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in geodezijo

GREGORY ONYIBE

BIM WORKFLOWS AND LIBRARIES FOR CONCRETE FORMWORK DESIGN OPTIMIZATION

BIM KNJIŽNICE IN DELOVNI POSTOPEK OPTIMIZACIJE NAČRTOVANJA OPAŽEV BETONSKIH KONSTRUKCIJ

BIM A+ European Master in Building Information Modelling

Master thesis No.:

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Co supervisor: **Assist. Prof. Tomo Cerovšek, Ph.D**

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Izvleček:

Tehnologija opaževanja je sestavni del gradbene industrije od uvedbe betona kot primarnega gradbenega materiala v večini gradbenih projektov. Njihovo načrtovanje je v veliki meri odvisno od pogojev projekta, tradicionalni postopki načrtovanja opažev in načrtovanja običajno temeljijo na individualni intuiciji in izkušnjah tehnologa. Implementacija BIM pri procesu načrtovanja in planiranju opažev omogoča optimiranje v smislu učinkovitejše uporabe tehnologije.

Magistrsko delo daje pregled obstoječih BIM knjižnic opažnih tehnologij in delovnih tokov od zasnove opažne tehnologije do določitve količin opažnih elementov ter njihovo vključitev 4D in 5D simulacijo. Predstavljeni sta dve študiji delovnih tokov za primer enkratne uporabe in primer ponavljajoče se uporabe betonskega opaža. Obe študiji prikazujeta delovni postopek, njegove pomanjkljivosti ter priporočila za nadaljnji razvoj.Predstvljeni potek dela spodbuja sodelovanje med več disciplinami/specializacijami ter doprinese k povečanju produktivnosti in učinkovitosti izvedbe gradbenih projektiov

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BIBLIOGRAPHIC– DOKUMENTALISTIC INFORMATION AND ABSTRACT

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Abstract:

Formwork technology has been an integral part of the construction industry since the adoption of concrete as a primary building material in most construction projects. Formwork design and planning has largely been dependent on project specific conditions, traditional formwork design and planning processes typically relies on individual Designer/Planner intuition and opinion. With the implementation of BIM in formwork design and planning we see how traditional processes which are often seen to be tedious are being optimized, leading to even greater advancements in concrete formwork technology.

This thesis gives an overview of existing workflows of BIM based formwork design solutions and libraries, from design to quantity take-off, and attempts to incorporate 4D and 5D simulation in the design workflow. Two case studies are presented to show single use case and repetitive use case of concrete formwork. The workflow is incorporated in both case studies, after which recommendations on shortcomings of the workflow are proffered for further research. This workflow promotes collaboration among multiple disciplines/specializations and can help in improving productivity and efficiency in construction projects.

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1 INTRODUCTION

Building Information Modeling (BIM) is the process through with relevant data is about a building model or structure is collated/stored all through the project lifecycle. This means from initial design, through to construction planning and eventual project operation. The inventory of data collated helps project participants to properly evaluate possible mistakes or deficiencies, this in turn helps avoid possible financial, technological, and environmental factors which may impede in successful completion of the project.

With BIM offering such advantages, it stands to reason that many designers and contractors prefer to implement BIM in early stages of construction projects, thus creating a more collaborative environment, with seamless information exchange among project participants and stakeholders. BIM has been instrumental in the evolution of building design, its construction as well as operation, it has changed the traditional workflows and processes typically associated with building design and construction. One such change is in the design and planning of formwork in construction projects. Most construction projects, use formworks as temporary place holders to support permanent structural members, which in most cases are concrete structural members. With formwork having such a pivotal role in construction project, it is important that construction projects incorporate an efficient formwork design and planning process, as it factors into speed, quality, cost, and safety of a project.

Industry experts have continuously strived in improving the efficiency of formwork design and planning, to make it less time consuming and better serve the demand for complex formwork systems resulting from advanced concrete building designs. BIM technology has been implemented to help fill the gap, that traditional formwork processes has proven unable to.

1.1 Objective of the Research

This research will focus on concrete formwork design and planning process, and how information is processed along the different stages of a construction project. This thesis aims to propose a BIM-based workflow for concrete formwork in AEC projects and validates its feasibility and performance. Therefore, the objectives of this thesis can be summarized as follows:

1) Based on academic literature reviews and existing BIM technology to develop a BIM-based project workflow for concrete formwork design and planning process.

2) Testing of developed workflow in multiple case studies, to validate the performance and feasibility of the proposed workflow.

1.2 Structure of the Dissertation

This dissertation is organized into five sections. Starting with the first two chapters, the base for the work is established. The first chapter gives a general introduction to the topic and sets a general outlook of the current situation and need for BIM in formwork design and planning. It also gives the aim and goals to be achieved in this work. The second chapter gives a review of existing literature on formwork and the AEC industry, illustrating the state of the art of existing technologies and BIM. The third chapter focuses on the existing formwork design processes used and attempts on improving on it, with the inclusion of time and costing in the workflow. Chapter four presents the implementation of the workflow, with a focus on single and multiple use case scenarios for concrete formworks. Chapter five presents the conclusion of the work and suggestions for future development.

2 LITERATURE REVIEW

2.1 CONCRETE FORMWORK IN GLOBAL AEC INDUSTRY

In over a century, we have seen great advancements in science and technology, most especially in the construction industry. These technological advancements have brought about tremendous improvement not just in construction materials, but as well as construction engineering and design, leading to the construction of complex structures from concrete[1].

In order to build these complex structures, formwork is needed, as its role is to provide a temporary shape in which concrete can be poured and formed[2]. It is estimated that about 25% of overall construction cost can be attributed to the use of formworks on a project. Hence by utilizing proper, safe and advanced formwork techniques, engineers/planners can save on both time and labor when executing large projects.[3].

In regards to global market size, in 2018 formwork market share was valued at USD 5.32 Billion, with growth potential to reach value of USD 6.37 billion by 2027, this gives a cumulative average growth rate (CAGR) of 2.29%, in a 10year span i.e. 2017-2027.[2]. This valuation is further enhanced when one factors in the rise in human population, which has triggered an increase in demand for residential and commercial construction projects. this presents growth opportunities in the formwork market space.[4]

Some of the foremost manufacturers of formwork include PERI GmbH; Doka Group; ULMA Construction; Acrow; PASCHAL Group; STRABAG SE; NOE Formwork; Mascon; MEVA Formwork Systems, Inc etc. Many if not most of the formwork manufacturers provide bespoke solutions to their client in line with construction needs. They do this by utilizing advanced technological tools like BIM to automate the design process and develop formwork systems that meet the requirement of the construction site.[4]

2.2 CONCRETE FORWORK SYSTEMS

Concrete formwork systems are typically used to provide temporary support, giving structural shape and texture to reinforced cement concrete (RCC) structures. [5]. A formwork system serves as a support system for new concrete, it includes not just the mold or surface for the concrete but also the supporting members and accessories e.g., braces, clamps, walling. props etc.[6]. There are various concrete formwork systems commonly used in construction industry, they can be broadly categorized into Conventional formwork systems and non-Conventional formwork systems.

Conventional formwork systems: majorly utilize timber, plywood, and steel. This system is typically installed by skilled carpenter on most project sites, the system is mostly composed of plywood sheets as surface forms to hold the newly placed concrete with timber frames as supports to resist the weight of the wet concrete, holding it in place until it achieves its intended form. [7]. Conventional formwork systems are still largely used in construction but are only suitable for small scale projects as they are less durable and too time consuming for larger projects.[7]

Figure 1: Example of Conventional formwork system[8]

Non-conventional systems are used because of the speed and accuracy of the formwork. These systems utilize advanced technology in their implementation, this greatly reduces time duration of the formwork installation, while maintaining its reliability, durability and building speed. Example of Non-conventional formwork systems are; Aluminum Formwork, Jump Formwork, Slip Formwork, Table form/Flying Formwork, Permanent Insulated Formwork.[3],

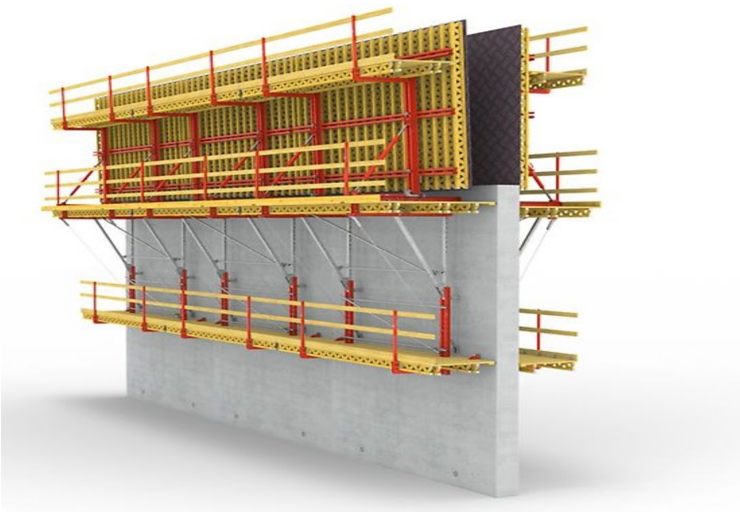


Figure 2: Example Non-Conventional Formwork System (SCS Climbing System)

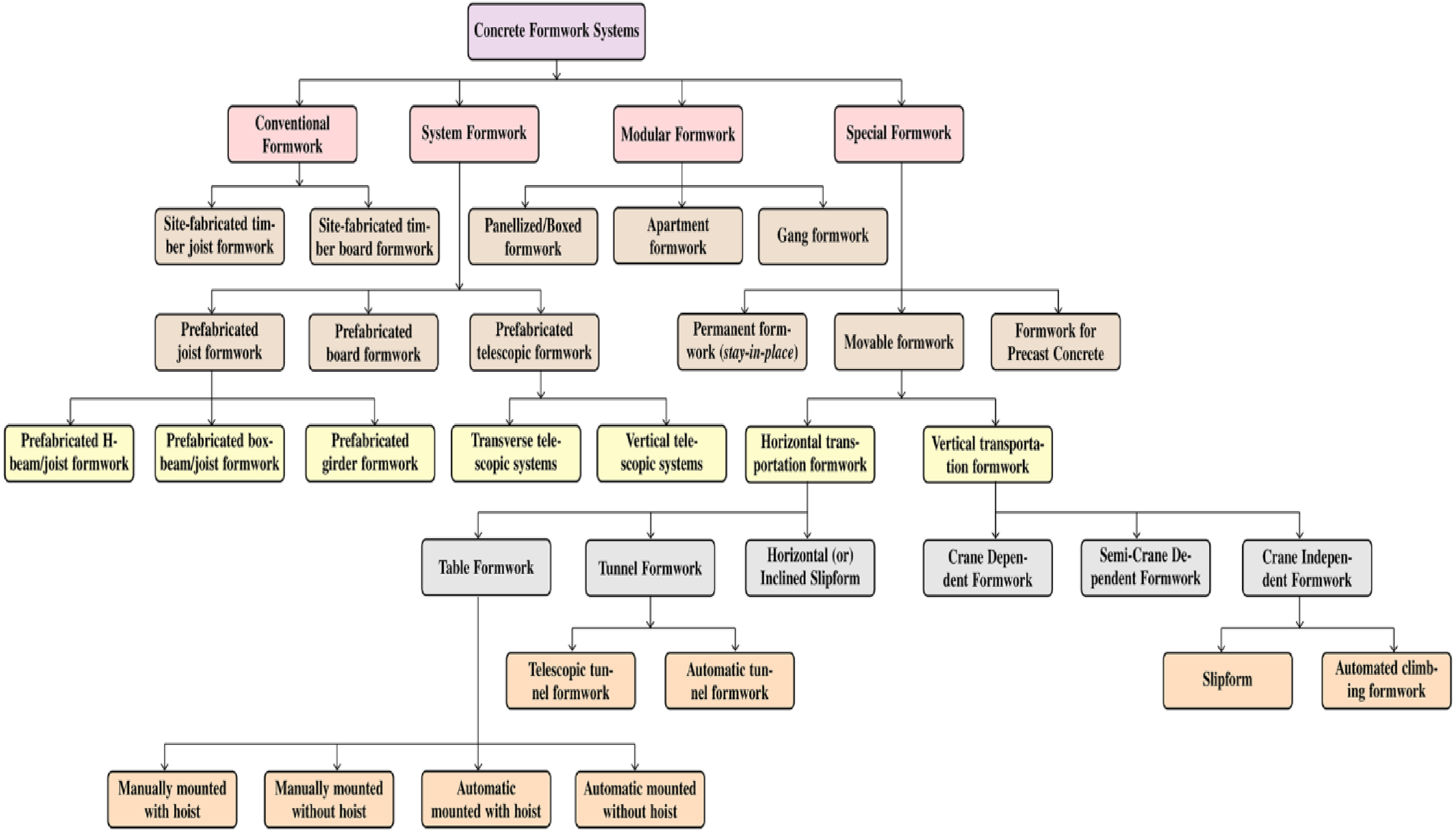


Figure 3: Classification of concrete formwork systems [9]

2.3 CONCRETE FORMWORK SYSTEM SELECTION

The importance of selecting the right formwork system cannot be over emphasized as it is key to the effective execution of a construction project. Therefore, when considering the choice of formwork system to be implemented on a project, standards such as quality, safety and economy are important in making an informed decision[10]. The formwork system should also be cost effective, most especially for highly repetitive project, like high rise buildings.[11].

However, as with many projects, formwork system selection depends largely on multiple criteria. Hanna [12] simplifies these criteria's Into four major categories general project design (i.e. architectural, structural etc.), specific project requirement, project site conditions, and organizational support. These factors gave rise to further research regarding Knowledge based supporting systems. Some of whom like Hannal et al[13], developing a ruled-based system designed primarily to aid formwork designers/planners select the ideal formwork system for construction projects. Also Kamarthi [14], whose "Neural Network" model for formwork selection was based on the factors proposed by Hanna. Tam[15] proposed combining "probabilistic neural network" and basic "algorithm" as a better alternative to Neural networks model in formwork . Elbeltagi[16], developed fuzzy logic systems based on similar formwork selection factors in Egypt, to aid formwork selection in both horizontal and vertical formwork.

From this Knowledge based decision system, knowledge acquisition techniques were derived that served as a means of assisting construction experts in decision making[17].

Knowledge based decision approach does have its draw backs, as decisions are made based on limited experiences, which in turn lead to overestimating the suitability of a formwork system, which causes late completion, cost increase and even accidents.[11].

Recent studies show the use of boosted decision trees (BDT) in aiding practitioners in critical decision-making scenarios, for example, in selecting the appropriate formwork system. The idea behind it being the use of a multistage approach to reduce the complexity of a decision into several smaller and simpler decisions, eventually leading to the ideal/required solution. BDT is used in formwork system selection, with the end goal being to determine the constructability i.e how ideal a formwork system is considering project specific constraints.[18]

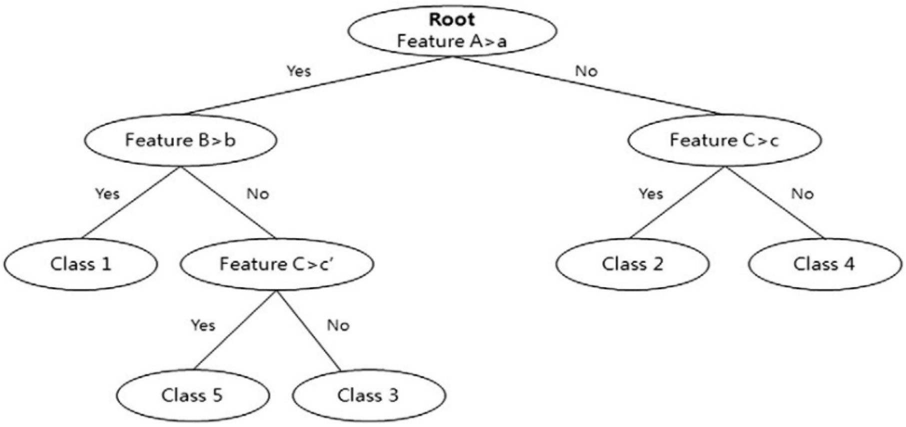


Figure 4 Schematic Design of Boosted tree [18]

When considering the amount of research that has gone into automating the selection of formwork systems, one can clearly observe the impact of formwork on AEC industry. Nevertheless, real world projects are still executed using formwork systems chosen based largely on individual experience and predisposition of the contractor/designer at the site.[18]

As a result of these dependency bias, the selection process cannot be consistent in every case, sadly this can have adverse effects on the overall cost of a project. Hence, more effort is required to ensure a fully automated selection method is developed[19]

2.4 CONCRETE FORMWORK DESIGN AND PLANNING

Before the introduction of digital technology in formwork design, traditional processes relied greatly on two-dimensional (2D) drawings, that contained information on object geometry, complex equations, design tables, charts and even information on formwork materials, applied loads and deflection.[20].

With the development of computer applications in construction engineering, scholars and scientists have labored to improve the formwork design by proposing methods, with the aim to automate the formwork systems design, selection and management process.[19].

In particular, Romanovskyi et al. [21] proposed using BIM as a support in the decision making process for formwork design on a model, using dynamo platform to implement the system they were able to extract relevant data from concrete elements, which they used to calculate concrete pressure on formwork surfaces as well as utilizing different panel combinations to get the ideal combination for each concrete element. BIM has been applied in designing and planning of required formwork component. B. Lee et al [22], developed a method that allows the automated forming of formwork components using an automatic layout for basic model structures. They converted random vertices in BIM data into mesh forms, which were further developed into constant forms using algorithm. Additionally, an algorithm was created by establishing a unique set of rules for faces of model members. Which after trial operations resulted in generating an automatic formwork layout for structural members, i.e., wall and deck.

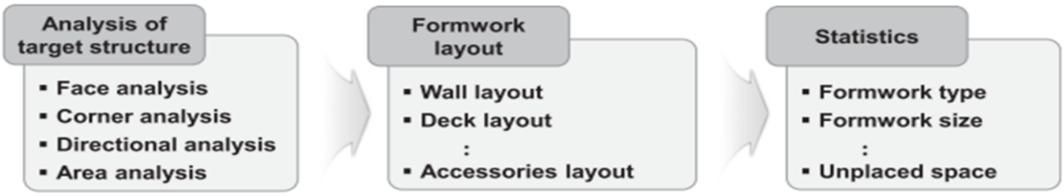


Figure 5: Operation process of the formwork automation design software [22]

C. Hyun et al [23], focused their research on optimizing the formwork design for a given building structure and choose the best formwork solution out of several hundreds of 3D formwork computer simulations generated with possible alternatives in different variables. The case study in his research showed that the recommended formwork design methodology successfully automates the formwork design in BIM modeling using IFC extension by comparing the different materials and costs. The result of the case study proved that the formwork design process could be greatly improved on by utilizing the proposed formwork design system.

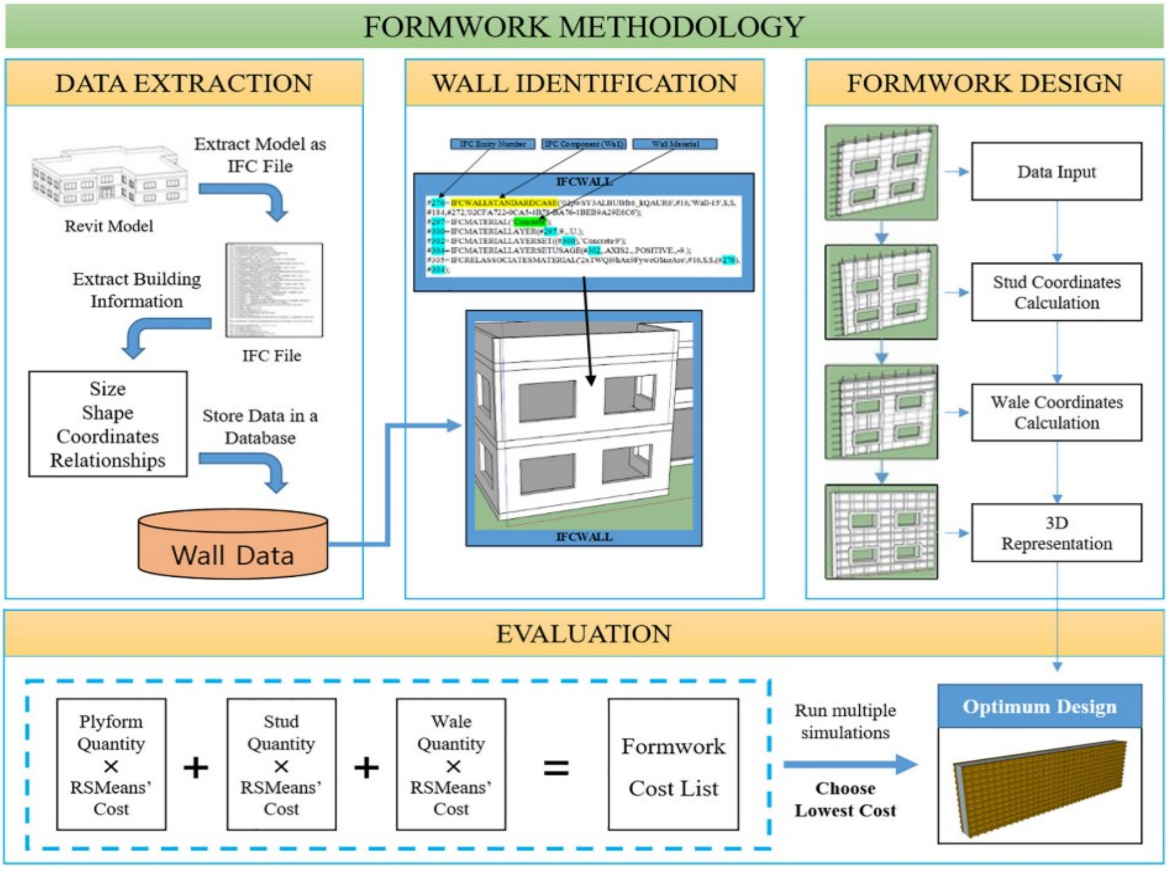


Figure 6: Overall Process in automatic formwork design [23]

Kannan and Santhi [24] conducted research on the automation of formwork systems by using BIM authoring software like Revit and AutoCAD and 3D formwork family files, to define the frame of a 21-story building. They designed a concrete formwork layout and simulation system using BIM that could predict construction schedules based on BIM formwork simulation. Although it is to be noted that the formwork system is limited to proprietary system of the Revit. Mansuri et al. [19] proposed a process of creating a plan that would enable the reusing of formwork based on data obtained from the BIM model and estimating the minimum required quantity of formwork for a project.

Similarly, Slawomir et al[25], whilst being aware of the problem of formwork system selection, chose to focus their research on optimizing formwork layout planning. Their research utilized a mixed integer linear programming modeling approach in formwork planning process. In the proposed case study, they use the geometry of the concrete elements in their model to determine the number and sizes of panels to be used. This enabled the minimizing of rental cost as by grouping elements into work zones to be completed in sequence, reusing the chosen panels. Formwork rental cost was found to be 7.31% lower than the typical rental methods.

2.5 BIM CONCRETE FORMWORK QUANTITY TAKE-OFF

Building Information Modeling (BIM) technology presents a new approach for quantity takeoff by extracting quantities directly from object-oriented digital models of a building [26]. However, since the quantities are extracted from BIM model objects, their correctness is dependent on the accuracy of the BIM model. In this sense, both traditional and BIM based QTO are similar in this regard [27].

[28] Cepni et al, proposed in their research the use of visual programming for estimating formwork both in Autodesk Revit and in IFC models. They successfully reduced the time it took for estimating formwork quantities as compared to traditional methods. Also, by applying the visual code in the IFC model they showed formwork estimation of quantities can be done in open BIM standards.

Khosakitchalert et al,[29] research focused on developing an automatic concrete formwork quantities takeoff. With the help of Dynamo scripting in Autodesk Revit software, they successfully extracted geometric data of structural model elements, keeping in mind the overlapping elements in the model, the algorithm was able to exclude these overlapping areas and give the precise and ideal geometric data needed for formwork estimation. This method was validated using a case study where the quantities generated were compared with those gotten from traditional processes

Zhang et al [30] proposed a general framework for determining the true cost of temporary construction structures (TCS) based on geometric properties of a BIM model. they termed this cost as “consumption” i.e quantity of labor, accessories, equipment etc. In a case study using formwork as an example of TCS, they automated the generation of consumption for formwork in a BIM model and compared that data to those derived from traditional means.

3 METHODOLOGY

3.1 FORMWORK DESIGN WORKFLOW

Formwork design utilizing BIM, includes the key components of formwork construction i.e., shape of the structure, formwork alignments, schedule of materials, construction sequence of the formwork etc. BIM based formwork libraries over time have been developed to incorporate actual structural model characteristics and imparting all parametric change that can arise in a construction process.

Formwork design can be implemented by incorporating formwork system libraries (using API or Plug-in) into a BIM model in a BIM authoring tool like AutoCAD, Revit or ArchiCAD etc. or by simply using any of the multiple vendor specific software solutions dedicated to formwork planning and design e.g., PERI, DOKA etc. the software allows the design and modelling of a detailed formwork system for concrete structures by a set of formwork elements. The major benefit in using these software solutions is the automatic generation of formwork drawings and list of formwork elements. This has led to the development of the proposed Formwork design workflow below.

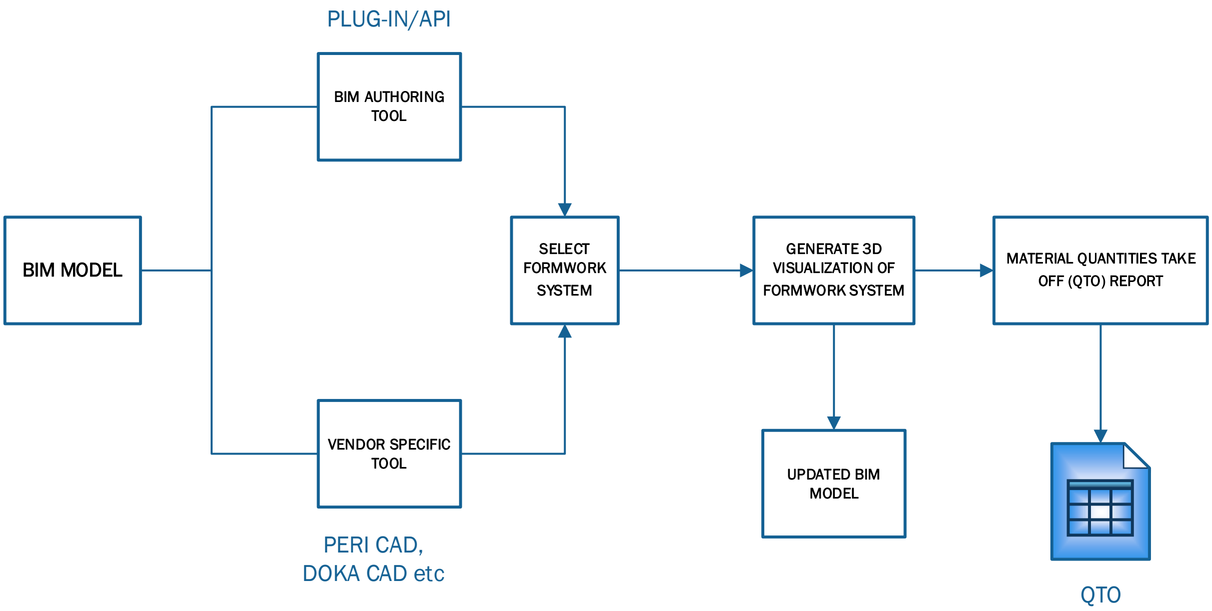


Figure 7: Formwork Design Workflow

The fig above gives a general layout of a formwork design workflow for a concrete structure. The workflow can be adopted for both generic libraries in BIM authoring tools (Revit, ArchiCAD) and in Vendor specific formwork software solutions (PERICAD, DOKACAD). The next section will discuss in detail the workflows involved when considering both options in formwork design.

3.2 OVERVIEW OF FORMWORK DESIGN WORKFLOW

In this section, a more in-depth look into the formwork design workflow utilized in both BIM authoring tool and Vendor specific solutions. To this end, the workflows of three common BIM enabled formwork planning Software providers, (DOKA, PERI and ULMA) will be examined, this selection is on the fact that they all provide BIM libraries that are compatible with Autodesk Revit and have their respective vendor specific formwork design solutions. Specific consideration is given to Autodesk Revit, due to its commercial preference as BIM authoring tool amongst industry professionals.

3.2.1 Doka Formwork Design Software (DFDS):

The DFDS offers multiple software solutions that are used collaboratively to provide a more efficient formwork planning process on construction projects. Some of which are discussed below:

- **Doka CAD 9 for Revit:**

This is the robust planning system combines fast, automated formwork planning with the performance of a CAD/BIM system. [31]. Other DKFS Software packages are used in collaboration with Doka CAD 9 for Revit such as TIPOS, Piece list Editor, Doka CAD 9 for AutoCAD. Fig below shows the general design process associated with using the Doka CAD 9 for Revit software.

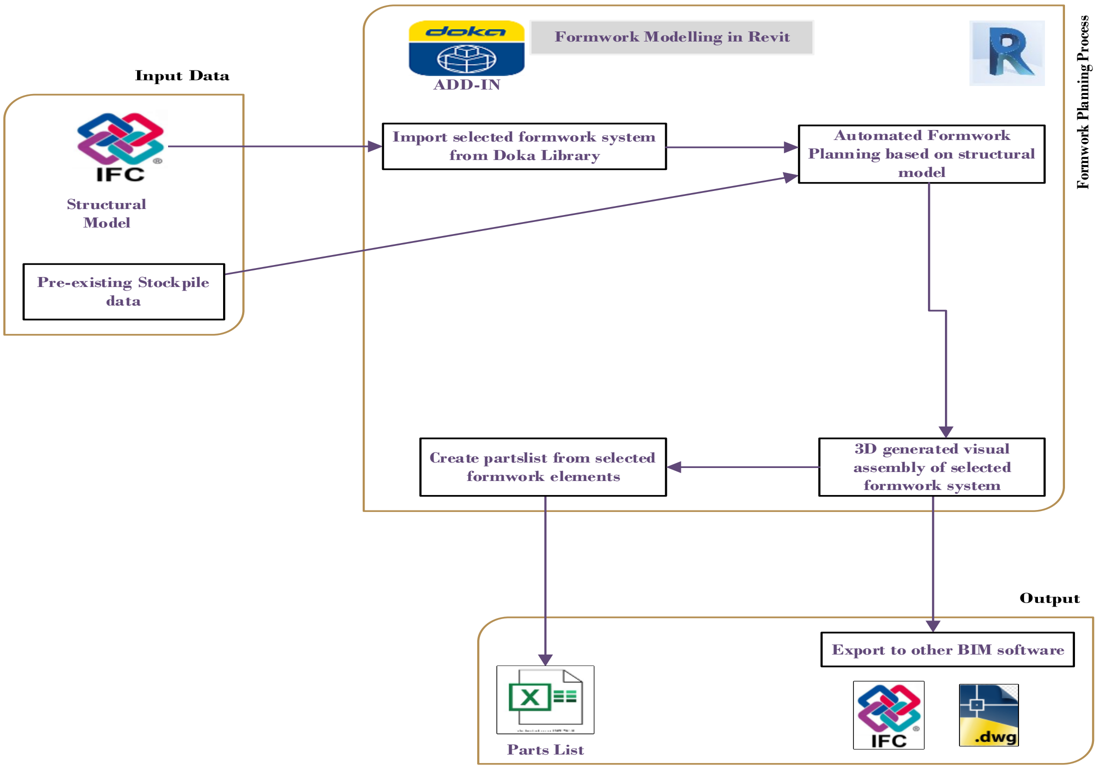


Figure 8: Doka CAD 9 Formwork planning Workflow in REVIT.

As is illustrated in Figure above, the forming process typical begins with importing the structural model into the BIM authoring tool (Revit), the formwork system is then selected from the list of available formwork systems in the Doka CAD libraries. The interactive settings allow for planners to automatically create formwork assemblies based on user parameters, e.g., existing formwork stockpile data, formwork panel size preference, accessories preference etc.

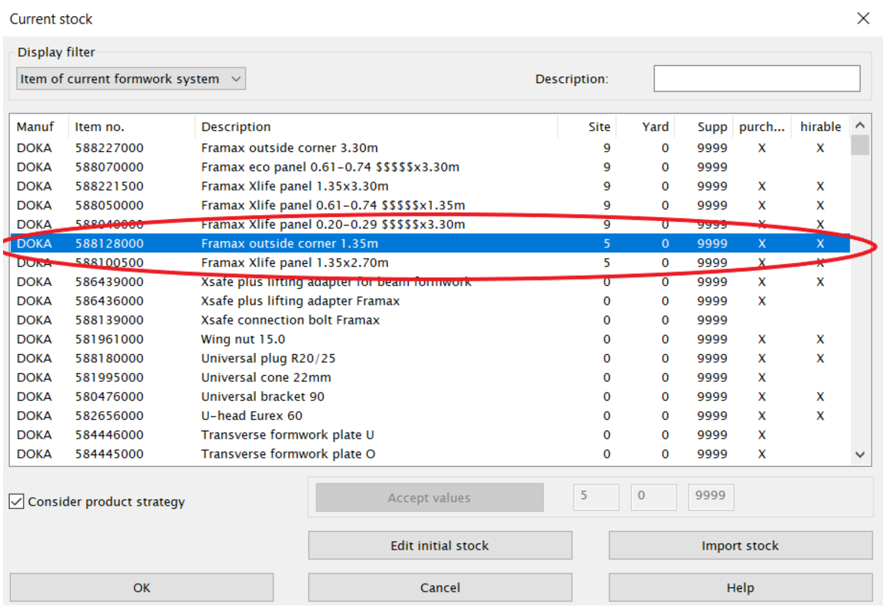


Figure 9: Stockpile Data Input Doka CAD

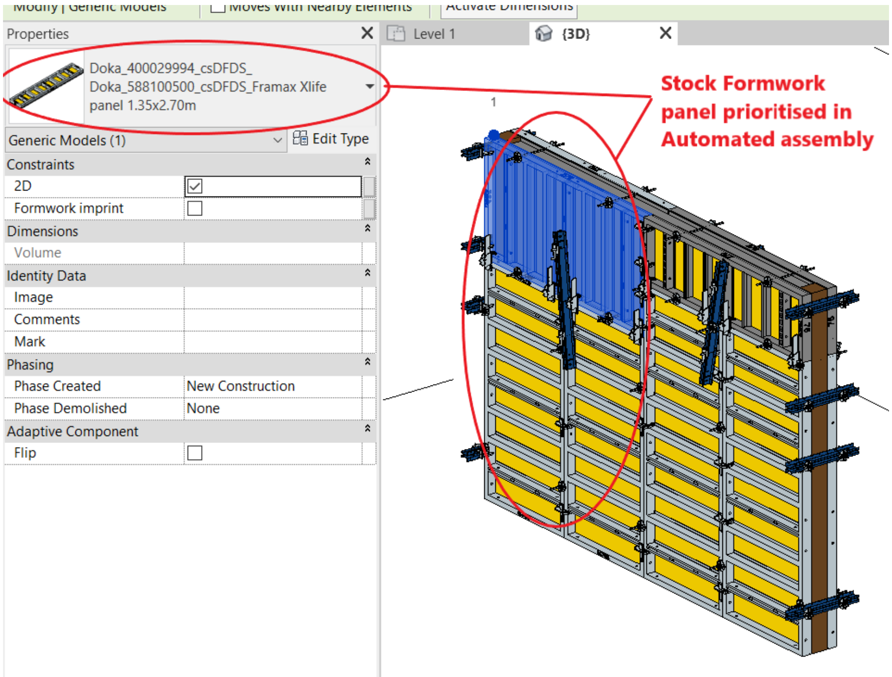


Figure 10: Formwork Automated forming in prioritizing Stockpile data.

The output data have two primary purposes, the first visualization, in terms of BIM, the model can be exported as an IFC file to be integrated into a coordination model; and the second, to be used as a primary source of geometry to generate analytical drawings by exporting the model as a .DWG file.

Tipos:

While the formwork design workflow is similar to Doka CAD, there however differ in that, unlike in Doka CAD 9 which is fully BIM enabled, TIPOS on the other hand is limited to .DXF file format exchanges and is not interoperable with other design tools that do not support .DXF fie exchange.

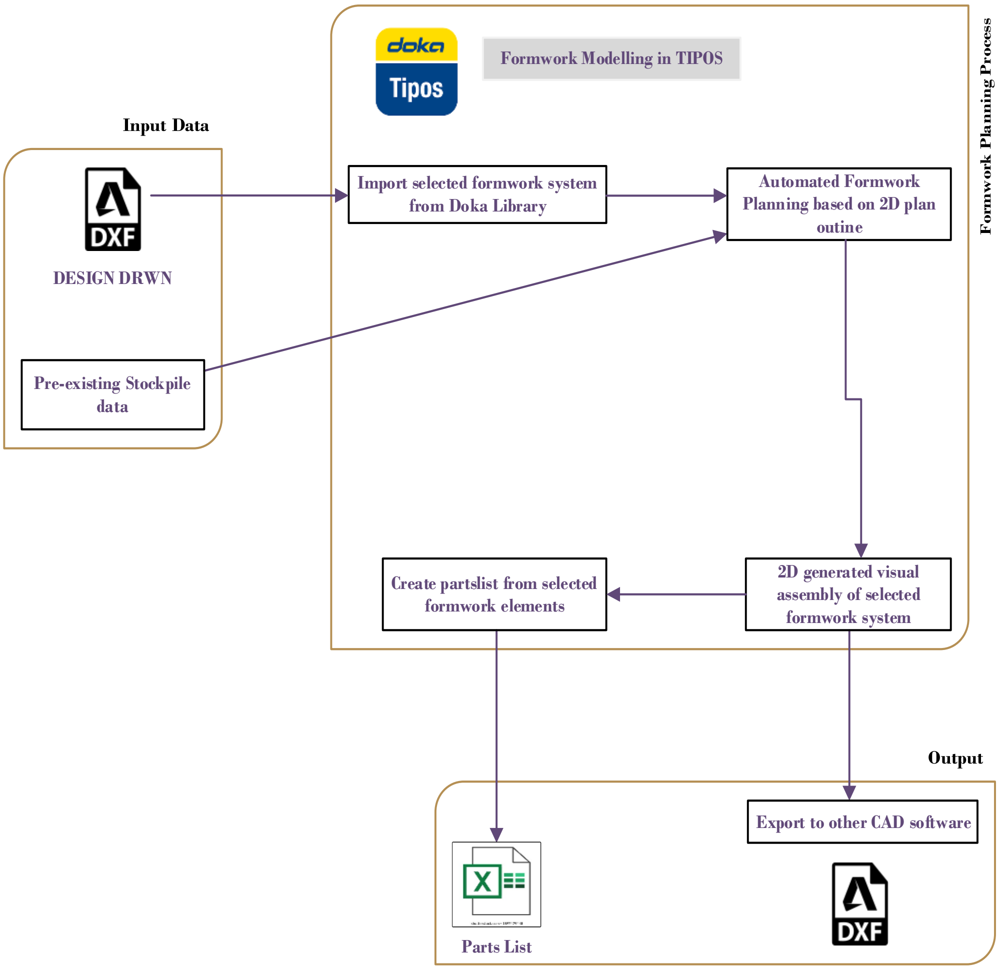


Figure 11: Formwork Design in TIPOS

3.2.2 PERI SYSTEMS:

PERI Library+: provides a plug-in for Autodesk Revit that contains PERI system components, which can be used in the Revit model. PERi Library+ contains available formwork types, accessories and has built-in "positioning intelligence". Peri Library+ also allows for different level of details LOD of formwork components during visualization/forming on a Revit model. [32]. the workflow below illustrates the formwork design process when using PERI Library + in Autodesk Revit software.

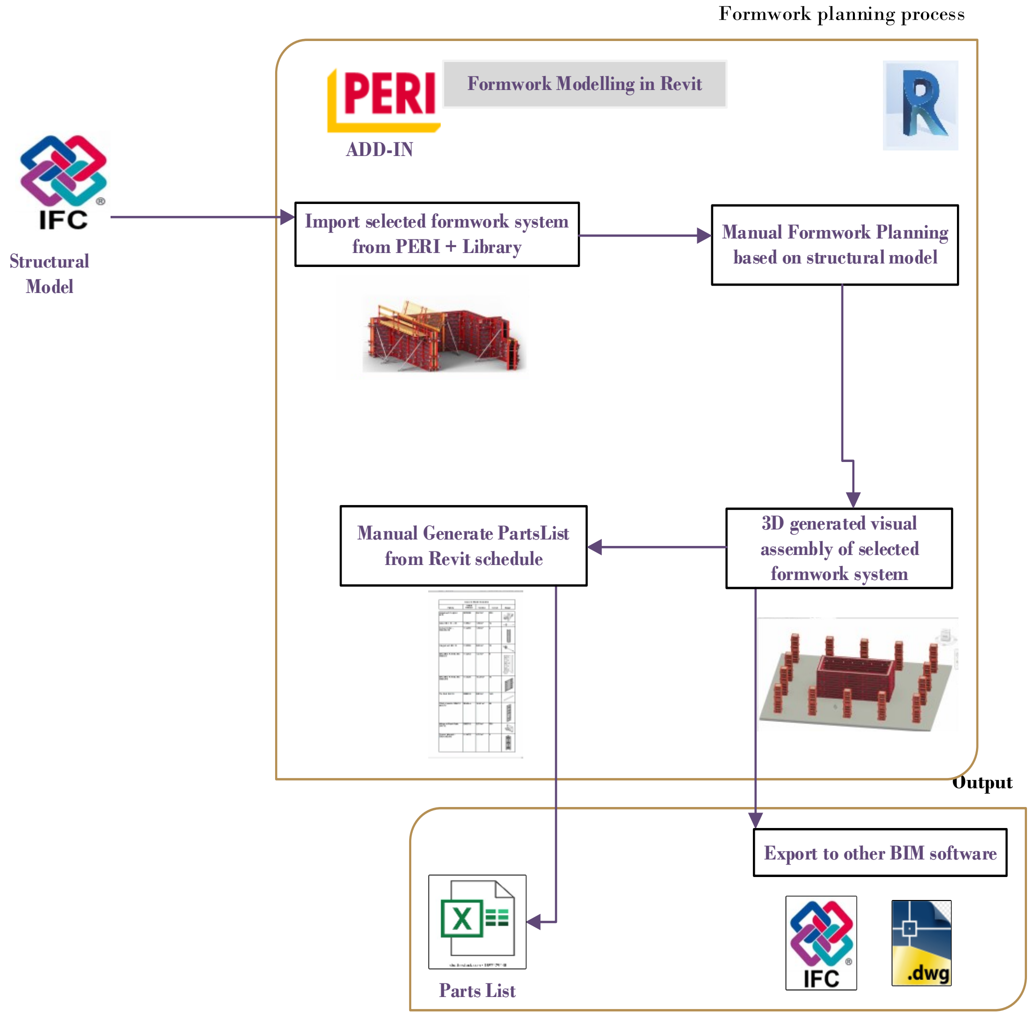


Figure 12: Peri Library + formwork design workflow

Peri CAD: A BIM solution provided by PERI, it contains all of PERI systems components for formwork design and planning. It features automated formwork system component assembly and Quantity take-off of design components. As shown in the figures below:

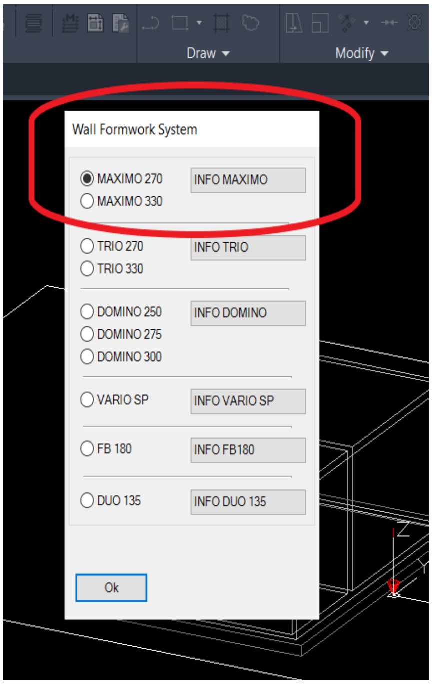


Figure 13: Formwork system selection PERICAD

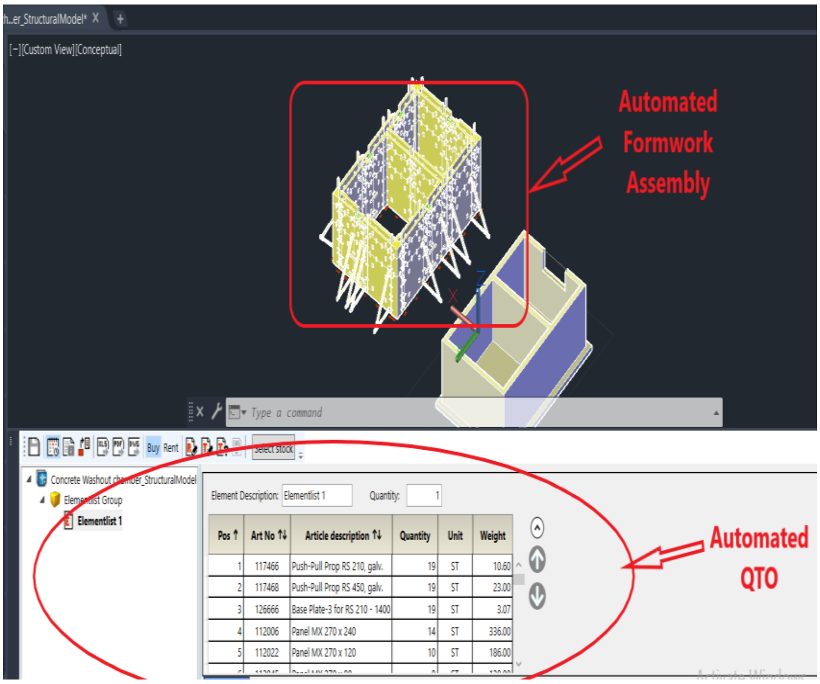


Figure 14: Formwork Automated Assembly and QTO in Peri CAD

3.2.3 ULMA STUDIO:

ULMA Studio add-in for Autodesk Revit, UMA Construction software for formwork planning. It includes a ULMA systems catalogue of articles and an automatic material list capability. The

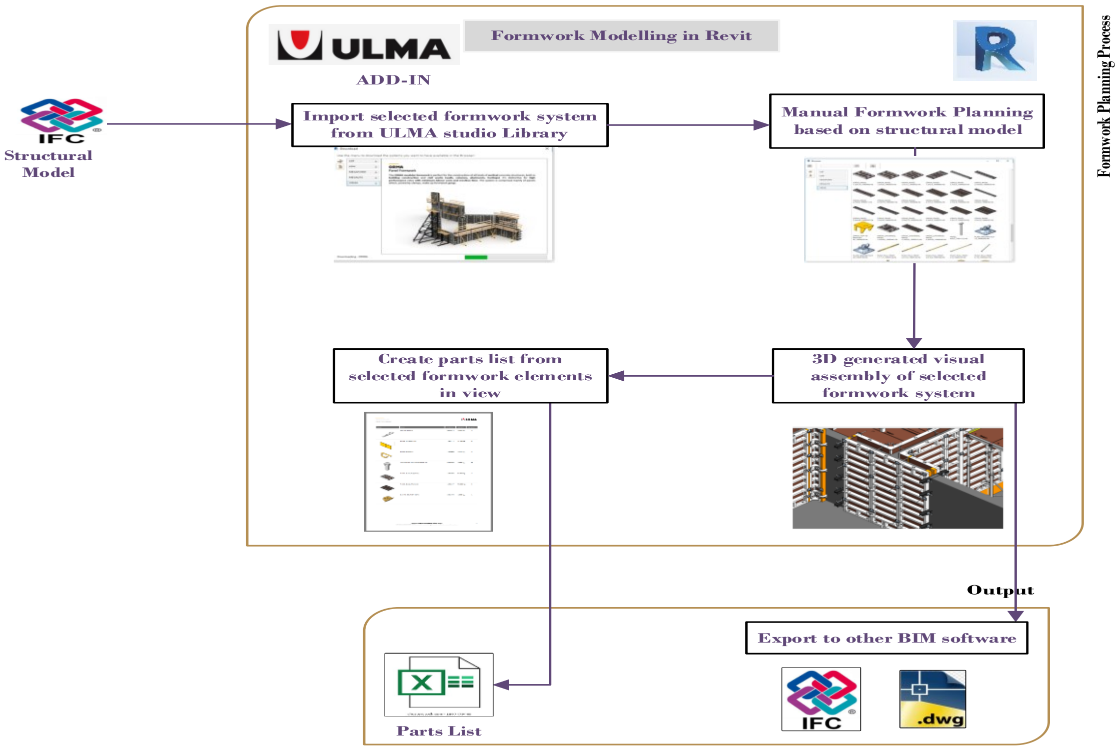


Figure 15: ULMA studio Formwork planning workflow in Revit

A comparison is made between three common formwork libraries in Autodesk Revit Authoring software i.e., Doka CAD, PERI Library+ and ULMA studios. Based on visualization, coordination, and quantity estimation. All three formwork vendors provide an extensive Revit library with vast array of formwork components for various formwork systems, and a high level of detail (LOD) of 400.

BIM LIBRARY CAPABILITIES	Doka CAD Libraries	PERI Libraries	ULMA Studios
Preset formwork system libraries	✔	✔	✔
Automated native formwork planning	✔	✗	✗
Manual placement of formwork model elements.	✔	✔	✔
Allows for pre-existing stockpile data, both from the contractor/supplier and on site.	✔	✗	✗
Automatically generates items list for export	✔	✗	✔
Readily accessible Formwork element data	✗	✔	✗
Supports BIM collaboration	✔	✔	✔
Level of Detail (LOD 400)	✔	✔	✔

Table 1: Comparison between common BIM Formwork libraries

In conclusion, Doka CAD 9 offers a more robust BIM library for formwork planning in Revit due to its Automated Component Forming System, which allows for quick and efficient formwork design for complex concrete structures and custom stockpile data entry, this stockpile data allows for contractors/planners better incorporate their existing formwork inventory into their design. This result brings about an automated formwork design, using existing formwork panels/parts and new inventory to be rented or bought depending on project conditions.

3.3 4D & 5D PLANNING WORKFLOW

In the previous section, the workflow was concluded with the 3D visualization of the Formwork Design and generation of QTO. For construction managers/planners the generated 3D Model has be translated in the construction phase hence the need for 4D/5D simulation to be incorporated in the design workflow. Most Formwork vendors offer online construction management and planning services to paid clients, however in this dissertation, a workflow is proposed to include 4D and 5D simulation in Formwork design. Bentley, Vico, Autodesk Revit, Autodesk Navisworks and BEXEL MANAGER are just a few of the programs that enable industry experts to execute 4D and 5D planning in construction projects.

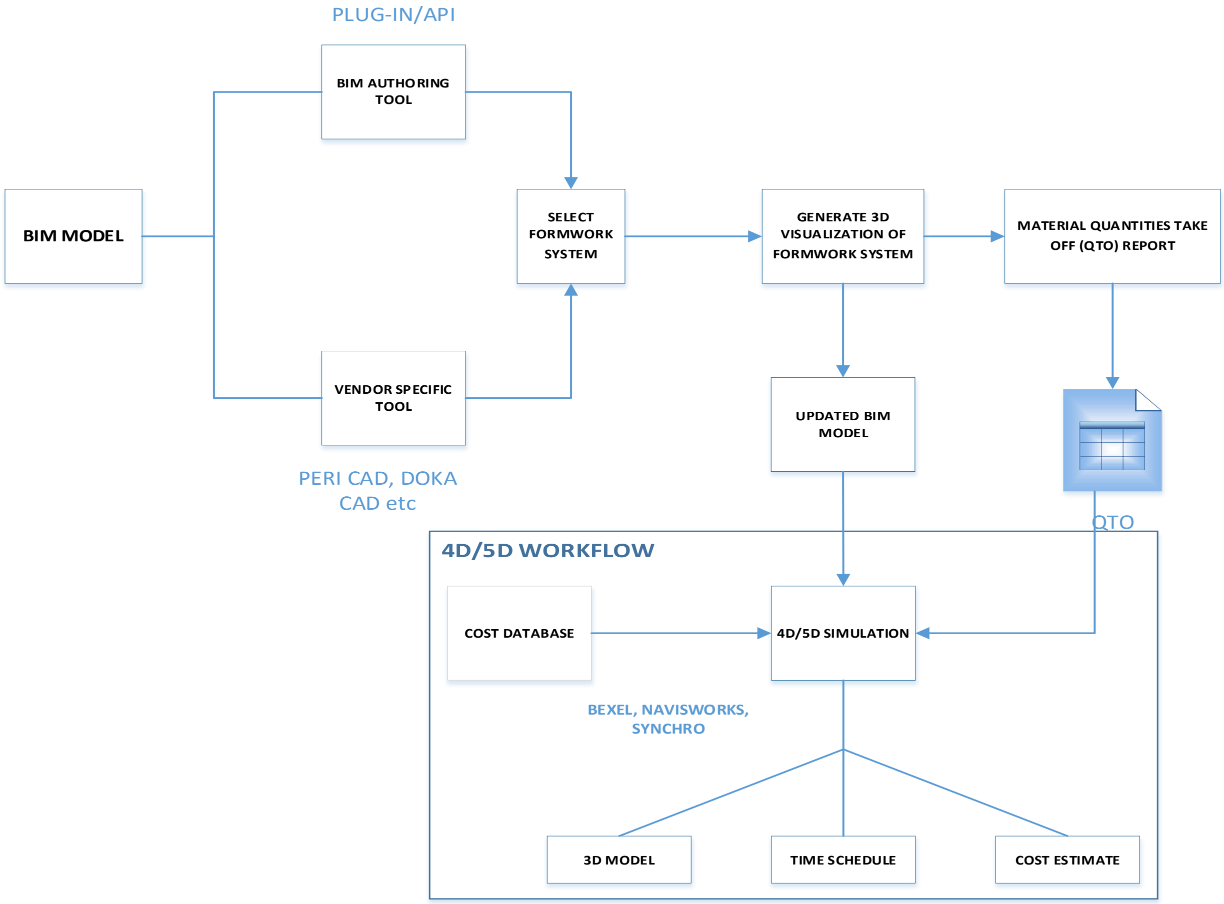


Figure 16: Proposed Optimized Formwork Design workflow to include 4D/5D simulation

This research thesis will be utilizing BEXEL manager 20 as the BIM management tool in executing 4D and 5D planning workflow since BEXEL has advanced Intelligent Construction capability.

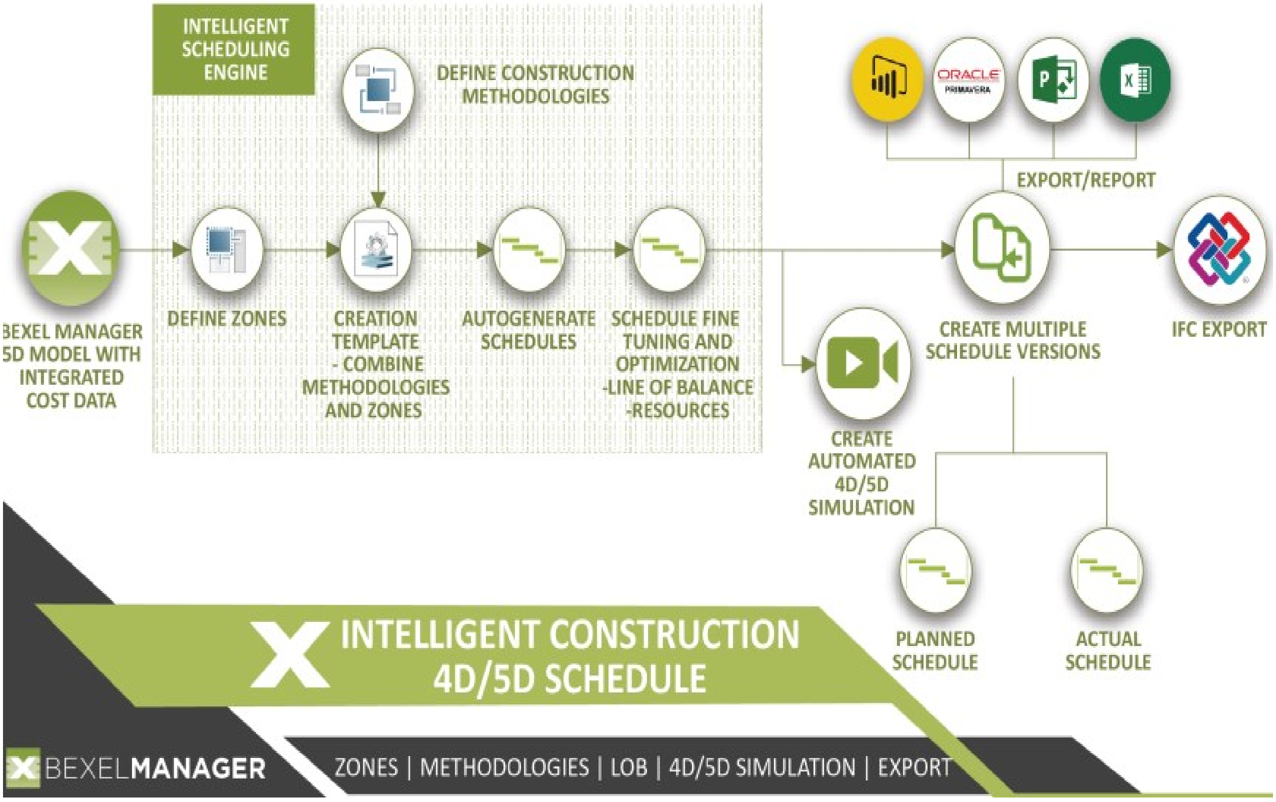


Figure 17: Bexel Intelligent construction 4D/5D workflow.[33]

4 CASE STUDIES

In this section, the workflows shown in the previous section will be tested on two case studies i.e. (case study 1 and case study 2). Case study 1 will illustrate the BIM workflow in formwork design optimization and planning for single-use case i.e., low-cost projects such as standalone structures e.g., retaining walls, box chambers etc. Case study 2 will illustrated workflow for multiple-use case. i.e., projects requiring the re-use/repetitive use of formworks during the construction phase of the project e.g., Highrise buildings, tunnels, bridges etc.

4.1 Case study 1: Concrete Caste-in situ Chamber

4.1.1 Project Description

To best illustrate the use of the proposed workflow in formwork single-use case, a concrete cast-in situ concrete chamber model has been developed using Autodesk Revit BIM authoring software. The structure is a 10m x 6m Reinforced concrete box chamber, it comprises of four external walls 300mm thick with an internal wall of same width dividing the chamber into two compartments. This case study will focus mostly on utilizing the proposed workflow in the thesis in designing the formwork elements required for the case study model and utilizing the designed formwork model elements in BIM management software for 4D and 5D planning simulations. Other aspects of the structure such as MEP, Architecture etc. will not be considered as they are not required in formwork design during the construction phase of a project.

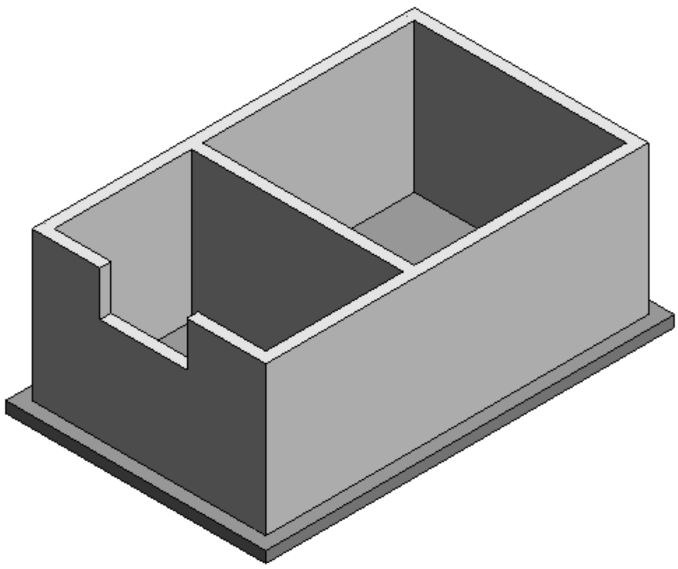


Figure 18: Case Study 1 Model (Concrete cast-in situ Chamber)

The software incorporated in the proposed workflow for this case study are below:

1. Autodesk Revit: is a BIM authoring tool commonly used for the AEC design with common functionality for authoring, documentation, analysis and visualisation
2. Doka Formwork Design Software (DFDS) 9: formwork design and high-performance planning software plugin for Revit. Enables the fast, automatic formwork planning in 3D with the performance of a BIM system.
3. BEXEL MANAGER: Enbables the use of models from varipus authoring environments that can be upgraded to 4D using scheduling capabilities and 5D – costs, providing an approach to manage budget and schedule. It also has strong capabilities in generating clash detection. The analysis in the software is integrated into a single solution.

4.1.2 Optimization Workflow

Formwork Design

In the Autodesk Revit BIM authoring tool, The Doka 9 systems has been utilized in designing the formwork model for the case study model due to its automated formwork forming system. A formwork system is chosen from the list of pre-existing formwork libraries available in the DOKA plugin for Revit. In this case study the Doka Frame Xlife Framed Formwork System library [Fig 19] is selected and utilized for the design of the formwork model for the concrete wall model.

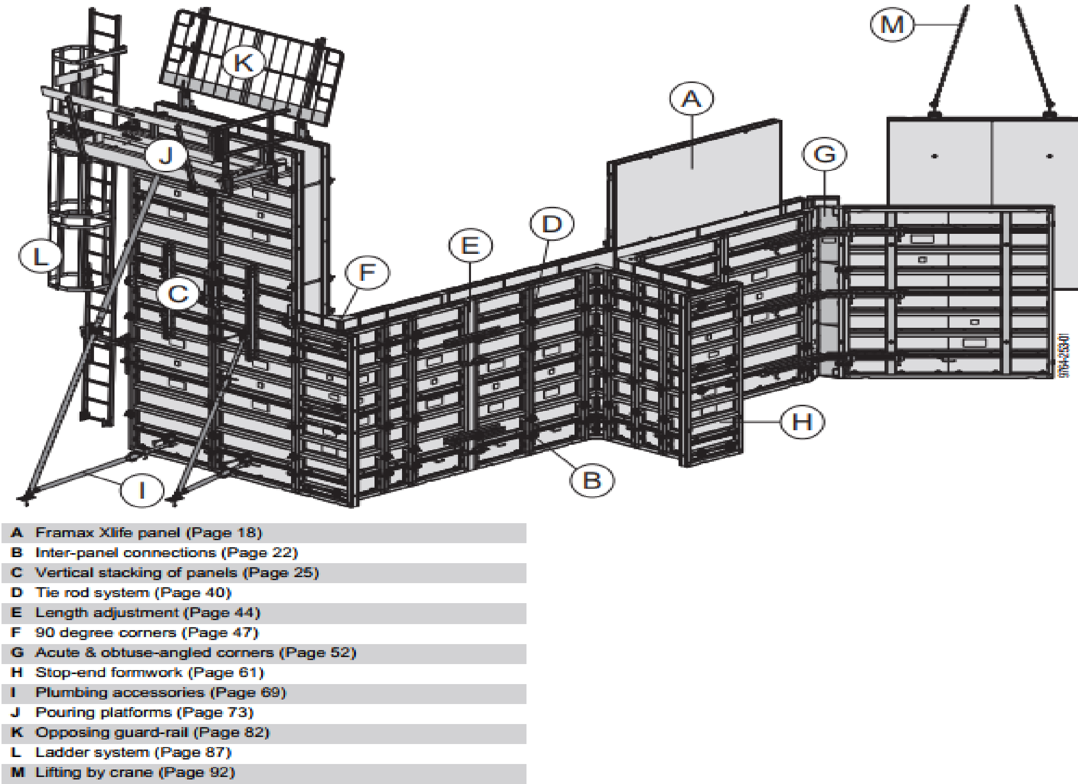


Figure 19: Doka Frame Xlife Framed Formwork System[34]

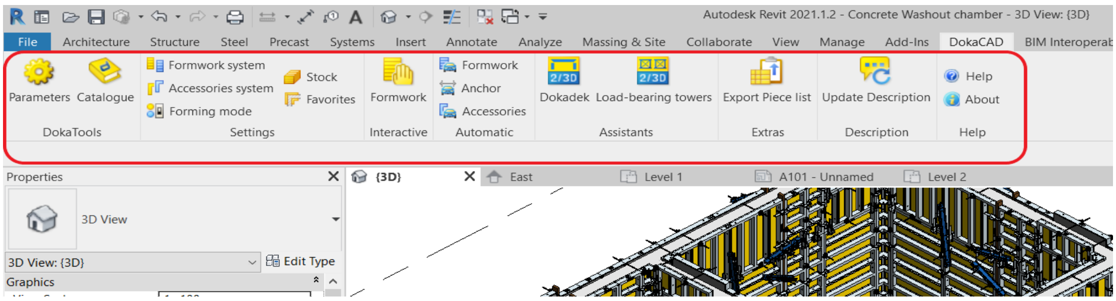


Figure 20: Doka9 Revit Plugin Interface

DFDS system (Doka) allows for automated and manual forming of formwork model elements, this allows planners to efficiently utilize various formwork system libraries available by allowing quick assembly of formwork model elements on the structural model. Planners can see how the formwork components are assembled, and make required adjustments if need be.

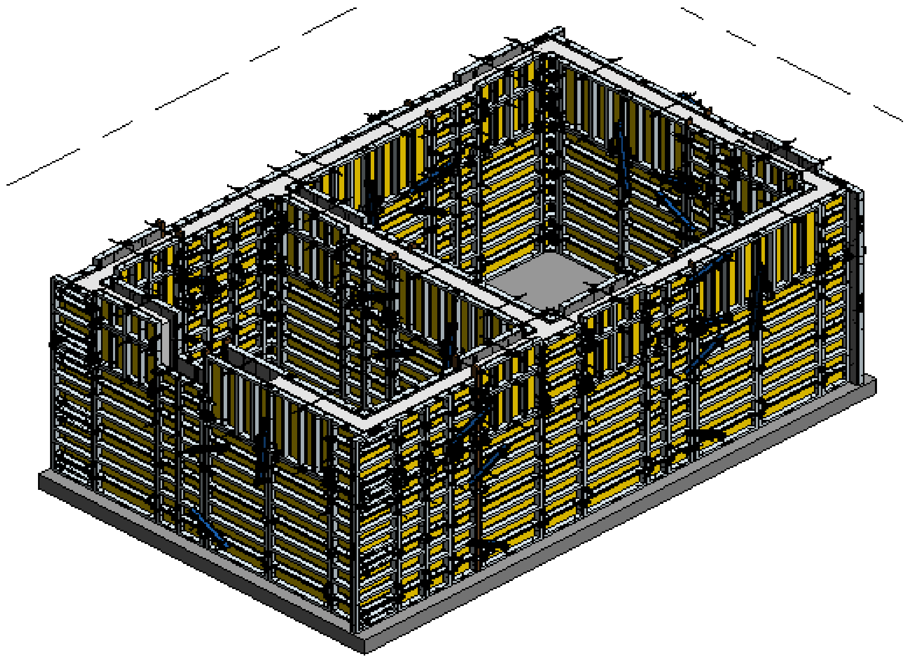
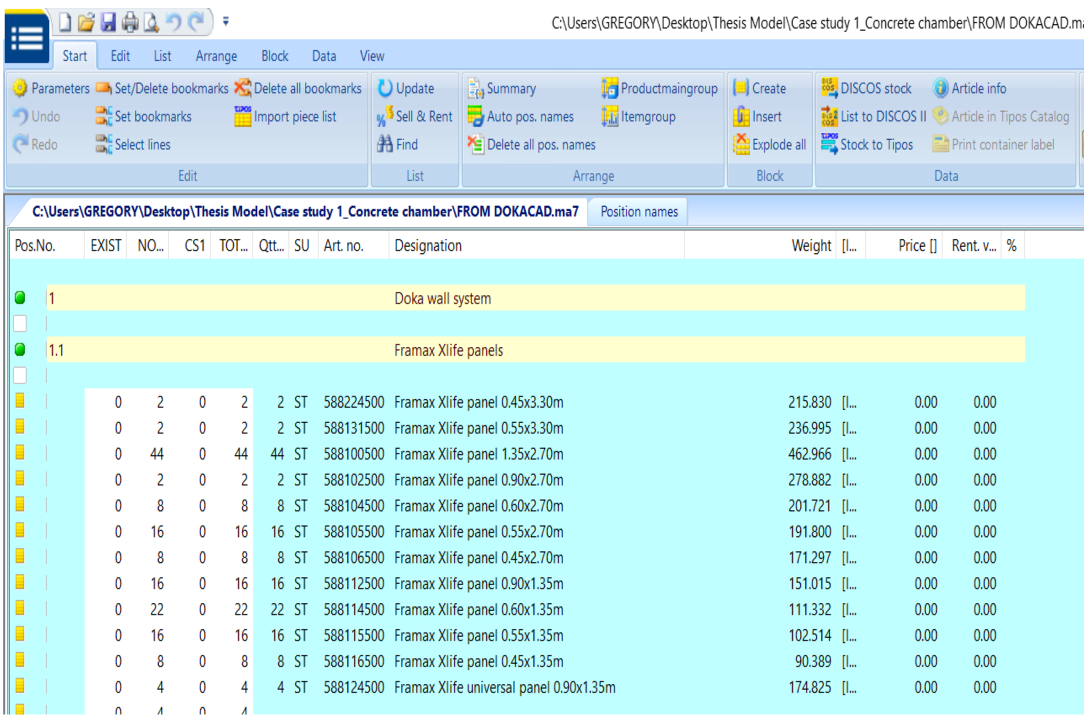


Figure 21: 3D generated visual assembly of selected formwork system

Quantity takes off

DFDS system allows for automated quantity take off (QTO) of selected formwork elements. These quantities are exported from the Autodesk Revit tool to the DFDS dedicated QTO software i.e., Piece list Editor. QTO data can be readily accessible to planning experts through excel.

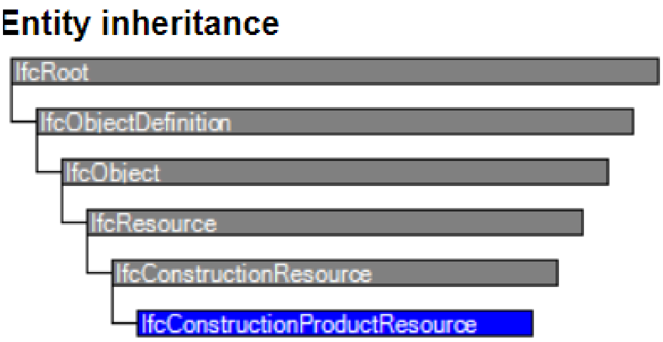


Pos.No.	EXIST	NO...	CS1	TOT...	Qtt...	SU	Art. no.	Designation	Weight	[l...	Price []	Rent. v...	%
1								Doka wall system					
1.1								Framax Xlife panels					
	0	2	0	2	2	ST	588224500	Framax Xlife panel 0.45x3.30m	215.830	[l...	0.00	0.00	
	0	2	0	2	2	ST	588131500	Framax Xlife panel 0.55x3.30m	236.995	[l...	0.00	0.00	
	0	44	0	44	44	ST	588100500	Framax Xlife panel 1.35x2.70m	462.966	[l...	0.00	0.00	
	0	2	0	2	2	ST	588102500	Framax Xlife panel 0.90x2.70m	278.882	[l...	0.00	0.00	
	0	8	0	8	8	ST	588104500	Framax Xlife panel 0.60x2.70m	201.721	[l...	0.00	0.00	
	0	16	0	16	16	ST	588105500	Framax Xlife panel 0.55x2.70m	191.800	[l...	0.00	0.00	
	0	8	0	8	8	ST	588106500	Framax Xlife panel 0.45x2.70m	171.297	[l...	0.00	0.00	
	0	16	0	16	16	ST	588112500	Framax Xlife panel 0.90x1.35m	151.015	[l...	0.00	0.00	
	0	22	0	22	22	ST	588114500	Framax Xlife panel 0.60x1.35m	111.332	[l...	0.00	0.00	
	0	16	0	16	16	ST	588115500	Framax Xlife panel 0.55x1.35m	102.514	[l...	0.00	0.00	
	0	8	0	8	8	ST	588116500	Framax Xlife panel 0.45x1.35m	90.389	[l...	0.00	0.00	
	0	4	0	4	4	ST	588124500	Framax Xlife universal panel 0.90x1.35m	174.825	[l...	0.00	0.00	
	0	4	0	4									

Figure 22: Automated QTO using Piece List Editor 9

IFC Export and Model View Definition

In considering open BIM data exchange using IFC. Ifc Mapping for formwork elements is captured under IfcConstructionProductResource, which is used to define products that are utilized in the performance of construction.



For this case study, formwork model elements generated by doka are exported using IFC 2x3 Coordination view as Model view definition. Custom-created User Defined Parameters/mapping table, to extract required formwork element data for 4D and 5D simulation.

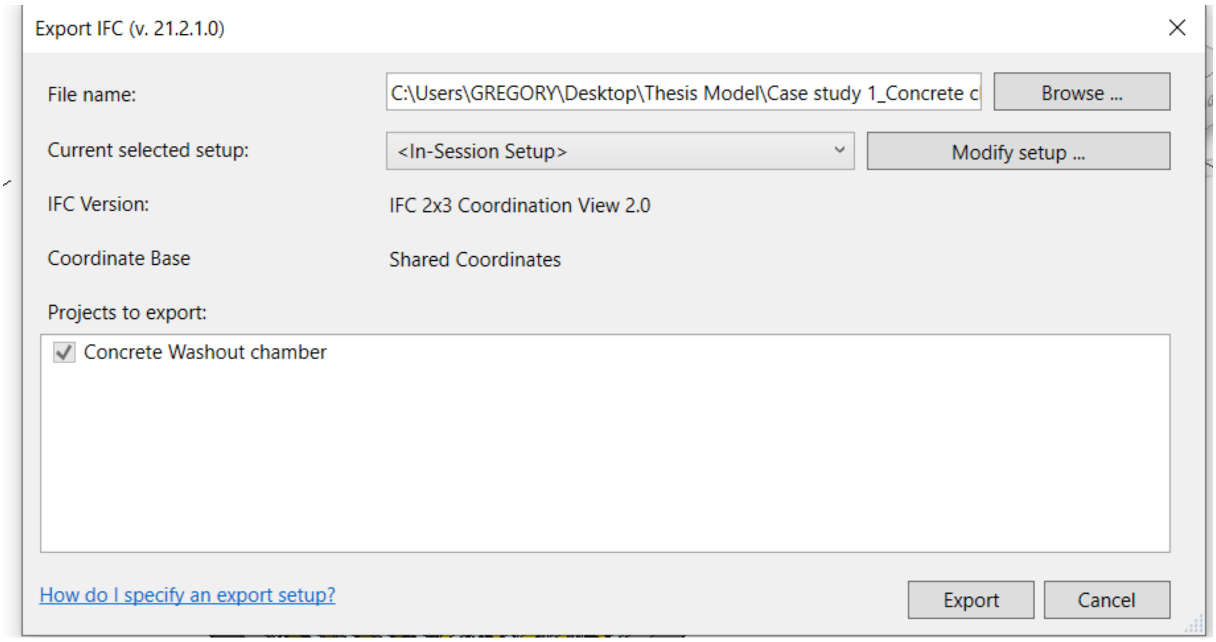


Figure 23: IFC Model View Definition

```
Formwork_UserDefinedParameterSets_2 - Notepad
File  Edit  Format  View  Help
#
PropertySet:    MyPropertySet   I       IfcWall, IfcBuildingElementProxy
MyName  TEXT    SpecialName
Thickness       LENGTH  Wall_thickness

PropertySet:    DokaSet I       IfcBuildingElementProxy
Itemgroup       TEXT    Doka_Itemgroup
Description     TEXT    Doka_Description
Article Number  Integer Doka_Article_Number
Area    Area    Doka_Area
Height  Length  Doka_Height
Length  Length  Doka_Length
Width   Length  Doka_Width
Uniclass Number Integer Classification.Uniclass.Pr.Number
Uniclass Description    TEXT    Classification.Uniclass.Pr.Description
```

Figure 24: Author Custom User Defined Parameters (Mapping table)

BIM Model Validation

The Formwork Model which has been opened in the BEXEL Manager 20, has been validated and shows that all required formwork element data specified in the MVD has been included in the IFC model. Other Model elements such as walls, slabs etc. exported in IFC, were also validated.

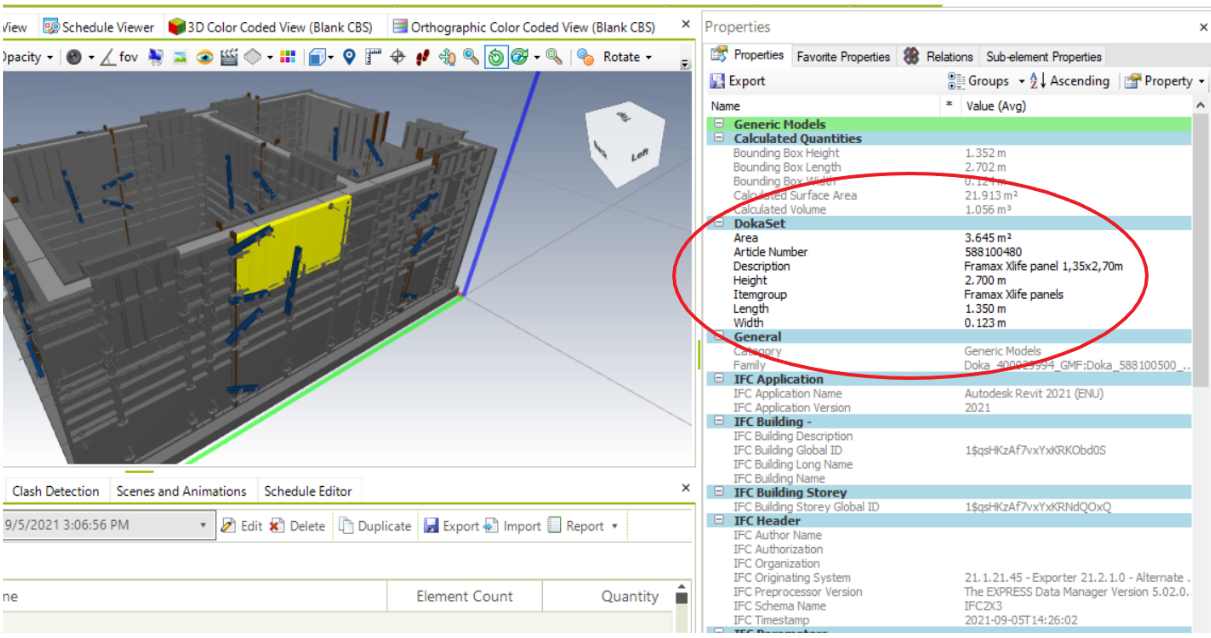


Figure 25: BIM model validation in Bexel Manager 20

4D & 5D simulation.

In this phase, segregation of the BIM model elements was done based on the category property of element in the Model using selection sets, similar segregation was done in creating the Custom Breakdown Structure (CBS) of the Case study model. See figures below. Based on the properties and selection sets created, different QTO tables are generated. See figures below.

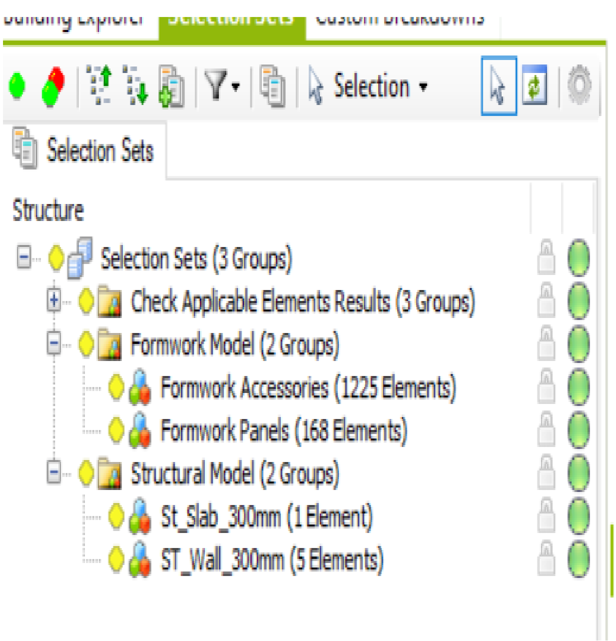


Figure 26: Selection sets in Bexel Manager

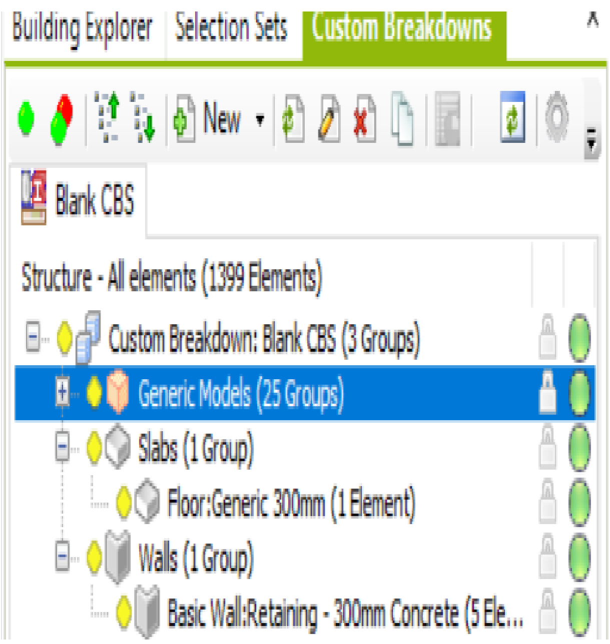


Figure 27: Custom Breakdown Structure Case study 1

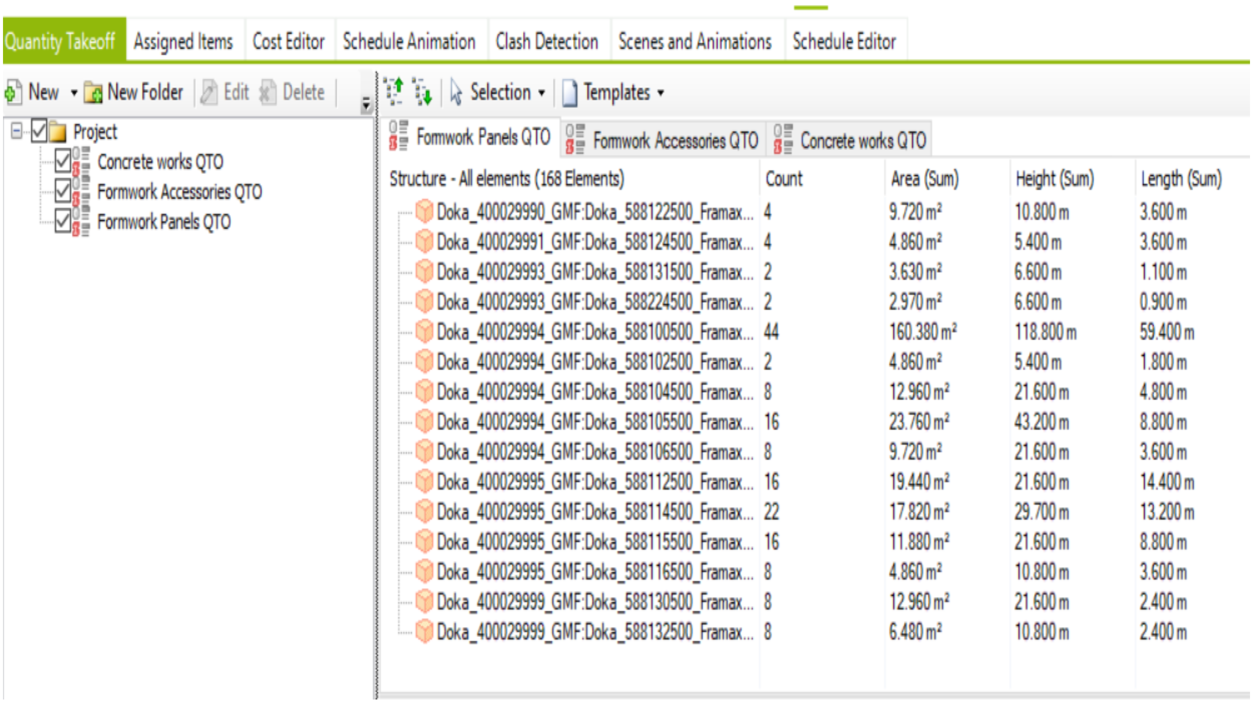


Figure 28: Automated QTO Formwork panels based of selection sets

The next step in the workflow is generating the cost classification. This was achieved by generating cost classification from the CBS. The Cost classification generated incorporated the 3 categories of elements in the model. All the cost items are automatically generated and attached to the building elements in the model smartly using CBS.

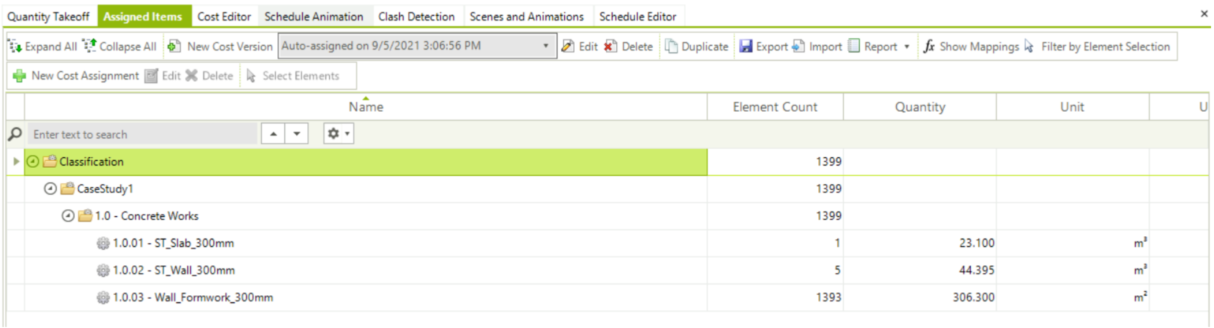


Figure 29: Generated Cost Classification in Bexel manager 20

Bexel Manager can simulate the schedule of the project by adding a fourth dimension—time into the model. This can be achieved using three different ways to add/incorporate the schedule into the building model:

1. Defining the tasks in the BEXEL MANAGER 20 directly.

2. Importing Primavera or MS Project schedule

3. Creating zones and methodologies to automate the generation of the schedule.

In this case study, the third option was used, a zone was created based on number of model structure in the project. The methodology level was created based on the cost classification created in the previous step.

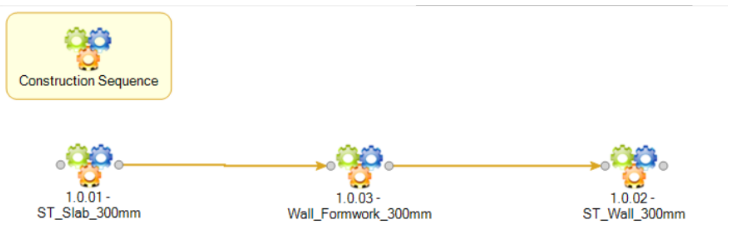


Figure 30: Methodology based on cost classification

Figure 31: Building section zone

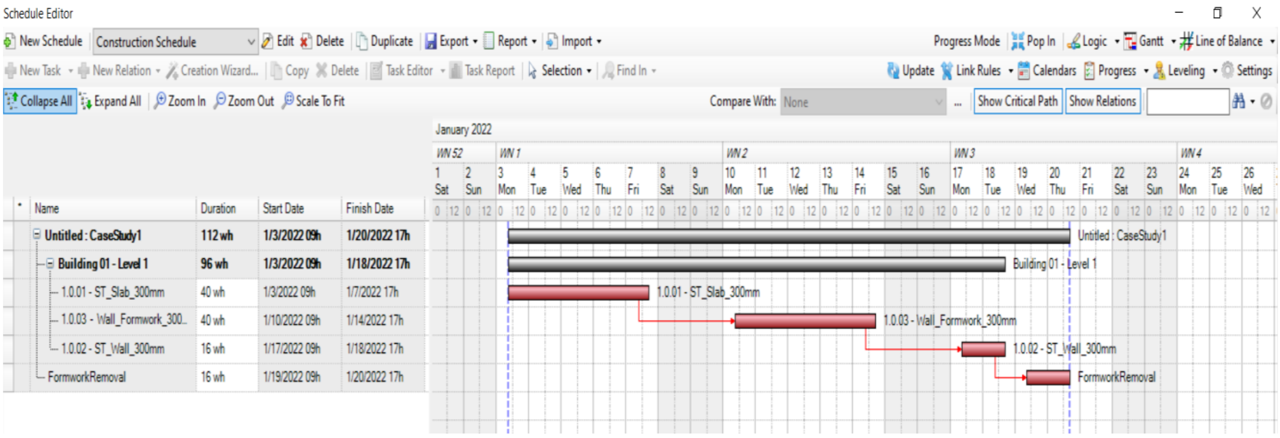


Figure 32: Gant Chart Work Schedule

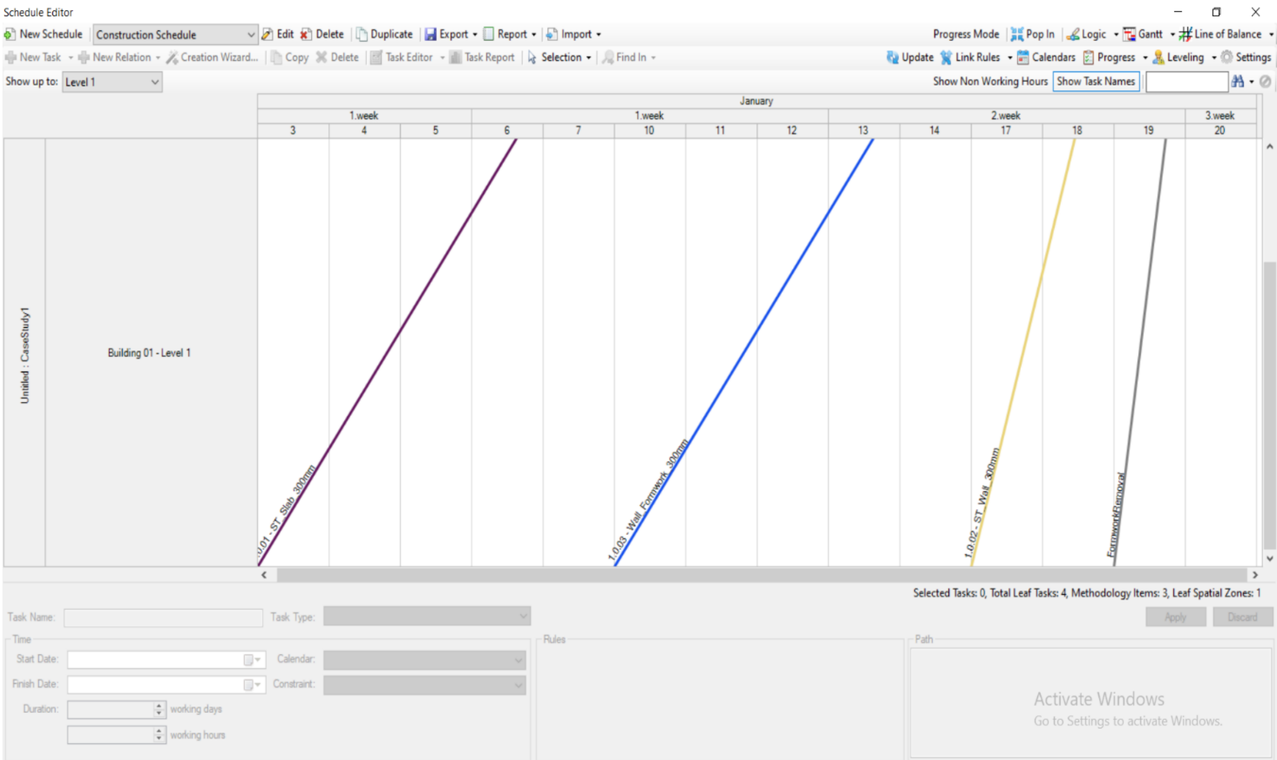


Figure 33: Line of Balance (LOB) view

A review of the case study shows that BIM technology can allow for fast and efficient automated Formwork Design process, as well as advanced construction management capabilities in single use cases. In this case study the Design process is automatic and reliable. Designs can be completed within minutes, and QTO generated with extreme precision. Similarly, by utilizing BEXEL manager construction components are derived directly from the building model, which reduces time and costs by avoiding over estimation of formwork equipment.

4.2 Case study 2 – 2storey Concrete Structure

4.2.1 Project Description

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 2021. The case study is a BIM model of a small Two-story residential building. The building is approximately 645m2. The building information model has been developed to contain generic models to represent only the concrete structure system i.e. (concrete structural foundation, structural walls, and structural slabs). Other aspects of the building model i.e., MEP, Architecture, etc. are not considered as they do not influence the design of formwork systems in a building project.

The primary purpose of the case study is twofold:

1) The case study will clarify how BIM technology can work for formwork design in a typical building model, requiring repetitive use of formwork elements.

2) Incorporate design data into 4D and 5D simulation.

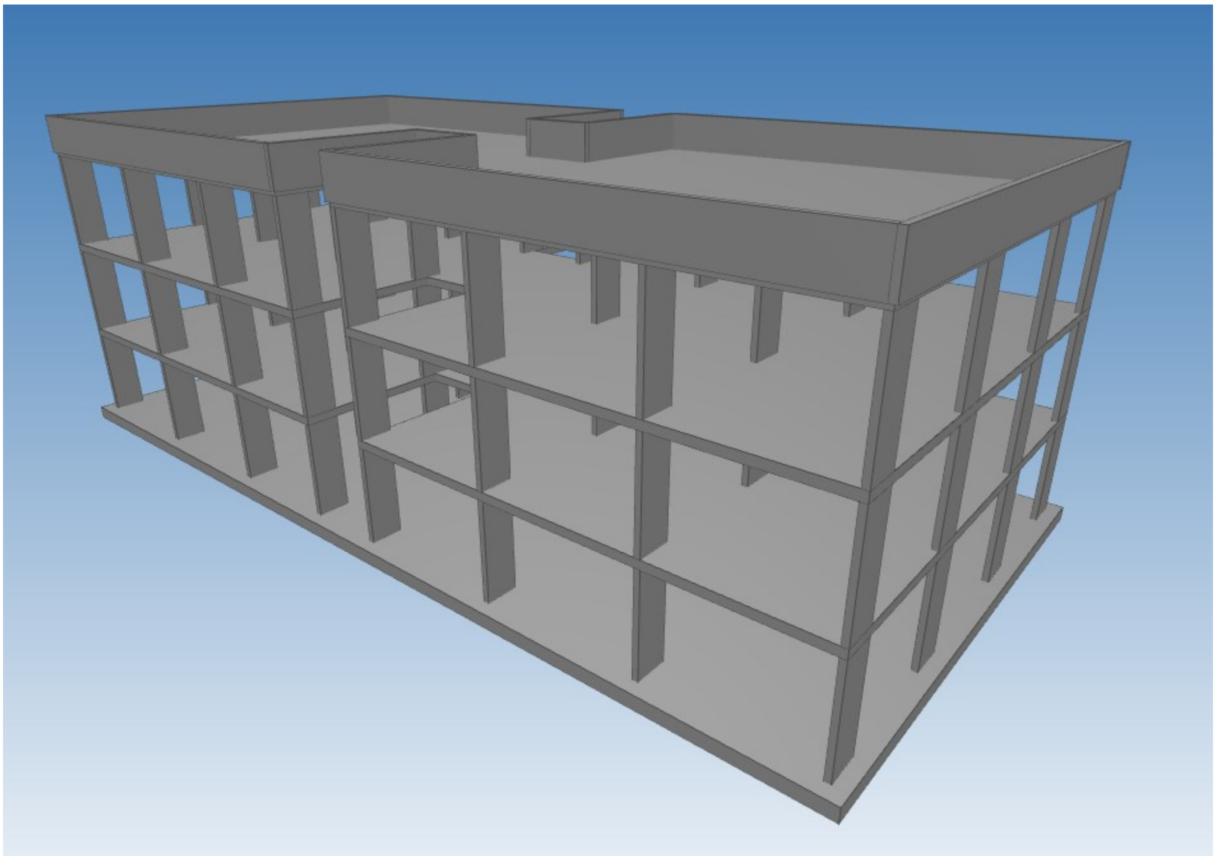


Figure 34: Structural Model - Case study 2

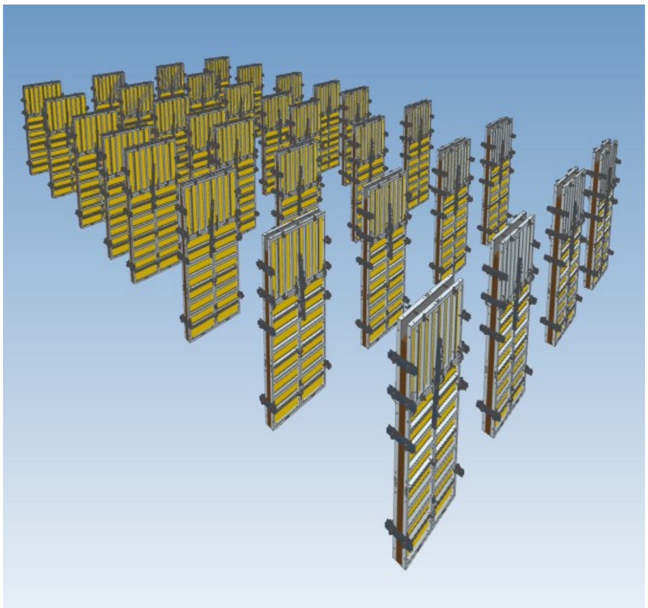


Figure 35: Wall formwork Model

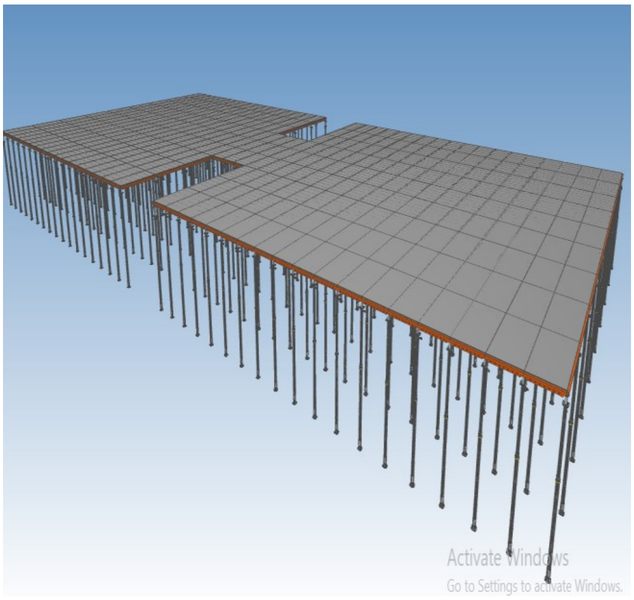


Figure 36: Slab Formwork Model

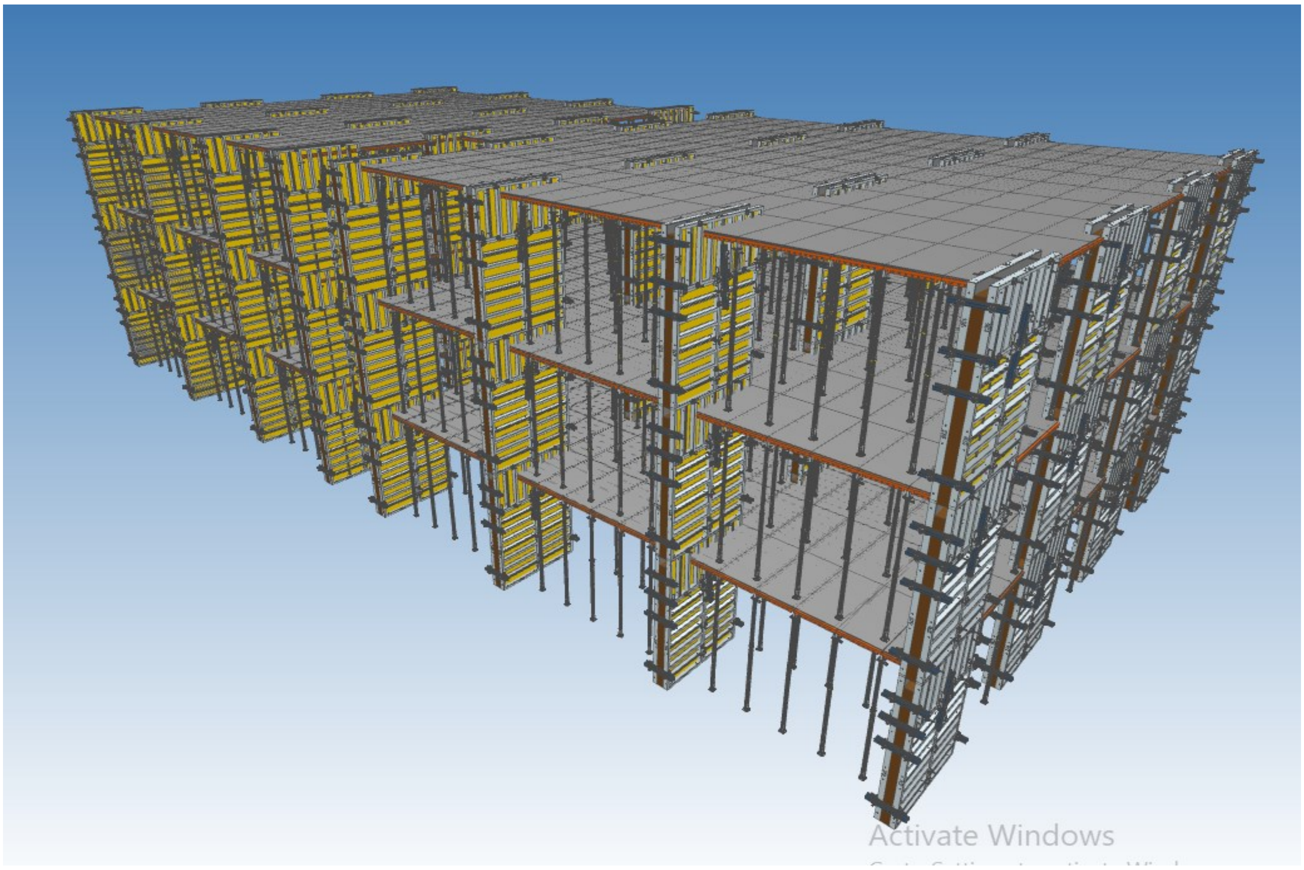


Figure 37: Model Structure showing formwork components

As with previous case study, DFDS (Doka CAD) systems will be utilized in formwork design. Autodesk Revit will serve as BIM authoring tool and Bexel Manager 20 has been utilized in creating 4D and 5D simulations.

4.2.2 Optimization Workflow

Formwork design.

In this process, formwork design was done based on building level each individual Model components such as slabs and walls were assigned to. As with the previous case study, The DFDS systems has been utilized in designing the formwork model due to its automated formwork forming system.

The Doka Framax Xlife Framed Formwork System library was selected and utilized for the design of the formwork for the concrete wall components of the structural Model, similarly Doka flex 1-2-4 – Formwork was utilized for the floor slabs.

The formwork design is not based on any STATIC Calculations but is solely based on geometrical consideration of the structural model. Hence the created views typically only display the completed state of the formwork model elements.

Quantity Take off

Doka CAD allows for the automatic creation of QTO of the formwork components generated, However, this is not a true representation of formwork quantities required for an entire project, as formwork is re-used repeatedly during the construction phase of a project.

IFC Export and MVD

The IFC export schema and model view definition utilized when exporting model data from BIM authoring software to BIM management tool is as previously stated in case study 1.

BIM Model Validation

The Formwork Model which has been exported in the BEXEL Manager 20, has been validated and shows that all required formwork element data specified in the MVD has been included in the IFC model. Other Model elements such as walls, slabs etc. exported in IFC, were also validated.

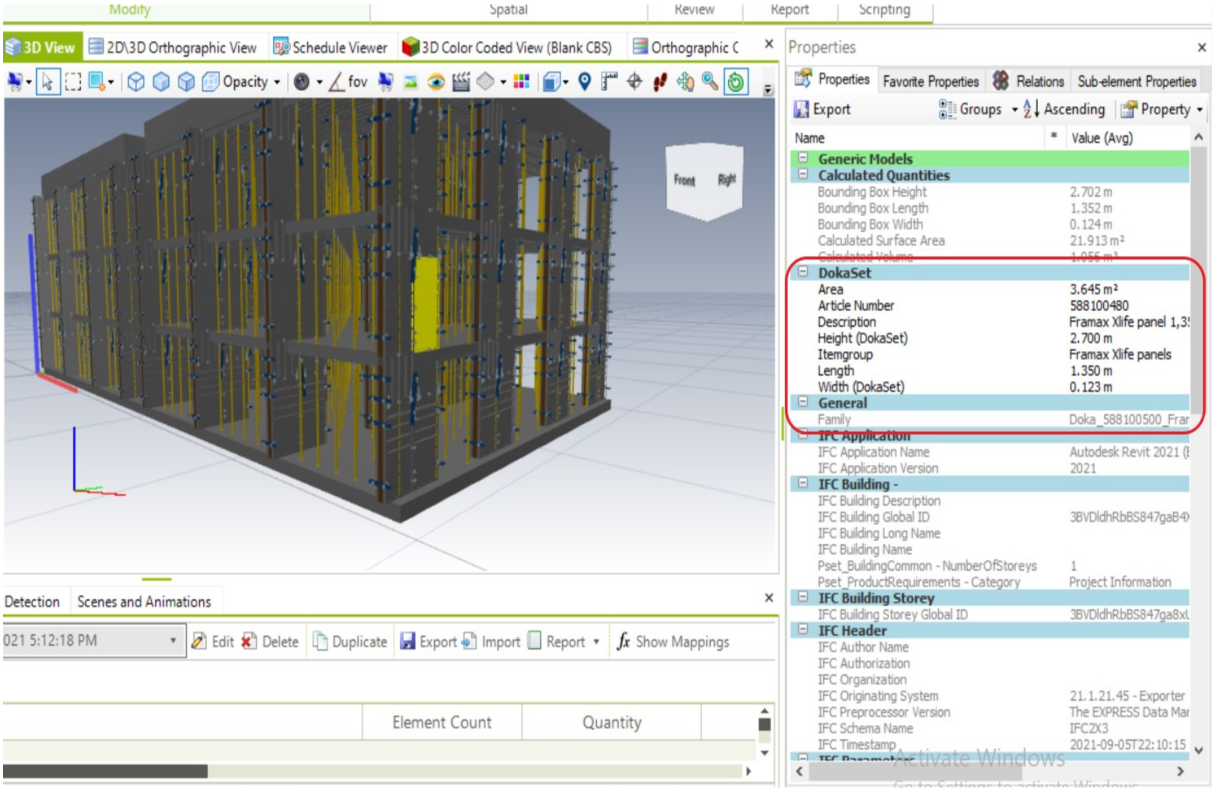


Figure 38: BIM validation in Bexel Manager 20 Case study 2

4D & 5D simulation.

In this phase, segregation of the BIM model elements was done using selection sets, model elements were grouped according to their respective building levels, category, and type properties. Then I started with a custom breakdown, where the BIM model was broken down by the selected attribute, in this case, model 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. Based on the CBS and selection sets created, different QTO tables are generated.

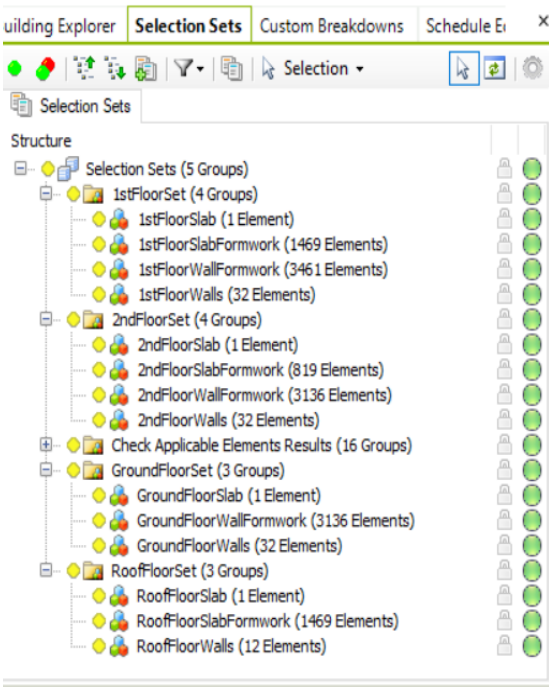


Figure 39: Selection Set Case study 2

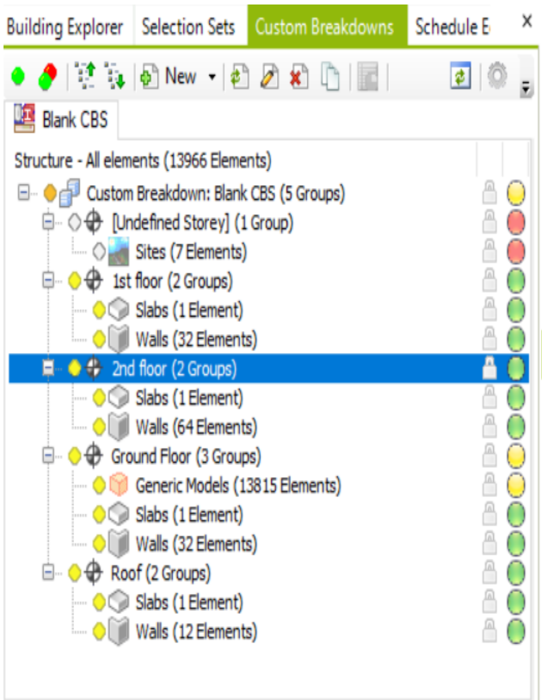


Figure 40: CBS case study 2

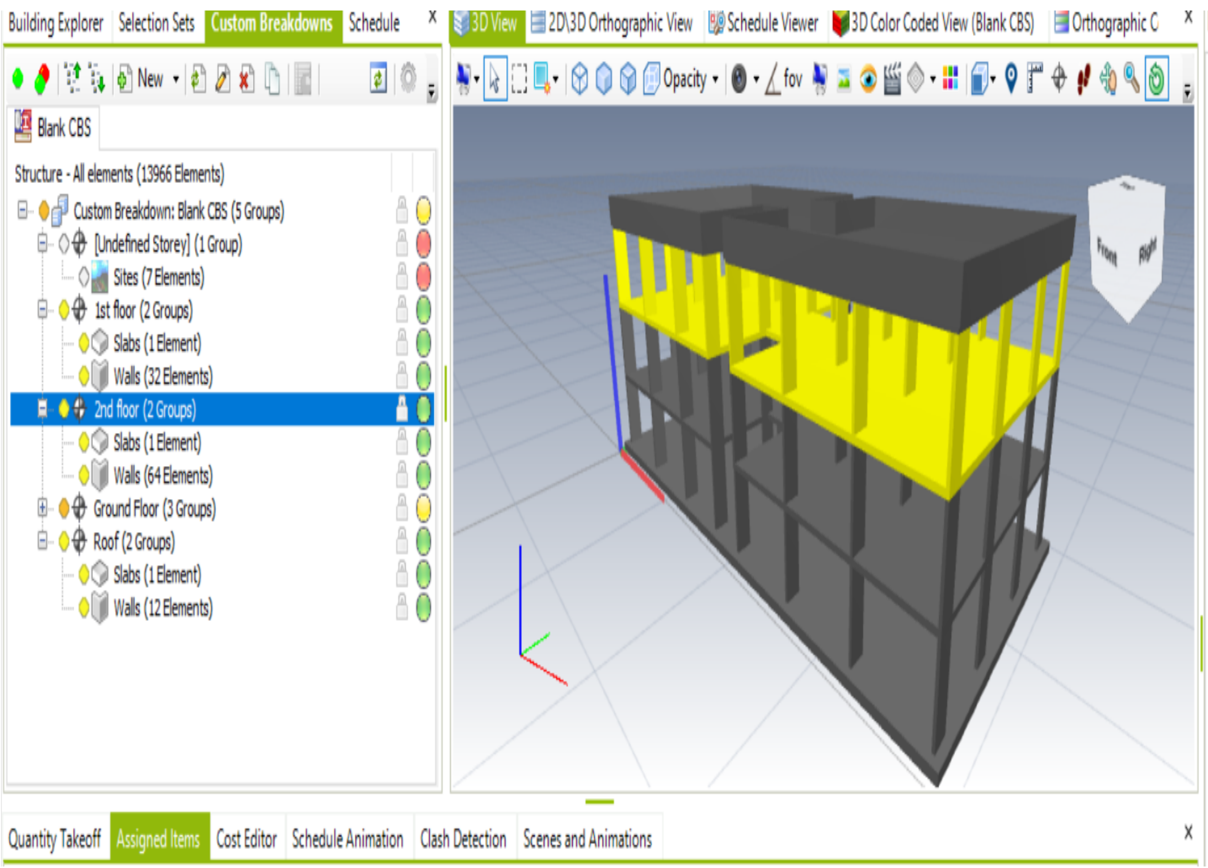


Figure 41: CBS based on BIM model level and element category

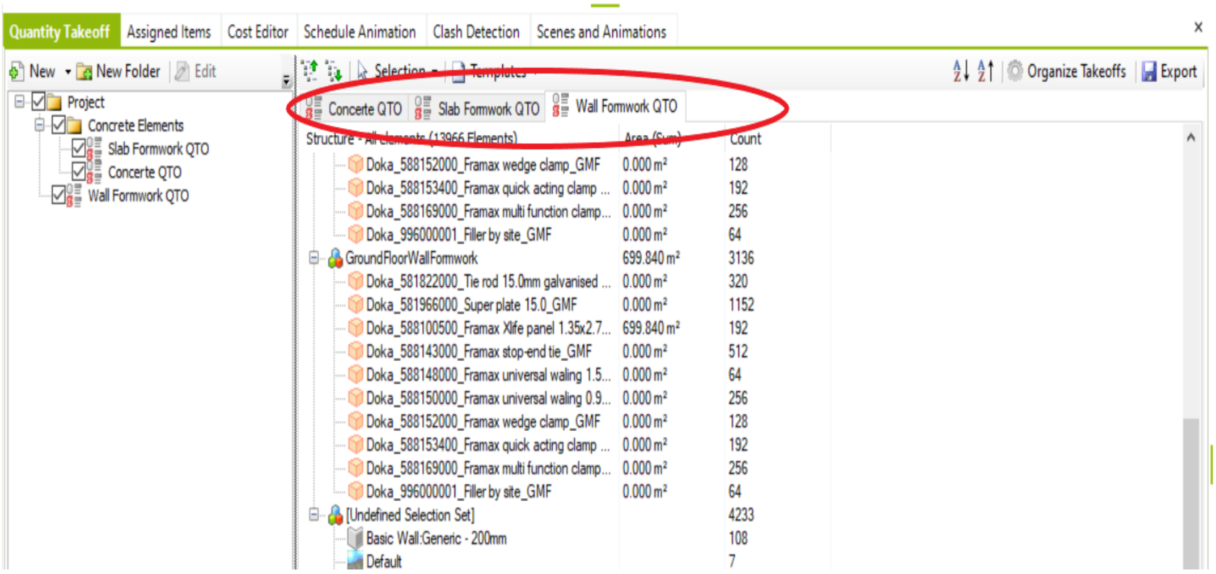


Figure 42: QTO of formwork elements

Cost Classification & Cost Items

In this step, the cost classification is generated not based on the QTO list, as done in the previous case study. All cost items associated with the cost classification system are manually created based on existing selection set hierarchy. Cost items are automatically assigned to BIM model elements by the required element properties in the element query.

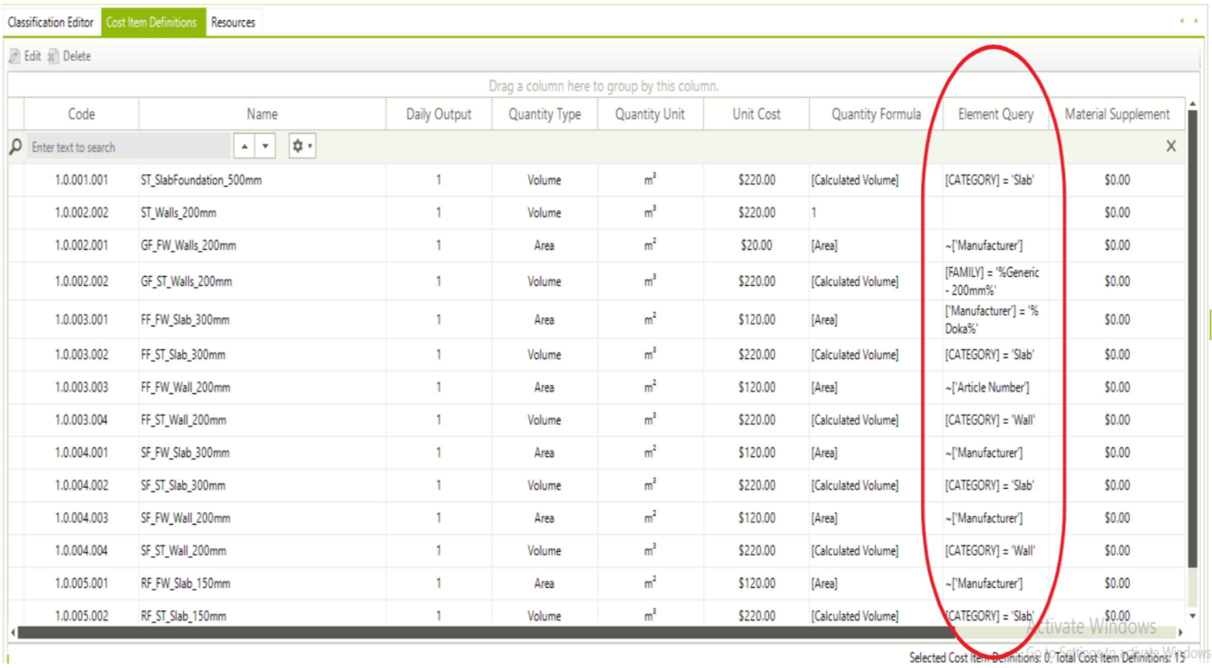


Figure 43: Cost Item showing Element query properties

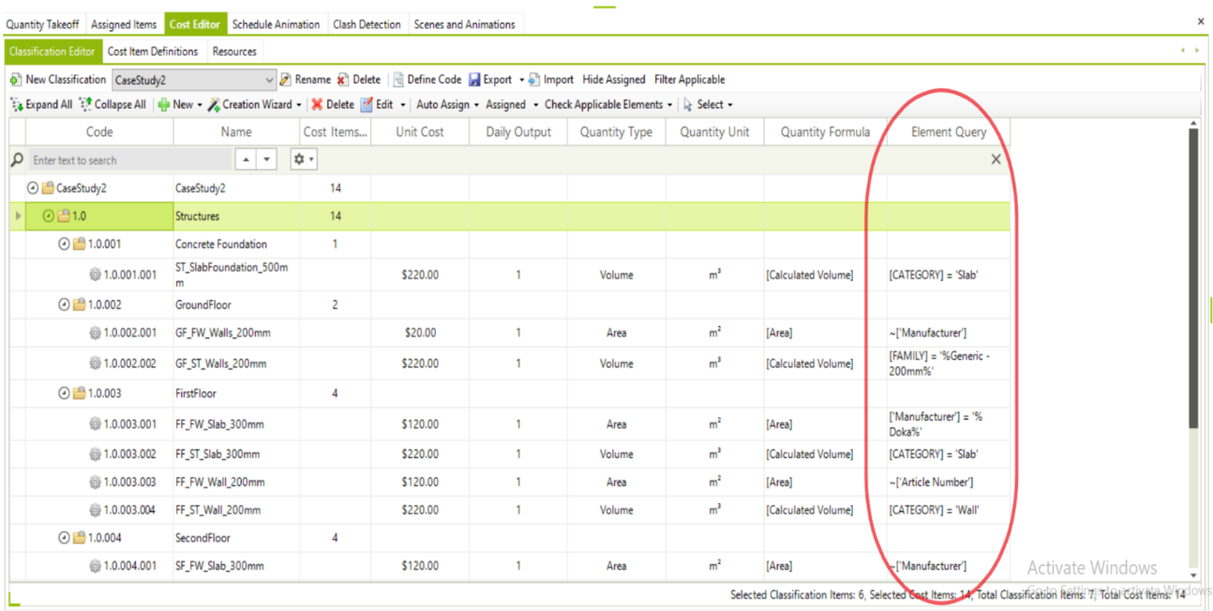


Figure 44: Cost Classification breakdown in Bexel Manager

4D & 5D simulation

Utilizing Intelligent construction Scheduling capabilities of Bexel Manager 20 I then simulate the time schedule of the project by creating zones and methodologies to automate the generation of the schedule.

For this case study, the following processes were undertaken

1) Defining the zones levels:

   As there is only one BIM model in the consideration, Zones are created based on the vertical division or Building stories of the project. The zone will be utilized for better coordination of construction work, and schedule creation. In this instance zones have been based on the previously defined selection sets.

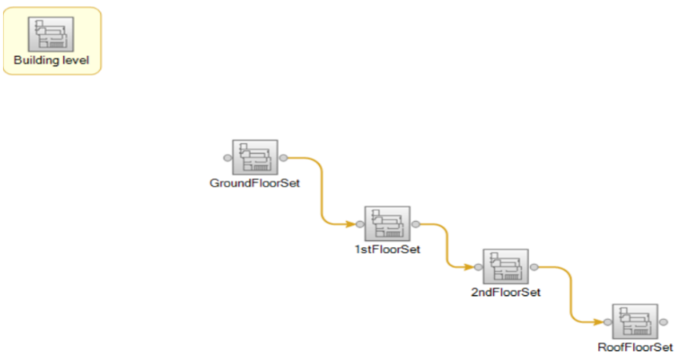


Figure 45: Zone (Building Level) Case study 2

2) Defining the construction methodologies for building categories and elements priorities. the methodology level was created based on the cost classification created in the previous step

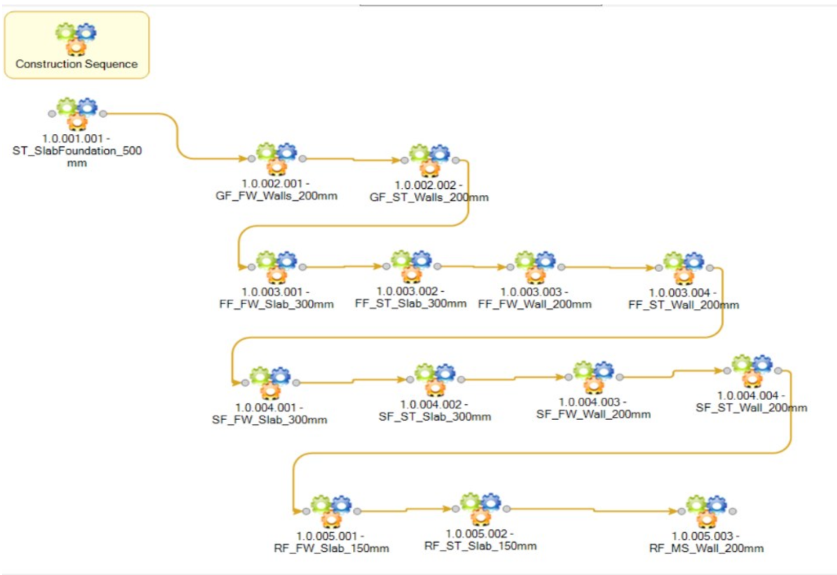


Figure 46: Methodology for construction sequence in Bexel Manager

3) Get the Gantt Chart & LOB View of the project schedule.

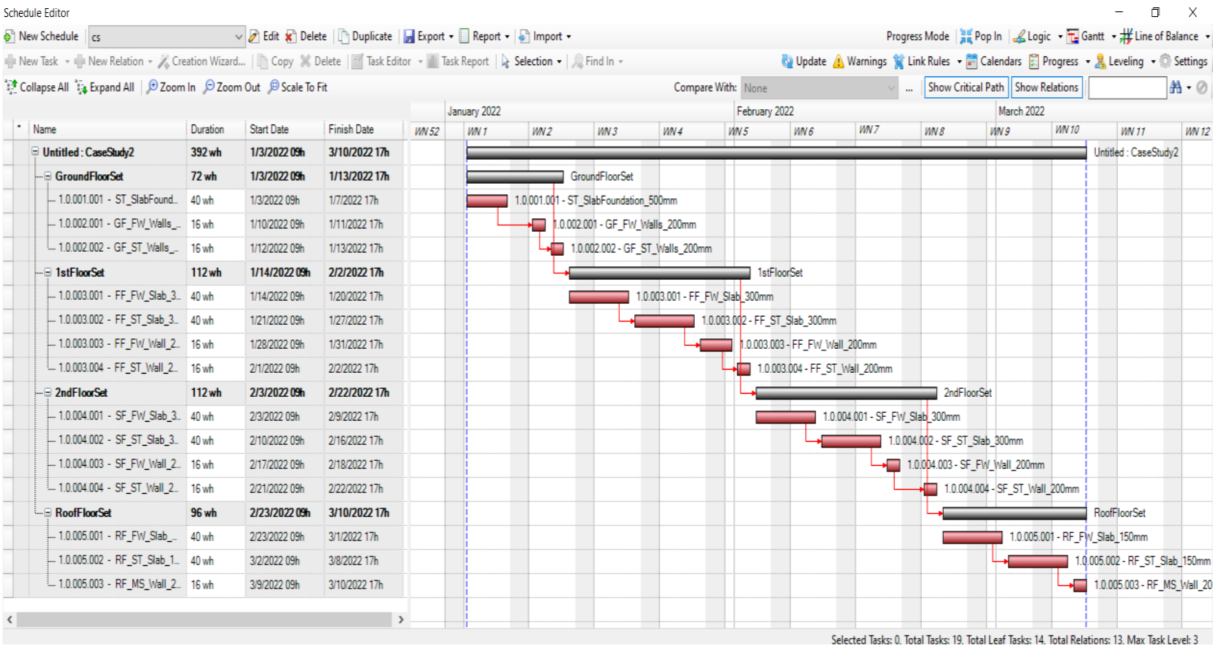


Figure 47: Gant Chart view of Construction schedule

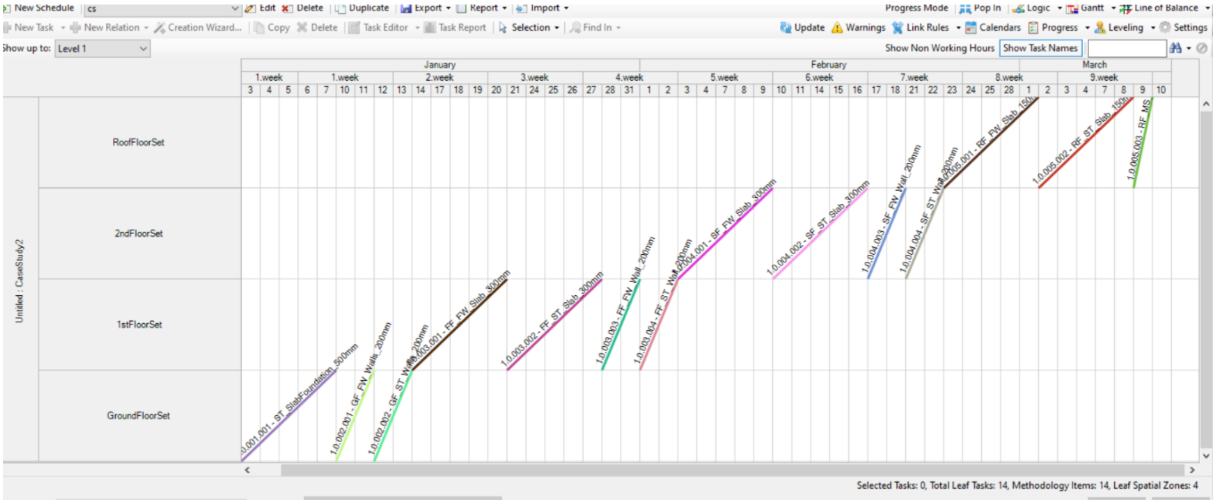


Figure 48: Line of Balance view

4) 4D simulation view.

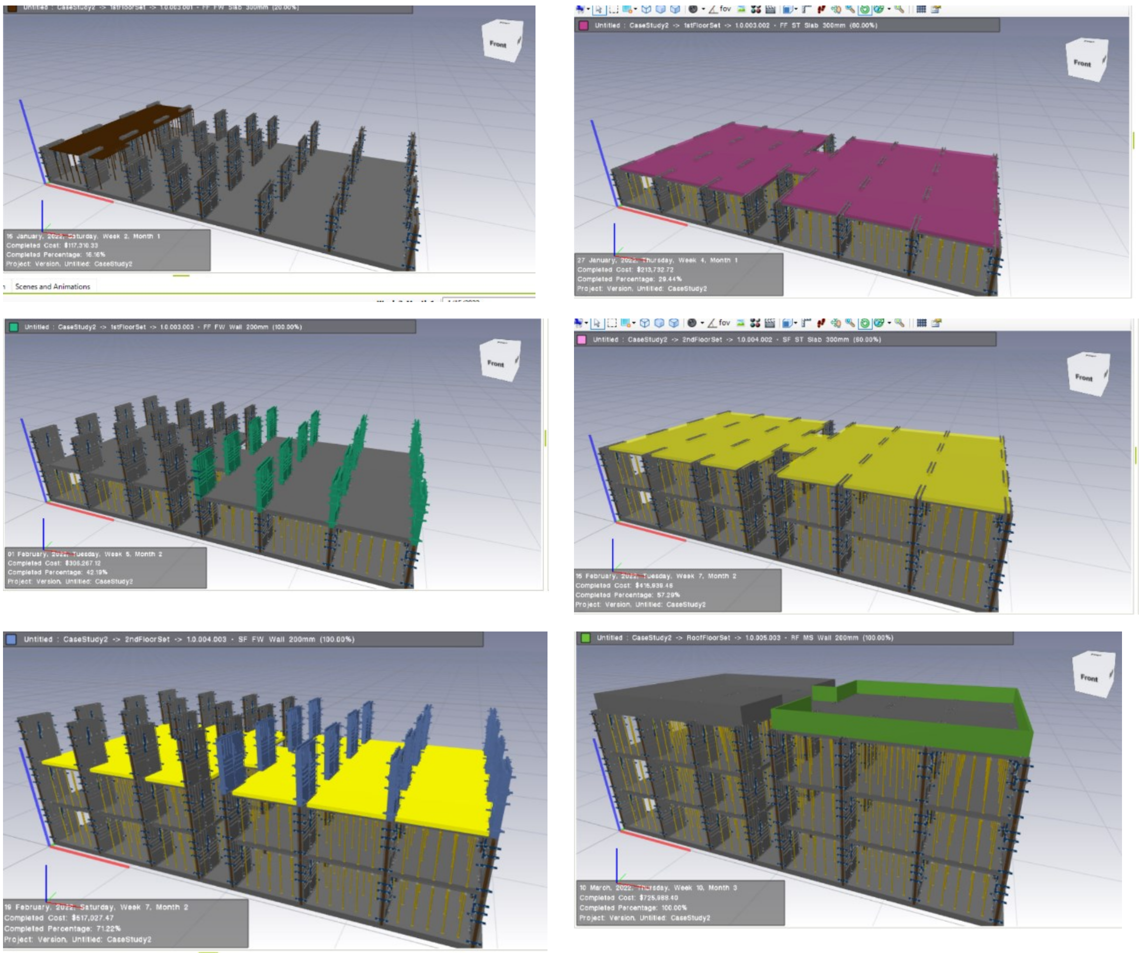


Figure 49: 4D simulation of BIM Model

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study shows that the formwork design and planning process can be mostly automated. Whilst the research has been limited to developing a workflow to incorporate BIM libraries compatible with Autodesk REVIT, it has been demonstrated from the overview of formwork libraries, advantages and constraints when using formwork libraries from multiple vendors. PERI and ULMA Revit libraries does contain a vast catalogues of formwork systems with advanced LOI and LOD but does not allow for automated formwork insertion, which limits the efficiency of the design workflow. However, this problem is remedied in the case of PERI, by utilizing PERICAD its proprietary BIM solution. Doka CAD software plugin with its automated forming capabilities allows for improved design workflow. A short coming would be, automatic formwork process is not applicable to a wider range of complex construction, for example, inclined slabs, staircases etc. such structural elements would require modelling the elements manually.

Additionally, the study has shown that formwork design workflow goes beyond geometric modeling of the formwork system and generating a quantity takeoff, as is with most vendor-based formwork BIM solutions. It is shown that the design workflow can be optimized by incorporating 4Dand 5D simulation into the design workflow. Which can be mostly automated utilizing advanced BIM management tools such as BEXEL Manager. 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.

Finally, Automated, and controlled workflow is necessary predisposition to any further optimization regarding time/cost tradeoff taking into account defining formwork phases based on available formwork system elements and time to buildup concrete construction. This acceptance of automated process in the design-planning workflow makes its possible for Project Managers/Designers control the outcome of the project, leading to greater efficiency, reduced cost, and shorter execution time, which benefits all stakeholders and industry as a whole

5.2 Recommendations for further research

In future research, I would recommend including the testing of the proposed workflow on different construction projects, integrating other BIM authoring software asides Autodesk Revit. I believe this will aid in evolving the workflow to cater for formwork design optimization in other various types of construction projects.

Furthermore, additional research can be done to ensure formwork libraries are able to incorporate automatic forming capabilities especially for complex structural geometry. Also, formwork libraries provided by Formwork manufactures should allow for planners/designers incorporate their own inventory data into to the formwork design, like Doka (provided they are compatible/same with the selected formwork system in the libraries). This gives a much realist approach when designing/planning for formwork use on a project. Also, further research needs to be done to include the re-usability factor in concrete formwork design and planning

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