volume than the volume of the whole left from the excavation due to the expansion of the material, and this value will depend on the properties of the material. For this case study, 20% was considered for this expansion, and was included in the calculations as the waste factor for each material resource on every cost item. The daily outputs for the excavation and backfill activities, as well as the daily resource requirements to accomplish the daily outputs are shown in Table 17. For the other activities the values used were the same as in Case Study A, shown in Table 14.

Table 17. Daily outputs and daily resource requirements for excavation and backfill activities

Design option	Activity	Daily output (m^3)	Material daily quantity (m^3)	Labour daily quantity (working hours)	Equipment daily quantity (unit)
Original Design	Excavation	70	70	16	- 1 small excavator
	Backfill	30	30	40	- 1 backhoe - 4 tamping rammers
VE design	Excavation	400	400	16	- 1 large excavator

When the resource mapping is complete, cost items are assigned to every correspondent element, to produce the Bill of Quantities. In Appendix 9 and Appendix 10 the complete BoQs can be found for the Original Design and VE options respectively.

To analyse the impact on the duration of the project, construction schedules were created for each design option, using the schedule procedure implemented in Case Study A and modifying the defined methodologies to incorporate the excavation and backfill activities. For the Original Design, the excavations were divided in phases, defined in the selection sets created for this purpose, to focus the initial excavations on the first foundations to be built, and allowing overlapping of excavation activities and construction of foundations for a more efficient construction progress. This division is shown in Figure 32. For the case of the floating slab in the VE option, since the foundation is a single monolithic concrete element, all the excavation was done in the same task.

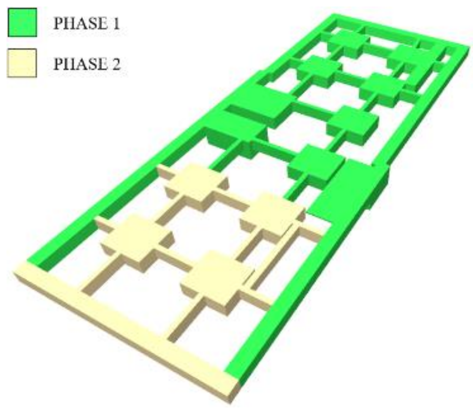
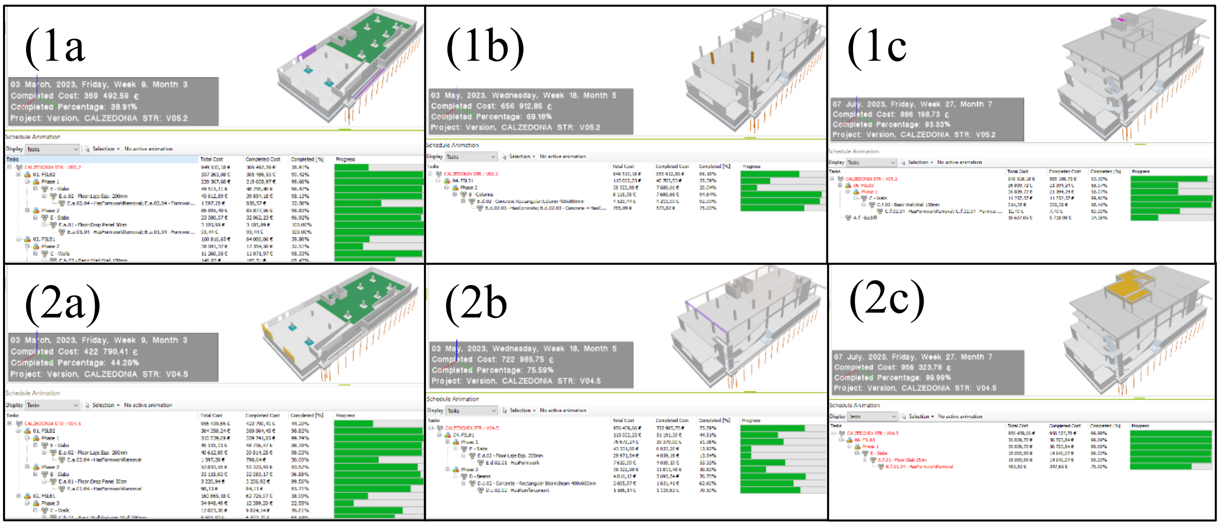


Figure 32. Division of the excavation into the construction phases for the Original Design

After adjusting the methodologies, the schedule was created for both scenarios, and then revised using the 4D simulation. With these analytics it is possible to make comparative analyses of the construction time between the two design options. A comparation between the progress is presented in Figure 33, and Gantt charts collapsed to the highest organizational levels of the schedules´ structures are shown in Figure 34 for the Original Design and in Figure 35 for the Value Engineering option. Enlarged images for these figures are presented in Appendix 7 and 8.



(1a) Original Design – 03/03/2023 – 38.91% Progress

(2a) VE Design – 03/03/2023 – 44,20% Progress

(1b) Original Design – 03/05/2023 – 69.18% Progress

(2b) VE Design – 03/05/2023 – 75,59% Progress

(1c) Original Design – 07/07/2023 – 93.33% Progress

(2c) VE Design – 07/07/2023 – 99.99% Progress

Figure 33. Comparison of 4D/5D simulations between the two design options

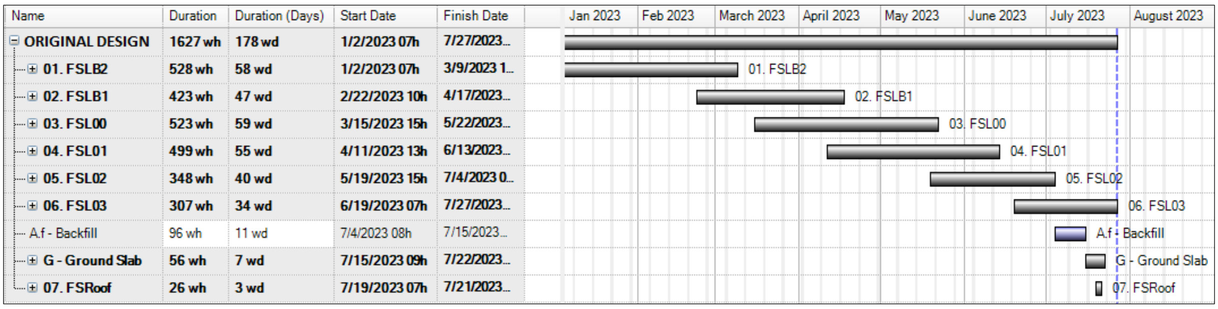


Figure 34. Resumed Gantt chart for the schedule of the Original Design option.

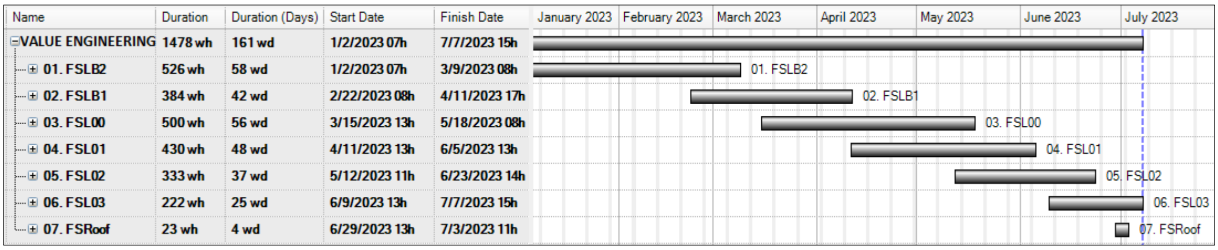


Figure 35. Resumed Gannt chart for the schedule of the Value Engineering option.

When comparing the total costs presented in the Bill of Quantities of both options, the VE design presents a higher cost, with an additional amount of €4 474. Nevertheless, when comparing the progress from the 4D/5D simulations, the VE option registers an approximate of 6% higher progress on the milestones presented. Also, by comparing the final dates on the schedules, the Original Design is finishing 20 days after than the VE option.

3.3. Case Study C: Change Management

3.3.1. Description of the case study

Case Study C is focused on the management of change orders due to modifications on the design. For this case, the model used represents a multi-storey building of approximately 24,000 m^2 to be used as a facility to centralize the IT operations and equipment of a large-scaled company, therefore it has large and complex MEP systems. An isometric view of the federated model of the building is shown in Figure 36. The scenario for this case study corresponds to several modifications done in the functional layout distribution, resulting in direct and indirect changes in the quantity and distribution of MEP elements, specifically cable trays and cable tray fittings. This case study has the objective to determine the cost of the modification of these elements using BIM-based QTO approach.

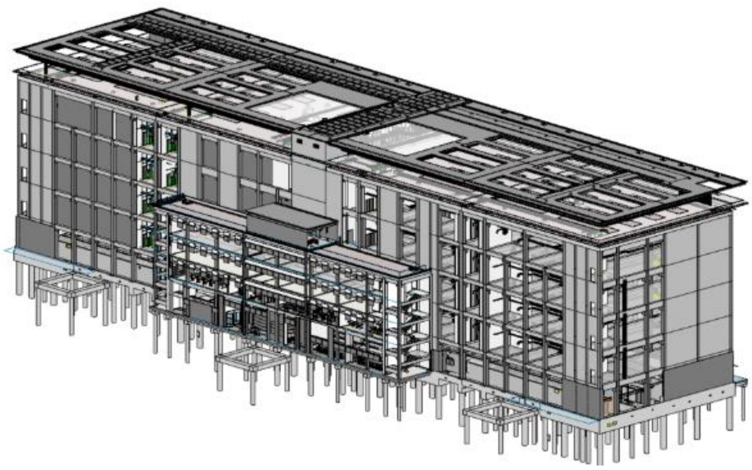


Figure 36. Isometric view of the BIM model represented the asset used for Case Study C.

3.3.2. Quantity Take-off preparation and results

Like Case Study B, in this case there was a scenario representing the original design and a second scenario that considers the modifications caused by changes in the layout distribution. Since the information from this project is divided into several models depending on their discipline, the first task was identifying which BIM models contained cable trays and cable tray fittings to centralize this information on a federated model. The elements to be studied came from models of electrical and HVAC disciplines, which all have the same project base point. Hence, the correspondent models were exported into IFC format using the project base point as location reference, and then revised on a model viewer to guarantee that the models were correctly located to be then imported into BEXEL Manager for analysis.

Once in BEXEL Manager, the first task was to organize the information, in this case by levels. When analysing the input information, since it came from multiple sources, the metadata defined in the spatial information property set, where the software identifies to which level an element belongs, had different values depending on the source model and none of them matched with the levels defined in the architectural model. Since the change order is a result of a modification performed in the architectural discipline, it becomes convenient to organize the information to be aligned to these levels, so the presentation of the change order can also be analysed according to the architectural modification on each level. To correct this issue, selection sets were created to group the information into the architectural level according to the location of each element. To perform this task, section planes were created aligned to each architectural level, and then by hiding and unhiding elements, these were grouped in the correspondent selection sets. In the case where cable trays route through different levels, they were assigned to the upper level for scheduling purposes, thinking that the upper level must be completed on the structural discipline to start building that cable tray line. Then, each selection set was checked to avoid any repetition caused by elements being included into more than one selection set and to ensure that every element was assigned to a level. Also, properties were created to indicate the defined level on each element. Using this property, it was possible to compare the original and modified models, to ensure the congruence in the definition of elements through a visual inspection. This was done using a model viewer that allowed grouping of elements according to property values and assigning a colour code depending on the source model, whether if it was from the original design or the modified scenario. This allowed the results to be analysed by level. The results of the organization are shown in Figure 37

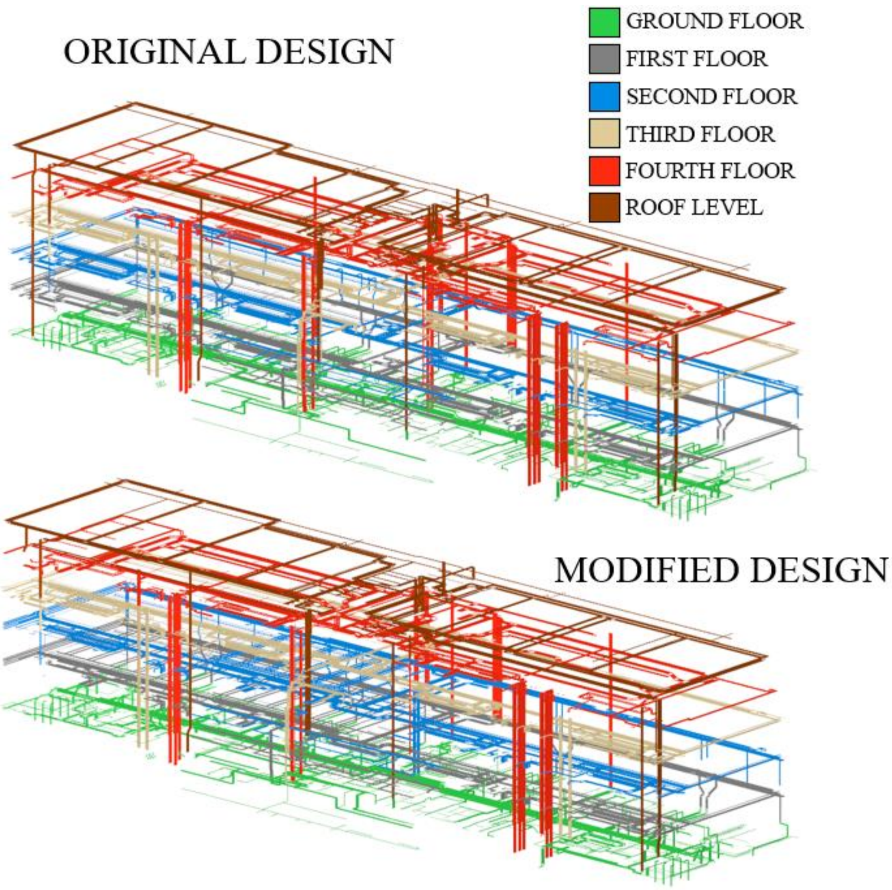


Figure 37. Organization of information according to architectural levels

Afterwards, considering how costs are defined for cable trays and cable tray fittings, these vary depending on the type of cable tray, and for each type, the cost also varies according to the size of the section of the tray. Therefore, the elements were organized first by type and then by size, obtaining this information from the properties of each element. A property check was also performed to ensure that all elements had the family type correctly defined according to the type of cable tray, as well as a correct size property.

When all the information was organized, the Quantity Take-off was done maintaining a WBS aligned with the organization of the information. In this case, a QTO was performed for cable trays, and another one for cable tray fittings, because of the different measures that these two element categories present. In the case of cable trays, the property that indicates length was used, because the cost of these elements will be defined by unit of length. A few manual measurements were performed to confirm the accuracy of the property used for these estimations. Also, a property check was done to all cable tray elements to ensure that there was no metadata missing on this property. In the case of cable tray fittings, only the element count was estimated with the QTO, because the cost of these elements is defined by unit. Figure 38 and Figure 39 show the results obtained with the quantity estimations for the Original Design and for the Modified scenario respectively. As shown, the information is organized first by the architectonical level, then by type of element and finally by size.

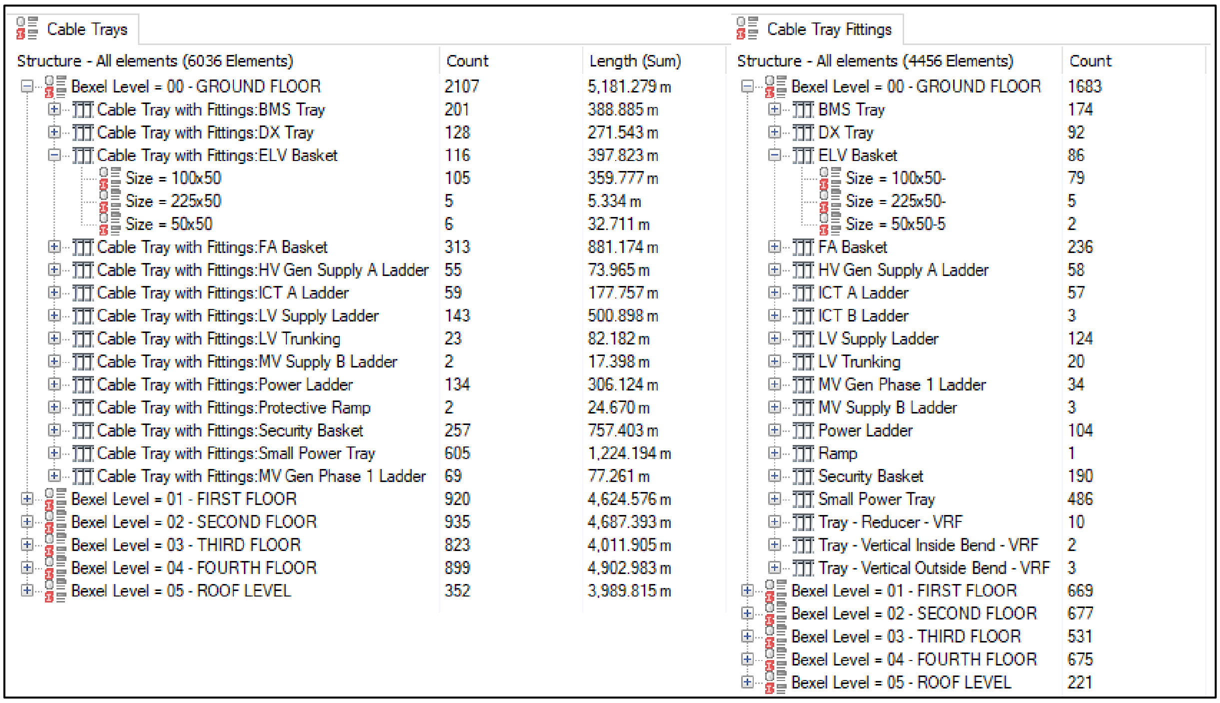
Cable Trays

Structure - All elements (5916 Elements)	Count	Length (Sum)
Bexel Level = 00 - GROUND FLOOR	2095	5,127.693 m
Cable Tray with Fittings:BMS Tray	186	401.730 m
Cable Tray with Fittings:DX Tray	125	217.754 m
Cable Tray with Fittings:ELV Basket	118	401.062 m
Size = 100x50	107	363.016 m
Size = 225x50	5	5.334 m
Size = 50x50	6	32.711 m
Cable Tray with Fittings:FA Basket	305	881.399 m
Cable Tray with Fittings:HV Gen Supply A Ladder	94	102.067 m
Cable Tray with Fittings:ICT A Ladder	58	176.061 m
Cable Tray with Fittings:LV Supply Ladder	155	521.659 m
Cable Tray with Fittings:LV Trunking	19	82.212 m
Cable Tray with Fittings:MV Supply B Ladder	2	17.398 m
Cable Tray with Fittings:Power Ladder	137	319.675 m
Cable Tray with Fittings:Protective Ramp	2	24.670 m
Cable Tray with Fittings:Security Basket	298	759.771 m
Cable Tray with Fittings:Small Power Tray	596	1,222.238 m
Bexel Level = 01 - FIRST FLOOR	904	4,469.419 m
Bexel Level = 02 - SECOND FLOOR	873	4,323.725 m
Bexel Level = 03 - THIRD FLOOR	817	4,022.145 m
Bexel Level = 04 - FOURTH FLOOR	884	4,894.699 m
Bexel Level = 05 - ROOF LEVEL	343	4,003.785 m

Cable Tray Fittings

Structure - All elements (4264 Elements)	Count
Bexel Level = 00 - GROUND FLOOR	1691
BMS Tray	159
DX Tray	93
ELV Basket	88
Size = 100x50-	81
Size = 225x50-	5
Size = 50x50-5	2
FA Basket	237
HV Gen Supply A Ladder	73
ICT A Ladder	53
ICT B Ladder	3
LV Supply Ladder	136
LV Trunking	16
MV Gen Phase 1 Ladder	1
MV Supply B Ladder	3
Power Ladder	105
Ramp	1
Security Basket	245
Small Power Tray	478
Bexel Level = 01 - FIRST FLOOR	621
Bexel Level = 02 - SECOND FLOOR	558
Bexel Level = 03 - THIRD FLOOR	523
Bexel Level = 04 - FOURTH FLOOR	660
Bexel Level = 05 - ROOF LEVEL	211

Figure 38. Results of Quantity Take-off for the Original Design



Cable Trays

Structure - All elements (6036 Elements)	Count	Length (Sum)
Bexel Level = 00 - GROUND FLOOR	2107	5,181.279 m
Cable Tray with Fittings:BMS Tray	201	388.885 m
Cable Tray with Fittings:DX Tray	128	271.543 m
Cable Tray with Fittings:ELV Basket	116	397.823 m
Size = 100x50	105	359.777 m
Size = 225x50	5	5.334 m
Size = 50x50	6	32.711 m
Cable Tray with Fittings:FA Basket	313	881.174 m
Cable Tray with Fittings:HV Gen Supply A Ladder	55	73.965 m
Cable Tray with Fittings:ICT A Ladder	59	177.757 m
Cable Tray with Fittings:LV Supply Ladder	143	500.898 m
Cable Tray with Fittings:LV Trunking	23	82.182 m
Cable Tray with Fittings:MV Supply B Ladder	2	17.398 m
Cable Tray with Fittings:Power Ladder	134	306.124 m
Cable Tray with Fittings:Protective Ramp	2	24.670 m
Cable Tray with Fittings:Security Basket	257	757.403 m
Cable Tray with Fittings:Small Power Tray	605	1,224.194 m
Cable Tray with Fittings:MV Gen Phase 1 Ladder	69	77.261 m
Bexel Level = 01 - FIRST FLOOR	920	4,624.576 m
Bexel Level = 02 - SECOND FLOOR	935	4,687.393 m
Bexel Level = 03 - THIRD FLOOR	823	4,011.905 m
Bexel Level = 04 - FOURTH FLOOR	899	4,902.983 m
Bexel Level = 05 - ROOF LEVEL	352	3,989.815 m

Cable Tray Fittings

Structure - All elements (4456 Elements)	Count
Bexel Level = 00 - GROUND FLOOR	1683
BMS Tray	174
DX Tray	92
ELV Basket	86
Size = 100x50-	79
Size = 225x50-	5
Size = 50x50-5	2
FA Basket	236
HV Gen Supply A Ladder	58
ICT A Ladder	57
ICT B Ladder	3
LV Supply Ladder	124
LV Trunking	20
MV Gen Phase 1 Ladder	34
MV Supply B Ladder	3
Power Ladder	104
Ramp	1
Security Basket	190
Small Power Tray	486
Tray - Reducer - VRF	10
Tray - Vertical Inside Bend - VRF	2
Tray - Vertical Outside Bend - VRF	3
Bexel Level = 01 - FIRST FLOOR	669
Bexel Level = 02 - SECOND FLOOR	677
Bexel Level = 03 - THIRD FLOOR	531
Bexel Level = 04 - FOURTH FLOOR	675
Bexel Level = 05 - ROOF LEVEL	221

Figure 39. Results of Quantity Take-off for the Modified Design

3.3.3. BIM Analytics procedure and results

When quantities were calculated, the definition of the CBS was done to estimate the costs for the two scenarios. The first step was to define the resources. Two types of resources were defined: material resources and a labour resource. The quantity types of the material resource, aligned with the measurements done in the QTO, were per unit of length for the cable trays, and per unit for the cable tray fittings. Unlike the previous case studies, where the elements analysed were structural, when analysing MEP elements, it is common to have multiple material resources, because of the great variety of parts that constitute these systems. As mentioned before, the costs of the cable trays and cable tray fittings were defined by type, and for each type of different costs were determined by size, resulting in more than 300 material resources. To create this important number of resources, an excel template was used to input the information of each resource. First, exporting the QTO information to excel it was possible to have the sizes of cable trays and cable tray fittings depending on the type of element. Then, a naming convention was established for each material resource:

CATEGORY_FAMILYTYPE_SIZE

where the category was CT for cable trays or CTF for cable tray fittings, then the family type and size equal to the property values which were used for the organization of the WBS. This made possible to automatize the creation of these codes using a concatenate function to join the information according to the naming convention. The complete list for the resources is presented in Appendix 11.

Once all resources were created, the CBS was defined using the creation wizard tool from the WBS used in the QTOs, according to the process previously defined. With the structure created, resources were assigned to each cost item. Due to the great amount of resources and cost items, custom breakdown structures were created organized by type and then by level, to be able to select all elements from each size and type independently. This allowed to filter selected items in the CBS, and then assigning resources to all the cost items correspondent to the selected items. This procedure was repeated for each size of each type of cable tray and cable tray fitting. Using this organized workflow allowed to avoid leaving cost items without assigned resources or assigning incorrect resources to a cost item. When assigning the resources, also the daily outputs and the required quantities to match these daily outputs were defined. The values used are shown in Table 18. Once all resources were assigned, a final revision was done by selecting all cost items of each type of element and checking that all resources corresponding to that type were assigned and that no size resource was assigned to more than one cost item. A summarized Bill of Quantities is shown in Figure 40 for the Original Design and in Figure 41 for the modified scenario caused from the change order.

Table 18. Daily outputs and daily resource quantities required defined for the cost estimation

	Daily output	Material daily quantity	Labour daily quantity
Cable Trays	20 m	20 m	16 working hours
Cable Tray Fittings	40 units	40 units	16 working hours

Name	Element Count	Material Cost	Labor Cost	Equipment Cost	Base Construction Cost
Enter text to search					
Classification	10180	434 438,74 €	233 384,75 €	0,00 €	667 823,49 €
ChM01	10180	434 438,74 €	233 384,75 €	0,00 €	667 823,49 €
01 - 00 - GROUND FLOOR	3786	75 015,18 €	47 785,54 €	0,00 €	122 800,73 €
01.01 - Cable Trays	2095	64 666,69 €	41 021,54 €	0,00 €	105 688,24 €
01.02 - Cable Tray Fittings	1691	10 348,49 €	6 764,00 €	0,00 €	17 112,49 €
02 - 01 - FIRST FLOOR	1525	68 814,46 €	38 771,69 €	0,00 €	107 586,15 €
02.01 - Cable Trays	904	63 389,69 €	36 287,69 €	0,00 €	99 677,38 €
02.02 - Cable Tray Fittings	621	5 424,77 €	2 484,00 €	0,00 €	7 908,77 €
03 - 02 - SECOND FLOOR	1431	65 916,96 €	37 354,14 €	0,00 €	103 271,10 €
03.01 - Cable Trays	873	61 164,64 €	35 122,14 €	0,00 €	96 286,78 €
03.02 - Cable Tray Fittings	558	4 752,32 €	2 232,00 €	0,00 €	6 984,32 €
04 - 03 - THIRD FLOOR	1340	63 241,96 €	34 801,50 €	0,00 €	98 043,47 €
04.01 - Cable Trays	817	58 708,50 €	32 709,50 €	0,00 €	91 418,00 €
04.02 - Cable Tray Fittings	523	4 533,47 €	2 092,00 €	0,00 €	6 625,47 €
05 - 04 - FOURTH FLOOR	1544	101 816,43 €	41 797,59 €	0,00 €	143 614,02 €
05.01 - Cable Trays	884	94 936,28 €	39 157,59 €	0,00 €	134 093,87 €
05.02 - Cable Tray Fittings	660	6 880,16 €	2 640,00 €	0,00 €	9 520,16 €
06 - 05 - ROOF LEVEL	554	59 633,74 €	32 874,28 €	0,00 €	92 508,02 €
06.01 - Cable Trays	343	57 487,34 €	32 030,28 €	0,00 €	89 517,62 €
06.02 - Cable Tray Fittings	211	2 146,40 €	844,00 €	0,00 €	2 990,40 €

Figure 40. Bill of Quantities for the Original Design scenario, Case Study C.

Name	Element Count	Material Cost	Labor Cost	Equipment Cost	Base Construction Cost
Classification	10492	454 632,39 €	237 007,60 €	0,00 €	691 639,99 €
ChM02	10492	454 632,39 €	237 007,60 €	0,00 €	691 639,99 €
06 - 05 - ROOF LEVEL	573	58 318,86 €	32 802,52 €	0,00 €	91 121,38 €
06.02 - Cable Tray Fittings	221	2 176,61 €	884,00 €	0,00 €	3 060,61 €
06.01 - Cable Trays	352	56 142,26 €	31 918,52 €	0,00 €	88 060,78 €
05 - 04 - FOURTH FLOOR	1574	101 892,61 €	41 923,86 €	0,00 €	143 816,48 €
05.02 - Cable Tray Fittings	675	7 053,77 €	2 700,00 €	0,00 €	9 753,77 €
05.01 - Cable Trays	899	94 838,85 €	39 223,86 €	0,00 €	134 062,71 €
04 - 03 - THIRD FLOOR	1354	61 811,12 €	34 219,24 €	0,00 €	96 030,36 €
04.02 - Cable Tray Fittings	531	4 616,51 €	2 124,00 €	0,00 €	6 740,51 €
04.01 - Cable Trays	823	57 194,61 €	32 095,24 €	0,00 €	89 289,85 €
03 - 02 - SECOND FLOOR	1612	77 018,76 €	40 207,14 €	0,00 €	117 225,90 €
03.02 - Cable Tray Fittings	677	5 595,87 €	2 708,00 €	0,00 €	8 303,87 €
03.01 - Cable Trays	935	71 422,89 €	37 499,14 €	0,00 €	108 922,04 €
02 - 01 - FIRST FLOOR	1589	78 002,00 €	39 672,61 €	0,00 €	117 674,61 €
02.02 - Cable Tray Fittings	669	6 167,50 €	2 676,00 €	0,00 €	8 843,50 €
02.01 - Cable Trays	920	71 834,50 €	36 996,61 €	0,00 €	108 831,11 €
01 - 00 - GROUND FLOOR	3790	77 589,03 €	48 182,23 €	0,00 €	125 771,26 €
01.02 - Cable Tray Fittings	1683	10 634,87 €	6 732,00 €	0,00 €	17 366,87 €
01.01 - Cable Trays	2107	66 954,16 €	41 450,23 €	0,00 €	108 404,39 €

Figure 41. Bill of Quantities for the Modified Design scenario, Case Study C.

When costs are completed, it is possible to compare both estimations and extract the difference in cost to determine the impact of the change order. Also, with all the cost information linked in the construction model, it is possible to make queries of the data to understand better the information. As an example, Figure 42 shows a query done to observe the costs of the cable trays with type FA Basket. This was done using the custom breakdown selections and then simply filtering the BoQ by the selected elements. Additionally, the selected elements are shown in the model viewer to aid the user to understand the analysed elements regarding its location and geometrical representation, with the possibility to modify the viewpoint, hide/unhide models from other disciplines, change the view style and check the properties of the elements within the analysis. With a correct organization of the information, it becomes easy to customize any desired selection to query the information and perform a better analysis of the calculated costs.

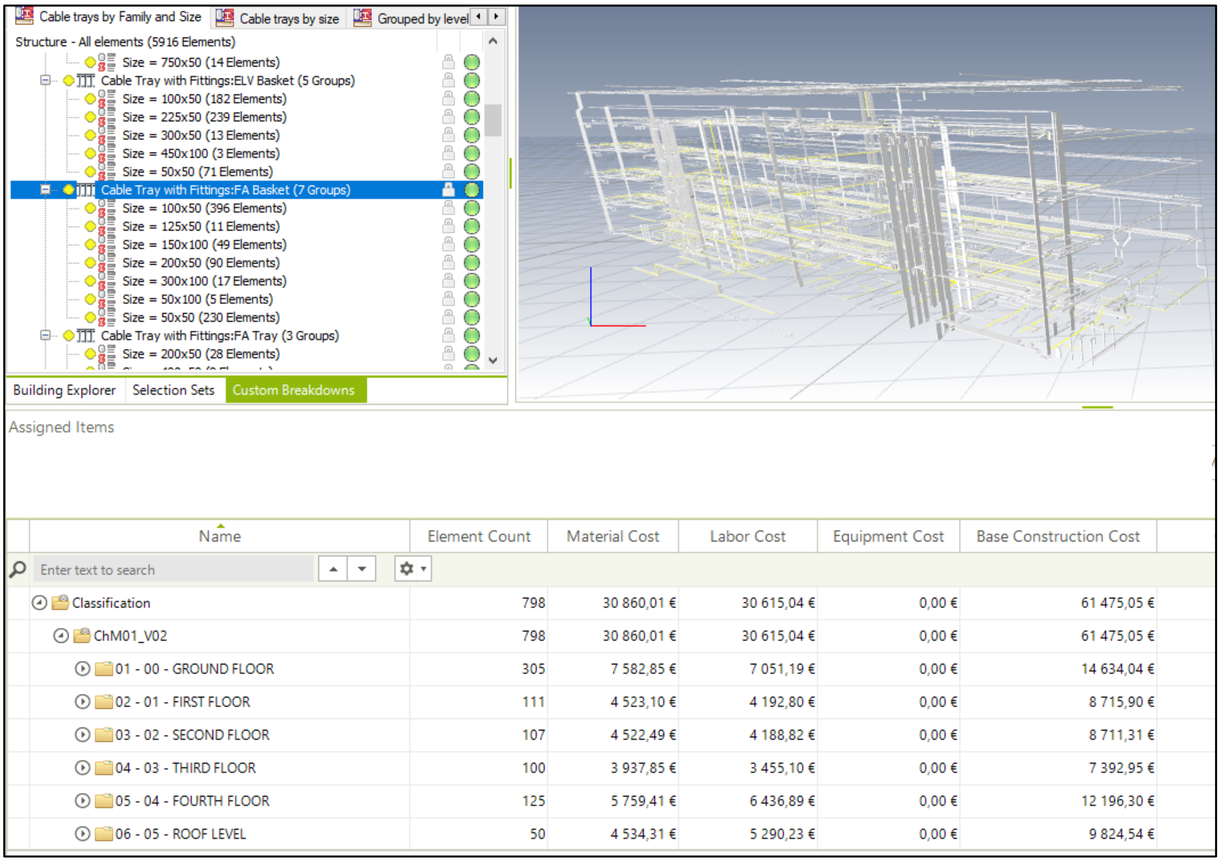


Figure 42. Query on the cost estimation for all cable trays with type FA Basket.

3.4. Case Study D: E-Procurement

3.4.1. Description of the case study

Case Study D was developed to study E-Procurement, but since this is a very wide subject as noted in the State of the Art, the decision studied was focused the election of a specific subcontract for the construction of a project. It is important to clarify that the E-Procurement System of a construction project goes beyond an election of a subcontractor, but the addressed case study focused on this segment of the E-Procurement System which represents a decision that has a great impact in the development of the projects, according to the ideas expressed by the professionals who participated in this study through interviews and round tables.

Using as a basis the structural model implemented in Case Study A, a scenario was created to choose a subcontract that would perform the concrete casting and finishing of slabs. The objective is to centralize all the cost information integrating the input from 3 bidding subcontractors and perform comparative analysis to choose the best option among all the bidders, based on quantity information. According to project requirements, there are two types of finishes for the concrete slabs: a troweled finish for parking lots and rooftops, and rough finish for mix-use spaces which will have architectural flooring tiles as final finish.

3.4.2. Preparations before the quantity extraction

To differentiate the concrete slabs according to its finish type, a property was added in BEXEL Manager to indicate the type of finish in each element. This allowed to group the information for quantity extraction categorising the slabs depending on this property. Figure 43 presents a colour coded view with the type of concrete finish, where the slabs on the two basement floors and the slab on the rooftop have a troweled finish, while the other ones have a rough concrete finish.

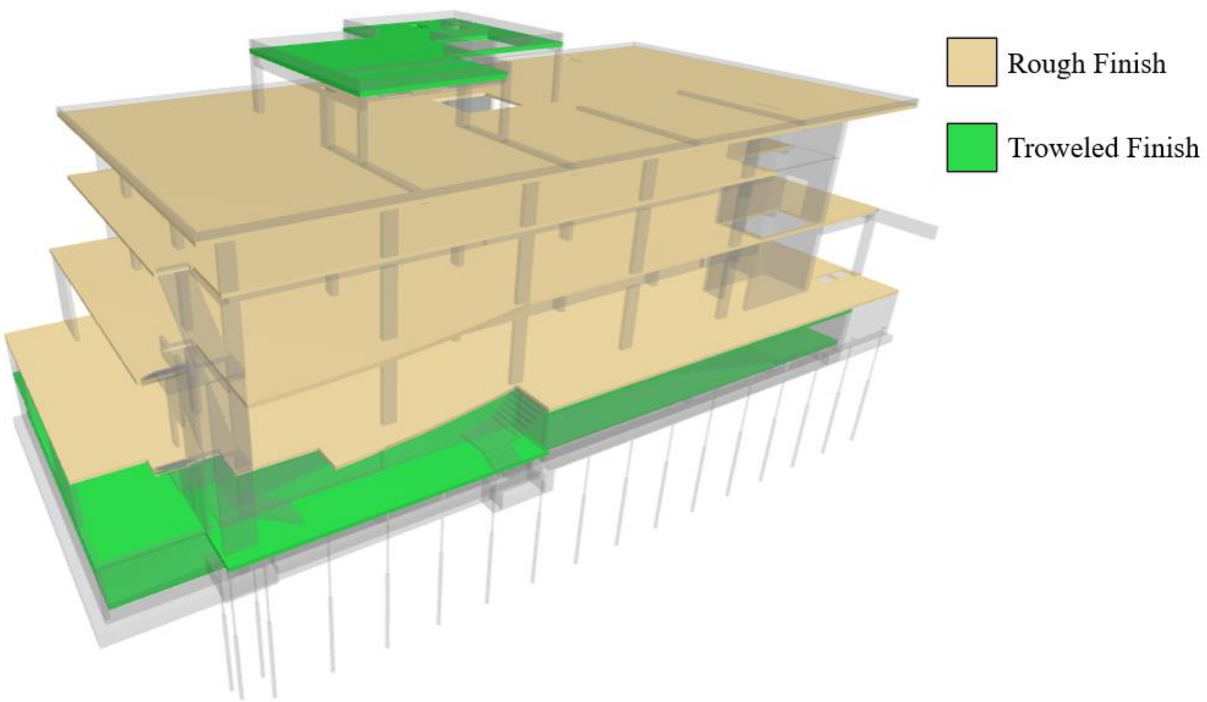
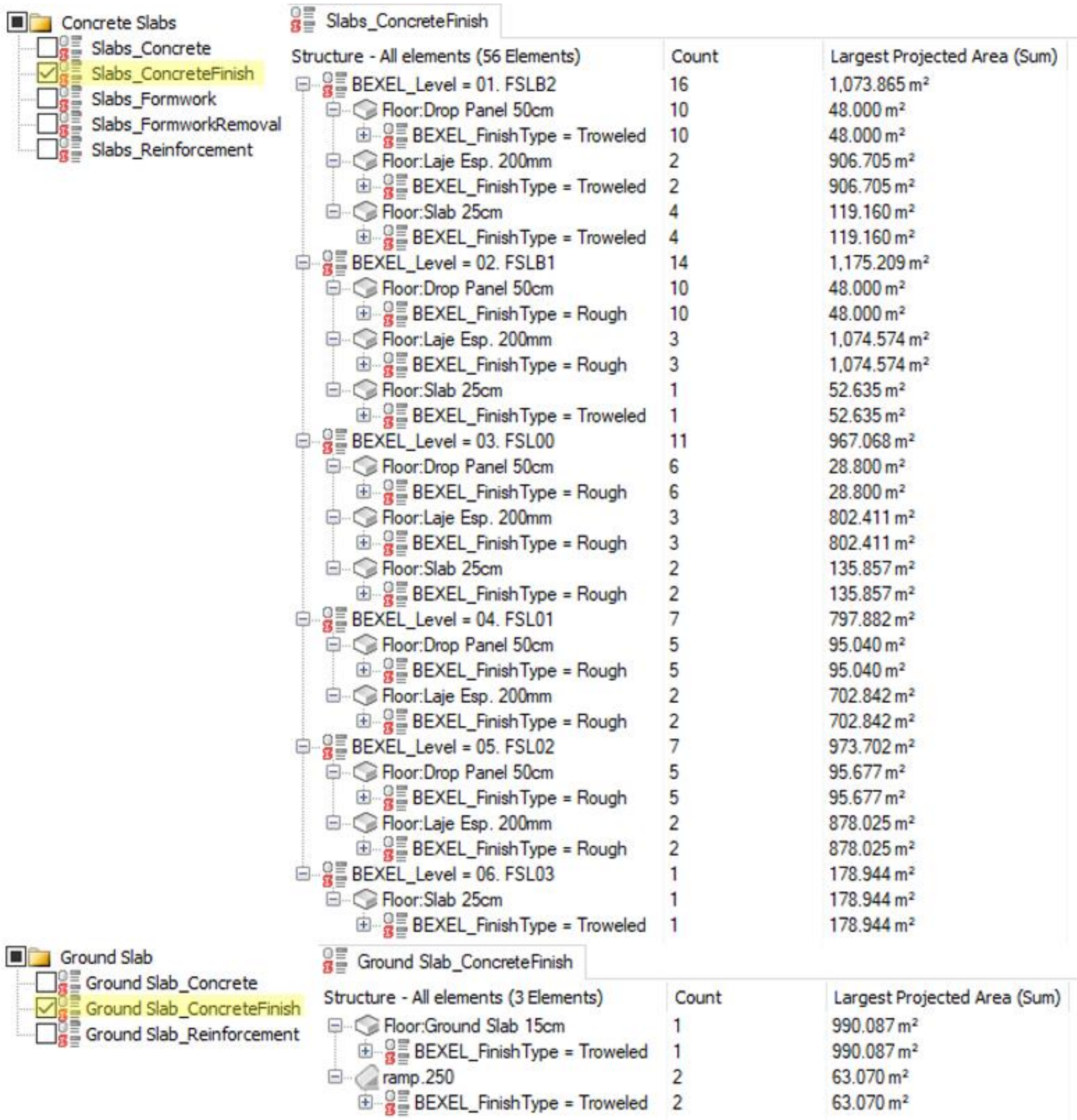


Figure 43. Colour coded 3D view of concrete slabs according to its finish.

Also, a property was created for all the elements that have a concrete finish to be measured, namely concrete and ground slabs. This property was used to group all these elements into the QTO to be then correctly organized into the Cost Breakdown Structure. The concrete finish was included into the WBS as activity, together with the formwork, reinforcement, concrete casting, and formwork removal previously defined. Once the properties were created, the additional QTO for concrete finish activity was performed. The quantity measured was the finish area. For this extraction, the values on the property named "Largest Projected Area" were used. This is a calculated property automatically created by BEXEL Manager, which measures the area of the largest side of the geometry of the element. The advantage of using this property is that it considers openings on the slab, and it cannot be modified, preventing an error in the estimation due to a human error of modifying these values. Then, the QTO is performed. The results obtained are presented in Figure 44. This information, together with the concrete volume calculated for the concrete cast activity, is the information provided to each bidding subcontract, which will provide a cost per unit of area for the cast and finish of the concrete slabs.



Structure - All elements (56 Elements)	Count	Largest Projected Area (Sum)
BEXEL_Level = 01. FSLB2	16	1,073.865 m²
Floor:Drop Panel 50cm	10	48.000 m²
BEXEL_FinishType = Troweled	10	48.000 m²
Floor:Laje Esp. 200mm	2	906.705 m²
BEXEL_FinishType = Troweled	2	906.705 m²
Floor:Slab 25cm	4	119.160 m²
BEXEL_FinishType = Troweled	4	119.160 m²
BEXEL_Level = 02. FSLB1	14	1,175.209 m²
Floor:Drop Panel 50cm	10	48.000 m²
BEXEL_FinishType = Rough	10	48.000 m²
Floor:Laje Esp. 200mm	3	1,074.574 m²
BEXEL_FinishType = Rough	3	1,074.574 m²
Floor:Slab 25cm	1	52.635 m²
BEXEL_FinishType = Troweled	1	52.635 m²
BEXEL_Level = 03. FSL00	11	967.068 m²
Floor:Drop Panel 50cm	6	28.800 m²
BEXEL_FinishType = Rough	6	28.800 m²
Floor:Laje Esp. 200mm	3	802.411 m²
BEXEL_FinishType = Rough	3	802.411 m²
Floor:Slab 25cm	2	135.857 m²
BEXEL_FinishType = Rough	2	135.857 m²
BEXEL_Level = 04. FSL01	7	797.882 m²
Floor:Drop Panel 50cm	5	95.040 m²
BEXEL_FinishType = Rough	5	95.040 m²
Floor:Laje Esp. 200mm	2	702.842 m²
BEXEL_FinishType = Rough	2	702.842 m²
BEXEL_Level = 05. FSL02	7	973.702 m²
Floor:Drop Panel 50cm	5	95.677 m²
BEXEL_FinishType = Rough	5	95.677 m²
Floor:Laje Esp. 200mm	2	878.025 m²
BEXEL_FinishType = Rough	2	878.025 m²
BEXEL_Level = 06. FSL03	1	178.944 m²
Floor:Slab 25cm	1	178.944 m²
BEXEL_FinishType = Troweled	1	178.944 m²

Structure - All elements (3 Elements)	Count	Largest Projected Area (Sum)
Floor:Ground Slab 15cm	1	990.087 m²
BEXEL_FinishType = Troweled	1	990.087 m²
ramp.250	2	63.070 m²
BEXEL_FinishType = Troweled	2	63.070 m²

Figure 44. QTO results for the concrete finish of slabs.

3.4.3. BIM Analytics procedure and results

For this case study, a CBS was developed in four different scenarios: one for each bidding subcontractor and one considering unit costs corresponding to the planned budget. Consequently, resources were created for each scenario. In this case, the resources were created as material resources to be able to assign a unit cost per unit of area but is not a material resource but a subcontract resource which considers all the associated costs to perform the activity. Therefore, equipment resources were not included, since the supply, use and maintenance of the necessary equipment is under the scope of the subcontract, and must be covered within the provided cost by each participant. The list of resources implemented in this case study are shown in Figure 45, with the added resources highlighted.

Code	Type	Quantity Type	Quantity Unit	Unit Cost
Enter text to search				
Concrete_Material	Material	Volume	m^3	100,00 €
ConcreteSlabs_Finish_Rough	Material	Area	m^2	1,25 €
ConcreteSlabs_Finish_SC1_Rough	Material	Area	m^2	1,15 €
ConcreteSlabs_Finish_SC1_Troweled	Material	Area	m^2	1,20 €
ConcreteSlabs_Finish_SC2_Rough	Material	Area	m^2	1,00 €
ConcreteSlabs_Finish_SC2_Troweled	Material	Area	m^2	1,60 €
ConcreteSlabs_Finish_SC3_Rough	Material	Area	m^2	1,45 €
ConcreteSlabs_Finish_SC3_Troweled	Material	Area	m^2	1,95 €
ConcreteSlabs_Finish_Troweled	Material	Area	m^2	1,75 €
Formwork_Material	Material	Area	m^2	10,00 €
InhouseWorkforce_Labor	Labor	Time	h	10,00 €
Micropiles_Installation	Material	Length	m	50,00 €
Reinforcement_Labor	Labor	Time	h	10,00 €
Reinforcement_Material	Material	Mass	kg	1,00 €

Figure 45. Resources implemented in the cost estimation for Case Study D

When resources are correctly assigned in each CBS, the elements are automatically assigned to generate a Bill of Quantities independent for each scenario. For each BoQ, it is possible not only to observe the total amount for each scenario, but also to filter the information to see only the costs related to the concrete finish activity. Figure 46 to Figure 49 show the complete BoQ and filtered data for each scenario.

Name	Element Count	Material Cost	Labor Cost	Equipment Cost	Base Construction Cost
Enter text to search					
Classification	389	703 056,30 €	210 012,83 €	0,00 €	913 069,13 €
CaseStudyD_Planned	389	703 056,30 €	210 012,83 €	0,00 €	913 069,13 €
A - Foundations	74	109 349,85 €	11 254,80 €	0,00 €	120 604,65 €
B - Columns	83	42 497,01 €	31 321,42 €	0,00 €	73 818,43 €
C - Walls	127	162 873,34 €	44 248,74 €	0,00 €	207 122,08 €
D - Beams	38	31 497,66 €	25 428,51 €	0,00 €	56 926,17 €
E - Slabs	56	320 299,19 €	91 712,96 €	0,00 €	412 012,14 €
F - Stairs	8	5 128,13 €	2 974,26 €	0,00 €	8 102,39 €
G - Ground Slab	3	31 411,12 €	3 072,14 €	0,00 €	34 483,26 €

Name	Element Count	Material Cost	Labor Cost	Equipment Cost	Base Construction Cost
HasConcreteFinish					
Classification	59	8 954,08 €	0,00 €	0,00 €	8 954,08 €
CaseStudyD_Planned	59	8 954,08 €	0,00 €	0,00 €	8 954,08 €
E - Slabs	56	7 111,06 €	0,00 €	0,00 €	7 111,06 €
E.a - 01. FSLB2	16	1 879,26 €	0,00 €	0,00 €	1 879,26 €
E.b - 02. FSLB1	14	1 495,33 €	0,00 €	0,00 €	1 495,33 €
E.c - 03. FSL00	11	1 208,84 €	0,00 €	0,00 €	1 208,84 €
E.d - 04. FSL01	7	997,35 €	0,00 €	0,00 €	997,35 €
E.e - 05. FSL02	7	1 217,13 €	0,00 €	0,00 €	1 217,13 €
E.f - 06. FSL03	1	313,15 €	0,00 €	0,00 €	313,15 €
G - Ground Slab	3	1 843,02 €	0,00 €	0,00 €	1 843,02 €

Figure 46. Bill of Quantities for the planned scenario, Case Study D

Name	Element Count	Material Cost	Labor Cost	Equipment Cost	Base Construction Cost
Enter text to search					
Classification	389	701 372,95 €	210 012,83 €	0,00 €	911 385,77 €
CaseStudyD_SC1	389	701 372,95 €	210 012,83 €	0,00 €	911 385,77 €
A - Foundations	74	109 349,85 €	11 254,80 €	0,00 €	120 604,65 €
B - Columns	83	42 497,01 €	31 321,42 €	0,00 €	73 818,43 €
C - Walls	127	162 873,34 €	44 248,74 €	0,00 €	207 122,08 €
D - Beams	38	31 497,66 €	25 428,51 €	0,00 €	56 926,17 €
E - Slabs	56	319 195,07 €	91 712,96 €	0,00 €	410 908,03 €
F - Stairs	8	5 128,13 €	2 974,26 €	0,00 €	8 102,39 €
G - Ground Slab	3	30 831,89 €	3 072,14 €	0,00 €	33 904,03 €

Name	Element Count	Material Cost	Labor Cost	Equipment Cost	Base Construction Cost
HasConcreteFinish					
Classification	59	7 270,73 €	0,00 €	0,00 €	7 270,73 €
CaseStudyD_SC1	59	7 270,73 €	0,00 €	0,00 €	7 270,73 €
E - Slabs	56	6 006,94 €	0,00 €	0,00 €	6 006,94 €
E.a - 01. FSLB2	16	1 288,64 €	0,00 €	0,00 €	1 288,64 €
E.b - 02. FSLB1	14	1 354,12 €	0,00 €	0,00 €	1 354,12 €
E.c - 03. FSL00	11	1 112,13 €	0,00 €	0,00 €	1 112,13 €
E.d - 04. FSL01	7	917,56 €	0,00 €	0,00 €	917,56 €
E.e - 05. FSL02	7	1 119,76 €	0,00 €	0,00 €	1 119,76 €
E.f - 06. FSL03	1	214,73 €	0,00 €	0,00 €	214,73 €
G - Ground Slab	3	1 263,79 €	0,00 €	0,00 €	1 263,79 €

Figure 47. Bill of Quantities considering the costs from Subcontractor#1, Case Study D

Name	Element Count	Material Cost	Labor Cost	Equipment Cost	Base Construction Cost
Enter text to search					
Classification	389	701 737,20 €	210 012,83 €	0,00 €	911 750,03 €
CaseStudyD_SC2	389	701 737,20 €	210 012,83 €	0,00 €	911 750,03 €
A - Foundations	74	109 349,85 €	11 254,80 €	0,00 €	120 604,65 €
B - Columns	83	42 497,01 €	31 321,42 €	0,00 €	73 818,43 €
C - Walls	127	162 873,34 €	44 248,74 €	0,00 €	207 122,08 €
D - Beams	38	31 497,66 €	25 428,51 €	0,00 €	56 926,17 €
E - Slabs	56	319 138,06 €	91 712,96 €	0,00 €	410 851,02 €
F - Stairs	8	5 128,13 €	2 974,26 €	0,00 €	8 102,39 €
G - Ground Slab	3	31 253,15 €	3 072,14 €	0,00 €	34 325,29 €

Name	Element Count	Material Cost	Labor Cost	Equipment Cost	Base Construction Cost
HasConcreteFinish					
Classification	59	7 634,99 €	0,00 €	0,00 €	7 634,99 €
CaseStudyD_SC2	59	7 634,99 €	0,00 €	0,00 €	7 634,99 €
E - Slabs	56	5 949,94 €	0,00 €	0,00 €	5 949,94 €
E.a - 01. FSLB2	16	1 718,18 €	0,00 €	0,00 €	1 718,18 €
E.b - 02. FSLB1	14	1 206,79 €	0,00 €	0,00 €	1 206,79 €
E.c - 03. FSL00	11	967,07 €	0,00 €	0,00 €	967,07 €
E.d - 04. FSL01	7	797,88 €	0,00 €	0,00 €	797,88 €
E.e - 05. FSL02	7	973,70 €	0,00 €	0,00 €	973,70 €
E.f - 06. FSL03	1	286,31 €	0,00 €	0,00 €	286,31 €
G - Ground Slab	3	1 685,05 €	0,00 €	0,00 €	1 685,05 €

Figure 48. Bill of Quantities considering the costs from Subcontractor#2, Case Study D

Name	Element Count	Material Cost	Labor Cost	Equipment Cost	Base Construction Cost
Enter text to search					
Classification	389	704 300,27 €	210 012,83 €	0,00 €	914 313,09 €
CaseStudyD_SC3	389	704 300,27 €	210 012,83 €	0,00 €	914 313,09 €
A - Foundations	74	109 349,85 €	11 254,80 €	0,00 €	120 604,65 €
B - Columns	83	42 497,01 €	31 321,42 €	0,00 €	73 818,43 €
C - Walls	127	162 873,34 €	44 248,74 €	0,00 €	207 122,08 €
D - Beams	38	31 497,66 €	25 428,51 €	0,00 €	56 926,17 €
E - Slabs	56	321 332,52 €	91 712,96 €	0,00 €	413 045,48 €
F - Stairs	8	5 128,13 €	2 974,26 €	0,00 €	8 102,39 €
G - Ground Slab	3	31 621,75 €	3 072,14 €	0,00 €	34 693,90 €

Name	Element Count	Material Cost	Labor Cost	Equipment Cost	Base Construction Cost
HasConcreteFinish					
Classification	59	10 198,05 €	0,00 €	0,00 €	10 198,05 €
CaseStudyD_SC3	59	10 198,05 €	0,00 €	0,00 €	10 198,05 €
E - Slabs	56	8 144,39 €	0,00 €	0,00 €	8 144,39 €
E.a - 01. FSLB2	16	2 094,04 €	0,00 €	0,00 €	2 094,04 €
E.b - 02. FSLB1	14	1 730,37 €	0,00 €	0,00 €	1 730,37 €
E.c - 03. FSL00	11	1 402,25 €	0,00 €	0,00 €	1 402,25 €
E.d - 04. FSL01	7	1 156,93 €	0,00 €	0,00 €	1 156,93 €
E.e - 05. FSL02	7	1 411,87 €	0,00 €	0,00 €	1 411,87 €
E.f - 06. FSL03	1	348,94 €	0,00 €	0,00 €	348,94 €
G - Ground Slab	3	2 053,65 €	0,00 €	0,00 €	2 053,65 €

Figure 49. Bill of Quantities considering the costs from Subcontractor#3, Case Study D

By comparing the results, the offer from Subcontractor #1 has the lowest cost. Although, by having the information incorporated within the construction model and being able to analyse the complete costs for each scenario, it is also possible to determine the weight the concrete finish activity has in the complete cost of the project, which rounds 1%. Considering that the differences between the offers, as well as the differences with the planned budget, these amounts are small in comparison with the total cost of the project. For the construction programme, this forms part of the information shared to the possible subcontractors, with the objective that they agree to accomplish the times and durations specified in the schedule. This perception can lead a project manager to decide between each option, not by which offer presents the lowest cost, but by considering other factors like previous successful working experiences with a bidding team for example. According to the criteria of the professionals who participated in the interviews for this study, the construction programme should be defined and optimised by the main contractor considering the interaction of all activities. It is not convenient to optimise the duration of an activity independently from other activities because it might not be possible to align the duration of activities, causing waste of resources due to overproduction.

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4. CONCEPTUAL FRAMEWORK FOR BIM-BASED QTO AND BIM ANALYTICS

Based on the information presented in the State of the Art and the experience of developing the Case Studies, this chapter compiles concepts, requirements, and important considerations to take into account when implementing BIM-based QTO processes, mainly for the production of BIM Analytics, which are tailored to support decision-making procedures such as those studied for this thesis investigation and other present in real projects. The chapter is divided in three parts, organizing the information depending on the phase they should be addressed regarding the stages of development of the project, whether if it is before starting the BIM-based QTO, during the quantity extraction and during the development of BIM Analytics.

4.1. Considerations before the Quantity Take-off process

For a correct execution of a BIM-based Quantity Take-off, it is important to consider this use from the beginning of the authoring process of a model, where information is generated. BIM-based QTO requires some principles to be able to structure the information correctly and in a controlled manner. Nowadays, BIM implementation has become more constant throughout the AEC industry, but there are still many cases where some systems are not completely modelled, and part of the project is being produced on a 2D scheme. Then is not possible to quantify these systems through a BIM-based process, recurring to 2D QTO processes which are slower, less accurate and more error-prone. Also, the inclusion of these information into the construction model which is further used for analytics and project control becomes much more limited. Then, it is of great importance to plan the authoring process at the earliest stages of a project, guaranteeing that all systems involved in the asset that must be quantified will be included in the information model. An example can be taken from Case Study B process, in which it was required the measurement of excavation and backfill on the terrain for the different types of foundations. Simple elements that represent this activity were generated in order to perform a proper extraction where volume quantities were adapted for a more accurate estimation.

As noted in the execution of the Case Studies, and a common agreement during the interviews with professionals, the definition of a Work Breakdown Structure is indispensable for Quantity Take-off. This structure will define the organization of the information, and for the intention to apply BIM analytics based on controlled quantities, it must be developed aligned with the Cost Breakdown Structure and the construction schedule. On a BIM-based process all this information is connected, therefore it requires planification before execution. Collaboration among stakeholders is crucial for a correct definition of the structure´s information, that must be approved by the different teams involved to ensure its alignment with the different uses that these data will have throughout the lifecycle of the project. Therefore, it is also important to define the process of collaboration and approval in official documents such as the BIM Execution Plan (BEP), that accordingly to International Standard ISO:19650-2 is ”a document that explains how the information management aspects of the appointment will be carried out by the delivery team” (International Organization for Standardization, 2018).

When the information´s structure is defined, it is also important to define the metadata that elements will contain to allow semantic relations within the information to be grouped according to the Work Breakdown Structure (WBS). The information must be classified aligned with the WBS, therefore the elements must contain information that indicates to which instance of the WBS an element must belong. This definition and organization of metadata is necessary to avoid omission or repetition of quantities during the BIM-based QTO process. One method to accomplish this order is through the implementation of classification standards. As discussed during the interviews with professionals in Section 2.3, the use of standardized classification systems brings advantages around the use of a defined classification, in which stakeholders can understand what the element represents through the definitions contained in the standard. But an important limitation within these standards is the detail that can be accomplished, especially for very specific assets. Nowadays, the complexity of the projects is more demanding, and the detail required to characterize each element is sometimes not fully covered in the use of defined classification standards, reaching limitations when defining codes for specific elements, according to the discussion with professionals based on their experience, presented in section 2.3. For that reason, when intending to implement a classification standard, it is recommended to first study the definitions of the standard in accordance with the level of detail the information will require, to guarantee that the definitions in the standard will cover the required level of detail that elements and systems will have.

Another approach to classify information is through a semantic characterization using the metadata contained in each element. This approach can also be combined with a standard classification, creating a hybrid classification where the higher levels of hierarchy in a classification are defined within a standard, and the more detailed levels will be defined by the users, which will use characteristics defined in the elements´ metadata to group them according to the Work Breakdown Structure. To guide the responsible team to define the classification used in the project it can be consulted the International Standard *ISO 12006-2: Building construction – Organization of information about construction works – Part 2: Framework for classification*. This standard provides a set of recommended classification requirements, as well as some examples of classification tables to guide the user for the definition of the classification system that will be used for the complete life cycle of the project, from the briefing and design to the construction and operation of an asset. It also provides guides to document the classification system using classification tables and how to present the relationships between the different object classes classified in these tables (ISO - International Organization for Standardization, 2015).

Once the classification of elements is set, whether it is by semantical characteristics of the objects or basing on an established classification system, this information must be included within the metadata of each element, to enable the correct grouping and querying of these data and map each element with the WBS. It is also important to communicate which properties will contain the relevant information for each element type. This will allow the user building the structure for QTO to understand how to filter each instance and control the data for a correct connection between the construction model and the WBS. This information can be defined in the Information Delivery Manual, which is a document that describes the processes for information to be required and exchanged in the design, construction, and operation of an asset. The International Standard ISO 29481: Building Information Models – Information delivery manual, is a standard that provides guidance for the creation and management of information, and it is divided in two parts: a first part focused in concepts and definitions through a methodology definition

(ISO - International Organization for Standardization, 2016b), and a second part which is an interaction framework that offers guidance for defining the information that is required in an information model for a proper information management through the BIM implementation (ISO - International Organization for Standardization, 2016a). The use of Product Data Templates to generate Product Data Sheets for each object class is also convenient, where metadata that an object class will contain can be specifically indicated. For the creation of Data Templates for construction objects, the European Standard prEN-17473: *Building information modelling (BIM) - Data templates for construction objects used in the life cycle of any built asset - Data templates based on harmonised technical specifications under the Construction Products Regulation (CPR)* can be consulted (European Commitee for Standardization, 2020). Based on this definition, the construction model, where the elements are mapped to the WBS can be built in a faster, accurate and less error-prone process, because the user building this model can easily understand what properties must be used to classify the elements and to map each element to the correspondent instance in the WBS.

Another important aspect to consider based on the construction strategy, is the division of elements that allow information to be structured with the construction execution phases according to the planned construction process. As discussed during the interviews, it is a good practice to author a BIM model in the same manner as the project is going to be built. This is important to consider mainly in reinforced concrete structures, where the division and geometrical limits of some elements such as slabs and beams is not so clear. This aspect was evidenced also during the execution of Case Study A, where it was necessary to return to the authoring software and modify the height of the columns to divide them according to the division of levels, and the division of concrete slabs and beams, to be able to create a construction schedule aligned with the phases of the construction strategy. Even though some BIM-based QTO software allow the division of elements directly on this type of software, it is better to define the geometry of the elements in the authoring software to maintain a correct order in the identification properties of all elements. Also, the divisions, as well as other modifications done in an analysis software could be lost when the design model is updated, which is a common situation throughout the data lifecycle. Therefore, it is convenient to perform all geometrical modifications in an authoring software. Also, the definition of joints between elements, namely concrete elements must be done in the same manner the real elements are going to be built. Errors in the definition of these types of joints can lead to repetition in volume quantities, where two elements can be clashing in a certain space, or discrepancies in measurements of surface area used to estimate formwork for example.

One of the main challenges that involves what has been previously discussed and a common agreement between the interviewees is the consideration of the construction strategy during early stages of design. Traditional contract systems are based on bidding processes for the election of the main contractor, which in many cases is not known during the majority of the design process. This causes that the models received by the main contractor does not have a proper structure to perform the planned BIM uses, resulting in reworks that in some cases require the repetition of partial or total of the authoring process. Through BIM implementation, other forms of contract and execution of the projects have become more popular, seeking to avoid this lack communication between the different parties during the work stages. One of these forms of contracts discussed during the interviews of this study is the Integrated Project Delivery (IPD). The IPD is defined by the American Institution of Architects as a “project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction" (AIA - American Institute of Architects, 2007). In this manner, specialists in the construction execution can participate since early stages of the design, and the construction strategy can evolve since the beginning of the definition of the project. In comparison with more traditional methodologies, approaches such as IPD represent a modification in the working culture and way of thinking of the leaders involved, so it is not something that happens from one day to another and requires a lot of effort and teamwork to be successful. Still, the improvement of collaboration among stakeholders allowed by collaborative methodologies such as IPD, fosters the correct structure of information required for the design stages, construction process and operation phases of the building, optimising the execution of the project and avoiding reworks during the last stages of development. Furthermore, IPD approaches are aligned with the designation of efforts recommended by MacLeamy in the Effort Curve shown in Figure 7, where smart efforts should be implemented in the early stages of the project where the ability to control the costs is higher and the associated costs of design changes are lower.

4.2. Considerations during the Quantity Take-off process

Based on the experience gained during the execution of the Case Studies, important considerations for a correct BIM-based Quantity take-off were discovered. Practically all the quantities extracted from the model come from element properties, whether they are calculated properties or originated during the authoring process. Therefore, the correct election of this properties and its accuracy becomes indispensable. To ensure the accuracy of quantities, it is recommended to manually test the results of main properties used for quantity extraction, such as lengths, sizes, areas, and volumes. It is possible that an element contains several properties of the same quantity, due to the authoring process or exportation process that a file can suffer. For example, a pipe element could contain multiple properties regarding its size, as well as its length. Therefore, it is important to revise and test the properties that are being considered, to ensure that the measurements reported in the property values are the measurements intended in the quantities. Also, it is required to run property checks to guarantee that all elements from a certain QTO group have the properties used for the quantities, to avoid errors and omissions in the estimation. Additionally, the revision of units is also crucial to avoid errors in the quantifications. Most geometrical properties indicate the units for their values, and still this must be checked to avoid a scale mistake, especially when receiving a BIM model authored by a third party and were authoring protocols are unknown. Additionally, Quality Assurance/Quality Check (QA/QC) must be implemented to ensure correct procedures and proper results. A Quality Compliance Plan must be defined for BIM-based QTO processes, which must be integrated within the BIM project standards, fundamentally on the BIM Execution Plan (BEP).

Moreover, it is important to think with the end in mind when defining the Work Breakdown structure for the Quantity Take-off. Consider that the same structure will be maintained in case of cost estimations and planification of the construction schedule. Therefore, the structure built must allow the organization and grouping of elements throughout all the analytics planned to be performed, to avoid reworks after the Quantity Take-off execution, that might not result in quantity modifications but in the structure of the information. Additionally, the structure must allow the information to update correctly when the model is updated. One of the great advantages of BIM-based QTO is the automatized update of quantities when the model is updated, whether it is because of a change order, a value engineering, or a progress report. But if the structure is not properly configured, these updates might also cause reworks for the correct analysis of quantities.

Once the QTO is done, it is also very important to run completion checks to ensure that all elements are being included in the estimation. These revisions can be performed through a combination of element selection procedures and visual revisions. Using the model viewer of the software, it is possible to hide assigned elements and select the visible elements to understand what elements are being left out of the estimation. This process should also be applied comparing different groups of elements on the QTO defined by the levels of hierarchy of the WBS, to check for repeated elements that could cause duplication of quantities, due to errors in the mapping process of elements.

4.3. Considerations to perform BIM Analytics based on quantity information

The BIM analytics performed in this study are based on the cost estimation and the automatized construction scheduling. Regarding the cost estimation, the correct definition of resources is a very important part of the process. The definition of material, labour and equipment resources should be aligned with the construction strategy, so the analytics generated would be representative for the construction process. An example can be taken from Case Study A, where the labour resources were divided into two resources: “Reinforcement_Labour” and “InhouseWorkforce_Labour”. This was done thinking in a construction strategy that will subcontract the workforce for the reinforcement activities, while the rest of the activities were going to be performed by the same type of labour resource hired directly by the main contractor. This allowed not only to group correctly the costs for these to resources, but also to analyse and level these resources independently, to avoid picks in the number of workers at a certain period of the project.

The definition of the resources should also follow a naming convention. Based on the name of the resource, it could also be possible to group the quantities of each resource. An example could be when having different resources that are related to the activities of a single subcontract. If the naming convention is correctly defined, all the resources that involve a certain contract could be grouped as well for management of that subcontractor. A proper naming convention can also facilitate an automatized process for defining these instances, in cases where it is required to create many resource instances. A clear exemplification can be taken from Case Study C, where the resources for defining costs for the cable trays and cable tray fittings were defined regarding the type of cable tray, and then by its sizes, resulting in a great total amount of resource instances. Through a defined naming convention, it was possible to generate all the instances using concatenating formulas on an excel spreadsheet, and then imported into BEXEL Manager.

The units defined in each resource instance also require a detailed revision. These units must be aligned not only with the units of the correspondent quantities from the QTO, but also must allow a correct update when receiving external information, from recorded progress or from a bidding subcontractor for example, as shown in the case studies. In the case of progress report, the units in the resource instances must match with the reported units from the consumed resources coming from the construction site, to avoid mistakes and reworks. Also, as shown in Case Study D, the possible subcontractors were submitting a price of concrete finish per square meter, so the resource must be able to quantify square meters of concrete finish, as shown back on Figure 45.

For a correct progress tracking of a construction, the communication with the construction site is essential, and must be planned to be analysed properly. It is important to facilitate the mapping process of the consumed resources reported from the construction site to the construction model. This correlation can be done using the codes defined for the WBS and the Cost Breakdown Structure (CBS), which can also be mapped to the construction schedule. As discussed in the interviews, for the consumed material resources a methodology could be to report all the material that is taken from the material storage at the construction site, and every time a material is requested in this station, it must be indicated the activity in which that material will be used according to the structure of the construction schedule. These reports can even contain the codes from the WBS, so they can be automatically mapped for a more efficient procedure. Nevertheless, this procedure requires a lot of control at the construction site to create the reports, as well as organization from the leaders at the field to identify the activities in which the material will be used for. A similar logic can be implemented for the equipment resources, where the control of hours used can be reported using the codes of the activities where the equipment is used. The greatest challenge comes with the report of labour resources mapped to the activities they participate. But nowadays technology allows to track the location of workforce using tracking devices placed on the protection gear of the workers and based on their location on the construction site during certain periods, it can be identified in which activity each worker was participating, as well as record the duration of the activities. Also, more traditional techniques can be implemented such as daily reports of the activities performed and the quantity of workers that performed each activity, which can be more error-prone but does not require an additional investment on the tracking devices and the software to analyse the data. It is important to keep in mind the level of detail of the information that can be reported from the construction site. For example, it becomes too complicated to report the amount of reinforcement that was consumed for a specific element. The reports obtain in the construction site usually correspond to higher levels of hierarchy in the structure of the information, e.g., the amount of reinforcement consumed for the columns of the second level of a building. Therefore, the structure of the information, as well as the procedures to incorporate the received information in the construction model should be able to input information on higher levels of hierarchy, and not only on the most breakdown levels of information.

The importance of reporting the consumed resources is not only for the purpose of registering progress, but also to generate statistics regarding the performance of each resource to be further used for the definition of daily outputs for future projects. As shown in the case studies, these daily outputs can define the duration of the activities, creating a data driven construction schedule. Nowadays, as discussed during the interviews, the quantities required to perform an activity and its duration is mainly based on the experience of construction managers, which are assuming great responsibilities when defining these data. With a correct registration of consumed resources, databases can be generated with resource performances to produce more data driven analytics. When registering this data, it is important to identify characteristics of the work done and the condition of the project, to use these data in similar projects with similar conditions.

Even though BIM analytics tools allow the automatized generation of construction schedules through the definition of zones and methodologies, and automatically setting durations based on daily outputs, it is important to take advantage of the graphical simulations developed when having a construction model linked to these schedules, namely 4D analysis, for a deep revision of the construction process defined in the schedule and a better interpretation of the construction strategy. By studying the 4D simulation, it is possible to find errors and omissions that would be much harder to identify by just analysing Gantt charts and create additional relationships between the activities to correct these issues.

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5. TOOL FOR THE IMPROVEMENT OF DECISION-MAKING FOR THE CONSTRUCTION PHASE

Based on BIM-based quantity extractions, it is possible to analyse several management indicators and scenarios during the construction management of a project, aiming for the use of more efficient, reliable and less error prone information, in order to take more data driven decisions. Nevertheless, as shown in the case studies implemented, the analytics resulted in cost estimations, construction scheduling and 4D/5D analyses. They are not visualized in the same interface, even though all data is linked within the construction model. The clearest example is in Change Management or Value Engineering Case Studies, where information is developed in two different construction models, each one representing a different scenario, and then information needs to be manually arranged for a proper comparison. Hence, it became valuable to develop a tool that could centralize the generated information on a single analytics dashboard view, but still maintaining the connection within the information to improve the comprehension of the results for a more efficient process of interpretation and decision-making.

The development of this tool was done by creating dashboard templates in Power BI, which is an open data analytics software from Microsoft that allows the creation of interactive dashboards and reports. This software was chosen because it is accessible for any Microsoft user that can install the desktop version. Also, for the use of the tool among stakeholders, the created templates can then be easily shared through a link, without the need of additional software licenses. In this manner, data from different sources such as authoring software, BIM-based QTO software and BIM analytics is gathered, centralized, and interconnected in Power BI to create interactive dashboards.

To determine the most relevant information that should be included on the tool in order to optimize the support for decision-making, each case study was discussed during the interviews with the professionals as already explained in section 2.3. During the second part of the interview, discussions were performed to understand how the information should be presented and which data should be shown to improve the decision-making process. The interviewed professionals gave their opinion based on their experience to determine how to compare the scenarios for each case study, as well as identifying most relevant Key Performance Indicators used in each type of decision-making addressed. After developing the tool, a round table with the same professionals was performed to validate the information exposed and seek for opportunities of improvement for each case.

5.1. Configuration of input data into Power BI

5.1.1. Integration of the model viewer

A geometrical visualization of the information is required for a better interpretation of data. Traditionally, redline plans were used to mark changes, but with the integration of BIM, 3D visualization and automatic update of plans when updating a model improved this process, as discussed during the performed interviews in Section 2.3. Also, this is the reason all evaluated software in Section 2.2 include a model viewer on their interface, with different features to study the information. Consequently, it was defined that the developed templates must include a model viewer as well, connected to all reported data to support the comprehension of the results. There are multiple developments to incorporate a visual with a model viewer in Power BI. After some investigation, the visual called 3DBI developed by "KG-dev" was chosen to be used in this tool, because of the ability to focus on an element selected indirectly through another visual, its simplicity to generate multiple model viewer visuals on a single dashboard, and for the obtained student license delivered to support this study. 3DBI can export 3D models directly from Revit, which was the authoring software used in the case studies of this investigation. It generates a JSON database with the geometrical information, as well as tables which include structured metadata from the elements. Then the visual interprets and connects this information to generate an interactive 3D view of the model.

Each element in the model viewer is mapped using the correspondent element ID. 3DBI uses the Revit ID as a first instance for this mapping, which can also be connected to other IDs such as GUID or IFC GUID since they are included among the metadata exported from the models. Therefore, the process to connect the information and results from different sources through the element ID became crucial, starting with the definition of the element ID to be used. A first approach was done using IFC GUID because it does not depend on the authoring software, ergo it is openBIM metadata. It is also constant ID, there is no scenario in which this ID will modify its value, regardless of different export processes. It is also frozen in BEXEL Manager, preventing the modification of this property value. After some tests in the learning process to link data in Power BI, a major issue was found using this ID. This identity value is composed by numbers, uppercase and lowercase letters. In some scenarios, two different elements can present almost the same IFC GUID, with the only distinction that one or more letters change from uppercase to lowercase or vice versa. The problem is encountered when information is integrated in Power BI. This software does not make a distinction between uppercase or lowercase letters, so in the mentioned scenario, both ID values are interpreted as equally, mixing information, and causing errors. For this reason, a decision was made to use Revit ID for the identification of elements. This ID is composed only by numbers, avoiding misinterpretation in Power BI. On the other hand, it is an ID that can only be found in models authored in Autodesk Revit. Also, there are situations where the value of this ID might change, especially when working collaboratively, where multiple modelers are uploading information on a central model. It is important to consider these disadvantages when using this identity to map elements within databases from different software.

5.1.2. Connecting information from different sources

The next step was to understand how to map the information generated in BEXEL Manager to the model viewer in Power BI using the Revit ID. To accomplish this, additional Work Breakdown Structures (WBS) and Cost Breakdown Structures (CBS) were created, adding an additional level, which groups by Revit ID, obtaining correspondent quantities and information specifically for each element. By having the same structure as the WBS and CBS created before the code in each level of hierarchy is the same, enabling to link information using this code. Then it was not necessary to recreate the cost estimations and BoQs with these new structures, because they were only used to connect the information already created with the databases from the model viewer in Power BI.

To export the BIM model into Power BI using 3DBI, the software developer provided a Power BI template that it's configured with the inclusion of a JSON database, as well as the tables containing metadata from the model, and it is only required to configure the location of the exported JSON database from Revit and select the desired metadata to be included in Power BI. But in the case of templates where two different model viewers where required to represent different scenarios, such as in Value Engineering and Change Management, this information was generated and included manually. In the case of the JSON database, it was still generated using the 3DBI export plugin on Revit, then the database was manually imported and mapped into Power BI. In the case of the tables containing metadata, these tables were automatically generated from the BIM model using Dynamo in Revit, which is presented in Appendix 16. A script was developed to extract from the model the following information for each element:

- Element´s Revit ID
- Category name
- Family Type name
- Family Type´s Revit ID

Then this information is tabled in a spreadsheet, maintaining the same structure as the one used in 3DBI template. These tables are then imported into Power BI and relationships are established to link the information.

The definition of relationships within different databases through primary keys was fundamental for correct interconnections between data on the visuals. As mentioned before, the primary key used to connect with the databases from the model viewer was the Revit ID of the elements, but not all databases had this level of detail, namely databases containing costs, and execution dates of the activities. It was fundamental to obtain one-to-one or one-to-many relationships between databases, to avoid an incorrect grouping of data on the dashboards. Therefore, multiple primary keys were defined, which guaranteed no repetition in at least one within each pair of databases connected. Activity codes were used in various cases to connect cost and schedule information, but considering that the projects were divided in phases, most activities were executed in two or three different moments during the construction simulation, ergo the activity codes were not entirely unique. This situation was solved by a controlled manipulation of the tabled data, with functions such as concatenate, allowing to unify data from two different columns into one single column, e.g., activity code and construction phase. Through this combination, it was possible to obtain primary keys with no repetition throughout the tables, permitting the connection of databases with one-to-one or one-to-many relationships. Other controlled manipulations of data were done through commands that merged or appended different tables, to combine data within one table to be able to create a single visual that enclosed data from two different sources.

5.2. Progress Tracking: preparation of template and results

For the presentation of the information and results regarding the Progress Tracking case study, two templates were developed, mainly with information from the authoring software for the model viewer, the Bill of Quantities, and data from the construction schedule for both planned and actual scenarios. Figure 50 shows the arrangement and connection within the databases containing all relevant information, and its description correspond as follows:

a. Model viewer information: tabled data and JSON database containing the geometrical and metadata for the creation of the model viewer. Is linked to other databases using the Revit ID as primary key.
b. Quantities, costs, and schedule for actual scenario: Tabled information obtained from the QTO, CBS and construction schedule containing the progress report from BEXEL Manager. It contains the actual costs and dates of activities, as well as breakdown costs of labour and

material resources. The primary key used to connect data was a Task ID, which is an ID generated in BEXEL Manager for the identification of each task in the construction schedule.

c. Quantities, costs, and schedule for planned scenario: Same information extracted from BEXEL Manager described in (b) but for the planned scenario. The Task ID was used as primary key as well.
d. Element properties: properties of elements created and extracted from BEXEL Manager to represent different groupings defined in this software, such as correct levels, element categories, and construction phases. The Revit ID was used as primary key for the connection of this information.
e. Connection between activities and elements ID: Tabled database extracted from BEXEL Manager by the creation of additional WBS with the added level containing the Revit ID. Through this database it was possible to determine the activity code for each element, thus connecting the activities with the model viewer.
f. Planned vs. Actual information: Tabled data created from the merge and append of cost and schedule information from the planned and actual scenarios, to obtain comparisons like cost differences, activity status (e.g., on time or delayed). It is linked using the Task ID and code-phase concatenation as primary key.

Once the information is correctly organized, different visuals are created to present the information. As mentioned before, for this case study the information is presented in two templates. The first template presents the main information to understand the project and evaluate the construction progress. It includes the model viewer which is interactive depending on the selection of the information in the dashboard. The colour code of the model viewer is configured to identify elements that are built, which are included in the progress report, and elements that are still planned to be constructed. Also, slicers were included to filter the model according to properties, such as element categories, levels, and construction phases, as well as the status of the activities. Then, a matrix with the same structure used in the WBS and CBS presents the costs and finish dates for each activity, according to the correspondent scenario. Next to the matrix, a graph shows the total costs grouped by activity types. Finally, on the right main values are showed, indicating the latest date of progress report, total costs for both scenarios as well as the cost difference, and the earned value cost used as a key performance indicator, which was agreed along the performed interviews for this study that is the most common used KPI to evaluate construction progress. Figure 51 presents the complete first template for Progress Tracking, while Figure 52 and Figure 53 presents the template filtering some information to show the interaction of the information with the filters.

The second template is focused on resource quantities and costs, as well as cash flows using S-curves graphics. On the top, graphs present the cost of material and labour resources together with the quantities. All graphs are arranged to show comparison between the two scenarios, maintaining the same colour code in all visuals. On the bottom, S-curve graphs are presented using the accumulated total costs, material costs and labour costs. Some slicers were also included to filter the information among element categories and completion status. The complete template is showed in Figure 54, while Figure 55 present the information filtering only foundations, columns and walls that are already built, showing also that the S-curve graphs display the accumulated costs for both scenarios when placing the pointer over the curve. Larger images for these figures are presented in Appendix 12.

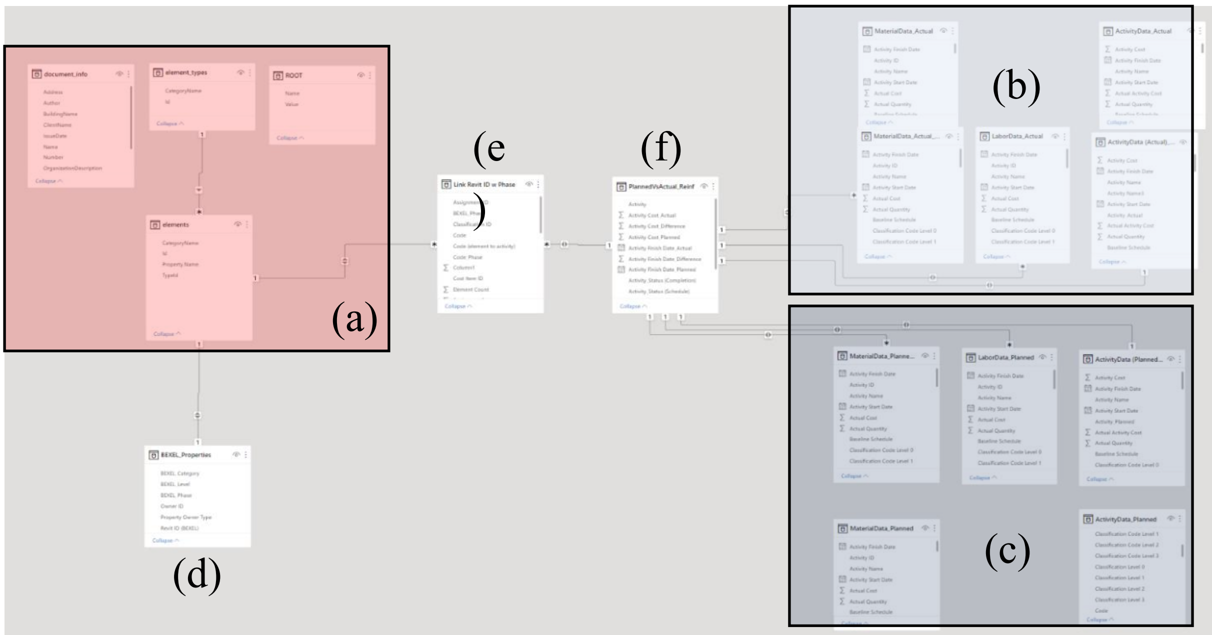

Figure 50. Connection of databases for the Progress Tracking dashboards

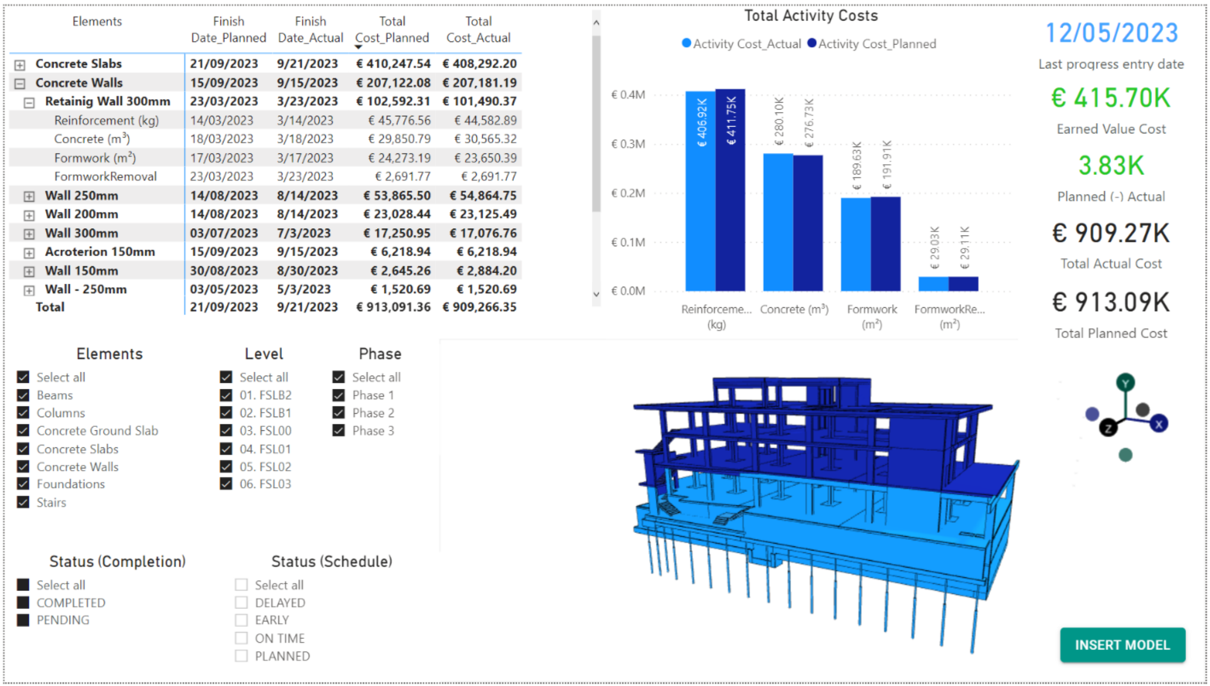

Figure 51. Template #1 for Progress Tracking with no filters applied.

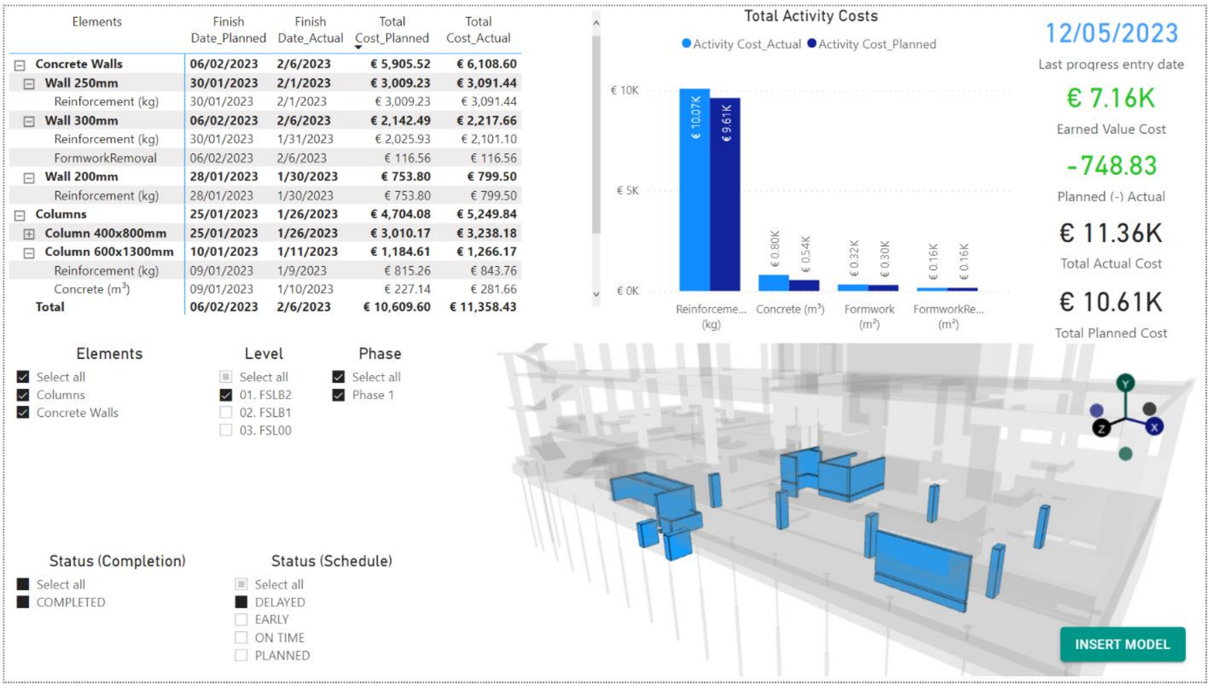

Figure 52. Template #1 for Progress Tracking, filtering the delayed elements on the first level

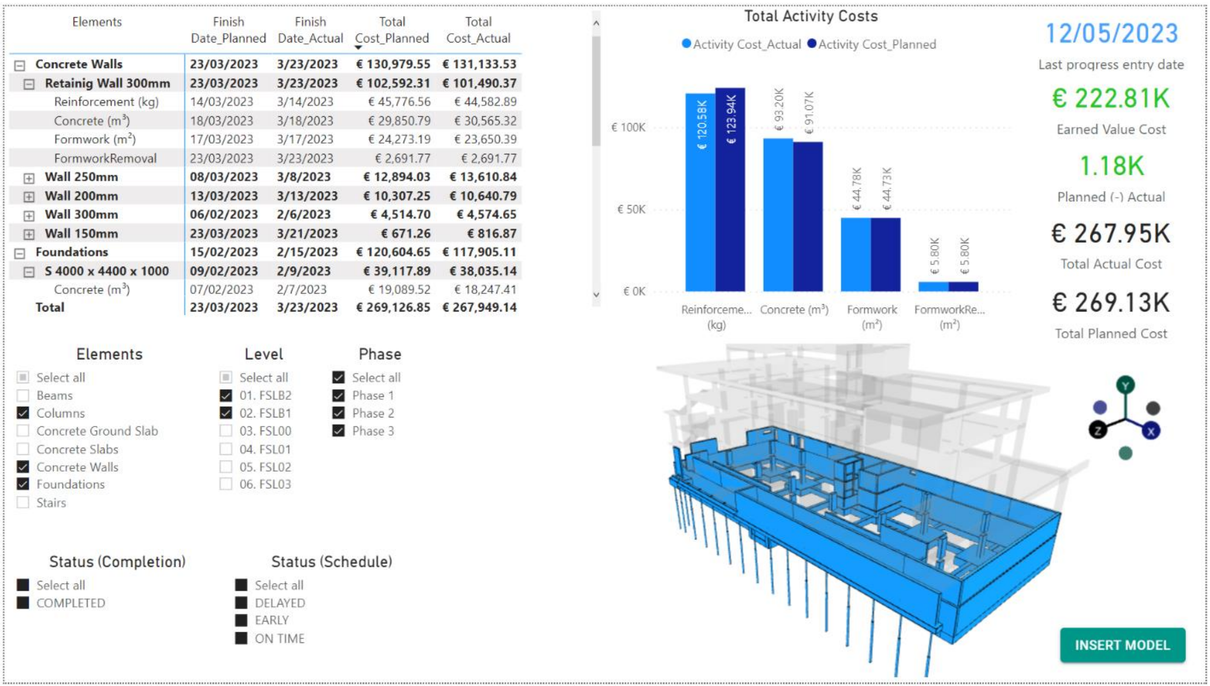

Figure 53. Template #1 for Progress Tracking, filtering foundations, walls, and columns located in the first two levels.

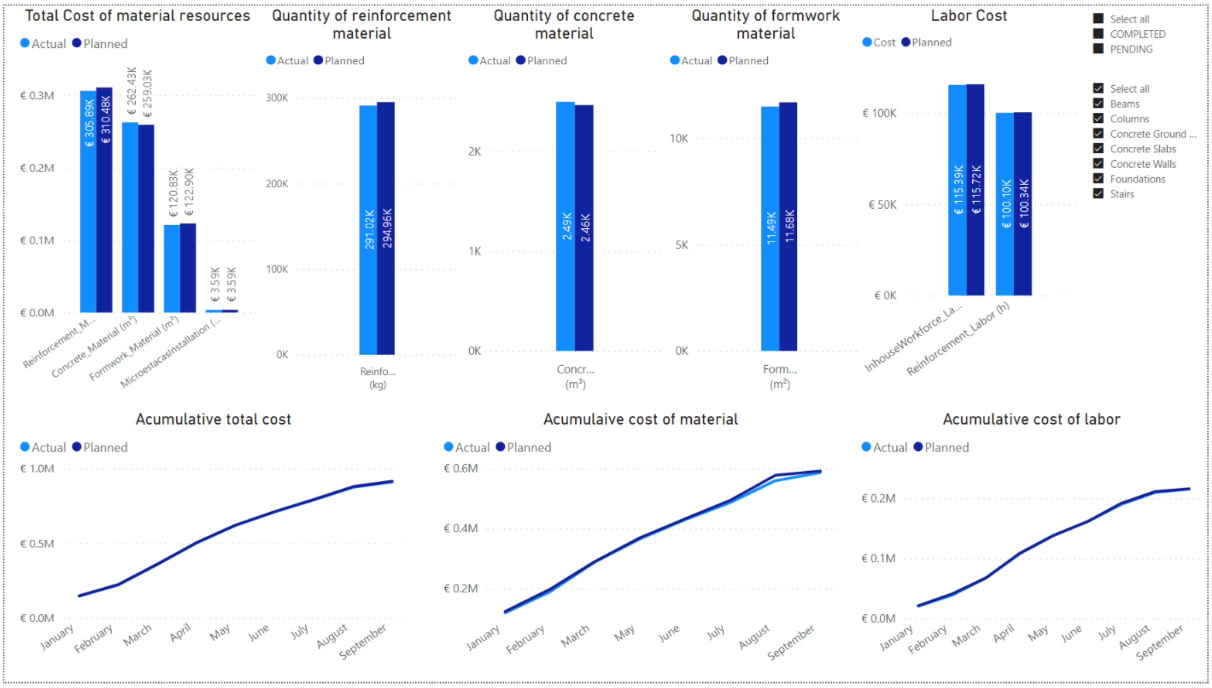

Figure 54. Template #2 for Progress Tracking with no filters applied.

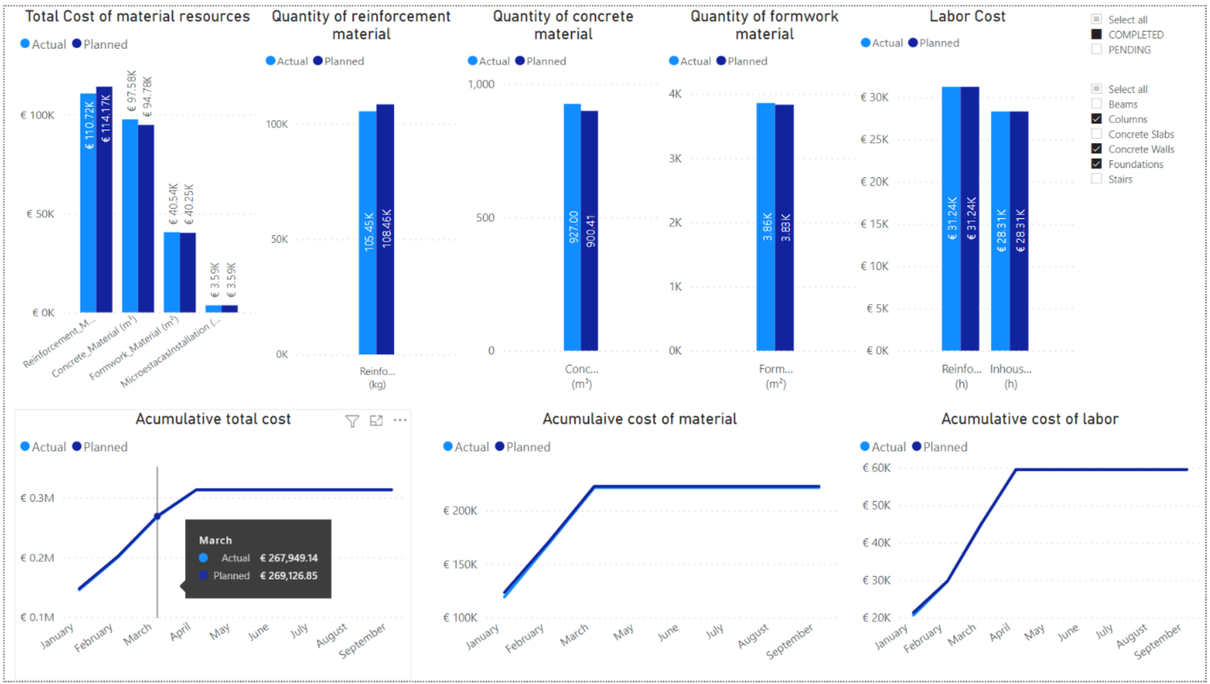

Figure 55. Template #2 for Progress Tracking, filtered by foundations walls and columns that are already built.

5.3. Value Engineering: preparation of template and results

In the case study focused on Value Engineering, the results are centralized in two templates. Information for the model viewer was obtained from Revit authoring software, while quantities, cost and schedule data were obtained from the construction model in BEXEL Manager, shown in section 3.2. In this case, since both analysed scenarios correspond to two different models, the 3D visualization for the template includes two model viewers. In this case, to generate the tabled databases containing metadata for the model viewer, a Dynamo script was used to extract and organize the information from the BIM model in Revit. Figure 56 presents the connection of all databases used to create the dashboards, and its description is as follows:

a. Model viewer information for original design: Geometrical mesh and metadata for the 3D viewer of the model representing the original scenario. Revit ID is used as primary key.
b. Model viewer information for value engineering: information required for the model viewer visual containing the 3D model from the value engineering scenario. The tabled databases were generated using the created Dynamo script on Revit.
c. Quantities, costs, and schedule information for the original design: Information obtained from the Cost Breakdown Structure and the construction schedule developed in BEXEL Manager, for the original design scenario. To obtain primary keys, activity codes were concatenated with Task IDs to connect material, labour, and equipment data; also, activity codes, phases and levels were concatenated to map activity data with the Revit IDs to be furthermore connected with the model viewer databases.
d. Quantities, costs, and schedule information for value engineering: Same structure of information described in (c) but from the model representing the VE scenario.
e. Connection between quantity information and model viewer: A combination of data through append commands was done for the connection between quantity, cost, and schedule information and the information that generates the model viewer, to have a single source of this connection and avoid redundance within the relationships among databases.
f. Merged properties: Since the information is extracted from two different BIM models, some properties are present only in one of the sources. Therefore, some databases were generated through merging and appending other databases from the two models to create a single source and be able to create visuals that contained all the properties from both models.
g. Colour code: Both model viewers in the template are colour coded according to element categories. This database was created to guarantee the same selection of colours for the two viewers.

Similar to the structure in Progress Tracking tool, the first template for this case presents the information to understand and perform a general comparison between both scenarios, while the second template presents more granular information regarding costs and quantities divided by type of resource and type of activity, as well as accumulated costs. As shown in Figure 57, both model viewers are included here, as well as slicers to filter the information according to common properties. Also, a structured matrix presents costs and finished dates for every instance in both scenarios. Circular graphs are included to present total costs depending on type of resource. Figure 58 presents the template with applied filters regarding the difference in the foundation system and Figure 59 shows the result of selecting a single column in one of the model viewers. Figure 60 presents the result for the second template and Figure 61 shows this template with applied filters according to element categories for the first level.

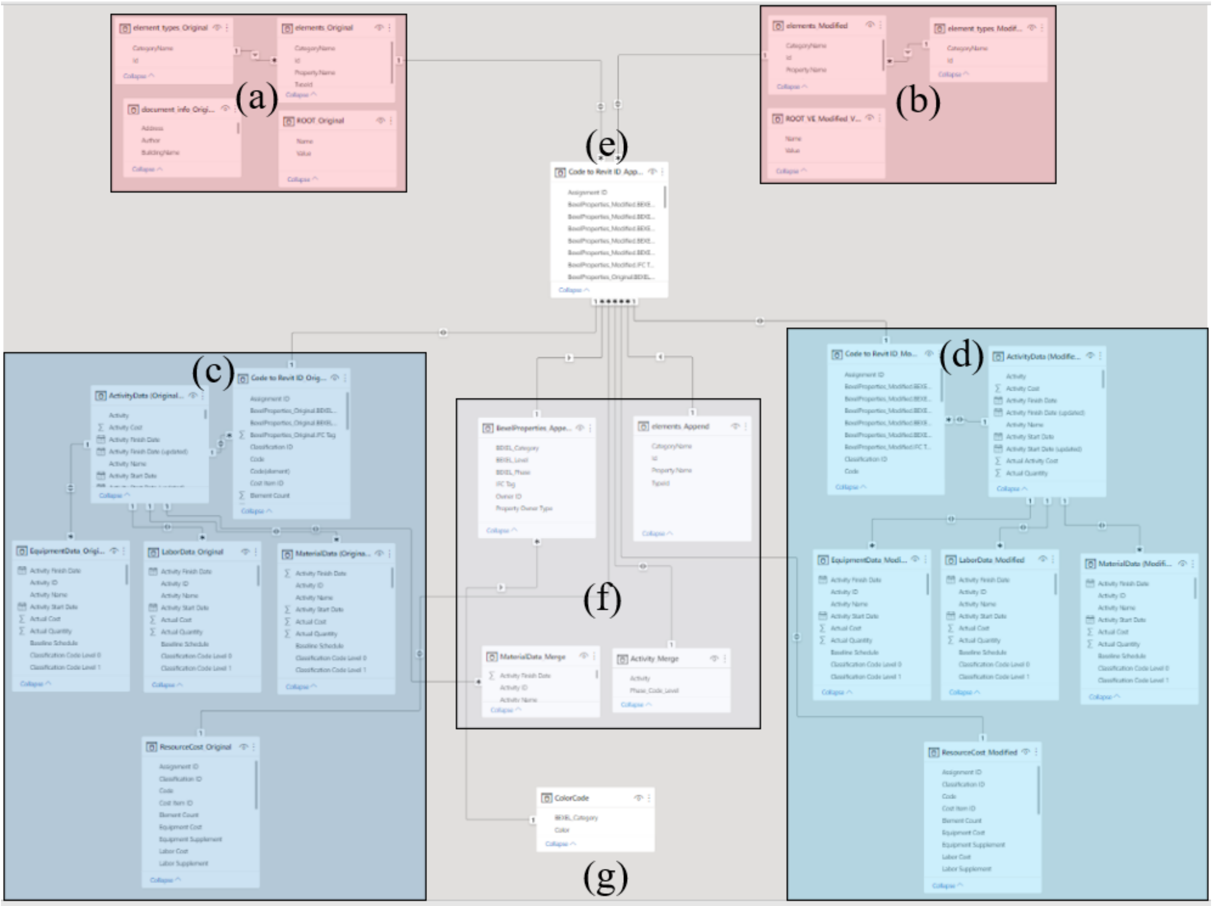

Figure 56. Distribution of databases for templates of Value Engineering

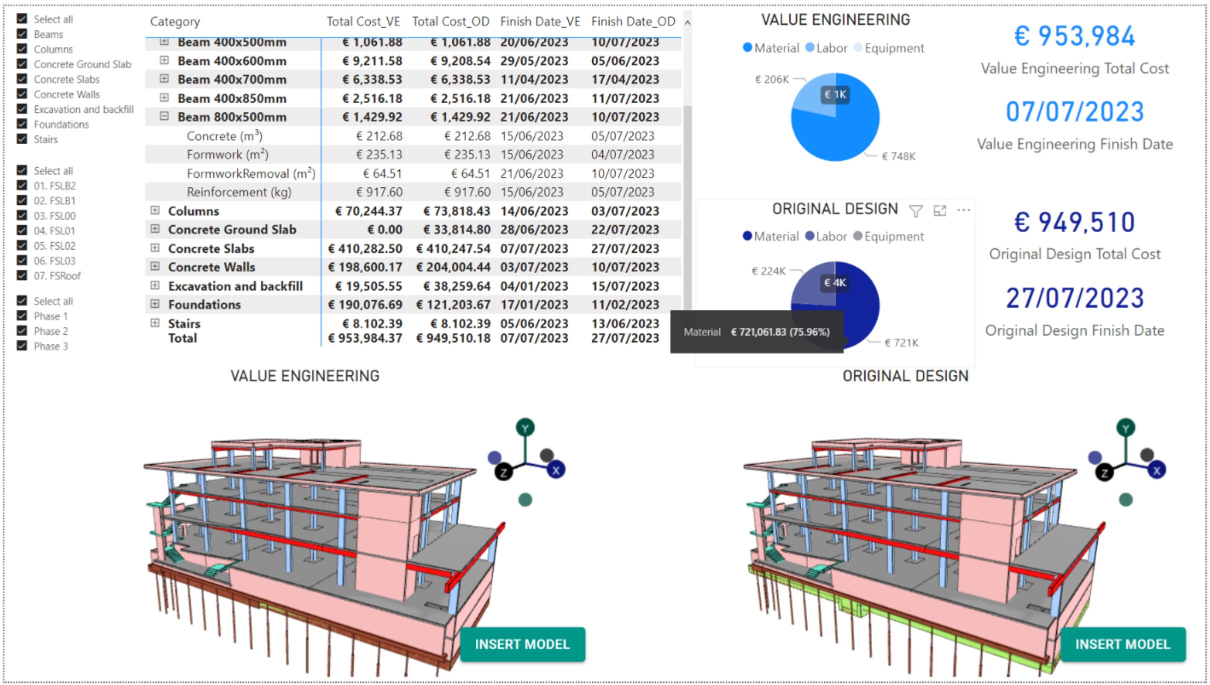

Figure 57. Template #1 for Value Engineering with no filters applied.

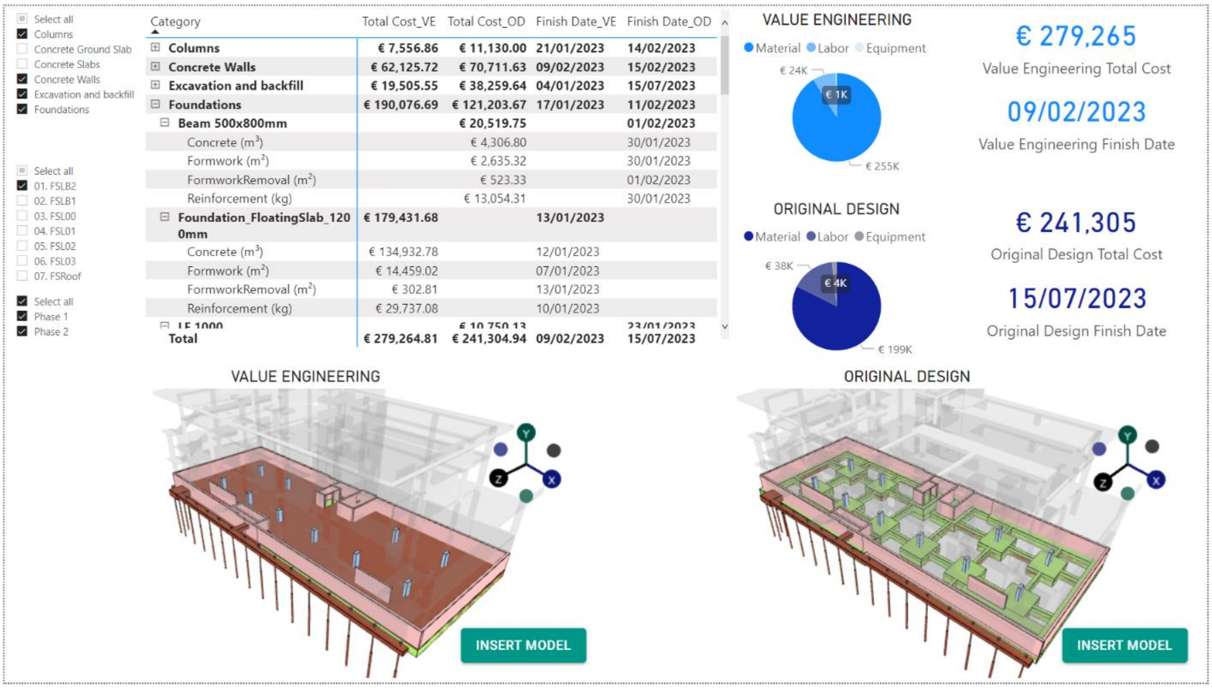

Figure 58. Template #1 for Value Engineering filtered by columns, walls, foundations, excavation and fill only on the first level

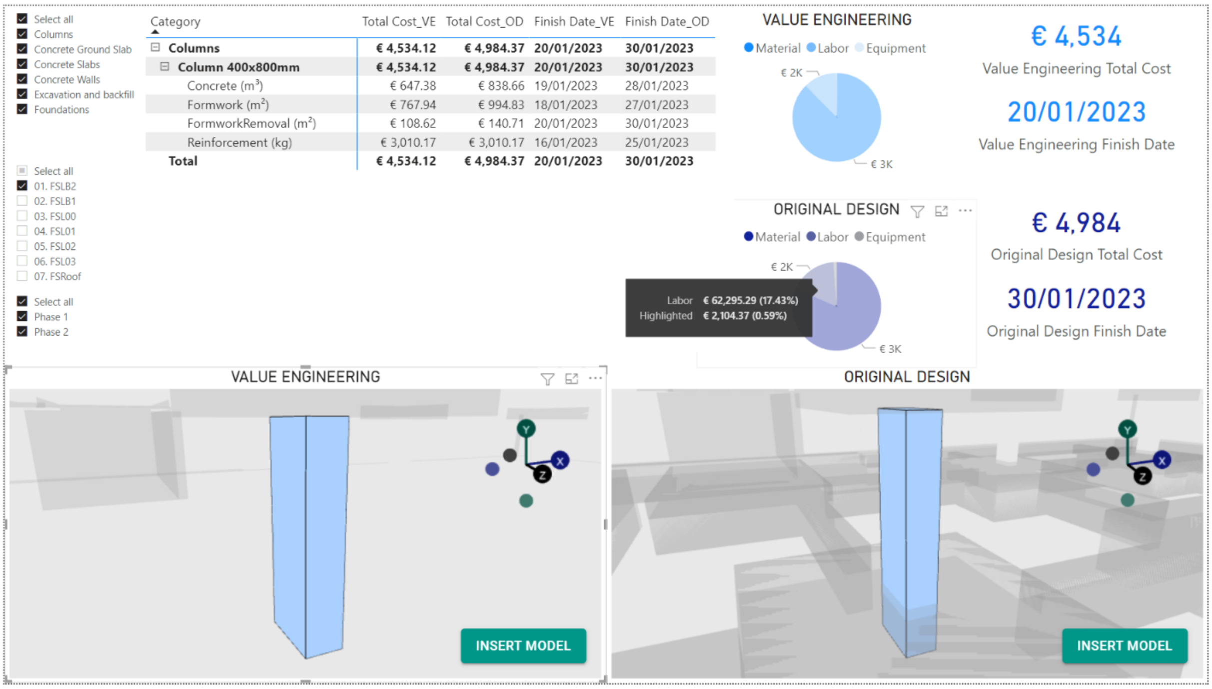

Figure 59. Template #1 for Value Engineering filtered on a specific column.

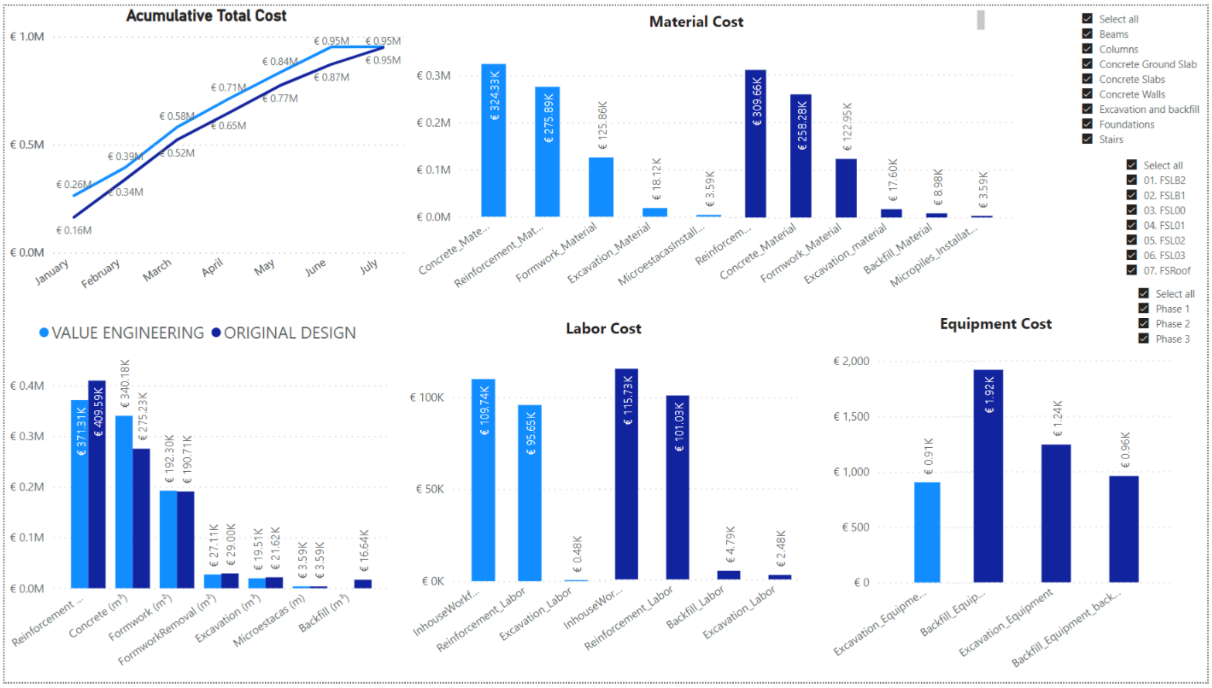

Figure 60. Template #2 for Value Engineering with no filters applied

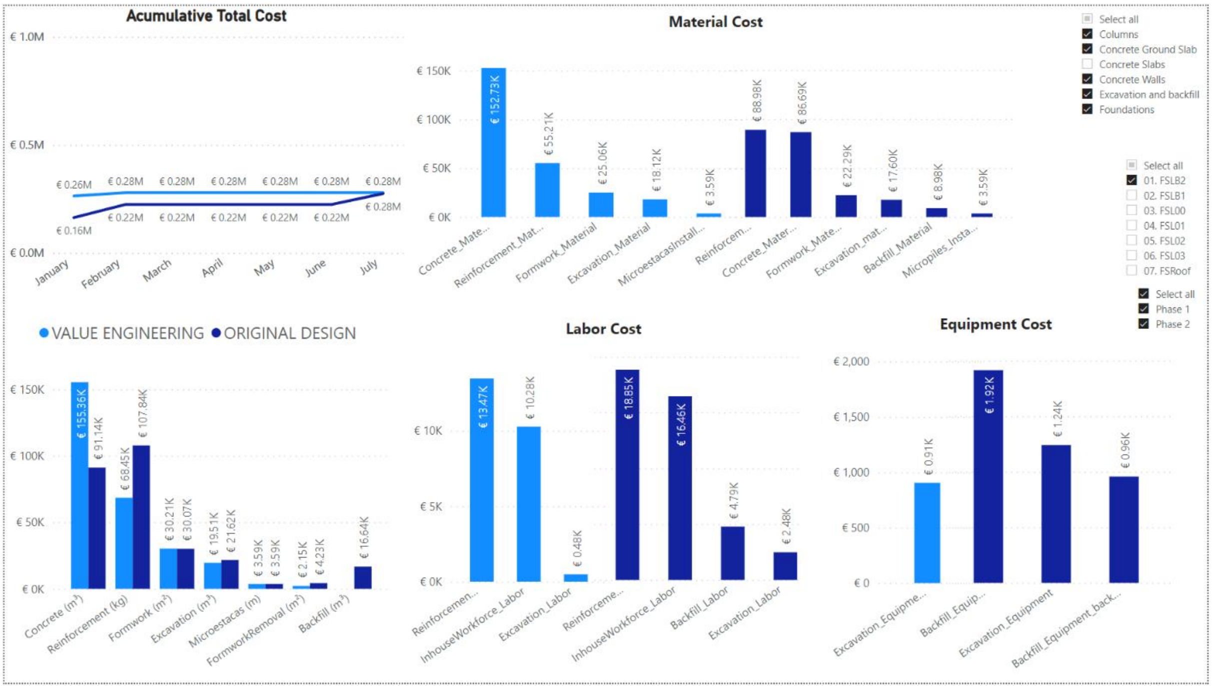

Figure 61. Template #2 for Value Engineering filtered by columns, ground slab, walls, foundation, excavation and fill only on the first level

5.4. Change Management: preparation of template and results

Aligned with the development of Case Study C, the Change Management tool for analysing results is focused on centralizing the cost information for cost comparison and assessment of a change order. The dashboards for this case are developed in one template, presenting the cost estimation for both scenarios: original design, and the as-built design subject to the approval of the change order. Similar to the Power BI templates for Value Engineering, the information for Change Management is obtained from two different models, requiring the unification of data through merging and appending manipulations to guarantee the correct interaction within the different visuals. The diagram presented in Figure 62 explains the organization and relationships between databases, which explanation is as follows:

a. Model viewer, original design: Tabled metadata and JSON database containing data to generate the geometry of the elements for the model viewer for the original design. Analogous to the organization of these data for the previous templates, the Revit IDs of the elements were used as primary key to link these databases with the other information.
b. Model viewer, as-built scenario: Same type of information and connections as in (a), but for the model viewer of the as-built scenario. The tabled metadata in this case was extracted using a Dynamo script on Autodesk Revit.
c. Quantities and costs for as-built design: Tabled data containing the quantities and cost for cable trays and cable tray fittings for the modified design, obtained from BEXEL Manager. The information used as primary key in this case is the Revit ID, which is labelled as IFC Tag property in the construction model.
d. Quantities and costs for original design: Same structure of information as in (c) but containing data of cable trays and cable tray fittings for the original design.
e. Unified information: databases created by the union of the information from the two scenarios, to be able to unify information such as family types and elements for common visuals, to guarantee a correct interaction of the dashboards when filtering information through this visual.

Once the information was organized, the multiple visuals that conform the template were created. As shown in Figure 63, and in accordance with the organization of the databases, this template includes to model viewers, one for each scenario. Also, slicers that allow to filter information by category and by level. A matrix with the same hierarchical structure as the CBS of the case study shows the quantities and costs for the two scenarios, and bar graphics allow to analyse the cost depending on the two types of resources defined: labour and material resources. At the top right, cards show the total costs for each scenario, and the cost difference which represents the total cost of the change order when no filters are applied. The information on the dashboards changes accordingly when filters are applied, as shown in Figure 64, where information is filtered to show quantities and costs corresponding only to the first three levels, where the majority of changes in the architectural functional layout distribution were located. Enlarged images for these figures are presented in Appendix 14.

Figure 62. Distribution of databases for Change Management dashboards

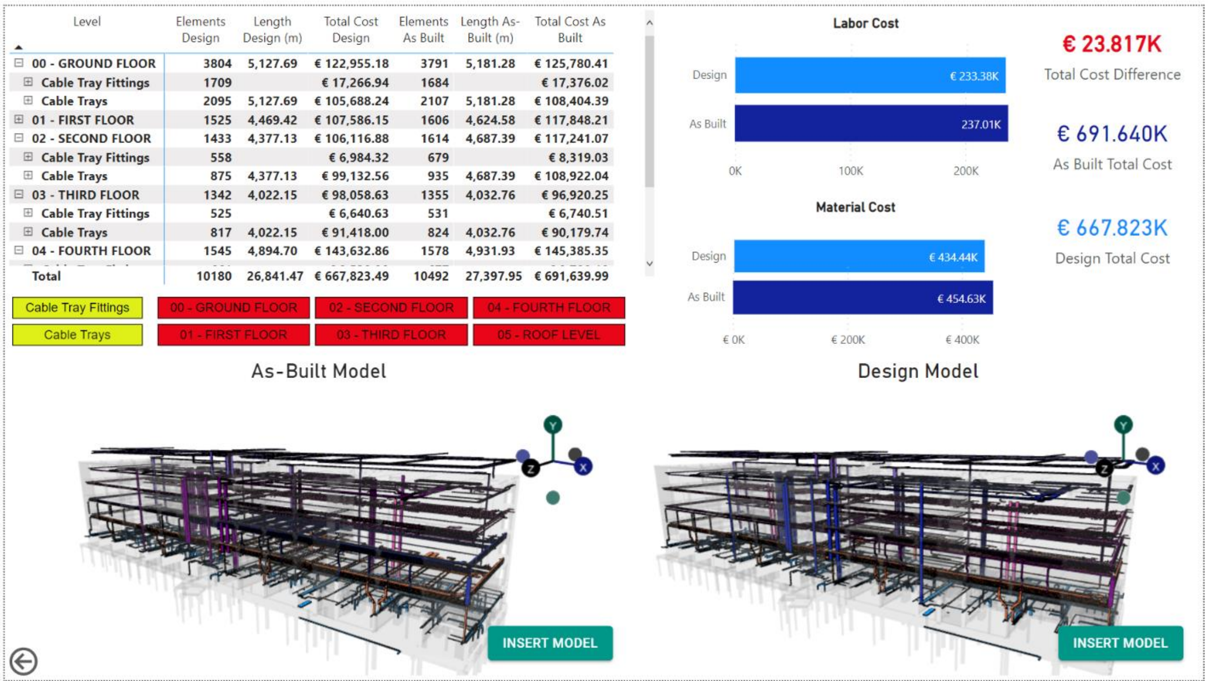

Figure 63. Template for Change Management with no filters applied.

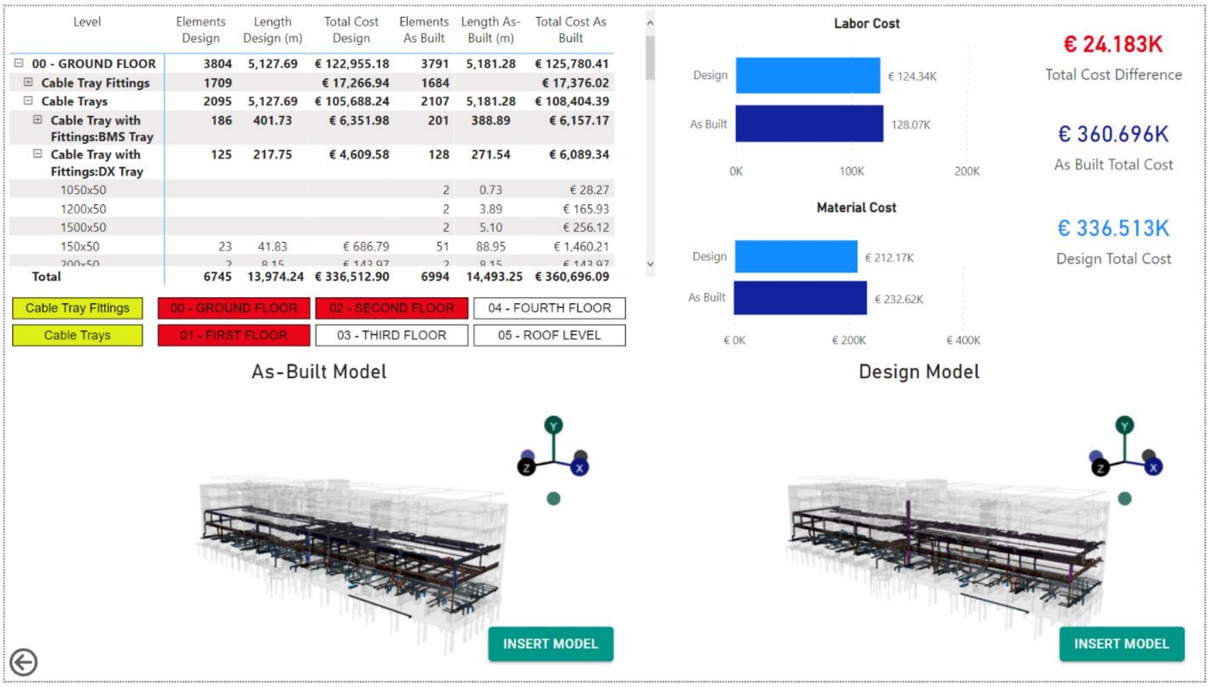

Figure 64. Template for Change Management template, presenting the information corresponding only to the first three levels.

5.5. E-Procurement: preparation of template and results

The E-Procurement template, more specifically focused on the election of a specific subcontractor among multiple bidders, was created with the objective to allow a complete cost comparison within the offers and considering the cost estimated for the planned budget. For the creation of the visuals, data was extracted from the authoring software as input for the model viewer, and from the construction model containing several Cost Breakdown Structures to represent all the scenarios, as explained in Section 3.4. The arrangement of multiple databases for this template is presented in Figure 65, and its explanation is as follows:

a. Information for the model viewer: Databases used as input for the model viewer visual. The Revit ID of the elements were used as primary keys to set relationships with other databases.
b. Quantity and cost information: Databases extracted from results obtained in BEXEL Manager, representing the costs and quantities for each scenario.
c. Unified information: Tables created by the combination of information from different scenarios, to create a single source that contained common properties, such as levels, construction phases, and finish types of concrete.
d. Connection between activities and elements: A database created for the connection between the activities containing the quantity and cost information of each scenario, and the elements identifications for a correct interaction with the model viewer. This database was connected to the information explained in (b) and (c) with a concatenated property joining the activity code and the construction phase. Also, it contains the elements IDs corresponding to each activity to be linked with the information for the model viewer.

When all the information was organized in Power BI, interactive visuals were created to present the results. As shown in Figure 66, the template includes a model viewer with a colour code to reference the two types of concrete finish for the slabs. Slicers were included to filter the information by level, construction phase, element category, activity type and concrete finish type for the slabs. Also, a bar graph compares the total costs for each scenario including the planned budget and the offers from three different subcontractors. Then, a matrix with the structure of the CBS presents the costs for these scenarios. In this case, quantities are not included because they are the same for all scenarios, since the main contractor provided the quantities to the shortlisted subcontractors to get comparable offers. On the right, cards with total costs and unit costs are organized to compare each offer. Also, a space was left to include characteristics for each subcontractor that cannot be quantified but could have great impact on the decision. In this case, previous experiences for each subcontractor were written as an example. Information can also be filtered for a better comprehension of the cost estimations. Figure 67 shows the template filtered by the concrete finish activity, which represents the total costs of the offers made by each bidder.

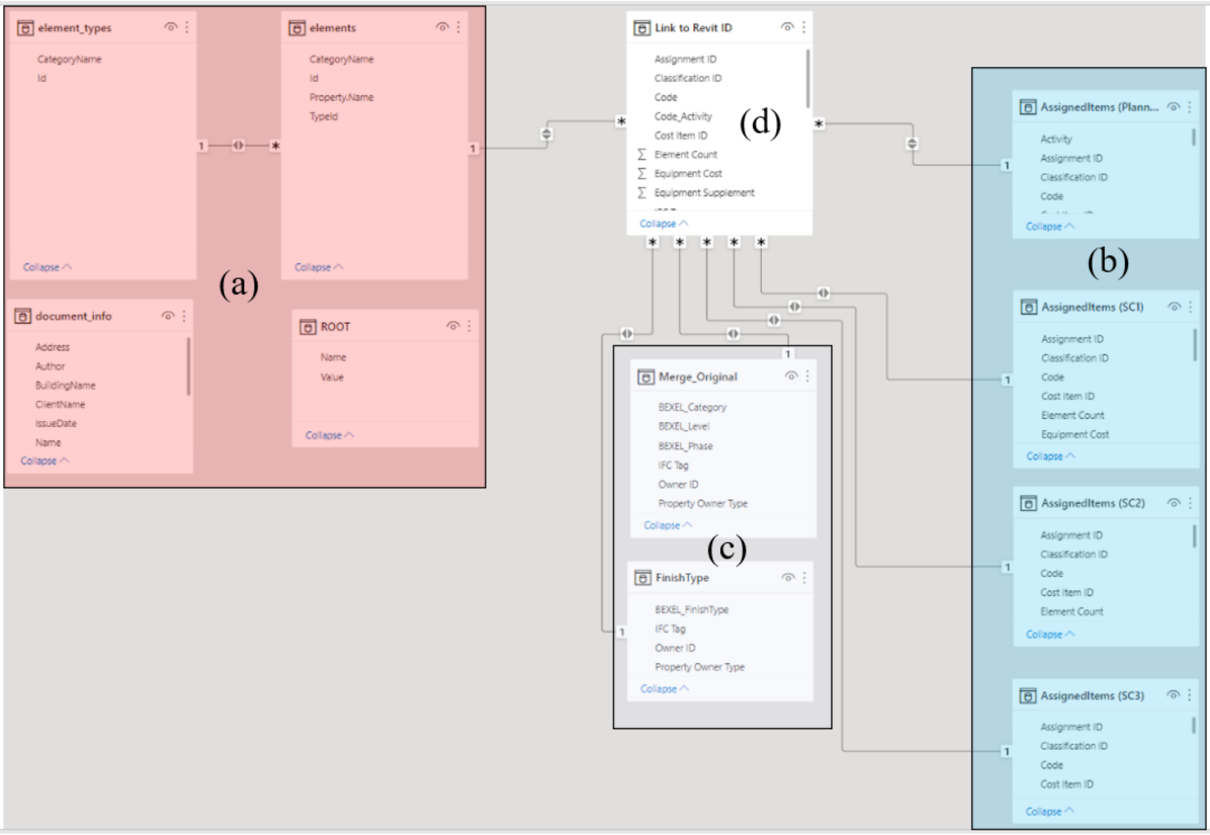

Figure 65. Distribution of databases for E-Procurement template

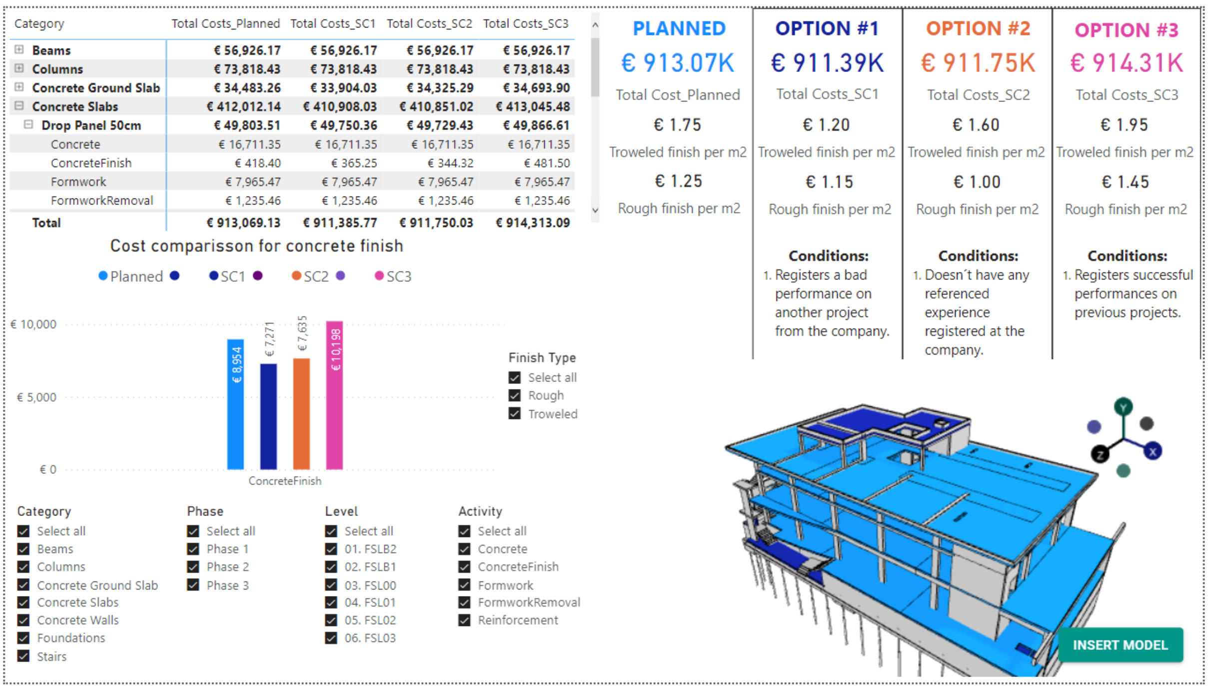

Figure 66. Template for E-Procurement with no filters applied

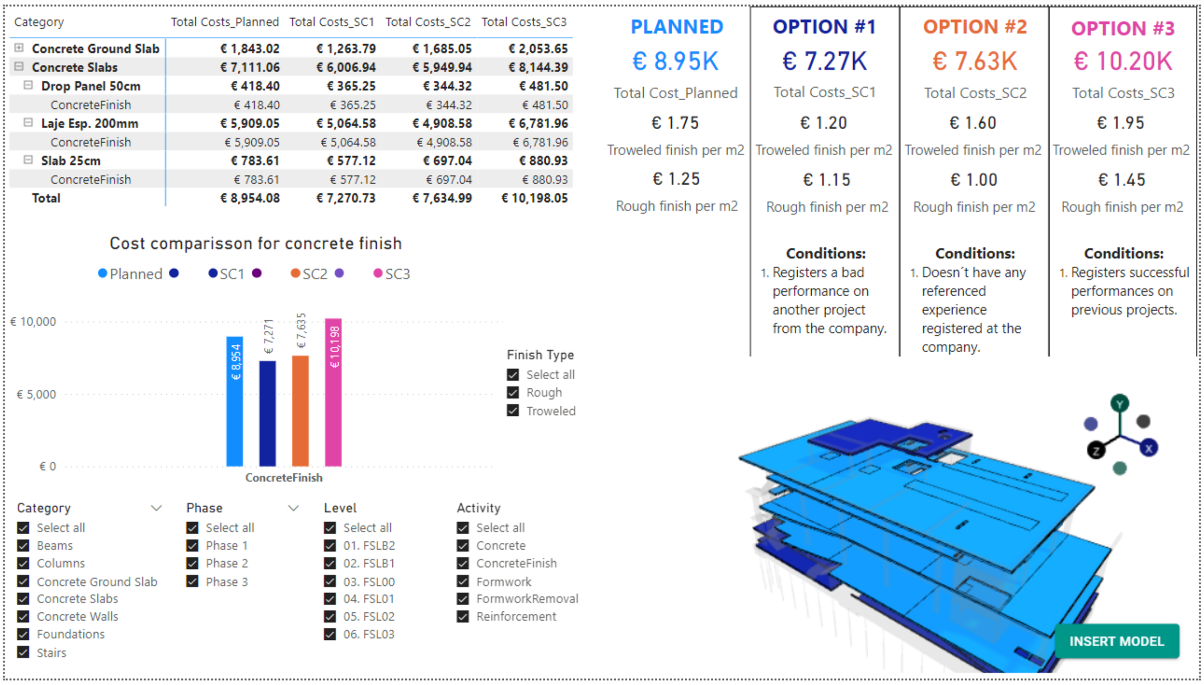

Figure 67. Template for E-Procurement filtered by the concrete finish activity

5.6. Validation of the Tool: Round Table with interviewed professionals

When the tools for each type of decision-making addressed were finished, a round table was done with the five professionals who participated in the interviews and guided the required information to be included in the template dashboards. During this meeting, each participant gave their professional opinion about the information exposed and how the data was presented. Valuable discussions took place regarding the importance of the developed tool for the AEC Industry nowadays, and the potential it possesses to guide the decision-making process. Also, future developments were advocated that can succeed based on the methodology used to construct the presented tool, and how information in the Design, Construction, and Operation of assets should be generated to feed and compose the proposed developments. Minor adjustments for the dashboards were suggested and corrected afterwards. At the end, all the participants extended their satisfaction with the development and agreed on the results. It is important to underline that this study was developed in collaboration with a company *BIMMS – BIM Management Solutions*, and the leaders of the company, which many of them participated as interviewees, expressed their approval with the results accomplished and the tools developed.

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6. CONCLUSIONS

Quantity information is a key aspect to connect the technical solution from the design to the construction strategy and cost management. Through BIM implementation, using BIM-based Quantity Take-off as a basis, it is possible to improve the Construction Management together with Project Management, and to take decisions throughout the lifecycle of a project more data-driven and aiming to optimise the results of these decisions. Even though during the last decade the modelled-based QTO has gain popularity as an applied BIM use, there is still lack of standardisation for the execution of the process and for the generation of the structured information required as the main input for a complete construction model. This study accomplished to identify the main challenges encountered in the structuration of information models intended for BIM-based QTO and to frame the main considerations and requirements that can be used as guidelines to improve the development of construction models. Furthermore, the development of an assessment tool based on quantity extraction was achieved, which is a valuable tool that can be implemented to support decision-making processes and assist stake holders to improve business intelligence and take more data-driven decisions.

Through a literature review, main concepts were centralized, as well as main challenges exposed by several authors to aid the study of modelled-based quantity extraction. Moreover, existing initiatives for standardisation of the process were presented which are still only local initiatives, from where it is possible to conclude the need for global initiatives that aim to standardise the structuration of the information requirements and the execution processes to improve the collaboration and results for this subject. For a more technical analysis, several software developed for BIM-based QTO and perform BIM analytics based on quantity information were studied, to provide a better comprehension of the solutions offered within the software available in the market. Additionally, an evaluation tool was developed to assist teams that are searching for software to implement these BIM uses, to guide them with proposed criteria for the evaluation of software and finally to be able to quantify the performance of each software for the different criteria for a better comparison and election of the software.

The conceptualisation developed in this study is supported by the experience and criteria of professionals who participated throughout interviews and round tables. On these they provide their knowledge and professional opinion about the optimal solutions for challenges encountered nowadays around quantity extraction helping to determine how decisions taken can be more data-driven to achieve optimal results. The election of the interviewees was done considering their experience to encompass different fields within the AEC Industry: Design Manager, Information Manager, Preconstruction Manager, and Industry Regulator. All the elected professionals have been involved in decision-making processes for different types of projects and in different stages of the lifecycle of the project. Moreover, all elected professionals have a background in BIM, whether with experience directly in the execution of BIM uses or working together with BIM specialists, which gives them a proper knowledge to understand how digitalisation can improve decision-making processes through BIM Implementation.

With a proper construction model that connects the quantity information with the technical solution, it is possible to link the engineering design with the construction strategy and use this model to generate analytics that will enhance the control and management of projects. Within this model, it is possible to create automatised cost structures that will provide stakeholders with a better comprehension and management of the costs associated with production but also to automatically update the cost information when incorporating changes on the technical solution to analyse the impact of these changes. Construction programming process can be improved by the automation of the generation of construction schedules, resulting in more complete and accurate construction programmes in which the duration of activities is based on statistics from resource performances and avoiding omission or repetition of activities. With the linked structures of cost estimation and construction scheduling with the construction model it is possible to generate 4D/5D simulations that allow a better comprehension and analysis of the construction strategy, improvement in cashflow management and optimisation of delay analysis.

The structure of the information in a BIM model is fundamental for a proper modelled-based quantity extraction. All instances contained in a model must be identified according to two aspects: classification and unique identification. The classification system will allow a correct organization and grouping of the information for the quantity extraction. The foundation for the classification system must be the Work Breakdown Structure and the levels of hierarchy defined in this structure. There are standardised classification systems such as Uniformat, Uniclass or Masterformat which can be implemented as classification systems and will bring benefits to the structuration of the information. Nevertheless, the implemented classification system must guarantee an alignment with the levels of hierarchy and the level of detail of the WBS. The standardisation of the structure of the information aligned with the WBS will also allow the generation of statistics that can be further used for future projects with similar characteristics. Regarding the unique identification of elements and instances on a BIM model, this identification is done using different elements´ ID´s that may vary depending on the authoring software. This identification is used to connect the information within different databases on different platforms, e.g., information from the authoring software with the BIM-based QTO software and then with assessment tools. It is important to verify that constancy of these identification values along different platforms despite export processes, as well as the accessibility of this information within the different platforms implemented.

One of the main challenges found to implement a proper information structure that allows standardised and controlled quantity extraction processes, is the incorporation of the construction strategy into early stages of the design where information is authored. According to the professional criteria of the interviewees who participated in this study, this challenge requires a high level of collaboration and transparency of information which nowadays is not accomplished in most projects, and which requires changes in the manner of how business is done among the industry and how information is shared. One solution proposed to overcome this challenge is through collaborative methodologies, namely Integrated Project Delivery, which allows the integration of professionals with expertise in different stages of development of a project to interact and participate throughout all the lifecycle of the project.

Throughout the development of this study, it was achieved the creation of an assessment tool to assist stakeholders to better comprehend the variables involved in decision-making processes and to make more data driven decisions based on quantity information for four types of decisions: Progress Tracking, Value Engineering, Change Management and E-Procurement. This tool allows to gather, centralise, and present interactive information using visual dashboards that allow an interactive and user-friendly analysis of the information and was developed in an open format to enhance collaboration. The information included in the templates and dashboards that conform the tool were defined based on the professional opinion of the interviewees who participated in this study, and the final result of the assessment tool were approved by these professionals, as well as by the leaders of BIMMS – BIM Management Solutions, the company that participated as partner in collaboration with the development of this study.

Based on the methodologies and ideas created with the development of the assessment tool presented in this study, further developments are suggested as a continuance of this study, as follows:

- The incorporation of Risk Management and Risk Analyses for the different scenarios studied. Based on statistics and simulation of the design options, it could be possible to rate the risk associated to the option and eventually indicate a success rate. This will optimise the analyses of design options for Value Engineering and Change Management, as well as incorporating Risk Analysis to the election of a subcontractor.
- The development of a tool incorporated within the BIM-based QTO software for the assessment of indirect costs, that allows the calculation of costs and duration of activities relying on the duration and execution of other activities. In this manner, when design changes and progress reports are incorporated to the construction model, the indirect cost and durations of these activities will automatically update as well. A clear example can be associated with the tower crane at a construction site, where milestones can be defined for the assembly and deconstruction of the tower crane based the execution and completion of other activities, allowing the automatised update of this milestones and its associated indirect costs with the incorporation of changes in the design and progress reports. This tool will be useful to enhance the consideration of indirect costs in Progress Tracking, Value Engineering and Change Management Assessment.
- The creation of a tool that allows the incorporation of utility costs resulting from the operation of the built asset. This tool will allow the consideration of utilities gained when a built asset is finished early and can start operating before the estimated period, or on the contrary consider the costs of lost utilities due to a delay in the final delivery. This can be implemented to optimise the analysis of Progress Tracking, Value Engineering and Change Management.
- For Value Engineering (VE), create a tool with an overall perspective of a project centralising several value engineering options on a same project, allowing to filter for each VE option to study the costs and variables associated to each case, and still be able to analyse the impact of each VE on the total costs of the project. When a specific VE is selected, it will lead the user to a tool developed in this study.
- Considering the different stages of Value Engineering: identification, rough cost estimation, design of the option and detailed cost estimation, for the first stage a tool can be developed to assist the identification of possible VE design options, based on the weight that the associated costs of a specific system have on the total costs of the project. Using statistics from past projects with similar characteristics, it is possible to define possible weights that a system or discipline should have for a specific type of project. Therefore, a dynamic template that shows the actual weight of the associated cost of a system and its comparison with the weights based on statistics, possible VE options can be identified. Moreover, for the second stage of VE which is the rough cost estimation, a tool can be developed creating a template that presents the rough estimation of costs based on statistics as well and including the associated costs of the design of the VE.

All these tools linked together with the one developed in this study can represent a powerful platform for evaluation and management of Value Engineering. These tools can also be able to create records of all the VE options that were studied on a project, that will serve for the identification and assessment of VE options for future projects with similar conditions.

- For Change Management, develop a tool that will incorporate all the change orders associated within a project, that will serve as a complete scope of the project allowing the selection of each change order that will lead to the tool developed in this study for each case. Moreover, incorporate the identification of the impacted zone of the change order to identify and map what other activities, systems, subcontractors, and suppliers can be affected by a change order.
- For Change Management, create a tool that will be able to estimate the associated costs of the change order as a rough estimation based on statistics, before a detailed cost estimation for a previous analysis of the change orders. Furthermore, include the analysis of a change order within the whole scope of the project to determine if the associated cost can be recovered or not. This tool will require to study the structure of information required to generate statistics from concluded projects to be implemented for the analyses of current and future projects.
- For E-Procurement, develop a tool that will present the complete E-Procurement System of a project. This tool will gather, map and present for each instance of the project the information of the supplier or subcontractor together with the status of the purchase or engaging of the component. The selection of an instance will take the user to the tool developed in this study. This will allow a complete analysis and control of the procurement of the project and its supply change. Moreover, it will allow to identify omissions of merged scopes within components of a project.
- For the selection of a subcontractor, study the generation of information required to incorporate more Key Performance Indicators for the assessment of this decision. Some suggested KPIs will be:
  - Technical pre-requisites evaluating required certifications and capabilities
  - Rentability index to assess the duration of the execution of the activity or supply of a resource (especially when imports are involved)
  - Reputation credibility
  - Financial stability
- Development of a platform that allows an online system for supply options in the AECO industry. This web-based platform can allow main contractors to post the services or resources required, then suppliers and subcontractors will be able to assess the defined requirements and offer their services, resulting in optioneering for the main contractor as well as for the suppliers and subcontractors. Furthermore, with the incorporation of the KPIs mentioned in the previous point, it will be possible to rate the experience from both parties, and justifying the rate based on the KPIs, to seek for the optimisation of the provided services and the contract conditions of the service.

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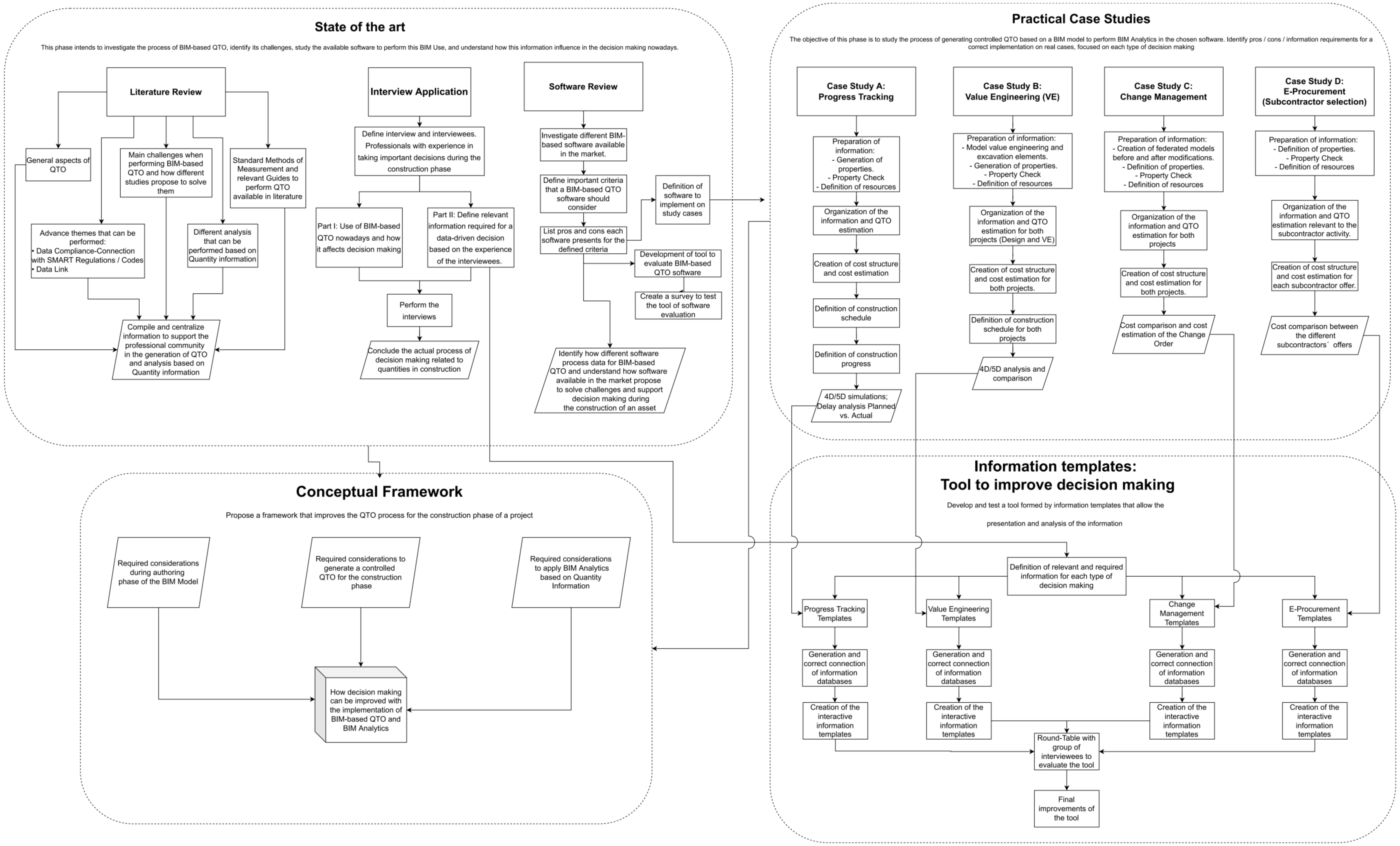
LIST OF ACRONYMS AND ABBREVIATIONS:

2D	2 Dimensions
3D	3 Dimensions
4D	4 Dimensions
5D	5 Dimensions
API	Application Programming Interface
BCF	BIM Collaboration Format
BEP	BIM Execution Plan
BIM	Building Information Modelling
BoQ	Bill of Quantities
CBS	Cost Breakdown Structure
CDE	Common Data Environment
CMO	Compositely modelled objects
CSV	Comma-separated Values
EPS	E-Procurement System
GDP	Gross Domestic Product
HVAC	Heating, Ventilation and Air Conditioning
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IMO	Individually modelled objects
IPD	Integrated Project Delivery
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LNEC	*Laboratório Nacional de Engenharia Civil*
LOD	Level of Development
LOIN	Level of Information Need
MEP	Mechanical, Electrical and Plumbing
PDT	Product Data Template
PDS	Product Data Sheet
PMBOK	Project Management Body of Knowledge
prEN	Proposed European Standard
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
QA/QC	Quality Assurance and Quality Check
QS	Quantity Surveyor
QTO	Quantity Take-off
VE	Value Engineering
WBS	Work Breakdown Structure
XML	Extensible Markup Language

APPENDICES

APPENDIX 1: WORKFLOW OF DISSERTATION´S DEVELOPMENT - METHODOLOGY



APPENDIX 2: ORGANIZATION OF SUB-CRITERIA FOR EACH CRITERION FOR THE SOFTWARE TOOL EVALUATION (FIGURE 10)

APPENDIX 3: RESULTS OF THE EVALUATION SOFTWARE TOOL TEST (TABLE 11)

Criteria \ Software	Weight	SOFTWARE A		SOFTWARE B		SOFTWARE C		SOFTWARE D		SOFTWARE E		SOFTWARE F		SOFTWARE G	
		Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
How to adapt information to be interpreted?	10%	3.67	0.37	3.87	0.39	2.00	0.20	3.33	0.33	2.33	0.23	4.33	0.43	1.08	0.11
How to rely on the accuracy of information?	10%	2.88	0.29	4.25	0.43	0.75	0.08	1.75	0.18	2.75	0.28	2.09	0.21	1.75	0.18
User-friendly	5%	3.75	0.19	3.75	0.19	4.38	0.22	3.13	0.16	4.38	0.22	1.25	0.06	4.38	0.22
Availability for evaluation	5%	5.00	0.25	3.50	0.18	0.00	0.00	3.50	0.18	4.13	0.21	2.50	0.13	3.50	0.18
Available training and user guides	10%	5.00	0.50	3.13	0.31	2.50	0.25	4.38	0.44	3.75	0.38	4.38	0.44	3.13	0.31
Scheduling and 4D analysis	10%	5.00	0.50	4.00	0.40	0.00	0.00	1.75	0.18	2.50	0.25	5.00	0.50	3.00	0.30
Cost estimation and 5D analysis	10%	5.00	0.50	5.00	0.50	3.00	0.30	5.00	0.50	2.50	0.25	5.00	0.50	5.00	0.50
Progress tracking	10%	3.50	0.35	3.50	0.35	0.53	0.05	0.88	0.09	5.00	0.50	5.00	0.50	0.88	0.09
Other features	5%	3.00	0.15	2.00	0.10	1.25	0.06	2.00	0.10	2.00	0.10	0.75	0.04	1.25	0.06
Collaboration among stakeholders	5%	4.63	0.23	3.25	0.16	3.75	0.19	4.38	0.22	5.00	0.25	5.00	0.25	5.00	0.25
Interoperability with other software	5%	4.75	0.24	3.25	0.16	2.25	0.11	2.25	0.11	1.63	0.08	2.75	0.14	1.75	0.09
Creation of reports	10%	5.00	0.50	4.50	0.45	2.25	0.23	2.25	0.23	4.25	0.43	3.25	0.33	1.50	0.15
Model Viewer	5%	5.00	0.25	5.00	0.25	3.75	0.19	4.00	0.20	3.38	0.17	3.50	0.18	3.50	0.18
TOTAL	**100%**	**56.17**	**4.31**	**48.99**	**3.86**	**26.40**	**1.87**	**38.58**	**2.90**	**43.58**	**3.33**	**44.80**	**3.69**	**35.71**	**2.60**
OVERALL SCORE			**86%**		**77%**		**37%**		**58%**		**67%**		**74%**		**52%**

APPENDIX 4: SET OF QUESTIONS FOR THE INTERVIEWS

1st Part:

1.1 In your opinion, what are the main uses or purposes to perform Quantity Takeoff for a construction project?

1.2 In your experience, have you used BIM-based Quantity Takeoff information in a construction project? If the answer is yes, can you describe how this information was generated, how it was used, and what are the main challenges during this process?

1.3 What improvements do you think can be achieved by having a reliable quantity takeoff linked to a construction model that can automatically update quantities when modifying the model?

1.4 During the construction process, what decisions do you consider that are based more on the experience of the project manager and its construction team, and less data-driven?

2nd Part:

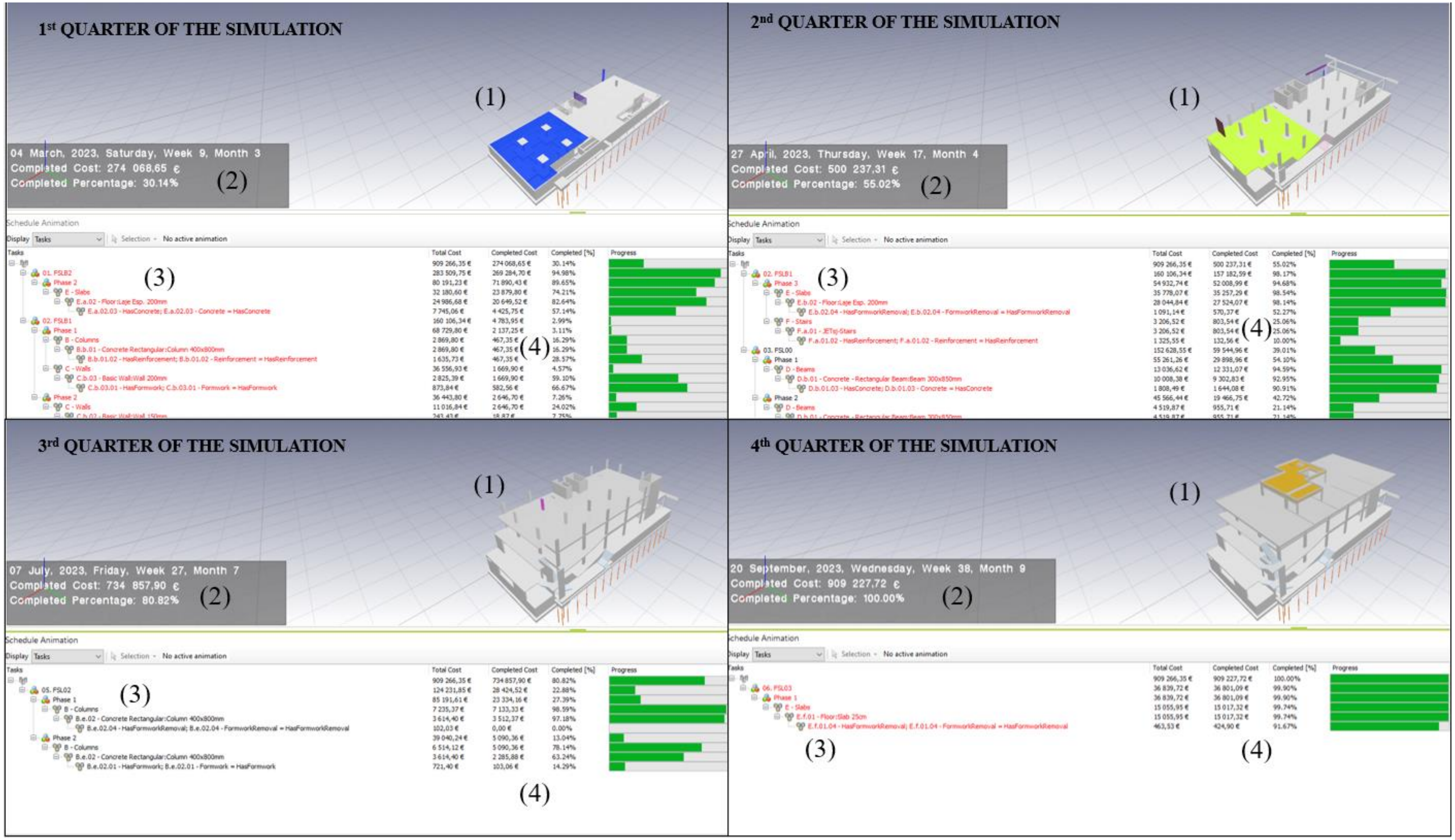
2.1 Imagine the following scenario: You are the main contractor for a multi-story construction project, and you have a meeting with the developer of the project to present the construction progress of the first month of construction. What information will you present to explain the progress done?

2.2 Imagine the following scenario: The construction team is proposing a modification of the type of foundation from isolated footings to a single floating slab, to improve the construction schedule. What information would you present to the Appointing Party to demonstrate that the modification will be an improvement in the time and cost of the construction process?

2.3 Imagine the following scenario: During the construction project of an asset that has an important electrical system, the architectural distribution suffered modifications that affect the quantities of elements in the electrical system, namely cable trays, and cable tray fittings, resulting in a change order for this modification. What level of information on the quantities do you consider important to present for the approval of the change order and what analytics will you consider most relevant to present as well?

2.4 Imagine the following scenario: As project manager of a main contractor company, you need to choose a subcontract for concrete casting and finishing of slabs in a multi-story building. What information would you provide to the subcontractors and what information would you ask each possible subcontractor, to make a comparison between the bidders and choose the best candidate?

APPENDIX 5: 4D/5D SIMULATION FOR CASE STUDY A (FIGURE 21)



APPENDIX 6: BILL OF QUANTITIES FOR CASE STUDY A.

Item code	Description	Quantity Type	Item count	Quantity	Unit Cost	Material Cost	Labour Cost	Total Cost
	Case Study A		389			€ 694,102.22	€ 216,533.84	€ 910,636.06
	Case Study A		389			€ 694,102.22	€ 216,533.84	€ 910,636.06
A	Foundations		74			€ 109,349.85	€ 11,254.80	€ 120,604.65
A.d	JETsj-SC-Microestacas:Microestacas N80 101.6x9.0 Selagem 5m	Length	18	71.70 m	€ 50.00	€ 3,585.00	€ 0.00	€ 3,585.00
A.a	Beams		27			€ 17,473.29	€ 2,447.45	€ 19,920.74
A.a.01	Concrete - Rectangular Beam:Beam 500x800mm		27			€ 17,473.29	€ 2,447.45	€ 19,920.74
A.a.01.01	Reinforcement	Mass	27	11,118 kg	€ 1.17	€ 11,703.26	€ 1,351.06	€ 13,054.31
A.a.01.02	Formwork	Area	27	159.03 m²	€ 13.43	€ 1,590.30	€ 545.25	€ 2,135.55
A.a.01.03	Concrete cast	Volume	27	39.71 m³	€ 108.46	€ 4,179.73	€ 127.06	€ 4,306.80
A.a.01.04	Formwork Removal	Area	27	159.03 m²	€ 2.67	€ 0.00	€ 424.08	€ 424.08
A.b	Slabs		16			€ 47,372.85	€ 4,326.97	€ 51,699.82
A.b.01	Footing-Rectangular:S 4000 x 4400 x 1000		10			€ 35,833.54	€ 3,284.35	€ 39,117.89
A.b.01.01	Reinforcement	Mass	10	14,960 kg	€ 1.17	€ 15,747.37	€ 1,817.92	€ 17,565.29
A.b.01.02	Formwork	Area	10	148.19 m²	€ 13.95	€ 1,559.85	€ 508.07	€ 2,067.92
A.b.01.03	Concrete cast	Volume	10	176.00 m³	€ 108.46	€ 18,526.32	€ 563.20	€ 19,089.52
A.b.01.04	Formwork Removal	Area	10	148.19 m²	€ 2.67	€ 0.00	€ 395.16	€ 395.16
A.b.02	Foundation Slab:LF 1000		2			€ 9,872.70	€ 877.43	€ 10,750.13
A.b.02.01	Reinforcement	Mass	2	4,145 kg	€ 1.17	€ 4,363.41	€ 503.73	€ 4,867.13
A.b.02.02	Formwork	Area	2	35.71 m²	€ 13.95	€ 375.87	€ 122.43	€ 498.30
A.b.02.03	Concrete cast	Volume	2	48.77 m³	€ 108.46	€ 5,133.42	€ 156.06	€ 5,289.48
A.b.02.04	Formwork Removal	Area	2	35.71 m²	€ 2.67	€ 0.00	€ 95.22	€ 95.22
A.b.03	Foundation Slab:LF 200		1			€ 194.56	€ 22.90	€ 217.47
A.b.03.01	Reinforcement	Mass	1	77 kg	€ 1.17	€ 80.93	€ 9.34	€ 90.27
A.b.03.02	Formwork	Area	1	1.75 m²	€ 13.95	€ 18.42	€ 6.00	€ 24.42
A.b.03.03	Concrete cast	Volume	1	0.90 m³	€ 108.46	€ 95.21	€ 2.89	€ 98.11
A.b.03.04	Formwork Removal	Area	1	1.75 m²	€ 2.67	€ 0.00	€ 4.67	€ 4.67
A.b.04	Foundation Slab:LF 300		3			€ 1,472.04	€ 142.29	€ 1,614.33
A.b.04.01	Reinforcement	Mass	3	608 kg	€ 1.17	€ 640.26	€ 73.91	€ 714.18
A.b.04.02	Formwork	Area	3	7.46 m²	€ 13.95	€ 78.53	€ 25.58	€ 104.11
A.b.04.03	Concrete cast	Volume	3	7.16 m³	€ 108.46	€ 753.25	€ 22.90	€ 776.15
A.b.04.04	Formwork Removal	Area	3	7.46 m²	€ 2.67	€ 0.00	€ 19.89	€ 19.89
A.c	Structural Foundations		13			€ 40,918.72	€ 4,480.38	€ 45,399.09
A.c.01	Wall Foundation:Sc 1300 x 800 CEN		4			€ 17,336.02	€ 1,856.72	€ 19,192.74
A.c.01.01	Reinforcement	Mass	4	7,008 kg	€ 1.17	€ 7,377.03	€ 851.63	€ 8,228.65
A.c.01.02	Formwork	Area	4	121.61 m²	€ 13.95	€ 1,280.14	€ 416.96	€ 1,697.09
A.c.01.03	Concrete cast	Volume	4	82.45 m³	€ 108.46	€ 8,678.85	€ 263.84	€ 8,942.69
A.c.01.04	Formwork Removal	Area	4	121.61 m²	€ 2.67	€ 0.00	€ 324.30	€ 324.30
A.c.02	Wall Foundation:Sc 1300 x 800 EXC		3			€ 13,710.28	€ 1,476.20	€ 15,186.48
A.c.02.01	Reinforcement	Mass	3	5,536 kg	€ 1.17	€ 5,827.13	€ 672.70	€ 6,499.83
A.c.02.02	Formwork	Area	3	97.63 m²	€ 13.95	€ 1,027.71	€ 334.74	€ 1,362.46
A.c.02.03	Concrete cast	Volume	3	65.13 m³	€ 108.46	€ 6,855.44	€ 208.41	€ 7,063.85
A.c.02.04	Formwork Removal	Area	3	97.63 m²	€ 2.67	€ 0.00	€ 260.35	€ 260.35
A.c.03	Wall Foundation:Sc 1500 x 1000 CEN		1			€ 3,156.51	€ 319.56	€ 3,476.07
A.c.03.01	Reinforcement	Mass	1	1,292 kg	€ 1.17	€ 1,359.89	€ 156.99	€ 1,516.88
A.c.03.02	Formwork	Area	1	18.69 m²	€ 13.95	€ 196.76	€ 64.09	€ 260.84
A.c.03.03	Concrete cast	Volume	1	15.20 m³	€ 108.46	€ 1,599.87	€ 48.64	€ 1,648.50
A.c.03.04	Formwork Removal	Area	1	18.69 m²	€ 2.67	€ 0.00	€ 49.84	€ 49.84
A.c.04	Wall Foundation:Sc 2400 x 1000 CEN		1			€ 1,315.69	€ 142.63	€ 1,458.32
A.c.04.01	Reinforcement	Mass	1	530 kg	€ 1.17	€ 558.32	€ 64.45	€ 622.77
A.c.04.02	Formwork	Area	1	9.55 m²	€ 13.95	€ 100.53	€ 32.74	€ 133.27

Item code	Description	Quantity Type	Item count	Quantity	Unit Cost	Material Cost	Labour Cost	Total Cost
A.c.04.03	Concrete cast	Volume	1	6.24 m³	€ 108.46	€ 656.84	€ 19.97	€ 676.81
A.c.04.04	Formwork Removal	Area	1	9.55 m²	€ 2.67	€ 0.00	€ 25.47	€ 25.47
A.c.05	Wall Foundation:Sc 600 x 600 CEN		1			€ 683.91	€ 97.72	€ 781.63
A.c.05.01	Reinforcement	Mass	1	256 kg	€ 1.17	€ 268.96	€ 31.05	€ 300.01
A.c.05.02	Formwork	Area	1	9.36 m²	€ 13.95	€ 98.53	€ 32.09	€ 130.62
A.c.05.03	Concrete cast	Volume	1	3.01 m³	€ 108.46	€ 316.42	€ 9.62	€ 326.04
A.c.05.04	Formwork Removal	Area	1	9.36 m²	€ 2.67	€ 0.00	€ 24.96	€ 24.96
A.c.06	Wall Foundation:Sc 900 x 900 CEN		3			€ 4,716.32	€ 587.54	€ 5,303.86
A.c.06.01	Reinforcement	Mass	3	1,836 kg	€ 1.17	€ 1,932.63	€ 223.11	€ 2,155.74
A.c.06.02	Formwork	Area	3	48.45 m²	€ 13.95	€ 510.00	€ 166.11	€ 676.11
A.c.06.03	Concrete cast	Volume	3	21.60 m³	€ 108.46	€ 2,273.69	€ 69.12	€ 2,342.81
A.c.06.04	Formwork Removal	Area	3	48.45 m²	€ 2.67	€ 0.00	€ 129.20	€ 129.20
B	Columns		83			€ 42,497.01	€ 31,321.42	€ 73,818.43
B.a	01. FSLB2		12			€ 6,509.21	€ 4,620.80	€ 11,130.00
B.a.01	Concrete Rectangular:Column 400x800mm		10			€ 4,800.00	€ 3,507.29	€ 8,307.29
B.a.01.01	Formwork	Area	10	68.40 m²	€ 24.24	€ 720.00	€ 938.06	€ 1,658.06
B.a.01.02	Reinforcement	Mass	10	2,964 kg	€ 1.69	€ 3,120.00	€ 1,896.96	€ 5,016.96
B.a.01.03	Concrete cast	Volume	10	9.12 m³	€ 153.26	€ 960.00	€ 437.76	€ 1,397.76
B.a.01.04	Formwork Removal	Area	10	68.40 m²	€ 3.43	€ 0.00	€ 234.51	€ 234.51
B.a.02	Concrete Rectangular:Column 600x1300mm		1			€ 717.11	€ 467.51	€ 1,184.61
B.a.02.01	Formwork	Area	1	5.14 m²	€ 24.24	€ 54.11	€ 70.49	€ 124.60
B.a.02.02	Reinforcement	Mass	1	482 kg	€ 1.69	€ 507.00	€ 308.26	€ 815.26
B.a.02.03	Concrete cast	Volume	1	1.48 m³	€ 153.26	€ 156.00	€ 71.14	€ 227.14
B.a.02.04	Formwork Removal	Area	1	5.14 m²	€ 3.43	€ 0.00	€ 17.62	€ 17.62
B.a.03	Concrete Rectangular:Column 600x1800mm		1			€ 992.11	€ 646.00	€ 1,638.10
B.a.03.01	Formwork	Area	1	7.04 m²	€ 24.24	€ 74.11	€ 96.55	€ 170.65
B.a.03.02	Reinforcement	Mass	1	667 kg	€ 1.69	€ 702.00	€ 426.82	€ 1,128.82
B.a.03.03	Concrete cast	Volume	1	2.05 m³	€ 153.26	€ 216.00	€ 98.50	€ 314.50
B.a.03.04	Formwork Removal	Area	1	7.04 m²	€ 3.43	€ 0.00	€ 24.14	€ 24.14
B.b	02. FSLB1		10			€ 3,705.26	€ 2,707.38	€ 6,412.65
B.b.01	Concrete Rectangular:Column 400x800mm		10			€ 3,705.26	€ 2,707.38	€ 6,412.65
B.b.01.01	Formwork	Area	10	52.80 m²	€ 24.24	€ 555.79	€ 724.11	€ 1,279.90
B.b.01.02	Reinforcement	Mass	10	2,288 kg	€ 1.69	€ 2,408.42	€ 1,464.32	€ 3,872.74
B.b.01.03	Concrete cast	Volume	10	7.04 m³	€ 153.26	€ 741.05	€ 337.92	€ 1,078.97
B.b.01.04	Formwork Removal	Area	10	52.80 m²	€ 3.43	€ 0.00	€ 181.03	€ 181.03
B.c	03. FSL00		21			€ 12,873.78	€ 9,571.24	€ 22,445.02
B.c.01	Concrete Rectangular:Column 300x800mm		11			€ 5,766.42	€ 4,377.99	€ 10,144.41
B.c.01.01	Formwork	Area	11	96.97 m²	€ 24.24	€ 1,020.74	€ 1,329.87	€ 2,350.61
B.c.01.02	Reinforcement	Mass	11	3,448 kg	€ 1.69	€ 3,629.05	€ 2,206.46	€ 5,835.52
B.c.01.03	Concrete cast	Volume	11	10.61 m³	€ 153.26	€ 1,116.63	€ 509.18	€ 1,625.82
B.c.01.04	Formwork Removal	Area	11	96.97 m²	€ 3.43	€ 0.00	€ 332.47	€ 332.47
B.c.02	Concrete Rectangular:Column 400x800mm		10			€ 7,107.36	€ 5,193.25	€ 12,300.61
B.c.02.01	Formwork	Area	10	101.28 m²	€ 24.24	€ 1,066.11	€ 1,388.98	€ 2,455.09
B.c.02.02	Reinforcement	Mass	10	4,389 kg	€ 1.69	€ 4,619.79	€ 2,808.83	€ 7,428.61
B.c.02.03	Concrete cast	Volume	10	13.50 m³	€ 153.26	€ 1,421.47	€ 648.19	€ 2,069.66
B.c.02.04	Formwork Removal	Area	10	101.28 m²	€ 3.43	€ 0.00	€ 347.25	€ 347.25
B.d	04. FSL01		17			€ 9,574.50	€ 7,092.61	€ 16,667.11
B.d.01	Concrete Rectangular:Column 300x800mm		9			€ 4,491.97	€ 3,412.53	€ 7,904.51
B.d.01.01	Formwork	Area	9	75.73 m²	€ 24.24	€ 797.16	€ 1,038.58	€ 1,835.74
B.d.01.02	Reinforcement	Mass	9	2,684 kg	€ 1.69	€ 2,825.45	€ 1,717.87	€ 4,543.32
B.d.01.03	Concrete cast	Volume	9	8.26 m³	€ 153.26	€ 869.37	€ 396.43	€ 1,265.80
B.d.01.04	Formwork Removal	Area	9	75.73 m²	€ 3.43	€ 0.00	€ 259.65	€ 259.65
B.d.02	Concrete Rectangular:Column 400x800mm		8			€ 5,082.52	€ 3,680.08	€ 8,762.61
B.d.02.01	Formwork	Area	8	69.40 m²	€ 24.24	€ 730.53	€ 951.77	€ 1,682.30

Item code	Description	Quantity Type	Item count	Quantity	Unit Cost	Material Cost	Labour Cost	Total Cost
B.d.02.02	Reinforcement	Mass	8	3,162 kg	€ 1.69	€ 3,328.00	€ 2,023.42	€ 5,351.42
B.d.02.03	Concrete cast	Volume	8	9.73 m³	€ 153.26	€ 1,024.00	€ 466.94	€ 1,490.94
B.d.02.04	Formwork Removal	Area	8	69.40 m²	€ 3.43	€ 0.00	€ 237.94	€ 237.94
B.e	05. FSL02		17			€ 7,882.40	€ 5,867.09	€ 13,749.49
B.e.01	Concrete Rectangular:Column 300x800mm		9			€ 3,705.55	€ 2,815.13	€ 6,520.68
B.e.01.01	Formwork	Area	9	62.47 m²	€ 24.24	€ 657.63	€ 856.80	€ 1,514.43
B.e.01.02	Reinforcement	Mass	9	2,214 kg	€ 1.69	€ 2,330.76	€ 1,417.10	€ 3,747.87
B.e.01.03	Concrete cast	Volume	9	6.81 m³	€ 153.26	€ 717.16	€ 327.02	€ 1,044.18
B.e.01.04	Formwork Removal	Area	9	62.47 m²	€ 3.43	€ 0.00	€ 214.20	€ 214.20
B.e.02	Concrete Rectangular:Column 400x800mm		8			€ 4,176.84	€ 3,051.96	€ 7,228.80
B.e.02.01	Formwork	Area	8	59.52 m²	€ 24.24	€ 626.53	€ 816.27	€ 1,442.80
B.e.02.02	Reinforcement	Mass	8	2,579 kg	€ 1.69	€ 2,714.95	€ 1,650.69	€ 4,365.64
B.e.02.03	Concrete cast	Volume	8	7.94 m³	€ 153.26	€ 835.37	€ 380.93	€ 1,216.30
B.e.02.04	Formwork Removal	Area	8	59.52 m²	€ 3.43	€ 0.00	€ 204.07	€ 204.07
B.f	06. FSL03		6			€ 1,951.86	€ 1,462.30	€ 3,414.16
B.f.01	Concrete Rectangular:Column 300x300mm		1			€ 156.90	€ 129.52	€ 286.42
B.f.01.01	Formwork	Area	1	3.57 m²	€ 24.24	€ 37.62	€ 49.01	€ 86.63
B.f.01.02	Reinforcement	Mass	1	87 kg	€ 1.69	€ 91.21	€ 55.46	€ 146.67
B.f.01.03	Concrete cast	Volume	1	0.27 m³	€ 153.26	€ 28.07	€ 12.80	€ 40.86
B.f.01.04	Formwork Removal	Area	1	3.57 m²	€ 3.43	€ 0.00	€ 12.25	€ 12.25
B.f.02	Concrete Rectangular:Column 300x400mm		2			€ 406.78	€ 320.09	€ 726.86
B.f.02.01	Formwork	Area	2	7.85 m²	€ 24.24	€ 82.66	€ 107.69	€ 190.35
B.f.02.02	Reinforcement	Mass	2	235 kg	€ 1.69	€ 247.86	€ 150.70	€ 398.55
B.f.02.03	Concrete cast	Volume	2	0.72 m³	€ 153.26	€ 76.26	€ 34.78	€ 111.04
B.f.02.04	Formwork Removal	Area	2	7.85 m²	€ 3.43	€ 0.00	€ 26.92	€ 26.92
B.f.03	Concrete Rectangular:Column 400x800mm		3			€ 1,388.18	€ 1,012.70	€ 2,400.88
B.f.03.01	Formwork	Area	3	19.64 m²	€ 24.24	€ 206.68	€ 269.28	€ 475.96
B.f.03.02	Reinforcement	Mass	3	858 kg	€ 1.69	€ 903.50	€ 549.33	€ 1,452.83
B.f.03.03	Concrete cast	Volume	3	2.64 m³	€ 153.26	€ 278.00	€ 126.77	€ 404.77
B.f.03.04	Formwork Removal	Area	3	19.64 m²	€ 0.00	€ 0.00	€ 67.32	€ 67.32
C	Walls		127			€ 162,873.34	€ 44,248.74	€ 207,122.08
C.a	01. FSLB2		23			€ 55,736.85	€ 14,959.31	€ 70,696.16
C.a.01	Basic Wall:Retainig Wall 300mm		7			€ 42,846.77	€ 11,404.15	€ 54,250.92
C.a.01.01	Formwork	Area	7	947.10 m²	€ 13.53	€ 9,969.50	€ 2,841.31	€ 12,810.81
C.a.01.02	Reinforcement	Mass	7	17,036 kg	€ 1.42	€ 17,933.06	€ 6,290.36	€ 24,223.42
C.a.01.03	Concrete cast	Volume	7	141.97 m³	€ 111.26	€ 14,944.21	€ 851.82	€ 15,796.03
C.a.01.04	Formwork Removal	Area	7	947.10 m²	€ 1.50	€ 0.00	€ 1,420.65	€ 1,420.65
C.a.02	Basic Wall:Wall 150mm		1			€ 403.20	€ 121.15	€ 524.35
C.a.02.01	Formwork	Area	1	15.16 m²	€ 13.53	€ 159.62	€ 45.49	€ 205.11
C.a.02.02	Reinforcement	Mass	1	126 kg	€ 1.42	€ 132.86	€ 46.60	€ 179.46
C.a.02.03	Concrete cast	Volume	1	1.05 m³	€ 111.26	€ 110.72	€ 6.31	€ 117.03
C.a.02.04	Formwork Removal	Area	1	15.16 m²	€ 1.50	€ 0.00	€ 22.75	€ 22.75
C.a.03	Basic Wall:Wall 200mm		5			€ 3,259.55	€ 926.26	€ 4,185.81
C.a.03.01	Formwork	Area	5	98.57 m²	€ 13.53	€ 1,037.57	€ 295.71	€ 1,333.28
C.a.03.02	Reinforcement	Mass	5	1,151 kg	€ 1.42	€ 1,211.99	€ 425.13	€ 1,637.12
C.a.03.03	Concrete cast	Volume	5	9.59 m³	€ 111.26	€ 1,009.99	€ 57.57	€ 1,067.56
C.a.03.04	Formwork Removal	Area	5	98.57 m²	€ 1.50	€ 0.00	€ 147.85	€ 147.85
C.a.04	Basic Wall:Wall 250mm		6			€ 5,659.66	€ 1,560.73	€ 7,220.39
C.a.04.01	Formwork	Area	6	149.66 m²	€ 13.53	€ 1,575.37	€ 448.98	€ 2,024.35
C.a.04.02	Reinforcement	Mass	6	2,116 kg	€ 1.42	€ 2,227.79	€ 781.44	€ 3,009.23
C.a.04.03	Concrete cast	Volume	6	17.64 m³	€ 111.26	€ 1,856.49	€ 105.82	€ 1,962.31
C.a.04.04	Formwork Removal	Area	6	149.66 m²	€ 1.50	€ 0.00	€ 224.49	€ 224.49
C.a.05	Basic Wall:Wall 300mm		4			€ 3,567.67	€ 947.02	€ 4,514.70
C.a.05.01	Formwork	Area	4	77.71 m²	€ 13.53	€ 817.98	€ 233.12	€ 1,051.10

Item code	Description	Quantity Type	Item count	Quantity	Unit Cost	Material Cost	Labour Cost	Total Cost
C.a.05.02	Reinforcement	Mass	4	1,425 kg	€ 1.42	€ 1,499.83	€ 526.10	€ 2,025.93
C.a.05.03	Concrete cast	Volume	4	11.87 m³	€ 111.26	€ 1,249.86	€ 71.24	€ 1,321.10
C.a.05.04	Formwork Removal	Area	4	77.71 m²	€ 1.50	€ 0.00	€ 116.56	€ 116.56
C.b	02. FSLB1		32			€ 47,510.82	€ 12,772.56	€ 60,283.39
C.b.01	Basic Wall:Retainig Wall 300mm		17			€ 38,173.17	€ 10,168.22	€ 48,341.39
C.b.01.01	Formwork	Area	17	847.41 m²	€ 13.53	€ 8,920.14	€ 2,542.24	€ 11,462.38
C.b.01.02	Reinforcement	Mass	17	15,158 kg	€ 1.42	€ 15,956.20	€ 5,596.94	€ 21,553.14
C.b.01.03	Concrete cast	Volume	17	126.32 m³	€ 111.26	€ 13,296.83	€ 757.92	€ 14,054.75
C.b.01.04	Formwork Removal	Area	17	847.41 m²	€ 1.50	€ 0.00	€ 1,271.12	€ 1,271.12
C.b.02	Basic Wall:Wall 150mm		1			€ 113.85	€ 33.06	€ 146.92
C.b.02.01	Formwork	Area	1	3.76 m²	€ 13.53	€ 39.62	€ 11.29	€ 50.91
C.b.02.02	Reinforcement	Mass	1	38 kg	€ 1.42	€ 40.49	€ 14.20	€ 54.69
C.b.02.03	Concrete cast	Volume	1	0.32 m³	€ 111.26	€ 33.74	€ 1.92	€ 35.67
C.b.02.04	Formwork Removal	Area	1	3.76 m²	€ 1.50	€ 0.00	€ 5.65	€ 5.65
C.b.03	Basic Wall:Wall 200mm		8			€ 4,767.90	€ 1,353.54	€ 6,121.44
C.b.03.01	Formwork	Area	8	143.57 m²	€ 13.53	€ 1,511.30	€ 430.72	€ 1,942.02
C.b.03.02	Reinforcement	Mass	8	1,688 kg	€ 1.42	€ 1,776.33	€ 623.08	€ 2,399.41
C.b.03.03	Concrete cast	Volume	8	14.06 m³	€ 111.26	€ 1,480.27	€ 84.38	€ 1,564.65
C.b.03.04	Formwork Removal	Area	8	143.57 m²	€ 1.50	€ 0.00	€ 215.36	€ 215.36
C.b.04	Basic Wall:Wall 250mm		6			€ 4,455.90	€ 1,217.74	€ 5,673.64
C.b.04.01	Formwork	Area	6	112.84 m²	€ 13.53	€ 1,187.80	€ 338.52	€ 1,526.32
C.b.04.02	Reinforcement	Mass	6	1,693 kg	€ 1.42	€ 1,782.60	€ 625.28	€ 2,407.88
C.b.04.03	Concrete cast	Volume	6	14.11 m³	€ 111.26	€ 1,485.50	€ 84.67	€ 1,570.17
C.b.04.04	Formwork Removal	Area	6	112.84 m²	€ 1.50	€ 0.00	€ 169.26	€ 169.26
C.c	03. FSL00		17			€ 20,366.64	€ 5,630.01	€ 25,996.64
C.c.01	Basic Wall:Wall - 250mm		1			€ 1,191.38	€ 329.31	€ 1,520.69
C.c.01.01	Formwork	Area	1	31.85 m²	€ 13.53	€ 335.26	€ 95.55	€ 430.81
C.c.01.02	Reinforcement	Mass	1	444 kg	€ 1.42	€ 466.97	€ 163.80	€ 630.77
C.c.01.03	Concrete cast	Volume	1	3.70 m³	€ 111.26	€ 389.14	€ 22.18	€ 411.33
C.c.01.04	Formwork Removal	Area	1	31.85 m²	€ 1.50	€ 0.00	€ 47.78	€ 47.78
C.c.02	Basic Wall:Wall 150mm		1			€ 537.72	€ 158.21	€ 695.93
C.c.02.01	Formwork	Area	1	18.70 m²	€ 13.53	€ 196.88	€ 56.11	€ 253.00
C.c.02.02	Reinforcement	Mass	1	177 kg	€ 1.42	€ 185.91	€ 65.21	€ 251.12
C.c.02.03	Concrete cast	Volume	1	1.47 m³	€ 111.26	€ 154.93	€ 8.83	€ 163.76
C.c.02.04	Formwork Removal	Area	1	18.70 m²	€ 1.50	€ 0.00	€ 28.06	€ 28.06
C.c.03	Basic Wall:Wall 200mm		5			€ 4,809.49	€ 1,369.58	€ 6,179.07
C.c.03.01	Formwork	Area	5	146.74 m²	€ 13.53	€ 1,544.62	€ 440.22	€ 1,984.83
C.c.03.02	Reinforcement	Mass	5	1,692 kg	€ 1.42	€ 1,780.84	€ 624.66	€ 2,405.50
C.c.03.03	Concrete cast	Volume	5	14.10 m³	€ 111.26	€ 1,484.03	€ 84.59	€ 1,568.62
C.c.03.04	Formwork Removal	Area	5	146.74 m²	€ 1.50	€ 0.00	€ 220.11	€ 220.11
C.c.04	Basic Wall:Wall 250mm		8			€ 10,260.13	€ 2,815.45	€ 13,075.58
C.c.04.01	Formwork	Area	8	265.02 m²	€ 13.53	€ 2,789.68	€ 795.06	€ 3,584.74
C.c.04.02	Reinforcement	Mass	8	3,871 kg	€ 1.42	€ 4,074.79	€ 1,429.31	€ 5,504.10
C.c.04.03	Concrete cast	Volume	8	32.26 m³	€ 111.26	€ 3,395.66	€ 193.55	€ 3,589.21
C.c.04.04	Formwork Removal	Area	8	265.02 m²	€ 1.50	€ 0.00	€ 397.53	€ 397.53
C.c.05	Basic Wall:Wall 300mm		2			€ 3,567.91	€ 957.46	€ 4,525.37
C.c.05.01	Formwork	Area	2	82.40 m²	€ 13.53	€ 867.37	€ 247.20	€ 1,114.57
C.c.05.02	Reinforcement	Mass	2	1,399 kg	€ 1.42	€ 1,473.03	€ 516.69	€ 1,989.72
C.c.05.03	Concrete cast	Volume	2	11.66 m³	€ 111.26	€ 1,227.52	€ 69.97	€ 1,297.49
C.c.05.04	Formwork Removal	Area	2	82.40 m²	€ 1.50	€ 0.00	€ 123.60	€ 123.60
C.d	04. FSL01		13			€ 15,345.05	€ 4,209.34	€ 19,554.39
C.d.01	Basic Wall:Wall 150mm		1			€ 437.06	€ 128.51	€ 565.57
C.d.01.01	Formwork	Area	1	15.16 m²	€ 13.53	€ 159.62	€ 45.49	€ 205.11
C.d.01.02	Reinforcement	Mass	1	144 kg	€ 1.42	€ 151.33	€ 53.08	€ 204.41

Item code	Description	Quantity Type	Item count	Quantity	Unit Cost	Material Cost	Labour Cost	Total Cost
C.d.01.03	Concrete cast	Volume	1	1.20 m³	€ 111.26	€ 126.11	€ 7.19	€ 133.30
C.d.01.04	Formwork Removal	Area	1	15.16 m²	€ 1.50	€ 0.00	€ 22.75	€ 22.75
C.d.02	Basic Wall:Wall 200mm		2			€ 2,185.99	€ 619.56	€ 2,805.55
C.d.02.01	Formwork	Area	2	65.37 m²	€ 13.53	€ 688.11	€ 196.11	€ 884.23
C.d.02.02	Reinforcement	Mass	2	776 kg	€ 1.42	€ 817.02	€ 286.59	€ 1,103.61
C.d.02.03	Concrete cast	Volume	2	6.47 m³	€ 111.26	€ 680.85	€ 38.81	€ 719.66
C.d.02.04	Formwork Removal	Area	2	65.37 m²	€ 1.50	€ 0.00	€ 98.06	€ 98.06
C.d.03	Basic Wall:Wall 250mm		8			€ 9,183.84	€ 2,516.85	€ 11,700.69
C.d.03.01	Formwork	Area	8	235.75 m²	€ 13.53	€ 2,481.54	€ 707.24	€ 3,188.78
C.d.03.02	Reinforcement	Mass	8	3,473 kg	€ 1.42	€ 3,655.80	€ 1,282.34	€ 4,938.14
C.d.03.03	Concrete cast	Volume	8	28.94 m³	€ 111.26	€ 3,046.50	€ 173.65	€ 3,220.15
C.d.03.04	Formwork Removal	Area	8	235.75 m²	€ 1.50	€ 0.00	€ 353.62	€ 353.62
C.d.04	Basic Wall:Wall 300mm		2			€ 3,538.16	€ 944.42	€ 4,482.58
C.d.04.01	Formwork	Area	2	79.43 m²	€ 13.53	€ 836.08	€ 238.28	€ 1,074.36
C.d.04.02	Reinforcement	Mass	2	1,400 kg	€ 1.42	€ 1,473.86	€ 516.99	€ 1,990.85
C.d.04.03	Concrete cast	Volume	2	11.67 m³	€ 111.26	€ 1,228.22	€ 70.01	€ 1,298.23
C.d.04.04	Formwork Removal	Area	2	79.43 m²	€ 1.50	€ 0.00	€ 119.14	€ 119.14
C.e	05. FSL02		13			€ 12,712.59	€ 3,488.24	€ 16,200.82
C.e.01	Basic Wall:Wall 150mm		1			€ 307.78	€ 90.33	€ 398.11
C.e.01.01	Formwork	Area	1	10.60 m²	€ 13.53	€ 111.62	€ 31.81	€ 143.43
C.e.01.02	Reinforcement	Mass	1	102 kg	€ 1.42	€ 107.00	€ 37.53	€ 144.53
C.e.01.03	Concrete cast	Volume	1	0.85 m³	€ 111.26	€ 89.16	€ 5.08	€ 94.25
C.e.01.04	Formwork Removal	Area	1	10.60 m²	€ 1.50	€ 0.00	€ 15.91	€ 15.91
C.e.02	Basic Wall:Wall 200mm		2			€ 1,809.12	€ 512.35	€ 2,321.47
C.e.02.01	Formwork	Area	2	53.92 m²	€ 13.53	€ 567.59	€ 161.76	€ 729.36
C.e.02.02	Reinforcement	Mass	2	643 kg	€ 1.42	€ 677.20	€ 237.54	€ 914.74
C.e.02.03	Concrete cast	Volume	2	5.36 m³	€ 111.26	€ 564.33	€ 32.17	€ 596.50
C.e.02.04	Formwork Removal	Area	2	53.92 m²	€ 1.50	€ 0.00	€ 80.88	€ 80.88
C.e.03	Basic Wall:Wall 250mm		8			€ 7,654.93	€ 2,098.01	€ 9,752.94
C.e.03.01	Formwork	Area	8	196.57 m²	€ 13.53	€ 2,069.20	€ 589.72	€ 2,658.92
C.e.03.02	Reinforcement	Mass	8	2,894 kg	€ 1.42	€ 3,046.76	€ 1,068.71	€ 4,115.47
C.e.03.03	Concrete cast	Volume	8	24.12 m³	€ 111.26	€ 2,538.97	€ 144.72	€ 2,683.69
C.e.03.04	Formwork Removal	Area	8	196.57 m²	€ 1.50	€ 0.00	€ 294.86	€ 294.86
C.e.04	Basic Wall:Wall 300mm		2			€ 2,940.76	€ 787.54	€ 3,728.30
C.e.04.01	Formwork	Area	2	67.18 m²	€ 13.53	€ 707.20	€ 201.55	€ 908.76
C.e.04.02	Reinforcement	Mass	2	1,157 kg	€ 1.42	€ 1,218.30	€ 427.34	€ 1,645.65
C.e.04.03	Concrete cast	Volume	2	9.64 m³	€ 111.26	€ 1,015.25	€ 57.87	€ 1,073.12
C.e.04.04	Formwork Removal	Area	2	67.18 m²	€ 1.50	€ 0.00	€ 100.78	€ 100.78
C.f	06. FSL03		29			€ 11,201.40	€ 3,189.28	€ 14,390.68
C.f.01	Basic Wall:Acroterion 150mm		20			€ 4,796.99	€ 1,421.95	€ 6,218.94
C.f.01.01	Formwork	Area	20	171.63 m²	€ 13.53	€ 1,806.62	€ 514.89	€ 2,321.51
C.f.01.02	Reinforcement	Mass	20	1,550 kg	€ 1.42	€ 1,631.11	€ 572.14	€ 2,203.25
C.f.01.03	Concrete cast	Volume	20	12.91 m³	€ 111.26	€ 1,359.26	€ 77.48	€ 1,436.74
C.f.01.04	Formwork Removal	Area	20	171.63 m²	€ 1.50	€ 0.00	€ 257.44	€ 257.44
C.f.02	Basic Wall:Wall 150mm		1			€ 243.14	€ 71.24	€ 314.38
C.f.02.01	Formwork	Area	1	8.32 m²	€ 13.53	€ 87.62	€ 24.97	€ 112.59
C.f.02.02	Reinforcement	Mass	1	81 kg	€ 1.42	€ 84.83	€ 29.75	€ 114.58
C.f.02.03	Concrete cast	Volume	1	0.67 m³	€ 111.26	€ 70.69	€ 4.03	€ 74.72
C.f.02.04	Formwork Removal	Area	1	8.32 m²	€ 1.50	€ 0.00	€ 12.49	€ 12.49
C.f.03	Basic Wall:Wall 200mm		2			€ 1,102.45	€ 312.65	€ 1,415.10
C.f.03.01	Formwork	Area	2	33.05 m²	€ 13.53	€ 347.93	€ 99.16	€ 447.09
C.f.03.02	Reinforcement	Mass	2	391 kg	€ 1.42	€ 411.55	€ 144.36	€ 555.91
C.f.03.03	Concrete cast	Volume	2	3.26 m³	€ 111.26	€ 342.96	€ 19.55	€ 362.51
C.f.03.04	Formwork Removal	Area	2	33.05 m²	€ 1.50	€ 0.00	€ 49.58	€ 49.58

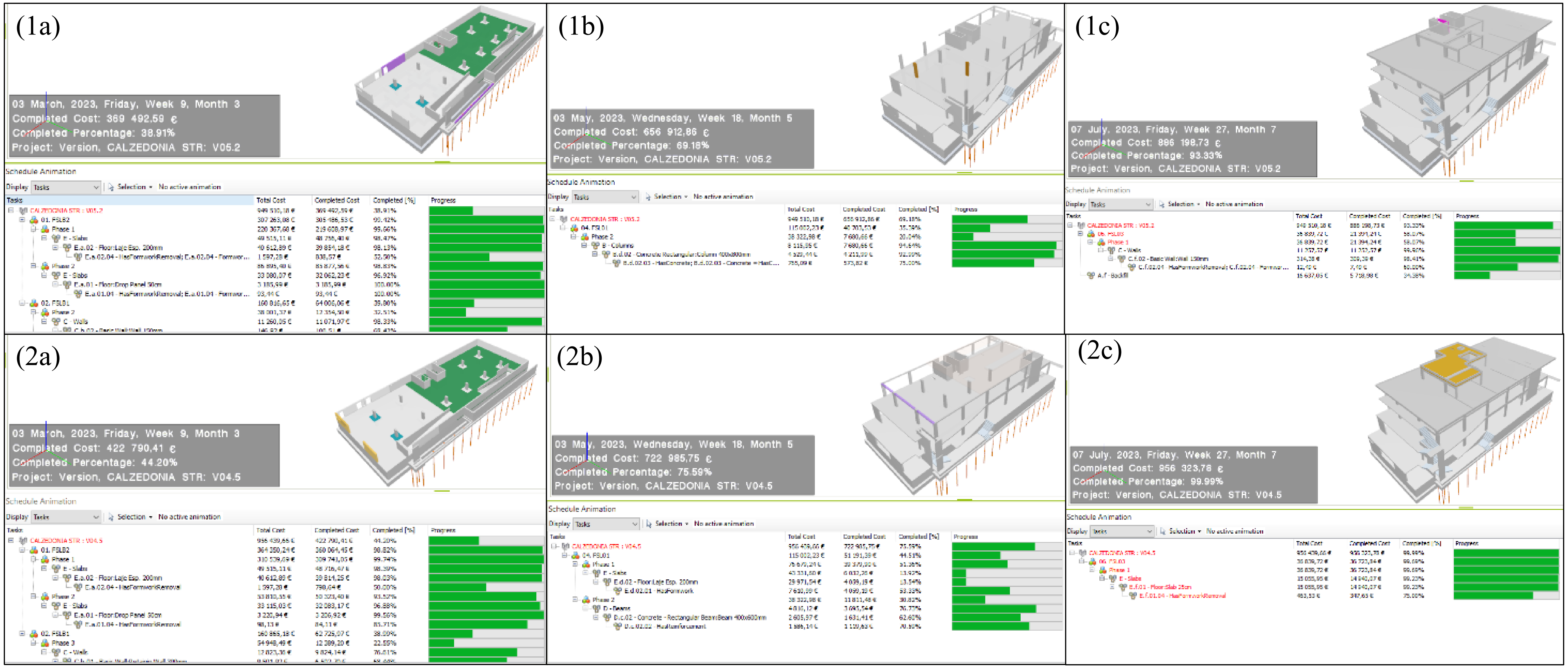
Item code	Description	Quantity Type	Item count	Quantity	Unit Cost	Material Cost	Labour Cost	Total Cost
C.f.04	Basic Wall:Wall 250mm		6			€ 5,058.83	€ 1,383.43	€ 6,442.26
C.f.04.01	Formwork	Area	6	128.53 m²	€ 13.53	€ 1,352.90	€ 385.58	€ 1,738.48
C.f.04.02	Reinforcement	Mass	6	1,920 kg	€ 1.42	€ 2,021.42	€ 709.05	€ 2,730.47
C.f.04.03	Concrete cast	Volume	6	16.00 m³	€ 111.26	€ 1,684.51	€ 96.02	€ 1,780.53
C.f.04.04	Formwork Removal	Area	6	128.53 m²	€ 1.50	€ 0.00	€ 192.79	€ 192.79
D	Beams		38			€ 31,497.66	€ 25,428.51	€ 56,926.17
D.a	02. FSLB1		1			€ 252.00	€ 215.71	€ 467.72
D.a.01	Concrete - Rectangular Beam:Beam 300x450mm		1			€ 252.00	€ 215.71	€ 467.72
D.a.01.01	Formwork	Area	1	5.04 m²	€ 23.33	€ 53.05	€ 64.51	€ 117.56
D.a.01.02	Reinforcement	Mass	1	142 kg	€ 1.82	€ 149.21	€ 108.87	€ 258.08
D.a.01.03	Concrete cast	Volume	1	0.47 m³	€ 126.60	€ 49.74	€ 10.08	€ 59.82
D.a.01.04	Formwork Removal	Area	1	5.04 m²	€ 6.40	€ 0.00	€ 32.26	€ 32.26
D.b	03. FSL00		12			€ 14,328.55	€ 11,435.44	€ 25,763.98
D.b.01	Concrete - Rectangular Beam:Beam 300x850mm		10			€ 10,769.77	€ 8,655.68	€ 19,425.45
D.b.01.01	Formwork	Area	10	171.76 m²	€ 23.33	€ 1,807.96	€ 2,198.47	€ 4,006.43
D.b.01.02	Reinforcement	Mass	10	6,385 kg	€ 1.82	€ 6,721.36	€ 4,903.91	€ 11,625.27
D.b.01.03	Concrete cast	Volume	10	21.28 m³	€ 126.60	€ 2,240.45	€ 454.07	€ 2,694.52
D.b.01.04	Formwork Removal	Area	10	171.76 m²	€ 6.40	€ 0.00	€ 1,099.24	€ 1,099.24
D.b.02	Concrete - Rectangular Beam:Beam 400x700mm		2			€ 3,558.77	€ 2,779.76	€ 6,338.53
D.b.02.01	Formwork	Area	2	50.52 m²	€ 23.33	€ 531.82	€ 646.69	€ 1,178.52
D.b.02.02	Reinforcement	Mass	2	2,157 kg	€ 1.82	€ 2,270.21	€ 1,656.35	€ 3,926.56
D.b.02.03	Concrete cast	Volume	2	7.19 m³	€ 126.60	€ 756.74	€ 153.37	€ 910.10
D.b.02.04	Formwork Removal	Area	2	50.52 m²	€ 6.40	€ 0.00	€ 323.35	€ 323.35
D.c	04. FSL01		7			€ 5,523.37	€ 4,534.84	€ 10,058.21
D.c.01	Concrete - Rectangular Beam:Beam 300x500mm		5			€ 3,030.44	€ 2,552.16	€ 5,582.61
D.c.01.01	Formwork	Area	5	57.36 m²	€ 23.33	€ 603.82	€ 734.24	€ 1,338.06
D.c.01.02	Reinforcement	Mass	5	1,729 kg	€ 1.82	€ 1,819.97	€ 1,327.85	€ 3,147.82
D.c.01.03	Concrete cast	Volume	5	5.76 m³	€ 126.60	€ 606.66	€ 122.95	€ 729.61
D.c.01.04	Formwork Removal	Area	5	57.36 m²	€ 6.40	€ 0.00	€ 367.12	€ 367.12
D.c.02	Concrete - Rectangular Beam:Beam 400x600mm		2			€ 2,492.92	€ 1,982.68	€ 4,475.60
D.c.02.01	Formwork	Area	2	38.14 m²	€ 23.33	€ 401.46	€ 488.18	€ 889.64
D.c.02.02	Reinforcement	Mass	2	1,490 kg	€ 1.82	€ 1,568.59	€ 1,144.45	€ 2,713.04
D.c.02.03	Concrete cast	Volume	2	4.97 m³	€ 126.60	€ 522.86	€ 105.97	€ 628.83
D.c.02.04	Formwork Removal	Area	2	38.14 m²	€ 6.40	€ 0.00	€ 244.09	€ 244.09
D.d	05. FSL02		11			€ 7,428.11	€ 6,096.10	€ 13,524.22
D.d.01	Concrete - Rectangular Beam:Beam 300x500mm		5			€ 3,097.39	€ 2,613.88	€ 5,711.27
D.d.01.01	Formwork	Area	5	59.04 m²	€ 23.33	€ 621.51	€ 755.75	€ 1,377.26
D.d.01.02	Reinforcement	Mass	5	1,764 kg	€ 1.82	€ 1,856.92	€ 1,354.81	€ 3,211.72
D.d.01.03	Concrete cast	Volume	5	5.88 m³	€ 126.60	€ 618.97	€ 125.44	€ 744.42
D.d.01.04	Formwork Removal	Area	5	59.04 m²	€ 6.40	€ 0.00	€ 377.88	€ 377.88
D.d.02	Concrete - Rectangular Beam:Beam 400x450mm		4			€ 1,695.49	€ 1,384.52	€ 3,080.01
D.d.02.01	Formwork	Area	4	28.73 m²	€ 23.33	€ 302.45	€ 367.78	€ 670.22
D.d.02.02	Reinforcement	Mass	4	993 kg	€ 1.82	€ 1,044.78	€ 762.27	€ 1,807.06
D.d.02.03	Concrete cast	Volume	4	3.31 m³	€ 126.60	€ 348.26	€ 70.58	€ 418.84
D.d.02.04	Formwork Removal	Area	4	28.73 m²	€ 6.40	€ 0.00	€ 183.89	€ 183.89
D.d.03	Concrete - Rectangular Beam:Beam 400x600mm		2			€ 2,635.23	€ 2,097.71	€ 4,732.94
D.d.03.01	Formwork	Area	2	40.46 m²	€ 23.33	€ 425.88	€ 517.88	€ 943.76
D.d.03.02	Reinforcement	Mass	2	1,574 kg	€ 1.82	€ 1,657.01	€ 1,208.95	€ 2,865.96
D.d.03.03	Concrete cast	Volume	2	5.25 m³	€ 126.60	€ 552.34	€ 111.94	€ 664.28
D.d.03.04	Formwork Removal	Area	2	40.46 m²	€ 6.40	€ 0.00	€ 258.94	€ 258.94
D.e	06. FSL03		7			€ 3,965.63	€ 3,146.41	€ 7,112.05
D.e.01	Concrete - Rectangular Beam:Beam 300x500mm		4			€ 1,144.42	€ 959.65	€ 2,104.07
D.e.01.01	Formwork	Area	4	21.34 m²	€ 23.33	€ 224.64	€ 273.16	€ 497.81
D.e.01.02	Reinforcement	Mass	4	655 kg	€ 1.82	€ 689.83	€ 503.30	€ 1,193.13

Item code	Description	Quantity Type	Item count	Quantity	Unit Cost	Material Cost	Labour Cost	Total Cost
D.e.01.03	Concrete cast	Volume	4	2.18 m³	€ 126.60	€ 229.94	€ 46.60	€ 276.55
D.e.01.04	Formwork Removal	Area	4	21.34 m²	€ 6.40	€ 0.00	€ 136.58	€ 136.58
D.e.02	Concrete - Rectangular Beam:Beam 400x500mm		1			€ 584.61	€ 477.27	€ 1,061.88
D.e.02.01	Formwork	Area	1	9.90 m²	€ 23.33	€ 104.19	€ 126.69	€ 230.88
D.e.02.02	Reinforcement	Mass	1	342 kg	€ 1.82	€ 360.32	€ 262.89	€ 623.20
D.e.02.03	Concrete cast	Volume	1	1.14 m³	€ 126.60	€ 120.11	€ 24.34	€ 144.45
D.e.02.04	Formwork Removal	Area	1	9.90 m²	€ 6.40	€ 0.00	€ 63.35	€ 63.35
D.e.03	Concrete - Rectangular Beam:Beam 400x850mm		1			€ 1,423.13	€ 1,093.05	€ 2,516.18
D.e.03.01	Formwork	Area	1	18.77 m²	€ 23.33	€ 197.53	€ 240.20	€ 437.74
D.e.03.02	Reinforcement	Mass	1	873 kg	€ 1.82	€ 919.20	€ 670.65	€ 1,589.84
D.e.03.03	Concrete cast	Volume	1	2.91 m³	€ 126.60	€ 306.40	€ 62.10	€ 368.50
D.e.03.04	Formwork Removal	Area	1	18.77 m²	€ 6.40	€ 0.00	€ 120.10	€ 120.10
D.e.04	Concrete - Rectangular Beam:Beam 800x500mm		1			€ 813.47	€ 616.45	€ 1,429.92
D.e.04.01	Formwork	Area	1	10.08 m²	€ 23.33	€ 106.11	€ 129.02	€ 235.13
D.e.04.02	Reinforcement	Mass	1	504 kg	€ 1.82	€ 530.53	€ 387.07	€ 917.60
D.e.04.03	Concrete cast	Volume	1	1.68 m³	€ 126.60	€ 176.84	€ 35.84	€ 212.68
D.e.04.04	Formwork Removal	Area	1	10.08 m²	€ 6.40	€ 0.00	€ 64.51	€ 64.51
E	Slabs		56			€ 313,188.13	€ 97,059.42	€ 410,247.54
E.a	01. FSLB2		16			€ 62,883.14	€ 19,712.04	€ 82,595.18
E.a.01	Floor:Drop Panel 50cm		10			€ 6,255.16	€ 1,762.24	€ 8,017.40
E.a.01.01	Formwork	Area	10	90.24 m²	€ 17.19	€ 949.89	€ 601.60	€ 1,551.49
E.a.01.02	Reinforcement	Mass	10	2,640 kg	€ 1.35	€ 2,778.95	€ 792.00	€ 3,570.95
E.a.01.03	Concrete cast	Volume	10	24.00 m³	€ 110.60	€ 2,526.32	€ 128.00	€ 2,654.32
E.a.01.04	Formwork Removal	Area	10	90.24 m²	€ 2.67	€ 0.00	€ 240.64	€ 240.64
E.a.02	Floor:Laje Esp. 200mm		2			€ 50,407.08	€ 16,104.04	€ 66,511.12
E.a.02.01	Formwork	Area	2	980.67 m²	€ 17.19	€ 10,322.85	€ 6,537.81	€ 16,860.66
E.a.02.02	Reinforcement	Mass	2	19,947 kg	€ 1.35	€ 20,996.50	€ 5,984.00	€ 26,980.50
E.a.02.03	Concrete cast	Volume	2	181.33 m³	€ 110.60	€ 19,087.73	€ 967.11	€ 20,054.84
E.a.02.04	Formwork Removal	Area	2	980.67 m²	€ 2.67	€ 0.00	€ 2,615.12	€ 2,615.12
E.a.03	Floor:Slab 25cm		4			€ 6,220.90	€ 1,845.76	€ 8,066.66
E.a.03.01	Formwork	Area	4	102.16 m²	€ 17.19	€ 1,075.32	€ 681.04	€ 1,756.36
E.a.03.02	Reinforcement	Mass	4	2,561 kg	€ 1.35	€ 2,695.31	€ 768.16	€ 3,463.47
E.a.03.03	Concrete cast	Volume	4	23.28 m³	€ 110.60	€ 2,450.28	€ 124.15	€ 2,574.43
E.a.03.04	Formwork Removal	Area	4	102.16 m²	€ 2.67	€ 0.00	€ 272.41	€ 272.41
E.b	02. FSLB1		14			€ 69,099.04	€ 21,534.94	€ 90,633.98
E.b.01	Floor:Drop Panel 50cm		10			€ 6,088.42	€ 1,614.40	€ 7,702.82
E.b.01.01	Formwork	Area	10	74.40 m²	€ 17.19	€ 783.16	€ 496.00	€ 1,279.16
E.b.01.02	Reinforcement	Mass	10	2,640 kg	€ 1.35	€ 2,778.95	€ 792.00	€ 3,570.95
E.b.01.03	Concrete cast	Volume	10	24.00 m³	€ 110.60	€ 2,526.32	€ 128.00	€ 2,654.32
E.b.01.04	Formwork Removal	Area	10	74.40 m²	€ 2.67	€ 0.00	€ 198.40	€ 198.40
E.b.02	Floor:Laje Esp. 200mm		3			€ 59,437.00	€ 18,826.63	€ 78,263.63
E.b.02.01	Formwork	Area	3	1,134.73 m²	€ 17.19	€ 11,944.55	€ 7,564.88	€ 19,509.42
E.b.02.02	Reinforcement	Mass	3	23,633 kg	€ 1.35	€ 24,877.00	€ 7,089.95	€ 31,966.95
E.b.02.03	Concrete cast	Volume	3	214.85 m³	€ 110.60	€ 22,615.46	€ 1,145.85	€ 23,761.31
E.b.02.04	Formwork Removal	Area	3	1,134.73 m²	€ 2.67	€ 0.00	€ 3,025.95	€ 3,025.95
E.b.03	Floor:Slab 25cm		1			€ 3,573.62	€ 1,093.91	€ 4,667.53
E.b.03.01	Formwork	Area	1	63.16 m²	€ 17.19	€ 664.84	€ 421.07	€ 1,085.91
E.b.03.02	Reinforcement	Mass	1	1,447 kg	€ 1.35	€ 1,523.64	€ 434.24	€ 1,957.88
E.b.03.03	Concrete cast	Volume	1	13.16 m³	€ 110.60	€ 1,385.13	€ 70.18	€ 1,455.31
E.b.03.04	Formwork Removal	Area	1	63.16 m²	€ 2.67	€ 0.00	€ 168.43	€ 168.43
E.c	03. FSL00		11			€ 57,176.39	€ 17,773.07	€ 74,949.46
E.c.01	Floor:Drop Panel 50cm		6			€ 3,639.58	€ 956.69	€ 4,596.27
E.c.01.01	Formwork	Area	6	43.36 m²	€ 17.19	€ 456.42	€ 289.07	€ 745.49
E.c.01.02	Reinforcement	Mass	6	1,584 kg	€ 1.35	€ 1,667.37	€ 475.20	€ 2,142.57

Item code	Description	Quantity Type	Item count	Quantity	Unit Cost	Material Cost	Labour Cost	Total Cost
E.c.01.03	Concrete cast	Volume	6	14.40 m³	€ 110.60	€ 1,515.79	€ 76.80	€ 1,592.59
E.c.01.04	Formwork Removal	Area	6	43.36 m²	€ 2.67	€ 0.00	€ 115.63	€ 115.63
E.c.02	Floor:Laje Esp. 200mm		3			€ 44,410.15	€ 14,079.09	€ 58,489.24
E.c.02.01	Formwork	Area	3	849.48 m²	€ 17.19	€ 8,941.85	€ 5,663.17	€ 14,605.01
E.c.02.02	Reinforcement	Mass	3	17,650 kg	€ 1.35	€ 18,578.63	€ 5,294.91	€ 23,873.55
E.c.02.03	Concrete cast	Volume	3	160.45 m³	€ 110.60	€ 16,889.67	€ 855.74	€ 17,745.41
E.c.02.04	Formwork Removal	Area	3	849.48 m²	€ 2.67	€ 0.00	€ 2,265.27	€ 2,265.27
E.c.03	Floor:Slab 25cm		2			€ 9,126.66	€ 2,737.29	€ 11,863.95
E.c.03.01	Formwork	Area	2	153.79 m²	€ 17.19	€ 1,618.79	€ 1,025.24	€ 2,644.03
E.c.03.02	Reinforcement	Mass	2	3,736 kg	€ 1.35	€ 3,932.69	€ 1,120.82	€ 5,053.51
E.c.03.03	Concrete cast	Volume	2	33.96 m³	€ 110.60	€ 3,575.17	€ 181.14	€ 3,756.32
E.c.03.04	Formwork Removal	Area	2	153.79 m²	€ 2.67	€ 0.00	€ 410.09	€ 410.09
E.d	04. FSL01		7			€ 50,833.61	€ 15,422.04	€ 66,255.65
E.d.01	Floor:Drop Panel 50cm		5			€ 11,865.68	€ 3,028.59	€ 14,894.27
E.d.01.01	Formwork	Area	5	129.32 m²	€ 17.19	€ 1,361.26	€ 862.13	€ 2,223.40
E.d.01.02	Reinforcement	Mass	5	5,227 kg	€ 1.35	€ 5,502.31	€ 1,568.16	€ 7,070.47
E.d.01.03	Concrete cast	Volume	5	47.52 m³	€ 110.60	€ 5,002.10	€ 253.44	€ 5,255.54
E.d.01.04	Formwork Removal	Area	5	129.32 m²	€ 2.67	€ 0.00	€ 344.85	€ 344.85
E.d.02	Floor:Laje Esp. 200mm		2			€ 38,967.92	€ 12,393.46	€ 51,361.38
E.d.02.01	Formwork	Area	2	750.66 m²	€ 17.19	€ 7,901.71	€ 5,004.41	€ 12,906.12
E.d.02.02	Reinforcement	Mass	2	15,459 kg	€ 1.35	€ 16,272.78	€ 4,637.74	€ 20,910.52
E.d.02.03	Concrete cast	Volume	2	140.54 m³	€ 110.60	€ 14,793.44	€ 749.53	€ 15,542.97
E.d.02.04	Formwork Removal	Area	2	750.66 m²	€ 2.67	€ 0.00	€ 2,001.77	€ 2,001.77
E.e	05. FSL02		7			€ 61,477.24	€ 19,280.09	€ 80,757.32
E.e.01	Floor:Drop Panel 50cm		5			€ 11,900.96	€ 3,009.61	€ 14,910.57
E.e.01.01	Formwork	Area	5	125.98 m²	€ 17.19	€ 1,326.08	€ 839.85	€ 2,165.93
E.e.01.02	Reinforcement	Mass	5	5,262 kg	€ 1.35	€ 5,539.22	€ 1,578.68	€ 7,117.90
E.e.01.03	Concrete cast	Volume	5	47.84 m³	€ 110.60	€ 5,035.66	€ 255.14	€ 5,290.80
E.e.01.04	Formwork Removal	Area	5	125.98 m²	€ 2.67	€ 0.00	€ 335.94	€ 335.94
E.e.02	Floor:Laje Esp. 200mm		2			€ 49,576.28	€ 16,270.48	€ 65,846.76
E.e.02.01	Formwork	Area	2	1,022.03 m²	€ 17.19	€ 10,758.19	€ 6,813.52	€ 17,571.71
E.e.02.02	Reinforcement	Mass	2	19,317 kg	€ 1.35	€ 20,333.28	€ 5,794.99	€ 26,128.27
E.e.02.03	Concrete cast	Volume	2	175.61 m³	€ 110.60	€ 18,484.80	€ 936.56	€ 19,421.37
E.e.02.04	Formwork Removal	Area	2	1,022.03 m²	€ 2.67	€ 0.00	€ 2,725.41	€ 2,725.41
E.f	06. FSL03		1			€ 11,718.72	€ 3,337.23	€ 15,055.95
E.f.01	Floor:Slab 25cm		1			€ 11,718.72	€ 3,337.23	€ 15,055.95
E.f.01.01	Formwork	Area	1	173.82 m²	€ 17.19	€ 1,829.73	€ 1,158.83	€ 2,988.55
E.f.01.02	Reinforcement	Mass	1	4,921 kg	€ 1.35	€ 5,179.95	€ 1,476.28	€ 6,656.23
E.f.01.03	Concrete cast	Volume	1	44.74 m³	€ 110.60	€ 4,709.04	€ 238.59	€ 4,947.63
E.f.01.04	Formwork Removal	Area	1	173.82 m²	€ 2.67	€ 0.00	€ 463.53	€ 463.53
F	Stairs		8			€ 5,128.13	€ 2,974.26	€ 8,102.39
F.a	02. FSLB1		2			€ 1,915.29	€ 1,103.63	€ 3,018.92
F.a.01	JETsj-Stairs		2			€ 1,915.29	€ 1,103.63	€ 3,018.92
F.a.01.01	Formwork	Area	2	33.30 m²	€ 21.19	€ 350.53	€ 355.20	€ 705.73
F.a.01.02	Reinforcement	Mass	2	892 kg	€ 1.48	€ 938.86	€ 380.55	€ 1,319.41
F.a.01.03	Concrete cast	Volume	2	5.95 m³	€ 137.26	€ 625.91	€ 190.28	€ 816.18
F.a.01.04	Formwork Removal	Area	2	33.30 m²	€ 5.33	€ 0.00	€ 177.60	€ 177.60
F.b	03. FSL00		3			€ 1,661.27	€ 955.33	€ 2,616.59
F.b.01	Floor:Slab 25cm		1			€ 403.95	€ 240.08	€ 644.03
F.b.01.01	Formwork	Area	1	7.63 m²	€ 21.19	€ 80.26	€ 81.33	€ 161.60
F.b.01.02	Reinforcement	Mass	1	185 kg	€ 1.48	€ 194.21	€ 78.72	€ 272.93
F.b.01.03	Concrete cast	Volume	1	1.23 m³	€ 137.26	€ 129.47	€ 39.36	€ 168.83
F.b.01.04	Formwork Removal	Area	1	7.63 m²	€ 5.33	€ 0.00	€ 40.67	€ 40.67
F.b.02	JETsj-Stairs		2			€ 1,257.32	€ 715.25	€ 1,972.56

Item code	Description	Quantity Type	Item count	Quantity	Unit Cost	Material Cost	Labour Cost	Total Cost
F.b.02.01	Formwork	Area	2	21.10 m²	€ 21.19	€ 222.11	€ 225.07	€ 447.17
F.b.02.02	Reinforcement	Mass	2	590 kg	€ 1.48	€ 621.13	€ 251.76	€ 872.89
F.b.02.03	Concrete cast	Volume	2	3.93 m³	€ 137.26	€ 414.09	€ 125.88	€ 539.97
F.b.02.04	Formwork Removal	Area	2	21.10 m²	€ 5.33	€ 0.00	€ 112.53	€ 112.53
F.c	04. FSL01		3			€ 1,551.56	€ 915.31	€ 2,466.87
F.c.01	Floor:Slab 25cm		1			€ 403.95	€ 240.08	€ 644.03
F.c.01.01	Formwork	Area	1	7.63 m²	€ 21.19	€ 80.26	€ 81.33	€ 161.60
F.c.01.02	Reinforcement	Mass	1	185 kg	€ 1.48	€ 194.21	€ 78.72	€ 272.93
F.c.01.03	Concrete cast	Volume	1	1.23 m³	€ 137.26	€ 129.47	€ 39.36	€ 168.83
F.c.01.04	Formwork Removal	Area	1	7.63 m²	€ 5.33	€ 0.00	€ 40.67	€ 40.67
F.c.02	JETsj-Stairs		2			€ 1,147.62	€ 675.23	€ 1,822.84
F.c.02.01	Formwork	Area	2	21.10 m²	€ 21.19	€ 222.11	€ 225.07	€ 447.17
F.c.02.02	Reinforcement	Mass	2	528 kg	€ 1.48	€ 555.31	€ 225.08	€ 780.39
F.c.02.03	Concrete cast	Volume	2	3.52 m³	€ 137.26	€ 370.20	€ 112.54	€ 482.75
F.c.02.04	Formwork Removal	Area	2	21.10 m²	€ 5.33	€ 0.00	€ 112.53	€ 112.53
G	Ground Slab		3			€ 29,568.10	€ 4,246.70	€ 33,814.80
G.a	Floor:Ground Slab 15cm		1			€ 25,794.63	€ 3,118.80	€ 28,913.43
G.a.01	Reinforcement	Mass	1	9,653 kg	€ 1.25	€ 10,161.52	€ 1,930.69	€ 12,092.21
G.a.02	Concrete cast	Volume	1	148.51 m³	€ 113.26	€ 15,633.11	€ 1,188.12	€ 16,821.22
G.b	ramp.250		2			€ 3,773.47	€ 1,127.89	€ 4,901.37
G.b.01	Formwork	Area	2	63.07 m²	€ 17.19	€ 663.89	€ 420.46	€ 1,084.36
G.b.02	Reinforcement	Mass	2	1,547 kg	€ 1.35	€ 1,628.83	€ 464.22	€ 2,093.05
G.b.03	Concrete cast	Volume	2	14.07 m³	€ 110.60	€ 1,480.75	€ 75.02	€ 1,555.78
G.b.04	Formwork Removal	Area	2	63.07 m²	€ 2.67	€ 0.00	€ 168.19	€ 168.19

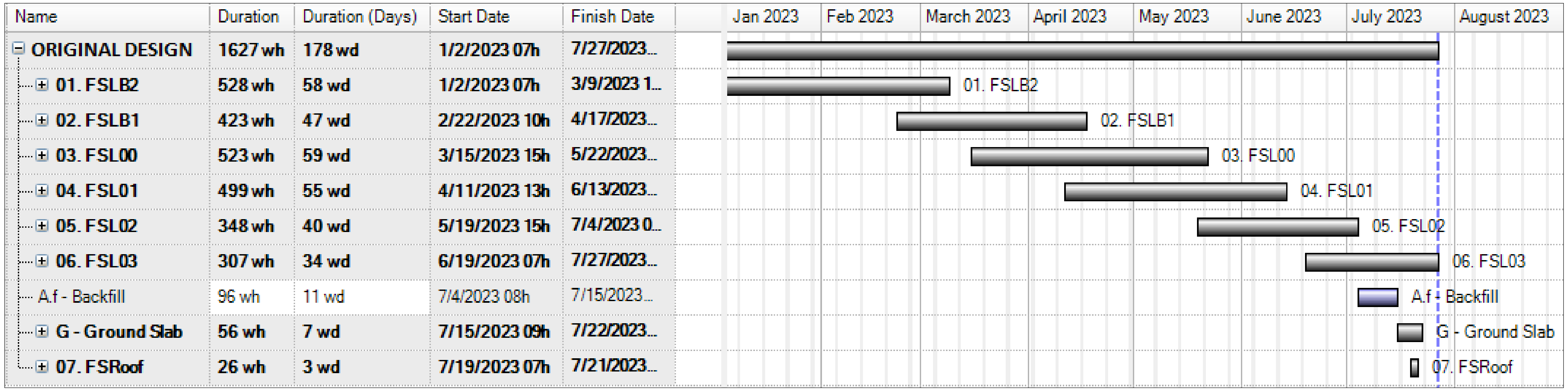
APPENDIX 7. COMPARISSON OF 4D/5D SIMULATIONS BETWEEN TWO DESIGN OPTIONS CASE STUDY B. (FIGURE 33)



(1a) Original Design – 03/03/2023 – 38.91% Progress **(1b)** Original Design – 03/05/2023 – 69.18% Progress **(1c)** Original Design – 07/07/2023 – 93.33% Progress

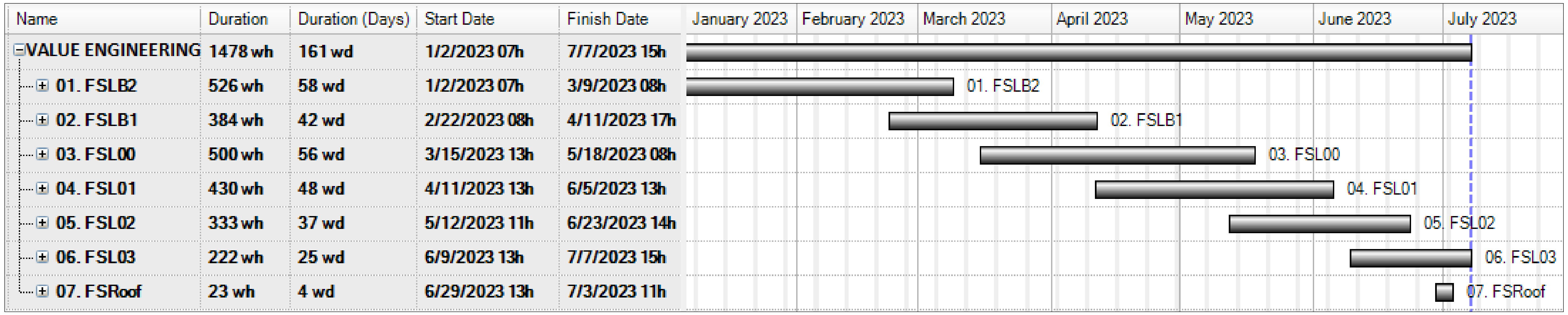
(2a) VE Design – 03/03/2023 – 44,20% Progress **(2b)** VE Design – 03/05/2023 – 75,59% Progress **(2c)** VE Design – 07/07/2023 – 99.99% Progress

APPENDIX 8. RESUMED GANNT CHARTS FOR THE SCHEDULE OF ORIGINAL DESIGN AND VALUE ENGINEERING OPTION (FIGURE 34 AND FIGURE 35)



Name	Duration	Duration (Days)	Start Date	Finish Date
ORIGINAL DESIGN	1627 wh	178 wd	1/2/2023 07h	7/27/2023...
01. FSLB2	528 wh	58 wd	1/2/2023 07h	3/9/2023 1...
02. FSLB1	423 wh	47 wd	2/22/2023 10h	4/17/2023...
03. FSL00	523 wh	59 wd	3/15/2023 15h	5/22/2023...
04. FSL01	499 wh	55 wd	4/11/2023 13h	6/13/2023...
05. FSL02	348 wh	40 wd	5/19/2023 15h	7/4/2023 0...
06. FSL03	307 wh	34 wd	6/19/2023 07h	7/27/2023...
A.f - Backfill	96 wh	11 wd	7/4/2023 08h	7/15/2023...
G - Ground Slab	56 wh	7 wd	7/15/2023 09h	7/22/2023...
07. FSRoof	26 wh	3 wd	7/19/2023 07h	7/21/2023...

Resumed Gantt chart for the schedule of the Original Design option.



Name	Duration	Duration (Days)	Start Date	Finish Date
VALUE ENGINEERING	1478 wh	161 wd	1/2/2023 07h	7/7/2023 15h
01. FSLB2	526 wh	58 wd	1/2/2023 07h	3/9/2023 08h
02. FSLB1	384 wh	42 wd	2/22/2023 08h	4/11/2023 17h
03. FSL00	500 wh	56 wd	3/15/2023 13h	5/18/2023 08h
04. FSL01	430 wh	48 wd	4/11/2023 13h	6/5/2023 13h
05. FSL02	333 wh	37 wd	5/12/2023 11h	6/23/2023 14h
06. FSL03	222 wh	25 wd	6/9/2023 13h	7/7/2023 15h
07. FSRoof	23 wh	4 wd	6/29/2023 13h	7/3/2023 11h

Resumed Gannt chart for the schedule of the Value Engineering option

APPENDIX 9: BILL OF QUANTITIES FOR CASE STUDY B: ORIGINAL DESIGN OPTION

Item code	Description	Quantity Type	Item Count	Quantity	Unit Cost	Material Cost	Labour Cost	Equipment Cost	Total Cost
	Case Study B		487			€ 721,161	€ 224,135	€ 4,214	€ 949,510
	Original Design		487			€ 721,161	€ 224,135	€ 4,214	€ 949,510
A	Foundations		172			€ 136,299	€ 18,951	€ 4,214	€ 159,463
A.d	JETsj-SC-Microestacas:Microestacas N80 101.6x9.0 Selagem 5m	Length	18	71.70 m	€ 50.00	€ 3,585	€ 0	€ 0	€ 3,585
A.a	Beams		27			€ 17,845	€ 2,674	€ 0	€ 20,520
A.a.01	Concrete - Rectangular Beam:Beam 500x800mm		27			€ 17,845	€ 2,674	€ 0	€ 20,520
A.a.01.01	Reinforcement	Mass	27	11,118 kg	€ 1.17	€ 11,703	€ 1,351	€ 0	€ 13,054
A.a.01.02	Formwork	Area	27	196.25 m^2	€ 13.43	€ 1,962	€ 673	€ 0	€ 2,635
A.a.01.03	Concrete cast	Volume	27	39.71 m^3	€ 108.46	€ 4,180	€ 127	€ 0	€ 4,307
A.a.01.04	Formwork removal	Area	27	196.25 m^2	€ 2.67	€ 0	€ 523	€ 0	€ 523
A.b	Slabs		16			€ 47,373	€ 4,327	€ 0	€ 51,700
A.b.01	Footing-Rectangular:S 4000 x 4400 x 1000		10			€ 35,834	€ 3,284	€ 0	€ 39,118
A.b.01.01	Reinforcement	Mass	10	14,960 kg	€ 1.17	€ 15,747	€ 1,818	€ 0	€ 17,565
A.b.01.02	Formwork	Area	10	148.19 m^2	€ 13.95	€ 1,560	€ 508	€ 0	€ 2,068
A.b.01.03	Concrete cast	Volume	10	176.00 m^3	€ 108.46	€ 18,526	€ 563	€ 0	€ 19,090
A.b.01.04	Formwork removal	Area	10	148.19 m^2	€ 2.67	€ 0	€ 395	€ 0	€ 395
A.b.02	Foundation Slab:LF 1000		2			€ 9,873	€ 877	€ 0	€ 10,750
A.b.02.01	Reinforcement	Mass	2	4,145 kg	€ 1.17	€ 4,363	€ 504	€ 0	€ 4,867
A.b.02.02	Formwork	Area	2	35.71 m^2	€ 13.95	€ 376	€ 122	€ 0	€ 498
A.b.02.03	Concrete cast	Volume	2	48.77 m^3	€ 108.46	€ 5,133	€ 156	€ 0	€ 5,289
A.b.02.04	Formwork removal	Area	2	35.71 m^2	€ 2.67	€ 0	€ 95	€ 0	€ 95
A.b.03	Foundation Slab:LF 200		1			€ 195	€ 23	€ 0	€ 217
A.b.03.01	Reinforcement	Mass	1	77 kg	€ 1.17	€ 81	€ 9	€ 0	€ 90
A.b.03.02	Formwork	Area	1	1.75 m^2	€ 13.95	€ 18	€ 6	€ 0	€ 24
A.b.03.03	Concrete cast	Volume	1	0.90 m^3	€ 108.46	€ 95	€ 3	€ 0	€ 98
A.b.03.04	Formwork removal	Area	1	1.75 m^2	€ 2.67	€ 0	€ 5	€ 0	€ 5
A.b.04	Foundation Slab:LF 300		3			€ 1,472	€ 142	€ 0	€ 1,614
A.b.04.01	Reinforcement	Mass	3	608 kg	€ 1.17	€ 640	€ 74	€ 0	€ 714
A.b.04.02	Formwork	Area	3	7.46 m^2	€ 13.95	€ 79	€ 26	€ 0	€ 104
A.b.04.03	Concrete cast	Volume	3	7.16 m^3	€ 108.46	€ 753	€ 23	€ 0	€ 776
A.b.04.04	Formwork removal	Area	3	7.46 m^2	€ 2.67	€ 0	€ 20	€ 0	€ 20
A.c	Structural Foundations		13			€ 40,919	€ 4,480	€ 0	€ 45,399
A.c.01	Wall Foundation:Sc 1300 x 800 CEN		4			€ 17,336	€ 1,857	€ 0	€ 19,193
A.c.01.01	Reinforcement	Mass	4	7,008 kg	€ 1.17	€ 7,377	€ 852	€ 0	€ 8,229
A.c.01.02	Formwork	Area	4	121.61 m^2	€ 13.95	€ 1,280	€ 417	€ 0	€ 1,697
A.c.01.03	Concrete cast	Volume	4	82.45 m^3	€ 108.46	€ 8,679	€ 264	€ 0	€ 8,943
A.c.01.04	Formwork removal	Area	4	121.61 m^2	€ 2.67	€ 0	€ 324	€ 0	€ 324
A.c.02	Wall Foundation:Sc 1300 x 800 EXC		3			€ 13,710	€ 1,476	€ 0	€ 15,186
A.c.02.01	Reinforcement	Mass	3	5,536 kg	€ 1.17	€ 5,827	€ 673	€ 0	€ 6,500
A.c.02.02	Formwork	Area	3	97.63 m^2	€ 13.95	€ 1,028	€ 335	€ 0	€ 1,362
A.c.02.03	Concrete cast	Volume	3	65.13 m^3	€ 108.46	€ 6,855	€ 208	€ 0	€ 7,064
A.c.02.04	Formwork removal	Area	3	97.63 m^2	€ 2.67	€ 0	€ 260	€ 0	€ 260
A.c.03	Wall Foundation:Sc 1500 x 1000 CEN		1			€ 3,157	€ 320	€ 0	€ 3,476
A.c.03.01	Reinforcement	Mass	1	1,292 kg	€ 1.17	€ 1,360	€ 157	€ 0	€ 1,517
A.c.03.02	Formwork	Area	1	18.69 m^2	€ 13.95	€ 197	€ 64	€ 0	€ 261
A.c.03.03	Concrete cast	Volume	1	15.20 m^3	€ 108.46	€ 1,600	€ 49	€ 0	€ 1,649
A.c.03.04	Formwork removal	Area	1	18.69 m^2	€ 2.67	€ 0	€ 50	€ 0	€ 50
A.c.04	Wall Foundation:Sc 2400 x 1000 CEN		1			€ 1,316	€ 143	€ 0	€ 1,458
A.c.04.01	Reinforcement	Mass	1	530 kg	€ 1.17	€ 558	€ 64	€ 0	€ 623
A.c.04.02	Formwork	Area	1	9.55 m^2	€ 13.95	€ 101	€ 33	€ 0	€ 133
A.c.04.03	Concrete cast	Volume	1	6.24 m^3	€ 108.46	€ 657	€ 20	€ 0	€ 677
A.c.04.04	Formwork removal	Area	1	9.55 m^2	€ 2.67	€ 0	€ 25	€ 0	€ 25
A.c.05	Wall Foundation:Sc 600 x 600 CEN		1			€ 684	€ 98	€ 0	€ 782
A.c.05.01	Reinforcement	Mass	1	256 kg	€ 1.17	€ 269	€ 31	€ 0	€ 300
A.c.05.02	Formwork	Area	1	9.36 m^2	€ 13.95	€ 99	€ 32	€ 0	€ 131
A.c.05.03	Concrete cast	Volume	1	3.01 m^3	€ 108.46	€ 316	€ 10	€ 0	€ 326
A.c.05.04	Formwork removal	Area	1	9.36 m^2	€ 2.67	€ 0	€ 25	€ 0	€ 25
A.c.06	Wall Foundation:Sc 900 x 900 CEN		3			€ 4,716	€ 588	€ 0	€ 5,304

Item code	Description	Quantity Type	Item Count	Quantity	Unit Cost	Material Cost	Labour Cost	Equipment Cost	Total Cost
A.c.06.01	Reinforcement	Mass	3	1,836 kg	€ 1.17	€ 1,933	€ 223	€ 0	€ 2,156
A.c.06.02	Formwork	Area	3	48.45 m²	€ 13.95	€ 510	€ 166	€ 0	€ 676
A.c.06.03	Concrete cast	Volume	3	21.60 m³	€ 108.46	€ 2,274	€ 69	€ 0	€ 2,343
A.c.06.04	Formwork removal	Area	3	48.45 m²	€ 2.67	€ 0	€ 129	€ 0	€ 129
A.e	Excavation		51			€ 17,600	€ 2,682	€ 1,341	€ 21,623
A.e.01	Excavation Concrete - Rectangular Beam 500x800mm	Volume	27	107.27 m³	€ 18.43	€ 1,609	€ 245	€ 123	€ 1,977
A.e.02	Excavation Footing-Rectangular 4000 x 4400 x 1000	Volume	10	440.88 m³	€ 18.43	€ 6,613	€ 1,008	€ 504	€ 8,125
A.e.03	Excavation Foundation Slab LF 1000	Volume	2	145.31 m³	€ 18.43	€ 2,180	€ 332	€ 166	€ 2,678
A.e.04	Excavation Foundation Slab LF 200	Volume	1	14.37 m³	€ 18.43	€ 216	€ 33	€ 16	€ 265
A.e.05	Excavation Foundation Slab LF 300	Volume	1	3.74 m³	€ 18.43	€ 56	€ 9	€ 4	€ 69
A.e.06	Excavation Wall Foundation 1300 x 800	Volume	6	391.66 m³	€ 18.43	€ 5,875	€ 895	€ 448	€ 7,218
A.e.07	Excavation Wall Foundation Sc 1300 x 800 CEN	Volume	2	23.75 m³	€ 18.43	€ 356	€ 54	€ 27	€ 438
A.e.08	Excavation Wall Foundation Sc 1500 x 1000 CEN	Volume	1	38.07 m³	€ 18.43	€ 571	€ 87	€ 44	€ 702
A.e.09	Excavation Wall Foundation Sc 600 x 600 CEN	Volume	1	8.27 m³	€ 18.43	€ 124	€ 19	€ 9	€ 152
A.f	Backfill		47			€ 8,977	€ 4,788	€ 2,873	€ 16,637
A.f.01	Backfill Concrete - Rectangular Beam 500x800mm	Volume	27	41.11 m³	€ 46.33	€ 1,028	€ 548	€ 329	€ 1,905
A.f.02	Backfill Footing-Rectangular 4000 x 4400 x 1000	Volume	10	144.29 m³	€ 46.33	€ 3,607	€ 1,924	€ 1,154	€ 6,685
A.f.03	Backfill Foundation Slab LF 1000	Volume	2	44.32 m³	€ 46.33	€ 1,108	€ 591	€ 355	€ 2,054
A.f.04	Backfill Wall Foundation Sc 1300 x 800	Volume	6	115.06 m³	€ 46.33	€ 2,877	€ 1,534	€ 920	€ 5,331
A.f.05	Backfill Wall Foundation Sc 1500 x 1000 CEN	Volume	1	11.78 m³	€ 46.33	€ 295	€ 157	€ 94	€ 546
A.f.06	Backfill Wall Foundation Sc 600 x 600 CEN	Volume	1	2.51 m³	€ 46.33	€ 63	€ 33	€ 20	€ 116
B	Columns		83			€ 42,497	€ 31,321	€ 0	€ 73,818
B.a	01. FSLB2		12			€ 6,509	€ 4,621	€ 0	€ 11,130
B.a.01	Concrete Rectangular:Column 400x800mm		10			€ 4,800	€ 3,507	€ 0	€ 8,307
B.a.01.01	Formwork	Area	10	68.40 m²	€ 24.24	€ 720	€ 938	€ 0	€ 1,658
B.a.01.02	Reinforcement	Mass	10	2,964 kg	€ 1.69	€ 3,120	€ 1,897	€ 0	€ 5,017
B.a.01.03	Concrete cast	Volume	10	9.12 m³	€ 153.26	€ 960	€ 438	€ 0	€ 1,398
B.a.01.04	Formwork removal	Area	10	68.40 m²	€ 3.43	€ 0	€ 235	€ 0	€ 235
B.a.02	Concrete Rectangular:Column 600x1300mm		1			€ 717	€ 468	€ 0	€ 1,185
B.a.02.01	Formwork	Area	1	5.14 m²	€ 24.24	€ 54	€ 70	€ 0	€ 125
B.a.02.02	Reinforcement	Mass	1	482 kg	€ 1.69	€ 507	€ 308	€ 0	€ 815
B.a.02.03	Concrete cast	Volume	1	1.48 m³	€ 153.26	€ 156	€ 71	€ 0	€ 227
B.a.02.04	Formwork removal	Area	1	5.14 m²	€ 3.43	€ 0	€ 18	€ 0	€ 18
B.a.03	Concrete Rectangular:Column 600x1800mm		1			€ 992	€ 646	€ 0	€ 1,638
B.a.03.01	Formwork	Area	1	7.04 m²	€ 24.24	€ 74	€ 97	€ 0	€ 171
B.a.03.02	Reinforcement	Mass	1	667 kg	€ 1.69	€ 702	€ 427	€ 0	€ 1,129
B.a.03.03	Concrete cast	Volume	1	2.05 m³	€ 153.26	€ 216	€ 98	€ 0	€ 314
B.a.03.04	Formwork removal	Area	1	7.04 m²	€ 3.43	€ 0	€ 24	€ 0	€ 24
B.b	02. FSLB1		10			€ 3,705	€ 2,707	€ 0	€ 6,413
B.b.01	Concrete Rectangular:Column 400x800mm		10			€ 3,705	€ 2,707	€ 0	€ 6,413
B.b.01.01	Formwork	Area	10	52.80 m²	€ 24.24	€ 556	€ 724	€ 0	€ 1,280
B.b.01.02	Reinforcement	Mass	10	2,288 kg	€ 1.69	€ 2,408	€ 1,464	€ 0	€ 3,873
B.b.01.03	Concrete cast	Volume	10	7.04 m³	€ 153.26	€ 741	€ 338	€ 0	€ 1,079
B.b.01.04	Formwork removal	Area	10	52.80 m²	€ 3.43	€ 0	€ 181	€ 0	€ 181
B.c	03. FSL00		21			€ 12,874	€ 9,571	€ 0	€ 22,445
B.c.01	Concrete Rectangular:Column 300x800mm		11			€ 5,766	€ 4,378	€ 0	€ 10,144
B.c.01.01	Formwork	Area	11	96.97 m²	€ 24.24	€ 1,021	€ 1,330	€ 0	€ 2,351
B.c.01.02	Reinforcement	Mass	11	3,448 kg	€ 1.69	€ 3,629	€ 2,206	€ 0	€ 5,836
B.c.01.03	Concrete cast	Volume	11	10.61 m³	€ 153.26	€ 1,117	€ 509	€ 0	€ 1,626
B.c.01.04	Formwork removal	Area	11	96.97 m²	€ 3.43	€ 0	€ 332	€ 0	€ 332
B.c.02	Concrete Rectangular:Column 400x800mm		10			€ 7,107	€ 5,193	€ 0	€ 12,301
B.c.02.01	Formwork	Area	10	101.28 m²	€ 24.24	€ 1,066	€ 1,389	€ 0	€ 2,455
B.c.02.02	Reinforcement	Mass	10	4,389 kg	€ 1.69	€ 4,620	€ 2,809	€ 0	€ 7,429
B.c.02.03	Concrete cast	Volume	10	13.50 m³	€ 153.26	€ 1,421	€ 648	€ 0	€ 2,070
B.c.02.04	Formwork removal	Area	10	101.28 m²	€ 3.43	€ 0	€ 347	€ 0	€ 347
B.d	04. FSL01		17			€ 9,574	€ 7,093	€ 0	€ 16,667
B.d.01	Concrete Rectangular:Column 300x800mm		9			€ 4,492	€ 3,413	€ 0	€ 7,905
B.d.01.01	Formwork	Area	9	75.73 m²	€ 24.24	€ 797	€ 1,039	€ 0	€ 1,836
B.d.01.02	Reinforcement	Mass	9	2,684 kg	€ 1.69	€ 2,825	€ 1,718	€ 0	€ 4,543
B.d.01.03	Concrete cast	Volume	9	8.26 m³	€ 153.26	€ 869	€ 396	€ 0	€ 1,266
B.d.01.04	Formwork removal	Area	9	75.73 m²	€ 3.43	€ 0	€ 260	€ 0	€ 260
B.d.02	Concrete Rectangular:Column 400x800mm		8			€ 5,083	€ 3,680	€ 0	€ 8,763

Item code	Description	Quantity Type	Item Count	Quantity	Unit Cost	Material Cost	Labour Cost	Equipment Cost	Total Cost
B.d.02.01	Formwork	Area	8	69.40 m²	€ 24.24	€ 731	€ 952	€ 0	€ 1,682
B.d.02.02	Reinforcement	Mass	8	3,162 kg	€ 1.69	€ 3,328	€ 2,023	€ 0	€ 5,351
B.d.02.03	Concrete cast	Volume	8	9.73 m³	€ 153.26	€ 1,024	€ 467	€ 0	€ 1,491
B.d.02.04	Formwork removal	Area	8	69.40 m²	€ 3.43	€ 0	€ 238	€ 0	€ 238
B.e	05. FSL02		17			€ 7,882	€ 5,867	€ 0	€ 13,749
B.e.01	Concrete Rectangular:Column 300x800mm		9			€ 3,706	€ 2,815	€ 0	€ 6,521
B.e.01.01	Formwork	Area	9	62.47 m²	€ 24.24	€ 658	€ 857	€ 0	€ 1,514
B.e.01.02	Reinforcement	Mass	9	2,214 kg	€ 1.69	€ 2,331	€ 1,417	€ 0	€ 3,748
B.e.01.03	Concrete cast	Volume	9	6.81 m³	€ 153.26	€ 717	€ 327	€ 0	€ 1,044
B.e.01.04	Formwork removal	Area	9	62.47 m²	€ 3.43	€ 0	€ 214	€ 0	€ 214
B.e.02	Concrete Rectangular:Column 400x800mm		8			€ 4,177	€ 3,052	€ 0	€ 7,229
B.e.02.01	Formwork	Area	8	59.52 m²	€ 24.24	€ 627	€ 816	€ 0	€ 1,443
B.e.02.02	Reinforcement	Mass	8	2,579 kg	€ 1.69	€ 2,715	€ 1,651	€ 0	€ 4,366
B.e.02.03	Concrete cast	Volume	8	7.94 m³	€ 153.26	€ 835	€ 381	€ 0	€ 1,216
B.e.02.04	Formwork removal	Area	8	59.52 m²	€ 3.43	€ 0	€ 204	€ 0	€ 204
B.f	06. FSL03		6			€ 1,952	€ 1,462	€ 0	€ 3,414
B.f.01	Concrete Rectangular:Column 300x300mm		1			€ 157	€ 130	€ 0	€ 286
B.f.01.01	Formwork	Area	1	3.57 m²	€ 24.24	€ 38	€ 49	€ 0	€ 87
B.f.01.02	Reinforcement	Mass	1	87 kg	€ 1.69	€ 91	€ 55	€ 0	€ 147
B.f.01.03	Concrete cast	Volume	1	0.27 m³	€ 153.26	€ 28	€ 13	€ 0	€ 41
B.f.01.04	Formwork removal	Area	1	3.57 m²	€ 3.43	€ 0	€ 12	€ 0	€ 12
B.f.02	Concrete Rectangular:Column 300x400mm		2			€ 407	€ 320	€ 0	€ 727
B.f.02.01	Formwork	Area	2	7.85 m²	€ 24.24	€ 83	€ 108	€ 0	€ 190
B.f.02.02	Reinforcement	Mass	2	235 kg	€ 1.69	€ 248	€ 151	€ 0	€ 399
B.f.02.03	Concrete cast	Volume	2	0.72 m³	€ 153.26	€ 76	€ 35	€ 0	€ 111
B.f.02.04	Formwork removal	Area	2	7.85 m²	€ 3.43	€ 0	€ 27	€ 0	€ 27
B.f.03	Concrete Rectangular:Column 400x800mm		3			€ 1,388	€ 1,013	€ 0	€ 2,401
B.f.03.01	Formwork	Area	3	19.64 m²	€ 24.24	€ 207	€ 269	€ 0	€ 476
B.f.03.02	Reinforcement	Mass	3	858 kg	€ 1.69	€ 903	€ 549	€ 0	€ 1,453
B.f.03.03	Concrete cast	Volume	3	2.64 m³	€ 153.26	€ 278	€ 127	€ 0	€ 405
B.f.03.04	Formwork removal	Area	3	19.64 m²	€ 3.43	€ 0	€ 67	€ 0	€ 67
C	Walls		127			€ 162,884	€ 44,253	€ 0	€ 207,138
C.a	01. FSLB2		23			€ 55,748	€ 14,964	€ 0	€ 70,712
C.a.01	Basic Wall:Retainig Wall 300mm		7			€ 42,858	€ 11,409	€ 0	€ 54,266
C.a.01.01	Formwork	Area	7	948.13 m²	€ 13.53	€ 9,980	€ 2,844	€ 0	€ 12,825
C.a.01.02	Reinforcement	Mass	7	17,036 kg	€ 1.42	€ 17,933	€ 6,290	€ 0	€ 24,223
C.a.01.03	Concrete cast	Volume	7	141.97 m³	€ 111.26	€ 14,944	€ 852	€ 0	€ 15,796
C.a.01.04	Formwork removal	Area	7	948.13 m²	€ 1.50	€ 0	€ 1,422	€ 0	€ 1,422
C.a.02	Basic Wall:Wall 150mm		1			€ 403	€ 121	€ 0	€ 524
C.a.02.01	Formwork	Area	1	15.16 m²	€ 13.53	€ 160	€ 45	€ 0	€ 205
C.a.02.02	Reinforcement	Mass	1	126 kg	€ 1.42	€ 133	€ 47	€ 0	€ 179
C.a.02.03	Concrete cast	Volume	1	1.05 m³	€ 111.26	€ 111	€ 6	€ 0	€ 117
C.a.02.04	Formwork removal	Area	1	15.16 m²	€ 1.50	€ 0	€ 23	€ 0	€ 23
C.a.03	Basic Wall:Wall 200mm		5			€ 3,260	€ 926	€ 0	€ 4,186
C.a.03.01	Formwork	Area	5	98.57 m²	€ 13.53	€ 1,038	€ 296	€ 0	€ 1,333
C.a.03.02	Reinforcement	Mass	5	1,151 kg	€ 1.42	€ 1,212	€ 425	€ 0	€ 1,637
C.a.03.03	Concrete cast	Volume	5	9.59 m³	€ 111.26	€ 1,010	€ 58	€ 0	€ 1,068
C.a.03.04	Formwork removal	Area	5	98.57 m²	€ 1.50	€ 0	€ 148	€ 0	€ 148
C.a.04	Basic Wall:Wall 250mm		6			€ 5,660	€ 1,561	€ 0	€ 7,220
C.a.04.01	Formwork	Area	6	149.66 m²	€ 13.53	€ 1,575	€ 449	€ 0	€ 2,024
C.a.04.02	Reinforcement	Mass	6	2,116 kg	€ 1.42	€ 2,228	€ 781	€ 0	€ 3,009
C.a.04.03	Concrete cast	Volume	6	17.64 m³	€ 111.26	€ 1,856	€ 106	€ 0	€ 1,962
C.a.04.04	Formwork removal	Area	6	149.66 m²	€ 1.50	€ 0	€ 224	€ 0	€ 224
C.a.05	Basic Wall:Wall 300mm		4			€ 3,568	€ 947	€ 0	€ 4,515
C.a.05.01	Formwork	Area	4	77.71 m²	€ 13.53	€ 818	€ 233	€ 0	€ 1,051
C.a.05.02	Reinforcement	Mass	4	1,425 kg	€ 1.42	€ 1,500	€ 526	€ 0	€ 2,026
C.a.05.03	Concrete cast	Volume	4	11.87 m³	€ 111.26	€ 1,250	€ 71	€ 0	€ 1,321
C.a.05.04	Formwork removal	Area	4	77.71 m²	€ 1.50	€ 0	€ 117	€ 0	€ 117
C.b	02. FSLB1		32			€ 47,511	€ 12,773	€ 0	€ 60,283
C.b.01	Basic Wall:Retainig Wall 300mm		17			€ 38,173	€ 10,168	€ 0	€ 48,341
C.b.01.01	Formwork	Area	17	847.41 m²	€ 13.53	€ 8,920	€ 2,542	€ 0	€ 11,462
C.b.01.02	Reinforcement	Mass	17	15,158 kg	€ 1.42	€ 15,956	€ 5,597	€ 0	€ 21,553
C.b.01.03	Concrete cast	Volume	17	126.32 m³	€ 111.26	€ 13,297	€ 758	€ 0	€ 14,055

Item code	Description	Quantity Type	Item Count	Quantity	Unit Cost	Material Cost	Labour Cost	Equipment Cost	Total Cost
C.b.01.04	Formwork removal	Area	17	847.41 m²	€ 1.50	€ 0	€ 1,271	€ 0	€ 1,271
C.b.02	Basic Wall:Wall 150mm		1			€ 114	€ 33	€ 0	€ 147
C.b.02.01	Formwork	Area	1	3.76 m²	€ 13.53	€ 40	€ 11	€ 0	€ 51
C.b.02.02	Reinforcement	Mass	1	38 kg	€ 1.42	€ 40	€ 14	€ 0	€ 55
C.b.02.03	Concrete cast	Volume	1	0.32 m³	€ 111.26	€ 34	€ 2	€ 0	€ 36
C.b.02.04	Formwork removal	Area	1	3.76 m²	€ 1.50	€ 0	€ 6	€ 0	€ 6
C.b.03	Basic Wall:Wall 200mm		8			€ 4,768	€ 1,354	€ 0	€ 6,121
C.b.03.01	Formwork	Area	8	143.57 m²	€ 13.53	€ 1,511	€ 431	€ 0	€ 1,942
C.b.03.02	Reinforcement	Mass	8	1,688 kg	€ 1.42	€ 1,776	€ 623	€ 0	€ 2,399
C.b.03.03	Concrete cast	Volume	8	14.06 m³	€ 111.26	€ 1,480	€ 84	€ 0	€ 1,565
C.b.03.04	Formwork removal	Area	8	143.57 m²	€ 1.50	€ 0	€ 215	€ 0	€ 215
C.b.04	Basic Wall:Wall 250mm		6			€ 4,456	€ 1,218	€ 0	€ 5,674
C.b.04.01	Formwork	Area	6	112.84 m²	€ 13.53	€ 1,188	€ 339	€ 0	€ 1,526
C.b.04.02	Reinforcement	Mass	6	1,693 kg	€ 1.42	€ 1,783	€ 625	€ 0	€ 2,408
C.b.04.03	Concrete cast	Volume	6	14.11 m³	€ 111.26	€ 1,485	€ 85	€ 0	€ 1,570
C.b.04.04	Formwork removal	Area	6	112.84 m²	€ 1.50	€ 0	€ 169	€ 0	€ 169
C.c	03. FSL00		17			€ 20,367	€ 5,630	€ 0	€ 25,997
C.c.01	Basic Wall:Wall - 250mm		1			€ 1,191	€ 329	€ 0	€ 1,521
C.c.01.01	Formwork	Area	1	31.85 m²	€ 13.53	€ 335	€ 96	€ 0	€ 431
C.c.01.02	Reinforcement	Mass	1	444 kg	€ 1.42	€ 467	€ 164	€ 0	€ 631
C.c.01.03	Concrete cast	Volume	1	3.70 m³	€ 111.26	€ 389	€ 22	€ 0	€ 411
C.c.01.04	Formwork removal	Area	1	31.85 m²	€ 1.50	€ 0	€ 48	€ 0	€ 48
C.c.02	Basic Wall:Wall 150mm		1			€ 538	€ 158	€ 0	€ 696
C.c.02.01	Formwork	Area	1	18.70 m²	€ 13.53	€ 197	€ 56	€ 0	€ 253
C.c.02.02	Reinforcement	Mass	1	177 kg	€ 1.42	€ 186	€ 65	€ 0	€ 251
C.c.02.03	Concrete cast	Volume	1	1.47 m³	€ 111.26	€ 155	€ 9	€ 0	€ 164
C.c.02.04	Formwork removal	Area	1	18.70 m²	€ 1.50	€ 0	€ 28	€ 0	€ 28
C.c.03	Basic Wall:Wall 200mm		5			€ 4,809	€ 1,370	€ 0	€ 6,179
C.c.03.01	Formwork	Area	5	146.74 m²	€ 13.53	€ 1,545	€ 440	€ 0	€ 1,985
C.c.03.02	Reinforcement	Mass	5	1,692 kg	€ 1.42	€ 1,781	€ 625	€ 0	€ 2,406
C.c.03.03	Concrete cast	Volume	5	14.10 m³	€ 111.26	€ 1,484	€ 85	€ 0	€ 1,569
C.c.03.04	Formwork removal	Area	5	146.74 m²	€ 1.50	€ 0	€ 220	€ 0	€ 220
C.c.04	Basic Wall:Wall 250mm		8			€ 10,260	€ 2,815	€ 0	€ 13,076
C.c.04.01	Formwork	Area	8	265.02 m²	€ 13.53	€ 2,790	€ 795	€ 0	€ 3,585
C.c.04.02	Reinforcement	Mass	8	3,871 kg	€ 1.42	€ 4,075	€ 1,429	€ 0	€ 5,504
C.c.04.03	Concrete cast	Volume	8	32.26 m³	€ 111.26	€ 3,396	€ 194	€ 0	€ 3,589
C.c.04.04	Formwork removal	Area	8	265.02 m²	€ 1.50	€ 0	€ 398	€ 0	€ 398
C.c.05	Basic Wall:Wall 300mm		2			€ 3,568	€ 957	€ 0	€ 4,525
C.c.05.01	Formwork	Area	2	82.40 m²	€ 13.53	€ 867	€ 247	€ 0	€ 1,115
C.c.05.02	Reinforcement	Mass	2	1,399 kg	€ 1.42	€ 1,473	€ 517	€ 0	€ 1,990
C.c.05.03	Concrete cast	Volume	2	11.66 m³	€ 111.26	€ 1,228	€ 70	€ 0	€ 1,297
C.c.05.04	Formwork removal	Area	2	82.40 m²	€ 1.50	€ 0	€ 124	€ 0	€ 124
C.d	04. FSL01		13			€ 15,345	€ 4,209	€ 0	€ 19,554
C.d.01	Basic Wall:Wall 150mm		1			€ 437	€ 129	€ 0	€ 566
C.d.01.01	Formwork	Area	1	15.16 m²	€ 13.53	€ 160	€ 45	€ 0	€ 205
C.d.01.02	Reinforcement	Mass	1	144 kg	€ 1.42	€ 151	€ 53	€ 0	€ 204
C.d.01.03	Concrete cast	Volume	1	1.20 m³	€ 111.26	€ 126	€ 7	€ 0	€ 133
C.d.01.04	Formwork removal	Area	1	15.16 m²	€ 1.50	€ 0	€ 23	€ 0	€ 23
C.d.02	Basic Wall:Wall 200mm		2			€ 2,186	€ 620	€ 0	€ 2,806
C.d.02.01	Formwork	Area	2	65.37 m²	€ 13.53	€ 688	€ 196	€ 0	€ 884
C.d.02.02	Reinforcement	Mass	2	776 kg	€ 1.42	€ 817	€ 287	€ 0	€ 1,104
C.d.02.03	Concrete cast	Volume	2	6.47 m³	€ 111.26	€ 681	€ 39	€ 0	€ 720
C.d.02.04	Formwork removal	Area	2	65.37 m²	€ 1.50	€ 0	€ 98	€ 0	€ 98
C.d.03	Basic Wall:Wall 250mm		8			€ 9,184	€ 2,517	€ 0	€ 11,701
C.d.03.01	Formwork	Area	8	235.75 m²	€ 13.53	€ 2,482	€ 707	€ 0	€ 3,189
C.d.03.02	Reinforcement	Mass	8	3,473 kg	€ 1.42	€ 3,656	€ 1,282	€ 0	€ 4,938
C.d.03.03	Concrete cast	Volume	8	28.94 m³	€ 111.26	€ 3,046	€ 174	€ 0	€ 3,220
C.d.03.04	Formwork removal	Area	8	235.75 m²	€ 1.50	€ 0	€ 354	€ 0	€ 354
C.d.04	Basic Wall:Wall 300mm		2			€ 3,538	€ 944	€ 0	€ 4,483
C.d.04.01	Formwork	Area	2	79.43 m²	€ 13.53	€ 836	€ 238	€ 0	€ 1,074
C.d.04.02	Reinforcement	Mass	2	1,400 kg	€ 1.42	€ 1,474	€ 517	€ 0	€ 1,991
C.d.04.03	Concrete cast	Volume	2	11.67 m³	€ 111.26	€ 1,228	€ 70	€ 0	€ 1,298
C.d.04.04	Formwork removal	Area	2	79.43 m²	€ 1.50	€ 0	€ 119	€ 0	€ 119

Item code	Description	Quantity Type	Item Count	Quantity	Unit Cost	Material Cost	Labour Cost	Equipment Cost	Total Cost
C.e	05. FSL02		13			€ 12,713	€ 3,488	€ 0	€ 16,201
C.e.01	Basic Wall:Wall 150mm		1			€ 308	€ 90	€ 0	€ 398
C.e.01.01	Formwork	Area	1	10.60 m²	€ 13.53	€ 112	€ 32	€ 0	€ 143
C.e.01.02	Reinforcement	Mass	1	102 kg	€ 1.42	€ 107	€ 38	€ 0	€ 145
C.e.01.03	Concrete cast	Volume	1	0.85 m³	€ 111.26	€ 89	€ 5	€ 0	€ 94
C.e.01.04	Formwork removal	Area	1	10.60 m²	€ 1.50	€ 0	€ 16	€ 0	€ 16
C.e.02	Basic Wall:Wall 200mm		2			€ 1,809	€ 512	€ 0	€ 2,321
C.e.02.01	Formwork	Area	2	53.92 m²	€ 13.53	€ 568	€ 162	€ 0	€ 729
C.e.02.02	Reinforcement	Mass	2	643 kg	€ 1.42	€ 677	€ 238	€ 0	€ 915
C.e.02.03	Concrete cast	Volume	2	5.36 m³	€ 111.26	€ 564	€ 32	€ 0	€ 596
C.e.02.04	Formwork removal	Area	2	53.92 m²	€ 1.50	€ 0	€ 81	€ 0	€ 81
C.e.03	Basic Wall:Wall 250mm		8			€ 7,655	€ 2,098	€ 0	€ 9,753
C.e.03.01	Formwork	Area	8	196.57 m²	€ 13.53	€ 2,069	€ 590	€ 0	€ 2,659
C.e.03.02	Reinforcement	Mass	8	2,894 kg	€ 1.42	€ 3,047	€ 1,069	€ 0	€ 4,115
C.e.03.03	Concrete cast	Volume	8	24.12 m³	€ 111.26	€ 2,539	€ 145	€ 0	€ 2,684
C.e.03.04	Formwork removal	Area	8	196.57 m²	€ 1.50	€ 0	€ 295	€ 0	€ 295
C.e.04	Basic Wall:Wall 300mm		2			€ 2,941	€ 788	€ 0	€ 3,728
C.e.04.01	Formwork	Area	2	67.18 m²	€ 13.53	€ 707	€ 202	€ 0	€ 909
C.e.04.02	Reinforcement	Mass	2	1,157 kg	€ 1.42	€ 1,218	€ 427	€ 0	€ 1,646
C.e.04.03	Concrete cast	Volume	2	9.64 m³	€ 111.26	€ 1,015	€ 58	€ 0	€ 1,073
C.e.04.04	Formwork removal	Area	2	67.18 m²	€ 1.50	€ 0	€ 101	€ 0	€ 101
C.f	06. FSL03		29			€ 11,201	€ 3,189	€ 0	€ 14,391
C.f.01	Basic Wall:Acroterion 150mm		20			€ 4,797	€ 1,422	€ 0	€ 6,219
C.f.01.01	Formwork	Area	20	171.63 m²	€ 13.53	€ 1,807	€ 515	€ 0	€ 2,322
C.f.01.02	Reinforcement	Mass	20	1,550 kg	€ 1.42	€ 1,631	€ 572	€ 0	€ 2,203
C.f.01.03	Concrete cast	Volume	20	12.91 m³	€ 111.26	€ 1,359	€ 77	€ 0	€ 1,437
C.f.01.04	Formwork removal	Area	20	171.63 m²	€ 1.50	€ 0	€ 257	€ 0	€ 257
C.f.02	Basic Wall:Wall 150mm		1			€ 243	€ 71	€ 0	€ 314
C.f.02.01	Formwork	Area	1	8.32 m²	€ 13.53	€ 88	€ 25	€ 0	€ 113
C.f.02.02	Reinforcement	Mass	1	81 kg	€ 1.42	€ 85	€ 30	€ 0	€ 115
C.f.02.03	Concrete cast	Volume	1	0.67 m³	€ 111.26	€ 71	€ 4	€ 0	€ 75
C.f.02.04	Formwork removal	Area	1	8.32 m²	€ 1.50	€ 0	€ 12	€ 0	€ 12
C.f.03	Basic Wall:Wall 200mm		2			€ 1,102	€ 313	€ 0	€ 1,415
C.f.03.01	Formwork	Area	2	33.05 m²	€ 13.53	€ 348	€ 99	€ 0	€ 447
C.f.03.02	Reinforcement	Mass	2	391 kg	€ 1.42	€ 412	€ 144	€ 0	€ 556
C.f.03.03	Concrete cast	Volume	2	3.26 m³	€ 111.26	€ 343	€ 20	€ 0	€ 363
C.f.03.04	Formwork removal	Area	2	33.05 m²	€ 1.50	€ 0	€ 50	€ 0	€ 50
C.f.04	Basic Wall:Wall 250mm		6			€ 5,059	€ 1,383	€ 0	€ 6,442
C.f.04.01	Formwork	Area	6	128.53 m²	€ 13.53	€ 1,353	€ 386	€ 0	€ 1,738
C.f.04.02	Reinforcement	Mass	6	1,920 kg	€ 1.42	€ 2,021	€ 709	€ 0	€ 2,730
C.f.04.03	Concrete cast	Volume	6	16.00 m³	€ 111.26	€ 1,685	€ 96	€ 0	€ 1,781
C.f.04.04	Formwork removal	Area	6	128.53 m²	€ 1.50	€ 0	€ 193	€ 0	€ 193
D	Beams		38			€ 31,498	€ 25,429	€ 0	€ 56,926
D.a	02. FSLB1		1			€ 252	€ 216	€ 0	€ 468
D.a.01	Concrete - Rectangular Beam:Beam 300x450mm		1			€ 252	€ 216	€ 0	€ 468
D.a.01.01	Formwork	Area	1	5.04 m²	€ 23.33	€ 53	€ 65	€ 0	€ 118
D.a.01.02	Reinforcement	Mass	1	142 kg	€ 1.82	€ 149	€ 109	€ 0	€ 258
D.a.01.03	Concrete cast	Volume	1	0.47 m³	€ 126.60	€ 50	€ 10	€ 0	€ 60
D.a.01.04	Formwork removal	Area	1	5.04 m²	€ 6.40	€ 0	€ 32	€ 0	€ 32
D.b	03. FSL00		12			€ 14,329	€ 11,435	€ 0	€ 25,764
D.b.01	Concrete - Rectangular Beam:Beam 300x850mm		10			€ 10,770	€ 8,656	€ 0	€ 19,425
D.b.01.01	Formwork	Area	10	171.76 m²	€ 23.33	€ 1,808	€ 2,198	€ 0	€ 4,006
D.b.01.02	Reinforcement	Mass	10	6,385 kg	€ 1.82	€ 6,721	€ 4,904	€ 0	€ 11,625
D.b.01.03	Concrete cast	Volume	10	21.28 m³	€ 126.60	€ 2,240	€ 454	€ 0	€ 2,695
D.b.01.04	Formwork removal	Area	10	171.76 m²	€ 6.40	€ 0	€ 1,099	€ 0	€ 1,099
D.b.02	Concrete - Rectangular Beam:Beam 400x700mm		2			€ 3,559	€ 2,780	€ 0	€ 6,339
D.b.02.01	Formwork	Area	2	50.52 m²	€ 23.33	€ 532	€ 647	€ 0	€ 1,179
D.b.02.02	Reinforcement	Mass	2	2,157 kg	€ 1.82	€ 2,270	€ 1,656	€ 0	€ 3,927
D.b.02.03	Concrete cast	Volume	2	7.19 m³	€ 126.60	€ 757	€ 153	€ 0	€ 910
D.b.02.04	Formwork removal	Area	2	50.52 m²	€ 6.40	€ 0	€ 323	€ 0	€ 323
D.c	04. FSL01		7			€ 5,523	€ 4,535	€ 0	€ 10,058
D.c.01	Concrete - Rectangular Beam:Beam 300x500mm		5			€ 3,030	€ 2,552	€ 0	€ 5,583
D.c.01.01	Formwork	Area	5	57.36 m²	€ 23.33	€ 604	€ 734	€ 0	€ 1,338

Item code	Description	Quantity Type	Item Count	Quantity	Unit Cost	Material Cost	Labour Cost	Equipment Cost	Total Cost
D.c.01.02	Reinforcement	Mass	5	1,729 kg	€ 1.82	€ 1,820	€ 1,328	€ 0	€ 3,148
D.c.01.03	Concrete cast	Volume	5	5.76 m³	€ 126.60	€ 607	€ 123	€ 0	€ 730
D.c.01.04	Formwork removal	Area	5	57.36 m²	€ 6.40	€ 0	€ 367	€ 0	€ 367
D.c.02	Concrete - Rectangular Beam:Beam 400x600mm		2			€ 2,493	€ 1,983	€ 0	€ 4,476
D.c.02.01	Formwork	Area	2	38.14 m²	€ 23.33	€ 401	€ 488	€ 0	€ 890
D.c.02.02	Reinforcement	Mass	2	1,490 kg	€ 1.82	€ 1,569	€ 1,144	€ 0	€ 2,713
D.c.02.03	Concrete cast	Volume	2	4.97 m³	€ 126.60	€ 523	€ 106	€ 0	€ 629
D.c.02.04	Formwork removal	Area	2	38.14 m²	€ 6.40	€ 0	€ 244	€ 0	€ 244
D.d	05. FSL02		11			€ 7,428	€ 6,096	€ 0	€ 13,524
D.d.01	Concrete - Rectangular Beam:Beam 300x500mm		5			€ 3,097	€ 2,614	€ 0	€ 5,711
D.d.01.01	Formwork	Area	5	59.04 m²	€ 23.33	€ 622	€ 756	€ 0	€ 1,377
D.d.01.02	Reinforcement	Mass	5	1,764 kg	€ 1.82	€ 1,857	€ 1,355	€ 0	€ 3,212
D.d.01.03	Concrete cast	Volume	5	5.88 m³	€ 126.60	€ 619	€ 125	€ 0	€ 744
D.d.01.04	Formwork removal	Area	5	59.04 m²	€ 6.40	€ 0	€ 378	€ 0	€ 378
D.d.02	Concrete - Rectangular Beam:Beam 400x450mm		4			€ 1,695	€ 1,385	€ 0	€ 3,080
D.d.02.01	Formwork	Area	4	28.73 m²	€ 23.33	€ 302	€ 368	€ 0	€ 670
D.d.02.02	Reinforcement	Mass	4	993 kg	€ 1.82	€ 1,045	€ 762	€ 0	€ 1,807
D.d.02.03	Concrete cast	Volume	4	3.31 m³	€ 126.60	€ 348	€ 71	€ 0	€ 419
D.d.02.04	Formwork removal	Area	4	28.73 m²	€ 6.40	€ 0	€ 184	€ 0	€ 184
D.d.03	Concrete - Rectangular Beam:Beam 400x600mm		2			€ 2,635	€ 2,098	€ 0	€ 4,733
D.d.03.01	Formwork	Area	2	40.46 m²	€ 23.33	€ 426	€ 518	€ 0	€ 944
D.d.03.02	Reinforcement	Mass	2	1,574 kg	€ 1.82	€ 1,657	€ 1,209	€ 0	€ 2,866
D.d.03.03	Concrete cast	Volume	2	5.25 m³	€ 126.60	€ 552	€ 112	€ 0	€ 664
D.d.03.04	Formwork removal	Area	2	40.46 m²	€ 6.40	€ 0	€ 259	€ 0	€ 259
D.e	06. FSL03		7			€ 3,966	€ 3,146	€ 0	€ 7,112
D.e.01	Concrete - Rectangular Beam:Beam 300x500mm		4			€ 1,144	€ 960	€ 0	€ 2,104
D.e.01.01	Formwork	Area	4	21.34 m²	€ 23.33	€ 225	€ 273	€ 0	€ 498
D.e.01.02	Reinforcement	Mass	4	655 kg	€ 1.82	€ 690	€ 503	€ 0	€ 1,193
D.e.01.03	Concrete cast	Volume	4	2.18 m³	€ 126.60	€ 230	€ 47	€ 0	€ 277
D.e.01.04	Formwork removal	Area	4	21.34 m²	€ 6.40	€ 0	€ 137	€ 0	€ 137
D.e.02	Concrete - Rectangular Beam:Beam 400x500mm		1			€ 585	€ 477	€ 0	€ 1,062
D.e.02.01	Formwork	Area	1	9.90 m²	€ 23.33	€ 104	€ 127	€ 0	€ 231
D.e.02.02	Reinforcement	Mass	1	342 kg	€ 1.82	€ 360	€ 263	€ 0	€ 623
D.e.02.03	Concrete cast	Volume	1	1.14 m³	€ 126.60	€ 120	€ 24	€ 0	€ 144
D.e.02.04	Formwork removal	Area	1	9.90 m²	€ 6.40	€ 0	€ 63	€ 0	€ 63
D.e.03	Concrete - Rectangular Beam:Beam 400x850mm		1			€ 1,423	€ 1,093	€ 0	€ 2,516
D.e.03.01	Formwork	Area	1	18.77 m²	€ 23.33	€ 198	€ 240	€ 0	€ 438
D.e.03.02	Reinforcement	Mass	1	873 kg	€ 1.82	€ 919	€ 671	€ 0	€ 1,590
D.e.03.03	Concrete cast	Volume	1	2.91 m³	€ 126.60	€ 306	€ 62	€ 0	€ 368
D.e.03.04	Formwork removal	Area	1	18.77 m²	€ 6.40	€ 0	€ 120	€ 0	€ 120
D.e.04	Concrete - Rectangular Beam:Beam 800x500mm		1			€ 813	€ 616	€ 0	€ 1,430
D.e.04.01	Formwork	Area	1	10.08 m²	€ 23.33	€ 106	€ 129	€ 0	€ 235
D.e.04.02	Reinforcement	Mass	1	504 kg	€ 1.82	€ 531	€ 387	€ 0	€ 918
D.e.04.03	Concrete cast	Volume	1	1.68 m³	€ 126.60	€ 177	€ 36	€ 0	€ 213
D.e.04.04	Formwork removal	Area	1	10.08 m²	€ 6.40	€ 0	€ 65	€ 0	€ 65
E	Slabs		56			€ 313,188	€ 97,059	€ 0	€ 410,248
E.a	01. FSLB2		16			€ 62,883	€ 19,712	€ 0	€ 82,595
E.a.01	Floor:Drop Panel 50cm		10			€ 6,255	€ 1,762	€ 0	€ 8,017
E.a.01.01	Formwork	Area	10	90.24 m²	€ 17.19	€ 950	€ 602	€ 0	€ 1,551
E.a.01.02	Reinforcement	Mass	10	2,640 kg	€ 1.35	€ 2,779	€ 792	€ 0	€ 3,571
E.a.01.03	Concrete cast	Volume	10	24.00 m³	€ 110.60	€ 2,526	€ 128	€ 0	€ 2,654
E.a.01.04	Formwork removal	Area	10	90.24 m²	€ 2.67	€ 0	€ 241	€ 0	€ 241
E.a.02	Floor:Laje Esp. 200mm		2			€ 50,407	€ 16,104	€ 0	€ 66,511
E.a.02.01	Formwork	Area	2	980.67 m²	€ 17.19	€ 10,323	€ 6,538	€ 0	€ 16,861
E.a.02.02	Reinforcement	Mass	2	19,947 kg	€ 1.35	€ 20,996	€ 5,984	€ 0	€ 26,981
E.a.02.03	Concrete cast	Volume	2	181.33 m³	€ 110.60	€ 19,088	€ 967	€ 0	€ 20,055
E.a.02.04	Formwork removal	Area	2	980.67 m²	€ 2.67	€ 0	€ 2,615	€ 0	€ 2,615
E.a.03	Floor:Slab 25cm		4			€ 6,221	€ 1,846	€ 0	€ 8,067
E.a.03.01	Formwork	Area	4	102.16 m²	€ 17.19	€ 1,075	€ 681	€ 0	€ 1,756
E.a.03.02	Reinforcement	Mass	4	2,561 kg	€ 1.35	€ 2,695	€ 768	€ 0	€ 3,463
E.a.03.03	Concrete cast	Volume	4	23.28 m³	€ 110.60	€ 2,450	€ 124	€ 0	€ 2,574
E.a.03.04	Formwork removal	Area	4	102.16 m²	€ 2.67	€ 0	€ 272	€ 0	€ 272
E.b	02. FSLB1		14			€ 69,099	€ 21,535	€ 0	€ 90,634

Item code	Description	Quantity Type	Item Count	Quantity	Unit Cost	Material Cost	Labour Cost	Equipment Cost	Total Cost
E.b.01	Floor:Drop Panel 50cm		10			€ 6,088	€ 1,614	€ 0	€ 7,703
E.b.01.01	Formwork	Area	10	74.40 m²	€ 17.19	€ 783	€ 496	€ 0	€ 1,279
E.b.01.02	Reinforcement	Mass	10	2,640 kg	€ 1.35	€ 2,779	€ 792	€ 0	€ 3,571
E.b.01.03	Concrete cast	Volume	10	24.00 m³	€ 110.60	€ 2,526	€ 128	€ 0	€ 2,654
E.b.01.04	Formwork removal	Area	10	74.40 m²	€ 2.67	€ 0	€ 198	€ 0	€ 198
E.b.02	Floor:Laje Esp. 200mm		3			€ 59,437	€ 18,827	€ 0	€ 78,264
E.b.02.01	Formwork	Area	3	1,134.73 m²	€ 17.19	€ 11,945	€ 7,565	€ 0	€ 19,509
E.b.02.02	Reinforcement	Mass	3	23,633 kg	€ 1.35	€ 24,877	€ 7,090	€ 0	€ 31,967
E.b.02.03	Concrete cast	Volume	3	214.85 m³	€ 110.60	€ 22,615	€ 1,146	€ 0	€ 23,761
E.b.02.04	Formwork removal	Area	3	1,134.73 m²	€ 2.67	€ 0	€ 3,026	€ 0	€ 3,026
E.b.03	Floor:Slab 25cm		1			€ 3,574	€ 1,094	€ 0	€ 4,668
E.b.03.01	Formwork	Area	1	63.16 m²	€ 17.19	€ 665	€ 421	€ 0	€ 1,086
E.b.03.02	Reinforcement	Mass	1	1,447 kg	€ 1.35	€ 1,524	€ 434	€ 0	€ 1,958
E.b.03.03	Concrete cast	Volume	1	13.16 m³	€ 110.60	€ 1,385	€ 70	€ 0	€ 1,455
E.b.03.04	Formwork removal	Area	1	63.16 m²	€ 2.67	€ 0	€ 168	€ 0	€ 168
E.c	03. FSL00		11			€ 57,176	€ 17,773	€ 0	€ 74,949
E.c.01	Floor:Drop Panel 50cm		6			€ 3,640	€ 957	€ 0	€ 4,596
E.c.01.01	Formwork	Area	6	43.36 m²	€ 17.19	€ 456	€ 289	€ 0	€ 745
E.c.01.02	Reinforcement	Mass	6	1,584 kg	€ 1.35	€ 1,667	€ 475	€ 0	€ 2,143
E.c.01.03	Concrete cast	Volume	6	14.40 m³	€ 110.60	€ 1,516	€ 77	€ 0	€ 1,593
E.c.01.04	Formwork removal	Area	6	43.36 m²	€ 2.67	€ 0	€ 116	€ 0	€ 116
E.c.02	Floor:Laje Esp. 200mm		3			€ 44,410	€ 14,079	€ 0	€ 58,489
E.c.02.01	Formwork	Area	3	849.48 m²	€ 17.19	€ 8,942	€ 5,663	€ 0	€ 14,605
E.c.02.02	Reinforcement	Mass	3	17,650 kg	€ 1.35	€ 18,579	€ 5,295	€ 0	€ 23,874
E.c.02.03	Concrete cast	Volume	3	0	€ 110.60	€ 16,890	€ 856	€ 0	€ 17,745
E.c.02.04	Formwork removal	Area	3	849.48 m²	€ 2.67	€ 0	€ 2,265	€ 0	€ 2,265
E.c.03	Floor:Slab 25cm		2			€ 9,127	€ 2,737	€ 0	€ 11,864
E.c.03.01	Formwork	Area	2	153.79 m²	€ 17.19	€ 1,619	€ 1,025	€ 0	€ 2,644
E.c.03.02	Reinforcement	Mass	2	3,736 kg	€ 1.35	€ 3,933	€ 1,121	€ 0	€ 5,054
E.c.03.03	Concrete cast	Volume	2	33.96 m³	€ 110.60	€ 3,575	€ 181	€ 0	€ 3,756
E.c.03.04	Formwork removal	Area	2	153.79 m²	€ 2.67	€ 0	€ 410	€ 0	€ 410
E.d	04. FSL01		7			€ 50,834	€ 15,422	€ 0	€ 66,256
E.d.01	Floor:Drop Panel 50cm		5			€ 11,866	€ 3,029	€ 0	€ 14,894
E.d.01.01	Formwork	Area	5	129.32 m²	€ 17.19	€ 1,361	€ 862	€ 0	€ 2,223
E.d.01.02	Reinforcement	Mass	5	5,227 kg	€ 1.35	€ 5,502	€ 1,568	€ 0	€ 7,070
E.d.01.03	Concrete cast	Volume	5	47.52 m³	€ 110.60	€ 5,002	€ 253	€ 0	€ 5,256
E.d.01.04	Formwork removal	Area	5	129.32 m²	€ 2.67	€ 0	€ 345	€ 0	€ 345
E.d.02	Floor:Laje Esp. 200mm		2			€ 38,968	€ 12,393	€ 0	€ 51,361
E.d.02.01	Formwork	Area	2	750.66 m²	€ 17.19	€ 7,902	€ 5,004	€ 0	€ 12,906
E.d.02.02	Reinforcement	Mass	2	15,459 kg	€ 1.35	€ 16,273	€ 4,638	€ 0	€ 20,911
E.d.02.03	Concrete cast	Volume	2	140.54 m³	€ 110.60	€ 14,793	€ 750	€ 0	€ 15,543
E.d.02.04	Formwork removal	Area	2	750.66 m²	€ 2.67	€ 0	€ 2,002	€ 0	€ 2,002
E.e	05. FSL02		7			€ 61,477	€ 19,280	€ 0	€ 80,757
E.e.01	Floor:Drop Panel 50cm		5			€ 11,901	€ 3,010	€ 0	€ 14,911
E.e.01.01	Formwork	Area	5	125.98 m²	€ 17.19	€ 1,326	€ 840	€ 0	€ 2,166
E.e.01.02	Reinforcement	Mass	5	5,262 kg	€ 1.35	€ 5,539	€ 1,579	€ 0	€ 7,118
E.e.01.03	Concrete cast	Volume	5	47.84 m³	€ 110.60	€ 5,036	€ 255	€ 0	€ 5,291
E.e.01.04	Formwork removal	Area	5	125.98 m²	€ 2.67	€ 0	€ 336	€ 0	€ 336
E.e.02	Floor:Laje Esp. 200mm		2			€ 49,576	€ 16,270	€ 0	€ 65,847
E.e.02.01	Formwork	Area	2	1,022.03 m²	€ 17.19	€ 10,758	€ 6,814	€ 0	€ 17,572
E.e.02.02	Reinforcement	Mass	2	19,317 kg	€ 1.35	€ 20,333	€ 5,795	€ 0	€ 26,128
E.e.02.03	Concrete cast	Volume	2	175.61 m³	€ 110.60	€ 18,485	€ 937	€ 0	€ 19,421
E.e.02.04	Formwork removal	Area	2	1,022.03 m²	€ 2.67	€ 0	€ 2,725	€ 0	€ 2,725
E.f	06. FSL03		1			€ 11,719	€ 3,337	€ 0	€ 15,056
E.f.01	Floor:Slab 25cm		1			€ 11,719	€ 3,337	€ 0	€ 15,056
E.f.01.01	Formwork	Area	1	173.82 m²	€ 17.19	€ 1,830	€ 1,159	€ 0	€ 2,989
E.f.01.02	Reinforcement	Mass	1	4,921 kg	€ 1.35	€ 5,180	€ 1,476	€ 0	€ 6,656
E.f.01.03	Concrete cast	Volume	1	44.74 m³	€ 110.60	€ 4,709	€ 239	€ 0	€ 4,948
E.f.01.04	Formwork removal	Area	1	173.82 m²	€ 2.67	€ 0	€ 464	€ 0	€ 464
F	Stairs		8			€ 5,128	€ 2,974	€ 0	€ 8,102
F.a	02. FSLB1		2			€ 1,915	€ 1,104	€ 0	€ 3,019
F.a.01	JETsj-Stairs		2			€ 1,915	€ 1,104	€ 0	€ 3,019
F.a.01.01	Formwork	Area	2	33.30 m²	€ 21.19	€ 351	€ 355	€ 0	€ 706

Item code	Description	Quantity Type	Item Count	Quantity	Unit Cost	Material Cost	Labour Cost	Equipment Cost	Total Cost
F.a.01.02	Reinforcement	Mass	2	892 kg	€ 1.48	€ 939	€ 381	€ 0	€ 1,319
F.a.01.03	Concrete cast	Volume	2	5.95 m³	€ 137.26	€ 626	€ 190	€ 0	€ 816
F.a.01.04	Formwork removal	Area	2	33.30 m²	€ 5.33	€ 0	€ 178	€ 0	€ 178
F.b	03. FSL00		3			€ 1,661	€ 955	€ 0	€ 2,617
F.b.01	Floor:Slab 25cm		1			€ 404	€ 240	€ 0	€ 644
F.b.01.01	Formwork	Area	1	7.63 m²	€ 21.19	€ 80	€ 81	€ 0	€ 162
F.b.01.02	Reinforcement	Mass	1	185 kg	€ 1.48	€ 194	€ 79	€ 0	€ 273
F.b.01.03	Concrete cast	Volume	1	1.23 m³	€ 137.26	€ 129	€ 39	€ 0	€ 169
F.b.01.04	Formwork removal	Area	1	7.63 m²	€ 5.33	€ 0	€ 41	€ 0	€ 41
F.b.02	JETsj-Stairs		2			€ 1,257	€ 715	€ 0	€ 1,973
F.b.02.01	Formwork	Area	2	21.10 m²	€ 21.19	€ 222	€ 225	€ 0	€ 447
F.b.02.02	Reinforcement	Mass	2	590 kg	€ 1.48	€ 621	€ 252	€ 0	€ 873
F.b.02.03	Concrete cast	Volume	2	3.93 m³	€ 137.26	€ 414	€ 126	€ 0	€ 540
F.b.02.04	Formwork removal	Area	2	21.10 m²	€ 5.33	€ 0	€ 113	€ 0	€ 113
F.c	04. FSL01		3			€ 1,552	€ 915	€ 0	€ 2,467
F.c.01	Floor:Slab 25cm		1			€ 404	€ 240	€ 0	€ 644
F.c.01.01	Formwork	Area	1	7.63 m²	€ 21.19	€ 80	€ 81	€ 0	€ 162
F.c.01.02	Reinforcement	Mass	1	185 kg	€ 1.48	€ 194	€ 79	€ 0	€ 273
F.c.01.03	Concrete cast	Volume	1	1.23 m³	€ 137.26	€ 129	€ 39	€ 0	€ 169
F.c.01.04	Formwork removal	Area	1	7.63 m²	€ 5.33	€ 0	€ 41	€ 0	€ 41
F.c.02	JETsj-Stairs		2			€ 1,148	€ 675	€ 0	€ 1,823
F.c.02.01	Formwork	Area	2	21.10 m²	€ 21.19	€ 222	€ 225	€ 0	€ 447
F.c.02.02	Reinforcement	Mass	2	528 kg	€ 1.48	€ 555	€ 225	€ 0	€ 780
F.c.02.03	Concrete cast	Volume	2	3.52 m³	€ 137.26	€ 370	€ 113	€ 0	€ 483
F.c.02.04	Formwork removal	Area	2	21.10 m²	€ 5.33	€ 0	€ 113	€ 0	€ 113
G	Ground Slab		3			€ 29,568	€ 4,247	€ 0	€ 33,815
G.a	Floor:Ground Slab 15cm		1			€ 25,795	€ 3,119	€ 0	€ 28,913
G.a.01	Reinforcement	Mass	1	9,653 kg	€ 1.25	€ 10,162	€ 1,931	€ 0	€ 12,092
G.a.02	Concrete cast	Volume	1	148.51 m³	€ 113.26	€ 15,633	€ 1,188	€ 0	€ 16,821
G.b	ramp.250		2			€ 3,773	€ 1,128	€ 0	€ 4,901
G.b.01	Formwork	Area	2	63.07 m²	€ 17.19	€ 664	€ 420	€ 0	€ 1,084
G.b.02	Reinforcement	Mass	2	1,547 kg	€ 1.35	€ 1,629	€ 464	€ 0	€ 2,093
G.b.03	Concrete cast	Volume	2	14.07 m³	€ 110.60	€ 1,481	€ 75	€ 0	€ 1,556
G.b.04	Formwork removal	Area	2	63.07 m²	€ 2.67	€ 0	€ 168	€ 0	€ 168

APPENDIX 10: BILL OF QUANTITIES FOR CASE STUDY B: VALUE ENGINEERING OPTION

Item code	Description	Quantity Type	Item count	Quantity	Unit Cost	Material Cost	Labour Cost	Equipment Cost	Total Cost
	Case Study B		341			€ 747,493	€ 205,585	€ 906	€ 953,984
	Value Engineering		341			€ 747,493	€ 205,585	€ 906	€ 953,984
A	Foundations		32			€ 201,564	€ 7,112	€ 906	€ 209,582
A.d	JETsj-SC-Microestacas:Microestacas N80 101.6x9.0 Selagem 5m	Length	18	71.70 m	€ 50.00	€ 3,585	€ 0	€ 0	€ 3,585
A.a	Slabs		3			€ 173,690	€ 5,873	€ 0	€ 179,563
A.a.01	Floor:Foundation_FloatingSlab_1200mm		2			€ 173,564	€ 5,868	€ 0	€ 179,432
A.a.01.01	Reinforcement	Mass	2	26,719 kg	€ 1.11	€ 26,719	€ 3,018	€ 0	€ 29,737
A.a.01.02	Formwork	Area	2	1,324.78 m^2	€ 10.91	€ 13,248	€ 1,211	€ 0	€ 14,459
A.a.01.03	Concrete cast	Volume	2	1,335.97 m^3	€ 101.00	€ 133,597	€ 1,336	€ 0	€ 134,933
A.a.01.04	Formwork removal	Area	2	1,324.78 m^2	€ 0.23	€ 0	€ 303	€ 0	€ 303
A.a.02	Foundation Slab:LF 200		1			€ 126	€ 5	€ 0	€ 131
A.a.02.01	Reinforcement	Mass	1	18 kg	€ 1.11	€ 18	€ 2	€ 0	€ 20
A.a.02.02	Formwork	Area	1	1.75 m^2	€ 10.91	€ 18	€ 2	€ 0	€ 19
A.a.02.03	Concrete cast	Volume	1	0.90 m^3	€ 101.00	€ 90	€ 1	€ 0	€ 91
A.a.02.04	Formwork removal	Area	1	1.75 m^2	€ 0.23	€ 0	€ 0	€ 0	€ 0
A.b	Structural Foundations		4			€ 5,730	€ 730	€ 0	€ 6,461
A.b.01	Wall Foundation:Sc 2400 x 1000 CEN		1			€ 1,250	€ 143	€ 0	€ 1,393
A.b.01.01	Reinforcement	Mass	1	530 kg	€ 1.12	€ 530	€ 64	€ 0	€ 595
A.b.01.02	Formwork	Area	1	9.55 m^2	€ 13.43	€ 96	€ 33	€ 0	€ 128
A.b.01.03	Concrete cast	Volume	1	6.24 m^3	€ 103.20	€ 624	€ 20	€ 0	€ 644
A.b.01.04	Formwork removal	Area	1	9.55 m^2	€ 2.67	€ 0	€ 25	€ 0	€ 25
A.b.02	Wall Foundation:Sc 900 x 900 CEN		3			€ 4,481	€ 588	€ 0	€ 5,068
A.b.02.01	Reinforcement	Mass	3	1,836 kg	€ 1.12	€ 1,836	€ 223	€ 0	€ 2,059
A.b.02.02	Formwork	Area	3	48.45 m^2	€ 13.43	€ 484	€ 166	€ 0	€ 651
A.b.02.03	Concrete cast	Volume	3	21.60 m^3	€ 103.20	€ 2,160	€ 69	€ 0	€ 2,229
A.b.02.04	Formwork removal	Area	3	48.45 m^2	€ 2.67	€ 0	€ 129	€ 0	€ 129
A.c	Walls		4			€ 442	€ 26	€ 0	€ 468
A.c.01	Basic Wall:Retaining - 600mm Concrete		4			€ 442	€ 26	€ 0	€ 468
A.c.01.01	Reinforcement	Mass	4	137 kg	€ 1.11	€ 137	€ 15	€ 0	€ 153
A.c.01.02	Formwork	Area	4	7.62 m^2	€ 10.91	€ 76	€ 7	€ 0	€ 83
A.c.01.03	Concrete cast	Volume	4	2.29 m^3	€ 101.00	€ 229	€ 2	€ 0	€ 231
A.c.01.04	Formwork removal	Area	4	7.62 m^2	€ 0.23	€ 0	€ 2	€ 0	€ 2
A.e	Excavation		3			€ 18,117	€ 483	€ 906	€ 19,506
A.e.01	Reference = EXCAV_Foundation_FloatingSlab_1200mm	Volume	2	1,186.51 m^3	€ 16.15	€ 17,798	€ 475	€ 890	€ 19,162
A.e.02	Reference = EXCAV_Foundation_FloatingSlab_1200mm_ElevatorShaft	Volume	1	20.36 m^3	€ 16.15	€ 305	€ 8	€ 15	€ 329
A.e.03	Reference = EXCAV_Foundation_LF 200	Volume	1	0.90 m^3	€ 16.15	€ 14	€ 0	€ 1	€ 15
B	Columns		81			€ 40,404	€ 29,840	€ 0	€ 70,244
B.a	01. FSLB2		10			€ 4,417	€ 3,140	€ 0	€ 7,557
B.a.01	Concrete Rectangular:Column 400x800mm		10			€ 4,417	€ 3,140	€ 0	€ 7,557
B.a.01.01	Formwork	Area	10	52.80 m^2	€ 24.24	€ 556	€ 724	€ 0	€ 1,280
B.a.01.02	Reinforcement	Mass	10	2,964 kg	€ 1.69	€ 3,120	€ 1,897	€ 0	€ 5,017
B.a.01.03	Concrete cast	Volume	10	7.04 m^3	€ 153.26	€ 741	€ 338	€ 0	€ 1,079
B.a.01.04	Formwork removal	Area	10	52.80 m^2	€ 3.43	€ 0	€ 181	€ 0	€ 181
B.b	02. FSLB1		10			€ 3,705	€ 2,707	€ 0	€ 6,413
B.b.01	Concrete Rectangular:Column 400x800mm		10			€ 3,705	€ 2,707	€ 0	€ 6,413
B.b.01.01	Formwork	Area	10	52.80 m^2	€ 24.24	€ 556	€ 724	€ 0	€ 1,280
B.b.01.02	Reinforcement	Mass	10	2,288 kg	€ 1.69	€ 2,408	€ 1,464	€ 0	€ 3,873
B.b.01.03	Concrete cast	Volume	10	7.04 m^3	€ 153.26	€ 741	€ 338	€ 0	€ 1,079
B.b.01.04	Formwork removal	Area	10	52.80 m^2	€ 3.43	€ 0	€ 181	€ 0	€ 181
B.c	03. FSL00		21			€ 12,874	€ 9,571	€ 0	€ 22,445
B.c.01	Concrete Rectangular:Column 300x800mm		11			€ 5,766	€ 4,378	€ 0	€ 10,144
B.c.01.01	Formwork	Area	11	96.97 m^2	€ 24.24	€ 1,021	€ 1,330	€ 0	€ 2,351
B.c.01.02	Reinforcement	Mass	11	3,448 kg	€ 1.69	€ 3,629	€ 2,206	€ 0	€ 5,836
B.c.01.03	Concrete cast	Volume	11	10.61 m^3	€ 153.26	€ 1,117	€ 509	€ 0	€ 1,626
B.c.01.04	Formwork removal	Area	11	96.97 m^2	€ 3.43	€ 0	€ 332	€ 0	€ 332
B.c.02	Concrete Rectangular:Column 400x800mm		10			€ 7,107	€ 5,193	€ 0	€ 12,301
B.c.02.01	Formwork	Area	10	101.28 m^2	€ 24.24	€ 1,066	€ 1,389	€ 0	€ 2,455
B.c.02.02	Reinforcement	Mass	10	4,389 kg	€ 1.69	€ 4,620	€ 2,809	€ 0	€ 7,429
B.c.02.03	Concrete cast	Volume	10	13.50 m^3	€ 153.26	€ 1,421	€ 648	€ 0	€ 2,070

B.c.02.04	Formwork removal	Area	10	101.28 m^2	€ 3.43	€ 0	€ 347	€ 0	€ 347
B.d	04. FSL01		17			€ 9,574	€ 7,093	€ 0	€ 16,667
B.d.01	Concrete Rectangular:Column 300x800mm		9			€ 4,492	€ 3,413	€ 0	€ 7,905
B.d.01.01	Formwork	Area	9	75.73 m^2	€ 24.24	€ 797	€ 1,039	€ 0	€ 1,836
B.d.01.02	Reinforcement	Mass	9	2,684 kg	€ 1.69	€ 2,825	€ 1,718	€ 0	€ 4,543
B.d.01.03	Concrete cast	Volume	9	8.26 m^3	€ 153.26	€ 869	€ 396	€ 0	€ 1,266
B.d.01.04	Formwork removal	Area	9	75.73 m^2	€ 3.43	€ 0	€ 260	€ 0	€ 260
B.d.02	Concrete Rectangular:Column 400x800mm		8			€ 5,083	€ 3,680	€ 0	€ 8,763
B.d.02.01	Formwork	Area	8	69.40 m^2	€ 24.24	€ 731	€ 952	€ 0	€ 1,682
B.d.02.02	Reinforcement	Mass	8	3,162 kg	€ 1.69	€ 3,328	€ 2,023	€ 0	€ 5,351
B.d.02.03	Concrete cast	Volume	8	9.73 m^3	€ 153.26	€ 1,024	€ 467	€ 0	€ 1,491
B.d.02.04	Formwork removal	Area	8	69.40 m^2	€ 3.43	€ 0	€ 238	€ 0	€ 238
B.e	05. FSL02		17			€ 7,882	€ 5,867	€ 0	€ 13,749
B.e.01	Concrete Rectangular:Column 300x800mm		9			€ 3,705	€ 2,815	€ 0	€ 6,520
B.e.01.01	Formwork	Area	9	62.47 m^2	€ 24.24	€ 658	€ 857	€ 0	€ 1,514
B.e.01.02	Reinforcement	Mass	9	2,214 kg	€ 1.69	€ 2,331	€ 1,417	€ 0	€ 3,748
B.e.01.03	Concrete cast	Volume	9	6.81 m^3	€ 153.26	€ 717	€ 327	€ 0	€ 1,043
B.e.01.04	Formwork removal	Area	9	62.47 m^2	€ 3.43	€ 0	€ 214	€ 0	€ 214
B.e.02	Concrete Rectangular:Column 400x800mm		8			€ 4,177	€ 3,052	€ 0	€ 7,229
B.e.02.01	Formwork	Area	8	59.52 m^2	€ 24.24	€ 627	€ 816	€ 0	€ 1,443
B.e.02.02	Reinforcement	Mass	8	2,579 kg	€ 1.69	€ 2,715	€ 1,651	€ 0	€ 4,366
B.e.02.03	Concrete cast	Volume	8	7.94 m^3	€ 153.26	€ 835	€ 381	€ 0	€ 1,216
B.e.02.04	Formwork removal	Area	8	59.52 m^2	€ 3.43	€ 0	€ 204	€ 0	€ 204
B.f	06. FSL03		6			€ 1,952	€ 1,462	€ 0	€ 3,414
B.f.01	Concrete Rectangular:Column 300x300mm		1			€ 157	€ 130	€ 0	€ 286
B.f.01.01	Formwork	Area	1	3.57 m^2	€ 24.24	€ 38	€ 49	€ 0	€ 87
B.f.01.02	Reinforcement	Mass	1	87 kg	€ 1.69	€ 91	€ 55	€ 0	€ 147
B.f.01.03	Concrete cast	Volume	1	0.27 m^3	€ 153.26	€ 28	€ 13	€ 0	€ 41
B.f.01.04	Formwork removal	Area	1	3.57 m^2	€ 3.43	€ 0	€ 12	€ 0	€ 12
B.f.02	Concrete Rectangular:Column 300x400mm		2			€ 407	€ 320	€ 0	€ 727
B.f.02.01	Formwork	Area	2	7.85 m^2	€ 24.24	€ 83	€ 108	€ 0	€ 190
B.f.02.02	Reinforcement	Mass	2	235 kg	€ 1.69	€ 248	€ 151	€ 0	€ 399
B.f.02.03	Concrete cast	Volume	2	0.72 m^3	€ 153.26	€ 76	€ 35	€ 0	€ 111
B.f.02.04	Formwork removal	Area	2	7.85 m^2	€ 3.43	€ 0	€ 27	€ 0	€ 27
B.f.03	Concrete Rectangular:Column 400x800mm		3			€ 1,388	€ 1,013	€ 0	€ 2,401
B.f.03.01	Formwork	Area	3	19.64 m^2	€ 24.24	€ 207	€ 269	€ 0	€ 476
B.f.03.02	Reinforcement	Mass	3	858 kg	€ 1.69	€ 903	€ 549	€ 0	€ 1,453
B.f.03.03	Concrete cast	Volume	3	2.64 m^3	€ 153.26	€ 278	€ 127	€ 0	€ 405
B.f.03.04	Formwork removal	Area	3	19.64 m^2	€ 3.43	€ 0	€ 67	€ 0	€ 67
C	Walls		124			€ 155,887	€ 42,713	€ 0	€ 198,600
C.a	01. FSLB2		20			€ 48,716	€ 13,410	€ 0	€ 62,126
C.a.01	Basic Wall:Retainig Wall 300mm		7			€ 37,674	€ 10,337	€ 0	€ 48,010
C.a.01.01	Formwork	Area	7	748.95 m^2	€ 13.53	€ 7,884	€ 2,247	€ 0	€ 10,131
C.a.01.02	Reinforcement	Mass	7	17,036 kg	€ 1.42	€ 17,933	€ 6,290	€ 0	€ 24,223
C.a.01.03	Concrete cast	Volume	7	112.64 m^3	€ 111.26	€ 11,857	€ 676	€ 0	€ 12,533
C.a.01.04	Formwork removal	Area	7	748.95 m^2	€ 1.50	€ 0	€ 1,123	€ 0	€ 1,123
C.a.02	Basic Wall:Wall 150mm		1			€ 192	€ 62	€ 0	€ 254
C.a.02.01	Formwork	Area	1	3.00 m^2	€ 13.53	€ 32	€ 9	€ 0	€ 41
C.a.02.02	Reinforcement	Mass	1	126 kg	€ 1.42	€ 133	€ 47	€ 0	€ 179
C.a.02.03	Concrete cast	Volume	1	0.26 m^3	€ 111.26	€ 28	€ 2	€ 0	€ 29
C.a.02.04	Formwork removal	Area	1	3.00 m^2	€ 1.50	€ 0	€ 5	€ 0	€ 5
C.a.03	Basic Wall:Wall 200mm		2			€ 2,466	€ 710	€ 0	€ 3,176
C.a.03.01	Formwork	Area	2	66.15 m^2	€ 13.53	€ 696	€ 198	€ 0	€ 895
C.a.03.02	Reinforcement	Mass	2	1,006 kg	€ 1.42	€ 1,059	€ 371	€ 0	€ 1,430
C.a.03.03	Concrete cast	Volume	2	6.75 m^3	€ 111.26	€ 711	€ 41	€ 0	€ 751
C.a.03.04	Formwork removal	Area	2	66.15 m^2	€ 1.50	€ 0	€ 99	€ 0	€ 99
C.a.04	Basic Wall:Wall 250mm		6			€ 4,850	€ 1,362	€ 0	€ 6,213
C.a.04.01	Formwork	Area	6	110.61 m^2	€ 13.53	€ 1,164	€ 332	€ 0	€ 1,496
C.a.04.02	Reinforcement	Mass	6	2,116 kg	€ 1.42	€ 2,228	€ 781	€ 0	€ 3,009
C.a.04.03	Concrete cast	Volume	6	13.85 m^3	€ 111.26	€ 1,458	€ 83	€ 0	€ 1,541
C.a.04.04	Formwork removal	Area	6	110.61 m^2	€ 1.50	€ 0	€ 166	€ 0	€ 166
C.a.05	Basic Wall:Wall 300mm		4			€ 3,534	€ 939	€ 0	€ 4,473
C.a.05.01	Formwork	Area	4	76.25 m^2	€ 13.53	€ 803	€ 229	€ 0	€ 1,031
C.a.05.02	Reinforcement	Mass	4	1,425 kg	€ 1.42	€ 1,500	€ 526	€ 0	€ 2,026

C.a.05.03	Concrete cast	Volume	4	11.70 m³	€ 111.26	€ 1,231	€ 70	€ 0	€ 1,301
C.a.05.04	Formwork removal	Area	4	76.25 m²	€ 1.50	€ 0	€ 114	€ 0	€ 114
C.b	02. FSLB1		32			€ 47,545	€ 12,787	€ 0	€ 60,332
C.b.01	Basic Wall:Retainig Wall 300mm		17			€ 38,191	€ 10,176	€ 0	€ 48,367
C.b.01.01	Formwork	Area	17	849.13 m²	€ 13.53	€ 8,938	€ 2,547	€ 0	€ 11,486
C.b.01.02	Reinforcement	Mass	17	15,158 kg	€ 1.42	€ 15,956	€ 5,597	€ 0	€ 21,553
C.b.01.03	Concrete cast	Volume	17	126.32 m³	€ 111.26	€ 13,297	€ 758	€ 0	€ 14,055
C.b.01.04	Formwork removal	Area	17	849.13 m²	€ 1.50	€ 0	€ 1,274	€ 0	€ 1,274
C.b.02	Basic Wall:Wall 150mm		1			€ 114	€ 33	€ 0	€ 147
C.b.02.01	Formwork	Area	1	3.76 m²	€ 13.53	€ 40	€ 11	€ 0	€ 51
C.b.02.02	Reinforcement	Mass	1	38 kg	€ 1.42	€ 40	€ 14	€ 0	€ 55
C.b.02.03	Concrete cast	Volume	1	0.32 m³	€ 111.26	€ 34	€ 2	€ 0	€ 36
C.b.02.04	Formwork removal	Area	1	3.76 m²	€ 1.50	€ 0	€ 6	€ 0	€ 6
C.b.03	Basic Wall:Wall 200mm		8			€ 4,770	€ 1,354	€ 0	€ 6,125
C.b.03.01	Formwork	Area	8	143.78 m²	€ 13.53	€ 1,514	€ 431	€ 0	€ 1,945
C.b.03.02	Reinforcement	Mass	8	1,688 kg	€ 1.42	€ 1,776	€ 623	€ 0	€ 2,399
C.b.03.03	Concrete cast	Volume	8	14.06 m³	€ 111.26	€ 1,480	€ 84	€ 0	€ 1,565
C.b.03.04	Formwork removal	Area	8	143.78 m²	€ 1.50	€ 0	€ 216	€ 0	€ 216
C.b.04	Basic Wall:Wall 250mm		6			€ 4,470	€ 1,224	€ 0	€ 5,693
C.b.04.01	Formwork	Area	6	114.14 m²	€ 13.53	€ 1,201	€ 342	€ 0	€ 1,544
C.b.04.02	Reinforcement	Mass	6	1,693 kg	€ 1.42	€ 1,783	€ 625	€ 0	€ 2,408
C.b.04.03	Concrete cast	Volume	6	14.11 m³	€ 111.26	€ 1,485	€ 85	€ 0	€ 1,570
C.b.04.04	Formwork removal	Area	6	114.14 m²	€ 1.50	€ 0	€ 171	€ 0	€ 171
C.c	03. FSL00		17			€ 20,367	€ 5,630	€ 0	€ 25,997
C.c.01	Basic Wall:Wall - 250mm		1			€ 1,191	€ 329	€ 0	€ 1,521
C.c.01.01	Formwork	Area	1	31.85 m²	€ 13.53	€ 335	€ 96	€ 0	€ 431
C.c.01.02	Reinforcement	Mass	1	444 kg	€ 1.42	€ 467	€ 164	€ 0	€ 631
C.c.01.03	Concrete cast	Volume	1	3.70 m³	€ 111.26	€ 389	€ 22	€ 0	€ 411
C.c.01.04	Formwork removal	Area	1	31.85 m²	€ 1.50	€ 0	€ 48	€ 0	€ 48
C.c.02	Basic Wall:Wall 150mm		1			€ 538	€ 158	€ 0	€ 696
C.c.02.01	Formwork	Area	1	18.70 m²	€ 13.53	€ 197	€ 56	€ 0	€ 253
C.c.02.02	Reinforcement	Mass	1	177 kg	€ 1.42	€ 186	€ 65	€ 0	€ 251
C.c.02.03	Concrete cast	Volume	1	1.47 m³	€ 111.26	€ 155	€ 9	€ 0	€ 164
C.c.02.04	Formwork removal	Area	1	18.70 m²	€ 1.50	€ 0	€ 28	€ 0	€ 28
C.c.03	Basic Wall:Wall 200mm		5			€ 4,809	€ 1,370	€ 0	€ 6,179
C.c.03.01	Formwork	Area	5	146.74 m²	€ 13.53	€ 1,545	€ 440	€ 0	€ 1,985
C.c.03.02	Reinforcement	Mass	5	1,692 kg	€ 1.42	€ 1,781	€ 625	€ 0	€ 2,406
C.c.03.03	Concrete cast	Volume	5	14.10 m³	€ 111.26	€ 1,484	€ 85	€ 0	€ 1,569
C.c.03.04	Formwork removal	Area	5	146.74 m²	€ 1.50	€ 0	€ 220	€ 0	€ 220
C.c.04	Basic Wall:Wall 250mm		8			€ 10,260	€ 2,815	€ 0	€ 13,076
C.c.04.01	Formwork	Area	8	265.02 m²	€ 13.53	€ 2,790	€ 795	€ 0	€ 3,585
C.c.04.02	Reinforcement	Mass	8	3,871 kg	€ 1.42	€ 4,075	€ 1,429	€ 0	€ 5,504
C.c.04.03	Concrete cast	Volume	8	32.26 m³	€ 111.26	€ 3,396	€ 194	€ 0	€ 3,589
C.c.04.04	Formwork removal	Area	8	265.02 m²	€ 1.50	€ 0	€ 398	€ 0	€ 398
C.c.05	Basic Wall:Wall 300mm		2			€ 3,568	€ 957	€ 0	€ 4,525
C.c.05.01	Formwork	Area	2	82.40 m²	€ 13.53	€ 867	€ 247	€ 0	€ 1,115
C.c.05.02	Reinforcement	Mass	2	1,399 kg	€ 1.42	€ 1,473	€ 517	€ 0	€ 1,990
C.c.05.03	Concrete cast	Volume	2	11.66 m³	€ 111.26	€ 1,228	€ 70	€ 0	€ 1,297
C.c.05.04	Formwork removal	Area	2	82.40 m²	€ 1.50	€ 0	€ 124	€ 0	€ 124
C.d	04. FSL01		13			€ 15,345	€ 4,209	€ 0	€ 19,554
C.d.01	Basic Wall:Wall 150mm		1			€ 437	€ 129	€ 0	€ 566
C.d.01.01	Formwork	Area	1	15.16 m²	€ 13.53	€ 160	€ 45	€ 0	€ 205
C.d.01.02	Reinforcement	Mass	1	144 kg	€ 1.42	€ 151	€ 53	€ 0	€ 204
C.d.01.03	Concrete cast	Volume	1	1.20 m³	€ 111.26	€ 126	€ 7	€ 0	€ 133
C.d.01.04	Formwork removal	Area	1	15.16 m²	€ 1.50	€ 0	€ 23	€ 0	€ 23
C.d.02	Basic Wall:Wall 200mm		2			€ 2,186	€ 620	€ 0	€ 2,806
C.d.02.01	Formwork	Area	2	65.37 m²	€ 13.53	€ 688	€ 196	€ 0	€ 884
C.d.02.02	Reinforcement	Mass	2	776 kg	€ 1.42	€ 817	€ 287	€ 0	€ 1,104
C.d.02.03	Concrete cast	Volume	2	6.47 m³	€ 111.26	€ 681	€ 39	€ 0	€ 720
C.d.02.04	Formwork removal	Area	2	65.37 m²	€ 1.50	€ 0	€ 98	€ 0	€ 98
C.d.03	Basic Wall:Wall 250mm		8			€ 9,184	€ 2,517	€ 0	€ 11,701
C.d.03.01	Formwork	Area	8	235.75 m²	€ 13.53	€ 2,482	€ 707	€ 0	€ 3,189
C.d.03.02	Reinforcement	Mass	8	3,473 kg	€ 1.42	€ 3,656	€ 1,282	€ 0	€ 4,938
C.d.03.03	Concrete cast	Volume	8	28.94 m³	€ 111.26	€ 3,046	€ 174	€ 0	€ 3,220

C.d.03.04	Formwork removal	Area	8	235.75 m^2	€ 1.50	€ 0	€ 354	€ 0	€ 354
C.d.04	Basic Wall:Wall 300mm		2			€ 3,538	€ 944	€ 0	€ 4,483
C.d.04.01	Formwork	Area	2	79.43 m^2	€ 13.53	€ 836	€ 238	€ 0	€ 1,074
C.d.04.02	Reinforcement	Mass	2	1,400 kg	€ 1.42	€ 1,474	€ 517	€ 0	€ 1,991
C.d.04.03	Concrete cast	Volume	2	11.67 m^3	€ 111.26	€ 1,228	€ 70	€ 0	€ 1,298
C.d.04.04	Formwork removal	Area	2	79.43 m^2	€ 1.50	€ 0	€ 119	€ 0	€ 119
C.e	05. FSL02		13			€ 12,713	€ 3,488	€ 0	€ 16,201
C.e.01	Basic Wall:Wall 150mm		1			€ 308	€ 90	€ 0	€ 398
C.e.01.01	Formwork	Area	1	10.60 m^2	€ 13.53	€ 112	€ 32	€ 0	€ 143
C.e.01.02	Reinforcement	Mass	1	102 kg	€ 1.42	€ 107	€ 38	€ 0	€ 145
C.e.01.03	Concrete cast	Volume	1	0.85 m^3	€ 111.26	€ 89	€ 5	€ 0	€ 94
C.e.01.04	Formwork removal	Area	1	10.60 m^2	€ 1.50	€ 0	€ 16	€ 0	€ 16
C.e.02	Basic Wall:Wall 200mm		2			€ 1,809	€ 512	€ 0	€ 2,321
C.e.02.01	Formwork	Area	2	53.92 m^2	€ 13.53	€ 568	€ 162	€ 0	€ 729
C.e.02.02	Reinforcement	Mass	2	643 kg	€ 1.42	€ 677	€ 238	€ 0	€ 915
C.e.02.03	Concrete cast	Volume	2	5.36 m^3	€ 111.26	€ 564	€ 32	€ 0	€ 596
C.e.02.04	Formwork removal	Area	2	53.92 m^2	€ 1.50	€ 0	€ 81	€ 0	€ 81
C.e.03	Basic Wall:Wall 250mm		8			€ 7,655	€ 2,098	€ 0	€ 9,753
C.e.03.01	Formwork	Area	8	196.57 m^2	€ 13.53	€ 2,069	€ 590	€ 0	€ 2,659
C.e.03.02	Reinforcement	Mass	8	2,894 kg	€ 1.42	€ 3,047	€ 1,069	€ 0	€ 4,115
C.e.03.03	Concrete cast	Volume	8	24.12 m^3	€ 111.26	€ 2,539	€ 145	€ 0	€ 2,684
C.e.03.04	Formwork removal	Area	8	196.57 m^2	€ 1.50	€ 0	€ 295	€ 0	€ 295
C.e.04	Basic Wall:Wall 300mm		2			€ 2,941	€ 788	€ 0	€ 3,728
C.e.04.01	Formwork	Area	2	67.18 m^2	€ 13.53	€ 707	€ 202	€ 0	€ 909
C.e.04.02	Reinforcement	Mass	2	1,157 kg	€ 1.42	€ 1,218	€ 427	€ 0	€ 1,646
C.e.04.03	Concrete cast	Volume	2	9.64 m^3	€ 111.26	€ 1,015	€ 58	€ 0	€ 1,073
C.e.04.04	Formwork removal	Area	2	67.18 m^2	€ 1.50	€ 0	€ 101	€ 0	€ 101
C.f	06. FSL03		29			€ 11,201	€ 3,189	€ 0	€ 14,391
C.f.01	Basic Wall:Acroterion 150mm		20			€ 4,797	€ 1,422	€ 0	€ 6,219
C.f.01.01	Formwork	Area	20	171.63 m^2	€ 13.53	€ 1,807	€ 515	€ 0	€ 2,322
C.f.01.02	Reinforcement	Mass	20	1,550 kg	€ 1.42	€ 1,631	€ 572	€ 0	€ 2,203
C.f.01.03	Concrete cast	Volume	20	12.91 m^3	€ 111.26	€ 1,359	€ 77	€ 0	€ 1,437
C.f.01.04	Formwork removal	Area	20	171.63 m^2	€ 1.50	€ 0	€ 257	€ 0	€ 257
C.f.02	Basic Wall:Wall 150mm		1			€ 243	€ 71	€ 0	€ 314
C.f.02.01	Formwork	Area	1	8.32 m^2	€ 13.53	€ 88	€ 25	€ 0	€ 113
C.f.02.02	Reinforcement	Mass	1	81 kg	€ 1.42	€ 85	€ 30	€ 0	€ 115
C.f.02.03	Concrete cast	Volume	1	0.67 m^3	€ 111.26	€ 71	€ 4	€ 0	€ 75
C.f.02.04	Formwork removal	Area	1	8.32 m^2	€ 1.50	€ 0	€ 12	€ 0	€ 12
C.f.03	Basic Wall:Wall 200mm		2			€ 1,102	€ 313	€ 0	€ 1,415
C.f.03.01	Formwork	Area	2	33.05 m^2	€ 13.53	€ 348	€ 99	€ 0	€ 447
C.f.03.02	Reinforcement	Mass	2	391 kg	€ 1.42	€ 412	€ 144	€ 0	€ 556
C.f.03.03	Concrete cast	Volume	2	3.26 m^3	€ 111.26	€ 343	€ 20	€ 0	€ 363
C.f.03.04	Formwork removal	Area	2	33.05 m^2	€ 1.50	€ 0	€ 50	€ 0	€ 50
C.f.04	Basic Wall:Wall 250mm		6			€ 5,059	€ 1,383	€ 0	€ 6,442
C.f.04.01	Formwork	Area	6	128.53 m^2	€ 13.53	€ 1,353	€ 386	€ 0	€ 1,738
C.f.04.02	Reinforcement	Mass	6	1,920 kg	€ 1.42	€ 2,021	€ 709	€ 0	€ 2,730
C.f.04.03	Concrete cast	Volume	6	16.00 m^3	€ 111.26	€ 1,685	€ 96	€ 0	€ 1,781
C.f.04.04	Formwork removal	Area	6	128.53 m^2	€ 1.50	€ 0	€ 193	€ 0	€ 193
D	Beams		38			€ 31,586	€ 25,586	€ 0	€ 57,173
D.a	02. FSLB1		1			€ 252	€ 216	€ 0	€ 468
D.a.01	Concrete - Rectangular Beam:Beam 300x450mm		1			€ 252	€ 216	€ 0	€ 468
D.a.01.01	Formwork	Area	1	5.04 m^2	€ 23.33	€ 53	€ 65	€ 0	€ 118
D.a.01.02	Reinforcement	Mass	1	142 kg	€ 1.82	€ 149	€ 109	€ 0	€ 258
D.a.01.03	Concrete cast	Volume	1	0.47 m^3	€ 126.60	€ 50	€ 10	€ 0	€ 60
D.a.01.04	Formwork removal	Area	1	5.04 m^2	€ 6.40	€ 0	€ 32	€ 0	€ 32
D.b	03. FSL00		12			€ 14,329	€ 11,435	€ 0	€ 25,764
D.b.01	Concrete - Rectangular Beam:Beam 300x850mm		10			€ 10,770	€ 8,656	€ 0	€ 19,425
D.b.01.01	Formwork	Area	10	171.76 m^2	€ 23.33	€ 1,808	€ 2,198	€ 0	€ 4,006
D.b.01.02	Reinforcement	Mass	10	6,385 kg	€ 1.82	€ 6,721	€ 4,904	€ 0	€ 11,625
D.b.01.03	Concrete cast	Volume	10	21.28 m^3	€ 126.60	€ 2,240	€ 454	€ 0	€ 2,695
D.b.01.04	Formwork removal	Area	10	171.76 m^2	€ 6.40	€ 0	€ 1,099	€ 0	€ 1,099
D.b.02	Concrete - Rectangular Beam:Beam 400x700mm		2			€ 3,559	€ 2,780	€ 0	€ 6,339
D.b.02.01	Formwork	Area	2	50.52 m^2	€ 23.33	€ 532	€ 647	€ 0	€ 1,179
D.b.02.02	Reinforcement	Mass	2	2,157 kg	€ 1.82	€ 2,270	€ 1,656	€ 0	€ 3,927

D.b.02.03	Concrete cast	Volume	2	7.19 m³	€ 126.60	€ 757	€ 153	€ 0	€ 910
D.b.02.04	Formwork removal	Area	2	50.52 m²	€ 6.40	€ 0	€ 323	€ 0	€ 323
D.c	04. FSL01		7			€ 5,523	€ 4,535	€ 0	€ 10,058
D.c.01	Concrete - Rectangular Beam:Beam 300x500mm		5			€ 3,030	€ 2,552	€ 0	€ 5,583
D.c.01.01	Formwork	Area	5	57.36 m²	€ 23.33	€ 604	€ 734	€ 0	€ 1,338
D.c.01.02	Reinforcement	Mass	5	1,729 kg	€ 1.82	€ 1,820	€ 1,328	€ 0	€ 3,148
D.c.01.03	Concrete cast	Volume	5	5.76 m³	€ 126.60	€ 607	€ 123	€ 0	€ 730
D.c.01.04	Formwork removal	Area	5	57.36 m²	€ 6.40	€ 0	€ 367	€ 0	€ 367
D.c.02	Concrete - Rectangular Beam:Beam 400x600mm		2			€ 2,493	€ 1,983	€ 0	€ 4,476
D.c.02.01	Formwork	Area	2	38.14 m²	€ 23.33	€ 401	€ 488	€ 0	€ 890
D.c.02.02	Reinforcement	Mass	2	1,490 kg	€ 1.82	€ 1,569	€ 1,144	€ 0	€ 2,713
D.c.02.03	Concrete cast	Volume	2	4.97 m³	€ 126.60	€ 523	€ 106	€ 0	€ 629
D.c.02.04	Formwork removal	Area	2	38.14 m²	€ 6.40	€ 0	€ 244	€ 0	€ 244
D.d	05. FSL02		11			€ 7,517	€ 6,254	€ 0	€ 13,771
D.d.01	Concrete - Rectangular Beam:Beam 300x500mm		5			€ 3,184	€ 2,771	€ 0	€ 5,955
D.d.01.01	Formwork	Area	5	67.29 m²	€ 23.33	€ 708	€ 861	€ 0	€ 1,570
D.d.01.02	Reinforcement	Mass	5	1,762 kg	€ 1.82	€ 1,855	€ 1,354	€ 0	€ 3,209
D.d.01.03	Concrete cast	Volume	5	5.89 m³	€ 126.60	€ 620	€ 126	€ 0	€ 746
D.d.01.04	Formwork removal	Area	5	67.29 m²	€ 6.40	€ 0	€ 431	€ 0	€ 431
D.d.02	Concrete - Rectangular Beam:Beam 400x450mm		4			€ 1,695	€ 1,385	€ 0	€ 3,080
D.d.02.01	Formwork	Area	4	28.73 m²	€ 23.33	€ 302	€ 368	€ 0	€ 670
D.d.02.02	Reinforcement	Mass	4	993 kg	€ 1.82	€ 1,045	€ 762	€ 0	€ 1,807
D.d.02.03	Concrete cast	Volume	4	3.31 m³	€ 126.60	€ 348	€ 71	€ 0	€ 419
D.d.02.04	Formwork removal	Area	4	28.73 m²	€ 6.40	€ 0	€ 184	€ 0	€ 184
D.d.03	Concrete - Rectangular Beam:Beam 400x600mm		2			€ 2,638	€ 2,098	€ 0	€ 4,736
D.d.03.01	Formwork	Area	2	40.46 m²	€ 23.33	€ 426	€ 518	€ 0	€ 944
D.d.03.02	Reinforcement	Mass	2	1,574 kg	€ 1.82	€ 1,657	€ 1,209	€ 0	€ 2,866
D.d.03.03	Concrete cast	Volume	2	5.27 m³	€ 126.60	€ 555	€ 112	€ 0	€ 667
D.d.03.04	Formwork removal	Area	2	40.46 m²	€ 6.40	€ 0	€ 259	€ 0	€ 259
D.e	06. FSL03		7			€ 3,966	€ 3,146	€ 0	€ 7,112
D.e.01	Concrete - Rectangular Beam:Beam 300x500mm		4			€ 1,144	€ 960	€ 0	€ 2,104
D.e.01.01	Formwork	Area	4	21.34 m²	€ 23.33	€ 225	€ 273	€ 0	€ 498
D.e.01.02	Reinforcement	Mass	4	655 kg	€ 1.82	€ 690	€ 503	€ 0	€ 1,193
D.e.01.03	Concrete cast	Volume	4	2.18 m³	€ 126.60	€ 230	€ 47	€ 0	€ 277
D.e.01.04	Formwork removal	Area	4	21.34 m²	€ 6.40	€ 0	€ 137	€ 0	€ 137
D.e.02	Concrete - Rectangular Beam:Beam 400x500mm		1			€ 585	€ 477	€ 0	€ 1,062
D.e.02.01	Formwork	Area	1	9.90 m²	€ 23.33	€ 104	€ 127	€ 0	€ 231
D.e.02.02	Reinforcement	Mass	1	342 kg	€ 1.82	€ 360	€ 263	€ 0	€ 623
D.e.02.03	Concrete cast	Volume	1	1.14 m³	€ 126.60	€ 120	€ 24	€ 0	€ 144
D.e.02.04	Formwork removal	Area	1	9.90 m²	€ 6.40	€ 0	€ 63	€ 0	€ 63
D.e.03	Concrete - Rectangular Beam:Beam 400x850mm		1			€ 1,423	€ 1,093	€ 0	€ 2,516
D.e.03.01	Formwork	Area	1	18.77 m²	€ 23.33	€ 198	€ 240	€ 0	€ 438
D.e.03.02	Reinforcement	Mass	1	873 kg	€ 1.82	€ 919	€ 671	€ 0	€ 1,590
D.e.03.03	Concrete cast	Volume	1	2.91 m³	€ 126.60	€ 306	€ 62	€ 0	€ 368
D.e.03.04	Formwork removal	Area	1	18.77 m²	€ 6.40	€ 0	€ 120	€ 0	€ 120
D.e.04	Concrete - Rectangular Beam:Beam 800x500mm		1			€ 813	€ 616	€ 0	€ 1,430
D.e.04.01	Formwork	Area	1	10.08 m²	€ 23.33	€ 106	€ 129	€ 0	€ 235
D.e.04.02	Reinforcement	Mass	1	504 kg	€ 1.82	€ 531	€ 387	€ 0	€ 918
D.e.04.03	Concrete cast	Volume	1	1.68 m³	€ 126.60	€ 177	€ 36	€ 0	€ 213
D.e.04.04	Formwork removal	Area	1	10.08 m²	€ 6.40	€ 0	€ 65	€ 0	€ 65
E	Slabs		56			€ 313,207	€ 97,076	€ 0	€ 410,282
E.a	01. FSLB2		16			€ 62,902	€ 19,728	€ 0	€ 82,630
E.a.01	Floor:Drop Panel 50cm		10			€ 6,274	€ 1,779	€ 0	€ 8,052
E.a.01.01	Formwork	Area	10	92.00 m²	€ 17.19	€ 968	€ 613	€ 0	€ 1,582
E.a.01.02	Reinforcement	Mass	10	2,640 kg	€ 1.35	€ 2,779	€ 792	€ 0	€ 3,571
E.a.01.03	Concrete cast	Volume	10	24.00 m³	€ 110.60	€ 2,526	€ 128	€ 0	€ 2,654
E.a.01.04	Formwork removal	Area	10	92.00 m²	€ 2.67	€ 0	€ 245	€ 0	€ 245
E.a.02	Floor:Laje Esp. 200mm		2			€ 50,407	€ 16,104	€ 0	€ 66,511
E.a.02.01	Formwork	Area	2	980.67 m²	€ 17.19	€ 10,323	€ 6,538	€ 0	€ 16,861
E.a.02.02	Reinforcement	Mass	2	19,947 kg	€ 1.35	€ 20,996	€ 5,984	€ 0	€ 26,981
E.a.02.03	Concrete cast	Volume	2	181.33 m³	€ 110.60	€ 19,088	€ 967	€ 0	€ 20,055
E.a.02.04	Formwork removal	Area	2	980.67 m²	€ 2.67	€ 0	€ 2,615	€ 0	€ 2,615
E.a.03	Floor:Slab 25cm		4			€ 6,221	€ 1,846	€ 0	€ 8,067
E.a.03.01	Formwork	Area	4	102.16 m²	€ 17.19	€ 1,075	€ 681	€ 0	€ 1,756

E.a.03.02	Reinforcement	Mass	4	2,561 kg	€ 1.35	€ 2,695	€ 768	€ 0	€ 3,463
E.a.03.03	Concrete cast	Volume	4	23.28 m³	€ 110.60	€ 2,450	€ 124	€ 0	€ 2,574
E.a.03.04	Formwork removal	Area	4	102.16 m²	€ 2.67	€ 0	€ 272	€ 0	€ 272
E.b	02. FSLB1		14			€ 69,099	€ 21,535	€ 0	€ 90,634
E.b.01	Floor:Drop Panel 50cm		10			€ 6,088	€ 1,614	€ 0	€ 7,703
E.b.01.01	Formwork	Area	10	74.40 m²	€ 17.19	€ 783	€ 496	€ 0	€ 1,279
E.b.01.02	Reinforcement	Mass	10	2,640 kg	€ 1.35	€ 2,779	€ 792	€ 0	€ 3,571
E.b.01.03	Concrete cast	Volume	10	24.00 m³	€ 110.60	€ 2,526	€ 128	€ 0	€ 2,654
E.b.01.04	Formwork removal	Area	10	74.40 m²	€ 2.67	€ 0	€ 198	€ 0	€ 198
E.b.02	Floor:Laje Esp. 200mm		3			€ 59,437	€ 18,827	€ 0	€ 78,264
E.b.02.01	Formwork	Area	3	1,134.73 m²	€ 17.19	€ 11,945	€ 7,565	€ 0	€ 19,509
E.b.02.02	Reinforcement	Mass	3	23,633 kg	€ 1.35	€ 24,877	€ 7,090	€ 0	€ 31,967
E.b.02.03	Concrete cast	Volume	3	214.85 m³	€ 110.60	€ 22,615	€ 1,146	€ 0	€ 23,761
E.b.02.04	Formwork removal	Area	3	1,134.73 m²	€ 2.67	€ 0	€ 3,026	€ 0	€ 3,026
E.b.03	Floor:Slab 25cm		1			€ 3,574	€ 1,094	€ 0	€ 4,668
E.b.03.01	Formwork	Area	1	63.16 m²	€ 17.19	€ 665	€ 421	€ 0	€ 1,086
E.b.03.02	Reinforcement	Mass	1	1,447 kg	€ 1.35	€ 1,524	€ 434	€ 0	€ 1,958
E.b.03.03	Concrete cast	Volume	1	13.16 m³	€ 110.60	€ 1,385	€ 70	€ 0	€ 1,455
E.b.03.04	Formwork removal	Area	1	63.16 m²	€ 2.67	€ 0	€ 168	€ 0	€ 168
E.c	03. FSL00		11			€ 57,176	€ 17,773	€ 0	€ 74,949
E.c.01	Floor:Drop Panel 50cm		6			€ 3,640	€ 957	€ 0	€ 4,596
E.c.01.01	Formwork	Area	6	43.36 m²	€ 17.19	€ 456	€ 289	€ 0	€ 745
E.c.01.02	Reinforcement	Mass	6	1,584 kg	€ 1.35	€ 1,667	€ 475	€ 0	€ 2,143
E.c.01.03	Concrete cast	Volume	6	14.40 m³	€ 110.60	€ 1,516	€ 77	€ 0	€ 1,593
E.c.01.04	Formwork removal	Area	6	43.36 m²	€ 2.67	€ 0	€ 116	€ 0	€ 116
E.c.02	Floor:Laje Esp. 200mm		3			€ 44,410	€ 14,079	€ 0	€ 58,489
E.c.02.01	Formwork	Area	3	849.48 m²	€ 17.19	€ 8,942	€ 5,663	€ 0	€ 14,605
E.c.02.02	Reinforcement	Mass	3	17,650 kg	€ 1.35	€ 18,579	€ 5,295	€ 0	€ 23,874
E.c.02.03	Concrete cast	Volume	3	160.45 m³	€ 110.60	€ 16,890	€ 856	€ 0	€ 17,745
E.c.02.04	Formwork removal	Area	3	849.48 m²	€ 2.67	€ 0	€ 2,265	€ 0	€ 2,265
E.c.03	Floor:Slab 25cm		2			€ 9,127	€ 2,737	€ 0	€ 11,864
E.c.03.01	Formwork	Area	2	153.79 m²	€ 17.19	€ 1,619	€ 1,025	€ 0	€ 2,644
E.c.03.02	Reinforcement	Mass	2	3,736 kg	€ 1.35	€ 3,933	€ 1,121	€ 0	€ 5,054
E.c.03.03	Concrete cast	Volume	2	33.96 m³	€ 110.60	€ 3,575	€ 181	€ 0	€ 3,756
E.c.03.04	Formwork removal	Area	2	153.79 m²	€ 2.67	€ 0	€ 410	€ 0	€ 410
E.d	04. FSL01		7			€ 50,834	€ 15,422	€ 0	€ 66,256
E.d.01	Floor:Drop Panel 50cm		5			€ 11,866	€ 3,029	€ 0	€ 14,894
E.d.01.01	Formwork	Area	5	129.32 m²	€ 17.19	€ 1,361	€ 862	€ 0	€ 2,223
E.d.01.02	Reinforcement	Mass	5	5,227 kg	€ 1.35	€ 5,502	€ 1,568	€ 0	€ 7,070
E.d.01.03	Concrete cast	Volume	5	47.52 m³	€ 110.60	€ 5,002	€ 253	€ 0	€ 5,256
E.d.01.04	Formwork removal	Area	5	129.32 m²	€ 2.67	€ 0	€ 345	€ 0	€ 345
E.d.02	Floor:Laje Esp. 200mm		2			€ 38,968	€ 12,393	€ 0	€ 51,361
E.d.02.01	Formwork	Area	2	750.66 m²	€ 17.19	€ 7,902	€ 5,004	€ 0	€ 12,906
E.d.02.02	Reinforcement	Mass	2	15,459 kg	€ 1.35	€ 16,273	€ 4,638	€ 0	€ 20,911
E.d.02.03	Concrete cast	Volume	2	140.54 m³	€ 110.60	€ 14,793	€ 750	€ 0	€ 15,543
E.d.02.04	Formwork removal	Area	2	750.66 m²	€ 2.67	€ 0	€ 2,002	€ 0	€ 2,002
E.e	05. FSL02		7			€ 61,477	€ 19,280	€ 0	€ 80,757
E.e.01	Floor:Drop Panel 50cm		5			€ 11,901	€ 3,010	€ 0	€ 14,911
E.e.01.01	Formwork	Area	5	125.98 m²	€ 17.19	€ 1,326	€ 840	€ 0	€ 2,166
E.e.01.02	Reinforcement	Mass	5	5,262 kg	€ 1.35	€ 5,539	€ 1,579	€ 0	€ 7,118
E.e.01.03	Concrete cast	Volume	5	47.84 m³	€ 110.60	€ 5,036	€ 255	€ 0	€ 5,291
E.e.01.04	Formwork removal	Area	5	125.98 m²	€ 2.67	€ 0	€ 336	€ 0	€ 336
E.e.02	Floor:Laje Esp. 200mm		2			€ 49,576	€ 16,270	€ 0	€ 65,847
E.e.02.01	Formwork	Area	2	1,022.03 m²	€ 17.19	€ 10,758	€ 6,814	€ 0	€ 17,572
E.e.02.02	Reinforcement	Mass	2	19,317 kg	€ 1.35	€ 20,333	€ 5,795	€ 0	€ 26,128
E.e.02.03	Concrete cast	Volume	2	175.61 m³	€ 110.60	€ 18,485	€ 937	€ 0	€ 19,421
E.e.02.04	Formwork removal	Area	2	1,022.03 m²	€ 2.67	€ 0	€ 2,725	€ 0	€ 2,725
E.f	06. FSL03		1			€ 11,719	€ 3,337	€ 0	€ 15,056
E.f.01	Floor:Slab 25cm		1			€ 11,719	€ 3,337	€ 0	€ 15,056
E.f.01.01	Formwork	Area	1	173.82 m²	€ 17.19	€ 1,830	€ 1,159	€ 0	€ 2,989
E.f.01.02	Reinforcement	Mass	1	4,921 kg	€ 1.35	€ 5,180	€ 1,476	€ 0	€ 6,656
E.f.01.03	Concrete cast	Volume	1	44.74 m³	€ 110.60	€ 4,709	€ 239	€ 0	€ 4,948
E.f.01.04	Formwork removal	Area	1	173.82 m²	€ 2.67	€ 0	€ 464	€ 0	€ 464
F	Stairs		8			€ 5,128	€ 2,974	€ 0	€ 8,102

F.a	02. FSLB1		2			€ 1,915	€ 1,104	€ 0	€ 3,019
F.a.01	JETsj-Stairs		2			€ 1,915	€ 1,104	€ 0	€ 3,019
F.a.01.01	Formwork	Area	2	33.30 m²	€ 21.19	€ 351	€ 355	€ 0	€ 706
F.a.01.02	Reinforcement	Mass	2	892 kg	€ 1.48	€ 939	€ 381	€ 0	€ 1,319
F.a.01.03	Concrete cast	Volume	2	5.95 m³	€ 137.26	€ 626	€ 190	€ 0	€ 816
F.a.01.04	Formwork removal	Area	2	33.30 m²	€ 5.33	€ 0	€ 178	€ 0	€ 178
F.b	03. FSL00		3			€ 1,661	€ 955	€ 0	€ 2,617
F.b.01	Floor:Slab 25cm		1			€ 404	€ 240	€ 0	€ 644
F.b.01.01	Formwork	Area	1	7.63 m²	€ 21.19	€ 80	€ 81	€ 0	€ 162
F.b.01.02	Reinforcement	Mass	1	185 kg	€ 1.48	€ 194	€ 79	€ 0	€ 273
F.b.01.03	Concrete cast	Volume	1	1.23 m³	€ 137.26	€ 129	€ 39	€ 0	€ 169
F.b.01.04	Formwork removal	Area	1	7.63 m²	€ 5.33	€ 0	€ 41	€ 0	€ 41
F.b.02	JETsj-Stairs		2			€ 1,257	€ 715	€ 0	€ 1,973
F.b.02.01	Formwork	Area	2	21.10 m²	€ 21.19	€ 222	€ 225	€ 0	€ 447
F.b.02.02	Reinforcement	Mass	2	590 kg	€ 1.48	€ 621	€ 252	€ 0	€ 873
F.b.02.03	Concrete cast	Volume	2	3.93 m³	€ 137.26	€ 414	€ 126	€ 0	€ 540
F.b.02.04	Formwork removal	Area	2	21.10 m²	€ 5.33	€ 0	€ 113	€ 0	€ 113
F.c	04. FSL01		3			€ 1,552	€ 915	€ 0	€ 2,467
F.c.01	Floor:Slab 25cm		1			€ 404	€ 240	€ 0	€ 644
F.c.01.01	Formwork	Area	1	7.63 m²	€ 21.19	€ 80	€ 81	€ 0	€ 162
F.c.01.02	Reinforcement	Mass	1	185 kg	€ 1.48	€ 194	€ 79	€ 0	€ 273
F.c.01.03	Concrete cast	Volume	1	1.23 m³	€ 137.26	€ 129	€ 39	€ 0	€ 169
F.c.01.04	Formwork removal	Area	1	7.63 m²	€ 5.33	€ 0	€ 41	€ 0	€ 41
F.c.02	JETsj-Stairs		2			€ 1,148	€ 675	€ 0	€ 1,823
F.c.02.01	Formwork	Area	2	21.10 m²	€ 21.19	€ 222	€ 225	€ 0	€ 447
F.c.02.02	Reinforcement	Mass	2	528 kg	€ 1.48	€ 555	€ 225	€ 0	€ 780
F.c.02.03	Concrete cast	Volume	2	3.52 m³	€ 137.26	€ 370	€ 113	€ 0	€ 483
F.c.02.04	Formwork removal	Area	2	21.10 m²	€ 5.33	€ 0	€ 113	€ 0	€ 113
G	Ground Slab		2			€ 3,773	€ 1,128	€ 0	€ 4,901
G.a	ramp.250		2			€ 3,773	€ 1,128	€ 0	€ 4,901
G.a.01	Formwork	Area	2	63.07 m²	€ 17.19	€ 664	€ 420	€ 0	€ 1,084
G.a.02	Reinforcement	Mass	2	1,547 kg	€ 1.35	€ 1,629	€ 464	€ 0	€ 2,093
G.a.03	Concrete cast	Volume	2	14.07 m³	€ 110.60	€ 1,481	€ 75	€ 0	€ 1,556
G.a.04	Formwork removal	Area	2	63.07 m²	€ 2.67	€ 0	€ 168	€ 0	€ 168

APPENDIX 11: RESOURCES DEFINED FOR THE COST ESTIMATION IN CASE STUDY C

Code	Type	Quantity Type	Unit	Unit Cost
CT_A100 ICT Ladder_650x100	Material	Length	m	€ 37.17
CT_A100 Network Trunking_150x150	Material	Length	m	€ 15.92
CT_A100 Network Trunking_150x75	Material	Length	m	€ 10.29
CT_ATS Ladder_350x125	Material	Length	m	€ 26.54
CT_BMS Tray_100x100	Material	Length	m	€ 9.67
CT_BMS Tray_225x50	Material	Length	m	€ 10.29
CT_BMS Tray_300x100	Material	Length	m	€ 19.67
CT_BMS Tray_75x50	Material	Length	m	€ 6.54
CT_Control Ladder_200x125	Material	Length	m	€ 17.17
CT_Data Trunking_150x75	Material	Length	m	€ 10.29
CT_Drip Tray_200x50	Material	Length	m	€ 9.67
CT_Drip Tray_300x50	Material	Length	m	€ 12.17
CT_Drip Tray_400x50	Material	Length	m	€ 14.67
CT_Drip Tray_450x50	Material	Length	m	€ 15.92
CT_Drip Tray_500x50	Material	Length	m	€ 17.17
CT_Drip Tray_600x50	Material	Length	m	€ 19.67
CT_Drip Tray_800x50	Material	Length	m	€ 24.67
CT_DX Tray_1050x50	Material	Length	m	€ 30.92
CT_DX Tray_1200x50	Material	Length	m	€ 34.67
CT_DX Tray_1500x100	Material	Length	m	€ 79.67
CT_DX Tray_1500x50	Material	Length	m	€ 42.17
CT_DX Tray_150x50	Material	Length	m	€ 8.42
CT_DX Tray_200x50	Material	Length	m	€ 9.67
CT_DX Tray_225x50	Material	Length	m	€ 10.29
CT_DX Tray_300x100	Material	Length	m	€ 19.67
CT_DX Tray_300x50	Material	Length	m	€ 12.17
CT_DX Tray_400x50	Material	Length	m	€ 14.67
CT_DX Tray_450x50	Material	Length	m	€ 15.92
CT_DX Tray_50x400	Material	Length	m	€ 14.67
CT_DX Tray_600x100	Material	Length	m	€ 34.67
CT_DX Tray_600x50	Material	Length	m	€ 19.67
CT_DX Tray_750x50	Material	Length	m	€ 23.42
CT_DX Tray_900x50	Material	Length	m	€ 27.17
CT_ELV Basket_100x50	Material	Length	m	€ 7.17
CT_ELV Basket_225x50	Material	Length	m	€ 10.29
CT_ELV Basket_300x50	Material	Length	m	€ 12.17
CT_ELV Basket_450x100	Material	Length	m	€ 27.17
CT_ELV Basket_50x50	Material	Length	m	€ 5.92

CT_FA Basket_100x50	Material	Length	m	€ 7.17
CT_FA Basket_125x50	Material	Length	m	€ 7.79
CT_FA Basket_150x100	Material	Length	m	€ 12.17
CT_FA Basket_200x100	Material	Length	m	€ 14.67
CT_FA Basket_200x50	Material	Length	m	€ 9.67
CT_FA Basket_300x100	Material	Length	m	€ 19.67
CT_FA Basket_50x100	Material	Length	m	€ 7.17
CT_FA Basket_50x50	Material	Length	m	€ 5.92
CT_FA Tray_200x50	Material	Length	m	€ 9.67
CT_FA Tray_400x50	Material	Length	m	€ 14.67
CT_FA Tray_50x50	Material	Length	m	€ 5.92
CT_HV Gen Supply A Ladder_350x100	Material	Length	m	€ 22.17
CT_HV Gen Supply A Ladder_500x100	Material	Length	m	€ 29.67
CT_ICT A Ladder_650x100	Material	Length	m	€ 37.17
CT_ICT B Ladder_650x100	Material	Length	m	€ 37.17
CT_Inter-Hall Networking Trunking_150x150	Material	Length	m	€ 15.92
CT_L&SP Trunking_100x100	Material	Length	m	€ 9.67
CT_L&SP Trunking_50x50	Material	Length	m	€ 5.92
CT_LV Critical Ladder_650x100	Material	Length	m	€ 37.17
CT_LV Critical Ladder_650x125	Material	Length	m	€ 45.29
CT_LV Critical Ladder_950x125	Material	Length	m	€ 64.04
CT_LV Essential Ladder_950x100	Material	Length	m	€ 52.17
CT_LV Essential Ladder_950x125	Material	Length	m	€ 64.04
CT_LV Supply A Ladder_500x125	Material	Length	m	€ 35.92
CT_LV Supply A Ladder_900x125	Material	Length	m	€ 60.92
CT_LV Supply A Ladder_950x125	Material	Length	m	€ 64.04
CT_LV Supply B Ladder_900x125	Material	Length	m	€ 60.92
CT_LV Supply B Ladder_950x125	Material	Length	m	€ 64.04
CT_LV Supply Ladder_200x100	Material	Length	m	€ 14.67
CT_LV Supply Ladder_200x125	Material	Length	m	€ 17.17
CT_LV Supply Ladder_275x100	Material	Length	m	€ 18.42
CT_LV Supply Ladder_300x125	Material	Length	m	€ 23.42
CT_LV Supply Ladder_350x100	Material	Length	m	€ 22.17
CT_LV Supply Ladder_350x125	Material	Length	m	€ 26.54
CT_LV Supply Ladder_500x125	Material	Length	m	€ 35.92
CT_LV Supply Ladder_650x100	Material	Length	m	€ 37.17
CT_LV Supply Ladder_950x125	Material	Length	m	€ 64.04
CT_LV Supply to Batteries Ladder_450x125	Material	Length	m	€ 32.79
CT_LV Supply to Batteries Ladder_500x125	Material	Length	m	€ 35.92
CT_LV Supply to Batteries Ladder_650x100	Material	Length	m	€ 37.17
CT_LV Supply to Batteries Ladder_900x125	Material	Length	m	€ 60.92
CT_LV Supply to Batteries Ladder_950x125	Material	Length	m	€ 64.04
CT_LV Supply Tray_200x50	Material	Length	m	€ 9.67
CT_LV Supply Tray_300x50	Material	Length	m	€ 12.17
CT_LV Supply Tray_600x50	Material	Length	m	€ 19.67
CT_LV Trunking_100x50	Material	Length	m	€ 7.17

CT_LV Trunking_225x50	Material	Length	m	€ 10.29
CT_LV Trunking_300x50	Material	Length	m	€ 12.17
CT_LV Trunking_50x50	Material	Length	m	€ 5.92
CT_MV Gen Phase 1 Ladder_200x125	Material	Length	m	€ 17.17
CT_MV Gen Phase 1 Ladder_350x100	Material	Length	m	€ 22.17
CT_MV Gen Phase 1 Ladder_350x125	Material	Length	m	€ 26.54
CT_MV Gen Phase 1 Ladder_500x100	Material	Length	m	€ 29.67
CT_MV Gen Phase 1 Ladder_650x125	Material	Length	m	€ 45.29
CT_MV Gen Phase 2 Ladder_200x125	Material	Length	m	€ 17.17
CT_MV Gen Phase 2 Ladder_650x125	Material	Length	m	€ 45.29
CT_MV Supply A Ladder_200x125	Material	Length	m	€ 17.17
CT_MV Supply A Ladder_350x125	Material	Length	m	€ 26.54
CT_MV Supply A Ladder_650x125	Material	Length	m	€ 45.29
CT_MV Supply B Ladder_200x125	Material	Length	m	€ 17.17
CT_MV Supply B Ladder_350x125	Material	Length	m	€ 26.54
CT_MV Supply B Ladder_650x125	Material	Length	m	€ 45.29
CT_Power Ladder_200x125	Material	Length	m	€ 17.17
CT_Power Ladder_350x125	Material	Length	m	€ 26.54
CT_Power Ladder_500x125	Material	Length	m	€ 35.92
CT_Power Ladder_650x125	Material	Length	m	€ 45.29
CT_Power Ladder_950x100	Material	Length	m	€ 52.17
CT_Power Ladder_950x125	Material	Length	m	€ 64.04
CT_Protective Ramp_210x65	Material	Length	m	€ 11.49
CT_PV Tray_150x100	Material	Length	m	€ 12.17
CT_PV Tray_300x100	Material	Length	m	€ 19.67
CT_Security Basket_100x50	Material	Length	m	€ 7.17
CT_Security Basket_125x100	Material	Length	m	€ 10.92
CT_Security Basket_150x100	Material	Length	m	€ 12.17
CT_Security Basket_450x100	Material	Length	m	€ 27.17
CT_Security Basket_500x100	Material	Length	m	€ 29.67
CT_Security Basket_50x100	Material	Length	m	€ 7.17
CT_Security Basket_50x50	Material	Length	m	€ 5.92
CT_Security Basket_75x50	Material	Length	m	€ 6.54
CT_Small Power Tray_100x50	Material	Length	m	€ 7.17
CT_Small Power Tray_125x100	Material	Length	m	€ 10.92
CT_Small Power Tray_150x125	Material	Length	m	€ 14.04
CT_Small Power Tray_150x50	Material	Length	m	€ 8.42
CT_Small Power Tray_200x100	Material	Length	m	€ 14.67
CT_Small Power Tray_200x125	Material	Length	m	€ 17.17
CT_Small Power Tray_200x50	Material	Length	m	€ 9.67
CT_Small Power Tray_225x50	Material	Length	m	€ 10.29
CT_Small Power Tray_300x100	Material	Length	m	€ 19.67
CT_Small Power Tray_300x50	Material	Length	m	€ 12.17
CT_Small Power Tray_400x100	Material	Length	m	€ 24.67
CT_Small Power Tray_50x100	Material	Length	m	€ 7.17
CT_Small Power Tray_50x125	Material	Length	m	€ 7.79

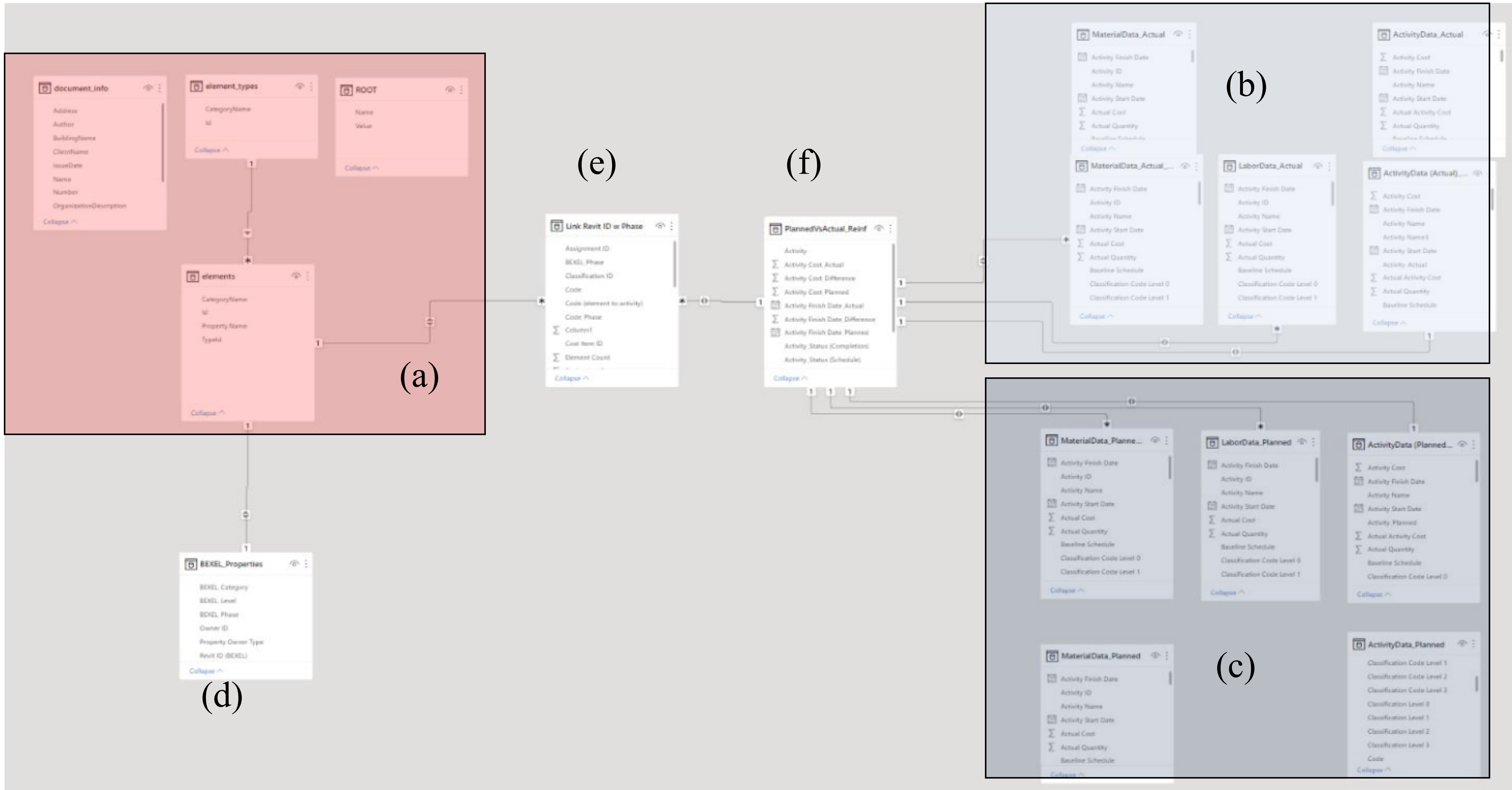
CT_Small Power Tray_50x50	Material	Length	m	€ 5.92
CT_Small Power Tray_75x50	Material	Length	m	€ 6.54
CT_VRF Tray_150x50	Material	Length	m	€ 8.42
CT_VRF Tray_225x100	Material	Length	m	€ 15.92
CT_VRF Tray_225x50	Material	Length	m	€ 10.29
CT_VRF Tray_300x100	Material	Length	m	€ 19.67
CT_VRF Tray_450x100	Material	Length	m	€ 27.17
CT_VRF Tray_450x50	Material	Length	m	€ 15.92
CT_VRF Tray_500x100	Material	Length	m	€ 29.67
CT_VRF Tray_600x100	Material	Length	m	€ 34.67
CT_VRF Tray_750x100	Material	Length	m	€ 42.17
CT_VRF Tray_900x100	Material	Length	m	€ 49.67
CTF_A100 ICT Ladder_650x100	Material	Numeric		€ 18.58
CTF_A100 Network Trunking_150x150	Material	Numeric		€ 7.96
CTF_A100 Network Trunking_150x75-	Material	Numeric		€ 5.15
CTF_BMS Tray_100x100	Material	Numeric		€ 4.83
CTF_BMS Tray_225x50-	Material	Numeric		€ 5.15
CTF_BMS Tray_300x100	Material	Numeric		€ 9.83
CTF_BMS Tray_50x75-7	Material	Numeric		€ 3.27
CTF_BMS Tray_75x50-7	Material	Numeric		€ 3.27
CTF_Data Trunking_150x75-	Material	Numeric		€ 5.15
CTF_Drip Tray_600x50-	Material	Numeric		€ 9.83
CTF_DX Tray_100x600	Material	Numeric		€ 17.33
CTF_DX Tray_1200x50	Material	Numeric		€ 17.33
CTF_DX Tray_1500x50	Material	Numeric		€ 21.08
CTF_DX Tray_150x50-	Material	Numeric		€ 4.21
CTF_DX Tray_200x50-	Material	Numeric		€ 4.83
CTF_DX Tray_225x50-	Material	Numeric		€ 5.15
CTF_DX Tray_300x50-	Material	Numeric		€ 6.08
CTF_DX Tray_400x50-	Material	Numeric		€ 7.33
CTF_DX Tray_450x50-	Material	Numeric		€ 7.96
CTF_DX Tray_50x300-	Material	Numeric		€ 6.08
CTF_DX Tray_50x400-	Material	Numeric		€ 7.33
CTF_DX Tray_600x100	Material	Numeric		€ 17.33
CTF_DX Tray_600x50-	Material	Numeric		€ 9.83
CTF_DX Tray_750x50-	Material	Numeric		€ 11.71
CTF_DX Tray_900x50-	Material	Numeric		€ 13.58
CTF_ELV Basket_100x450	Material	Numeric		€ 13.58
CTF_ELV Basket_100x50-	Material	Numeric		€ 3.58
CTF_ELV Basket_225x50-	Material	Numeric		€ 5.15
CTF_ELV Basket_300x50-	Material	Numeric		€ 6.08
CTF_ELV Basket_50x100-	Material	Numeric		€ 3.58
CTF_ELV Basket_50x50-5	Material	Numeric		€ 2.96
CTF_FA Basket_100x100	Material	Numeric		€ 4.83
CTF_FA Basket_100x50-	Material	Numeric		€ 3.58
CTF_FA Basket_125x100	Material	Numeric		€ 5.46

CTF_FA Basket_125x50-	Material	Numeric	€ 3.90
CTF_FA Basket_150x100	Material	Numeric	€ 6.08
CTF_FA Basket_150x50-	Material	Numeric	€ 4.21
CTF_FA Basket_200x100	Material	Numeric	€ 0.00
CTF_FA Basket_200x50-	Material	Numeric	€ 4.83
CTF_FA Basket_300x100	Material	Numeric	€ 9.83
CTF_FA Basket_500x100	Material	Numeric	€ 14.83
CTF_FA Basket_50x100-	Material	Numeric	€ 3.58
CTF_FA Basket_50x50-5	Material	Numeric	€ 2.96
CTF_FA Tray_200x50-	Material	Numeric	€ 4.83
CTF_FA Tray_400x50-	Material	Numeric	€ 7.33
CTF_FA Tray_50x50-5	Material	Numeric	€ 2.96
CTF_HV Gen Supply A Ladder_100x500	Material	Numeric	€ 14.83
CTF_HV Gen Supply A Ladder_350x100	Material	Numeric	€ 11.08
CTF_HV Gen Supply A Ladder_500x100	Material	Numeric	€ 14.83
CTF_ICT A Ladder_650x100	Material	Numeric	€ 18.58
CTF_ICT B Ladder_650x100	Material	Numeric	€ 18.58
CTF_Inter-Hall Network Trunking_150x150	Material	Numeric	€ 7.96
CTF_L&SP Trunking_50x50-5	Material	Numeric	€ 2.96
CTF_LV Critical Ladder_650x100	Material	Numeric	€ 18.58
CTF_LV Critical Ladder_650x125	Material	Numeric	€ 22.65
CTF_LV Critical Ladder_950x125	Material	Numeric	€ 32.02
CTF_LV Essential Ladder_950x100	Material	Numeric	€ 26.08
CTF_LV Essential Ladder_950x125	Material	Numeric	€ 32.02
CTF_LV Supply A Ladder_500x125	Material	Numeric	€ 17.96
CTF_LV Supply A Ladder_900x125	Material	Numeric	€ 30.46
CTF_LV Supply A Ladder_950x125	Material	Numeric	€ 32.02
CTF_LV Supply B Ladder_900x125	Material	Numeric	€ 30.46
CTF_LV Supply B Ladder_950x125	Material	Numeric	€ 32.02
CTF_LV Supply Ladder_125x200	Material	Numeric	€ 8.58
CTF_LV Supply Ladder_125x350	Material	Numeric	€ 13.27
CTF_LV Supply Ladder_125x500	Material	Numeric	€ 17.96
CTF_LV Supply Ladder_200x125	Material	Numeric	€ 8.58
CTF_LV Supply Ladder_300x125	Material	Numeric	€ 11.71
CTF_LV Supply Ladder_350x100	Material	Numeric	€ 11.08
CTF_LV Supply Ladder_350x125	Material	Numeric	€ 13.27
CTF_LV Supply Ladder_500x125	Material	Numeric	€ 17.96
CTF_LV Supply Ladder_650x100	Material	Numeric	€ 18.58
CTF_LV Supply Ladder_950x125	Material	Numeric	€ 32.02
CTF_LV Supply to Batteries Ladder_450x125	Material	Numeric	€ 16.40
CTF_LV Supply to Batteries Ladder_500x125	Material	Numeric	€ 17.96
CTF_LV Supply to Batteries Ladder_650x100	Material	Numeric	€ 18.58
CTF_LV Supply to Batteries Ladder_900x125	Material	Numeric	€ 30.46
CTF_LV Supply to Batteries Ladder_950x125	Material	Numeric	€ 32.02
CTF_LV Supply Tray_150x100	Material	Numeric	€ 6.08
CTF_LV Supply Tray_200x50-	Material	Numeric	€ 4.83

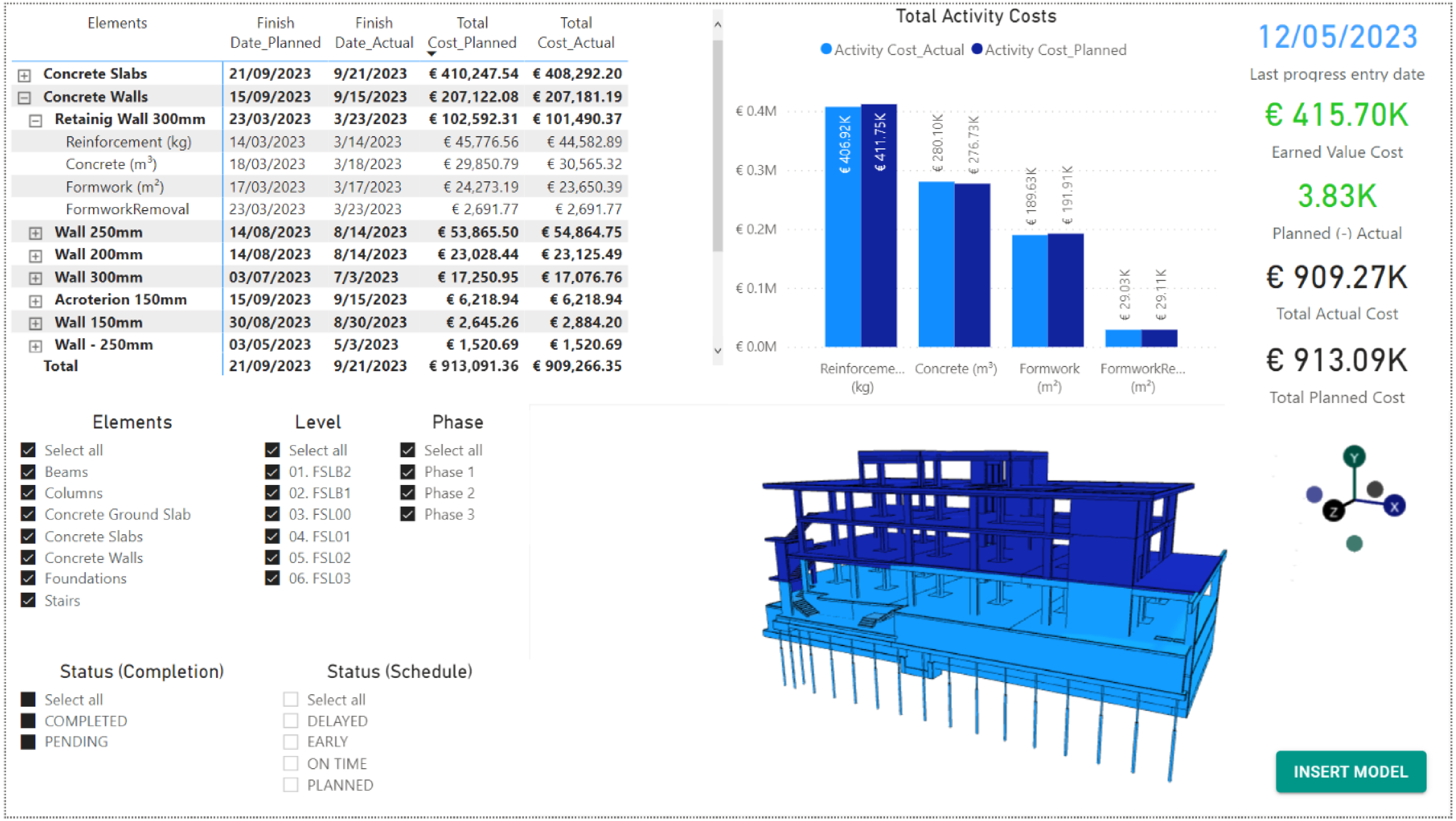
CTF_LV Supply Tray_300x100	Material	Numeric	€ 9.83
CTF_LV Supply Tray_300x50-	Material	Numeric	€ 6.08
CTF_LV Supply Tray_600x50-	Material	Numeric	€ 9.83
CTF_LV Trunking_100x50-	Material	Numeric	€ 3.58
CTF_LV Trunking_225x50-	Material	Numeric	€ 5.15
CTF_LV Trunking_300x50-	Material	Numeric	€ 6.08
CTF_LV Trunking_50x50-5	Material	Numeric	€ 2.96
CTF_MV Gen Phase 1 Ladder_100x500	Material	Numeric	€ 14.83
CTF_MV Gen Phase 1 Ladder_200x125	Material	Numeric	€ 8.58
CTF_MV Gen Phase 1 Ladder_350x125	Material	Numeric	€ 13.27
CTF_MV Gen Phase 1 Ladder_500x100	Material	Numeric	€ 14.83
CTF_MV Gen Phase 1 Ladder_650x125	Material	Numeric	€ 22.65
CTF_MV Gen Phase 2 Ladder_200x125	Material	Numeric	€ 8.58
CTF_MV Supply A Ladder_200x125	Material	Numeric	€ 8.58
CTF_MV Supply A Ladder_350x125	Material	Numeric	€ 13.27
CTF_MV Supply B Ladder_200x125	Material	Numeric	€ 8.58
CTF_MV Supply B Ladder_350x125	Material	Numeric	€ 13.27
CTF_MV Supply B Ladder_650x125	Material	Numeric	€ 22.65
CTF_Power Ladder_200x125	Material	Numeric	€ 8.58
CTF_Power Ladder_350x125	Material	Numeric	€ 13.27
CTF_Power Ladder_500x125	Material	Numeric	€ 17.96
CTF_Power Ladder_650x125	Material	Numeric	€ 22.65
CTF_Power Ladder_900x125	Material	Numeric	€ 30.46
CTF_Power Ladder_950x100	Material	Numeric	€ 26.08
CTF_Power Ladder_950x125	Material	Numeric	€ 32.02
CTF_PV Tray_150x100	Material	Numeric	€ 6.08
CTF_PV Tray_300x100	Material	Numeric	€ 9.83
CTF_Ramp_210x65-	Material	Numeric	€ 5.75
CTF_Security Basket_100x100	Material	Numeric	€ 4.83
CTF_Security Basket_100x50-	Material	Numeric	€ 3.58
CTF_Security Basket_125x100	Material	Numeric	€ 5.46
CTF_Security Basket_150x100	Material	Numeric	€ 6.08
CTF_Security Basket_450x100	Material	Numeric	€ 13.58
CTF_Security Basket_500x100	Material	Numeric	€ 14.83
CTF_Security Basket_50x100-	Material	Numeric	€ 3.58
CTF_Security Basket_50x50-5	Material	Numeric	€ 2.96
CTF_Security Basket_75x50-5	Material	Numeric	€ 3.27
CTF_Security Basket_75x50-7	Material	Numeric	€ 3.27
CTF_Small Power Tray_100x100	Material	Numeric	€ 4.83
CTF_Small Power Tray_100x125	Material	Numeric	€ 5.46
CTF_Small Power Tray_100x50-	Material	Numeric	€ 3.58
CTF_Small Power Tray_125x100	Material	Numeric	€ 5.46
CTF_Small Power Tray_150x125	Material	Numeric	€ 7.02
CTF_Small Power Tray_150x50-	Material	Numeric	€ 4.21
CTF_Small Power Tray_200x100	Material	Numeric	€ 7.33
CTF_Small Power Tray_200x125	Material	Numeric	€ 8.58

CTF_Small Power Tray_200x50-	Material	Numeric		€ 4.83
CTF_Small Power Tray_225x100	Material	Numeric		€ 7.96
CTF_Small Power Tray_225x125	Material	Numeric		€ 9.36
CTF_Small Power Tray_225x50-	Material	Numeric		€ 5.15
CTF_Small Power Tray_300x100	Material	Numeric		€ 9.83
CTF_Small Power Tray_300x50-	Material	Numeric		€ 6.08
CTF_Small Power Tray_400x100	Material	Numeric		€ 12.33
CTF_Small Power Tray_50x100-	Material	Numeric		€ 3.58
CTF_Small Power Tray_50x125-	Material	Numeric		€ 3.90
CTF_Small Power Tray_50x50-5	Material	Numeric		€ 2.96
CTF_Small Power Tray_75x50-5	Material	Numeric		€ 3.27
CTF_Small Power Tray_75x50-7	Material	Numeric		€ 3.27
CTF_Tray - Reducer - VRF_1050x50	Material	Numeric		€ 15.46
CTF_Tray - Reducer - VRF_1200x50	Material	Numeric		€ 17.33
CTF_Tray - Reducer - VRF_1500x50	Material	Numeric		€ 21.08
CTF_Tray - Reducer - VRF_300x50-	Material	Numeric		€ 6.08
CTF_Tray - Reducer - VRF_450x50-	Material	Numeric		€ 7.96
CTF_Tray - Reducer - VRF_600x50-	Material	Numeric		€ 9.83
CTF_Tray - Reducer - VRF_750x50-	Material	Numeric		€ 11.71
CTF_Tray - Reducer - VRF_900x50-	Material	Numeric		€ 13.58
CTF_Tray - Vertical Inside Bend - VRF_150x50-	Material	Numeric		€ 4.21
CTF_Tray - Vertical Inside Bend - VRF_600x50-	Material	Numeric		€ 4.21
CTF_Tray - Vertical Outside Bend - VRF_150x50-	Material	Numeric		€ 4.21
CTF_Tray - Vertical Outside Bend - VRF_600x50-	Material	Numeric		€ 4.21
CTF_VRF Tray_100x600	Material	Numeric		€ 17.33
CTF_VRF Tray_150x50-	Material	Numeric		€ 4.21
CTF_VRF Tray_225x100	Material	Numeric		€ 7.96
CTF_VRF Tray_225x50-	Material	Numeric		€ 5.15
CTF_VRF Tray_300x100	Material	Numeric		€ 9.83
CTF_VRF Tray_400x50-	Material	Numeric		€ 7.33
CTF_VRF Tray_450x100	Material	Numeric		€ 13.58
CTF_VRF Tray_450x50-	Material	Numeric		€ 7.96
CTF_VRF Tray_500x100	Material	Numeric		€ 14.83
CTF_VRF Tray_600x100	Material	Numeric		€ 17.33
CTF_VRF Tray_750x100	Material	Numeric		€ 21.08
CTF_VRF Tray_900x100	Material	Numeric		€ 24.83
Labour	Labour	Time	h	€ 10.00

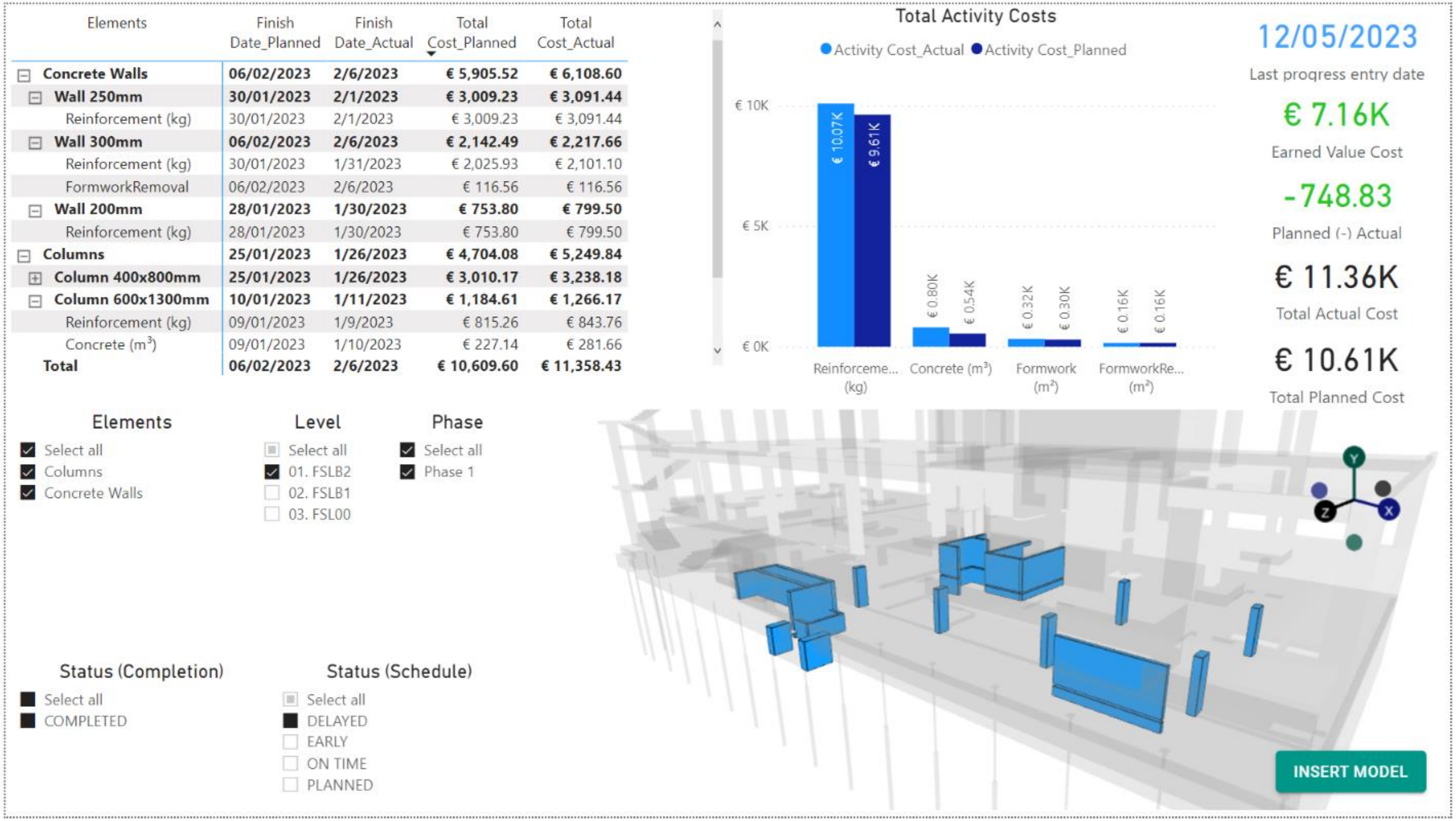
APPENDIX 12: ENLARGED IMAGES FOR PROGRESS TRACKING TOOL



Connection of databases for the Progress Tracking dashboards

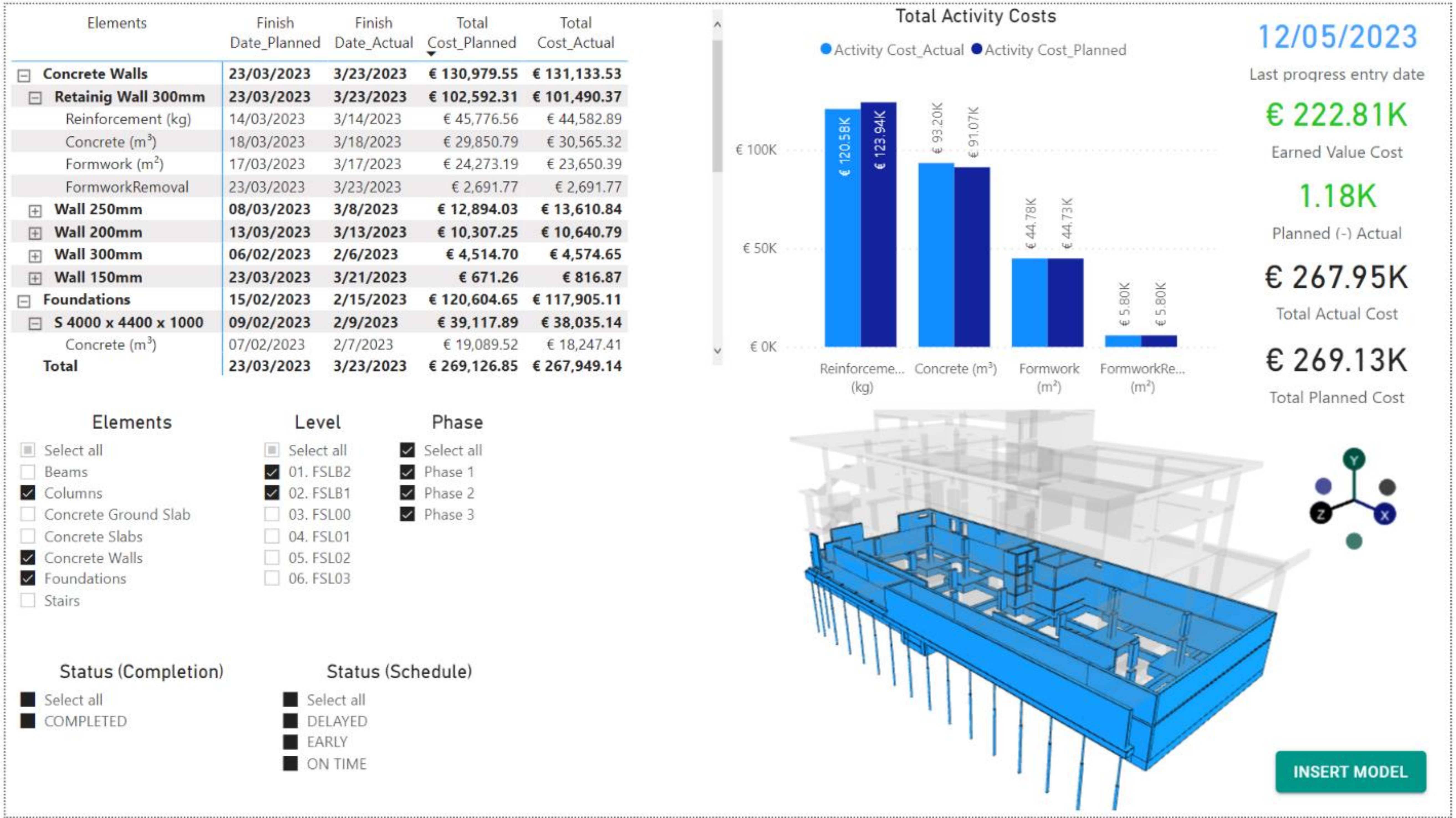


Template #1 for Progress Tracking with no filters applied.



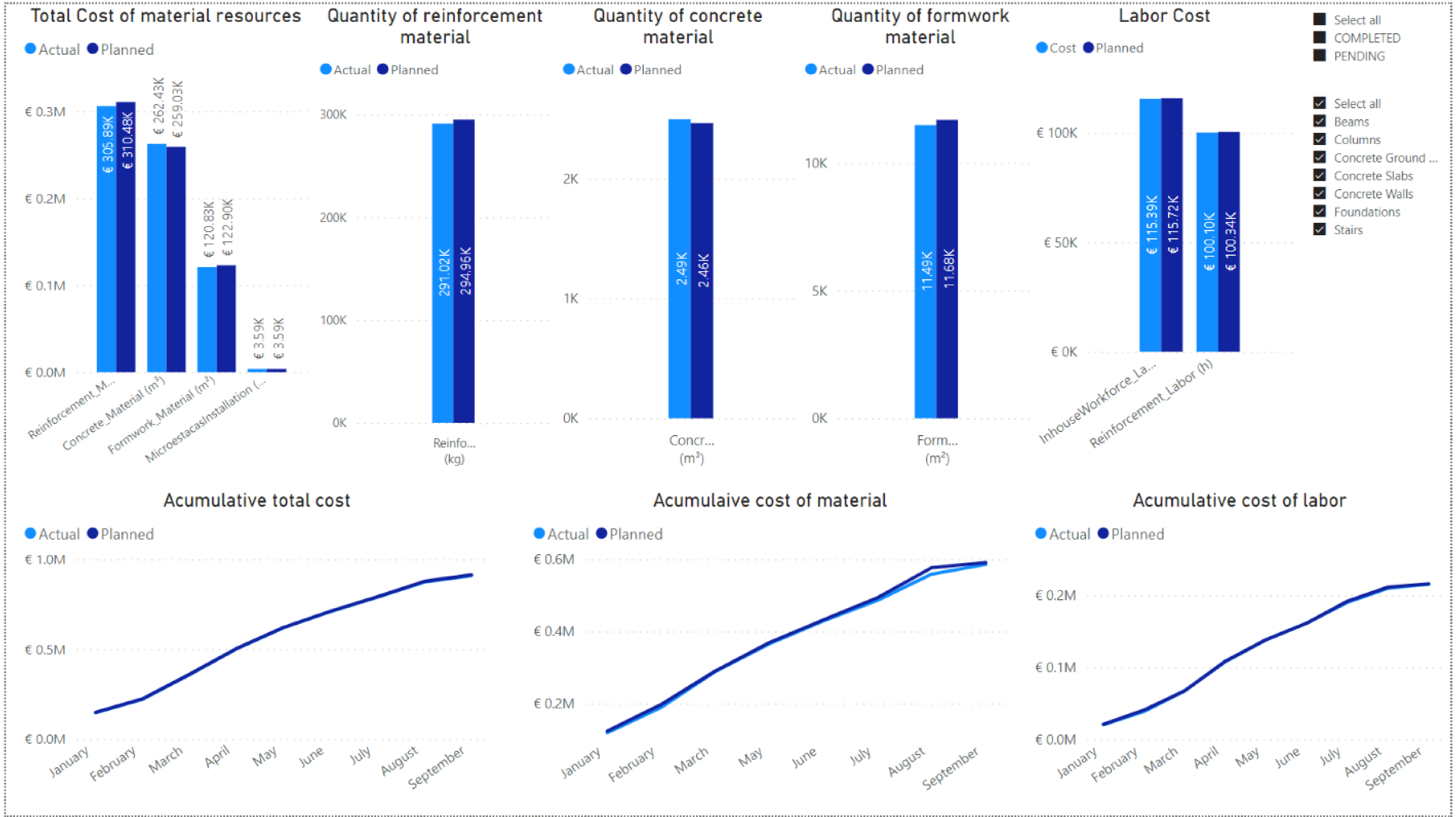
Elements	Finish Date_Planned	Finish Date_Actual	Total Cost_Planned	Total Cost_Actual
Concrete Walls	**06/02/2023**	**2/6/2023**	**€ 5,905.52**	**€ 6,108.60**
Wall 250mm	**30/01/2023**	**2/1/2023**	**€ 3,009.23**	**€ 3,091.44**
Reinforcement (kg)	30/01/2023	2/1/2023	€ 3,009.23	€ 3,091.44
Wall 300mm	**06/02/2023**	**2/6/2023**	**€ 2,142.49**	**€ 2,217.66**
Reinforcement (kg)	30/01/2023	1/31/2023	€ 2,025.93	€ 2,101.10
FormworkRemoval	06/02/2023	2/6/2023	€ 116.56	€ 116.56
Wall 200mm	**28/01/2023**	**1/30/2023**	**€ 753.80**	**€ 799.50**
Reinforcement (kg)	28/01/2023	1/30/2023	€ 753.80	€ 799.50
Columns	**25/01/2023**	**1/26/2023**	**€ 4,704.08**	**€ 5,249.84**
Column 400x800mm	**25/01/2023**	**1/26/2023**	**€ 3,010.17**	**€ 3,238.18**
Column 600x1300mm	**10/01/2023**	**1/11/2023**	**€ 1,184.61**	**€ 1,266.17**
Reinforcement (kg)	09/01/2023	1/9/2023	€ 815.26	€ 843.76
Concrete (m^3)	09/01/2023	1/10/2023	€ 227.14	€ 281.66
Total	**06/02/2023**	**2/6/2023**	**€ 10,609.60**	**€ 11,358.43**

Template #1 for Progress Tracking, filtering the delayed elements on the first level

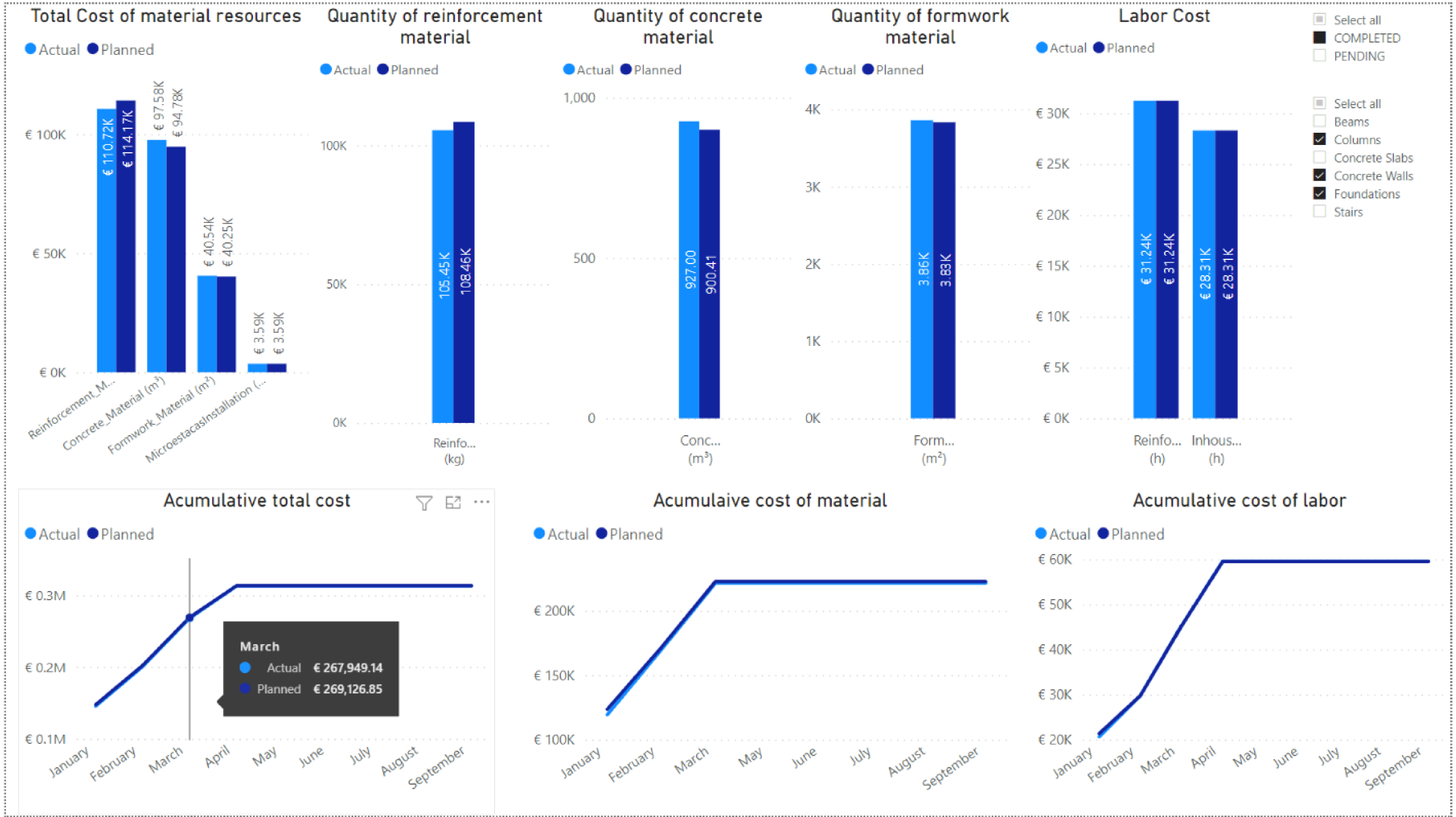


Elements	Finish Date_Planned	Finish Date_Actual	Total Cost_Planned	Total Cost_Actual
Concrete Walls	**23/03/2023**	**3/23/2023**	**€ 130,979.55**	**€ 131,133.53**
Retainig Wall 300mm	**23/03/2023**	**3/23/2023**	**€ 102,592.31**	**€ 101,490.37**
Reinforcement (kg)	14/03/2023	3/14/2023	€ 45,776.56	€ 44,582.89
Concrete (m^3)	18/03/2023	3/18/2023	€ 29,850.79	€ 30,565.32
Formwork (m^2)	17/03/2023	3/17/2023	€ 24,273.19	€ 23,650.39
FormworkRemoval	23/03/2023	3/23/2023	€ 2,691.77	€ 2,691.77
Wall 250mm	**08/03/2023**	**3/8/2023**	**€ 12,894.03**	**€ 13,610.84**
Wall 200mm	**13/03/2023**	**3/13/2023**	**€ 10,307.25**	**€ 10,640.79**
Wall 300mm	**06/02/2023**	**2/6/2023**	**€ 4,514.70**	**€ 4,574.65**
Wall 150mm	**23/03/2023**	**3/21/2023**	**€ 671.26**	**€ 816.87**
Foundations	**15/02/2023**	**2/15/2023**	**€ 120,604.65**	**€ 117,905.11**
S 4000 x 4400 x 1000	**09/02/2023**	**2/9/2023**	**€ 39,117.89**	**€ 38,035.14**
Concrete (m^3)	07/02/2023	2/7/2023	€ 19,089.52	€ 18,247.41
Total	**23/03/2023**	**3/23/2023**	**€ 269,126.85**	**€ 267,949.14**

Template #1 for Progress Tracking, filtering foundations, walls, and columns located in the first two levels

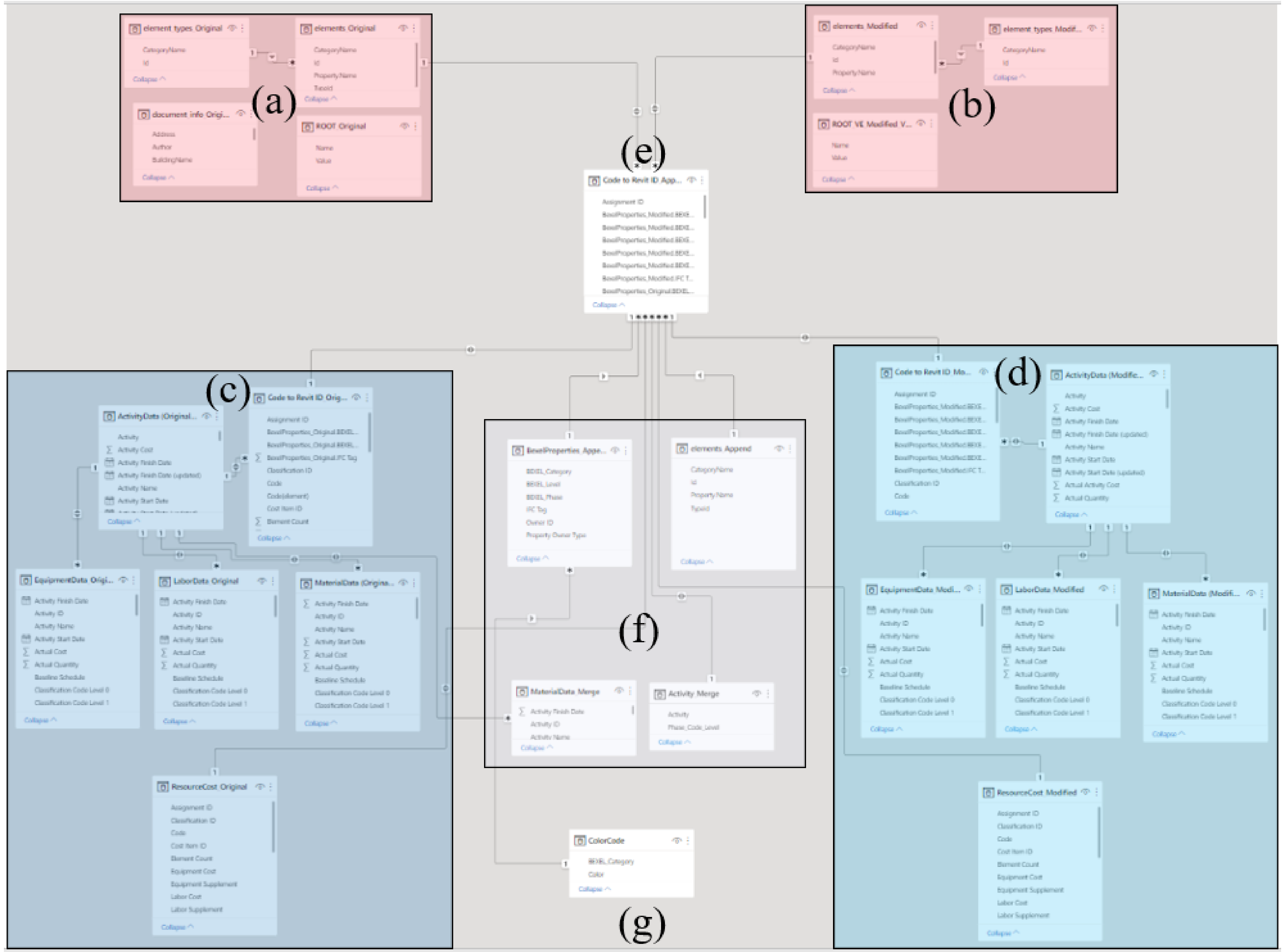


Template #2 for Progress Tracking with no filters applied.

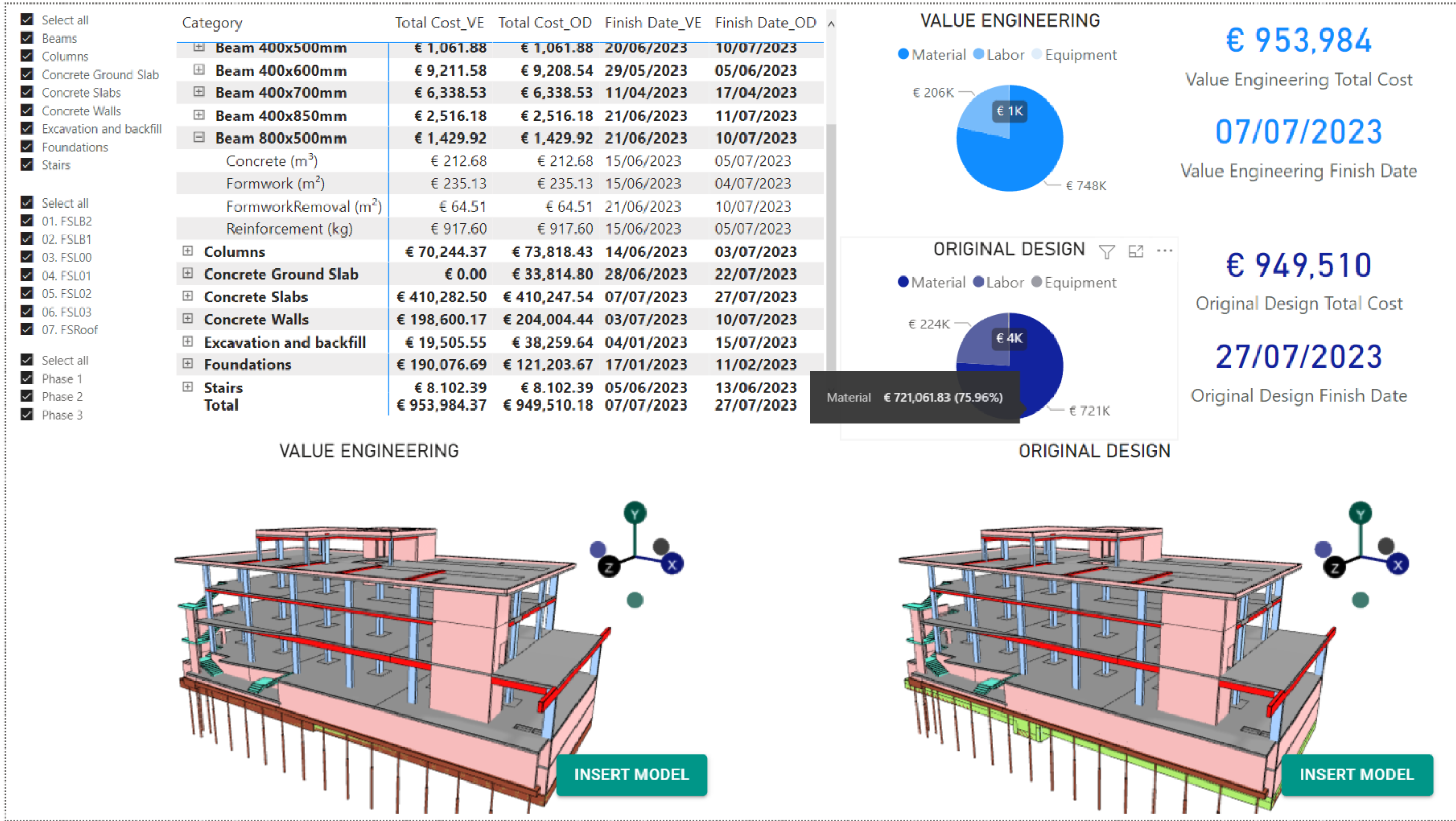


Template #2 for Progress Tracking, filtered by foundations walls and columns that are already built.

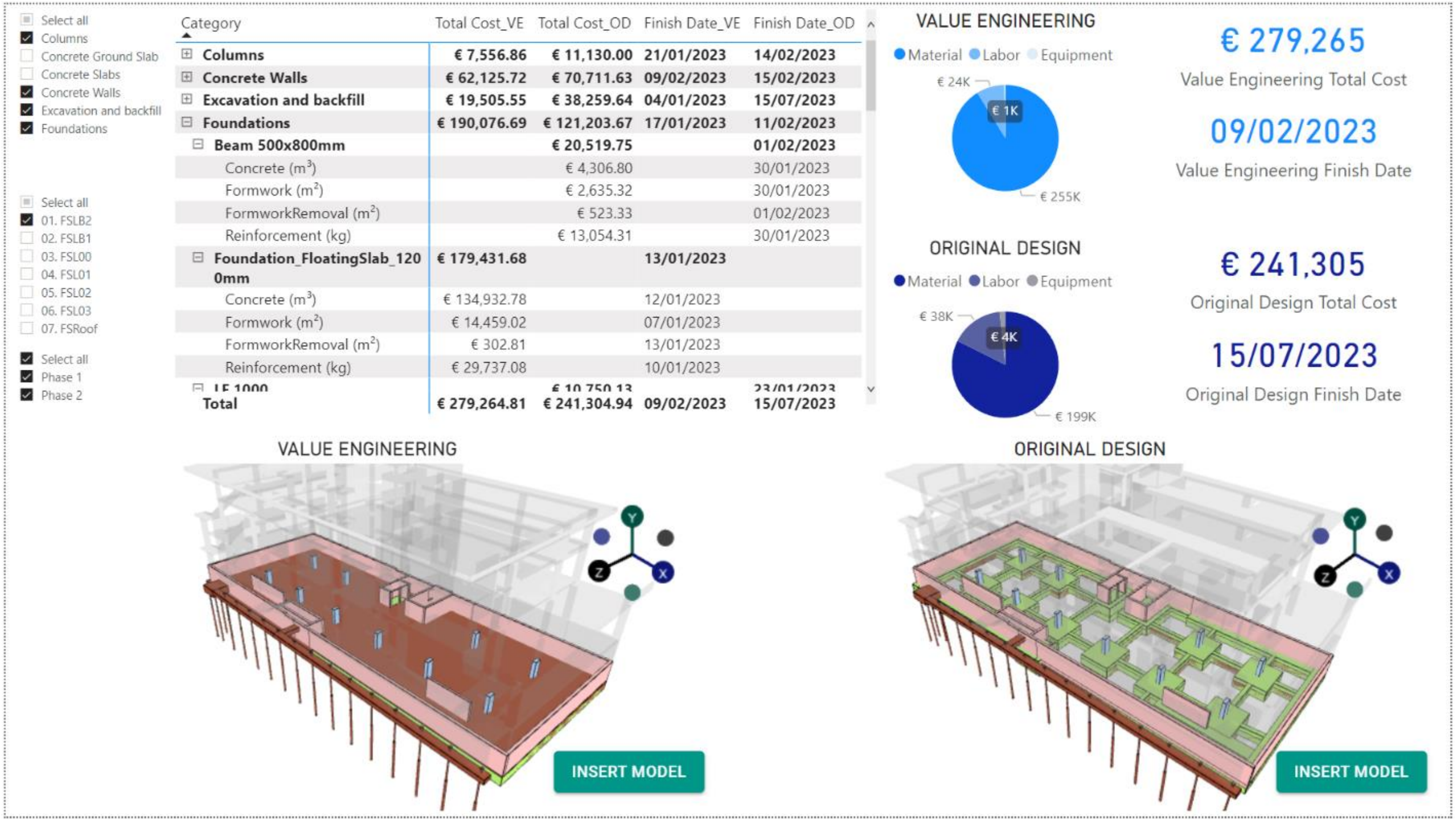
APPENDIX 13: ENLARGED FIGURES FOR VALUE ENGINEERING TOOL



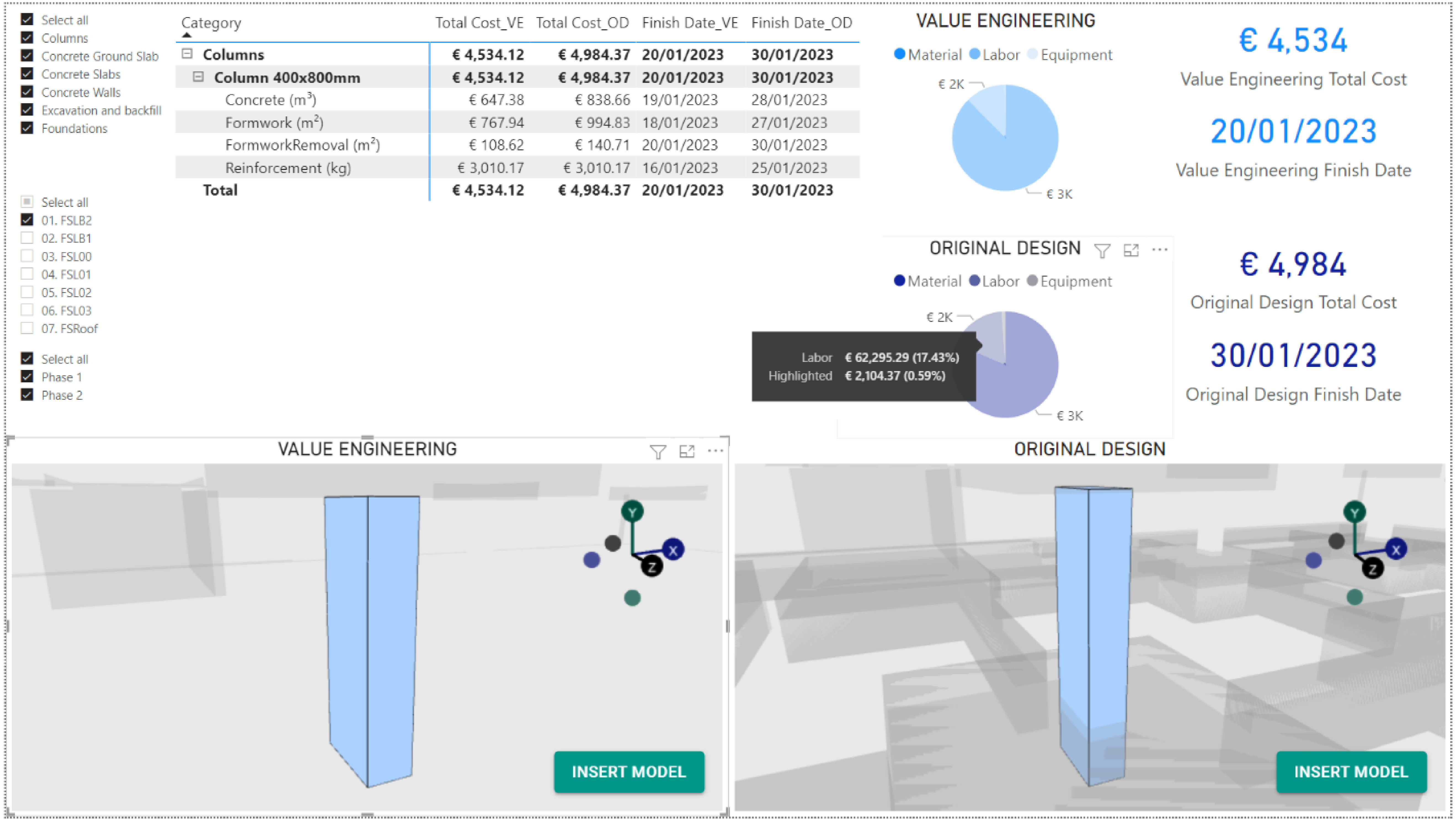
Distribution of databases for templates of Value Engineering



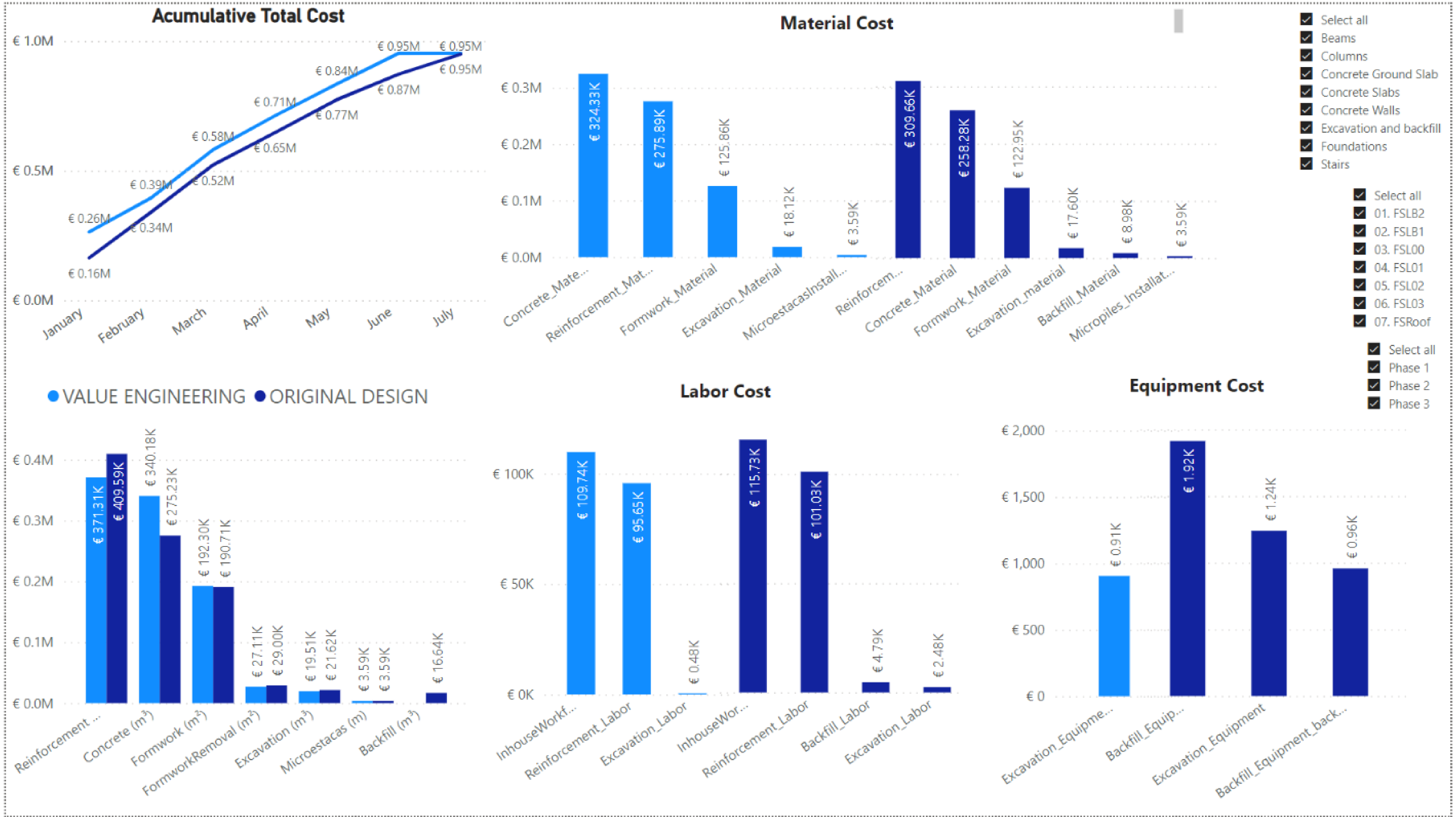
Template #1 for Value Engineering with no filters applied.



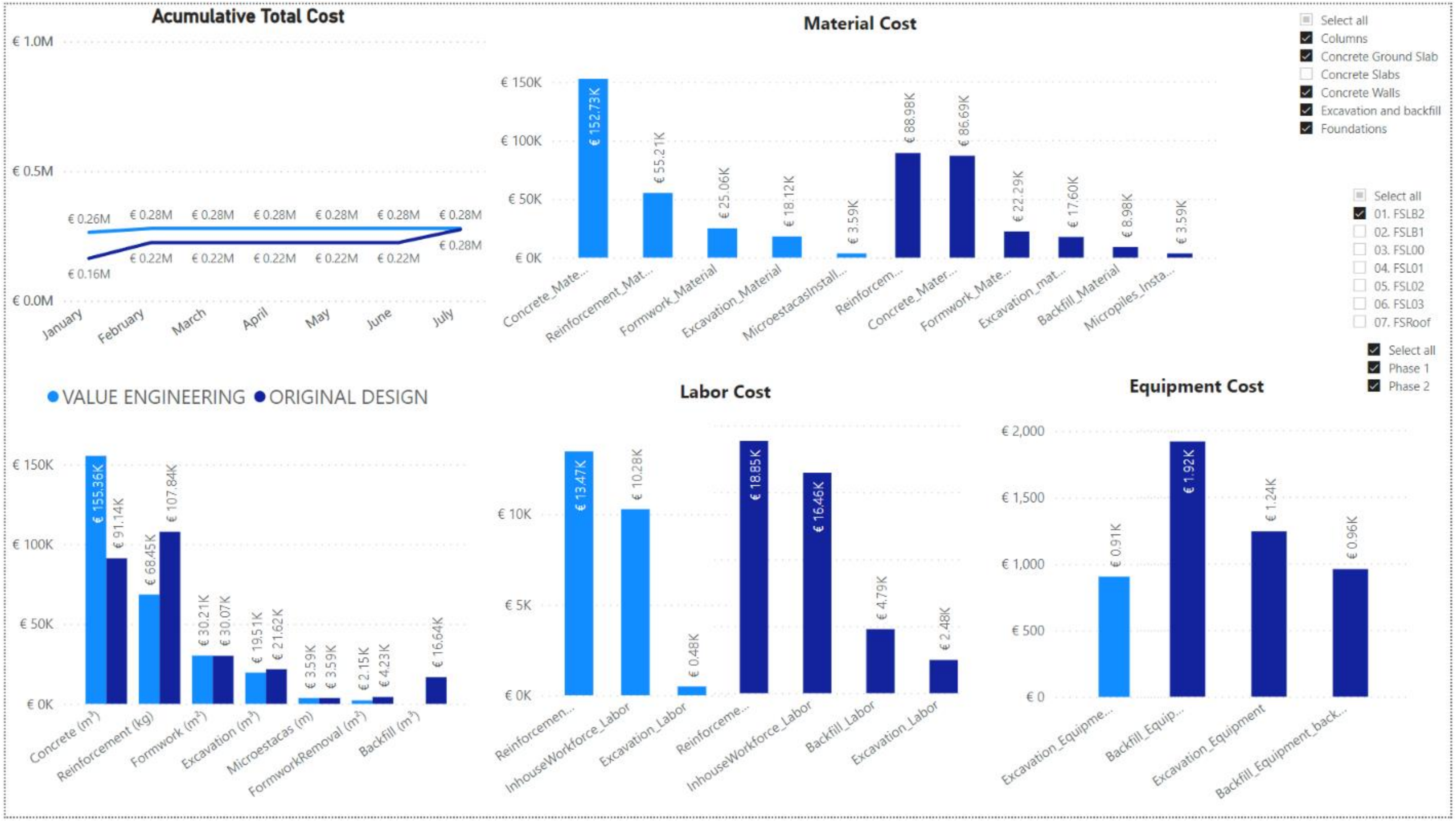
Template #1 for Value Engineering filtered by columns, walls, foundations, excavation and fill only on the first level



Template #1 for Value Engineering filtered on a specific column.

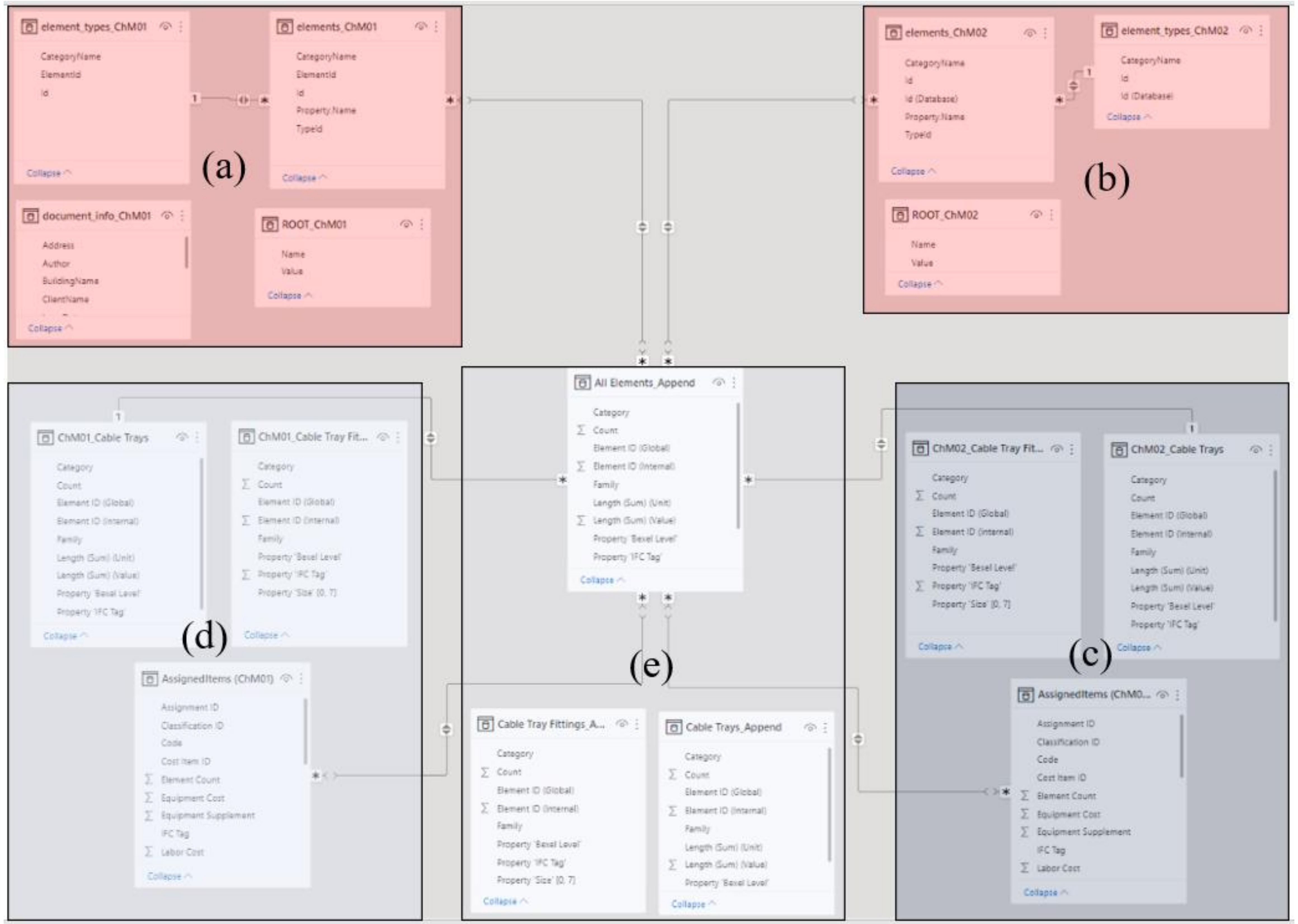


Template #2 for Value Engineering with no filters applied

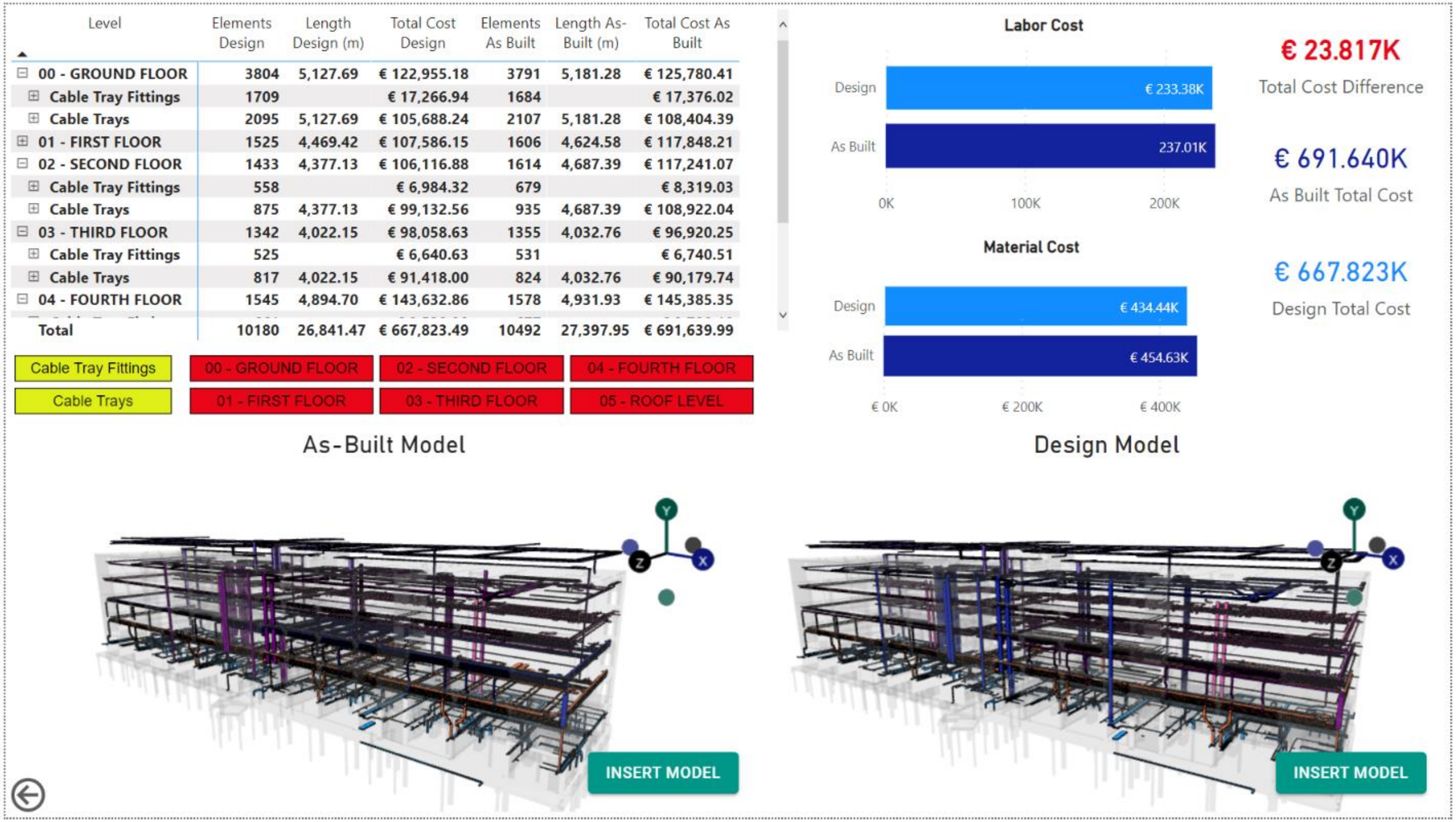


Template #2 for Value Engineering filtered by columns, ground slab, walls, foundation, excavation and fill only on the first level

APPENDIX 14: ENLARGED IMAGES FOR CHANGE MANAGEMENT TOOL

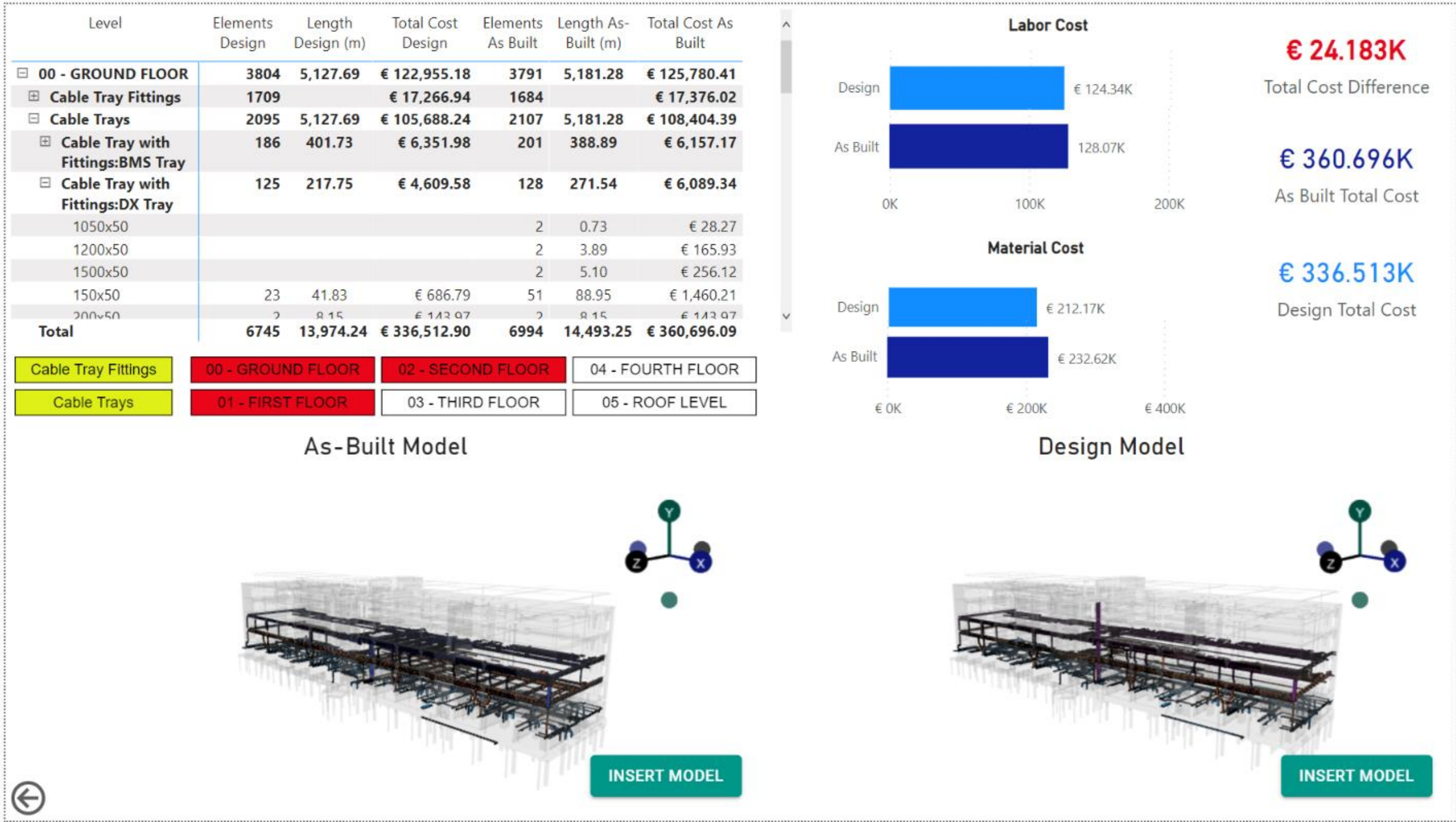


Distribution of databases for Change Management dassboards



Level	Elements Design	Length Design (m)	Total Cost Design	Elements As Built	Length As-Built (m)	Total Cost As Built
00 - GROUND FLOOR	3804	5,127.69	€ 122,955.18	3791	5,181.28	€ 125,780.41
Cable Tray Fittings	1709		€ 17,266.94	1684		€ 17,376.02
Cable Trays	2095	5,127.69	€ 105,688.24	2107	5,181.28	€ 108,404.39
01 - FIRST FLOOR	1525	4,469.42	€ 107,586.15	1606	4,624.58	€ 117,848.21
02 - SECOND FLOOR	1433	4,377.13	€ 106,116.88	1614	4,687.39	€ 117,241.07
Cable Tray Fittings	558		€ 6,984.32	679		€ 8,319.03
Cable Trays	875	4,377.13	€ 99,132.56	935	4,687.39	€ 108,922.04
03 - THIRD FLOOR	1342	4,022.15	€ 98,058.63	1355	4,032.76	€ 96,920.25
Cable Tray Fittings	525		€ 6,640.63	531		€ 6,740.51
Cable Trays	817	4,022.15	€ 91,418.00	824	4,032.76	€ 90,179.74
04 - FOURTH FLOOR	1545	4,894.70	€ 143,632.86	1578	4,931.93	€ 145,385.35
Total	10180	26,841.47	€ 667,823.49	10492	27,397.95	€ 691,639.99

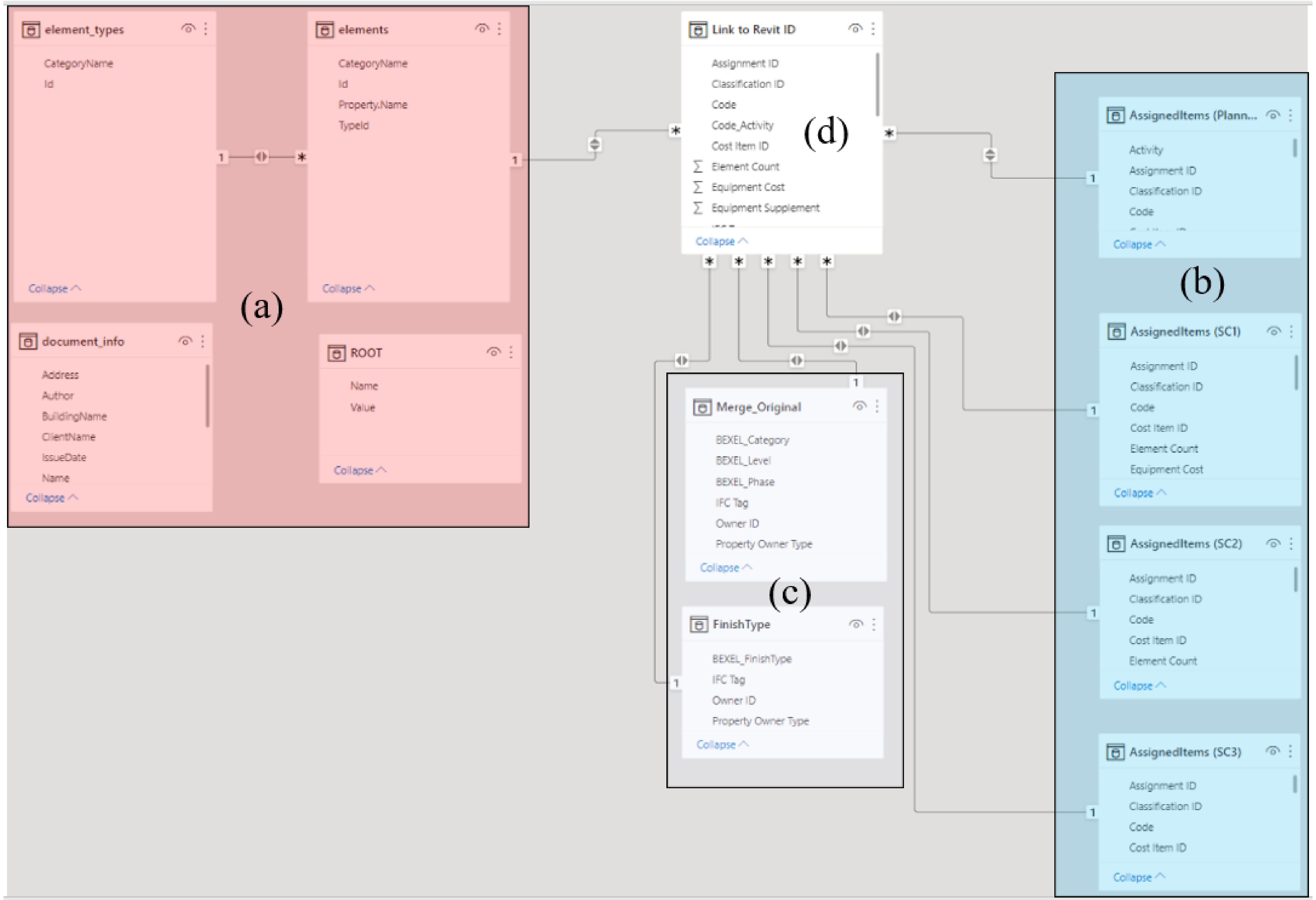
Template for Change Management with no filters applied



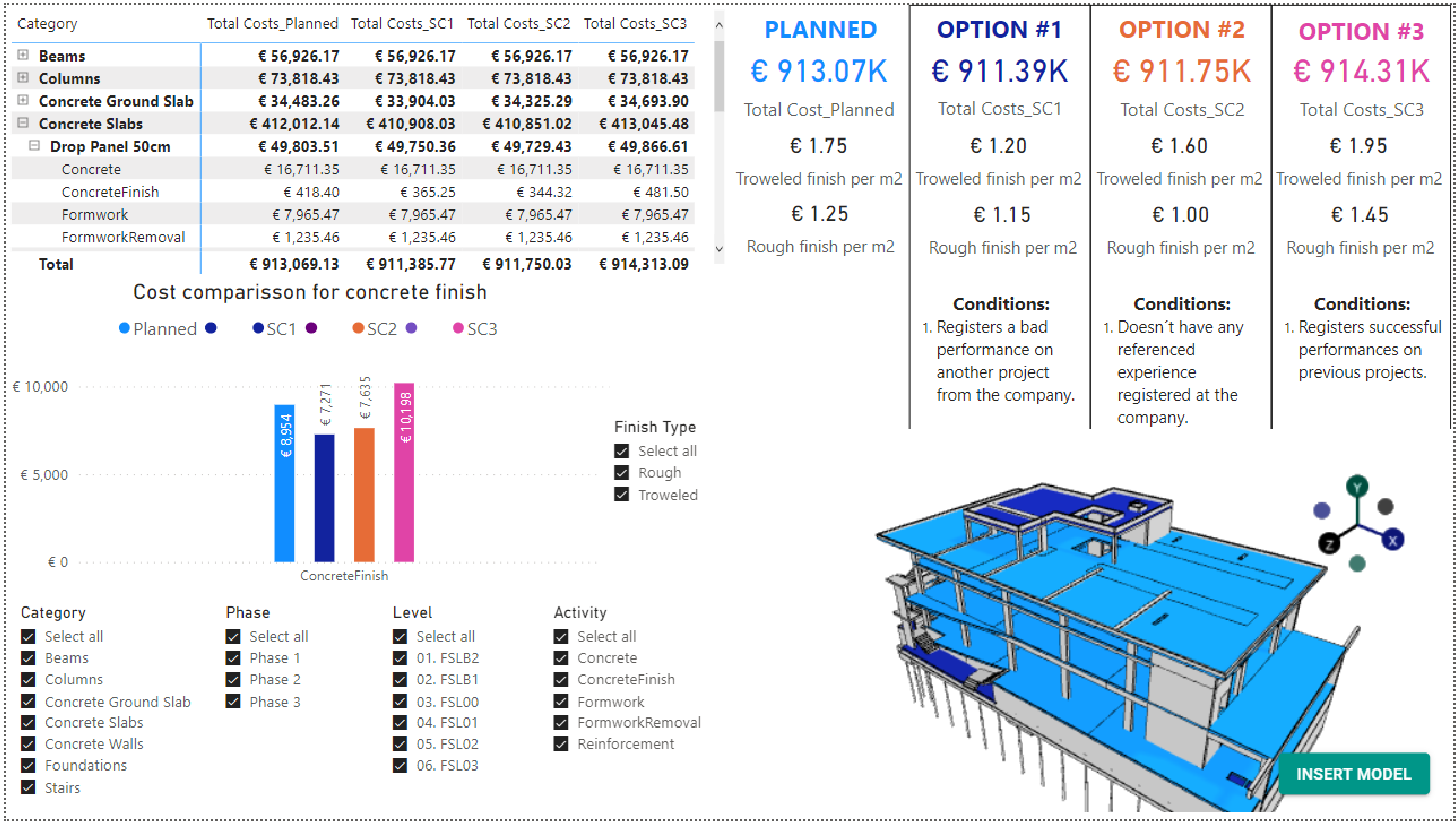
Level	Elements Design	Length Design (m)	Total Cost Design	Elements As Built	Length As-Built (m)	Total Cost As Built
00 - GROUND FLOOR	**3804**	**5,127.69**	**€ 122,955.18**	**3791**	**5,181.28**	**€ 125,780.41**
Cable Tray Fittings	**1709**		**€ 17,266.94**	**1684**		**€ 17,376.02**
Cable Trays	**2095**	**5,127.69**	**€ 105,688.24**	**2107**	**5,181.28**	**€ 108,404.39**
Cable Tray with Fittings:BMS Tray	**186**	**401.73**	**€ 6,351.98**	**201**	**388.89**	**€ 6,157.17**
Cable Tray with Fittings:DX Tray	**125**	**217.75**	**€ 4,609.58**	**128**	**271.54**	**€ 6,089.34**
1050x50				2	0.73	€ 28.27
1200x50				2	3.89	€ 165.93
1500x50				2	5.10	€ 256.12
150x50	23	41.83	€ 686.79	51	88.95	€ 1,460.21
200x50	2	8.15	€ 143.07	2	8.15	€ 143.07
Total	**6745**	**13,974.24**	**€ 336,512.90**	**6994**	**14,493.25**	**€ 360,696.09**

Template for Change Management template, presenting the information corresponding only to the first three levels

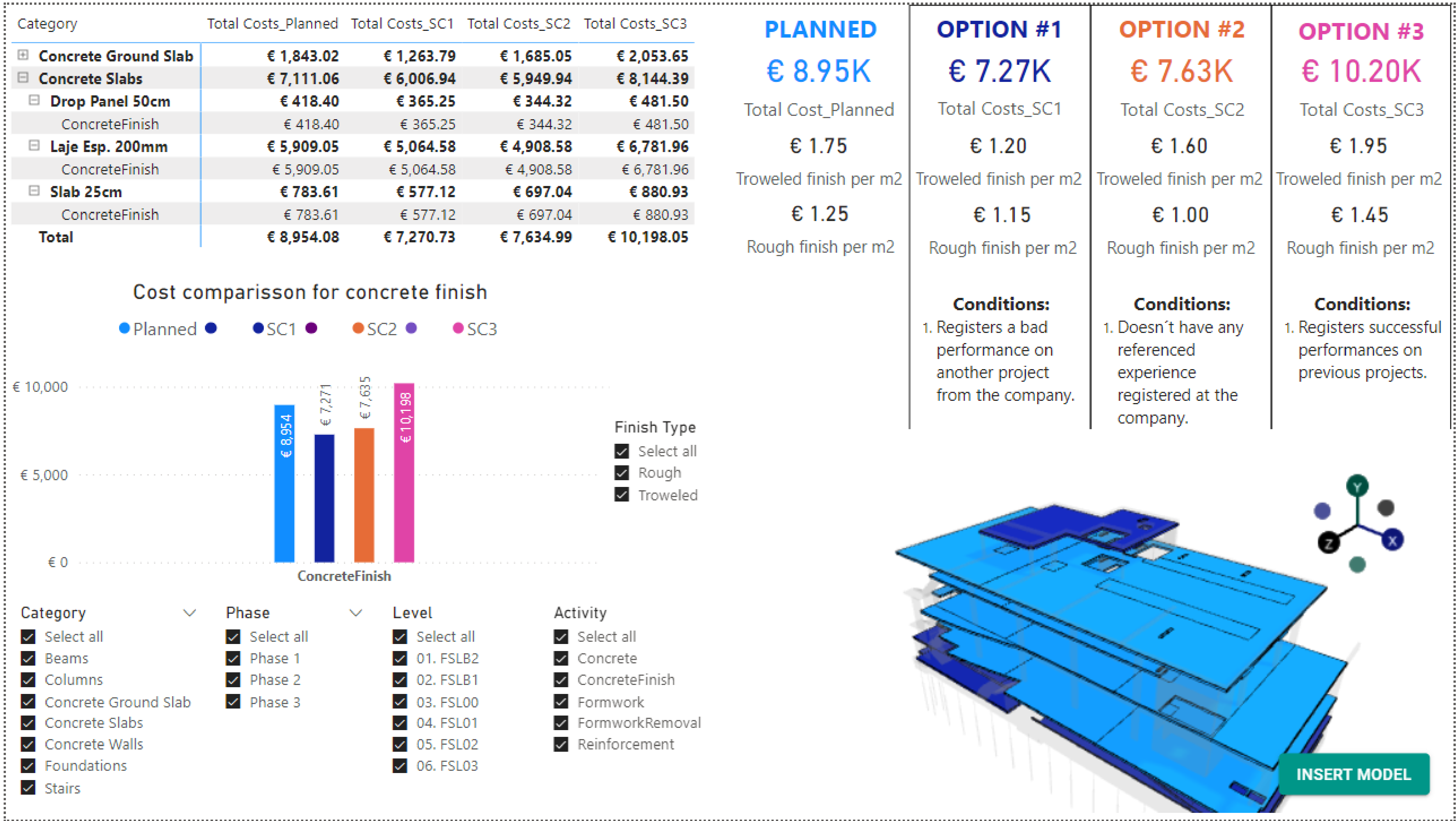
APPENDIX 15. ENLARGED FIGURES FOR E-PROCUREMENT TOOL



Distribution of databases for E-Procurement template



Template for E-Procurement with no filters applied



Category	Total Costs_Planned	Total Costs_SC1	Total Costs_SC2	Total Costs_SC3
⊞ Concrete Ground Slab	€ 1,843.02	€ 1,263.79	€ 1,685.05	€ 2,053.65
⊟ Concrete Slabs	€ 7,111.06	€ 6,006.94	€ 5,949.94	€ 8,144.39
⊟ Drop Panel 50cm	€ 418.40	€ 365.25	€ 344.32	€ 481.50
ConcreteFinish	€ 418.40	€ 365.25	€ 344.32	€ 481.50
⊟ Laje Esp. 200mm	€ 5,909.05	€ 5,064.58	€ 4,908.58	€ 6,781.96
ConcreteFinish	€ 5,909.05	€ 5,064.58	€ 4,908.58	€ 6,781.96
⊟ Slab 25cm	€ 783.61	€ 577.12	€ 697.04	€ 880.93
ConcreteFinish	€ 783.61	€ 577.12	€ 697.04	€ 880.93
Total	€ 8,954.08	€ 7,270.73	€ 7,634.99	€ 10,198.05

Template for E-Procurement filtered by the concrete finish activity

APPENDIX 16: DYNAMO SCRIPT USED TO EXTRACT PROPERTY VALUES FROM MODELS IN REVIT