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WORKFLOWS FOR THE AUTOMATION OF 4D & 5D BIM MODELS

POSTOPKI AVTOMATIZIRANE IZDELAVE 4D IN 5D BIM MODELOV

BIM A+ European Master in Building Information Modelling

Master thesis No.:

Supervisor:
Assist. Prof. Aleksander Srdic, Ph.D.

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Izvleček:

Uporaba informacijskega modeliranja zgradb (BIM- Building Information Modelling) omogoča kakovostnejšo graditev v smislu končnega produkta, zanesljivejšega izračuna gradbenih predizmer (količin), boljše časovno planiranje izvedbe gradnje ter s tem zmanjšanje negotovosti in stroškov projekta. Tako BIM pridobiva vse več pozornosti tudi na področju gradbene operative oziroma v fazi priprave na gradnjo in gradnje same. Zaradi kompleksnosti gradbenih projektov je ključnega pomena avtomatizacija postopka planiranja izvedbe (4D) in ocene stroškov (5D), ki še vedno predstavlja izziv za vse udeležence graditve (AEC -architecture, engineering and construction). V nalogi je podan predlog postopka izdelave 4D / 5D modela BIM, ki se začne z izdelavo gradbenih predizmer oziroma popisa količin na osnovi izbranih parametrov konstrukcijskih elementov, sledi postopek ocene stroškov s popisom del in na koncu avtomatizira terminsko planiranje gradnje (zaporedje tehnoloških postopkov). S ciljem preprečevanja izgube informacij pri prenosu informacijskega modela med različnimi orodji je implementacija predlaganega postopka izvedena z minimalnim številom različnih orodij. Predvsem je bila uporabljena programska oprema Bexel Manager, njegova preveritev pa je bila izvedena na dveh primerih več etažnih zgradb. Prvi primer je bil izdelan na osnovi IFC datoteke že izdelanega modela zgradbe, drugi pa temelji na lastno izdelanem modelu 3D BIM modelu zgradbe.

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BIBLIOGRAPHIC– DOKUMENTALISTIC INFORMATION AND ABSTRACT

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Abstract:

The use of building information modelling has provided a means to improve overall product quality, accurate quantity determination and improved scheduling, reducing total project uncertainties and costs. Building Information Modelling (BIM) has recently gained much attention in the construction industry. Due to the complexity of construction projects, it is essential to provide BIM models with construction automation of schedules and cost estimating that can automatically update the changes during the construction process. Defining workflow for automated generation of optimised 4D/5D BIM simulation and analysis is still a big challenge in the AEC field. This thesis suggests a workflow for creating the 4D/5D BIM model that starts with generating a proper QTO based on the desired properties and parameters of building elements then establish with the cost estimating process through the defined QTO and finally automate the generation of the construction schedules (Construction sequencing) of the project. One of the main focuses is also the integration of this workflow with the least amount of software to avoid the loss of information when transferring the information model between different platforms. Bexel Manager software has been mainly used to apply this workflow. Two case studies of small multi-storey buildings have been used to test the workflow, one of the case studies has only access to the IFC file, and the other is modelled from scratch in the authoring software.

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I would like to thank my parents, who have supported me to participate in this master and have given me the strength to pass through my hard times. I also thank my mentors for helping me through this journey. A special thank for GeoPortal Company who provided me with the case study to test my proposed workflow. Finally, thanks to all my family and friends who stood next to me through all this time.

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1. INTRODUCTION

This chapter first presents the background to the study. To clarify the context and focus of the study, the problem description is then given, followed by the purpose and research questions. Finally, this chapter concludes with an outline of the report.

1.1 Background

Building Information Modelling (BIM) is the documentation handle that comprises of data almost the different stages of a project, such as design, construction, facility management and operation. The utilise of Building Data Modelling has given a implies to extend the in general quality of the item and a method to speed up the process, to determine quantities precisely and to make strides scheduling, in this manner diminishing the contingencies and costs of the overall project. Building information modelling has as of late picked up a large centre within the AEC field. Stands BIM for the advancement and utilise of computer-generated 5D models to reenact the planning, design, construction and operation of the facility. It makes a difference all parties included within the development project to picture in a mimicked environment what is to be built and to dissect or classify potential issues in planning, construction or operation [1].

BIM has critical benefits within the construction industry, and it can be utilised in each perspective of construction or at each stage of development, i.e. at initiation, planning, execution, performance and monitoring, at last at closure. Moreover, BIM can be utilised within the upkeep stage of the project. When construction projects are overseen with conventional strategies and paper-based apparatuses, it may be challenging to wrap up the project on time and within budget. With the BIM innovation, modellers appear each small detail in demonstrating and by limiting the audits and reworks, time can be spared, and projects can be completed beneath budget by sparing time and cash and efficiency in construction projects can be expanded, collaborative plan and coordination can be accomplished. Exact and speedier design choices can be made in early stages, precise and quicker quantity take-off can be computerised, material squander can be limited since the innovation BIM's capacity to distinguish plan clashes sometime recently construction starts on-site, and limits blunders can diminish delays and cost overruns [1].

5D BIM multi-dimensional functions:

- 3D - parametric design models and space programming tools, i.e. using the spatial dimensions of width, length and depth to represent an object, which enables 3D visualisations and walkthroughs, collision detection and coordination, and objects planning [2].

- 4D - that is 3D plus "time". The ability to link individual 3D parts or assemblies to the project delivery schedule, including resource and quantity planning and modular prefabrication to support tracking and project phasing. In addition to collaboration, 4D simulations act as a communication tool to identify potential bottlenecks. Both planners and contractors can use them on BIM site to check, guide and track construction activities [2].

- 5D - that is 4D plus "cost". Integration of design with estimating, scheduling and costing, including the creation of bills of quantities and the derivation of productivity rates and labour costs [3].

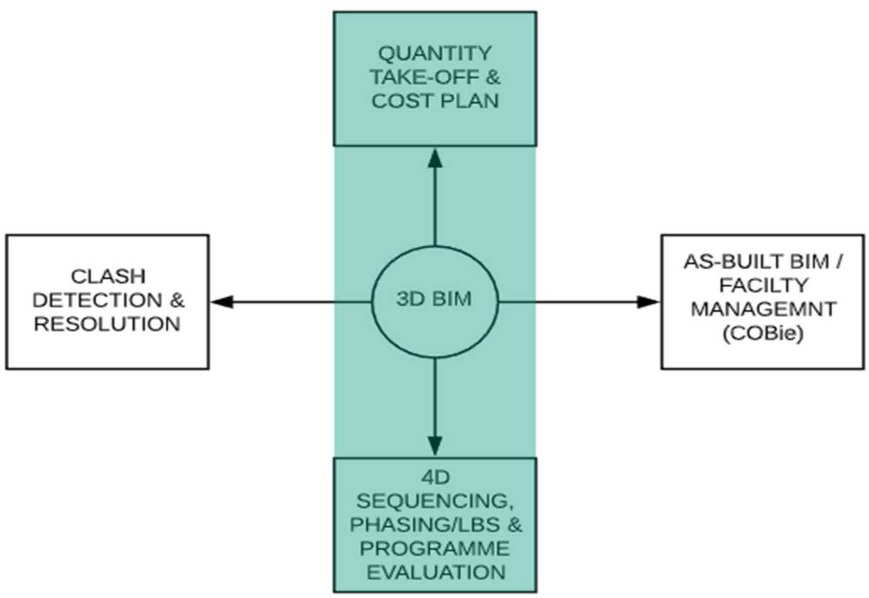


Figure 1: 3D BIM Phases Focus

1.2 Problem description

Taking into consideration the thesis workflow, the main goal of this thesis is to generate take-off solutions for engineers and surveyors who use any authoring software and a BIM management tool (e.g. BEXEL MANAGER) regarding the processes of modelling and taking off the quantities of various categories of building elements to increase the accuracy of the quantity take-off and minimise the time consumed for the process. Then to use this generated quantity take-off for creating the cost estimation and construction sequencing (construction scheduling) for the project .

Building information models are to be developed to represent the possible LOD for quantity take-off and cost estimation, covering essential work items, such as structural works and architectural works.

1.3 Purpose and Research questions

For construction companies

Are the IFC models received from the designers inconsistent and confusing to use?

Are they missing vital information to support the BIM processes?

Are the employees and partners having difficulty deriving real benefit from the BIM models?

More users, more value. Standardised data can be used to create ready-made views for your BIM tools. The data is easy to use because it can be found from the same place in every project. There are less training and fewer project-specific problems. The users should not need any specialised BIM knowledge or skills to use the models.

More use cases, more value. Enriched BIM enables you to use data that is not from the designer BIM in processes such as cost QTO estimation, procurement and scheduling. Because the models are standardised, you can automate these analyses and simulations. This makes your data-driven BIM processes as practical and interactive as possible.

Big picture, significant value. Standardised and rich data allows you to compare and analyse BIM data across multiple projects. Finally, consistent data from all your projects allows you to take advantage of machine learning.

For designers

Does the IFC data exchange gives extra effort and work?

Is the model received from other parties not suitable for the required purposes?

Makes IFC data exchange processes effective. You can continue to make the most efficient use of your model creation tool and still offer your customers world-class data exchange services.

Solves liability problems with IFC data exchange. You have full control over the IFC models you create and the requirements they must meet. You do not have to worry about whether you are exchanging the correct data, how the data is used, and who is responsible for the use of the data.

Makes IFC easy to use. You can use the models you receive from the other parties most effectively in your model authoring tool, regardless of where they come from or what application they come from.

For special consultants

Are the IFC models received from other disciplines inconsistent, cumbersome and lack essential data for the required analysis?

Save time and money. Using BIM them as the basis for your analysis allows you to complete your analysis in a fraction of the time it would take to set everything up manually. Not only does this save you time and money, but it also allows you to offer your customers a more timely and frequent premium service.

This makes IFC models easy, reliable and relevant. Use the data you receive from other parties in the most effective way.

Enriched models. Add missing data and reorganise models to meet the needs of your analytical software.

1.4 Thesis structure

The dissertation comprises six chapters. The remaining chapters are as follows. Chapter 2 describes the methods used in this thesis to study the problems. Chapter 3 gives an overview of the relevant literature and explains more about 4D/5D workflows and the generation of workflow automation with its implementation in construction planning. Chapter 4 is the practical part, where 2 case studies examine the intended workflows. Chapter 5 then presents the discussion, results and reflection. The work concludes with the conclusion and recommendation in chapter 6.

2 METHODOLOGY

Deductive approach was used to perform this work in order to combine practice and theory. First, a topic of interest was selected, and the hypothesis for this study was derived, i.e., **How can a fully integrated workflow with a high degree of dependency be created for the generation of an automatic construction sequencing schedules?** In order to validate this hypothesis, the study was limited to addressing specific research questions [4].

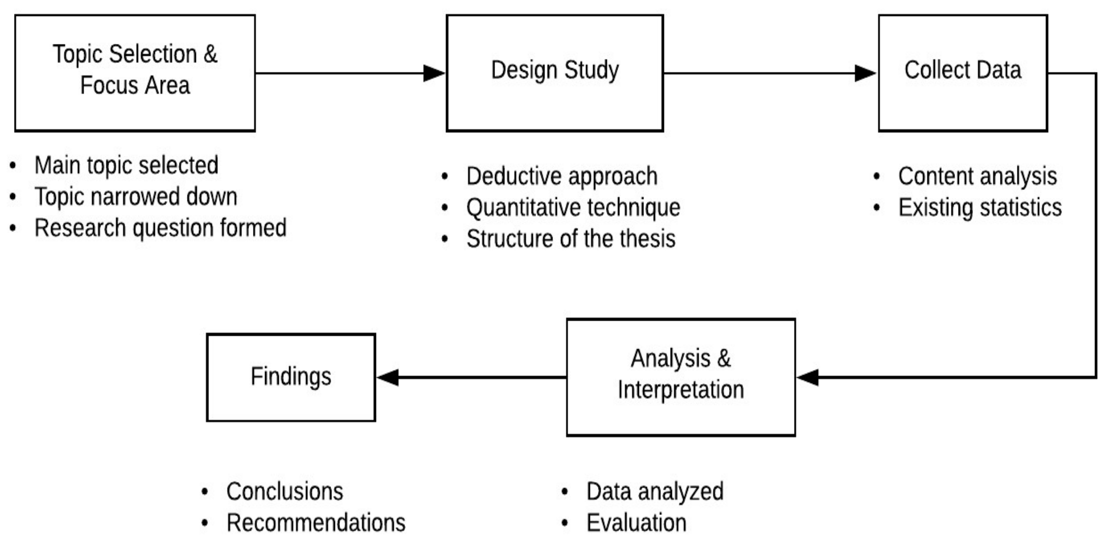


Figure 2: Adopted Methodology [4]

3 LITERATURE REVIEW

3.1 Workflows for automated generation of optimised 4D/5D BIM simulations

Building Information Modelling (BIM) offers both opportunities and challenges for the profession of project cost management [5]. As quantification becomes increasingly automated, and BIM models evolve, the role of the project cost manager will need to adapt accordingly to provide more complex cost management services, including 4D time and 5D cost modelling and sharing cost information/data with the project team as part of a BIM integrated project management approach [5].

BIM facilitates a more integrated design and construction process that produces higher quality projects with lower costs and durations. However, the development of models that enable the exchange of project information needs to be adapted to the level of detail of its use [6].

RICS (2014) claims that this BIM will enable project cost managers to spend more time on providing knowledge and expertise to the project team for in-depth consultation - automating processes such as quantification will significantly reduce the time spent on technical processes and provide more time and the digital tools for higher quality and more sophisticated cost management services. The BIM environment needs the project cost management for playing a vital role to embrace the 5th dimension – the '5D Project Cost Manager' [7]. Additional value is added for the cost management services, but still, the BIM ability is a crucial skill to have by the cost manager to share the cost data in the model and analysing according to his experience the information generated by the model.

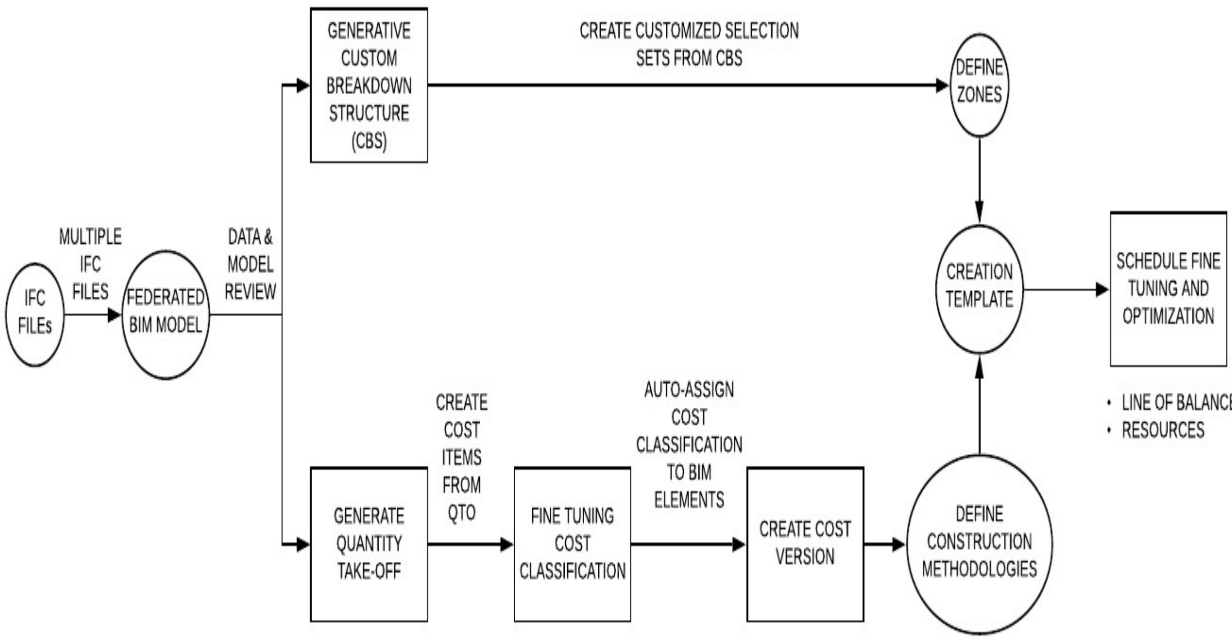


Figure 3: Proposed Workflow for automated generation of optimised 4D/5D BIM simulations

3.2 Quantity Take-off

Building Information Modelling (BIM) software has allowed the industry to begin to move toward BIM-based quantity take-off (QTO) and estimating [8]. Automation QTO and cost estimation in an integrated BIM authoring environment can benefit building designers. It can help them determine whether or not related building designs are consistent with pricing strategies in specific property markets. In particular, synchronising model designs with the associated cost estimate can help designers avoid cost issues related to each designed building component. Nevertheless, the challenges for such a solution include considerable issues such as classification system, measurement methods for building components, price information, etc. These issues depend on the dependence of countries and therefore require ad hoc solutions for specific markets.

Bentley, Vico, Autodesk Revit, Autodesk Navisworks and BEXEL MANAGER are just a few of the programs that are enabling the industry to move to BIM-based QTO and estimation [8]. Three-dimensional models developed in BIM programs are data-rich, intelligent models that can link individual elements to the material they represent in the model. This intelligence can speed up a QTO construction project while increasing the accuracy of the estimate. Because the transition to BIM-based material quantification and construction cost estimation is still in an early stage, not all data associated with a construction project and required for a complete QTO project is included in the 3D models [8].

This thesis will investigate why 3D models do not contain 100 percent of the data required to perform a quantity take-off and the desirability of developing a model to the point where a full quantity take-off is possible.

To fully capture the potential benefits of BIM models, they must be information-rich and contain comprehensive and accurate data [9]. This requires considerable time and expertise on the part of the BIM modellers and BIM the team. In many projects, incomplete/ imprecise data means that the BIM model falls far short of its potential [9]. There are many reasons for this, but the main reasons are whether design fees include a surcharge for entering fully comprehensive data and whether the BIM team has the expertise/knowledge/information to enter the required information into the model. Many clients do not see the value in paying the necessary fees for comprehensive models or may not have sufficient knowledge/expertise to know if this has been achieved. One quantity surveyor noted that he knew of an informal BIM forum for young BIM modellers to exchange information on how "stupid" BIM models can be developed quickly, giving the impression that they are functional models that can quickly meet their customers' requirements [9]. Then it is usually the rest of the project team (contractors, subcontractors and surveyors) who have to work with the unsuitable models and develop the further information required for construction.

The accuracy of quantity is related to defining the Levels of Development (LODs) because the use of BIM should follow a standard for defining the LODs of 3D model components [10]. Thus, it is necessary to explore the guidelines for defining the LOD to have consistency in communication and execution by facilitating a detailed definition of BIM [10]. Such an endeavour would require the cooperation of all parties, such as architects, estimators and schedulers, involved in a project. Each party can embed the information in a model according to its requirements [10].

The estimator must include a suitable rate for the waste of those items that are likely to create waste amid construction. The essential part for cost estimation is the quantity take-ff because it regularly determines the quantity and unit of measure for the cost of the contractor's work and equipment. All of this information improves the exactness of the 4D/5D simulation at the diverse stages of the project.

The information regularly shows in a model that incorporates structural steel, interior partitions exterior walls, doors, windows, building envelope glass, concrete, roofs and ceilings. Concrete information in a model is ordinarily exact. In any case, the information is still fastidiously examined, particularly on the off chance that the general contractor is self-performing the work.

Information ordinarily not display within the model incorporate temporary structures, concrete formwork, structural connections, Jobsite overhead, finishes, countertops, temporary fencing, wood blocking, fire protection and rebar.

Issues and impemdeiants of the BIM-based quantity take-off have been explored in few studies in practice. A study by Firat [11] said that to perform quantity take-off directly, and some rules should be made to gain the appropriate BIM Model. Smith [12] inspected the utilise of BIM for project cost management within the construction industry. He detailed that inadequate or off base data within the BIM model could be a critical issue that all firms are aiming to avoid it.

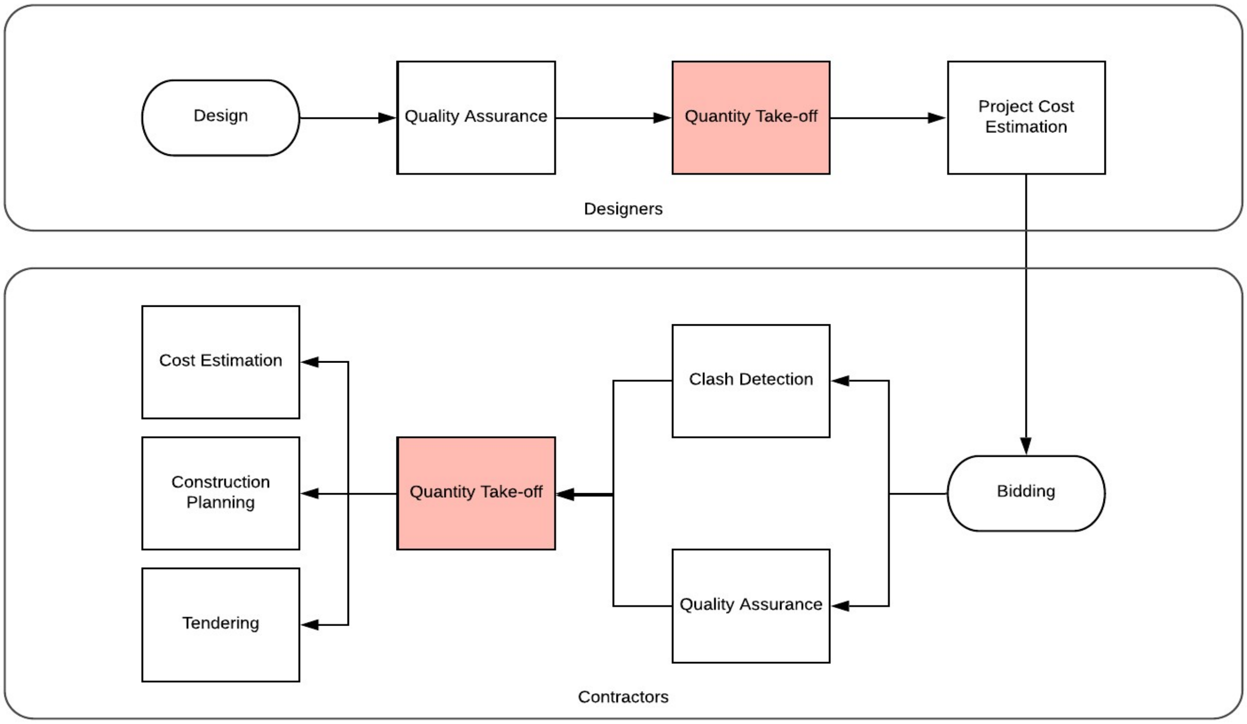


Figure 4: QTO Role in Project Life-cycle

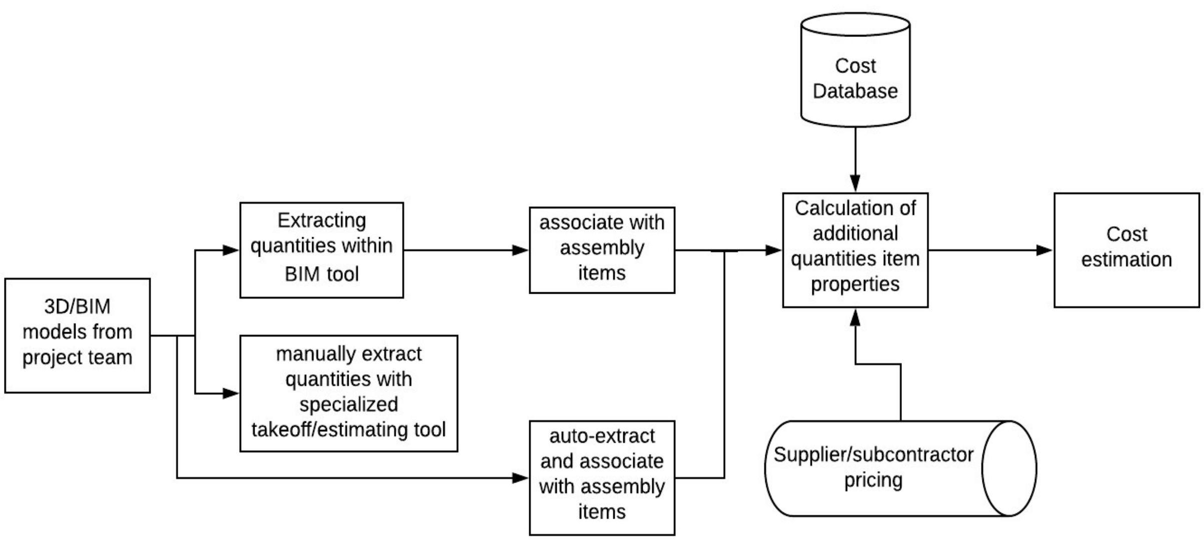


Figure 5: Proposed Workflow for QTO Generation leads to proper Cost Estimation

What quantities do you want?

It's often known from Cost Consultants/Contractors that there is not enough information to perform pricing with IFC models [13]. However, they are less open when asked what they want. As far as I can tell, there are no published instructions from RICS (Royal Institute from Chartered Surveyors) or others that specify precisely what data is required for the different types of IFC elements.

Authoring software has a lot of quantitative data that it can export. I would suggest that much of this is not needed for most projects. The difficulty for modellers is to know precisely what is needed for costing purposes. While there is much visible information that is needed, I also know that these cost consultants derive other data from the information provided. Modellers can export absolutely everything, but that probably creates as many problems as it solves [13]. I am sure Cost Consultants/Contractors do not want to drown in more quantitative data than they need. What we need is to understand clearly what is needed by others.

Quantity Model Standards

The Base Quantities suggested by buildingSMART are a good starting point and probably the prominent place to supplement more quantity data with.

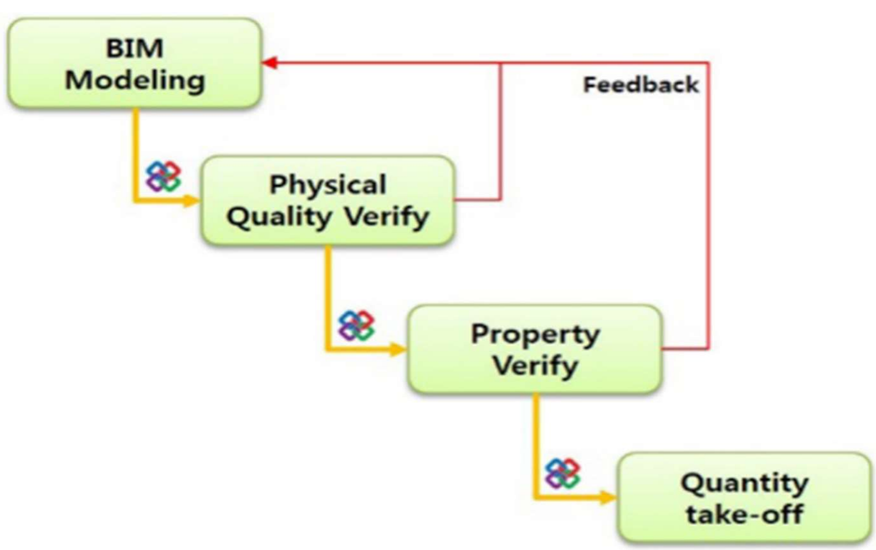


Figure 6: Open BIM-based QTO process

3.3 BIM Cost Estimation & Cost Classification:

BIM can be used to facilitate cost estimations during the life cycle of a project. Cost estimation is a process that can be used to produce BIM correct quantity and cost estimates that are useful for calculating quantities of materials and generating quick revisions when necessary [14]. The use of BIM for construction estimates has been studied in several researches. BIM supports the estimation process by extracting the information and quantity data from a BIM model and then using the quantity data to calculate the construction costs by multiplying the unit costs by the quantity data [10]. This Master thesis focuses on the integrated workflow based on creating the proper quantity take-off that should be used for generating the cost items with the required cost classification.

Moreover, recent research has investigated BIM for quantity take-off by using ArchiCAD software. The comes about to appear that BIM software makes a difference to form construction objects to calculate the quantities and costs of construction works [10]. The precision of the quantity measurements can be more accurate and faster by using BIM for automated quantity take-off [10]. Defining the Levels of Development (LODs) affects the precision of the quantity strongly because the utilise of BIM ought to take after a standard for characterising the LODs of 3D model components [10].

Although there are several BIM tools can generate the quantification of modelling elements, these tools cannot perform cost estimation, and it has to be done in another software. [15]. Although there are several BIM tools can generate the quantification of modelling elements, these tools cannot perform cost estimation, and it has to be done in another software, and as it is known that IFC organises these data exchange between the BIM tool and the cost estimator software. Many studies proved that there are some losses of data in the transfer process (export-import) which causes inaccurate quantities and subsequently, inaccurate cost estimation [15].

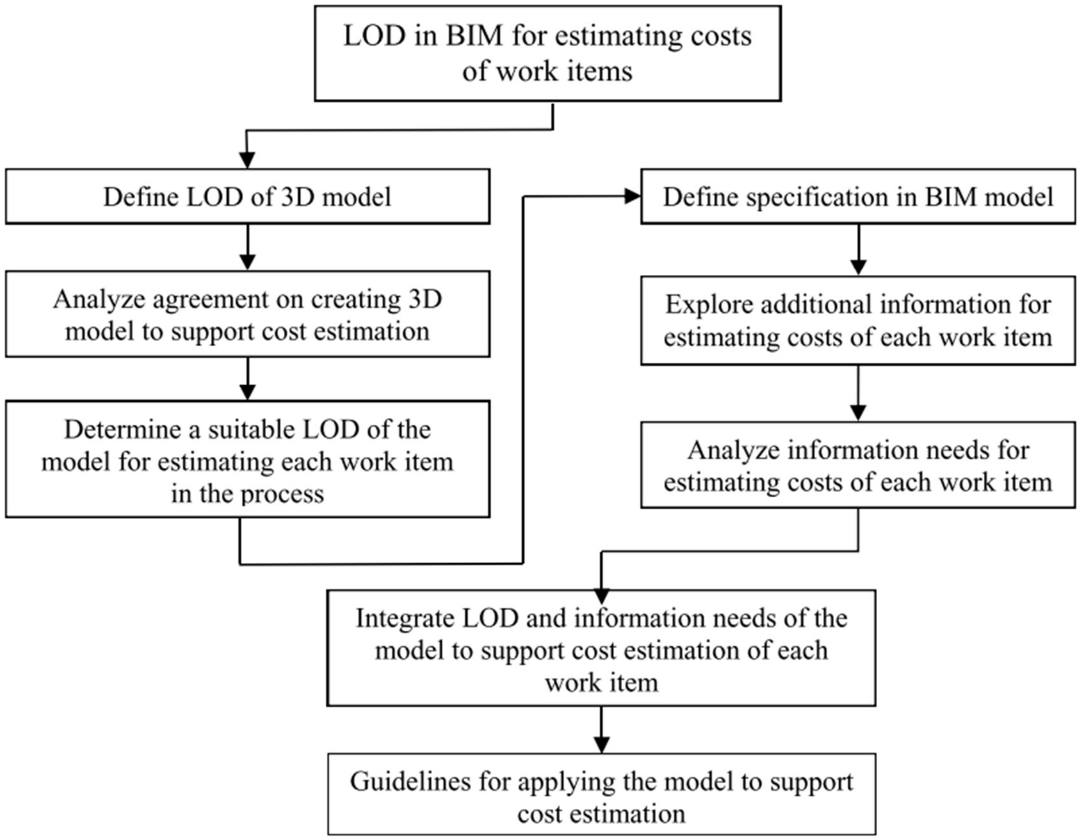


Figure 7: LOD in BIM for cost estimating [10]

An accurate estimate of project costs is crucial for the success (and completion) of a project. However, cost estimation and budget management are two of the most difficult challenges facing project managers today [16].

In 2016, according to PMI, only 53% of projects were completed within their original budget, and these missed budgets and failed projects accounted for up to $122 million per $1 billion of money wasted [16]. **Quantity take-offs are an integral part of the cost estimation process**. The information from a quantity take-off is incorporated into a final detailed estimate, along with things like labour costs, office overhead costs, subcontractor costs, and equipment rentals [17].

It is vital to know the data required to bolster estimation tasks and dissected the information based on the level of agreement. The planning of a Building Data demonstrate for fetched estimation ought to centre on the creation of a 3D demonstrate and the level of information content. In expansion, a 3D model impacts the amount of work, whereas the level of data impacts the obtained quantity and unit costs [10].

Moreover, estimates for material purchases require more point by point data than estimates for tenders. Therefore, during implementation BIM throughout the life cycle of a project, information that can support any work operation should be considered.

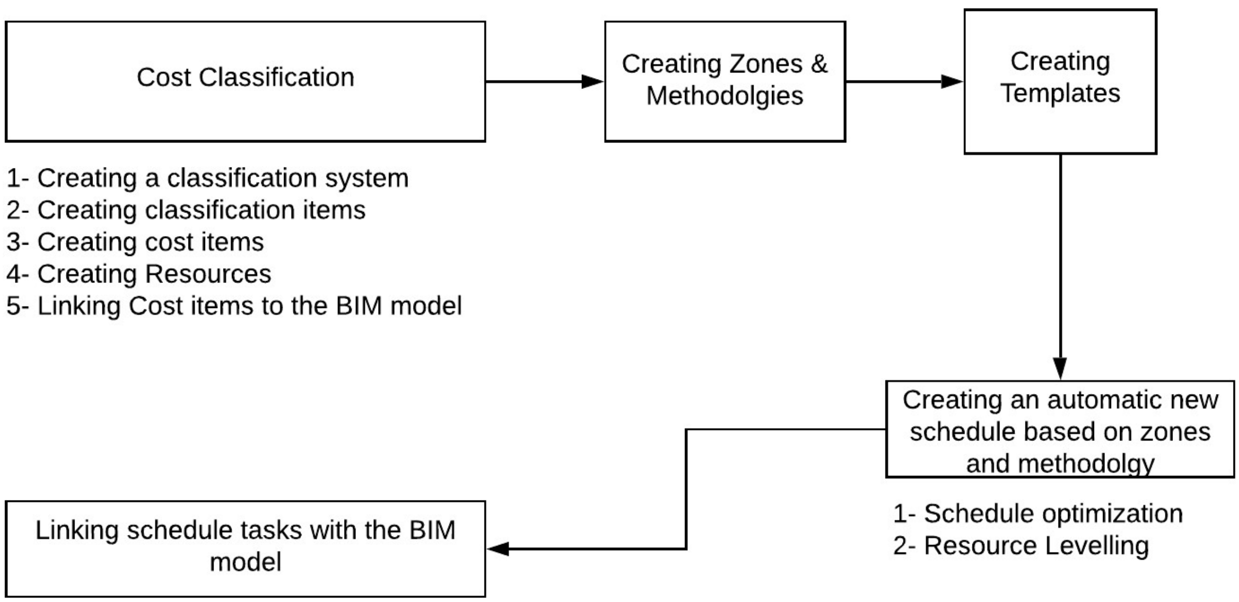


Figure 8: Proposed Workflow for the Cost Classification & Cost Estimation to create automated schedules

3.4 Intelligent Scheduling

Construction planning had improved when construction managers realised that traditional planning is irrelevant to day-to-day operations and a time-consuming distraction [18]. It has become an integral part of most construction projects but remains a time-consuming, error-prone and tedious task that is done manually [18]. As a result, a wealth of research has been conducted to explore how the scheduling process could be improved by automating activity generation, estimating duration, and defining the flow logic [18]. With the technological progress and the predominance of building information modelling (BIM) and 3D modelling in the architectural, engineering and construction (AEC) industry, new possibilities for improving planning processes have recently emerged. The ability to use stored information BIM to assist in the generation of schedules could help to achieve significant time savings in planning compared to traditional manual planning methods [18].

A high degree of reusability is accomplished with the automated era of construction schedules and the integration of 4D visualisations, coming about in exact and adaptable construction schedules indeed in the event that changes in construction planning happen. The approach proposed need building data produced by planning CAD tools based on (IFC Industry Establishment Classes) [19].

Scheduling and planning are decisive for safe, efficient and high-quality construction. When using 4D, the computer becomes a training ground where processes, safety, unique relationships and more can be continuously observed and discussed before and during the entire project. Since a BIM management tool like BEXEL MANAGER 10 links the 3D resources (man, material, equipment and space) with the associated planning tasks, changes and the comparison of baselines with alternatives are quick and easy. Testing the process planning and executing "what if" scenarios is hugely efficient and exciting. Communication is crystal clear because you can see every step in the process. Cooperative knowledge sharing creates innovation and unique approaches that create competitive advantages. The result is an efficient, reliable and secure project management process that saves time and money [20].

Project managers usually create construction schedules that contain thousands of tasks down to the level of each work item. Arranging these tasks, allocating and balancing resources is a challenging task, even for the most experienced project managers [21].

BEXEL's scheduling engine implements advanced scheduling algorithms specifically designed to provide us with the functionality to create fully automated blueprints and ease the pain of manual 4D sequencing. This software relies on users to provide accurate and meaningful data and define building standards and methodology - the rest is up to the software itself! Several options are available for automatic, intelligent planning, and schedules can be customised to meet any need or criterion [21]. The engine finds the optimal solution in terms of minimum construction costs & time and resource balancing - it delivers fully detailed construction plans in seconds for even the most complex projects containing hundreds of thousands of elements [21].

Initially, the generated schedules can be further refined by the user by introducing a specific arrangement of phases and elements in both temporal and spatial terms, or by implementing user-defined calendars for tasks and subcontractors. Resource quantities can be changed for each individual task, subcontractor or phase. Finally, all task durations can be manually modified before the schedule is exported to more common primavera or project platforms [21].

The first step in modelling a construction sequence is to define the granularity for the underlying model [19]. This study assumes that one construction task results in the construction of precisely one component. If multiple design tasks are required to construct a component, the corresponding construction sequences can be replaced by a single construction task, as shown in Figure 9.

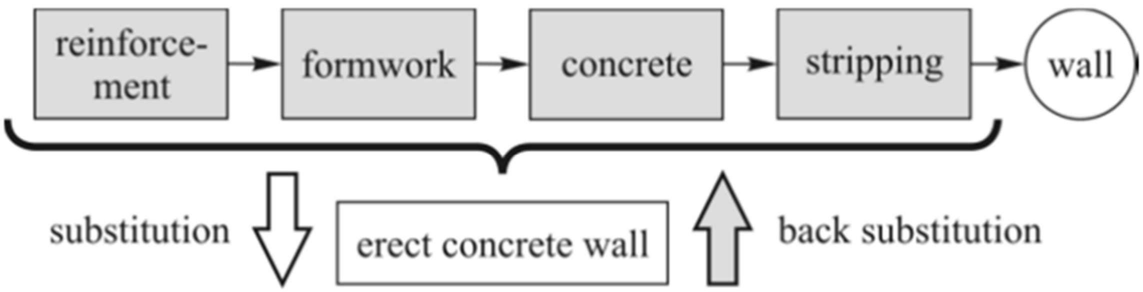


Figure 9: Example of Construction Sequences for reinforced concrete wall [19].

Creation of Methodologies & Zones:

The advanced way of creating schedules is based on the definition of methodology and zones, as it allows users to create a 4D/5D model BIM with the 4D/5D animation simultaneously, the schedules created are better optimised, and the entire process is highly automated, allowing the creation of complex detailed schedules for large construction projects with a large number of tasks and relationships.

Creation methodology that essentially represents the order (sequence) in which the work is carried out. The methodology is based on cost classification, as all types of work carried out for a project are represented, described and quantified in the cost classification. The creation methodology allows the user to define the sequence of the construction works and the relationships between the different types of works. As a simple example, the user defines in the methodology that the foundation works are performed only after the completion of the excavation and preparation works, that the superstructure is performed after the completion of the foundation. This is basically a common construction logic used by every designer and Project Manager user. In this case, the designer "teaches" the automatic design engine the logic of the construction process through Creation Methodology.

Moreover, **construction zones**, which are basically the spatial distribution of the work. The construction works are distributed by buildings (if the project consists of more than one building), by floors (vertical distribution) and by construction sequence - phases (horizontal distribution)

4 PRACTICAL PART

4.1 Case study 1

Introduction

In the previous sections, the proposed workflows of cost estimating and scheduling automation in BIM were introduced. In this chapter, a BIM model of a multi-story residential building will be utilised to illustrate the process of scheduling automation and cost estimating in BIM with the desired workflow. The building is a four-story building in Ljubljana Slovenia, designed using ALLPLAN A NEMETSCHEK COMPANY. The structure model has been created by Geoportal company, figure (10). The building is approximately 2250 m^2. This model contains only concrete works. BEXEL Manager has been mainly used as a BIM viewer for applying the workflow proposed in the thesis research. Bentley Synchro also has been used at the end of the workflow.

The first step is to utilise this building model to generate the QTO list by creating the proper custom breakdown structure and selection sets and then level the cost data on the list to estimate the project cost. The second step is to create a cost classification system and cost items based on the QTO list. The final step is to automate the generation of the construction schedule based on the methodologies and zones to simulate the project process in the 4D environment. The primary purpose of the case study is twofold:

1) The case study will clarify the proposed workflow in how BIM technology can work for cost and schedule controls automation.

2) Based on the existing workflow, what kind of improvements can be made in the future?

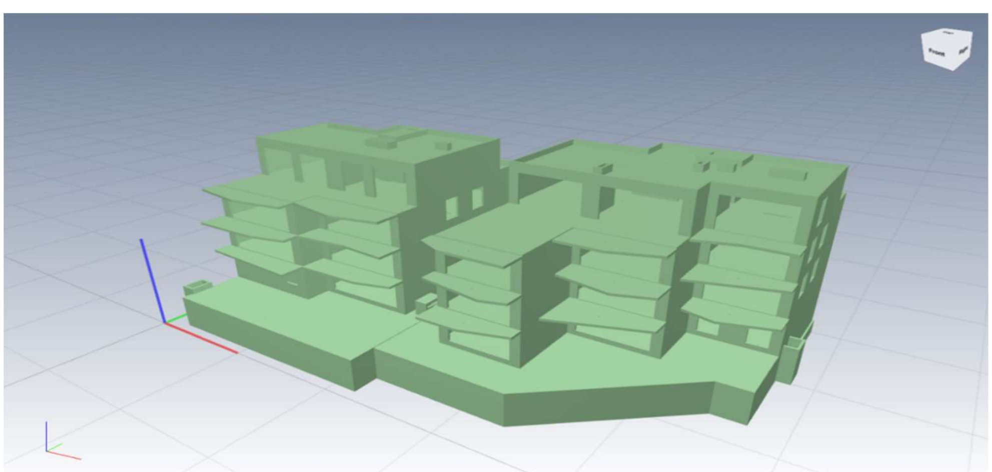


Figure10: Geoportal Company

Figure 11: The 3D view for the case study in BEXEL Manager

Problem Statement

In the IFC model received from the designer, there were no enough properties to segregate the building elements, for example, according to their categories such as beams, walls & slabs.

Through the workflow, it was mandatory to use another BIM viewer software (Bentley Synchro) to divide some building elements and at the same time try not to lose the automated schedules with tasks that will be created in BEXEL Manager. Also, transferring or exporting data from the IFC file from one platform to another between BIM viewer software caused some data to be lost concerning properties recently created in the IFC file in one of this bim viewer software.

Research Questions

1) Can BIM model be fully utilised by contractors for automated schedule and cost controls for concrete works?

2) What are the interoperability conditions for exchanging the IFC file between different BIM viewers even with different platforms?

3) What kind of optimisations can be adapted to obtain the ideal workflow based on the resources and durations?

Software Tools Used

The software tools used in this case study are specified as follows:

1. **ALLPLAN**: AllPlan Engineering is an ultimate BIM solution that supports the entire BIM process for structural and civil engineering, structural designers and contractors.

2. **BEXEL MANAGER**: Is a BIM viewer software mainly used for visualisation of the intelligent 3D model with schedueling and collaboration tools. It also has strong capabilities in generating clash detection. The analysis in the software is integrated into a single solution.

3. **Bentley Synchro**: SYNCHRO is integrated software that offers services for digital construction management. Robust 4D planning and task management functions are the main capabilities of the software that help to plan and optimise even complex civil, construction and industrial projects.

Workflow:

Custom Breakdown Structures & Selection Sets

This part starts with analysing and adding the required properties that should be attached to the building elements in the model for performing the 4D/5D simulation. So many properties have been added to the model through BEXEL Manager that can facilitate the segregation part for creating the custom breakdown structures and selection sets. Adding new properties can be useful in many ways. For example, you can add a new attribute that you can use to link selected elements to the schedule or Classification to create a 4D or 5D model. This is useful in case of missing information about which attribute to use to link the model to the schedule or Classification as the case of this case study. In general, I analyse the properties for different purposes:

- To extract quantities based on the selected attribute, the attribute must be defined correctly. I can extract quantities that are broken down by the selected attribute (for example, a material) directly from the BIM model.

- To link the BIM model to the schedule, resulting in a 4D BIM model. So, I check whether the elements contain a property that allows me to link the elements of the BIM model to the activities of the schedule. Elements that do not have the prescribed property are not linked to the activities of the schedule and are not displayed by the 4D simulation.

- To check the list of works. For this purpose, I check whether the elements have a property that allows me to uniquely link the elements in the list of works to the elements in the BIM model. The elements must also have correctly defined units of measurement and prices. This is also the basis for creating a high-quality 5D BIM model.

As we can recognise, attribute verification is an extremely versatile topic that relates to several phases in the project life-cycle and forms the basis for creating a high-quality and credible 4D and 5D BIM model.

Selection sets are used for the workflow in various ways: -

- In the process of linking the schedule to the BIM model, where a selection set can correspond to a task or a group of tasks in the schedule.

- In the process of creating a 5D BIM model, where a selection set of elements can correspond to a proposal in the Classification.

Then I started with a custom breakdown, where the BIM model was broken down by the selected attribute, in this case, concrete works categories. The custom breakdown structure gives us information about how many elements of the BIM model have the selected attribute and what value it has. It was created based on various criteria, including Properties and selection sets.

Properties need to be added to the modelling elements Pset_MaterialConcrete:

- Water impermeability
- Maximum aggregate size
- Admixtures description
- **Compressive strength**

The custom breakdown structure has been created based on the concrete element categories and segregated to levels and then to building parts (A, B) as shown in figure (13). As all of the elements are recognised as generic models due to the lack of interoperability between the authoring software and the BIM viewer as shown in figure (12), it was mandatory to create these elements segregation.

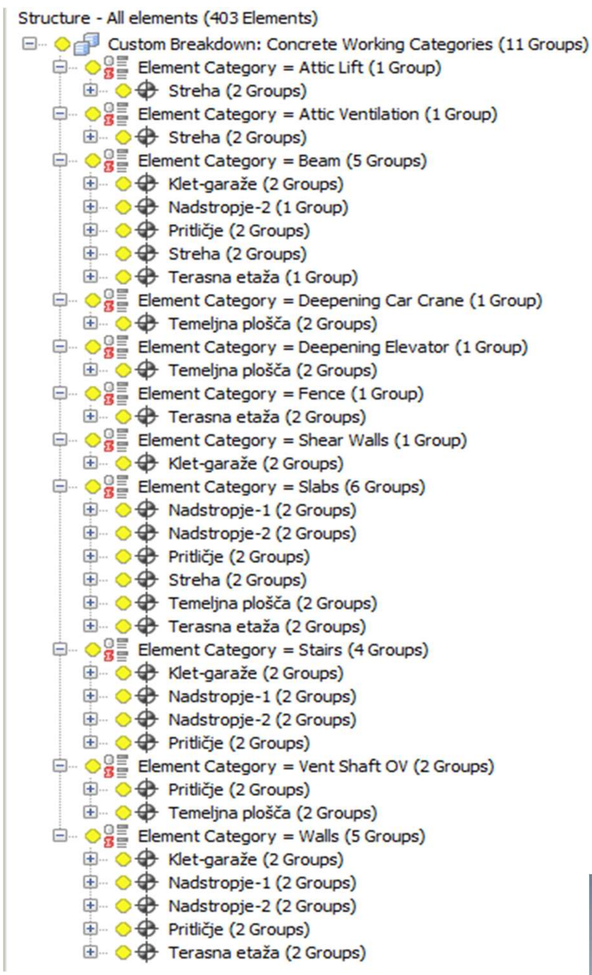


Figure 13: Concrete working categories CBS

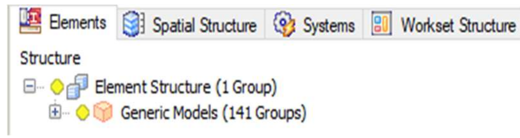


Figure 12: Source Element Categories

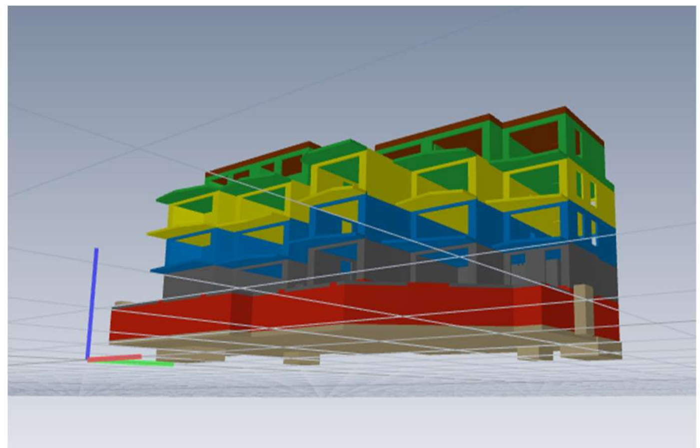


Figure 14: Construction sequencing CBS according to building storeys

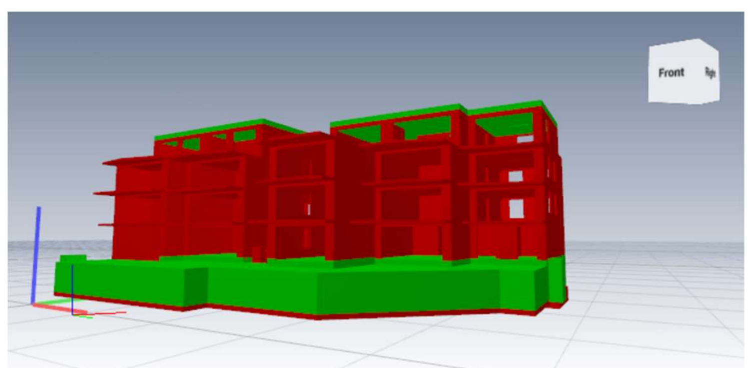


Figure 15: Construction sequencing CBS according to Concrete compressive strength

Quantity take-off

Based on the properties and selection sets created, different QTO tables are generated, as shown in figure (16).

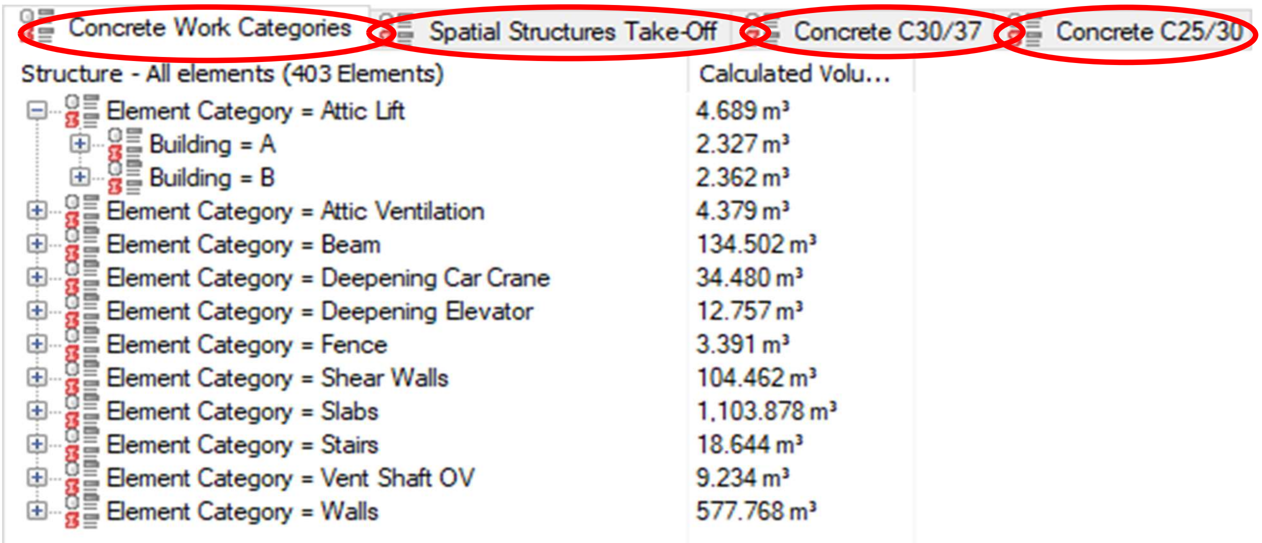


Figure 16: QTO Concrete tables

Cost Classification & Cost Items:

Since I have already created the QTO list based on CBS, then the next step in the integrated workflow is generating the cost classification based on the QTO list, as shown in figure (17). All of the cost items are automatically generated and attached to the building elements in the model smartly using CBS, as shown in figure (18). As mentioned above, the BIM building model is located at a lower LOD. The following steps should be taken to generate more accurate project costs:

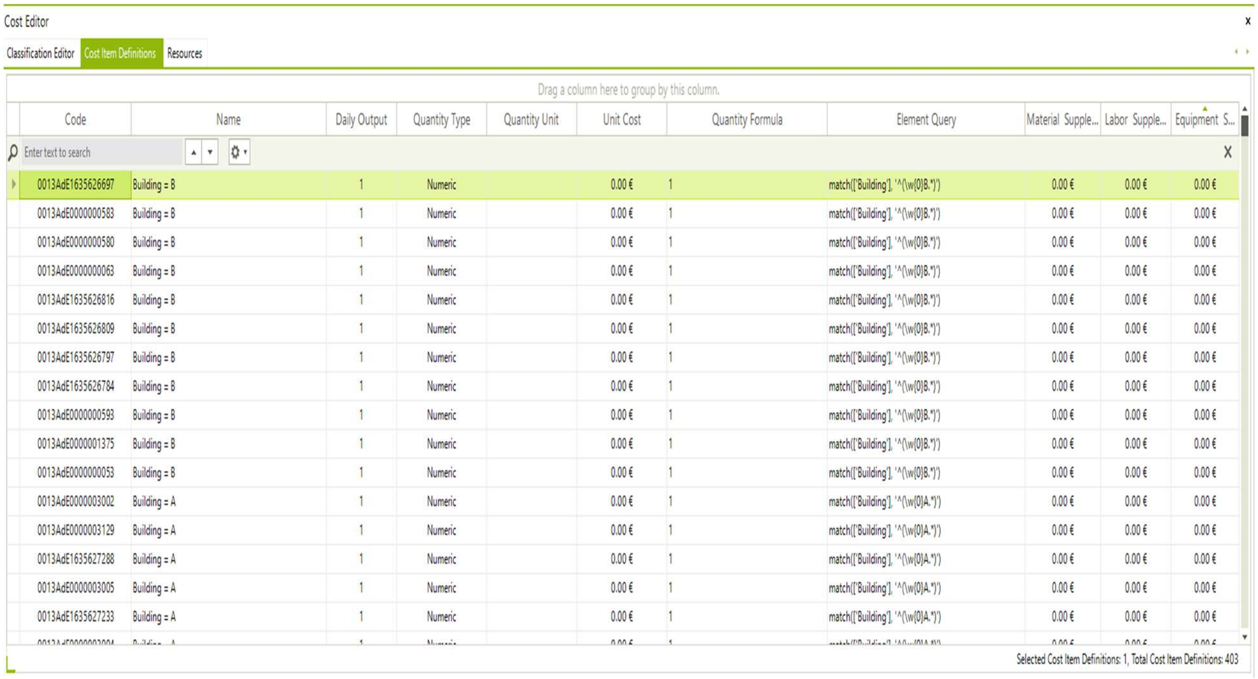
1) All of the building elements should have a property with a unique code based on the generated cost classification.

2) The unit cost for each building element should be attached, or a quantity formula shall be defined to calculate the unit cost.

Code	Name	Cost Items Count	Unit Cost	Element Query
Concrete Work Categories	Concrete Work Categories	403		
Attic Lift	Attic Lift	9		match(['Element Category'], '^(\w{0}Attic Lift.*)')
Streha	Streha	9		['Storey Name'] = 'Streha'
Attic Ventilation	Attic Ventilation	29		match(['Element Category'], '^(\w{0}Attic Ventilation.*)')
Beam	Beam	48		match(['Element Category'], '^(\w{0}Beam.*)')
Deepening Car Crane	Deepening Car Crane	10		match(['Element Category'], '^(\w{0}Deepening Car Crane.*)')
Deepening Elevator	Deepening Elevator	10		match(['Element Category'], '^(\w{0}Deepening Elevator.*)')
Fence	Fence	6		match(['Element Category'], '^(\w{0}Fence.*)')
Shear Walls	Shear Walls	25		match(['Element Category'], '^(\w{0}Shear Walls.*)')
Slabs	Slabs	47		match(['Element Category'], '^(\w{0}Slabs.*)')
Stairs	Stairs	25		match(['Element Category'], '^(\w{0}Stairs.*)')
Vent Shaft OV	Vent Shaft OV	19		match(['Element Category'], '^(\w{0}Vent Shaft OV.*)')
Pritličje	Pritličje	10		['Storey Name'] = 'Pritličje'
Temeljna plošča	Temeljna plošča	9		['Storey Name'] = 'Temeljna plošča'
Walls	Walls	175		match(['Element Category'], '^(\w{0}Walls.*)')

Selected Classification Items: 40, Selected Cost Items: 403, Total Classification Items: 40, Total Cost Items: 403

Figure 17: Generated Cost Classification in Bexel Manager 10


Cost Editor
Classification Editor | Cost Item Definitions | Resources
Drag a column here to group by this column.

Code	Name	Daily Output	Quantity Type	Quantity Unit	Unit Cost	Quantity Formula	Element Query	Material Supple...	Labor Supple...	Equipment S...
0013AdE1635626697	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE0000000583	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE0000000580	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE0000000063	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE1635626816	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE1635626809	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE1635626797	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE1635626784	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE0000000593	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE0000001375	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE0000000053	Building = B	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}B.*)')	0.00 €	0.00 €	0.00 €
0013AdE0000003002	Building = A	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}A.*)')	0.00 €	0.00 €	0.00 €
0013AdE0000003129	Building = A	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}A.*)')	0.00 €	0.00 €	0.00 €
0013AdE1635627288	Building = A	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}A.*)')	0.00 €	0.00 €	0.00 €
0013AdE0000003005	Building = A	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}A.*)')	0.00 €	0.00 €	0.00 €
0013AdE1635627233	Building = A	1	Numeric		0.00 €	1	match(['Building'], '^(\w{0}A.*)')	0.00 €	0.00 €	0.00 €

Selected Cost Item Definitions: 1, Total Cost Item Definitions: 403

Figure 18: Generated Cost items in Bexel Manager 10

Construction Intelligent Scheduling (Automatic Schedule Generation):

By using the same model, BEXEL MANAGER 10 can simulate the schedule of the project by adding the fourth dimension—time into the model. The time frame we set up for this case is starting at APR. 1st 2020 and the project would approximately last three months and completed by JUL. 5th. As stated before, there are three different ways to add/incorporate the schedule into the building model:

1. Defining the tasks in the BEXEL MANAGER 10 directly.
2. Importing Primavera or MS Project schedule
3. Creating zones and methodologies to automate the generation of the schedule.

For this case study, the third approach was used, creating the zones and methodologies, and the steps are stated as follows:

1) Defining the zones levels and phases.
2) Defining the construction methodologies for building categories and elements priorities.
3) Get the Gantt Chart & LOB View of the project schedule.
4) 4D simulation view.

Step 1: Defining Zone Items:

The most crucial spatial division of the project is the division by buildings. Therefore, the first step in creating zones is to determine the building sequence between specific buildings on the project, as shown in figure (19).

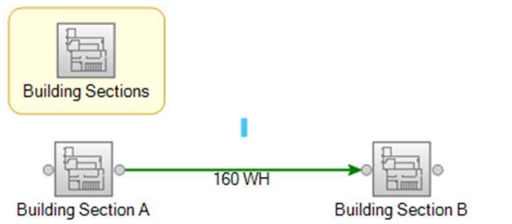


Figure 19: Building Sections Zones

The next level of the spatial division of the project is division by Building Storeys or vertical division. It is usually used in construction planning and contributes significantly to more effortless organisation of construction work, better resource planning and generally to a more efficient construction process. The construction sequence by the floor is simple and defined by gravity and always has a final start sequence from bottom to top. The user should only associate the floors or building levels of the project with the Finish-Start relationships to get a correct definition of the floor zones, as shown in figure (20).

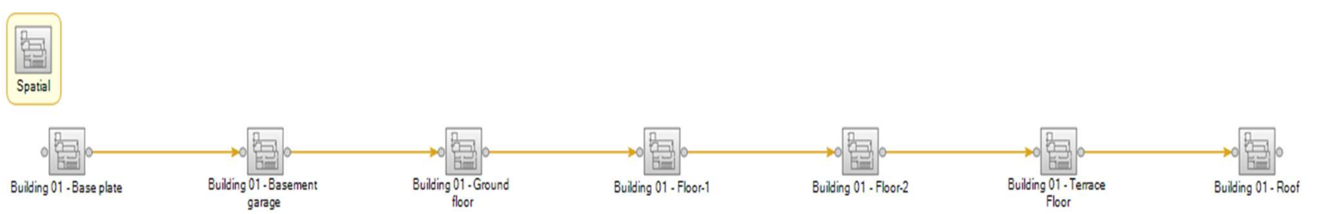


Figure 20: Spatial Zones Levels

Step 2: Defining Methodology Items:

The process of creating a new methodology is similar to the process of creating a zone but is more complicated than spatial distribution due to the complex nature of the works. There are two main differences between the zones and the methodology. The methodology is based on a specific classification and can be applied to various similar projects, unlike the zones, which are more based on a specific project and consist of selection sets, buildings, levels, etc.

The methodology is usually established at two levels. Uniformat (as the most common) for physically-based work item segregation and master format (as the most common, but also many other national classification standards) for material-based work item segregation. These two classification systems are complementary.

This is typically defined in the cost classification structure so that the user only needs to define the correct work sequence between these subgroups of work in the methodology. At the first level, the sequence and relationships between workgroups (defined in the Uniform Classification) are defined. In reality, the Bexel Manager user is, therefore, able to define this sequence by merely linking "chapters" or classification items from the cost classification and defining the nature of the relationship between the tasks.

In this case study, there were no properties attached to the building elements for neither the Uniformat nor MasterFormat classifications, so the methodology level was created based on the cost classification created in the previous step, as shown in figure (21).

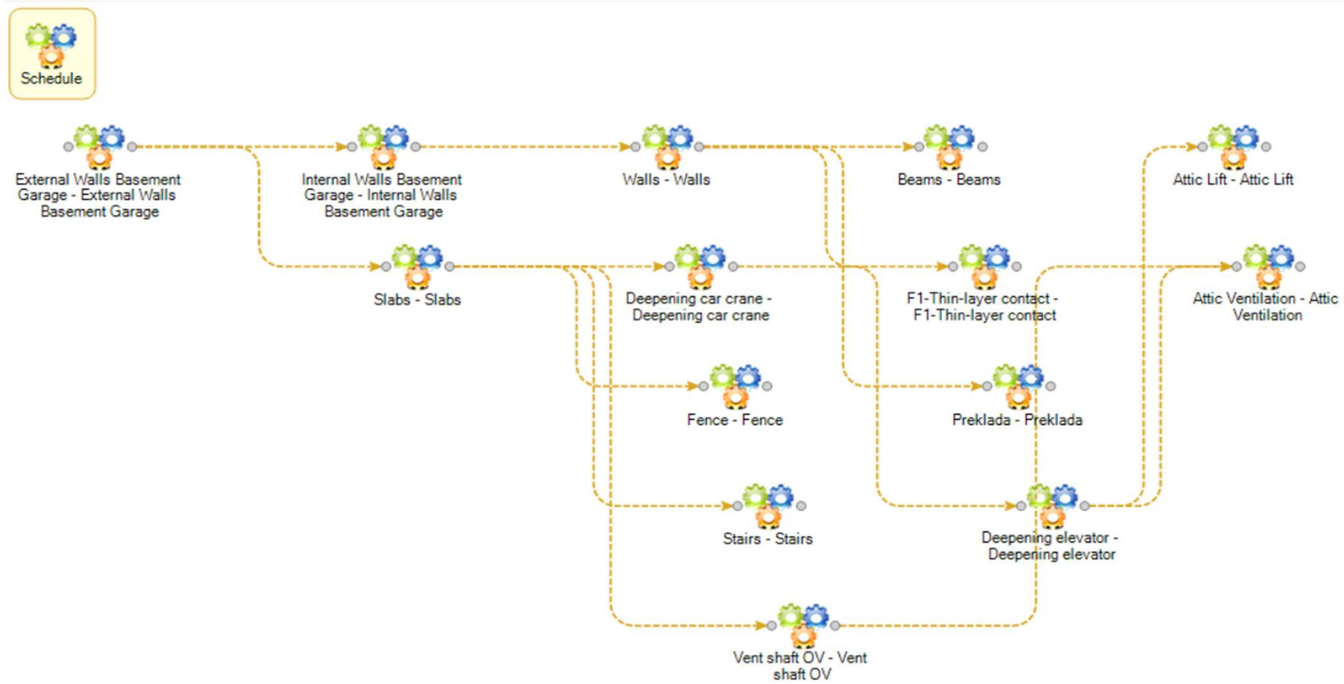


Figure 21: Methodology items tree

Step 3: Gantt & LOB Charts View:

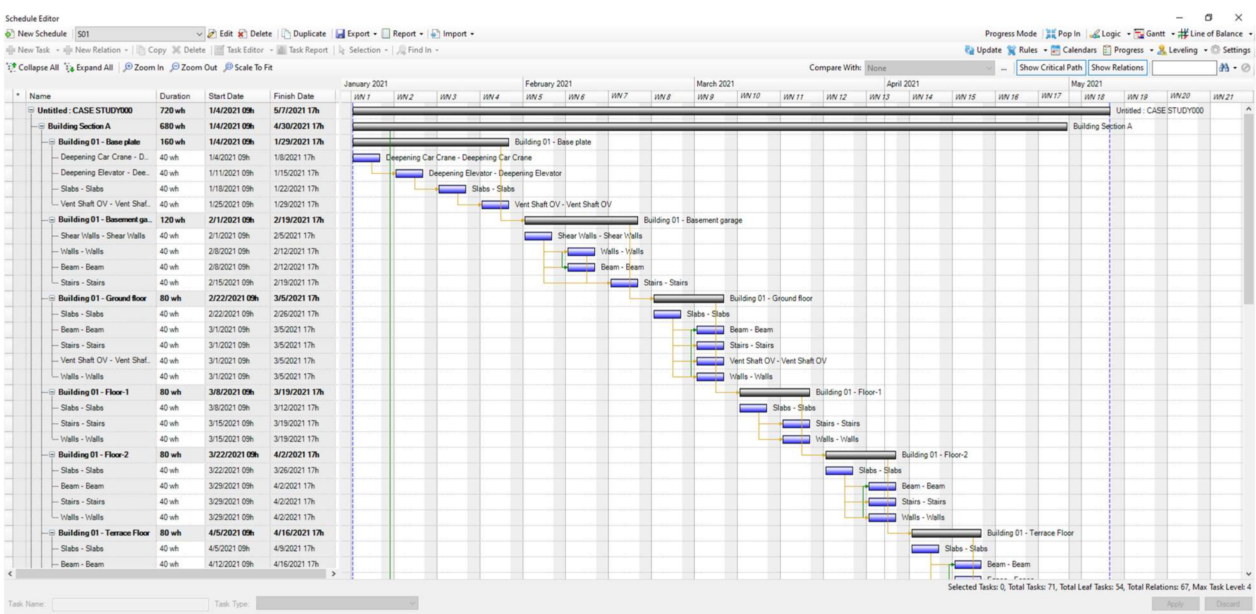


Figure 22: Gantt Chart View

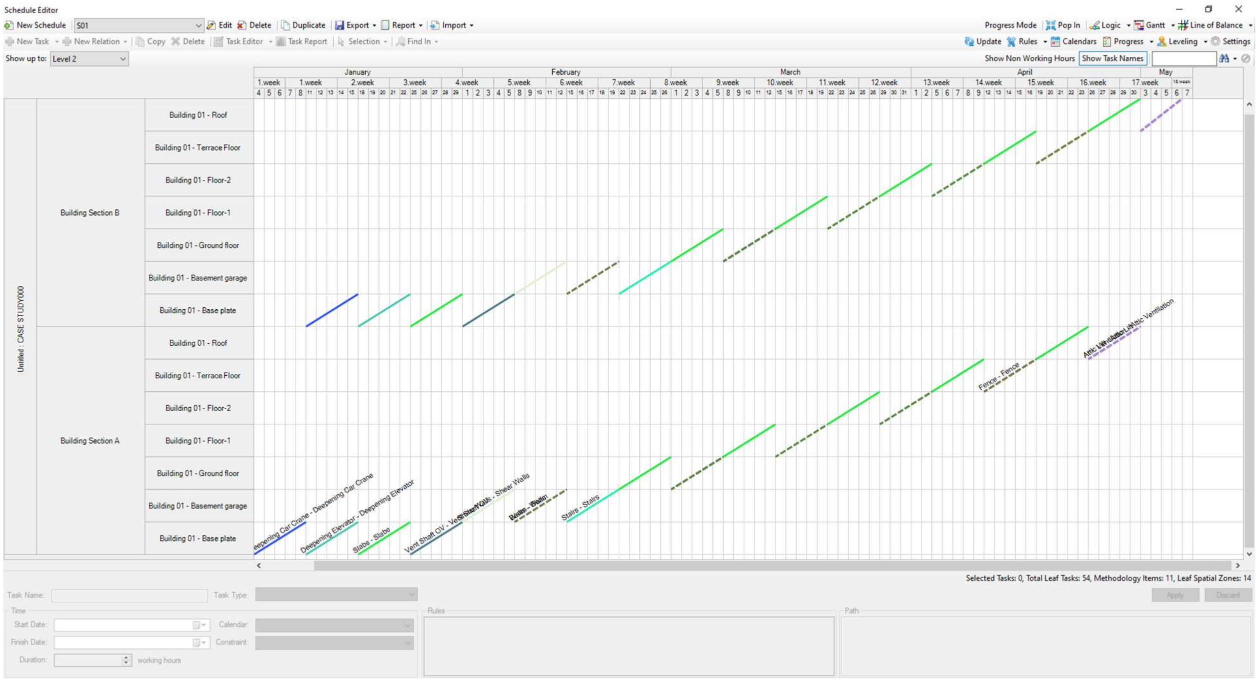


Figure 23: Line of Balance Chart View

By having these views, you can modify the tasks and activities in order to optimise the schedule based on the resources and cost if it is available in the model.

Step 4: 4D simulation

For creating the 4D simulation, I faced a problem with four wall building elements that were modelled in the authoring software each one of them as one element through all of the building levels as shown in figure (24), which is not possible through the construction sequencing of the project. Since I do not have access to the authoring tool source file, and also is not possible to sub-divide the building elements in Bexel manager 10 in terms of trying to keep the integrity of the workflow in one software.

The solution to this problem was using another BIM viewer that can sub-divide the building elements and at the same time export the schedule created in Bexel Manager 10. Bentley SYNCHRO software has been used for this process, and the interoperability was quite good for having the main schedule with some loss of information. The walls have been sub-divided in SYNCHRO, and the new cost items and activity tasks have been added manually, and that was the only manual action to intervene in the workflow.

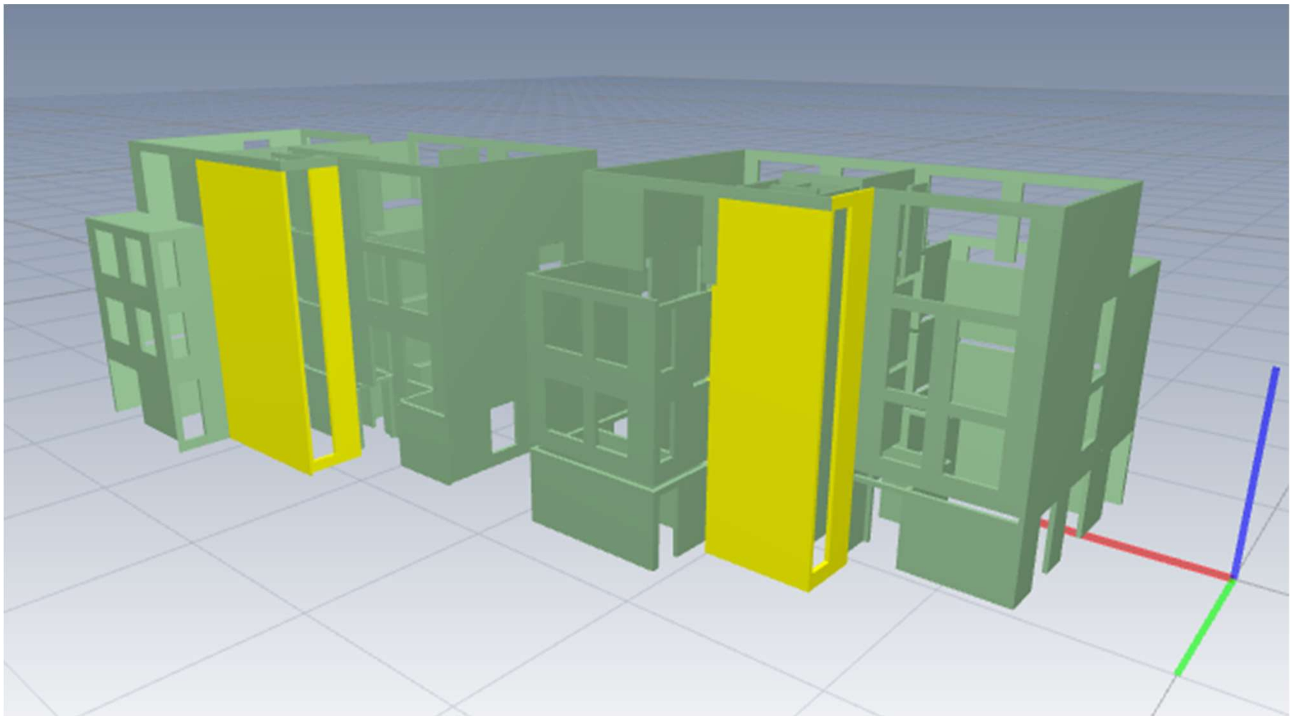


Figure 24: Walls before sub-dividing in Bexel Manager 10

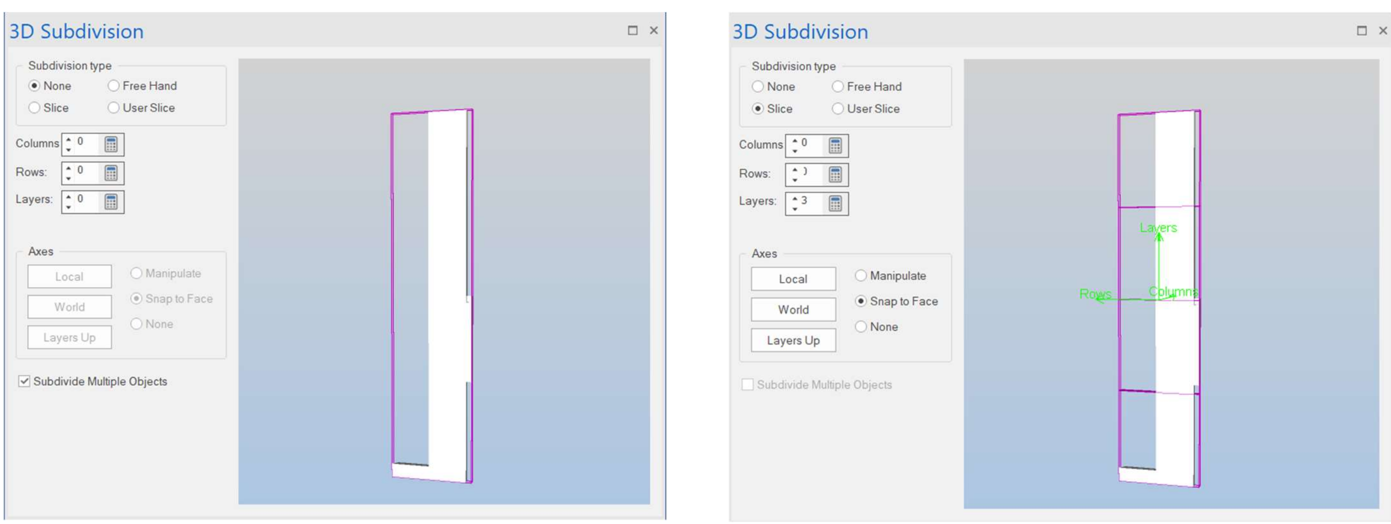


Figure 25: Walls Sub-dividing in SYNCHRO

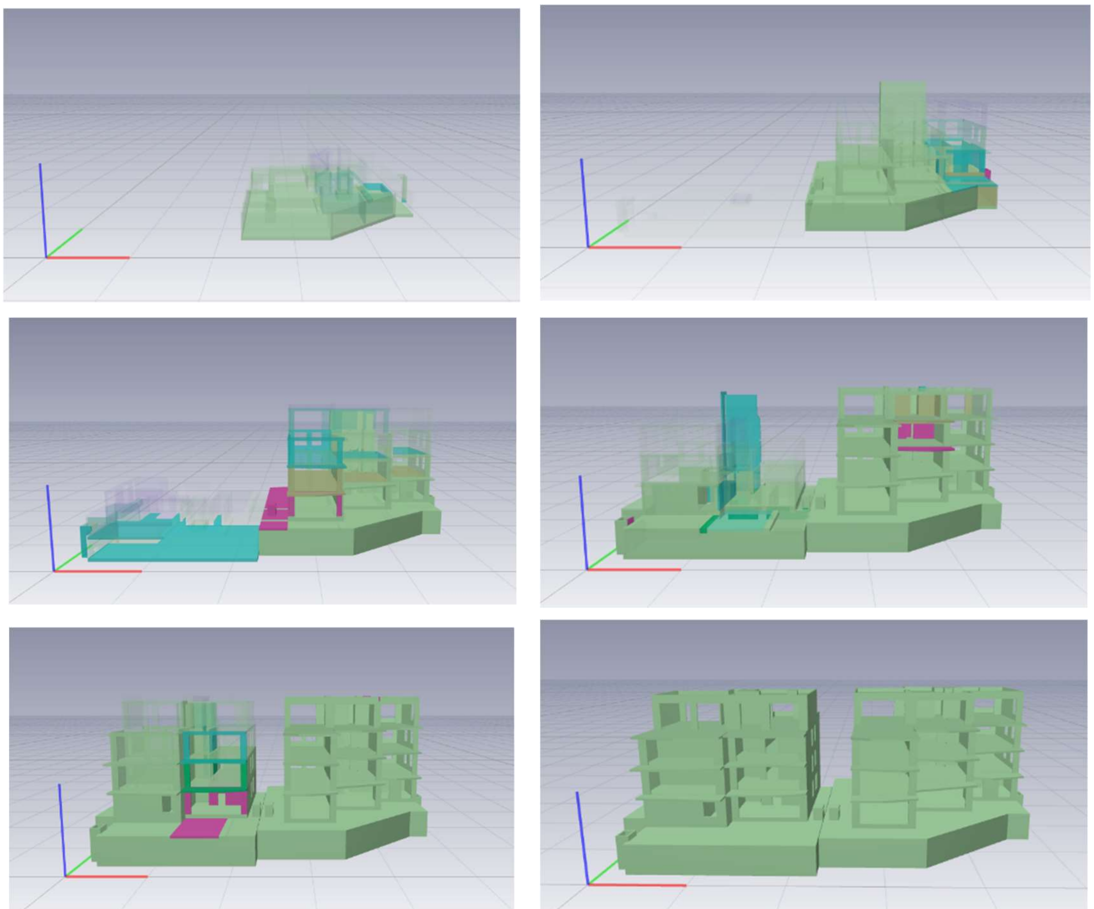


Figure 26: 4D Simulation in BEXEL MANAGER

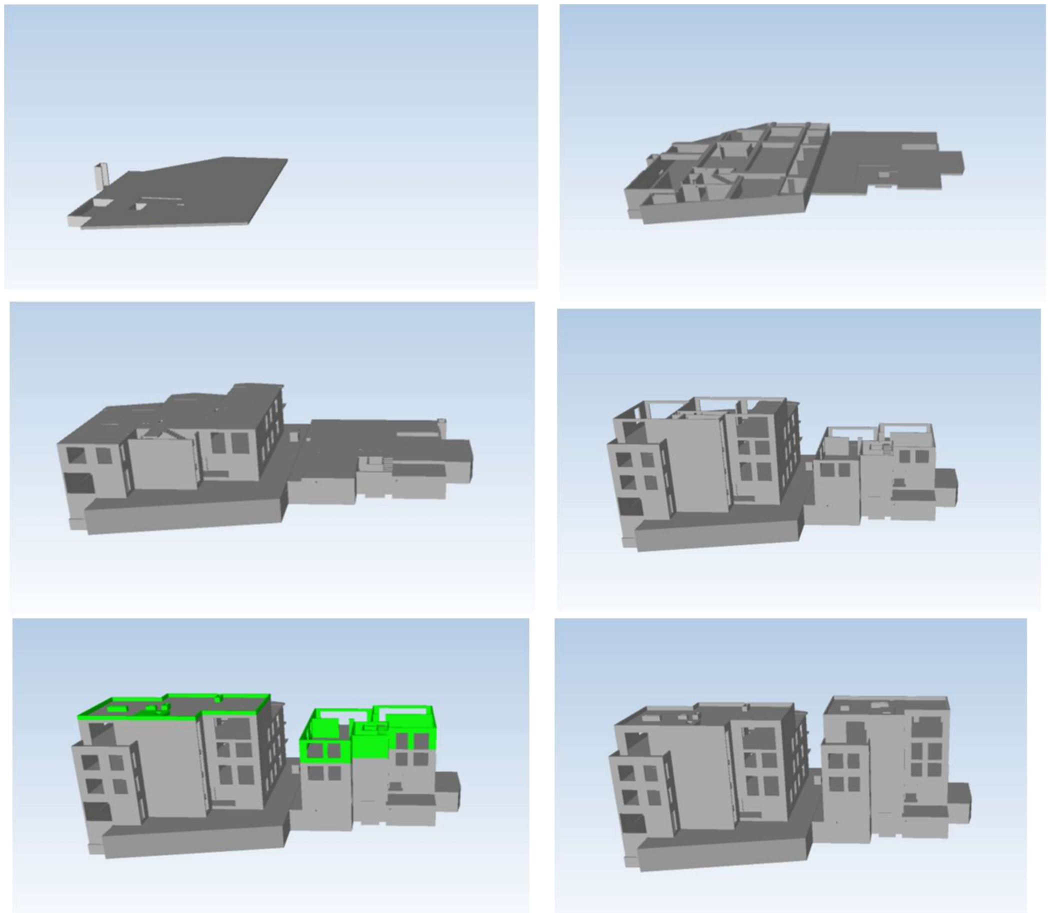


Figure 27: 4D Simulation in SYNCHRO

Conclusion

A review of the case study shows that the BIM technology brings with it many advanced construction management capabilities for project scheduling, cost estimating and even project control by contractors. In this case study, the QTO process is automatic and reliable. It is completed within minutes, as the quantities of BEXEL MANAGER construction components are "read" directly from the building model. This saves the contractors a considerable amount of time when estimating costs. On the other direction, the design changes in the building model can be updated and added to the QTO list in minutes, which means that the client can use the BIM technology to get faster cost feedback on design changes.

The cost classification can be either exported and used for creating the automatic schedules after forming the element queries or generated in the software based on the QTO list & CBS. The cost items also can be entirely generated by the software if the building elements have the same naming convention, keynotes and unit cost.

4.2 Case study 2

In this case study, I have full control over the 3D model as the model has been created by me from scratch in the authoring software, which is AUTODESK REVIT 2020. The case study is a BIM model of a small four-story residential building. The reinforcement of the building has been created using **SOFiSTiK 2020**. The building is approximately 725m^2. The Building information model has been developed to contain the following elements:

- Structure System: including structural foundation, structural columns, structural slabs, Structure walls and reinforcement.
- Exterior walls: including the bricklayer, the external insulation layer and the internal plaster layer.
- Internal walls: including the bricklayer and the plaster layer.
- Doors.
- Windows.
- The finishing layers of the internal floors and the roof.

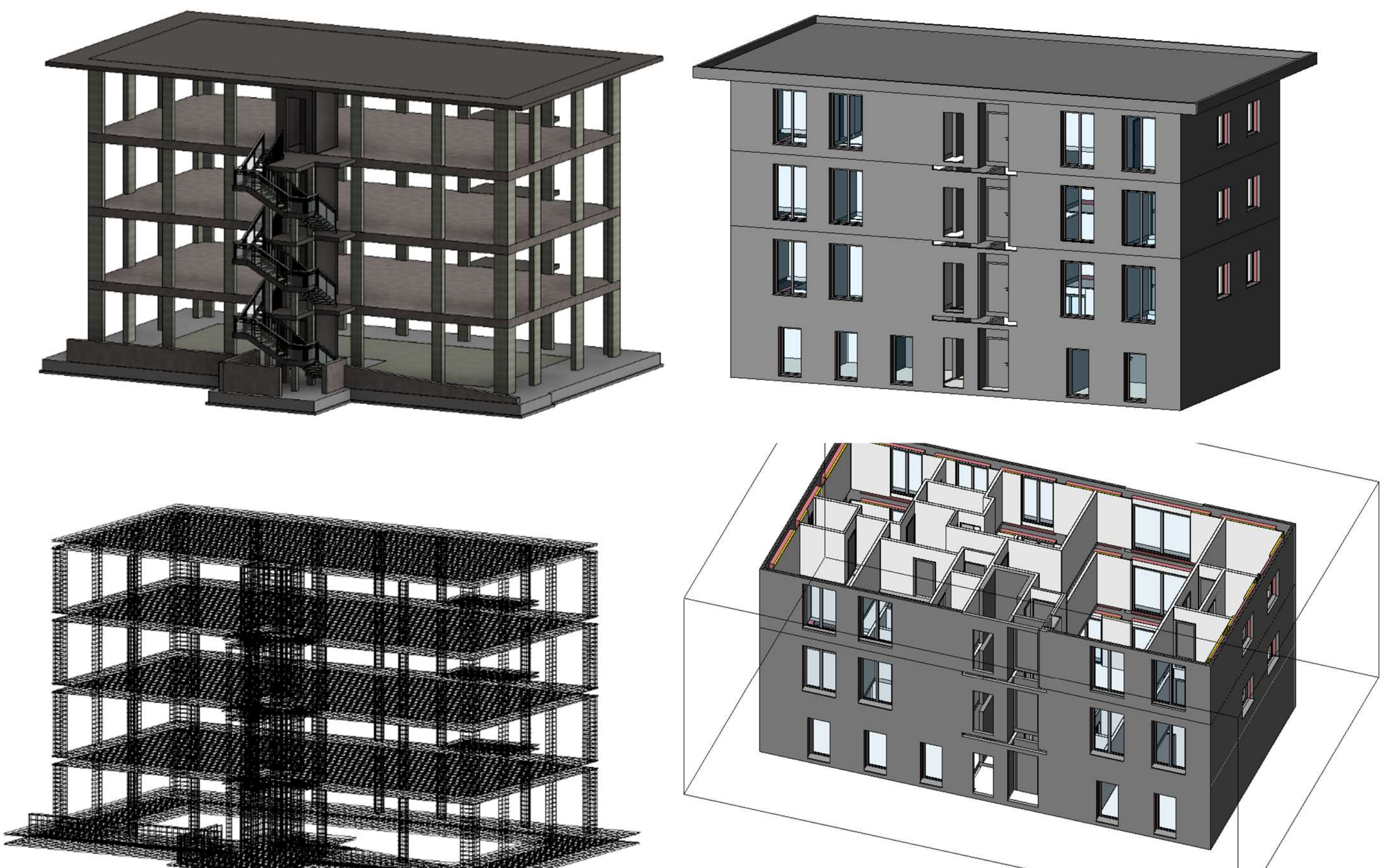


Figure 28: Different 3D views of the Structure & Architecture models

Autodesk Navisworks 2020 and **BEXEL Manager 10** have been mainly used to show in two different workflows how to elaborate the 4D/5D analyses and create the simulation.

MS Project and **Excel** also have been used for creating the schedule and price list in the first workflow.

The primary purpose of the case study is twofold:

1) The case study will clarify in two workflows with two different software about how BIM technology can work for cost and schedule controls automation.

2) Based on the simulation results from each workflow, In which phase of the project, these simulation results can be useful.

The workflow in Naviswork:

After creating the Revit Model from scratch, I proceed to export it in Naviswork to elaborate the 4D and 5D analyses. The steps were the following:

1. Creating the "Item Catalog" for the whole project, developing the rules for the Quantities Take-off matching the Total Cost Price List naming convention and adding in the description the information of the level to enable a query in excel later on.

2. Exporting the QTO report to excel and linking the three databases: the QTO, the Price List and the Gantt Chart. The result of it was a Gantt Chart with the total cost per task. I chose to perform this interoperability in Excel.

3. Importing the Gantt Chart, with the total cost, and assigning the corresponding elements to the tasks and creating the 4D and 5D simulation.

4. Creating the Resource Catalog, taking in consideration equipment, material, team/workers;

This case study will elucidate these four steps, focusing on the problem-solving perspective and critical thinking.

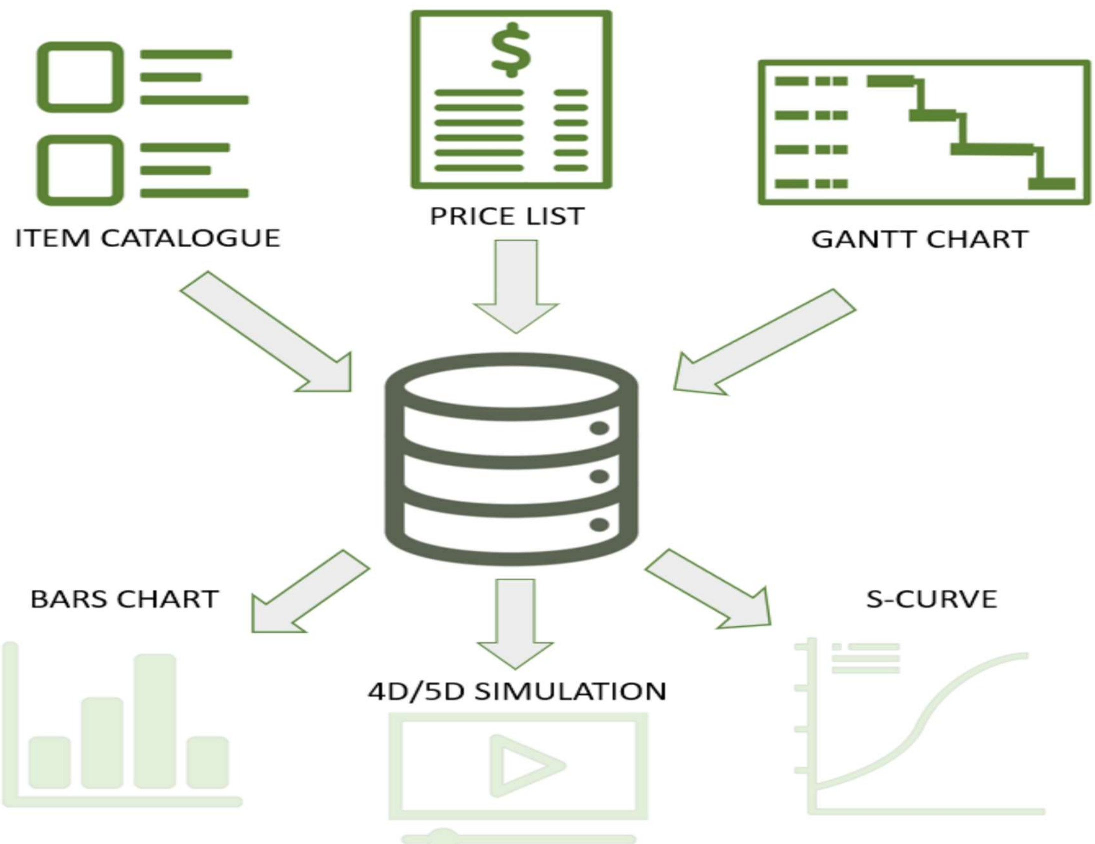


Figure 29: Case Study workflow in Navisworks

Quantities Take-off

There were two ways of performing the QTO of this project. Firstly, using a Total Cost Price List which assumes the three resources into one direct cost related by one measurement. Secondly, measuring the three resources using some correlation, pricing them individually and summing them at the end to get the Total Cost. With that in mind, I have chosen the first way and started the work developing the Total Cost Price List (TCPL) for the project.

Category		Direct Cost		% Indirect Cost	% General Cost	% Profit	Price	
Activity	Description	Value	euro/unit	15%	7%	5%	Value	euro/unit
Foundation Work	Excavation	11,50	m3	1,73	0,93	0,71	14,86	m3
	Iglu	68,71	m2	10,31	5,53	4,23	88,78	m2
Structural Work	Formwork	29,46	m2	4,42	2,37	1,81	38,06	m2
	Casting Concrete	92,19	m3	13,83	7,42	5,67	119,11	m3
	Formwork removal	8,32	m2	1,25	0,67	0,51	10,75	m2
	Reinforcment	2,62	kg	0,39	0,21	0,16	3,39	kg
	Scaffolding	82,50	m2	12,38	6,64	5,08	106,59	m2
	Stair	527,00	each	79,05	42,42	32,42	680,90	each
	Railing	26,00	m	3,90	2,09	1,60	33,59	m
Completition Work	Poroton 200mm	67,60	m2	10,14	5,44	4,16	87,34	m2
	Poroton 250mm	71,00	m2	10,65	5,72	4,37	91,73	m2
	Blockwork 150mm	53,20	m2	7,98	4,28	3,27	68,74	m2
	Blockwork 200mm	56,70	m2	8,51	4,56	3,49	73,26	m2
	Brick 10mm	45,60	m2	6,84	3,67	2,81	58,92	m2
	Internal wall insulation 35mm	52,00	m2	7,80	4,19	3,20	67,19	m2
	Internal wall insulation 85mm	61,00	m2	9,15	4,91	3,75	78,81	m2
	Floor insulation	20,80	m2	3,12	1,67	1,28	26,87	m2
	Low Density Concrete	16,63	m3	2,49	1,34	1,02	21,49	m3
Finising Work	Metal stud 50mm	10,00	m	1,50	0,81	0,62	12,92	m
	Metal stud 80mm	12,00	m	1,80	0,97	0,74	15,50	m
	Metal stud 95mm	13,00	m	1,95	1,05	0,80	16,80	m
	Metal stud 120mm	15,00	m	2,25	1,21	0,92	19,38	m
	Shaft Wall	17,50	m2	2,63	1,41	1,08	22,61	m2
	Plaster Board	19,43	m2	2,91	1,56	1,20	25,10	m2
	External Wall Insulation	70,00	m2	10,50	5,64	4,31	90,44	m2
	Floor Laminate	36,00	m2	5,40	2,90	2,21	46,51	m2
	Roof insulation and VCL	2,25	m2	0,34	0,18	0,14	2,91	m2
	Bitumen membrane	13,93	m2	2,09	1,12	0,86	18,00	m2
	Gravel	0,02	kg	0,00	0,00	0,00	0,03	kg
	Sliding Door	210,00	each	31,50	16,91	12,92	271,33	each
	Sliding Door Cassette	100,00	each	15,00	8,05	6,15	129,20	each
	Internal Door	235,00	each	35,25	18,92	14,46	303,63	each
	Internal Door Frame	25,00	each	3,75	2,01	1,54	32,30	each
	External Door	400,00	each	60,00	32,20	24,61	516,81	each
	External Door Frame	120,00	each	18,00	9,66	7,38	155,04	each
	Window	345,00	each	51,75	27,77	21,23	445,75	each
	Window frame	25,00	each	3,75	2,01	1,54	32,30	each

Figure 30: Total Cost Price List in Excel

With the price list in hand, I structured the QTO in Navisworks. The Work Breakdown Structure was thought to allow queries by the element, and by level, but instead of adding the levels to the WBS I added it to the "Item Map Rules" as a description. That increased the speed of the process of attaching elements to each "Take-off" in the "Quantification Workbook" in Navisworks.

Interoperability (QTO, TCPL, Gantt Chart)

The goal was to architecture a query that linked the Primary Quantity of the QTO per element, per task and per level with the TCPL of that task. Next, it was necessary to put it in an MS Project format, ready to be exported. The logical steps are explained below:

Table 1 – The problem

1.1.2	**Reinforced Concrete**	**6 days**	**Mon 2/10/20**	**Mon 2/17/20**		**€ 0,00**
1.1.2.1	Formwork and Reinforcement	4 days	Mon 2/10/20	Thu 2/13/20	4FS+1 eday	???
1.1.2.2	Casting Concrete and Formwork Removal	2 days	Fri 2/14/20	Mon 2/17/20	6	???

Table 1 represents what we need to solve in the Gantt Chart format. We started creating a Table 2 – Intermediate Table to prevent many to many relations between the Gantt Chart task and the QTO task since there are fewer tasks in the Gantt chart than in the TCPL. That occurred because I only created tasks in the Gantt chart when there were elements in the model to be attached.

Table 2 – Intermediate Table

Task	Task-related	
Formwork and Reinforcement	Formwork	Reinforcement
Casting Concrete and Formwork Removal	Casting Concrete	Formwork removal

With the tasks from Table 2, I got the Direct Cost from the TCPL, and with the Gantt chart WBS I got the elements and the level, then I searched for the QTO of each task of that element on that level. Finally, I multiplied the QTO value by the Direct Cost and summed them in the Gantt chart.

Table 3 – Hidden Table of Calculation

Element	Level	Tasks		Task Price		QTO		Price	
Reinforced Concrete	Foundation Level	Formwork	Reinforcement	29,46	2,62	74,44495	489,2885	2193,148	1281,936
Reinforced Concrete	Foundation Level	Casting Concrete	Formwork removal	92,19	8,32	114,9557	74,44495	10597,76	619,382

Resource Analysis tables

Resource Catalogs define and organise the resources available. In this stage, I cared about creating these resource analysis tables for some structure and architecture elements such as (Columns casting & formwork – External, Internal & Sliding doors – Architectural Roof layers) using Excel.

Basically, in the preliminary stage, it is not necessary to create the details of the resources for the cost estimating and settle for assigning the total cost of task/activity. Then in the further stages, I started assigning the resources for the activities to gain the total unit cost; these were the way I followed for the previously mentioned elements, but due to the lack of information about the cost of the other resources such as Team/worker, I did not implement all of them into Navisworks's Database.

Concrete Casting For COLUMNS							
Resources		U.M	Yield	Cost/ U.M	U.M	Unit Cost	U.M
1- Materials							
Ready-Mixed concrete 25/30◌ arrives the construction site with a cement mixer. The cost of transportation is included.		m3/m3	1.05	67.04	€/m3	70.39	€/m3
2- Equipment							
Compressed air vibrator for concrete, including labour or operation		h/m3	0.3	20	€/h	6	€/m3
Concrete pump, including labour for operation(10m3/hr)		h/m3	0.1	25	€/h	2.5	€/m3
3- Team/Workers							
Specialised construction worker		h/m3	0.3	24	€/h	7.2	€/m3
Qualified construction worker		h/m3	0.3	20.33	€/h	6.1	€/m3
Total €/m3	92.19						
Total time h/m3	0.3						

Figure 31: Resource Analysis Table

The workflow in Bexel Manager:

The same workflow that has been followed in the previous case study is applied here for obtaining the 4D/5D simulation. I started with using the plugin of Bexel manager in Revit for exporting the model. However, I noticed that some information and elements such as parts of the reinforcement had been lost during the export process. I tried again by exporting the model from Revit as an IFC file then open it in Bexel Manager, and it works better with almost all of the properties and the elements.

The following steps were followed for generating the schedule automation in the optimised way:

Custom Breakdown Structures & Selection Sets

The first step in this process is sorting elements by leading groups of works:

- Structure Works
- Architecture Works
- MEP (Not Available in the case study)
- Landscape and roads (Not available)

This could be quickly done by simply creating separate selection sets. In this case, since I had the source files of the Structure and the Architecture works, So I started my segregation with all of the building elements in the model then the next level was the families of each category. At the last level of segregation for the CBS, I used the levels of the building and the file source (STR. or ARC.)

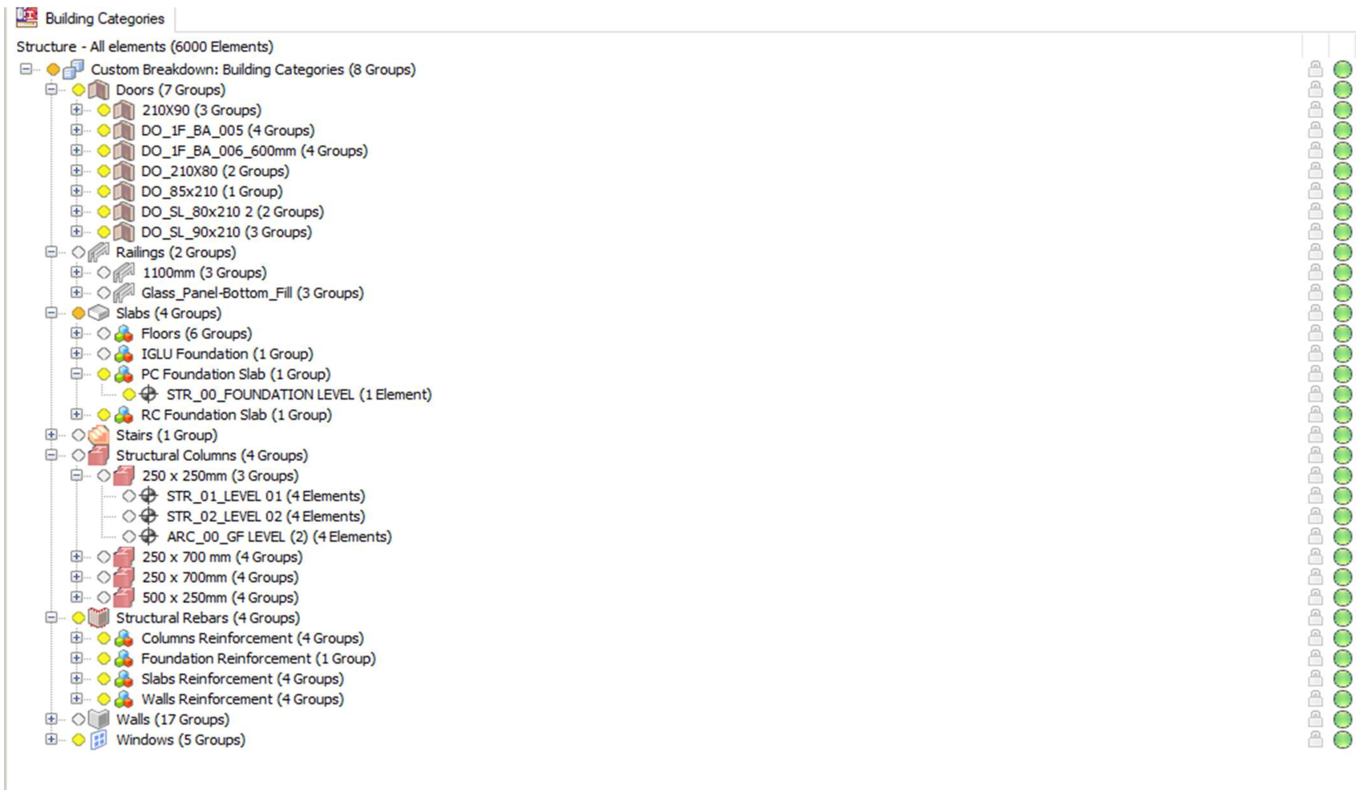
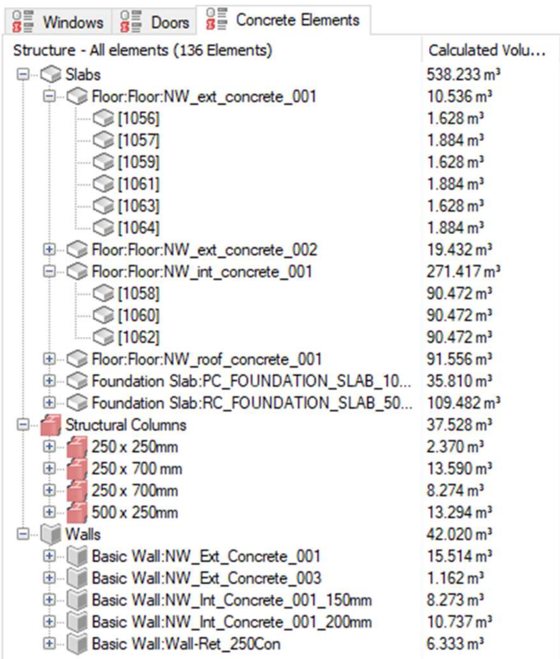


Figure 32: CBS CASE STUDY

Quantity Take-off

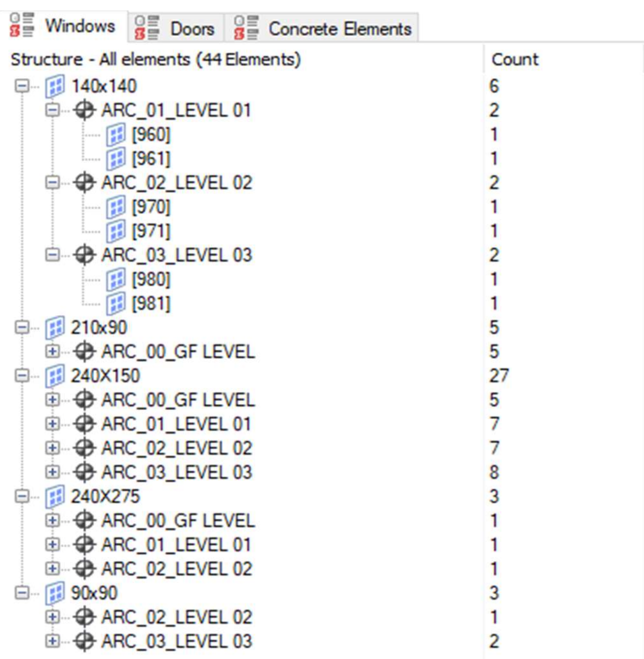
Like the prior case study, since the building BIM model is available for quantity take-off, it is easy to extract the QTO list directly from the building model. Based on the properties and selection sets created, different QTO tables are generated, as shown in the next figures.



Windows | Doors | Concrete Elements

Structure - All elements (136 Elements)	Calculated Volu...
Slabs	538.233 m³
Floor:Floor:NW_ext_concrete_001	10.536 m³
[1056]	1.628 m³
[1057]	1.884 m³
[1059]	1.628 m³
[1061]	1.884 m³
[1063]	1.628 m³
[1064]	1.884 m³
Floor:Floor:NW_ext_concrete_002	19.432 m³
Floor:Floor:NW_int_concrete_001	271.417 m³
[1058]	90.472 m³
[1060]	90.472 m³
[1062]	90.472 m³
Floor:Floor:NW_roof_concrete_001	91.556 m³
Foundation Slab:PC_FOUNDATION_SLAB_10...	35.810 m³
Foundation Slab:RC_FOUNDATION_SLAB_50...	109.482 m³
Structural Columns	37.528 m³
250 x 250mm	2.370 m³
250 x 700 mm	13.590 m³
250 x 700mm	8.274 m³
500 x 250mm	13.294 m³
Walls	42.020 m³
Basic Wall:NW_Ext_Concrete_001	15.514 m³
Basic Wall:NW_Ext_Concrete_003	1.162 m³
Basic Wall:NW_Int_Concrete_001_150mm	8.273 m³
Basic Wall:NW_Int_Concrete_001_200mm	10.737 m³
Basic Wall:Wall-Ret_250Con	6.333 m³

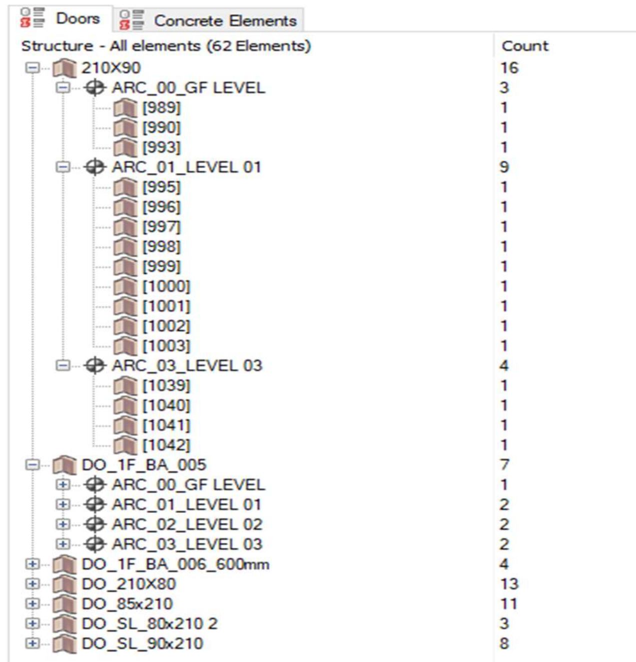
Figure 34: Concrete Elements QTO



Windows | Doors | Concrete Elements

Structure - All elements (44 Elements)	Count
140x140	6
ARC_01_LEVEL 01	2
[960]	1
[961]	1
ARC_02_LEVEL 02	2
[970]	1
[971]	1
ARC_03_LEVEL 03	2
[980]	1
[981]	1
210x90	5
ARC_00_GF LEVEL	5
240X150	27
ARC_00_GF LEVEL	5
ARC_01_LEVEL 01	7
ARC_02_LEVEL 02	7
ARC_03_LEVEL 03	8
240X275	3
ARC_00_GF LEVEL	1
ARC_01_LEVEL 01	1
ARC_02_LEVEL 02	1
90x90	3
ARC_02_LEVEL 02	1
ARC_03_LEVEL 03	2

Figure 35: Windows QTO



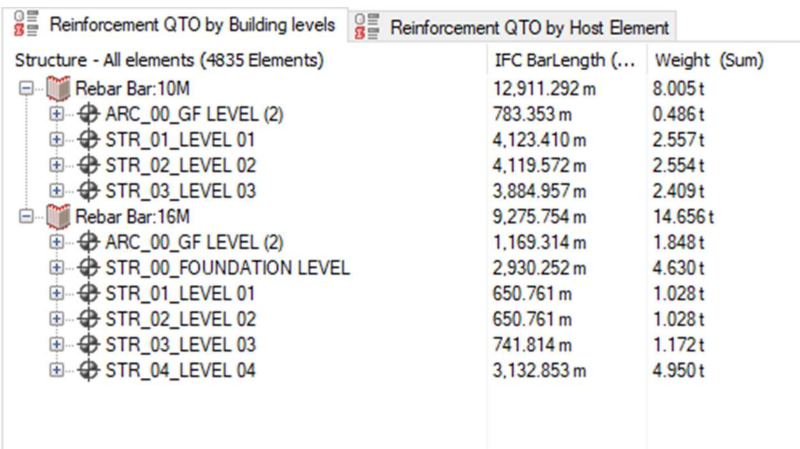
Doors | Concrete Elements

Structure - All elements (62 Elements)	Count
210X90	16
ARC_00_GF LEVEL	3
[989]	1
[990]	1
[993]	1
ARC_01_LEVEL 01	9
[995]	1
[996]	1
[997]	1
[998]	1
[999]	1
[1000]	1
[1001]	1
[1002]	1
[1003]	1
ARC_03_LEVEL 03	4
[1039]	1
[1040]	1
[1041]	1
[1042]	1
DO_1F_BA_005	7
ARC_00_GF LEVEL	1
ARC_01_LEVEL 01	2
ARC_02_LEVEL 02	2
ARC_03_LEVEL 03	2
DO_1F_BA_006_600mm	4
DO_210X80	13
DO_85x210	11
DO_SL_80x210 2	3
DO_SL_90x210	8

Figure 33: Door QTO

For generating the QTO steel reinforcement, several steps have been followed:

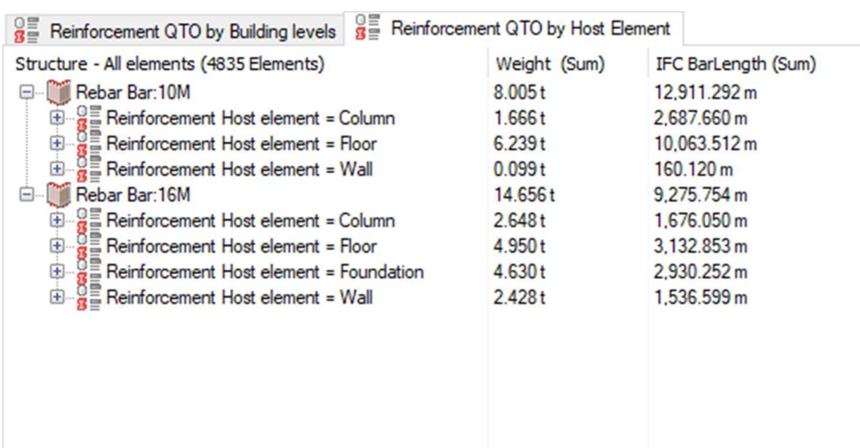
- Defining the host elements for the reinforcement in the authoring tool.
- Defining the levels for the reinforcement in the authoring tool.
- Assign the formula for calculating the total reinforcement weight needed from the bar length by adding a property of the theoretical weight (kg/m) for each bar diameter and multiplying it to the bar length.



Reinforcement QTO by Building levels | Reinforcement QTO by Host Element

Structure - All elements (4835 Elements)	IFC BarLength (...	Weight (Sum)
Rebar Bar:10M	12,911.292 m	8.005 t
ARC_00_GF LEVEL (2)	783.353 m	0.486 t
STR_01_LEVEL 01	4,123.410 m	2.557 t
STR_02_LEVEL 02	4,119.572 m	2.554 t
STR_03_LEVEL 03	3,884.957 m	2.409 t
Rebar Bar:16M	9,275.754 m	14.656 t
ARC_00_GF LEVEL (2)	1,169.314 m	1.848 t
STR_00_FOUNDATION LEVEL	2,930.252 m	4.630 t
STR_01_LEVEL 01	650.761 m	1.028 t
STR_02_LEVEL 02	650.761 m	1.028 t
STR_03_LEVEL 03	741.814 m	1.172 t
STR_04_LEVEL 04	3,132.853 m	4.950 t

Figure 36: Reinforcement QTO by Building Levels



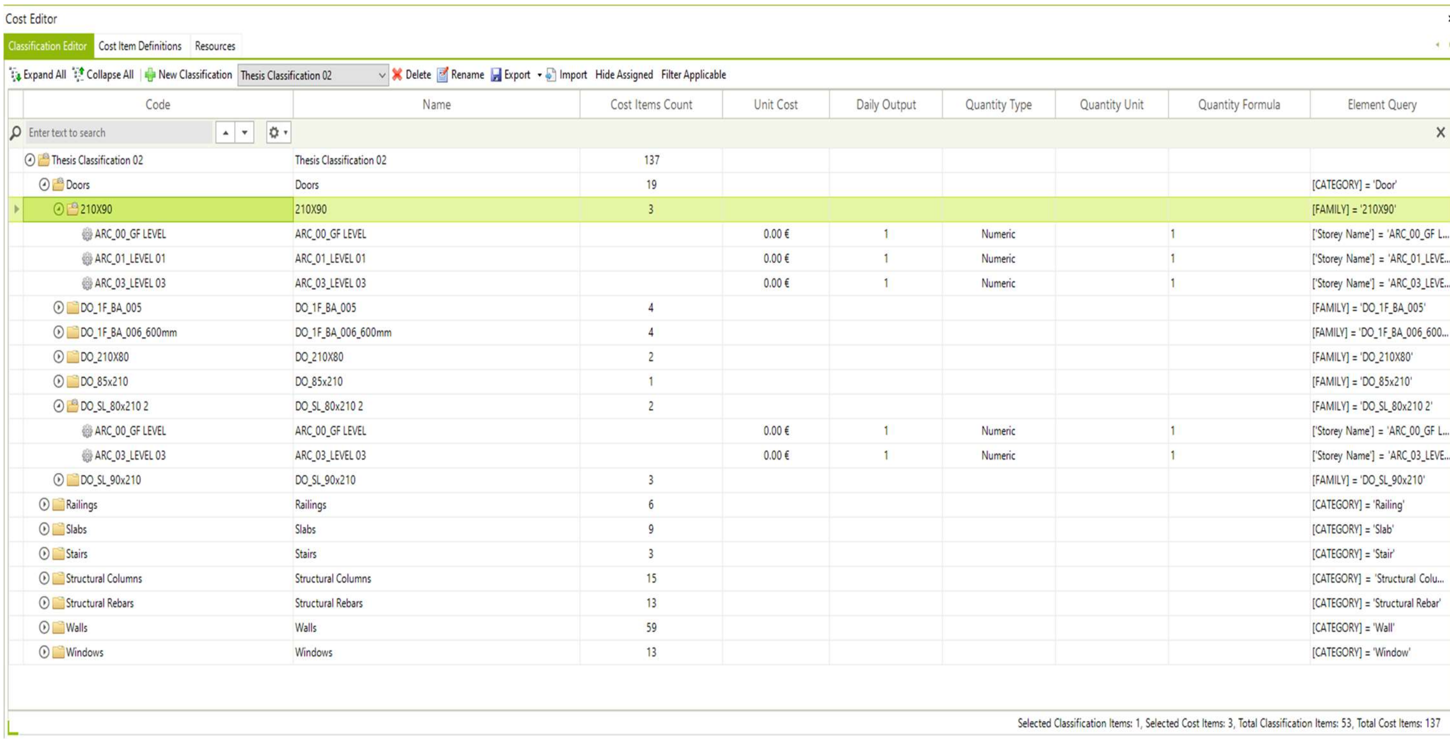
Reinforcement QTO by Building levels | Reinforcement QTO by Host Element

Structure - All elements (4835 Elements)	Weight (Sum)	IFC BarLength (Sum)
Rebar Bar:10M	8.005 t	12,911.292 m
Reinforcement Host element = Column	1.666 t	2,687.660 m
Reinforcement Host element = Floor	6.239 t	10,063.512 m
Reinforcement Host element = Wall	0.099 t	160.120 m
Rebar Bar:16M	14.656 t	9,275.754 m
Reinforcement Host element = Column	2.648 t	1,676.050 m
Reinforcement Host element = Floor	4.950 t	3,132.853 m
Reinforcement Host element = Foundation	4.630 t	2,930.252 m
Reinforcement Host element = Wall	2.428 t	1,536.599 m

Figure 37: Reinforcement QTO by Host Element

Cost Classification & Cost Items:

As the previous case study, Since I have already created the QTO list based on CBS, then the next step in the integrated workflow is generating the cost classification based on the QTO CBS list, as shown in figure (41). All of the cost items are automatically generated and attached to the building elements in the model smartly using the CBS.



Code	Name	Cost Items Count	Unit Cost	Daily Output	Quantity Type	Quantity Unit	Quantity Formula	Element Query
Thesis Classification 02	Thesis Classification 02	137						
Doors	Doors	19						[CATEGORY] = 'Door'
210X90	210X90	3						[FAMILY] = '210X90'
ARC_00_GF LEVEL	ARC_00_GF LEVEL		0.00 €	1	Numeric		1	['Storey Name'] = 'ARC_00_GF L...
ARC_01_LEVEL 01	ARC_01_LEVEL 01		0.00 €	1	Numeric		1	['Storey Name'] = 'ARC_01_LEVE...
ARC_03_LEVEL 03	ARC_03_LEVEL 03		0.00 €	1	Numeric		1	['Storey Name'] = 'ARC_03_LEVE...
DO_1F_BA_005	DO_1F_BA_005	4						[FAMILY] = 'DO_1F_BA_005'
DO_1F_BA_006_600mm	DO_1F_BA_006_600mm	4						[FAMILY] = 'DO_1F_BA_006_600...
DO_210X80	DO_210X80	2						[FAMILY] = 'DO_210X80'
DO_85x210	DO_85x210	1						[FAMILY] = 'DO_85x210'
DO_SL_80x210 2	DO_SL_80x210 2	2						[FAMILY] = 'DO_SL_80x210 2'
ARC_00_GF LEVEL	ARC_00_GF LEVEL		0.00 €	1	Numeric		1	['Storey Name'] = 'ARC_00_GF L...
ARC_03_LEVEL 03	ARC_03_LEVEL 03		0.00 €	1	Numeric		1	['Storey Name'] = 'ARC_03_LEVE...
DO_SL_90x210	DO_SL_90x210	3						[FAMILY] = 'DO_SL_90x210'
Railings	Railings	6						[CATEGORY] = 'Railing'
Slabs	Slabs	9						[CATEGORY] = 'Slab'
Stairs	Stairs	3						[CATEGORY] = 'Stair'
Structural Columns	Structural Columns	15						[CATEGORY] = 'Structural Colu...
Structural Rebars	Structural Rebars	13						[CATEGORY] = 'Structural Rebar'
Walls	Walls	59						[CATEGORY] = 'Wall'
Windows	Windows	13						[CATEGORY] = 'Window'

Selected Classification Items: 1, Selected Cost Items: 3, Total Classification Items: 53, Total Cost Items: 137

Figure 38: The generated Cost Classification based on QTO CBS list

At the end of the process, there is a basic Cost classification structure defined, with Classification and Cost Items created based on information from CBS and QTO.

This Classification is automatically created based on previously QTO WBS structure. It contains all Cost Items defined, with all works sorted in appropriate chapters but to be complete Cost Classification needs a certain amount of fine-tuning. Some cost Items need to be reorganised, quantity formulas and measuring units should be defined for Cost Items, and during following stages of the project, more information available can be added.

Creating 4D & 5D Simulation

With all information in MS Project, I took some time to use the software to extract reports and charts that would be important to monitor the construction, as shown in figure (31).

Figure 39: Reports Exported from MS Project

Then, I used the well-instrumented interoperability between MS Project and Navisworks by importing the Gantt Chart from MS Project to my federated model.

During the importation, I defined the Columns needed from the Gantt to create the simulation. The simulation goal is to show the scheduling, planning & cost estimating of the project aligned with the visualrepresentation.

After importing the Gantt chart structure, I needed to attach the elements imported from the Revit model inside Navisworks to the activities & tasks that have been imported from MS Project.

The result is as shown in the next figures:

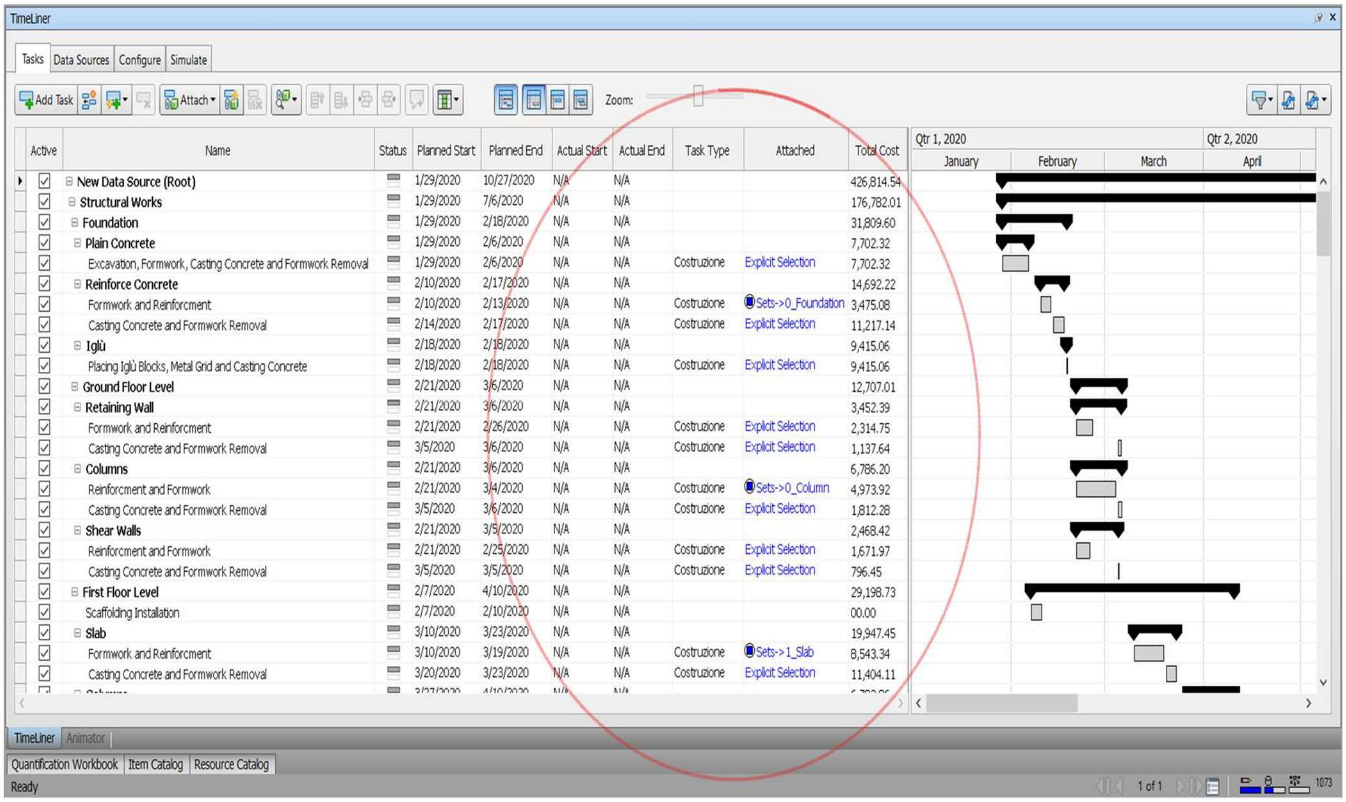


Figure 40: Attaching Elements in the Timeliner in Navisworks

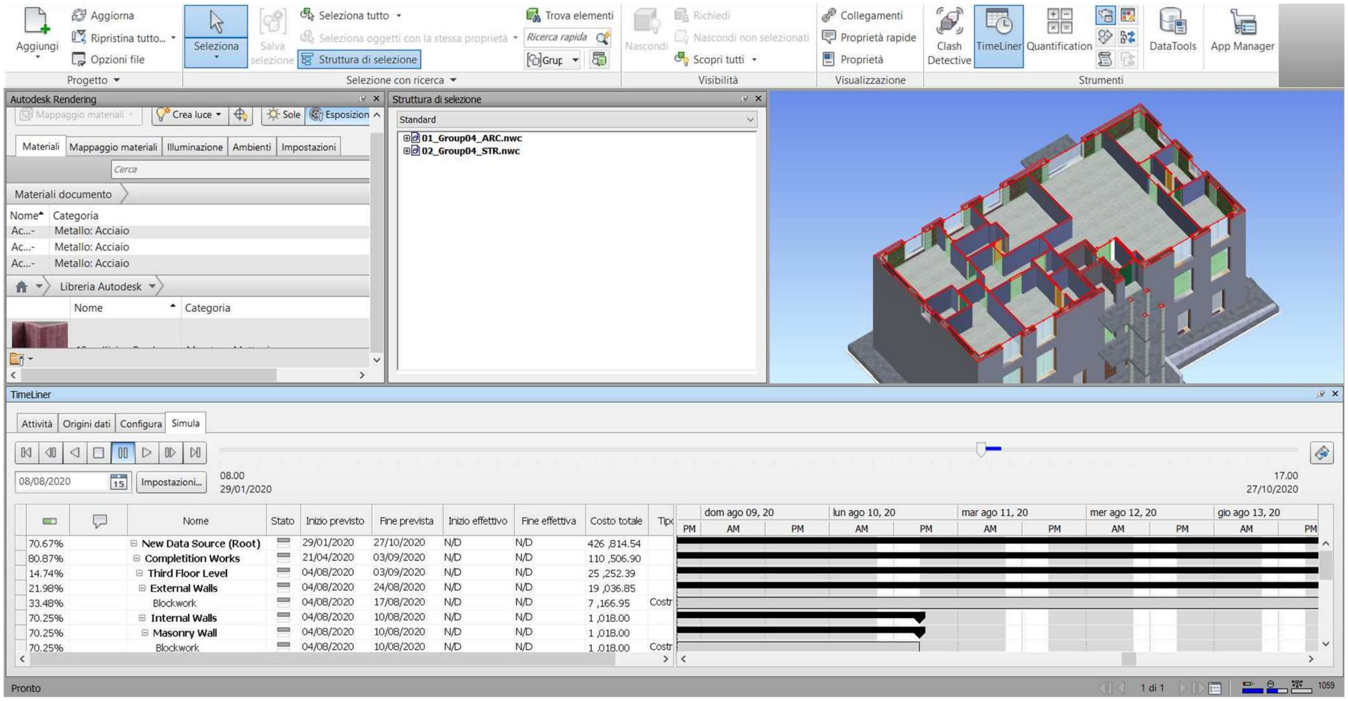


Figure 41: Navisworks window with the Timeliner, Gantt chart & section in the 3D view

Generate Automation Scheduling:

After Cost Classification on the project is defined, now we are moving to the most complex project management task because it has to take into account construction process technology, organisation of construction site, contractor's resources and time-frame defined by investor.

The first action in preparation for project scheduling is the definition of the spatial distribution of work. All activities on the project should be organised with specific spatial units (zones) that are defined along the horizontal and vertical axis.

In this case study, only vertical spatial distribution has been applied to imply subdivision of the project along the vertical axis into a logical order. Within the construction industry, it always implies division by levels or storeys, so I follow building stories (levels) of the project and define logical construction sequence from the lowest to the highest, as shown in figure (42).

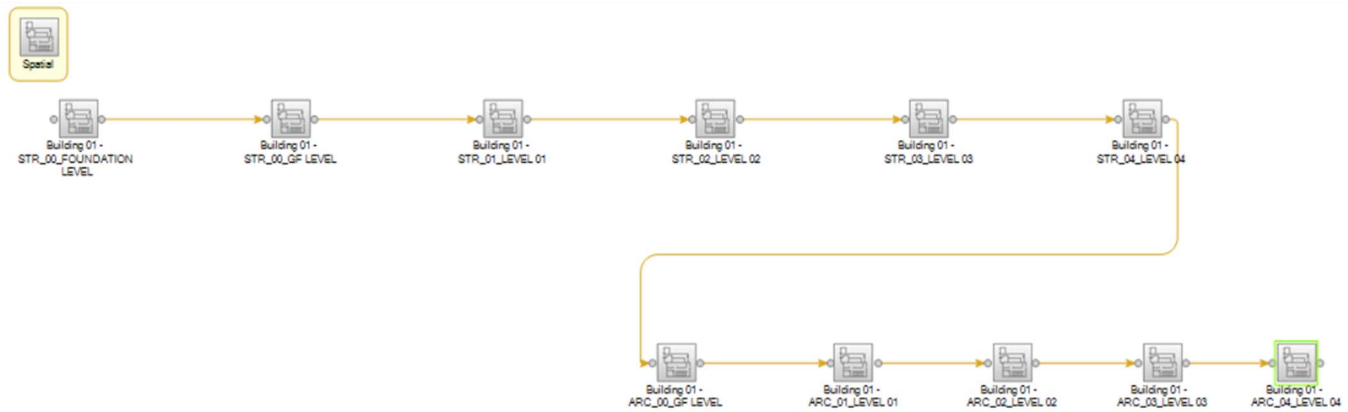


Figure 42: Spatial Vertical Zones (building levels)

Then the next step is creating the construction methodology, as shown in figure (43). To simplify it, the construction sequence for groups of works is nothing more than a definition of relations and sequence of execution of different types of works in construction as defined in project Cost classification structure. This "sequence" is more or less typical for any construction process with slight modifications depending on the type of building, construction technology or specific conditions on-site. However, the majority of construction works do follow specific universal rules.

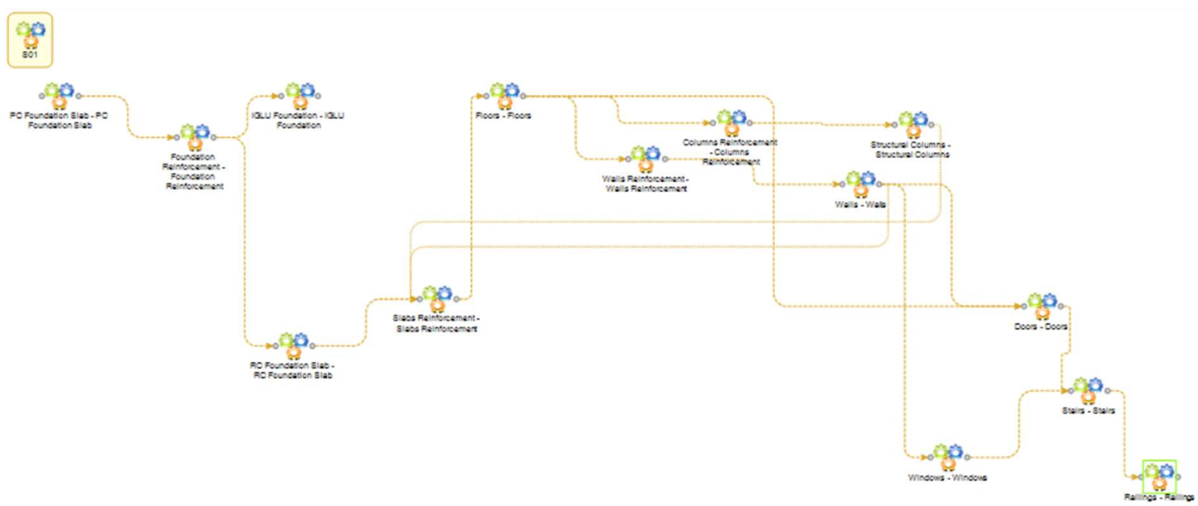


Figure 43: Construction Methodology tree (Construction sequence for groups of works)

Now after the spatial zones and construction methodology are created, all needed elements are here just need to be combined into creation template which is the final template document that will be used as a basis for automatic schedule creation. The schedule created can be analysed in the Gantt chart, LOB (Line of Balance) diagram as well as a series of analytical charts within the task report.

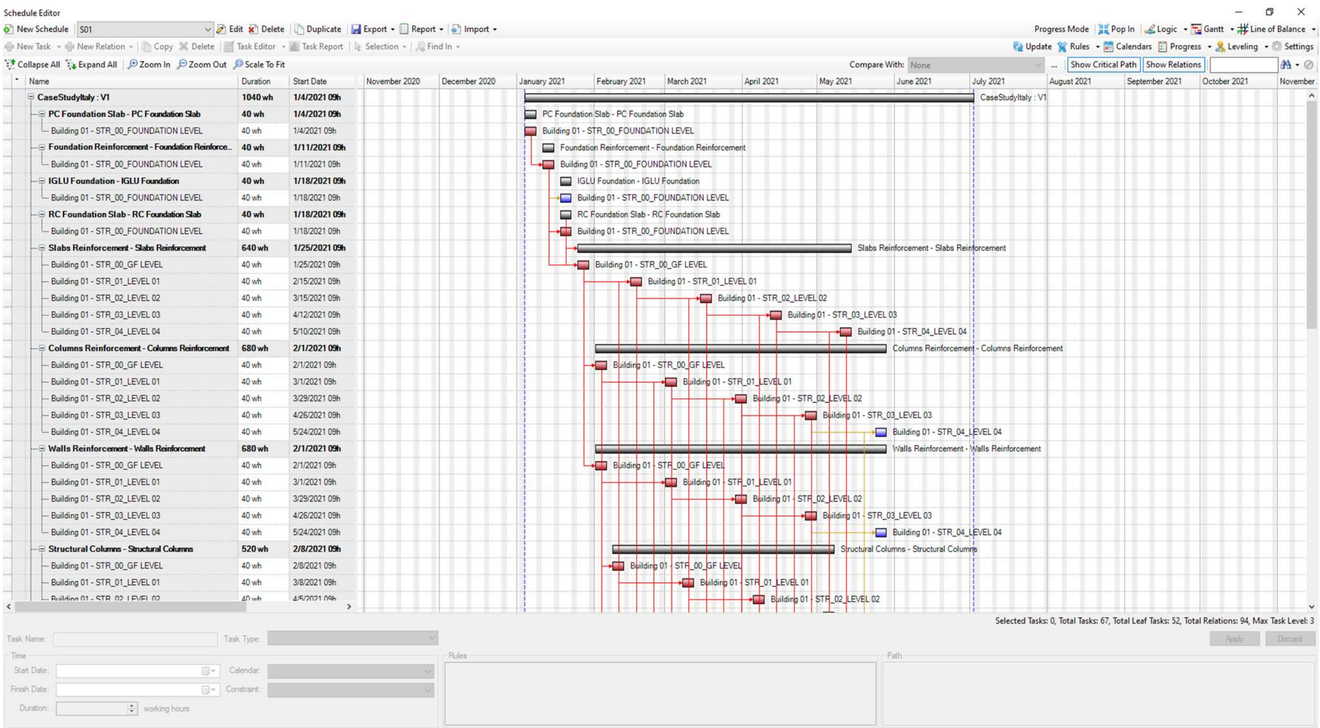


Figure 44: Schedule Gantt Chart

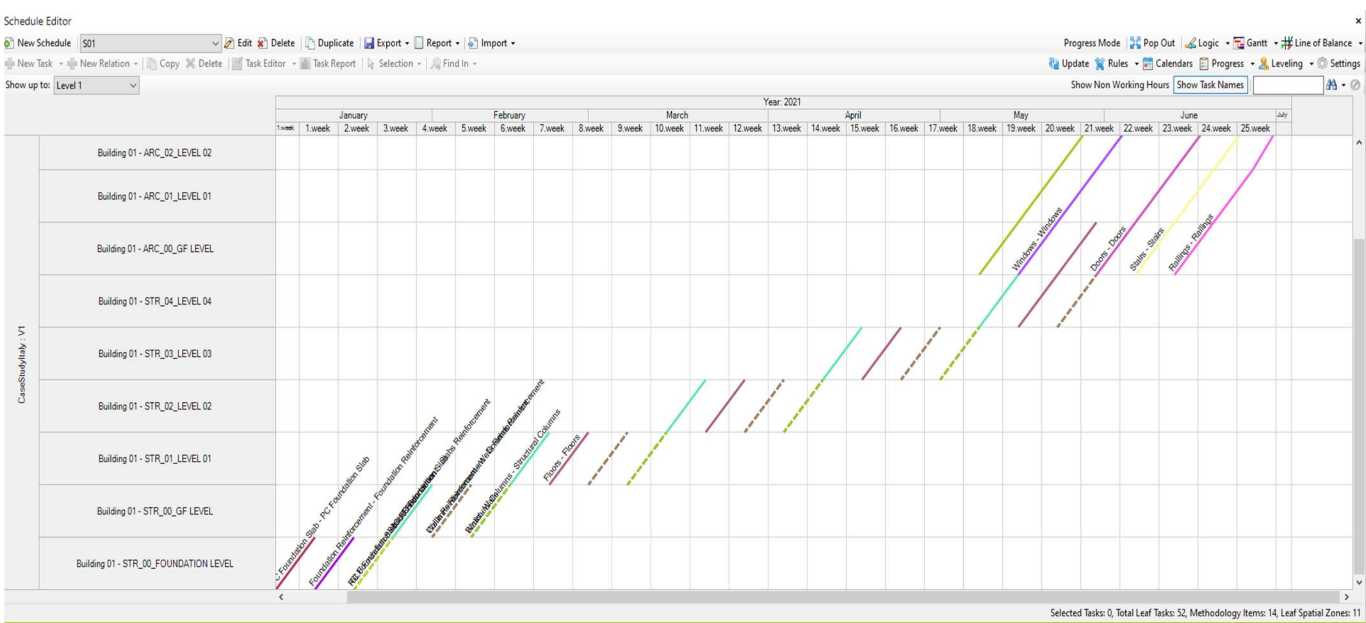


Figure 45: Schedule LOB Diagram

Conclusion:

Due to my observations through both workflows, in the **first workflow with Navisworks**, exporting the 3D model from Revit did not cause any loss in information or properties, because of the similarity in the platform (Autodesk). Moreover, there was more flexibility in the workflow for adding more details within the total cost price list related to the indirect costs and the tasks that are not modelled, such as the formwork and scaffolding. Using MsProject and Excel to create the schedule and the price list causes in slowing the workflow for connecting them to Naviswork and create the same CBS in the software. This workflow can be used for careful scheduling and control during the procurement and construction stage, where the delivery of materials and the erection of the project on the site has to be maintained.

On the other hand, for the **second workflow using Bexel Manager** which is integrated into one software, there was some loss of information and properties related to the percentage of the reinforcement hosted by the concrete elements, which needed to be modified by adding these properties again in the software for QTO issues. For the schedule creation, it saves much time since it is automatically generated based on the cost classification and cost items that have also been automatically created based on the QTO CBS tables. The whole workflow here is fully integrated and with a high level of dependency, but this feature limits the user for adding particular cost items related to the indirect cost and not modelled items.

5 ANALYSIS AND DISCUSSION

5.1 Properties and attributes for successful 4D/5D BIM Automation & Simulations

To perform successful 4D/5D automation & simulation, some several entities or properties can be added to the building elements to facilitate segregation work with the custom Breakdown Structure and create the necessary cost items for cost classifications. Further research has been done for the required entities with some examples in concrete works, especially a **concrete slab**, as shown in the following tables:

Properties (Concrete Works)	Examples
Element	Foundation slab Ground slab Floor slab Compression slab Bottom manhole slab Top manhole slab
Element Width	
Element Length	
Surface Inclination	
Crossection reinforcement	nonreinforced crossections rarely reinforced crossections M<100 kg/m3 moderately reinforced crossections 101<M<220 kg/m3 densly reinforced crossections 221<M<340 kg/m3"
Microreinforcement	microreinforcement: steel needles 10-15 kg/m3 microreinforcement: steel needles 15-20 kg/m3 microreinforcement: steel needles 20-25 kg/m3 microreinforcement: steel needles 25-30 kg/m3 microreinforcement: PP short fibers 1kg/m3 microreinforcement: PP long fibers 2-3 kg/m3 microreinforcement: PP long fibers 3-6 kg/m3
Mixing of concrete	concrete mixing in plant mixing on-site with mixer

External transport	external transport with mixer truck V= ...m^3 external transport of aggregate and cement in bags with truck
Transport distance	internal transport with a pump on the mixer truck internal transport with truck pump internal transport by concrete pipelines internal transport with concrete crane bucket internal transport with a backhoe loader
Internal transport	
Internal transport distance	
Internal transport height	
Concrete label	
Special requirements	sulphate resistant concrete hydrotechnical concrete nonshrinking concrete
Surface without formwork	
Treatment of surface without formwork	levelling with hand screed ribbed with a coarse wooden trowel smoothened with a steel trowel smoothened with screed rotary machine
Surface with formwork	Basic treatment of surface after removal of formwork (no special requirements). Ordinary treatment of surface after removal of formwork (not visible surface or lining cover). Easy treatment after removal of formwork (painted surface). Special treatment after removal of formwork (the visible surface of concrete - facade).
Special treatment of the surface with formwork	
Concrete temperature	
Concrete curing time	
Concrete curing techniques	covering with PVC foil and attaching the edges covering with moist geotextile and PVC foil

	constant spraying with water
Concrete curing surface	

Properties (Formwork Works)	**Examples**
Slab inclination	
Formwork decking and framework	formwork with boards and wooden beams formwork with planks and wooden beams formwork with three-layered sheet and wooden beams
Primary beams	
Secondary beams	
Formwork beams	
Formwork usage %	
Slab thickness	
Formwork supports	support with wooden girders support with telescopic floor prop N=20-30-60kN support with supporting towers
Prop heads	fixed head on the support lowering head on the support swivel head on support
Supports height	
Scaffolding	Scaffolding for formwork assembly is considered in this item
Internal transport	internal transport by crane internal transport by car crane internal transport by construction lift internal transport by a backhoe loader internal transport by hoisting cart internal transport manually
Internal transport distance	

5.2 Optimising 4D/5D BIM Automation & Simulations

In the workflow, the schedule is structured according to rules defined in construction zones and methodology to be created. All the tasks have a default duration value set during the creation process, and this could be easily adjusted.

Generally, construction phases were dimensioned in such a way to achieve even distribution of available resources throughout construction execution period, so task duration should be more or less uniform, but some works are faster than others, so some level of fine-tuning is necessary.

Some of the most common adjustments could be, reduction in duration for some repetitive structural work tasks, like formwork, reinforcement, and even more significant reduction for concrete pouring which has to be done in a short period of time due to nature of the material.

On the other hand, some complex, labour-intensive tasks with many elements to be installed like curtain walls, or HVAC ducts installation could be extended to reduce needed resources for these tasks, but all of these are just general recommendations, and it is project managers choice to adjust automatically generated schedule according to its needs and specifics of the project.

5.2.1 Benefits

4D/5D Automation Simulation is most profitable in the project planning and construction phase:

- In the planning Phase, it saves much time and plays a vital role in the communication between planners and clients.
- During the construction phase, it helps project stakeholders to identify problems and track the progress of construction in an integrated platform.
- With automatic schedule updates, the practice can be made more efficient, and human errors that might occur during the process of schedule updating can be prevented.
- With a high level of dependency in the workflow, automatic updates in related information in case of updates in any dependent part of the workflow.
- With importing a cost database to the software including the cost item classification, quantity formulas and resource data, an intelligent construction 5D schedule can be generated by adding element queries to cost items and auto-assign these cost items to model elements.

- A comparison between different cost versions can be generated with a detailed BOQ and can be exported to different formats.
- An intelligent construction 4D/5D schedule can be generated by defining several zones, and construction methodologies then combine them in a template for auto-generated schedules and schedule fine-tuning and optimisation.
- The used methodologies for schedule creation can be saved and used in another similar project with the same functionality.
- Progress tracking by importing progress data from the construction site, and the ability to adjust time range, activities and resources.
- Generate task reports for planned vs actual analysis, earned value analysis and monthly certificate.

5.2.2 Shortcomings

4D/5D Automation Simulation is a productive tool for the planning process, but it must be more adaptable to be recognised as one of the leading planning methods. As noted in the previous case studies, there is a high degree of dependency in the workflow, which means that any small error in any part of the workflow affects the entire process and results. Another thing is that the primary workflow is built based on the CBS of the building elements which is created by the properties and attributes, so having access to the source file of the authoring tools profoundly affects the process and make it easier and more adaptable to the required classifications.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The study has shown that the construction scheduling process can be mostly automated. A considerable reduction of time and cost can be achieved by using the proposed software workflow from Bexel Manager instead of the manual creation and tracking of construction schedules. In concrete terms, the project manager will have access to flexible construction schedules methodologies that can be stored in a database to be available for the automatic generation of the construction schedules in other similar projects. Also, a new quality of construction scheduling has been offered in the planning process by the integration of the 4D visualisations as compared to modern and commonly used software tools.

This workflow is completed, starting from an empty BIM model then a 5D BIM simulation with all information has been created related to quantity, cost, schedule, resources and other project parameters fully integrated and interconnected. That is now a robust workflow for Project Manager to control the project and achieve maximum efficiency of the process which in the end, results in lower costs, improves safety risks mitigation and shorter execution period, which benefits all stakeholders and industry as a whole. Such a level of automation and work-load reduction, as well as information integration within almost one single source 5D BIM (BEXEL MANAGER), is a significant step forward for the construction industry which always struggled to follow the development in other sectors due to its complex nature.

6.2 Recommendations for further research

In future research, I would recommend to include the testing of the proposed system on different construction projects in the matter of efficiency and practical applicability in updating schedules. In order to extend the applicability of the proposed workflow to various activities- not only structural work, architectural and finishing works, but also mechanical, electrical and plumbing (MEP) - It may also include the development of a method for automatic detection of objects associated with such activities.

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