TECHNISCHE UNIVERSITÄT DRESDEN

FAKULTÄT BAUINGENIEURWESEN

INSTITUT FÜR BAUINFORMATIK

Analysis of Constraints for 5D BIM Model Development in BIM tools

Analyse der Randbedingungen für die Entwicklung von 5D-Modellen mit BIM-Werkzeugen

Supervisors:

Prof. Dr.-Ing. habil. Karsten Menzel

Prof. Dr.-Ing. Raimar Scherer

Prathap Valluru, MSc.

Author:

Faisel Mohammed Muktar

Master Thesis

May 3, 2020

TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Bauingenieurwesen Institut für Bauinformatik

Task sheet for the Master Thesis
Aufgabenstellung für die Masterarbeit

Name / *Name* : Faisel Mohammed Muktar

Matriculation No.: 474 89 91
Immatrikulationsnummer .

Program / *Studiengang* : ACCESS

Title: **Analysis of constraints for 5D BIM model development in BIM tools**
Analyse der Randbedingungen für die Entwicklung von 5D- Modellen mit BIM-Werkzeugen

Goal:

Construction Project Management is a complex discipline in the Architecture, Engineering, and Construction (AEC) industry. The virtue of complexity in construction projects demands extensive research and efforts in formulating new organizational structures, techniques and methods towards the efficient management of construction activities. Moreover, there is a pressing need to devise new ways to integrate the construction management disciplines into Building Information Modelling (BIM) as BIM holds the key to a future of seamless interaction of various participants in a construction project. This thesis work aims to analyse and specify the constraints for the development of 5D-models (3D-geometry plus time plus cost dimension) using BIM-tools. Furthermore, it aims to study the quality of 5D BIM models which were generated using different BIM tools.

As a part of the thesis work, the student is expected to conduct detailed research on different national standards for project life cycle stages and to develop information requirements for 5D- BIM models according to the different building life cycle stages. Based on these requirements a 5D BIM model should be developed using different tools. The development process and the quality of the model developed are to be analysed.

Die besonderen Hinweise für die Anfertigung der Projektarbeit des Instituts sind zu beachten.

It is recommended to use the following tools for the comparison:

- Vico,
- Naviswork Manage,
- iTwo.

Scope of work:
The thesis work should address the following tasks.

1. Analysis of current leading national standards defining project life cycle stages. Identification of life cycle stages for which 5D-BIM models are required.

2. Analyse and determine the information requirements for 4D and 5D model development in different phases of the building life cycle. Map these details to the open-BIM-standard Industry Foundation Classes (IFC) and to available definitions of LoD (e.g. Level of Development defined by AIA).

3. Develop 3D, 4D, and 5D BIM models and analyse the import and export capabilities.

4. Investigate the constraints in BIM tools and compare the quality of 5D BIM models in different BIM tools.

Supervisor:	Prathap Valluru, M.Sc.
Responsible academic staff and first examiner:	Prof. Dr.-Ing. habil. Karsten Menzel
Signature:	
Second examiner:	Prof. Dr.-Ing. Raimar Scherer
Signature:	
Topic handed over to student:	04.11.2019
Expected Submission Date:	04.03.2020

Declaration of Originality

I confirm that this assignment is my own work and that I have not sought or used inadmissible help of third parties to produce this work. I have fully referenced and used inverted commas for all text directly quoted from a source. Any indirect quotations have been duly marked as such.

This work has not yet been submitted to another examination institution – neither in Germany nor outside Germany – neither in the same nor in a similar way and has not yet been published.

Dresden,

....

Faisel Mohammed Muktar

Abstract

One of the emerging approaches in the adoption of BIM in the AEC industry is the 5D-BIM method which integrates 3D model with project schedule and cost as it allows the prediction of project costs in the life-cycle of the project and optimization of project schedule. Despite its advantages, the introduction of 5D-BIM working method calls for a change in the way construction projects operate and demands shifts in company policies and national standards.

The study in this thesis comprises mainly of two major objectives. The first objective focuses on studying leading national standards in the construction industry that define construction project life-cycle phases. Also, at investigating the project phases requiring 5D BIM modeling and analyzing information required for 5D BIM model development. The second objective of the thesis is to develop 5D BIM models using different BIM tools that are popular in the AEC industry, and then to compare the qualities of the BIM models generated and to determine constraints in the 5D BIM model development process using the BIM tools.

For the first part the study, three national standards from three European countries were chosen: RIBA Plan of Work 2013 from UK, HOAI 2013 from Germany and SIA 112 from Switzerland. The project life-cycle phases defined by these standards were analyzed in relation to 5D BIM and level of BIM adoption in these standards and the suitability of these standards for BIM-based project.

In the second part of the study, procedures for BIM model development was developed based on the concept of BIM Level-2 where developing a BIM model is not confined to a single discipline (for example, architecture, structure or MEP) but rather collaboration exists in the modeling process between different disciplines, and clashes and other issues that may arise in the BIM models are resolved in early stages of the project life-cycle. A case study for 5D BIM modeling was developed for a 3-story office building project. By using Navisworks Manage and Vico Office, 5D BIM models were developed. The qualities of the BIM models from the BIM tools were analyzed and and constraints encountered in the 5D BIM model development process were determined.

The study showed that the three standards considered in the study have faced challenges to be implemented in a BIM-based construction project. It was found that the current version of RIBA Plan of Work was found to be more suitable for BIM-based project as compared to HOAI and SIA 112. It was also found that these national standards do not specify the stages for 5D BIM or any other BIM model development with the exception of HOAI regulation which was found to include in one of its project life-cycle phases the development of 3D or 4D model. However, based on the phase tasks in these standards, possible project stages at which 5D BIM model development will be required were identified.

From the case study of 5D BIM model development, some constraints were found in the 5D BIM model development process. These include absence of certain functionalities in BIM tools which make them rely on other applications; this in turn incurs cost and increases the chances of errors. The other constraint was interoperability issue between BIM tools; it was found that interoperability feature is not supported in both Navisworks Manage and Vico Office for exchanging 4D model and 5D model data

Keywords: *Building Information Modeling (BIM), 3D BIM, 4D BIM, 5D BIM, Project Life-Cycle, Project Life-cycle Phases, Project Scheduling, Cost Estimation, Level of Development (LOD), Navisworks Manage, Vico Office*

Acknowledgment

Since I started my thesis six months ago many people have lost their lives and many others were admitted to hospitals; COVID-19 has also directly or indirectly affected many people's lives. I really wish quick recovery to all patients and patience to all individuals who lost their loved ones. Due to this, first and foremost, I sincerely thank almighty God whose gratitude cannot be repaid for giving me the chance to stay alive to this day and bestowed upon me good health, which is the most precious asset that one can have, without which I would not be able to complete this important work.

Secondly, I would like to thank the staff members in the 'Institut für Bauinformatik' of TU Dresden including Prof. Dr.-Ing. habil. Karsten Menzel, Prof. Dr.-Ing. Raimar Scherer and Prathap Valluru. I would like to express my sincere gratitude to Prof. Dr.-Ing. habil. Karsten Menzel for accepting my request on the thesis topic and providing me the opportunity to do the thesis in the institute. I also present a heart-felt thanks to Prathap Valluru who directly supervised my work and provided me valuable information during the preparation of the thesis.

Furthermore, I would like to thank my parents and other family members for their unconditional support through their daily prayers. Even though it has been about 5 years since I met them physically, their prayers and supportive advice are always with me and they are the backbone for the person I am today. I also thank my beloved fiancee Fozia Seid for her continuous advice to be calm, to get rest, to eat food and not to stress myself at certain stressful moments during the thesis preparation. I can't wait until I meet them all face-to-face!

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Building Information Modeling (BIM) is a relatively new advancement and technology in the construction industry [Ilozor and Kelly, 2012]; it is however revolutionizing the architectural, engineering and construction (AEC) industry. It is believed that BIM has the potential to enhance project performance, data management, collaboration and communication between teams involved in the project [Lone et al., 2013]. Adoption of BIM working method in construction projects is referred to as the standard that brings various project teams together and work collaboratively while the teams are still able to work in different disciplines [Sediqi, 2018]. These and many more benefits of BIM led several professional institutions in different countries around the world to set standards, specifications and guidelines for the implementation of BIM in the AEC industry.

Construction projects have become complex due to the increasing involvement of several project stakeholders. It is believed that the adoption of 5D-BIM working method will not only help to reduce project cost and duration but also enhances greatly communication between project parties (client, owner, local authorities, designers, consultants, contractors, sub-contractors, etc.) The generation of 5D BIM model is illustrated in fig.1.1 below.

Figure 1.1: Integration of 3D model with project schedule and cost (5D BIM model) (Borrmann et al. [2015])

3D BIM model is an information-rich model used for visualization and coordination of construction planning, design, execution and production phases. Linking the 3D BIM model to a construction schedule with relevant dependencies on available resources (manpower, material and machinery) will generate a 4D BIM model. If the 4D BIM model is integrated with a model-based quantity calculation along with price calculation, the resulting model is a 5D BIM model.

1.1 Problem Statement

The introduction of 4D and 5D BIM in the AEC industry led to the production of many BIM applications by different companies to enable designers and contractors develop 4D and 5D BIM models in construction projects. However, the complexity of modern construction projects resulted the involvement of various stakeholders from diverse disciplines who use different BIM applications. This interdisciplinary interactions in construction projects resulted in certain challenges and constraints in information sharing and communications.

Another challenging factor is the adoption of 4D and 5D BIM working methods in leading national standards that are used in AEC industry. In different parts of the world, various national standards have been in use for construction project life-cycle management prior to the introduction of BIM working methods. The increasing demand for BIM working methods has led to amendments in traditional national standards. There is a need to study and analyze these traditional standards in relation to BIM.

1.2 Aims and Objectives of the Thesis

One of the purpose of this thesis is to conduct a comprehensive study on some leading national standards, that are currently implemented in the AEC industry of some countries, in relation to project life-cycle management and BIM working methods.

The second purpose of this study is to develop 5D BIM model by using some commonly used BIM tools from different companies. Works will be carried out in the different BIM tools and will be exchanged. This will allow to assess the challenges and constraints in 5D BIM modeling process using these BIM applications. The qualities of BIM models developed in the BIM tools will also be compared and analyzed.

The aims and objectives of the thesis are summarized as follow:

- To analyze current leading national standards defining project life-cycle stages and the identification of life-cycle stages for which 5D-BIM models are required.
- To investigate the level of BIM adoption in these standards and analyze their compatibility with BIM-working method.
- To analyze and determine the information requirements for 4D and 5D model development in different phases of the building life cycle. And to map these details to the open BIM-standard

Industry Foundation Classes (IFC) and to available definitions of Level of Development (LOD).

- To develop 3D, 4D and 5D BIM models using different BIM applications and analyze their import and export capabilities.
- To investigate the constraints in BIM tools and compare the quality of 5D BIM models developed in different BIM tools.

1.3 Organization of the Thesis

The thesis is divided into eight chapters which described briefly as follow:

Chapter 1: describes about general background, problem statement and the aims and objectives of the study.

Chapter 2: deals with the literature review about Building Information Modeling including , levels of BIM, BIM dimensions, and Level of Development in BIM and information management in project life-cycle construction projects in BIM working methods.

Chapter 3: provides the methodology adopted in the study.

Chapter 4: covers the conducted study on leading national standards in some European countries

Chapter 5: deals with the determination of project schedule and cost information that are needed for the development of 4D and 5D BIM models

Chapter 6: presents a practical case study of 5D BIM model development for a project using various BIM applications

Chapter 7: discusses the findings of the study in the form of analysis and comparisons of the results.

Chapter 8: Summarizes the overall study conducted in the thesis in the form of conclusions and providing suggestions for future studies.

Chapter 2

Review of Literature

This chapter provides background information for the study conducted in this thesis. First, Building Information Modeling (BIM) will be defined and various aspects of BIM such as BIM maturity levels and dimensions of BIM and common barriers to its adoption in the AEC industry will be discussed. Thereafter, construction project life-cycle management with BIM working methodology will be addressed.

2.1 Building Information Modeling (BIM)

Even though Building information modeling (BIM) is relatively new to the AEC industry, its acceptance rate worldwide is very rapid and it is expected that BIM will soon become the main standard to be employed in the AEC industry for information exchange and collaboration [Jayasena and Weddikkara, 2013]. BIM, however, is a complex concept that many people finds it hard to define. Some people view BIM as software tools; some believe that BIM is a 3D virtual modeling, while some others define it as a process. According to Deutsch [2011] BIM is a process for producing and managing data of a building through its entire life-cycle, starting from its planing stage up to its operations stage. Whereas a report published by Deutsche Bahn AG defined BIM as "BIM is a model-based, collaborative working method for the digital design, realization and management of assets over their entire life cycle" [DeutscheBahn, 2019]. Moreover, BIM Wiki[(1)] defines BIM as a term that describes the process of creating and managing digital information about a built asset (building, highway, bridge, dam, tunnel, etc.)

Even though BIM working method makes use of digital 3D models that area produced with the help of certain BIM tools, BIM is not just a 3D modeling tool as some people perceive it, nor is it merely of a 3D CAD model. BIM is a collaborative effort by those involved in the project (i.e. project stakeholders) in order to create and manage digital 3D model of a building and other associated data. Fig.2.1 below illustrates the collaboration and information exchange process in BIM.

(1) BIM Wiki, Part of Designing Buildings Wiki. https://www.designingbuildings.co.uk/wiki/Building_information_modelling_BIM

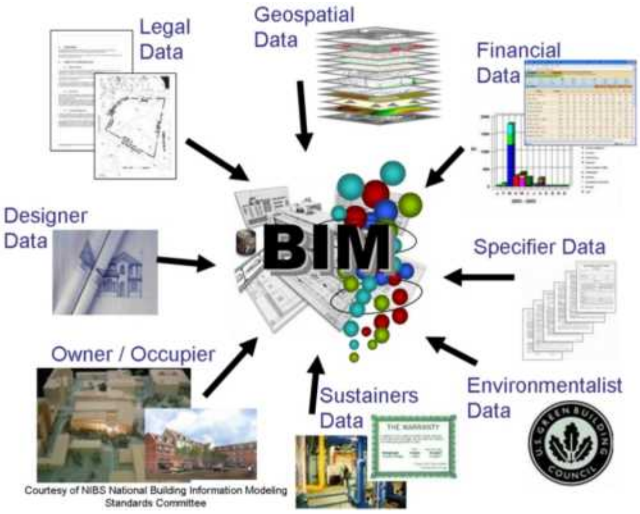


Figure 2.1: Communication, collaboration and Visualization with BIM model (Source: Arayici et al. [2012])

2.1.1 BIM Maturity Levels

Building information modeling (BIM) is a technique in the AEC industry that has been developing in various stages. The BIM method did not achieve its level of current maturity at one time, rather it experienced different levels. The range of levels that BIM can take is termed as "BIM maturity levels" [BIMwiki, 2019]. According to Succar [2010] BIM maturity represents the quality, repeatability and degrees of excellence in delivering a BIM model.

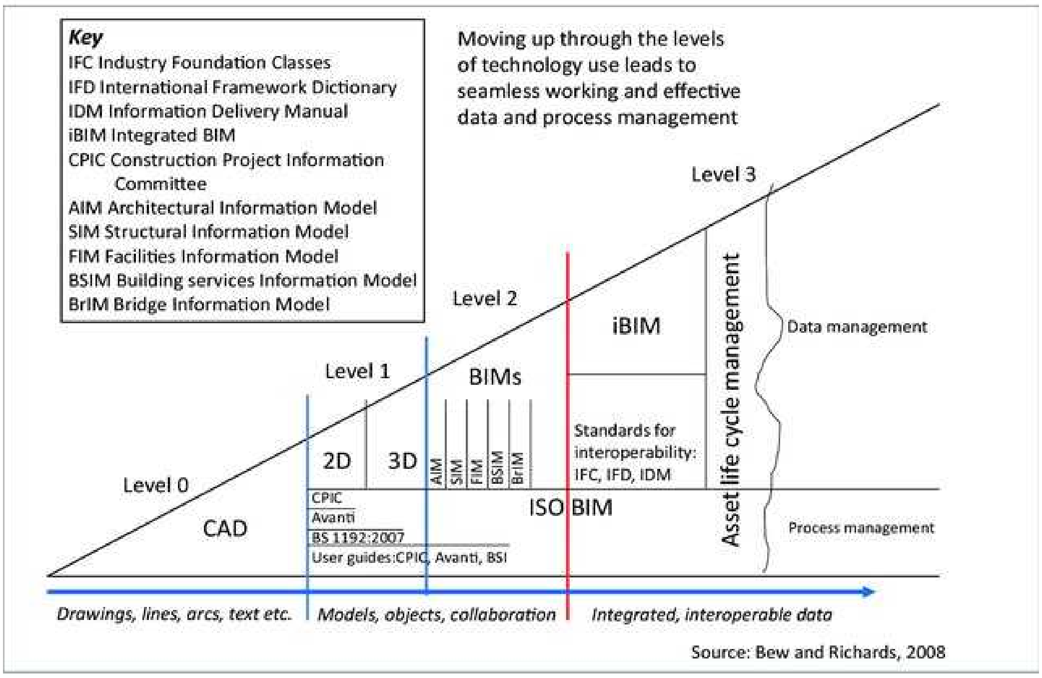


Figure 2.2: BIM maturity model (Adapted from: Bew and Richards [2008])

Several authors have discussed BIM maturity and developed BIM maturity models, including Bew and Richards [2008] and Succar [2009]. BIM maturity models support organizations in the AEC industry during the implementation of changes and improvement strategies [Amaratunga and Baldry, 2002].

BIM maturity model developed by Bew and Richards [2008] is the widely used model in the AEC industry in the UK, and standards and practices were developed and are still being developed to enable the adoption of the maturity levels [BRE, n.d.]. Fig.2.2 above illustrates this model.

The BIM maturity levels are briefly described as follow.

BIM Level 0

Some literature call this level as "Pre-BIM Status". It refers to the traditional practice where 2D CAD files were used during planning, design and construction stages. Depending on the size of the project, hundreds to thousands of drawings are shared among project parties in the life cycle of the project which can lead to lose of important documents, miscommunications, inability to track document versions and failure to understand project objectives. In this level data is exchanged through sending and receiving; there is no a common data environment for exchanging data between project parties [Borrmann et al., 2015].

BIM Level 1

This stage of BIM indicates the shift from the conventional 2D CAD to an object-based 3D modeling and documentation [Arayici, 2015]. In addition to 3D information, BIM level 1 also utilizes 2D information on construction projects [Sinclair, 2012].

At this level of BIM, the BIM model is not developed in a collaborative manner, but rather single-disciplinary BIM models are developed by different design teams. Design teams such as architectural, structural and MEP develop their own object-based 3D models using BIM tools such as Revit, Tekla, AECOSim, etc. Since the BIM model is not used collaboratively between design teams, during construction clashes and discrepancies among designs can occur which will lead to design revisions which in turn causes project delays and increased cost.

Such form of BIM where collaboration does not exist between parties and that only a single party uses the BIM is termed as '**Lonely BIM**' [Sinclair, 2012].

BIM Level 2

BIM level 2 marks the progress from individual modeling to collaboration and interoperability [Arayici, 2015]. Design teams from different disciplines (architecture, structures, MEP, etc.) still produce their individual 3D BIM models, and then this sub-models are compiled and integrated in a single place called Common Data Environment (CDE) and their consistencies and clashes are checked. BIM Level 2 does not require the individual models to exist in a single place [Sinclair, 2012]. This form of BIM where various parties collaborate and the BIM model is shared is known as '**Collaborative BIM**' [Sinclair, 2012].

Data exchange is carried out using native files which are compiled and managed in CDE which shows the status of the sub-models (Federated Models)and the level of access for other involved parties. From the integrated BIM model, 2D plans and specifications are generated and saved in PDF file formats [Borrmann et al., 2015]. Also, Borrmann et al. [2015] states that BIM level 2 does not necessitate the use of open standards (such as IFC); however, proprietary formats (for example .rvt for Revit) are sufficient for data exchange. Fig.2.3 below depicts the work flow and data exchange process in BIM Level 2.

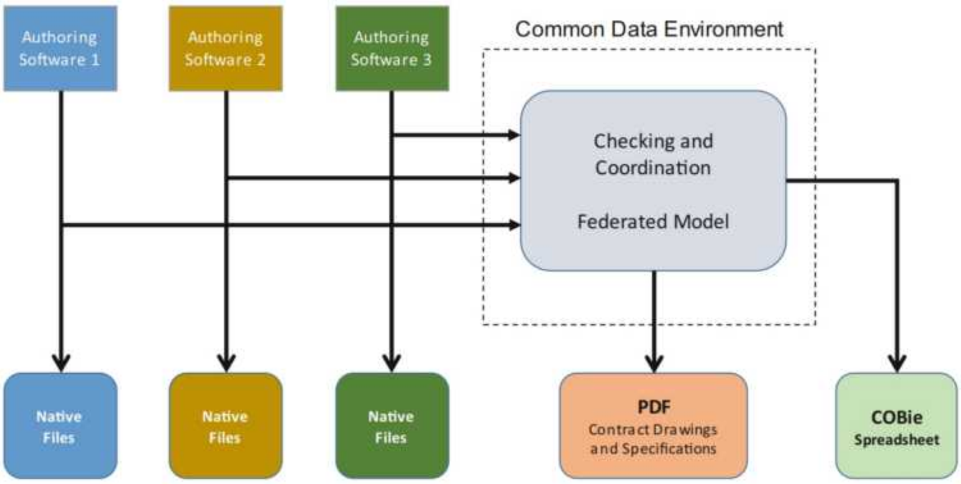


Figure 2.3: Work flow and data exchange in BIM Level 2 (Source: Borrmann et al. [2015])

BIM Level 2 is the minimum level of BIM which the UK government mandated its adoption for all centrally-procured projects by April 2016. The UK Government Construction Strategy published in May 2011, stated that the '...government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016'. This means for all government projects adoption of BIM Level 2 is mandatory from 2016.

BIM Level 3

The collaborated BIM which Level 2 was based on transitions to a fully integrated BIM in Level 3 where all parties work on a single BIM model for the project. As Arayici [2015] mentions, at this level of BIM, the distinct project life cycle phases will no longer exist as interaction and coordination between project stakeholders occur in real time. Cloud-based services can be used in order to ensure the continuous and consistent maintenance of data through the project life cycle. This form of BIM where full integration exists is terms as This form of BIM where various parties collaborate and the BIM model is shared is known as '**Integrated BIM (iBIM)**' [Sinclair, 2012].

Fig.2.4 below illustrates the information exchange process in the traditional construction methods and in a fully integrated BIM (iBIM). As indicated, in BIM Level 3, there is a central area (Common Data Environment) where all parties access information from and add information into.

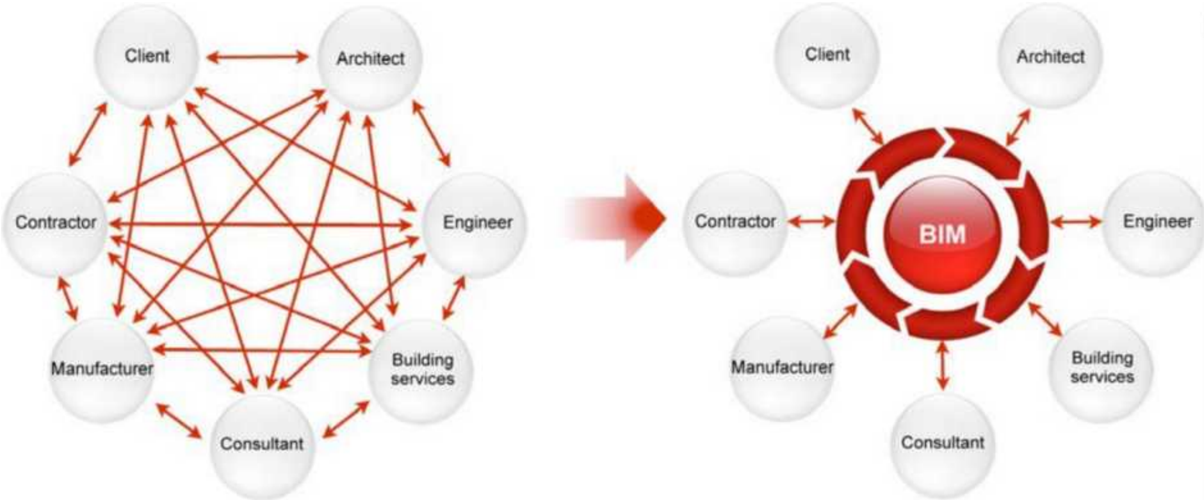


Figure 2.4: Information exchange in traditional working methods (left) and in integrated BIM (iBIM) (right) (Source: AllenConsultingGroup [2010] (cited by Sen [2012])

According to Borrmann et al. [2015], BIM Level 3 is based on the implementation of BIG Open BIM where ISO standards, such as IFC, IFD, IDM, are employed for data exchange and process descriptions.

2.1.2 Dimensions of BIM

Dimensions in building information modeling are used to describe the type of information required in the development of BIM model. The term was initially used to differentiate the information from traditional 2D CAD and the information from 3D BIM models, but its meaning in the AEC industry developed to refer to the information required for the proper management of construction projects during the design, construction and operation phases [BIMWiki, 2019].

Therefore, BIM is not only 3D modeling; other information can be incorporated into the 3D model and the BIM can be extended into other dimensions, such as 4D, 5D, 6D, 7D, etc. [Smith, 2014]. nD models can be incorporated into BIM to simulate the planning, design, construction and operation of a project [Ding et al., 2014]. Eastman et al. [2011] refers to this multidimensional characteristics of BIM as 'nD' modeling. This is due to the fact that as many dimensions as possible can be added to the BIM model [Smith, 2014]. Fig.2.5 below depicts BIM dimensions currently addressed in the AEC industry.

Figure 2.5: Dimensions of BIM method (Source: BibLus [n.d.])

The common dimensions of BIM circulating currently in literature and AEC industry are briefely described below.

3D BIM

3D BIM should not be confused with the traditional 3D CAD modeling. A 3D CAD model contains only a graphical (geometrical) entities such as lines, arch, circle, rectangle. Also, different views of the model (elevation, plan, side, section and 3D views) are not integrated; if a change is made to a view, all other views have to also be updated independently. Conversely, 3D BIM incorporates both graphical entities and semantically rich information related to the geometrical model. For example, a window in a 3D BIM model will contain geometrical information of the various components that make up the window, material type and properties, functional information, maintenance requirements, etc.

4D BIM

When construction project schedule is integrated to 3D BIM described above, the resulting model is called 4D BIM. Such a model utilizes BIM for project time allocation and construction sequence scheduling simulations" [Ding et al., 2014].

4D BIM is a powerful way of communicating and visualizing to understand construction plans and project milestones to identify issues and avoid conflicts before actual construction [Bloomberg et al., 2012]. According to Smith [2012] 4D BIM is useful for subcontractor management during construction stage; it allows contractors to identify when and where subcontractors are likely to work and allow them to modify and update the sequencing to avoid overlapping operations, thereby minimizing delays and risks to health and safety.

5D BIM

5D BIM incorporates an additional dimension of construction project cost information into the 4D BIM presented above. Therefore, 5D BIM stands for 3D BIM model + time (4D BIM) + Cost (5D BIM). 5D BIM enables project team to track the status of the project with respect to time and cost at any point in the life cycle of the project provided that the BIM model is updated. So, if a client requests for schedule and cost status of the project, it can simply be extracted from the 5D BIM model.

The development of 4D and 5D BIM has been a major advantage for the AEC industry. This is because speeding up project progress and reducing cost are the two most important aspects for project stakeholders in the AEC industry [Ding et al., 2014]. Since the development of 5D BIM involves parties from various disciplines working collaboratively, checking for clashes, applying visualization techniques, etc., even before the start of construction, this enhances project progress and saves cost compared to the traditional methods. Moreover, as Smith [2014] mentions 5D BIM is becoming popular in leading project cost management companies as it provides competitive advantages.

6D BIM

Once construction process is completed, the 5D BIM model along with other information relevant for operations and maintenance of the facility is prepared as an as-build model that can be used during operations phase of the project life cycle. 6D BIM represents this as-built BIM model that is rich in information and which can be used for facilities management [Smith, 2014]. During operations phase, occupants can use the data in 6D BIM to operate the facility.

7D BIM

7D BIM incorporates sustainability aspects into components of the model thereby enabling designers to meet carbon emission requirements [Smith, 2014].

8D BIM

8D BIM adds safety features and information in both design and construction stage of the construction project [Smith, 2014].

2.1.3 Barriers to BIM Adoption and Implementation in the AEC Industry

Advantages of BIM has been mentioned in earlier sections and also described in a more detailed manner in the coming sections. Despite these benefits that BIM offers, a number of barriers impede and slow down its adoption and implementation in the AEC industry. And these barriers are more pronounced in developing countries [Gerges et al., 2016]. According to [Deutsch, 2011] barriers to BIM application can be categorized into two: process barriers, which include legal and organizational factors; and technology barriers linked to the readiness of standards and obstacles encountered during implementation. On the other hand, Gerges et al. [2016] consider these barriers as technical and human related, which can be either internal or external obstacle to an organization. Furthermore, as depicted in fig.2.6 below, Liu et al. [2015] classified the main barriers of BIM into five:

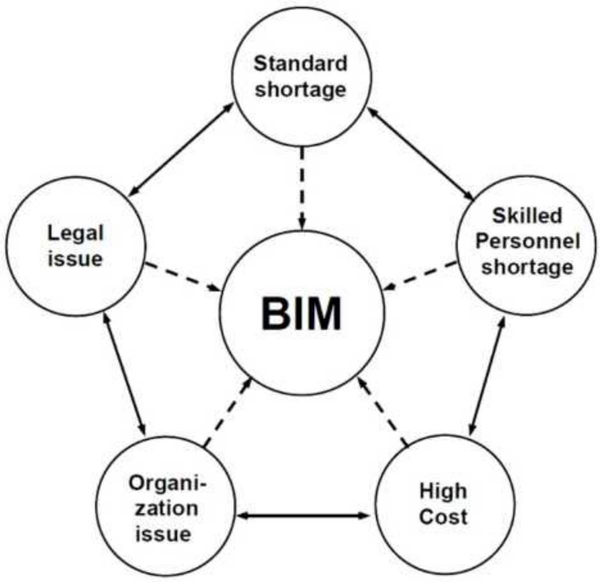


Figure 2.6: Main barriers of BIM and their relationships (Liu et al. [2015])

The following are the most common barriers to BIM adoption and implementation in the AEC industry raised in literature:

- **Client demand:** even though the use of BIM tools among design firms has increased, most clients still follow traditional methods and have not made BIM working method as a requirement. Many clients believe that altering the contract conditions to require new deliverables such as BIM will raise the tender price they receive [Eastman et al., 2011].

- **Lack of training:** Kiani et al. [2015] believes that cost and human related barriers, mainly learning and getting familiarized to new technology and working methods are the main hurdles to BIM implementation.

- **Cost factors:** in order an organization to adopt the BIM working method it will require to purchase a number of BIM tools and maintain the licenses on a regular basis. Also, its personnel will require training. These and other related procedures incur cost to the organization. Unless they foresee and identify advantage of BIM adoption to the organization in long term, many service providers do not want to make investments on BIM.

- **Interoperability:** it is one of the common barriers to BIM application in the AEC industry and it is the reason why software tools are developed to meet the requirement of multiple discipline [Thompson and Miner, 2006].

- Return on investment (ROI) issues;

- Organizational resistance to change;

- Conventional project delivery methods;

- Lack of standards and guidelines;

- Difficulty in measuring the benefits;

With regards to interoperability, which some authors cited as one the common and important obstacle to BIM adoption, Deutsch [2011], states that it is not the only barrier hindering BIM adoption and believes that it is not the most important one either. The author points out the following three inter-linked obstacles to BIM implementation in the industry:

1. "the need for well-defined transactional business process models;

2. the requirement that digital design data be computable; and, finally,

3. the need for well-developed practical strategies for the purposeful exchange of meaningful information between the many tools applied to industry processes today."

2.2 Construction Project Life-cycle Management

Construction projects, whether it be small or big, undergo various stages or phases starting from their inception up until their demolition. The combination of these phases make up the life-cycle of the construction project and they are called project life-cycle phases (PLPs). There are three main phases of a construction project-cycle, namely: design phase [D], construction phase [C] and operation phase [O] [Succar, 2009]. In this context, the operation phase also includes the maintenance. Under each of the three phases there are sub-phases which in turn comprise of several activities, sub-activities and tasks [Succar, 2009]. The construction project life-cycle phases and its subdivisions are depicted in Table 2.1 and Fig.2.7 below.

Table 2.1: Project life-cycle phases and sub-phases (Adapted from: Succar [2009])

Design Phase	Construction Phase	Operations Phase
D1: conceptualization, programming and cost planning	**C1**: construction planning and construction detailing	**O1**: occupancy and operations
D2: architectural, structural and systems design	**C2**: construction, manufacturing and procurement	**O2**: asset management and facility maintenance
D3: analysis, detailing, coordination and specification	**C3**: commissioning, as-built and handover	**O3**: decommissioning and major re-programming

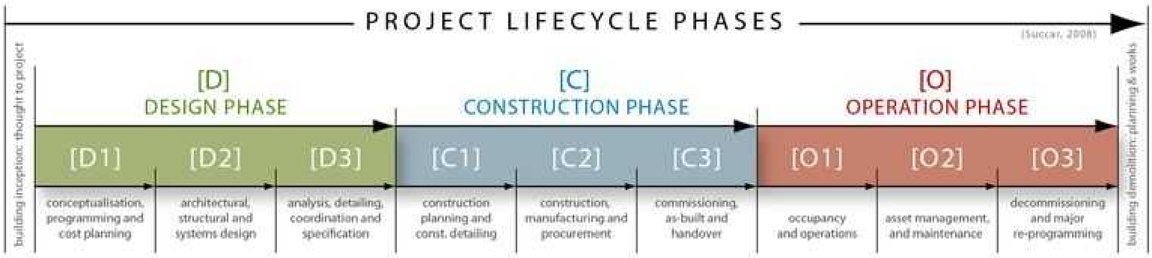


Figure 2.7: Project Life-cycle phases, sub-phases and further subdivisions (Adapted from: Succar [2009])

Project life-cycle management of a construction project enables the project team save money and time, decrease project risks and enhance the quality of the final product, and this technique has been in practice in the AEC industry for long time [Guo et al., 2009]. The management of project life-cycle is needed due to the fact that construction projects involve many project parties that want to share project information to one another Hoeber and Alsem [2016].

2.2.1 Integrated Project Life-cycle Management with BIM methodology

It is quite important that information related to the project should be shared, collected and saved throughout the life-cycle of the project. As construction projects are complex, they involve teams in various disciplines (architectural engineer, structural engineer, MEP engineer, construction manager, project manager, etc.). These actors in the project share project-related information to one another [Hoeber and Alsem, 2016]. Xu et al. [2014] state that information related to the construction project (for example a building) should be collected throughout its life-cycle and should be saved for use after the project completion. The authors also add that the project-related information captured during the project improves communication among the project team. The effective management of these project-related information from all project parties is a key for the success of the project.

Even though project information management in the whole life-cycle of a project is crucial, it is still poor and inefficient [Hoeber and Alsem, 2016]. At different stages of the project (conception, design, construction, etc.), information is misplaced, lost, mistakenly deleted, misunderstood, changed to different formats and saved other locations [Hoeber and Alsem, 2016]. The system in practice in today' AEC industry is designed in such a way that information at the different project phases is managed separately; the system is not applicable for complete life-cycle information management [Xu et al., 2014].

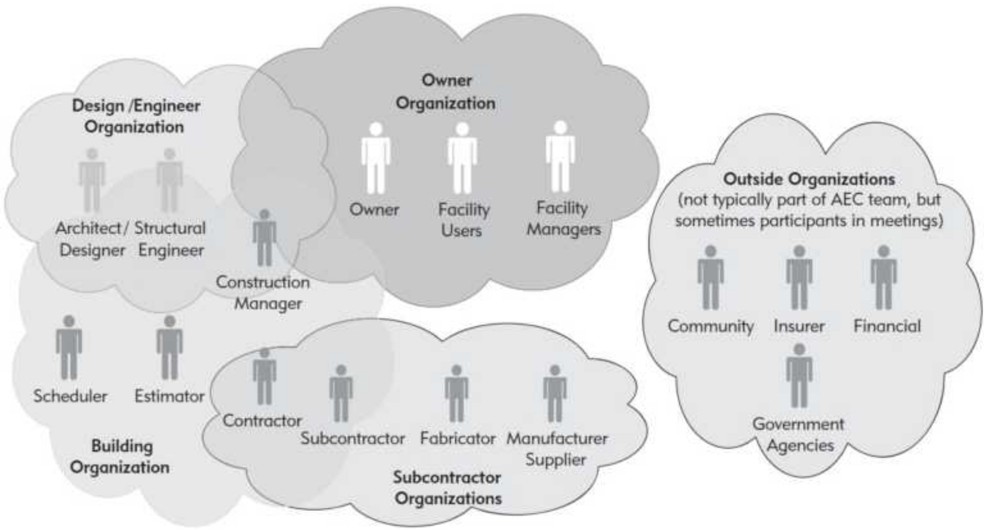


Figure 2.8: Diagram illustrating the fragmented nature of project team in AEC industry (Adapted from: Eastman et al. [2011])

This mismanagement can be attributed to the ineffective information management platform in the traditional project life-cycle methods which resulted project-related information to be stored in formats, locations and products that differ from one another [Xu et al., 2014]. This shows that the ineffectiveness of the traditional way of project life-cycle management where project-information is scattered in different phases. Fig.2.8 above depicts a concept diagram for existing organizational boundaries in construction project team in the traditional ways.

BIM has been used in the AEC industry to enhance project-life cycle management. However, the problem is every party develops a separate BIM model (architectural BIM, structural BIM, MEP BIM) in different phases of the project and the integration of these scattered BIM models has been a major challenge in the AEC industry [Xu et al., 2014]. According to Xu et al. [2014], if the project team cooperatively employ 3D BIM model that is rich with information in the whole project life-cycle, the flow of project integration in the whole project-life cycle will be enhanced greatly and an improved project delivery will be achieved. The enhancement of information management in the project life-cycle is achieved by the object-oriented technique used in BIM model development [Zhang and Hu, 2011]. Usage of proper BIM in the project enables the project team to view how the project will look in the near future. This is a useful tool for planning ahead and decision making. "if one captures information from the ordering and invoicing process, one has a very accurate model, not only for use during construction but also for its entire life- cycle." [Xu et al., 2014]. Fig.2.9 below illustrates how usage of BIM enables the project team to coordinate and work collectively in the entire project life-cycle, starting from initial design by the architect up to the facilities management in the operations and maintenance phase, using a BIM model.

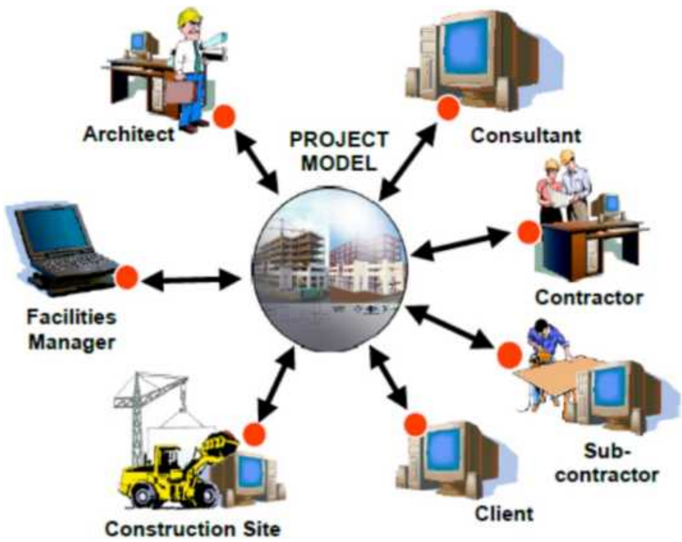


Figure 2.9: Collaboration and coordination in project life-cycle with the help of BIM modelling (Adapted from: Arayici [2015])

Project Information in the Life-Cycle of a Construction Project

The project life-cycle, starting from conception to demolition, contains many information that are related to the project. In the traditional methods, the management of these project-related information were scattered in various documents, computer applications and locations. BIM enables us the proper digital storage and management of all information related to the project [Becerik-Gerber et al., 2011]. Through BIM we can create a digital 3D model of the project loaded with all its related information, both graphical and non-graphical information "which include items such as the materials (for building components), weight, price, procedures, scale and size" [Kovács et al., 2006].

In order to achieve project life-cycle information management, the information management in the different project phases should be integrated. Building information modeling (BIM) is designated us an ideal tool for this integration. BIM allows for multi- disciplinary information to be superimposed within one model. The BIM model developed in the design phase with information relevant to the design phase (i.e. pre-construction) is transferred to the construction phase in order to develop the BIM model with information in the construction phase. The resulting BIM model is a bigger BIM with abundant information; this model is then further developed in the operation phase with relevant information at that stage. The final BIM model is not just a model for a single project phase; rather it contains accumulated information from all phases of the project (design, construction and operation). Fig.2.10 below illustrates the information flow phenomenon throughout the project life-cycle.

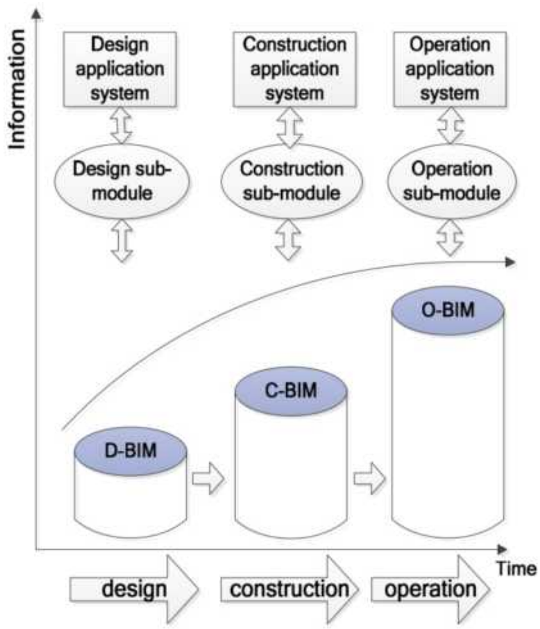


Figure 2.10: Accumulaiton of information in life-cycle of a project (Xu et al. [2014])

2.2.2 Level of Development/Detail (LOD) in BIM

In construction projects, a BIM model is developed in various distinct phases starting from preliminary design to final as-built BIM model. Level of Development/Detail (LOD) enables practitioners in the AEC industry to specify the reliability and clarity of the BIM model at the various stages of the project life-cycle.

In some literature the acronym LOD is used to refer Level of Development and others adopt it to mean Level of Detail. According to Ellis [2019], LOD is used in USA to refer 'Level of Development' whereas in UK the same acronym is understood as 'Level of Detail'. Level of Development definition for each model component was introduced and published by American Institute of Architects (AIA) in 2008 in the document 'AIA E202-2008: Building Information Modelling Protocol Exhibit' [Arayici, 2015]. Whereas definition of Level of Detail for BIM model components was released by AEC (UK) in 2009 within its 'Model Development Methodology'.

Even though some people can assume Level of Detail and Level of Development to mean the same thing, it is however not the case. As BIMForum [2019] explains Level of Detail in BIM model indicates the extent of detail added to the model, whereas Level of Development represents the degree of consideration made to the model's geometry and the information attached to it thereby showing the degree of reliability of the model for further usage by the project team. Thus, Level of Development represents both graphical and non-graphical detail, whereas Level of Detail depicts only the graphical/geometrical part of the BIM model. It is for this reason, in 2013 in UK, the term 'Level of Definition' was introduced in PAS 1192-2 Specification as a new classification system consisting of seven levels (1 to 7) to include both Level of Model Detail (LOD) and Level of Model Information (LOI) [Ellis, 2019].

AIA defines five Level of Development (LOD) classes, namely: LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500. Their brief description is a follow:

Table 2.2 below provides the five LOD definitions as per AIA which indicate the extent to which a BIM model is developed. The table also shows how the BIM model at certain LOD is used to prepare Cost Estimate and Project Schedule.

Table 2.2: Levels of Development (LOD) as per the American Institute of Architects (AIA),2008 (Source: Gaudin [2013]))

LOD	Model Content Requirement	Authorised Uses	
LOD 100	Overall building massing indicative of area, height, volume, location and orientation is modeled in 3D dimensions	Analysis	The model is analyzed based on volume, area and orientation by application of generalized performance criteria assigned to the representative BIM model
		Cost Estimating	The model is used to develop a cost estimate based on current area, volume or similar estimating techniques
		Schedule	The model is used for project phasing and construction
LOD 200	Model elements are modelled as generalised systems or assemblies with approximate quantities, size, shape, location and orientation. Non-geometric information can also be attached to the BIM model	Analysis	The model is analysed for performance of selected systems by application of generalised performance criteria assigned to the representative BIM model
		Cost Estimating	The model is used to develop a cost estimate based on approximate data provided and conceptual estimating techniques
		Schedule	The model is used to show ordered, time scaled appearance of major elements and systems
LOD 300	Model elements are modelled as specific assemblies accurate in terms of quantity, size, shape, location and orientation. Non geometric information is also attached to the BIM model	Analysis	The model is analysed for the performance of selected systems by application of specific performance criteria assigned to the representative BIM model
		Cost Estimating	The model is used to develop a cost estimate based on specific data provided and conceptual estimating techniques
		Schedule	The model is used to show an ordered, time scaled appearance of detailed elements and systems
		Construction	Suitable for the generation of traditional construction documents and shop drawings

continued . . .

. . . continued

LOD	Model Content Requirement	Authorised Uses	
LOD 400	BIM model components are modelled as specific assemblies accurate in terms of quantity, size, shape, location and orientation with complete fabrication, assembly and detailing information. Non-geometric information is also attached to the BIM model.	Analysis	The model is analysed for performance of approved systems based on specific BIM model
		Cost Estimating	Costs are based on the actual cost of specific elements at buyout
		Schedule	The model is used to show an ordered, time scaled appearance of detailed specific elements and systems including construction means and methods
		Construction	BIM model is the virtual representation of the proposed element and are suitable for construction.
LOD 500	BIM Model is modelled as constructed assemblies, actual and accurate in terms of size, shape, location, quantity and orientation. Non-geometric information may also be attached to the modelled elements	General Usage	The model is utilised for maintaining, altering and adding to a project but only to the extent that is consistent with any licences granted in the agreement or in a separate licensing agreement

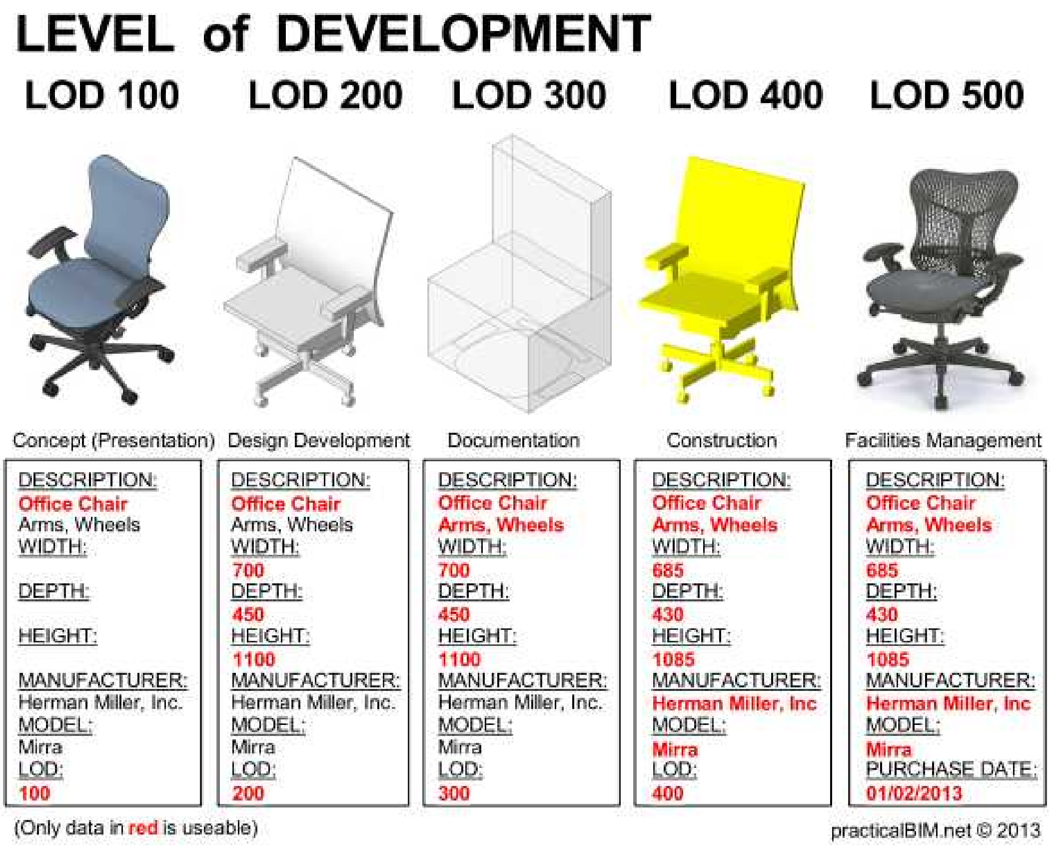


Figure 2.11: Example-1 of LOD for a chair element in a BIM model (Source: McPhee [2013])

Bedrick [2008] used the aforementioned five LOD classes and further developed them in the context of specific uses of the model, such as energy analysis, program compliance, cost estimation, project scheduling, sustainable material. Table 2.3 below depicts LOD definitions for 3D BIM content, project schedule and project cost estimate.

Table 2.3: LOD definition of 3D , 4D and 5D BIM modeling (Adapted from: Bedrick [2008])

	LOD 100	**LOD 200**	**LOD 300**	**LOD 400**	**LOD 500**
3D BIM model content	Non-geometric data or line work, areas, volume or zone	3D generic elements showing maximum size and purpose	Specific elements of confirmed 3D object geometry with dimensions, capacities and space relationships	Shop drawing containing manufacture, purchase, installation and other specified information	As-built model showing the actual model in the field
Project scheduling (4D BIM)	Total project construction duration	Time-scaled, ordered appearance of major activities	Time-scaled ordered appearance of detailed assemblies	Fabrication and assembly detail including construction methods and techniques, e.g. cranes, shoring system, etc.	
Project cost determination (5D BIM)	Conceptual cost estimation, for example price per square foot or cubic volume, i.e. Analogous Estimating (see section 5.2)	Estimated cost based on measurement of generic element	Estimated cost based on measure of specific assembly	Committed purchase price of specific assembly at buyout	As-built cost representing the actual cost as installed in the field

Chapter 3

Methodology

In the previous, chapter a detailed review of literature on various aspects of BIM were presented, including construction project life-cycle management in BIM working methodology, graphical and non-graphical information management and transmission through the project life-cycle phases, and the barriers and challenges faced in the adoption of BIM working methods in the AEC industry. Moreover, the concepts of BIM maturity levels and BIM dimensions were also discussed. In this chapter, on the basis of these ideas, a methodology for this research work will be presented.

3.1 Research Approach

The research work in this thesis is comprised of two major parts. Firstly, a study will be conducted on construction project life-cycle phases according to widely used traditional national construction standards in certain European countries. As these standards have existed for long time and have been in practice in the AEC industry of those countries, the compatibility of these standards with the relatively new BIM working method will be investigated, and the level of BIM adoption in these standards will also be examined. Furthermore, project stages that require 5D BIM model development will be determined and if these national standards specify the development of BIM models (3D, 4D and 5D models) in the project life-cycle phases they define, this will also be examined. The second part of the research work will focus first on the determination required data and information for the development of 4D and 5D BIM models, followed by the development of the BIM models starting from the creation of graphical CAD models to an integrated 4D and 5D BIM models.

For the purpose of this study the following three national standards from three different European countries was chosen:

- **Germany**: The HOAI Scale of Fees for Services by Architects and Engineers (German: Honorare für Architekten- und Ingenieurleistungen)
- **United Kingdom**: The RIBA Plan of Work
- **Switzerland**: The SIA 112 Standard published by Swiss Society of Engineers and Architects.

The BIM model development in this research work follows the concept of **Collaborative BIM** (BIM Level 2) discussed in section 2.1.1. Making Collaborative BIM model development process as basis, 3D, 4D and 5D BIM models explained in the previous chapter on BIM dimensions (see section 2.1.2) will be developed. At BIM level 2, all parties involved in the development of the BIM model (architect, structural engineer, interiors engineer, MEP engineer, etc.) create their own virtual 3D models and these models are then combined and coordinated through a common area often known as Common Data Environment (CDE). Also, several coordination meetings are held in various stages of the BIM model development process in order to solve clashes that may exist among coordinated 3D models. A similar concept is applied and demonstrated in this thesis work except that due to time constraints only two disciplines are considered for the Collaborative BIM model development, namely: architectural and structural; MEP and other BIM models are excluded in the study. Fig.3.1 below depicts the concept of Collaborative BIM model preparation adopted in this study.

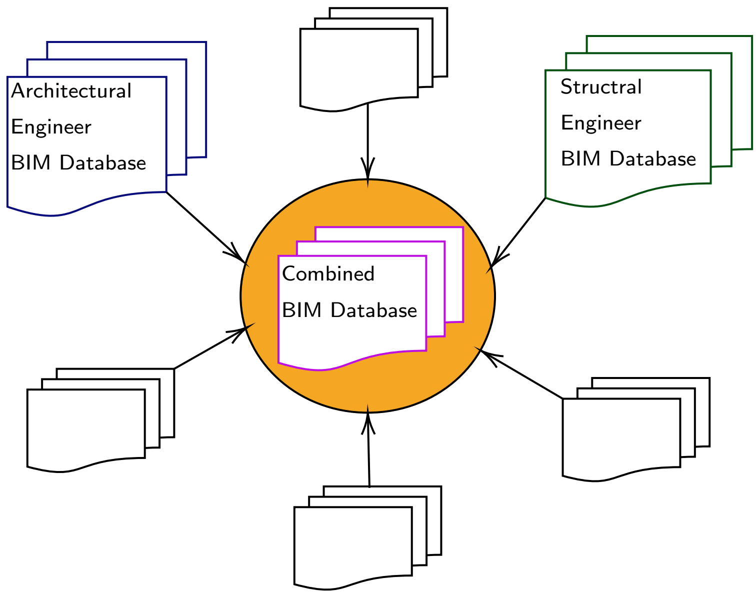


Figure 3.1: Schematic represention of Collaborative BIM

The motivation behind for adopting the aforementioned concept for BIM model development is due to the fact that collaborative BIM (BIM level 2) is the current level of BIM that the AEC industry, specially in countries where the BIM wokring method is implemented, are currently heading towards and several major companies on those countries have already adopted. These countries include UK, USA, Singapore, Denmark, Sweden, Finland, Germany, etc. The UK government even mandated fully collaborative BIM (i.e. BIM Level 2) for all publicly procured projects in the country since 2016. The AEC industry is shifting from BIM Level 1 (**Lonely BIM**) described in section 2.1.1, where even though individual disciplines might be using BIM tools (for example: Revit, Archicad, Tekla Structures, etc), but collaboration between different disciplines, coordination of BIM models and detection of clashes in different models prior to further development and commencement of construction does not exist.

3.2 Research Design and Analysis Approach

For the first part of the research work (i.e. the study on national standards), each of the three chosen standards will be first studied separately for project life-cycle phases defined in the standards and for the level of BIM adoption in the standards. Thereafter, qualitative analysis will be performed on these standards. As such, the project life-cycle phases of the three standards will be mapped to one another and the similarities and differences in project life-cycle phases will be analyzed. Additionally, comparative analysis based on the level of compatibility of the three standards to the BIM working method will also be conducted.

Even though the RIBA Plan of Work, HOAI regulation and SIA 112 standard for UK, Germany and Switzerland, respectively, are the basis for the conducted study, other supplementary standards and documents will also be referenced which facilitate the analysis of the three standards in relation to building information modeling. These referenced documents are shown in table 3.1 below:

Table 3.1: Reference national standards and documents for the research work

National standards and documents	**Published by**
1- United Kingdom	
RIBA Plan of Work 2013 Overview	Royal Institute of British Architects
BIM Overlay to The RIBA Outline of Work	Royal Institute of British Architects
2- Germany	
HOAI 2013	The Federal Government of Germany
Step-by-Step Plan for Digital Planning and Building	The Federal Ministry of Transport and Digital Infrastructure (BMVI)
Implementation of the Step-by-Step Plan for Digital Planning and Building. First progress report	The Federal Ministry of Transport and Digital Infrastructure (BMVI)
VDI 2552 Building Information Modeling (BIM)	Association of German Engineers (VDI)
3- Switzerland	
SIA 112: Model Construction Planning	Swiss Society of Engineers and Architects
SIA 1001/11: Supplementary Agreement for BIM	Swiss Society of Engineers and Architects
SIA 1001/11-K: Commentary on the application of the BIM supplementary agreement	Swiss Society of Engineers and Architects

Apart from the documents published by RIBA and the HOAI regulation, all the other documents in the above table were found in German; and for the purpose this study, they were translated to English using some online tools.

On the other hand, the study on BIM model development will be carried out by developing a 5D BIM model of a 3-story building structure as a case study which enables to demonstrate the Collaborative BIM model development process. Even though a building project is considered in this study, the methods, procedures and techniques applied can also be adopted to any type of construction project. The method that will be adopted for developing the Collaborative 5D BIM model of the chosen building structure is presented in fig.3.2 below. The procedure of BIM model development begins from the traditional graphical 2D CAD model (BIM Level 0) which then develops to non-coordinated individual 3D BIM models (BIM Level 1), which in turn progresses to a coordinated BIM model (BIM Level 2). This procedure is important as it shows the progress of model development from the traditional merely geometrical modeling to the state-of-the-art Collaborative BIM model development technique. The final output of the process is a 4D and 5D BIM model in the different BIM tools which are further qualitatively analyzed for quality of generated models and interoperability.

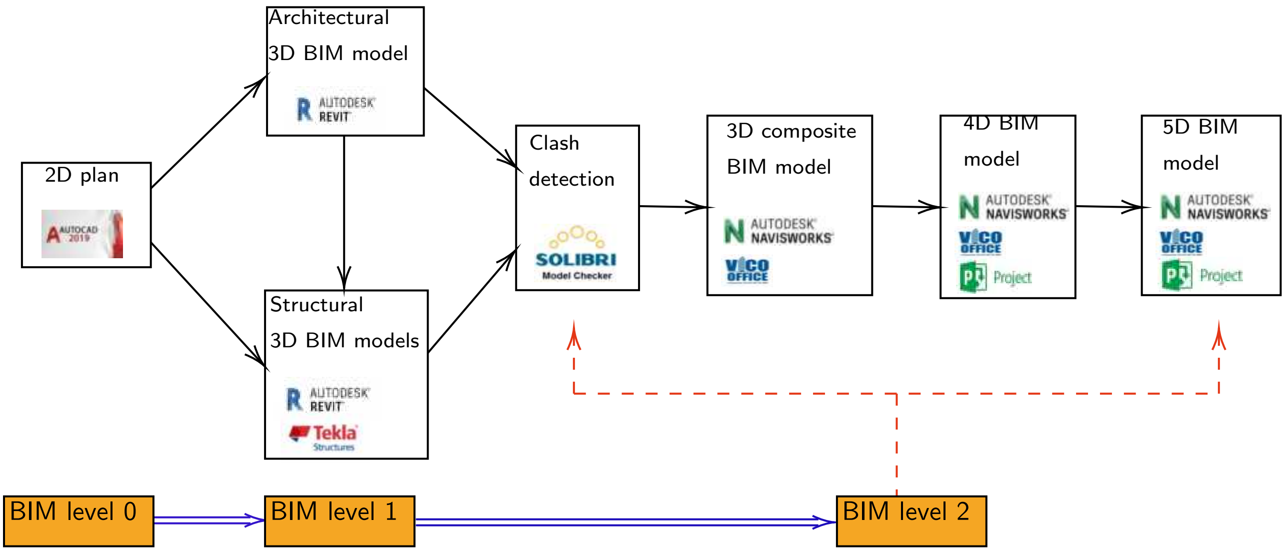


Figure 3.2: The process of 5D BIM model development and transformation from BIM Level 0 to BIM Level 2

Several BIM tools and other software applications will be utilized to produce the required results. Geometrical 2D models which are the basis for 3D BIM models will be created in AutoCAD; whereas 3D BIM models will be developed using Revit and Tekla Structures. Thereafter, 4D and 5D BIM models will be developed using Navisworks Manage and Vico Office, products of Autodesk and Trimble company, respectively. The objective of using these different BIM tools from different companies is that due to the competitive nature of the software industry, the working methods, supported functionalities, quality of developed BIM models, etc. usually vary among BIM applications from different companies. Due to this, in addition to developing 4D and 5D BIM models in the BIM tools, required processes for model development will also be clearly presented, qualitative analysis on produced models will be performed and the challenges and constraints encountered in the BIM model development process using those BIM tools will be documented. Table 3.2 below provides the details of the BIM tools and other software applications that will be used in this study.

Table 3.2: BIM tools and other applications used in the thesis work

BIM tools and other applications	**Company**	**Purpose**
AutoCAD	Autodesk	To creat 2D plan CAD model
Revit	Autodesk	To develop architectural and structural 3D BIM models
Tekla structures	Trimble	To develop structural 3D BIM model, clash detection
Solibri	Nemetschek	BIM quality checking (clash detection and safety)
Naviswors Manage	Autodesk	To creat composite BIM model (arch. + struc.), model-based quantity takeoff, 4D and 5D BIM visualization
Vico Office	Trimble	To creat composite BIM model (arch. + struc.), model-based quantity takeoff, cost estimation, project schedule development, 4D BIM visualization
Microsoft Project	Microsoft	project schedule development, cost estimation
Microsoft Excel	Microsoft	Quantifications, rate analysis and other general computations
Enscape	Enscape GmbH	Real-time rendering and virtual reality

One of the major tasks that will be done in the BIM model development process is cost estimation which provides the fifth dimension to the BIM model. The estimation is conducted for the resources that will be utilized on project activities. The normal practice in the AEC industry in the pricing of resources is that pricing databases (from the company, or regional and national price books) and quotations from suppliers are used. As these sources of information could not be accessed for this study, price information of resources will be obtained from Spon's Architects' and Builders' Price Books (AECOM [2015]) and Spon's European Construction Costs Handbook (Langdon and Everest [2000]) which are relevant sources for construction price information for UK and European countries including Germany, respectively.

Eventually, as a means to integrate the national standards considered in this study and the 4D and 5D BIM development process, construction project life-cycle phases defined by one of the standards will be chosen and a model will be developed illustrating how 3D, 4D and 5D BIM models develop through the different stages of the project life-cycle in accordance to the LOD classification defined by the American Institute of Architects (AIA) which was already described in detail in the previous chapter (see section 2.2.2).

Chapter 4

National Standards for Project Life-cycle Management

This chapter covers the first objective of the thesis work focusing on the study of national standards that are currently used for construction project life-cycle management in some European countries. Three national standards from three European countries were chosen for the purpose of this study: RIBA Plan of Work 2013 from UK, HOAI 2013 from Germany and SIA 112 from Switzerland. Each standard will be discussed separately in the following sections. First the project phases will be analyzed; and later on the level of BIM adoption in these standards and the compatibility of these standards with BIM-method of working will be investigated.

4.1 RIBA Plan of Work in the UK

RIBA Plan of Work is an organized document that divides and arranges project life-cycle of construction projects into different key stages. RIBA Plan of Work document was prepared and published by the Royal Institute of British Architects (RIBA)(1) which is a professional institution in the united kingdom (UK) that mainly serves architects in the UK but also in other parts of the world (2). RIBA Plan of Work 2013 is the current applicable document that organizes the various processes in building projects, including project briefing, designing, constructing, operating, into different key phases or stages.

According to RIBA Plan of Work 2013, the life-cycle of the construction project comprises of eight stages designated by numbers 0 to 7. Each of the eight stages is mapped to tasks. There are a total of eight tasks for the project stages and these tasks, with exception of three tasks, can be customized as per the requirement and need of the particular project. Brief description of project life-cycle stages as defined in RIBA Plan of Work 2013 is presented below.

- **Stage 0 - Strategic Definition:** decisions whether to continue the project and how to continue are made in this stage. Also, strategic consideration such as considering different sites for the project and whether to construct a new or extend or refurbish an existing structure is also made in this stage.

(1) RIBA, https://www.architecture.com/
(2) https://en.wikipedia.org/wiki/Royal_Institute_of_British_Architects

- **Stage 1 - Preparation and Brief:**. in this stage, the feasibility of the project is assessed; required documents for the appointment of suppliers (e.g. designer, independent advisor) is prepared and suppliers are appointed as needed. It is also in this stage that the initial Design Responsibility Matrix is prepared which will then be improved and finalized at the end of the next stage so that there will not be confusion regarding the designers in stages 3, 4, 5.

- **Stage 2 - Concept Design:** a concept or initial design is prepared in this stage based on the project brief obtained from the previous stage. The concept design also involves structural design plans, building management structures, outline requirements and preliminary cost details along with appropriate project strategies in conjunction with the design programme.

- **Stage 3 - Developed Design:** the concept design from the previous stage is developed sufficiently further in this stage i.e. designed in detail including all parts of the building and how these parts fit together. The information obtained from this stage will be used to obtain approvals from various authorities; it should therefore have sufficient information. Cost and program information from the previous stage are also updated.

- **Stage 4 - Technical Design:** any remaining technical works related to the design of the project is performed and finalized in this stage. Apart from answering queries related to the design which the contractor will raise during the construction stage (i.e. Stage 5), the design teams' work will be completed at the end of this stage.

- **Stage 5 - Construction:** the designed project from earlier stages is physically built and completed in this stage. Works carried out in this stage include mobilization, on-site construction, off-site manufacturing, testing and commissioning.

- **Stage 6 - Handover and Close Out:** it is a stage that the contractor transfers the physically completed, tested and commissioned project to the employer (client). Even thought, in this stage, the employer will be using the finished product, the contractor will be responsible to perform required maintenance works until the end of defects liability period (i.e. maintenance period).

- **Stage 7 - In Use:** this is the operations phase in the life-cycle of a construction project which follows the end of defects liability period. In this stage, the completed project is evaluated if its objectives as per the project brief prepared in **Stage 1** are met. Also, the performance of the project is reviewed based on received feedback regarding the completed product under operation and the project team.

4.1.1 Adoption of BIM Methods in RIBA Plan of Work

The UK government published its construction strategy in May 2011 which stated that "...Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016." This means that by 2016 all centrally-procured public projects were required to adopt and implement a minimum of Level 2 BIM [UKConstructionOnline, 2018]. As presented in section 2.1.1, at BIM Level 2, a 3D building information is developed with relevant data attached with the model; but the BIM is not developed at a single common environment but rather separated into different discipline models [BIMWiki, 2019]. This requirement of BIM which the UK government mandated led to the increasing adoption of BIM methods in the UK. Today, there are several organizations in the UK which publish guidelines, standards, codes of practice and specifications to enable the AEC industry in the UK and outside of UK to properly implement BIM. Some of these BIM guidelines include PAS 1192, BS 1192, NBS National BIM Library, CIC BIM Protocol, buildingSMART UK, etc.

The RIBA Plan of Work 2013 was published taking into account the UK government's mandate on the adoption of collaborative 3D BIM on government projects [Archigraphic, n.d.]. Unlike the previous publication Outline Plan of Work 2007, the current RIBA Plan of Work 2013 publication made planning permission and procurement activities as moveable tasks which reflects increasing requirements for sustainability and BIM [BIMWiki, 2019].

RIBA Plan of Work 2013 provides clear presentation of tasks involved in each stage of the project and the outputs required at that stage. It also allows a customized Plan of Work to be prepared for a specific project. According to RIBAPlanofWork2013Online [n.d.] the RIBA Plan of Work 2013:

- Acts across the full range of sectors and project sizes
- Provides straight-forward mapping for all forms of procurement
- Integrates sustainable design processes
- **Maps Building Information Modelling (BIM) processes**
- Provides flexible around (town) planning procedures

In May 2012 the Royal Institute of British Architects (RIBA) published the so called "BIM Overlay to the RIBA Outline Plan of Work" document which provides guidance on the activities needed at each of the different RIBA work stages to successfully design and manage construction projects in a BIM environment [Sinclair, 2012]. The BIM overlay publication is based on the previous Outline

Plan of Work 2007; however, a similar document has not yet been published for the definition of work stages as per the current RIBA Plan of Work 2013 [BIMWiki, 2019].

Table 4.1 below presents the BIM Overlay to the RIBA Outline Plan of Work published by RIBA in 2012. The BIM Overlay was prepared on an already existed overlay document called "Green Overlay to the RIBA Outline Plan of Work" published by RIBA in November 2011 for sustainability design. The texts highlighted in green correspond to the Green Overlay, whereas the texts highlighted in pink correspond to the BIM Overlay. The Green Overlay was included in the BIM Overlay due to the fact that in reality most of the changes made in the RIBA Outline Plan of Work to suit sustainability design are also pertinent to BIM [Sinclair, 2012].

The BIM Overlay provides indicative core BIM activities corresponding to each work stage of the project life-cycle. Also, as depicted in the table, the overlay identifies points in the project life-cycle for key data or information drops to take place, unlike the traditional working method which employed stage reports.

Table 4.1: BIM Overlay to the RIBA Outline Plan of Work (Adapted from Sinclair [2012])

	RIBA Work Stage	Description of Key Tasks	Core BIM Activities
Preparation	**Appraisal**	Identification of client's needs and objectives, business case, sustainability, life cycle and Facilities Management aspirations and possible constraints on development. Preparation of feasibility studies and assessment of options to enable the client to decide whether to proceed.	• Advise client on purpose of BIM including benefits and implications. Agree level and extent of BIM including 4D (time), 5D (cost) and 6D (FM) following software assessment. Advise client on Integrated Team scope of service in totality and for each designer including requirements for specialists and appointment of a BIM Model Manager. • Define long-term responsibilities, including ownership of model. • Define BIM Inputs and Outputs and scope of post-occupancy evaluation (Soft Landings). • Identify scope of and commission BIM surveys and investigation reports. • Data drop 1
	Design Brief	Development of initial statement of requirements into the Design Brief by or on behalf of the client, confirming key requirements and constraints. Identification of procurement method, project sustainability and BIM procedures, building design lifetime and project organisational structure and range of consultants and others to be engaged for the project, including definition of responsibilities.	

Design	**Concept**	Implementation of Design Brief and preparation of additional data. Agreement of Project Quality Plan including BIM and Change Control protocols. Preparation of Concept Design including outline proposals for structural and environmental strategies and services systems, site landscape and ecology, outline specifications, preliminary cost and energy plans. Review of procurement route.	• BIM pre-start meeting. • Initial model sharing with Design Team for strategic analysis and options appraisal. • BIM data used for environmental performance and area analysis. • Identify key model elements (e.g. prefabricated component) and create concept level parametric objects for all major elements. • Enable design team access to BIM data. • Agree extent of performance specified work. • Data drop 2
Design	**Design Development**	Development of concept design using project BIM data to include structural and environmental strategies and services systems, site landscape and ecology, updated outline specifications and cost and energy plans. Completion of Project Brief. *Application for detailed planning permission.*	• Data sharing and integration for design coordination and detailed analysis including data links between models. • Integration/development of generic/bespoke design components. • BIM data used for environmental performance and area analysis. • Data sharing for design coordination, technical analysis and addition of specification data. • Export data for Planning Application. • 4D and/or 5D assessment. • Data drop 3
	Technical Design	Preparation of technical design(s) and specifications, sufficient to coordinate components and elements of the project, BIM data and *information for statutory standards, sustainability assessment and construction safety.*	

Pre-Construction	**Production Information**	F1 Development of BIM data in sufficient detail to conclude co-ordination of design team inputs, to enable performance specified work to commence and enable a tender or tenders to be obtained. *Application for statutory approval.* F2 *Development of BIM data to integrate performance specified design work into model*. Review of BIM information provided by contractors and specialists, including integration into project BIM data	• Export data for Building Control Analysis. • Data sharing for conclusion of design co-ordination and detailed analysis with subcontractors. • Detailed modelling, integration and analysis. • Create production level parametric objects for all major elements (where appropriate and information exists this may be based on tier 2 supplier's information). • Embed specification to model. • Final review and sign off of model. • Enable access to BIM model to contractor(s). • Integration of subcontractor performance specified work model information into BIM model data. • Review construction sequencing (4D) with contractor. • Data drop 4.
	Tender Documentation	Preparation and/or collation of tender documentation in sufficient detail to enable a tender or tenders to be obtained for the project.	
	Tender Action	Identification and evaluation of potential contractors and/or specialists for the project. Obtaining and appraising tenders; submission of recommendations to the client.	
Construction	**Mobilisation**	Letting the building contract, appointing the contractor. Arranging site handover to the contractor.	• Agree timing and scope of 'Soft Landings'. • Coordinate and release of 'End of Construction' BIM record model data. • Use of 4D/5D BIM data for contract administration purposes. • Data drop 5
	Construction to Practical Completion	Administration of the building contract to Practical Completion. Clarification and resolution of design queries as they arise. Assist with preparation for commissioning, training, handover, future monitoring and maintenance.	
Use	**Post Practical Completion**	L1 Administration of the building contract after Practical Completion and making final inspections. L2 Assisting building user during initial occupation period.	• FM BIM model data issued as asset changes are made. • Study of parametric object information contained within BIM model data. • Data drop 6
R&D	**Model Maintenance & Developement**	L3 Review of project performance in use and comparison with BIM data. Analysis of BIM data for use on future projects, following feedback and research.	

4.2 HOAI in Germany

HOAI is an official regulation on fees for the services provided by architects and engineers in the state of Germany. It is the Federal Government of Germany which provides and amends the HOAI regulation. HOAI 2013 is the latest update and the currently applicable ordinance on fees for the services of architects and engineers. The HOAI fee regulation divides the life-cycle of the construction project, starting from inception to final handover to the employer, into different service phases, and payments to architects and engineers for services in each service phase is then made as percentage of fees provided in the HOAI regulation. These service phases defined by HOAI are also referred to as HOAI service profile.

According to HOAI 2013 the service profile for a building construction project consists of nine service phases which are described briefly below.

- **Service Phase 1 - Fundamental evaluation:** in this phase the requirements of the employer (client) analyzed and clarified; the proposed project site is visited and criteria for the selection of specialist suppliers (e.g. designers) is prepared.)

- **Service Phase 2 - Preliminary design (project and design preparation):** tasks at this phase include preparation of preliminary design, cost estimation, preparation of time schedule, analysis of coordination of services between various specialists involved in the planning. Also, if required for the project, creation of 3D or 4D BIM model is also made in this phase.

- **Service Phase 3 - Final design (integrated system design):** this stage involves the preparation of detailed, final and integrated design considering various standards, regulations, conditions and coordination with other specialists. Cost calculation (developing and detailing the already prepared cost estimate) and updating of the time schedule is prepared. Project description is also prepared in this phase.

- **Service Phase 4 - Planning permission application:** this is the phase in which all necessary documents required by various authorities are prepared, compiled, organized and submitted for permissions and clearances.

- **Service Phase 5 - Execution planning:** this phase involves the preparation of project execution plan based on the final design (**Service Phase 3**) and planning permission application (**Service Phase 4**).

- **Service Phase 6 - Preparation of contract award:** in this phase documents required for tendering and award of the contract are prepared, including preparation of bills of quantities (BOQ), specifications, schedule for contract awarding time, etc.

- **Service Phase 7 - Involvement in contract award:** tasks in this stage include taking part in the tendering process, evaluating received tender proposals, awarding of the contract to successful tenderer (i.e. the contractor in the next service phase) and preparation of contract documents considering all service areas.

- **Service Phase 8 - Project supervision (construction supervision and documentation):** this phase includes the supervision of the actual construction work at site taking into account public laws, contract documents, project documents (execution drawings, specifications, etc.), standards, etc. Cost controlling, monitoring of time schedule and documentation of the construction progress is also carried out. Moreover, all project documentations, until the project handover, are compiled and organized comprehensively and systematically. Project handover occurs in this service phase as well.

- **Service Phase 9 - Post-completion services:** this service phase comprises of the services of architects and engineers after the project handover. Since after the project handover the employer can claim for defects made by the contractor, architects and engineers will provide services including assessing the claimed defects taking into account the contract with the contractor and inspection of the project for the claimed defects. Finally, bonds and securities that were submitted during the contract award are released to the project executing company.

The services that architects and engineers provide in the above nine service phases are compensated or paid at different percentages of fees. The HOAI provides table of fees according to which these percentages are calculated. Fig.4.1 below shows the percentage of fee distribution throughout the project life-cycle as per HOAI 2013 fee order.

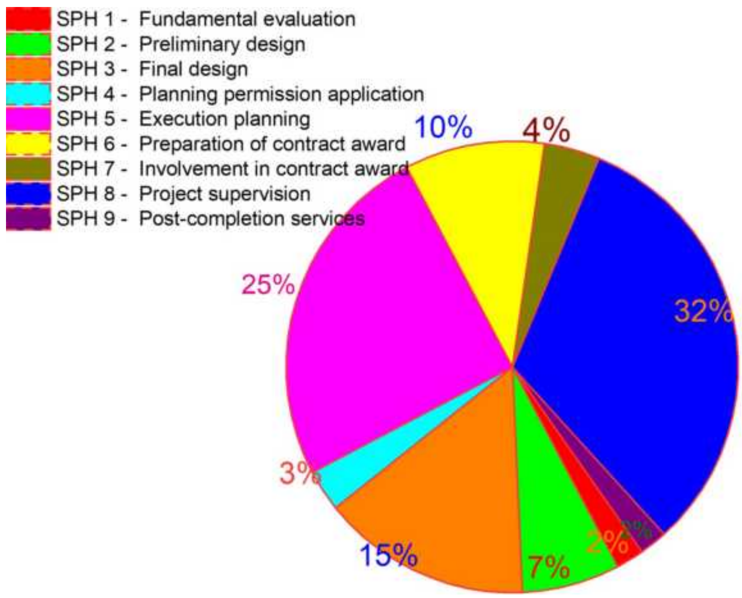


Figure 4.1: Percentage of fees for the service of architects and engineers as per HOAI

4.2.1 Adoption of BIM Working Methods in State of Germany and in HOAI Regulation

Similar to Singapore, USA, UK, Korea and Scandinavian countries, Germany is also transitioning from the traditional working methods to digitization of the AEC industry. This digital transformation affects all parties in the construction industry; consequently, a careful and planned transition is necessary to avoid economical damages to stakeholders [Borrmann et al., 2016]. In 2014, German national commission proposed adoption of digital methods such as BIM which enables the effective management of complex projects thereby reducing construction risks. This recommendation was made after investigating the cause of failure for some large-scale construction production in the country [Borrmann et al., 2016]. As a result, in 2015 the Federal Ministry of Transport and Digital Infrastructure (BMVI), in cooperation with Plan-build 4.0-Society for the Digitization of Planning and Construction of Guildings mbH (planen-bauen 4.0 GmbH), presented a strategic three-step plan titled "Stufenplan Digitales Planen und Bauen" (Step plan for Digital Planning and Construction) for the introduction of BIM working methods in public projects. The goal of this step-wise plan was to make digital planning and construction a nationwide adopted standard [BMVI, 2015]. Fig.4.2 below shows the three-phase plan which the German government has initiated for digitization of the AEC industry in the country.

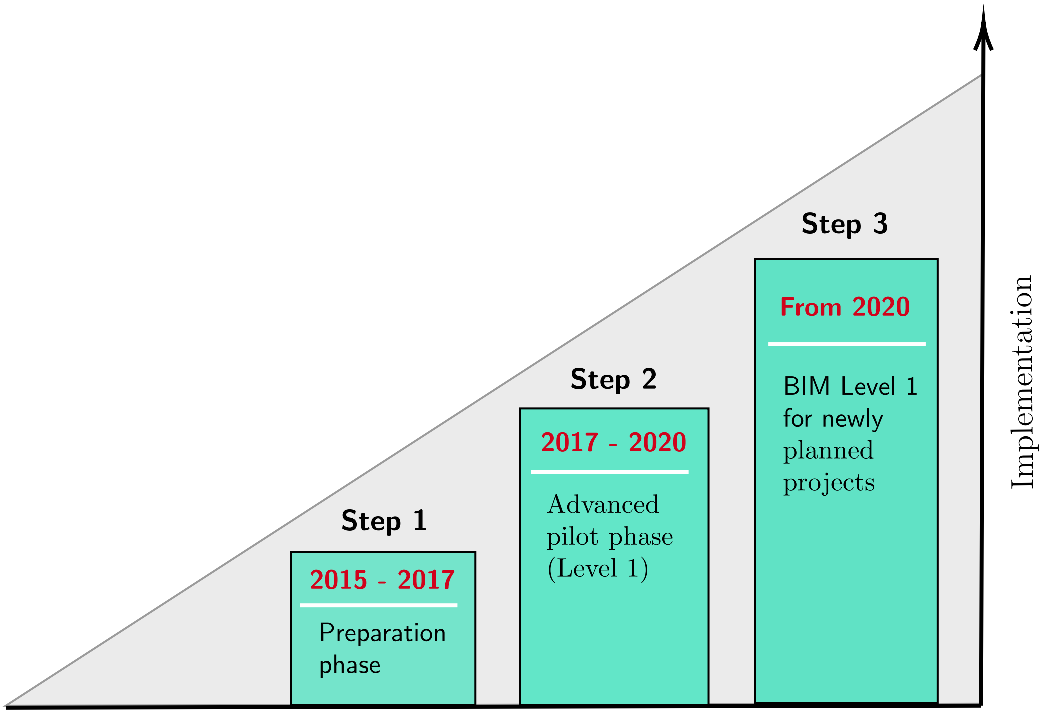


Figure 4.2: Schematic representation of phased plan for BIM method introduction

According to the first progress report for the implementation of the phased plan digital planning and construction published by BMVI in 2017 ([BMVI, 2017]), the three steps (phases) defined by BMVI for the implementation of digital construction are as follow:

- **Step 1 - Preparation phase (2015-2017):** this is preparatory phase in which four pilot projects are carried out and the BIM-Method is partially implemented. The projects comprise of two rail projects (Tunnel Rastatt and Bridge Filstal) and two road projects (Bridge Petersdorfer See and Viaduct Auenbachtal). The status of the projects are scientifically monitored and researched. The experience gained in these four pilot projects are used to define BIM framework, standards and recommendations to be implemented in the second phase.
- **Step 2 - Extended pilot phase (2017-2020):** in this phase, the number of pilot projects are increased to collect comprehensive experience of the BIM method of working both in planning and construction stages. The pilot projects are to be carried out according to the requirement of so-called "[BIM] **Performance Level 1**" (defined later). Guidelines, checklists and samples for using BIM are also developed to be used in future projects. Clarification of legal questions, and development of concept for databases to facilitate working with BIM are also the goal of this phase.
- **Step 3 - BIM Level 1 (Niveau 1) for all new projects (from 2020):** this phase marks the

regular implementation of BIM working method as per the requirement of Performance Level 1 in all transport and infrastructure projects.

The requirements of **BIM Performance Level 1** (German: Leistungsniveau 1 or Niveau 1) is as follow (Ref. BMVI [2017]):

- The client must define and specify exact required data and when required in the so-called "Client-Information-Requirements" (English: CIR, German: AIA).
- All services to be provided are to be delivered in digital form on the basis of model-based work.
- Vendor-neutral data formats are required during tendering to enable data exchange.
- BIM is to be included in the contract as the applicable planning tool of the project.
- Processes, interfaces, interactions and the technologies to be used have to be defined in the so-called "BIM Execution Plan" (English: BEP, German: BAP)
- To enable organized storage, exchange and to avoid loss of data generated from planning and construction processes, a Common Data Environment (CDE) is to be created.

In the implementation of the BIM method of working in the pilot projects mentioned earlier, the service phase as defined by the German Architects and Engineers Fee Regulations (HOAI) were considered and followed. As the released first progress report [BMVI, 2017] mentions, in Tunnel Rastatt pilot project BIM-Method was used in service phases 3 and 4 (i.e. Final Design and Planning for Approvals); in Bridge Filstal pilot project BIM-Method was used in service phases 5 and 8 (i.e. Execution Planning and Construction/Execution); in Bridge Petersdorfer See pilot project BIM was used in the construction phase (i.e. service phase 8 in HOAI); and in Viaduct Auenbachtal pilot project BIM was implemented in preliminary planning (i.e. service phase 2 in HOAI). As can be seen, the investigated pilot projects are located in different performance phases (service phases), and the BIM goals and application of BIM-Method in the projects is different [BMVI, 2017]. Implementing BIM in the pilot projects in various service phases of the HOAI helps to investigate its level of effectiveness on various stages of the project life-cycle.

Furthermore, the maturity level of BIM implementation in the pilot projects was evaluated. The BIM performance assessment consisted the preparation of an international-based BIM maturity metric but tailored to the specific need of Germany, i.e., considering the HOAI regulation and only for infrastructure projects [BMVI, 2017; Borrmann et al., 2016]. The BIM maturity metric comprises a total of 62 questions related to the application of BIM in infrastructure projects. By conducting interviews and coordinating with project managers, for each of the 62 questions the maturity of

BIM usage is graded with points 0 to 5; where 5 represents optimal BIM implementation and 0 indicates unavailability/non-existence of BIM [BMVI, 2017]. Points assigned for each category were then summed up to obtain overall evaluation according to categories. The questions were sorted into the following ten categories [Borrmann et al., 2016]:

1. Employer's Information Requirements (English: CIF; German: AIA)
2. BIM Execution Plan (English: BEP; German: BAP)
3. Technology used for BIM execution
4. Contracts
5. BIM team
6. BIM in preliminary [and final] design phase (HOAI Service Phase 2-3)
7. BIM in construction documentation phase (HOAI Service Phase 4-5)
8. BIM in the tendering phase (HOAI Service Phase 6-7)
9. BIM in the construction phase (HOAI Service Phase 8)
10. BIM in the operation phase

Fig.4.3 below depicts the result of BIM maturity level evaluation in the four infrastructure pilot projects. As the chart explains, BIM maturity was lowest in contracts, tendering phase and operation phase, whereas BIM maturity level was highest in BIM team, construction phase and Employer's Information Requirement (CIF/AIA).

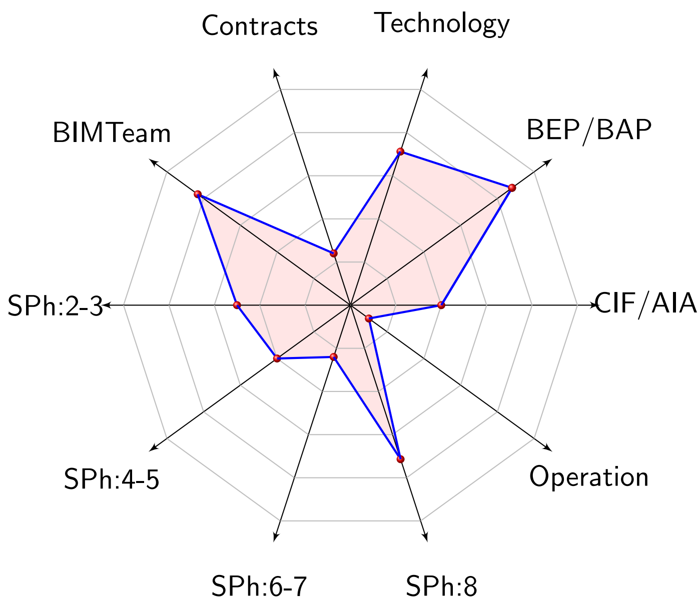


Figure 4.3: Averaged Maturity Level of all BIM pilot projects) (Adapted from: BMVI [2017])

Compatibility of HOAI Regulation with BIM-Method

Even though the HOAI regulation is widely used in the AEC industry in the state of Germany, it is challenging to undertake a BIM-based project adopting the current version of HOAI order of fees. The HOAI 2013 as an effort to incorporate BIM working method for the first time has included creation BIM model in the order of fees in service phase 2 (Preliminary Design) stating "3D or 4D building model creation" (see section 4.2 and appendix **??**). The option of developing BIM model is listed in special services; hence, not mandatory service. BIM method of workign, however, is not limited to creation of a 3D or 4D model in the planning phase, rather it is a procedure that will continue throughout the design phase to develop a D-BIM [an intelligent 3D model in the design stage comprising of both geometrical and non-geometrical data] [Archigraphic, n.d.]. Moreover, as indicated in the four BIM pilot projects earlier (see section4.2.1), usage of BIM is not limited to a single project stage; it can rather be used for tendering, contracts, execution, operation etc. Thus, in order to be applicable for BIM-based projects, an amendment to the current HOAI regulation is necessary [Archigraphic, n.d.]. Fig.4.4 below illustrates the difference in HOAI fee regulation for a construction project based on the classical method and the new BIM-Method.

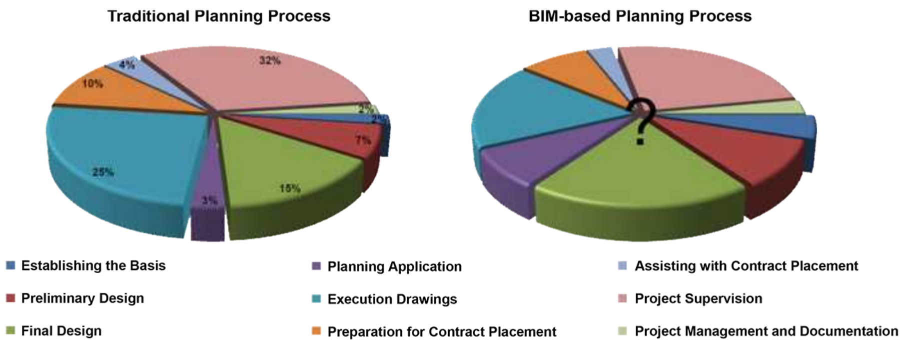


Figure 4.4: Percentage of Fees according as per HOAI 2013 vs BIM-enabled process (Source: Archigraphic [n.d.])

Another way to understand the level of HOAI regulation compatibility with BIM-Method is to observe the opinion of individuals in the AEC industry. [Eschenbruch et al., 2014], considering the HOAI as one of the fundamental problem area for the introduction of BIM in Germany, they conducted a survey to see how critical HOAI is for BIM implementation. The researchers interviewed various individuals in the AEC industry on a number of issues, including compatibility of HOAI and BIM, and their responses were rated 1 (not critical) to 5 (very critical). The respondents included administration, architects, structural engineer, technical building services (TGA-planner), construction company and project manager. Fig.4.5 shows the result of the survey data. The average score of the interview shows 3.4 which is a range between moderately critical and quite critical.

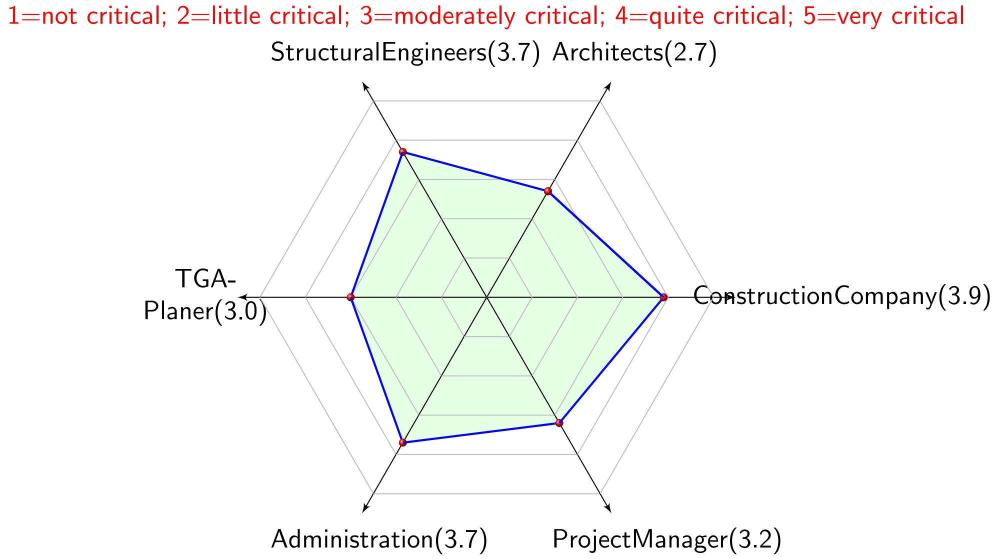


Figure 4.5: Criticality of HOAI for introduction of BIM-Method in Germany) (Adapted from: Eschenbruch et al. [2014])

Furthermore, an article posted on Archigraphic(3) website ([Archigraphic, n.d.]) mentions that implementing BIM-Method using current traditional techniques, for example HOAI, will cause shift of effort along the various project phases defined by that particular regulation for project life-cycle management. Such shift of effort leads to change of cost for services. Fig.4.6 below depicts the shift of effort in the project life-cycle if BIM is implemented compared to the traditional methods.

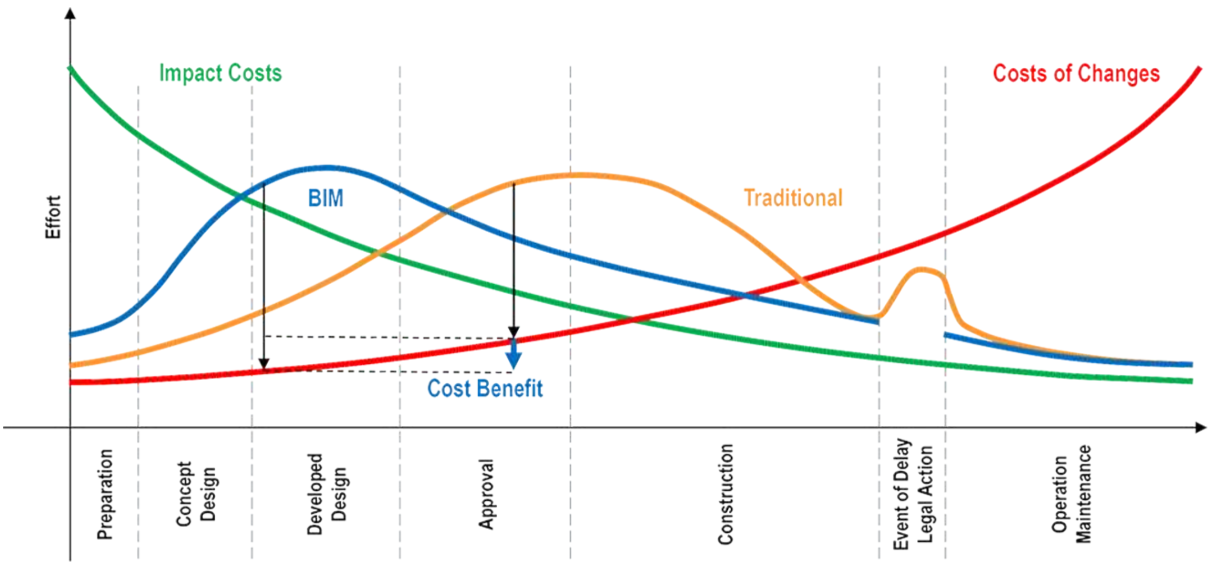


Figure 4.6: BIM vs Traditional technique for project life-cycle management (Source: Archigraphic [n.d.])

(3) Archigraphic, http://wordpress.archigraphic.de/en/2015/04/20/bim-vs-hoai/

Development of BIM Standards in Germany

In 2015, German Institute for Standardization (DIN) working together with planen-bauen 4.0 GmbH has founded the "Building Information Modeling (BIM)" national working committee (NA005-01-39AA) which has subordinate working groups which review, study, follow and consider international and European activities and also represent the interest of Germany there [BMVI, 2017]. The DIN working committee also cooperates with Association of German Engineers (VDI-Verein Deutscher Ingenieure) which is currently developing VDI 2552 BIM guideline. Some part of VDI 2552 BIM guideline has already been published as drafts and the remaining parts are under preparation.

The following VDI 2552 guidelines have been published as drafts (Ref. Vogel [2019] and Beuth [2020]):

- VDI 2552 Page 1 (Draft): BIM - Basics
- VDI 2552 Page 2 (Draft): BIM - Terms
- VDI 2552 Page 3 (Draft): BIM - Model-based quantity take-off for cost planning, scheduling, awarding and billing
- VDI 2552 Page 4 (Draft): BIM - Data exchange requirements
- VDI 2552 Page 5 (Draft): BIM - Data management
- VDI 2552 Page 7 (Draft): BIM - Processes
- VDI/BS-MT 2552 Page 8.1: BIM - Qualifications - Basic knowledge

The part of VDI 2552 BIM guideline currently under preparation and for which draft publications has not been made yet are as follow (Ref. Vogel [2019] and Beuth [2020]):

- VDI 2552 Page 6: BIM - Facility Management
- VDI/BS 2552 Page 8.2: BIM - Qualifications; Advanced knowledge
- VDI 2552 Page 9: BIM - Classifications
- VDI 2552 Page 10: BIM Client Information requirements (English: CIF; German: AIA) and BIM execution plans (English: BEP, German: BAP)
- VDI 2552 Page 11: BIM - Information exchange requirements
- VDI 2552 Page 11.3: BIM - Information exchange requirements; formwork and Scaffolding technology (in-situ concrete construction)

4.3 SIA 112 in Switzerland

SIA - Schweizer Architekten- und Ingenieursverein (Swiss Society of Engineers and Architects) is a private and the leading professional association in Switzerland in the AEC field comprising of more than 16000 members from architecture and engineering fields (4). The SIA publishes various standards and guidelines to support the AEC industry in the country, including standards for contracts, fee regulations for the service of engineer and architects and other non-standard publications (5). The contract norms published by SIA are the most commonly used forms of contract in Switzerland by the AEC indusry; even though Switzerland is one of the members who founded the International Federation of Consulting Engineers (FIDIC), the FIDIC forms of contract is rarely used in the country [Romy et al., 2019].

Among the standards and norms published by SIA, SIA 112 Model Bauplanung (Model Construction Planning), with its latest version published in 2014, provides sequence of works for construction projects with clear definitions of the scopes. Whereas regulations for services and fees for architects and engineers are covered in SIA 102 (Architects), SIA 103 (Engineers), SIA 105 (Landscape architects) and SIA 108 (Engineers in the fields of building technology, mechanical engineering and electrical engineering).

According to SIA 112 (2014) Service Model, the life-cycle of a construction project comprises of six phases; each phase further contains sub-phases. These project life cycle phases are listed below. Moreover, table 4.2 provides a detailed information of the six phases and their sub-phases along with the basic services to be provided at each stage.

- **Phase-1:** Strategic planning
- **Phase-2:** Preliminary studies
- **Phase-3:** Project planning/ configuration
- **Phase-4:** Call for tender
- **Phase-5:** Realization/ implementation
- **Phase-6:** Management

(4) SIA: http://www.sia.ch/en/the-sia/
(5) Architects Law: https://www.architects-law.ch/architect-law-in-general/fundamentals/sia-set-of-standards

Table 4.2: Construction project service phases according to SIA 112 standard

Phase	Sub-phase	Basic Services
1 STRATEGIC PLANNING	11 Formulation of requirements, solution strategies	none
2 PRELIMINARY STUDIES	21 Project definition and feasibility studies	none
	22 Selection process	none
3 PROJECT PLANNING	31 Preliminary project	- Study of possible solutions and rough estimation of construction costs - Pre-project and cost estimation
	32 Construction project	- Construction project - Detailed studies - Estimate of costs
	33 Approval procedure	- Approval procedure
4 CALL FOR TENDER	41 Tender, offer comparison, award	- Tender plans - Tendering and awarding
5 REALIZATION/ IMPLEMENTATION	51 Construction planning	- Execution plans - Contracts for works
	52 Execution/ Implementation	- Creative management - Construction management and cost control
	53 Commissioning, completion	- Commissioning - Documentation about the building - Management of warranty work - Final account
6 MANAGEMENT	61 Operation	none
	62 Supervision/ inspection / repair	none
	63 Maintenance	none

4.3.1 Adoption of BIM Methods in SIA 112

The Federal Government of Switzerland launched in April 2016 a digitization strategy for the entire economy of the country aiming to position Switzerland as an innovative and future-oriented economic and research location in the digital age. Even though this decision was not specifically to the construction industry, it has placed a great influence on the digital transformation of the AEC industry in Switzerland [BIMconnect, 2018]. Today, there are several organizations in Switzerland contributing to the digitization of the construction industry by establishing relevant guidelines and standards. Some of these organizations include Building Digital Switzerland, buildingSMART Switzerland and SIA 2051-BIM Method.

Similar to many countries in the world the AEC industry in Switzerland has been accustomed to the traditional methods of project life-cycle management (planning, designing, construction and facilities management). The SIA 112 service model presented in section 4.3 earlier is the leading standard employed by the construction industry in Switzerland. The SIA 112 performance model, however, by itself does not incorporate the BIM method of working. If adoption of the BIM method in a particular project is required by a client, a supplementary agreement document relevant for BIM published by the Swiss Association of Engineers and Architects (SIA) will need to be incorporated and the parties must agree on objectives and service contents and contractually stipulate them [BIMCommunity, 2018]. The supplementary agreement documents for BIM is the SIA 1001/11 (latest version 2018) and its related commentary SIA 1001/11-K. Therefore, there are no specific stages in the project life-cycle phases as defined by SIA 112 service model which mandates or specifies the development of BIM-based models; it is rather the choice of the client to opt either the traditional project life-cycle management methods or adopt the BIM method.

The SIA 1001/11 does not provide technical guidelines on how to implement the BIM method; rather it is an additional agreement to the traditional methods where the parties agree on the objectives and the various BIM-based services to be provided by architects and engineers. According to BIMCommunity [2018] "the supplementary agreement BIM was designed so that it can be used in addition to the classic SIA planning/construction contract 1001/1." However, fundamental technical guidelines for BIM and interpretation and definitions of BIM-related technical concepts and terminologies used in SIA 1001/11 are provided in SIA 2051: Building Information Modeling (BIM) - Fundamentals for the application of the BIM method which was published by SIA's centeral commission for BIM.

According to the SIA 1001/11 BIM supplementary agreement (latest version 2018) the following BIM-specific services are to be specially agreed by the parties:

- Participation in the development of the BIM project execution plan
- Provision and maintenance of the virtual project space (Common Data Environment CDE) according to a separate performance description
- BIM management services
- BIM coordination services
- Information and communication technologies (ICT) coordination services

Chapter 5

Information Requirement for 5D BIM Development

As outlined in the methodology (chapter 3), the second part of the study in this thesis focuses on developing a 5D BIM model using BIM tools. The BIM development will be covered in the next chapter. The focus of this chapter is to determine the various information required for developing the fourth dimension (schedule) and fifth dimension (cost) of a BIM model. These information will then be used to prepare a schedule and cost integrated 3D BIM model in the next chapter.

5.1 Project Scheduling

Project scheduling is not merely a matter of using scheduling software such as MS Project and Primavera. Developing a project schedule generally comprises of five steps or process which are described below:

- **Defining activities:** It is the process of identifying and documenting the specific actions to be carried out to produce the project deliverable (i.e. the product or service delivered by the project). In order to define the activities in the project, the so-called "Work Breakdown Structures (WBS)" should be created.

  Work Breakdown Structures (WBS) - it is a hierarchical decomposition of the project work to accomplish the project objectives and create the required deliverables. Each descending level of the WBS represents an increasingly detailed definition of the project work. At the highest level of the hierarchy, the project itself is shown. At the next level, the project's major subdivisions are shown. Each major subdivision is further subdivided into additional levels as required to identify in sufficient detail all of the work involved in the project. The lowest level of a WBS which cannot be subdivided any further is called a **work package**. WBS enables us to identify the various activities involved in the project and thereby allowing us to prepare project schedule and cost estimation. Fig.5.1 below provides an illustration of a WBS.

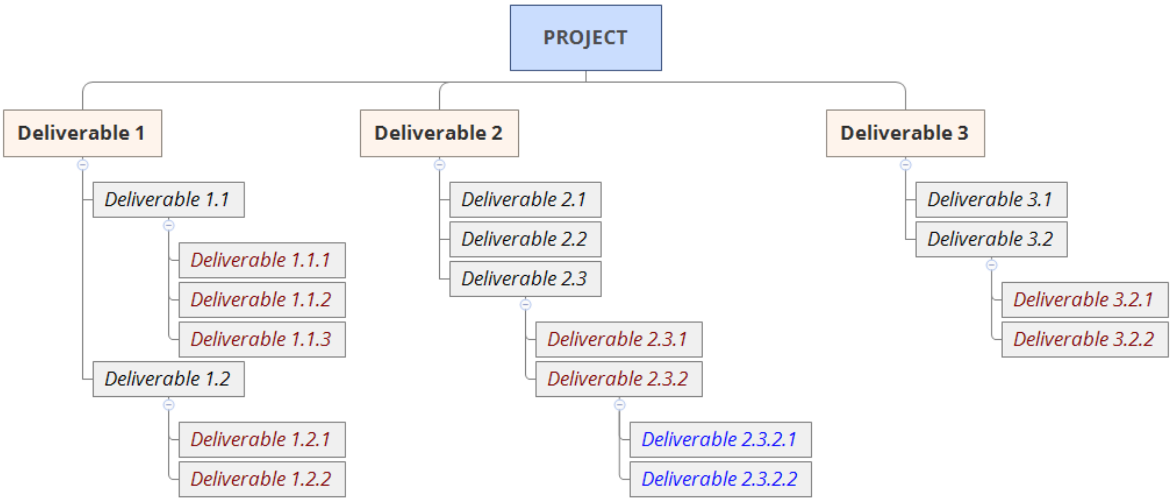


Figure 5.1: Illustration of Work Breakdown Structure (WBS)

- **Sequencing the activities:** It is the process of identifying and documenting relationships among the project activities; i.e. determining activity dependencies. There are four dependencies in project scheduling: Finish-to-Start (FS), Finish-to-Finish (FF), Start-to-start (SS), Start-to-finish (SF). In addition to the four dependencies, Leads and Lags between activities (if any) is also determined in this process. Leads are used in some circumstances to advance a successor activity with respect to the predecessor activity, and Lags are used in some circumstances some period of time is required to elapse between predecessor and successor activity without any work being performed.

- **Estimating activity resources:** This process involves determining the quantity and type of resources required to perform the activities. Project resources include: manpower, machinery (tools and equipment), money (funding) and other forms of resources needed to complete an activity.

- **Estimating activity duration:** It involves the process of estimating the number of work periods or duration needed to complete individual activities with available estimated resources. Some of the techniques used to estimate activity duration are:

  1. Expert Judgement: This technique of activity duration estimation utilizes the expertise of individuals in the area of project schedule development, management and control and other related disciplines.

  2. Analogous Estimating: In this technique, past projects with similar nature and complexity are used as basis for estimating the activity duration in the current project. This is usually used when there is no much information available about the activities in the current project. Therefore, this technique is suitable in the preliminary stages of the project life-cycle when detail design information cannot be accessed.

3. Parametric Estimating: This technique also uses information from past projects or other information sources but establishes relationship between them and the current project. It identities the unit duration and the number of units required for the current activity. For example, if in a previous project performing a 5 meter long activity required 2 working days, in the current project similar activity but with 10 meter length will require 4 working days.

4. Three-point Estimating: Unlike the above three techniques which considers a single scenario, Three-point Estimating technique takes into account uncertainties and risks in the determination of activity duration. It does that by considering three kinds of times: Most Likely Time (M), Optimistic Time (O) and Pessimistic Time (P).

Most Likely Time - is the duration of the activity considering most likely scenarios based on the availability of determined resources for the activity, assigned dependencies, the productivity of resources considered and other things related to the activity.
Optimistic Time - is the duration of the activity considering best-case scenarios.
Most Likely Time - is the duration of the activity considering worst-case scenarios.

$$ExpectedTime = \frac{Optimistic + 4 * MostLikely + Pessimistic}{6} \tag{5.1}$$

or

$$ExpectedTime = \frac{Optimistic + MostLikely + Pessimistic}{3} \tag{5.2}$$

The first formula uses the so-called "beta distribution" whereas the second uses "triangular distribution (average)" [Turner, 2017] .

- **Developing the schedule:** It involves the process of analyzing activity sequences, duration, required resources and schedule constraints to create schedule for the project.

The information required for developing a project schedule can be summarized as follow:

1. Activity (Task) list
2. Estimated duration
3. Milestone list
4. Activity dependencies

5. Lead and lag time information
6. Resource requirements
7. Risk register
8. Resource calendars
9. Project calendar
10. Working hours
11. Project information (name, start and end dates)
12. Schedule management plan: it is part of the project management plan which defines the method used and the level of accuracy along with other criteria required to sequence activities, and method and tool used to create the schedule and how the schedule is to be calculated.
13. Government and industry standards (if any) related to project schedule development.

The below diagram depicts the mapping of schedule information with the corresponding representation in IFC open standard.

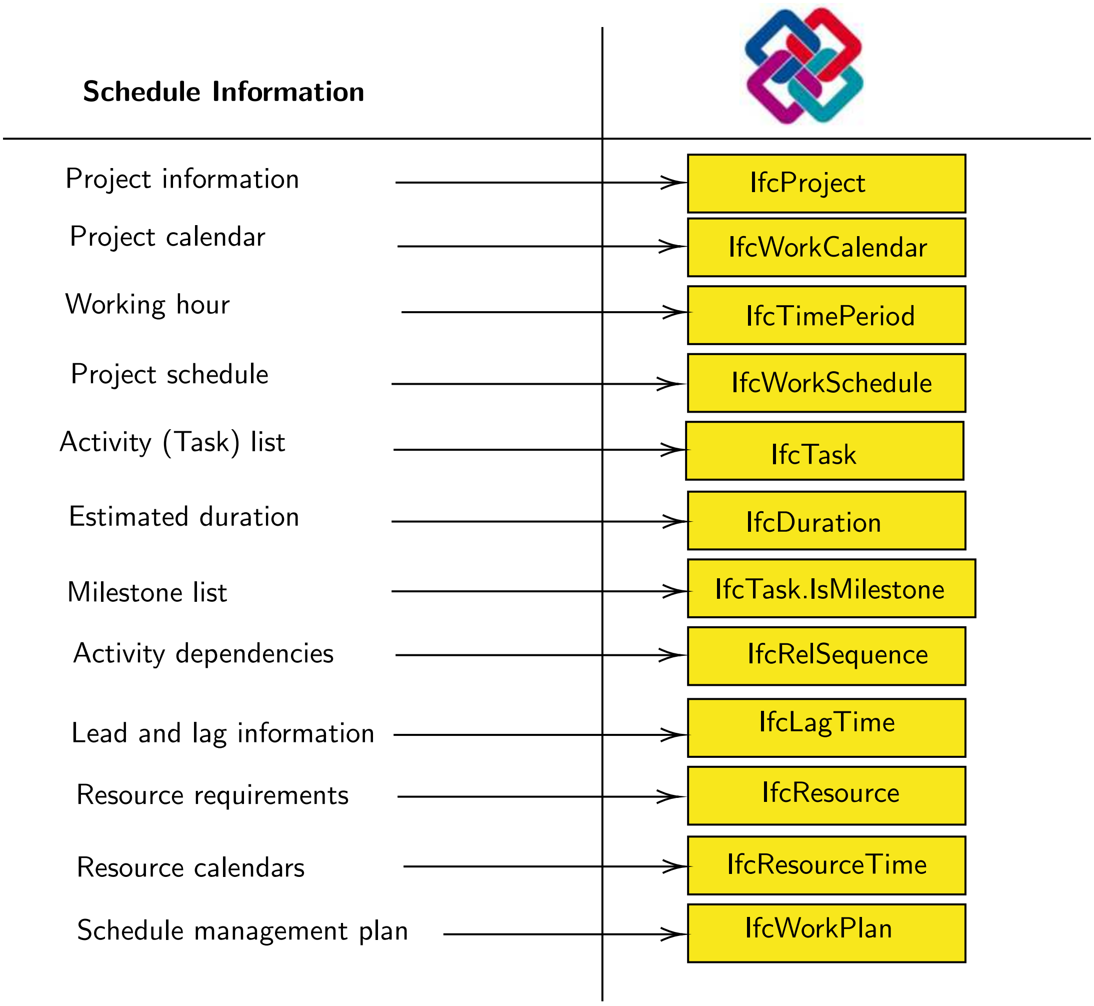


Fig.5.2 below provides the project schedule relationships in the open standard IFC schema.

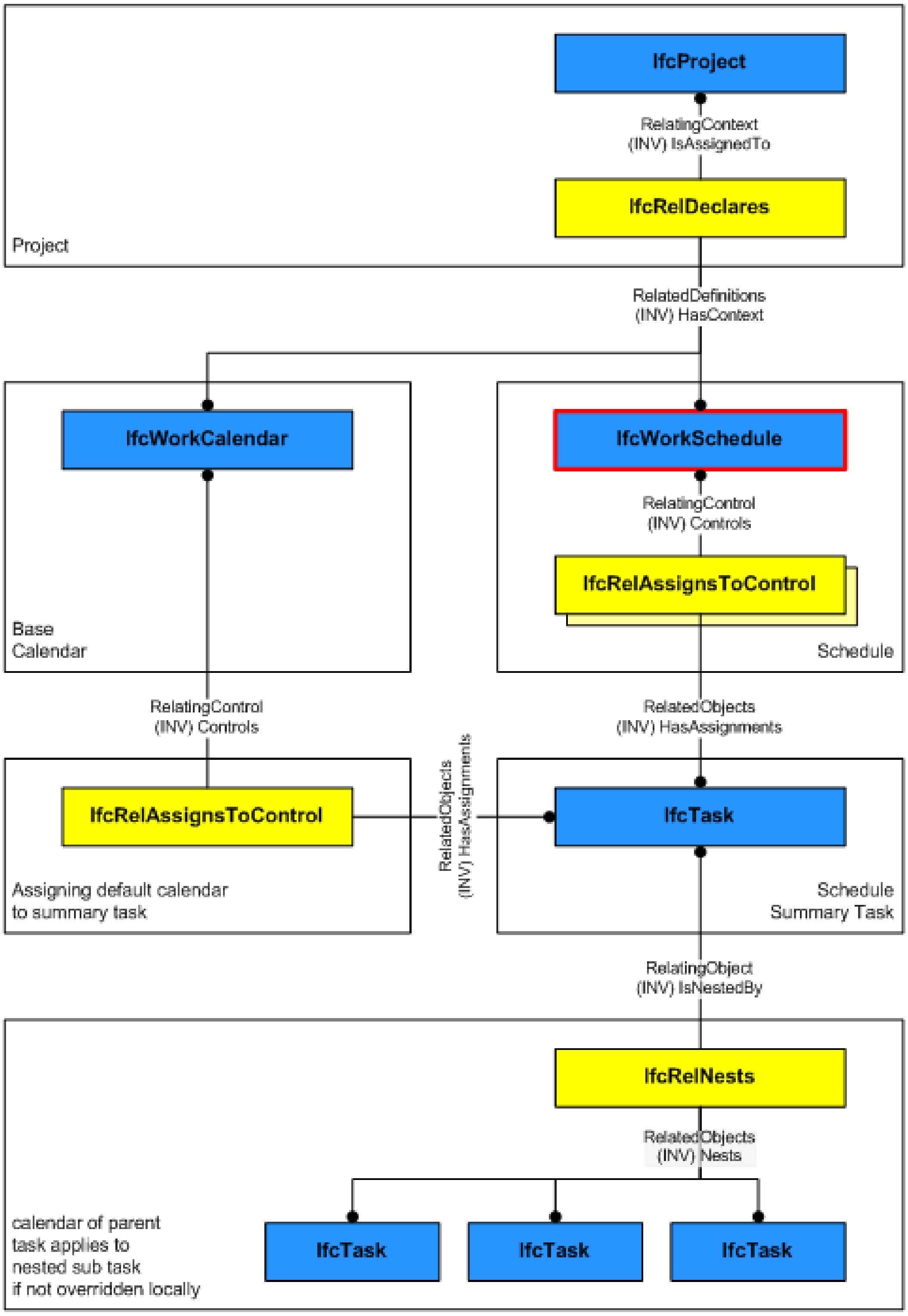


Figure 5.2: Work schedule relationships(Source: buildingSMART [n.d.])

5.2 Project Cost Estimating

Project cost estimation and calculation is one of the most important activities carried out throughout the life-cycle of the project. Due to the uniqueness of every construction project, cost estimation is one of the challenging tasks in the AEC industry today. Even thought cost estimation tools or methods of work collaboration facilitate the estimation work, estimation itself is not just a matter of using certain tools of estimation but rather requires experience and skills. Estimation process can be improved with the help of Building Information Modeling (BIM), but BIM should not be taken as a replacement for experience in estimation [Eastman et al., 2011].

According to the bill of quantities (BoQ) technique for estimation, estimation task comprises of five steps. First, the total project work is divided into BoQ-items; also known as cost-items. Second, quantities for the cost-items is computed. Third, required resources for each cost-item is calculated based on national and local prices for the resources (i.e. equipment and tools, manpower, material, etc.) or based on price database available in the company. Fourth, cost value of cost-items is determined by adding overheads to the already calculated costs of resources. Finally, all cost-items are added-up to give the cost of the project.

The main activities involved in cost estimation is briefly described below.

- **Determination of BoQ-items (cost-items):** This involves breaking down and grouping the project work into into elementary physical parts, with their own logical or functional identity relatable to the construction work. For example, BoQ-item for a building project may include: earthworks, foundation structures super-structures, plaster, fixtures, iron works and similar, external works, plumbing and sanitary equipment, electrical installations and lifting, air-conditioning system, fire safety system. The work breakdown structure discussed in section 5.1 is useful tool to create BoQ-items for the project.

- **Quantity Take-off (QTO):** This involves measuring the dimensions of the different components or elements constituting the necessary works of the project, such as length, width, thickness, weight, to determine the quantities of those components which will be used for cost estimation. As quantity take-off provides the quantities and the units of measure for works and resources which will be used in the estimation process, it is considered to be a significantly important task for cost estimation [Elbeltagi, n.d.].

  In the traditional ways of estimation, quantity take-off is carried out by manually reading the dimensions components from printed drawings or from CAD drawings available in a computer; and then these quantities are manually inserted into a spreadsheet to form the BoQ or into estimation tools. Nowadays, however, with the help of intelligent 3D BIM models automatic quantity take-off is possible. According to Ramaji et al. one of the primary reasons construction companies prefer working with BIM is due to its ability to facilitate cost estimation; quantity take-off is made from 3D BIM models and then linked to cost estimating database. Fig.5.3 below presents a conceptual diagram for the traditional and BIM-based quantity take-off and estimation process.

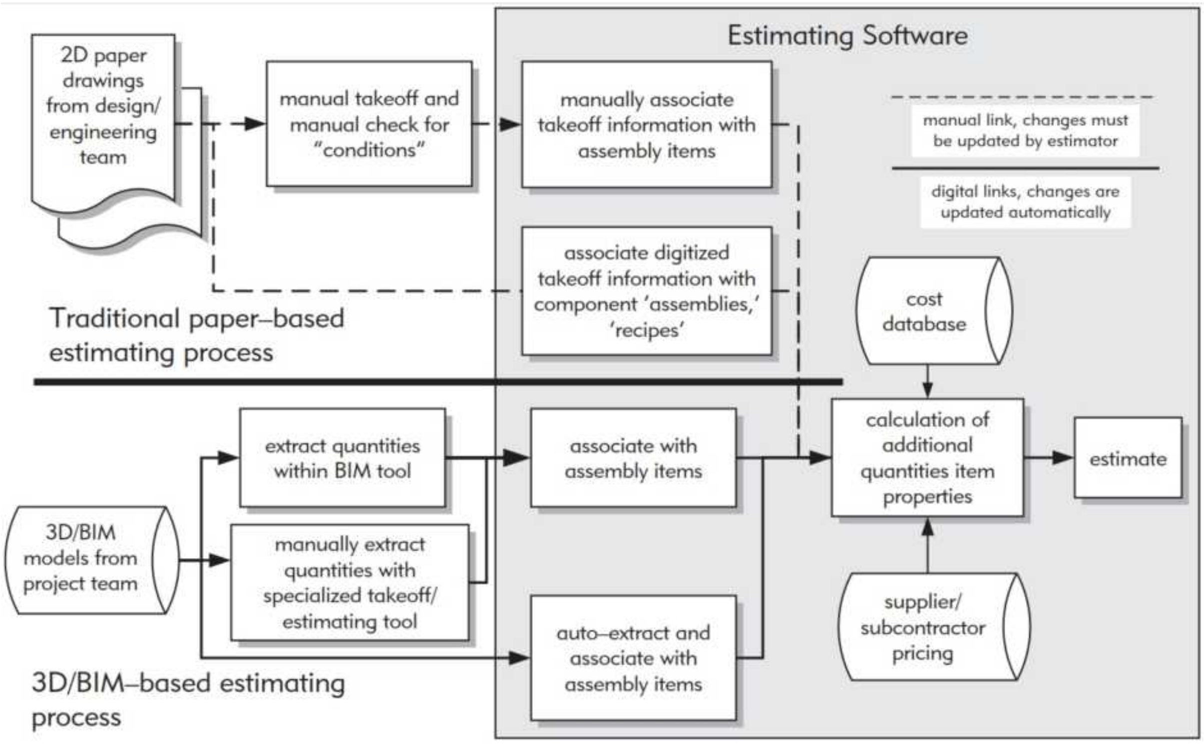


Figure 5.3: Traditional and BIM-based quantity take-off and estimation process(Adapted from: Eastman et al. [2011])

- **Estimating activity resources:** This step has been discussed in section 5.1 for developing a project schedule. The same can be used as an input for the activities' cost estimation. As this step identifies the types and quantity of the various resources required to complete project activities, it enables us to estimate the cost of activities based on the respective resource's price in the market or internal database.

- **Estimating activity duration:** This step has also been discussed in section 5.1 for developing a project schedule. The same can be used as an input for the activities' cost estimation. "[Activity] duration estimates will affect cost estimates when resources are charged per unit of time and when there are seasonal fluctuations in costs" [Turner, 2017].

- **Determination of prices (cost estimation):** It is the determination of the economic value of the calculated quantity take-offs and thereby estimating the cost of the project work [BibLus, n.d.]. The quantity take-off of each activity is multiplied by the unit price (unit rate) of that activity to give the cost estimate for that particular activity. Aggregation of cost estimates of all activities is what results in the project cost. The unit price (unit rate) information may be obtained from company's internal price database for activities or from price books available on the market/region or by performing the so-called "Rate Analysis". Fig.5.4 below depicts the flow chart of cost estimation in construction projects.

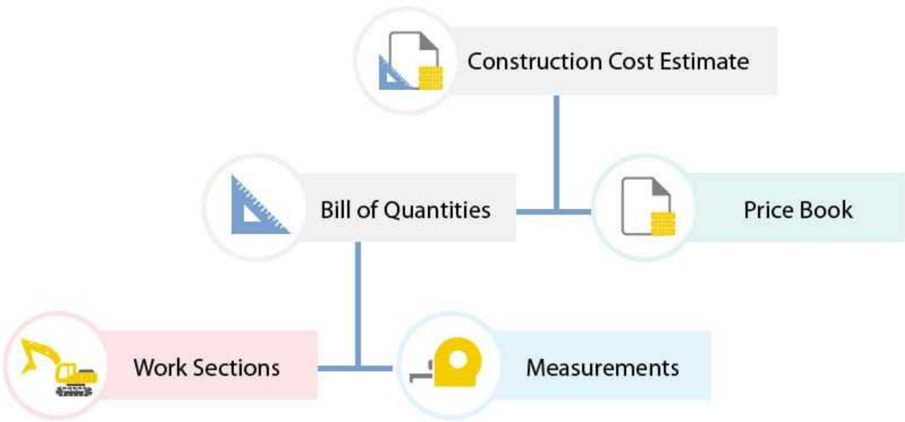


Figure 5.4: Flow chart of cost estimation process(Source: BibLus [n.d.])

Some of the techniques used for cost estimation are as follow:

1. Expert Judgment: This estimation technique is based on the expertise of individual(s) in previous similar projects or experience in cost estimation or experience in the construction industry.

2. Analogous estimating: This estimation technique makes use of information from previous similar project to estimation the current project. For example, if a previous similar project costed 2000 Euros for concreting in foundation, the same activity in the current project will cost 2000 Euros.

3. Parametric estimating: In this method, to estimate the cost of the current project, information from previous project is related to a variable in the current project. For example if 100 cubic meter of concreting in foundation in a previous similar project costed 2000 Euros, a similar task in the current project but with 200 cubic meter quantity will cost 4000 Euros. Therefore, this technique uses unit cost information from the previous similar project and project it to the current project. As a result, this technique will result a more accurate estimation compared to the analogous estimating technique.

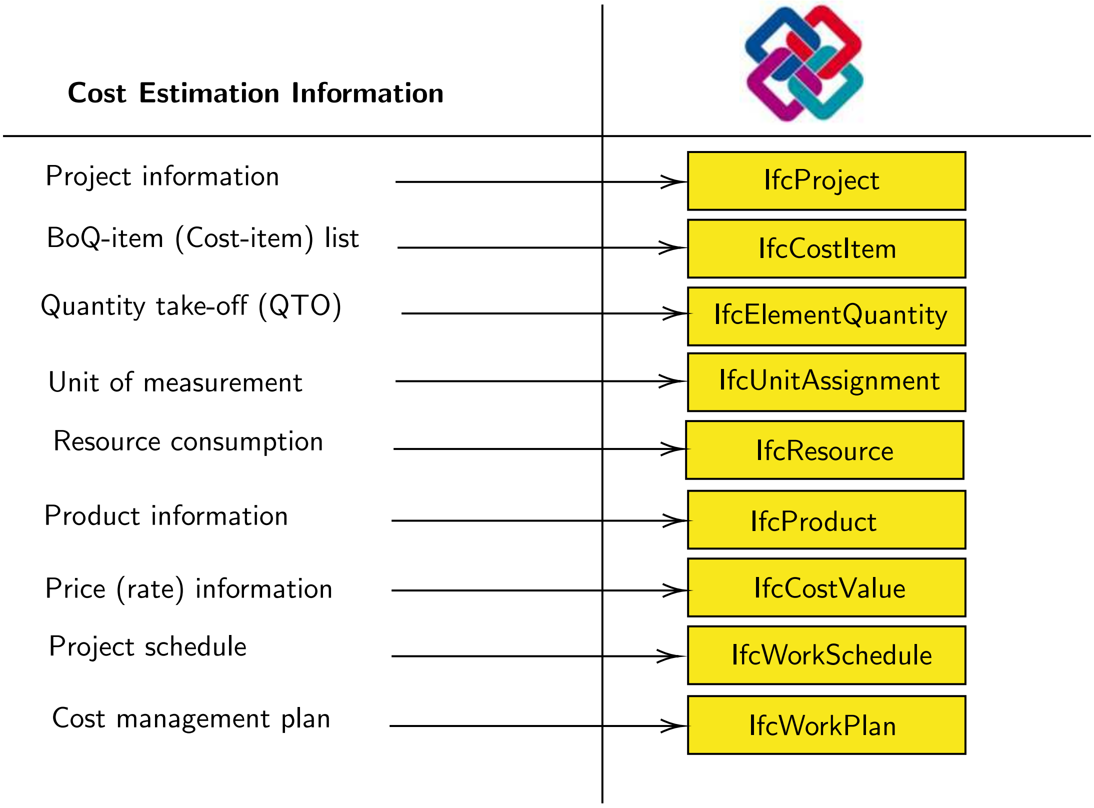
4. Three-point estimating: Similar to duration estimation technique discussed earlier in section 5.1, this cost estimation technique uses three scenarios to come up with the expected cost: **Most Likely Cost (M)**, **Optimistic Cost (O)** and **Pessimistic Cost (P)**. Then these three costs are put into an equation (see equations 5.1 and 5.2) to develop the expected cost estimate for that activity. According to Turner [2017], "cost estimates based on three points with an assumed distribution provide an expected cost and clarify the range of uncertainty around the expected cost".

5. Bottom-up estimating: This technique in cost estimation involves estimating individual activities in the project and then adding those estimates up to a higher level in order to produce the overall cost of the project.

The information required for developing a project cost estimate can be summarized as follow:

1. BoQ-item (Cost-item) list
2. Quantity take-off (QTO)
3. Unit of measurement
4. Resource consumption information
5. Product information (mode, type, shape, etc.)
6. Price (rate) information
7. Schedule information
8. Risk register: It helps to take into account project risks while estimating the cost.
9. Project information
10. Cost management plan: it is part of the project management plan and describes the methods to be used for cost estimation and the level of accuracy and precision required.
11. Market conditions: they are useful information for estimation as they show the products and services available in the market.
12. Currency exchange rate and inflation information: during the course of the project, currency exchange rates may fluctuate and inflation may occur. Therefore, these should be taken into account during the cost estimation.

The below diagram depicts the mapping of cost estimation information with the corresponding representation in IFC open standard.



Components of a Project Cost

Project Cost Estimate indicates the overall cost for the completion of the project work including the costs directly related to production process and those costs indirectly related to production and that have to be considered in the cost estimation.

- **Direct Costs:** these are the costs directly associated to the production process in the project. Costs included in the Direct Costs are costs of labor, material, tools and equipment including their fuel consumption and all other costs directly involved in the production process. Costs related to subcontract works are also included in Direct Costs [Bennett, 2003; Jackson, 2010].

- **Indirect Costs:** Chen and Liew [2002] defines Indirect Costs as "All costs that do not become part of the final installation but which are required for the orderly completion of the installation." They are costs which are not directly associated to the production process but business and the construction may not continue without them[Flanagan and Jewell, 2018]. Indirect Costs include costs related to supervision, planning and management, bonds and insurance, temporary site setups, temporary utilities, testing and inspections, job photographs, safety supplies, security fencing and barricades, trash and debris removal, cleanup, etc. In construction projects project-specific Indirect Costs are estimated in the Preliminaries (Prelims) items in the BoQ [Flanagan and Jewell, 2018].

- **Overhead:** According to Sears et al. [2008] Overhead and Indirect Cost indicate the same thing and they refer to all costs incurred during the completion of a project but are not associated directly to any specific work in the project. The authors divide Overhead into two: project or field overhead and office overhead. Job overhead are the indirect expenses related to a specific construction project, whereas office overhead (also called head office overhead) are those indirect expenses that are shared by more than one project. Office overhead include salaries of general and executive manager, tendering department, marketing, advertising, information technology, taxes, insurances, etc. 5 to 15% of the direct cost or more is normally considered as an allowance for job overhead [Sears et al., 2008].

- **Markup:** this is the amount added to the Cost Estimate at end of the estimation process to arrive at the Tender Price and it accounts for profit margin, exceptional risks, financing charges, cash flow, competition, etc. [Flanagan and Jewell, 2018]. According to Bennett [2003] Markup is the sum of amount for profit margin and contingency or risk.

  Fig.5.5 below illustrates the various cost elements involved in a construction project and in the cost built-up process.

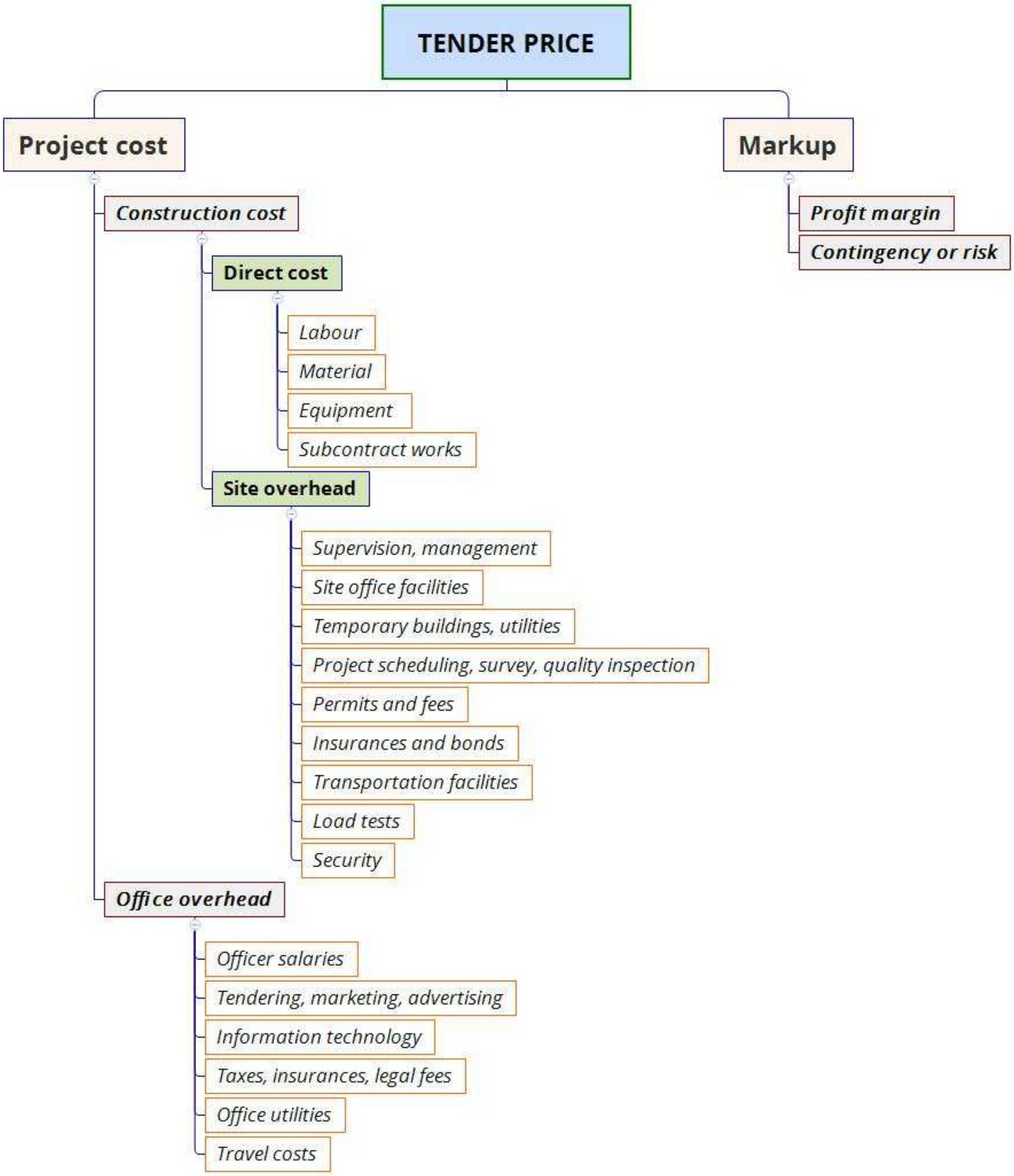


Figure 5.5: Cost elements in a construction project

Chapter 6

Case Study: 5D BIM Model Development

In the methodology chapter (i.e. chapter 3), it was indicated that BIM model of a building structure will be developed using various BIM tools and applications. This chapter will provide all the practical works and procedures for 5D BIM model development adopted in this study. The process will be presented sequentially; starting from geometrical CAD model creation to schedule and cost integrated 4D and 5D BIM model development.

6.1 2D Model Development

The building structure in the case study comprises of 3-story office building with structural and architectural components. The total built-up area of the building is 1360m2, with outer dimensions of each floor being 40.8m long and 10.95m wide. The building comprises of 36 rooms including office, conference and toilet rooms.

The preparation of 2D plans of the 3-story building in AutoCAD marks the first step adopted in the BIM model development process. Fig.6.1 below shows the ground floor plan. The other floor plans will have a similar structure with slight differences in the view. These 2D floor plans were exported to Revit in order to develop architectural 3D BIM models based on these floor plans.

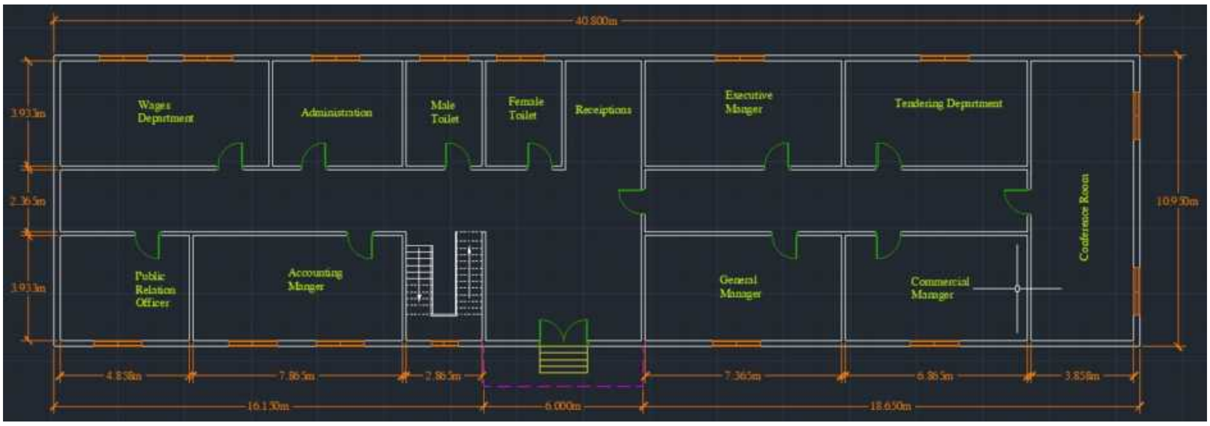


Figure 6.1: Ground floor plan of the 3-story office building

Based on the 2D floor plans, the column layout plan depicted in fig.6.2 below was also prepared. This layout plan was used as a basis for developing structural 3D BIM model in Revit and Tekla

Structures.

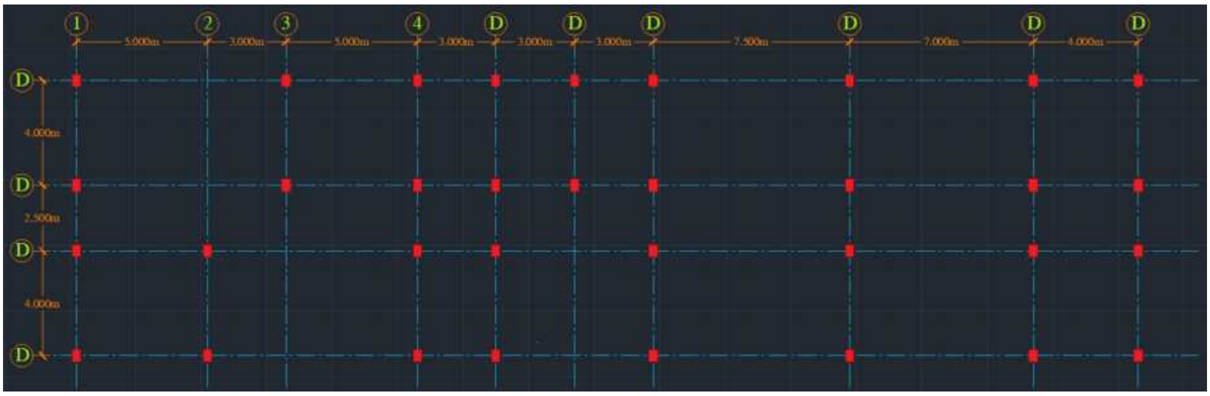


Figure 6.2: Column layout plan of the 3-story office building

6.2 3D BIM Model Development

The second step in the 5D BIM model development process is the development of 3D BIM models. Two kinds of 3D models were developed separately: architectural and structural.

6.2.1 Architectural 3D BIM Model

The architectural 3D model was prepared by importing the 2D floor plans from AutoCAD into respective levels created in Revit. Thereafter, using the 2D plans as guides, the merely graphical plans in the previous step were developed to 3D BIM models comprising of both geometrical and non-geometrical properties. Fig.6.3 below illustrates the placement of exterior walls and outer windows on the imported 2D plans.

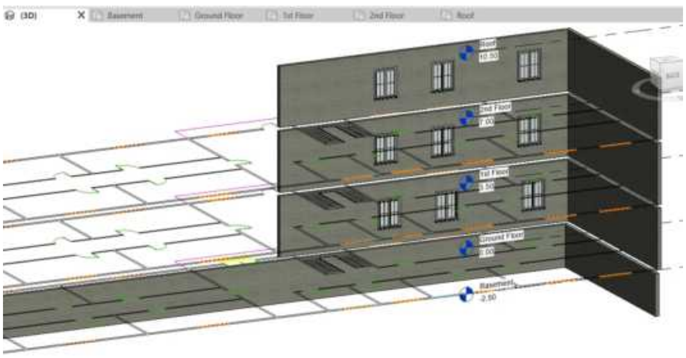


Figure 6.3: Process of developing 2D CAD plans to 3D BIM model in Revit

The completed architectural 3D BIM model developed in Revit and its orthographic projections showing the various views are depicted in fig.6.4.

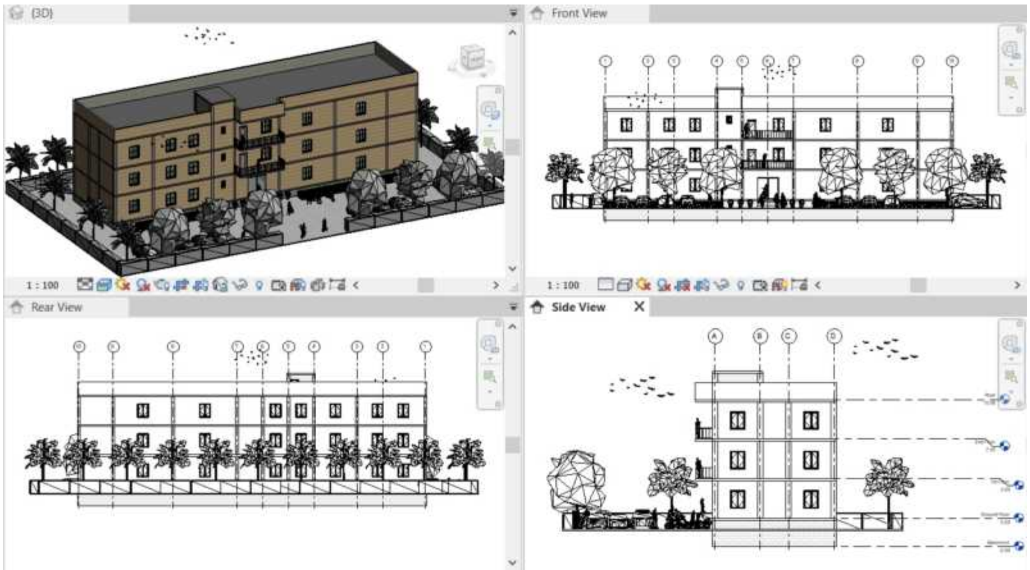


Figure 6.4: Orthographic projections of architectural 3D BIM model

The 3D model was then rendered and visualized using Enscape application along with Revit to produce a realistic architectural 3D model. Fig.6.5 below presents the finalized architectural 3D BIM model.

Figure 6.5: Visualization of completed architectural 3D BIM model

By introducing cutting planes from three sides of the 3D model, a sectional view of the model was generated which enables the visualization of the interiors and other details that do not appear in the exterior 3D model view. This is shown in the following fig.6.6.

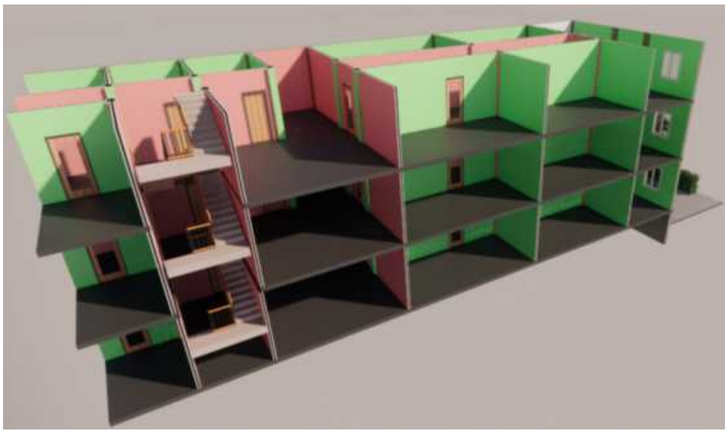


Figure 6.6: Sectional view of architectural 3D BIM model

6.2.2 Structural 3D BIM Model

Structural 3D BIM model was developed both in Revit and Tekla Structures. The 3D modeling in Tekla begins by importing the column layout plan created in AutoCAD which was presented in the previous section. Material properties and sizes of elements (foundations, columns, beams and slabs) were first defined in Tekla. Thereafter, by following the imported column layout plan, 3D BIM elements were placed for structural columns and foundations. This step is shown in fig.6.7 below. Once the foundations and columns were properly modeled, beams were positioned in-between columns and slabs were also placed over the beams and columns. The completed 3D model is presented in fig.6.8 below.

After some issues were discovered in transferring the 3D BIM model from Tekla Structures to Navisworks Manage and Vico Office, a second structural 3D BIM model was developed in Revit. This structural BIM model along with the architectural BIM model presented in the earlier section

(a) (b)

Figure 6.7: Modeling in Tekla Structures: importing 2D column layout plan from AutoCAD (a) and placing columns and foundations (b)

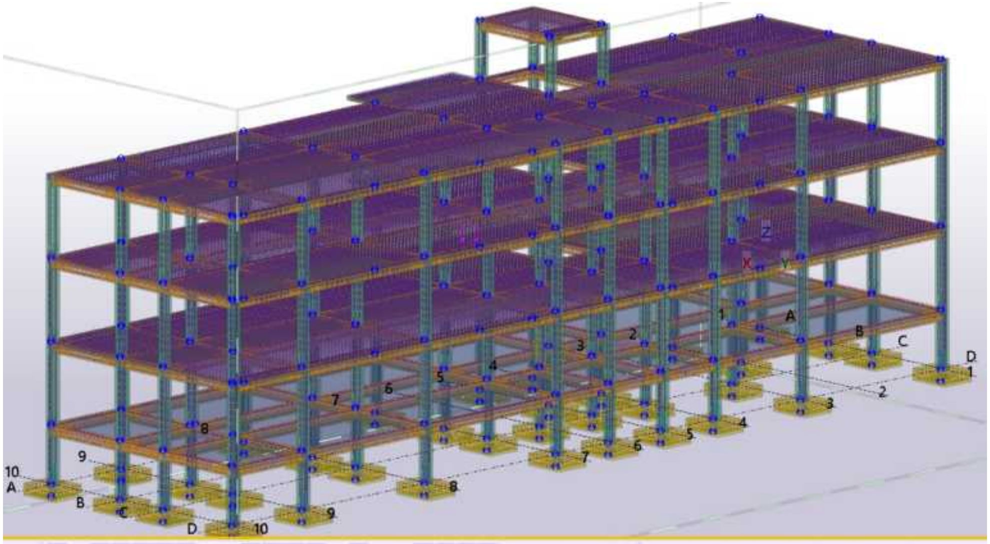


Figure 6.8: Completed structural 3D BIM model in Tekla Structures

was used in the subsequent 4D and 5D BIM model development processes. The completed 3D model in Revit is shown in the following fig.6.9.

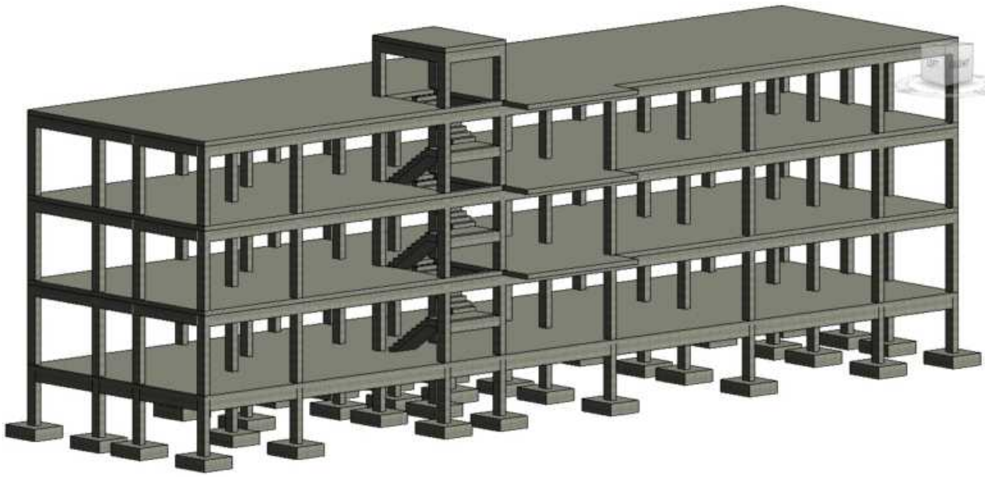


Figure 6.9: Structural 3D BIM model in Revit

6.2.3 Quality Check of 3D BIM Models

Quality check was performed on 3D BIM models before exporting them to 4D and 5D BIM tools for further BIM model development. The quality check performed include clash detection between model elements and safety issues (for example, if a safety barrier on a balcony is missing from the 3D model). These quality checks on 3D models were achieved in Solibri Model Checker (SMC). Fig.6.10 below shows the adopted procedure for quality check on 3D models. Following these steps, 3D models were revised several times to solve both detected clashes and safety issues.

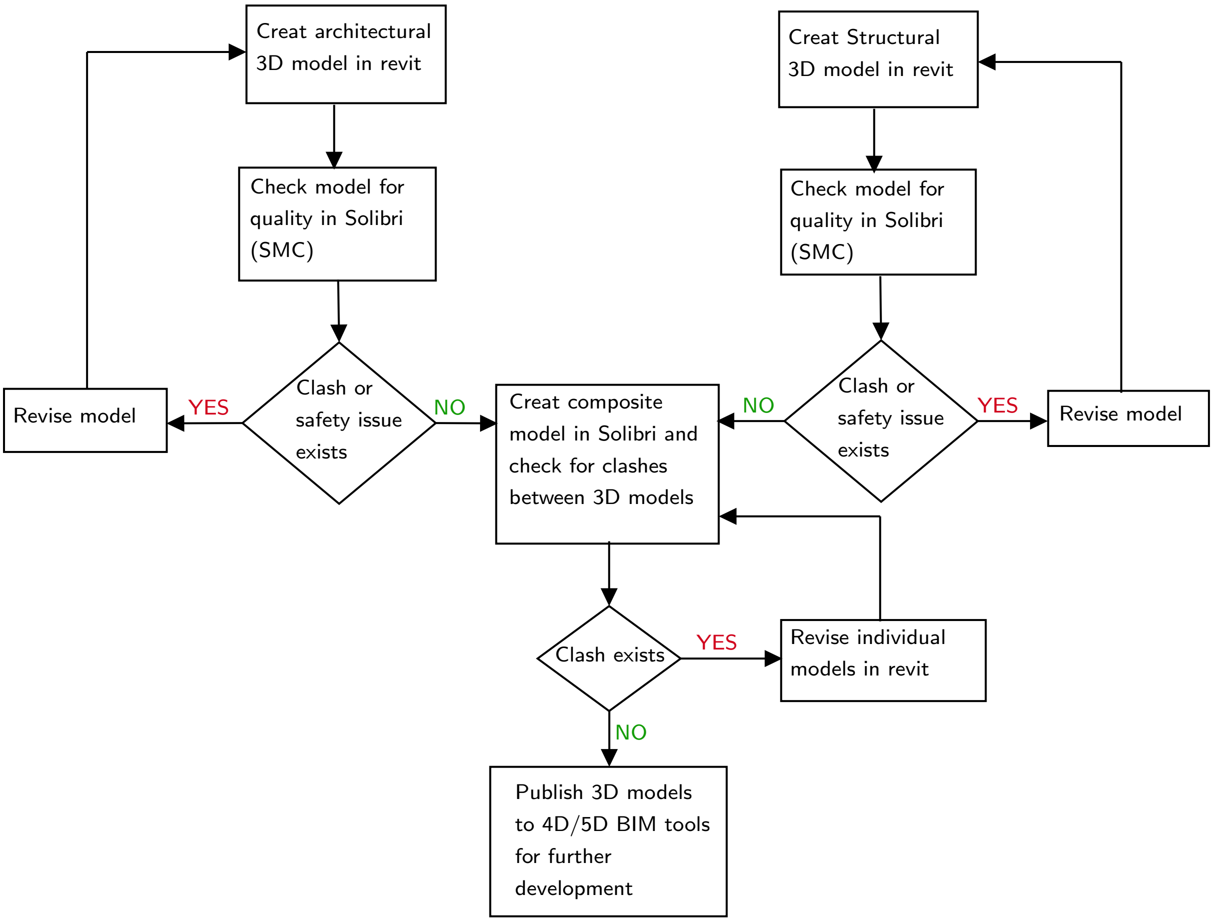


Figure 6.10: Flow chart showing quality checking and 3D BIM modeling procedure prior to exporting to 4D and 5D BIM tools

As indicated earlier, the quality checking was a repetitive process and adjustments were made to the models several times until clashes between model elements were eliminated and major safety issues do not exist. Some of the quality checking performed on the 3D models can be observed and visualized in the following fig.6.11.

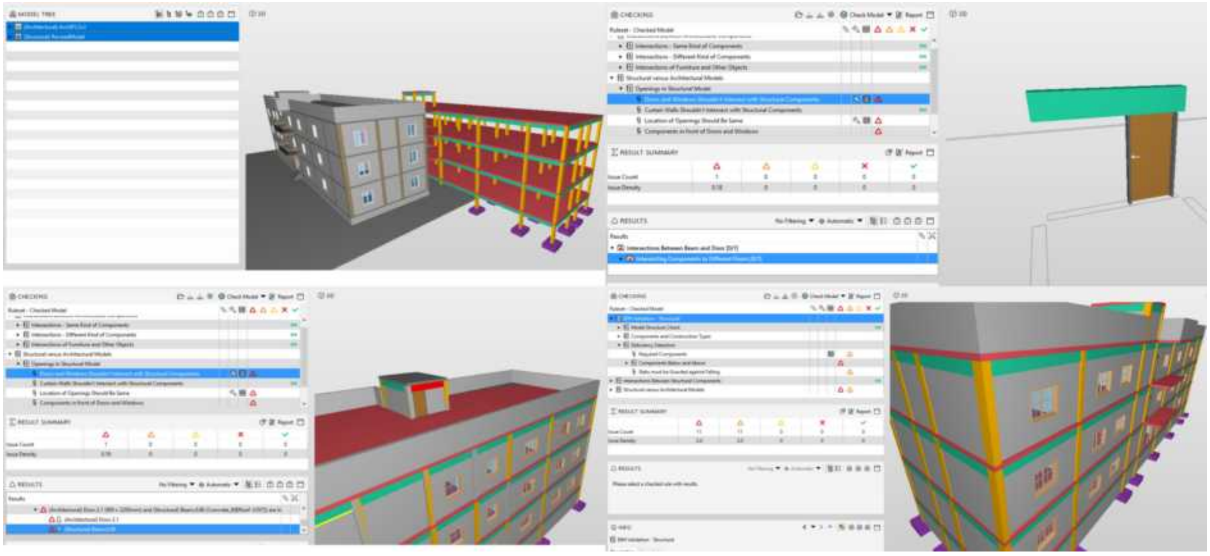


Figure 6.11: Quality checking in Solibri Model Checker (SMC)

6.3 4D and 5D BIM Model Development

This part of the BIM model development process introduces a fourth dimension (project schedule) and a fifth dimension (project cost) into the completed 3D BIM models presented in the previous section. The procedure begins by exporting and publishing the 3D models unto 4D and 5D BIM tools. In this study, Navisworks Manage and Vico Office were considered for the purpose. The outcome at the end of this process is a schedule and cost integrated 5D BIM model.

6.3.1 Project Schedule and Cost Estimate Preparation Processes

This section presents information related to the schedule preparation and cost estimation, including the processes followed, techniques adopted, included and excluded project work items and data sources used.

In the methodology chapter it was specified that the building model in the case study of this research work excludes MEP works; only architectural and structural works are considered. In addition, items related to project site preparation and management were also excepted from the project schedule and cost estimate. As such, both the project schedule and cost estimate are primarily based on the developed architectural and structural 3D BIM models. Moreover, landscaping items that were shown on the architectural 3D BIM model are also excluded in the cost estimation and schedule. This is because these items were added to the model after completion of the estimation and schedule in order to enhance the aesthetics of the architectural model.

Project Schedule

The process of project schedule preparation requires a proper planning of works and determination of duration for project activities. Some of the techniques presented in section 5.1 for project scheduling were implemented here. Firstly, the project was hierarchically decomposed by creating Work Breakdown Structure (WBS) which is displayed in fig.6.12 below. The WBS was then used as a guide to prepare activity lists and to sequence the activities.

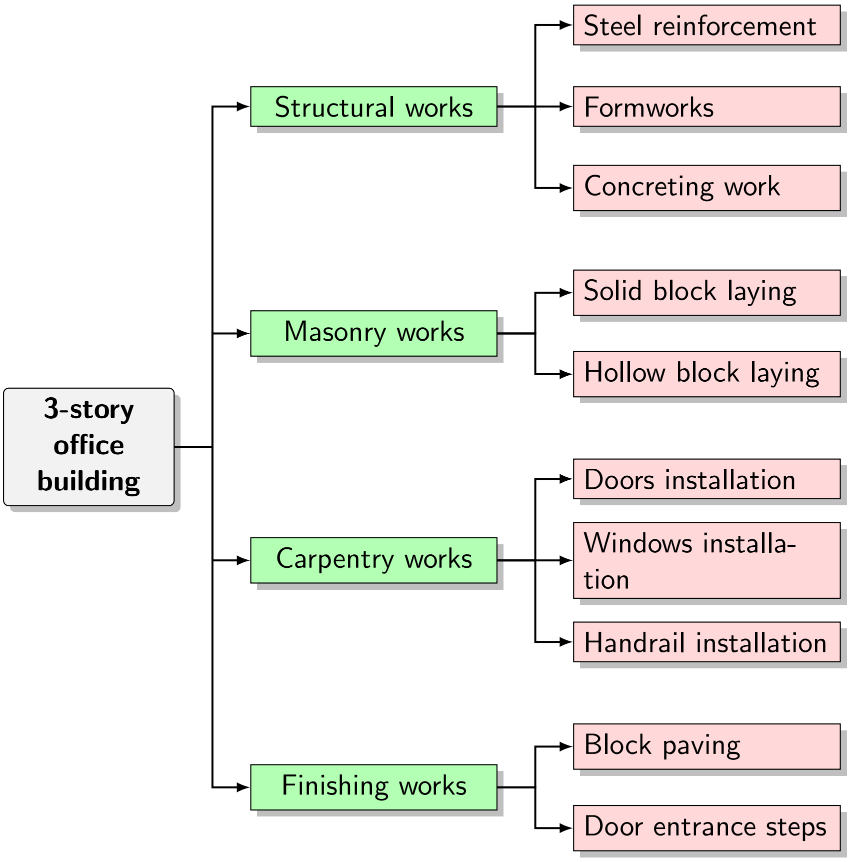


Figure 6.12: Work Breakdown Structure (WBS) of the project

The sequence of works for considered building structure in the case study follows the concept of frame structures. Accordingly, structural works (foundations, columns, beams, staircase and slabs) are completed first; followed by non-structural works (masonry works, carpentry works, etc.). Since gravity load acts vertically downward, structural works has to obviously commence from foundations and progress to higher floors consecutively. On the other hand, once the structural works are completed, the non-structural works can be started at any floor. However, it is a good practice to start from lower floors and proceed to upper ones, specially when labor and equipment resources are limited. Fig.6.13 below shows the complete sequence of works followed in the creation of project schedule for the BIM model.

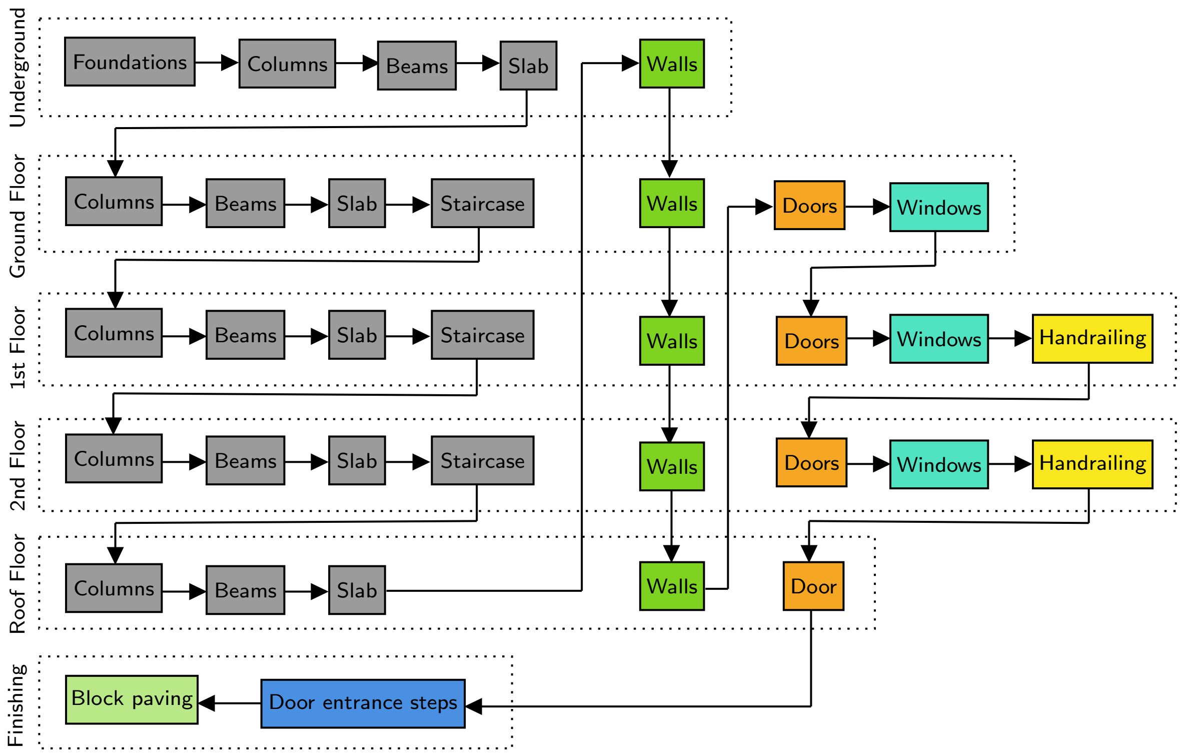


Figure 6.13: Sequence of works for the project

Duration of activities in the project schedule development process were determined based on certain work productivity rates. These productivity rates were considered on the basis of personal experience and literature found online related to building construction. Table 6.1 below provides productivity rates and crew information applied while developing the project schedule. In the table, the 'Productivity' column is the basic considered productivity without taking into account the labor resources assigned to the activities; whereas 'Crew productivity' is the actual productivity used for determining activity durations.

Table 6.1: Productivity rates and crews for project activities

Item description	Productivity	Crew	Crew productivity (UOM/Hr)
Steel fixing	1tonn/3mandays	3 steel fixers and 6 helpers	0.13tonn/hour
Formwork	3m2/manday	8 carpenters and 5 helpers	3m2/hour
Concreting	1m3/manhour	6 labours	6m3/hour
Excavation	100m3/day	2 labours	25m3/hour
Blockwork	3m3/manday	5 masons and 10 helpers	1.88m3/hour
Doors and windows installation	2nr./manday	2 carpenters and 4 helpers	0.5nr./hour
Handrailing	10m/manday	1 carpenter and 2 helpers	1.25m/hour
Block paving	20m2/manday	10 labours	25m2/hour

Cost Estimation

The process of cost estimation provided the fifth dimension to BIM model; and comparatively, it is the longest process in the integrated 5D BIM model development process. The steps and activities involved in cost estimation process were presented in earlier chapter (see: section 5.2). These were also implemented for the cost estimation in this study. The cost estimation was basically based on two major processes: **quantification** and **price determination** for utilized resources on project activities. The quantification process was based primarily on model-based takeoffs; however, non model-based virtual takeoffs , that were considered to be significant for the estimation, were also carried out for some items. For example, quantities of excavation for foundations and reinforcement steel for structural elements that were included in the cost estimate were non model-based as these were not included the 3D BIM model.

On the other hand, the price determination method for project activities comprised of three processes: assigning of activity resources, estimation of duration for which the resources will be utilized and pricing of the resources. And as it was already made clear in the methodology, price information of resources were obtained from Spon's Architects' and Builders' Price Books (AECOM [2015]) and Spon's European Construction Costs Handbook (Langdon and Everest [2000]) which are relevant sources for construction price information for UK and European countries including Germany, respectively. The following resources were covered in the pricing:

- Material resources

- Equipment resources
- Labour resources

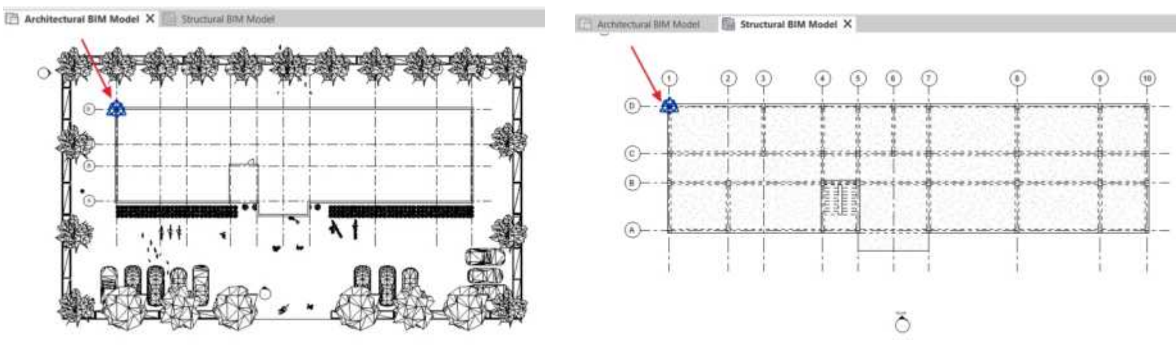
Furthermore, the cost estimation carried out in this study adopts the **Bottom-Up** estimation technique described in section 5.2. As such, the activities at lower level of the project work hierarchy were first priced and then aggregated to higher levels to generate cost estimate of the project.

6.3.2 Navisworks Manage

Importing of 3D BIM models to Navisworks Manage

3D BIM models (architectural and structural) prepared in Revit can be exported for Navisworks Manage in two ways. The first is by exporting the Revit file (.rvt) to an IFC (.ifc). Thereafter, in Navisworks Manage platform, the architectural and structural BIM models are imported as IFC files. The second way is using a Revit plugin which exports the Revil file (.rvt) to .nwc file format which Navisworks Manage can import. The second method, in addition to being faster , the imported models also appear with the material colors they were modeled in Revit, whereas when imported as IFCs every model element appears in gray color. Therefore, the second way was followed in this study.

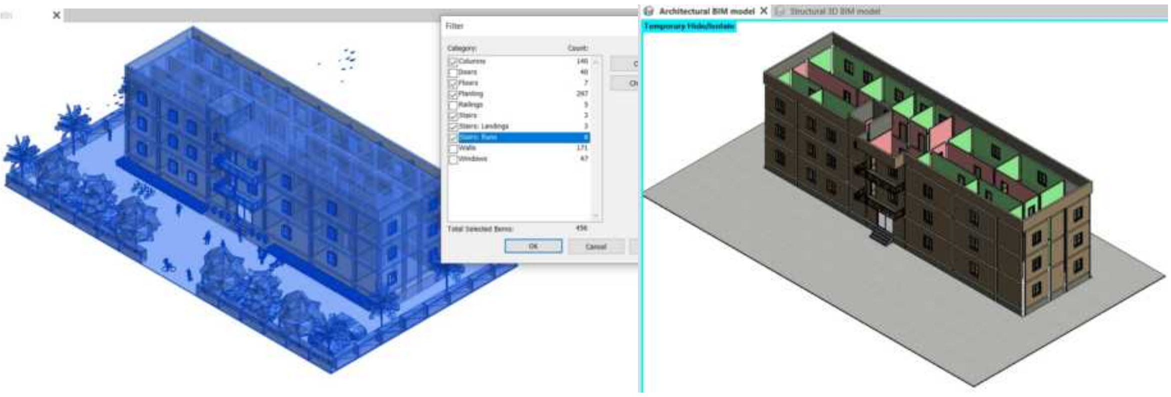
Since the architectural and structural models are imported to Navisworks Manage separately, it is necessary that the models fit together exactly so that a combined single 3D BIM model is achieved which will be used for developing 4D and 5D BIM models. Even though some trial and error technique can be applied in Navisworks to bring the models together, the simplest and accurate way is to set the origins of the models to a same point in Revit prior to exporting them to IFC and .nwc file formats. This process is shown in fig.6.14 below.



(a) (b)

Figure 6.14: Setting the origins of BIM models in Revit: architectural model (a) and structural model (b)

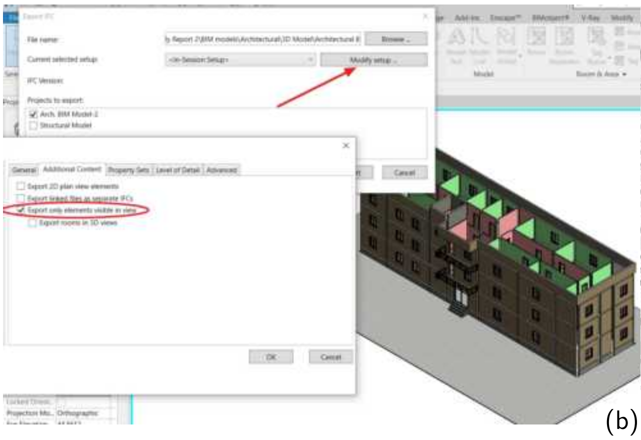
The architectural BIM model presented earlier in section 6.2.1, in addition to containing architectural components, it also comprises of structural elements such as columns, stairs and floor slabs. Nevertheless, these elements do not possess the required material properties, for example material type (concrete or steel), compressive strength of concrete, etc.; they are merely geometrical elements in order to allocate their spaces which helps in the modeling of architectural elements and to visualize the completed 3D model. The structural elements of the building model with the required specifications are included in the structural BIM model presented before in section 6.2.2. Since these structural members are found in both architectural and structural BIM models, when the BIM models are imported to Navisworks Manage and are combined to form a single BIM model in the manner explained earlier, duplication of components will occur, and Naviswork Manage's '**Clash Detective**' tool will regard these as detected clashes. Also, performing model quantification and estimation will duplicate the structural parts of the model. To avoid this issue, by making use of Revit's '**Filter**' tool, the structural components were filtered out from the architectural BIM model prior to exporting the model to IFC and .nwc formats. This will exclude structural elements from the architectural BIM model imported to Navisworks Manage. A similar technique is applied to avoid importing the landscaping, vechicles and peoples, that are observed in the architectural model, to Navisworks Manage. This approach of filtering out certain elements in Revit that are not needed for 4D and 5D BIM model development was also adopted in Vico Office. Fig.6.15 below demonstrates this procedure.



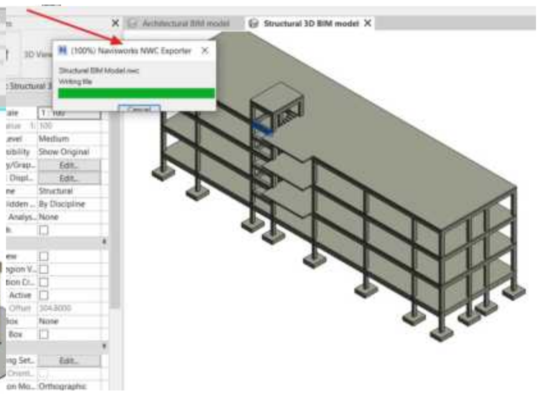
(a) Filtering out in progress (b) Architecural model ready for export

Figure 6.15: Filtering out process in Revit from architectural BIM model before exporting to IFC and .nwc formats

Once the filtering out was done, the .rvt file was exported to .nwc file format using Navisworks NWC exporter application. The elements hidden in the view are automatically excluded from the exported model. However, this automatic elimination and exclusion of hidden elements of Revit model from the export is not achieved when exporting to IFC. Therefore, in the settings of '**Export IFC**' window in Revit, the exporter is instructed to only export elements that are visible in the view. These two methods of model exporting in Revit are shown in the following fig.6.16.



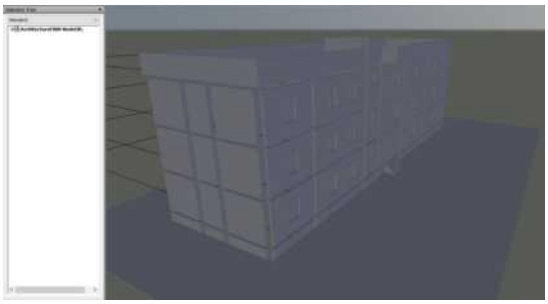
(a) Exporting architectural BIM model to IFC



(b) Exporting structural BIM model to .nwc using Navisworks NWC Exporter

Figure 6.16: Exporting Revit BIM models to IFC and NWC files

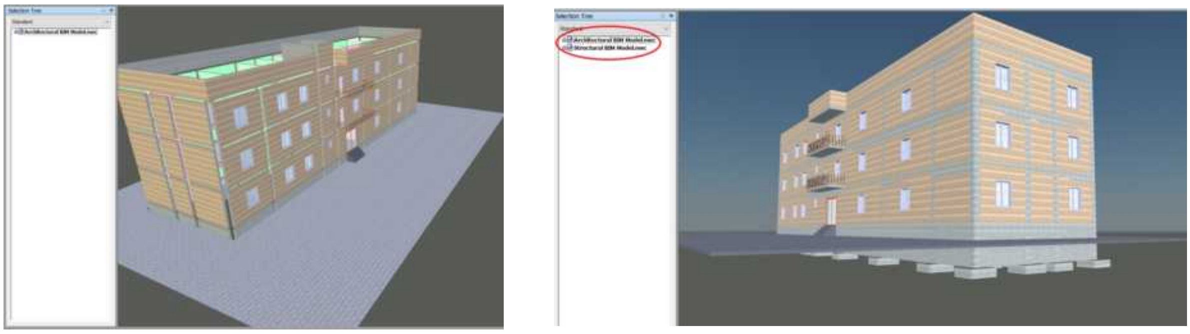
In Navisworks Manage, the BIM models exported earlier were then imported as IFC and NWC files. As the models were already set origin-to-origin, they fit together once imported. Thereafter, the combined BIM model was saved as NWF file, Naviswork Manage's native file format. This was the composite 3D BIM model upon which cost estimation and project scheduling was carried out. Fig.6.17 and fig.6.18 below depicts the model importing process in Navisworks.



(a) Imported architectural BIM model

(b) Architectural and structural combined BIM model

Figure 6.17: Importing BIM models to Navisworks Manage as IFC files



(a) Imported architectural BIM model (b) Architectural and structural combined BIM model

Figure 6.18: Importing BIM models to Navisworks Manage as NWC files

Scheduling and Estimation in Navisworks Manage

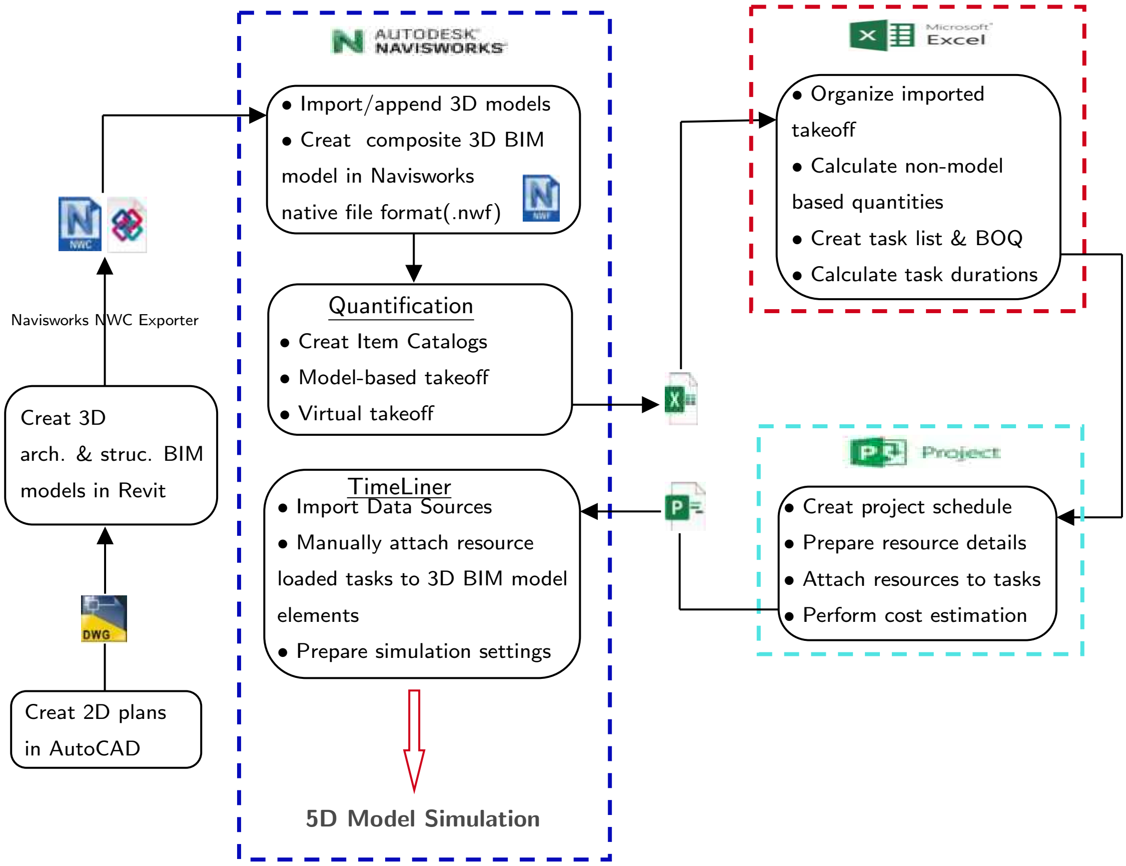


Figure 6.19: Procedure of 4D and 5D BIM model development in Navisworks Manage

The adopted procedure for 4D and 5D BIM model preparation in Navisworks Manage is shown in fig.6.19 above. Determination of model element quantities is the first step performed in Navisworks after the preparation of composite 3D BIM model. This was achieved through Naviswork Manage's '**Quantification**' tool which enables performing both model-based and virtual takeoffs. Thereafter, the takeoff data was exported to Microsoft Excel for further processing. The quantification process along with the steps is shown in fig.6.20 below.

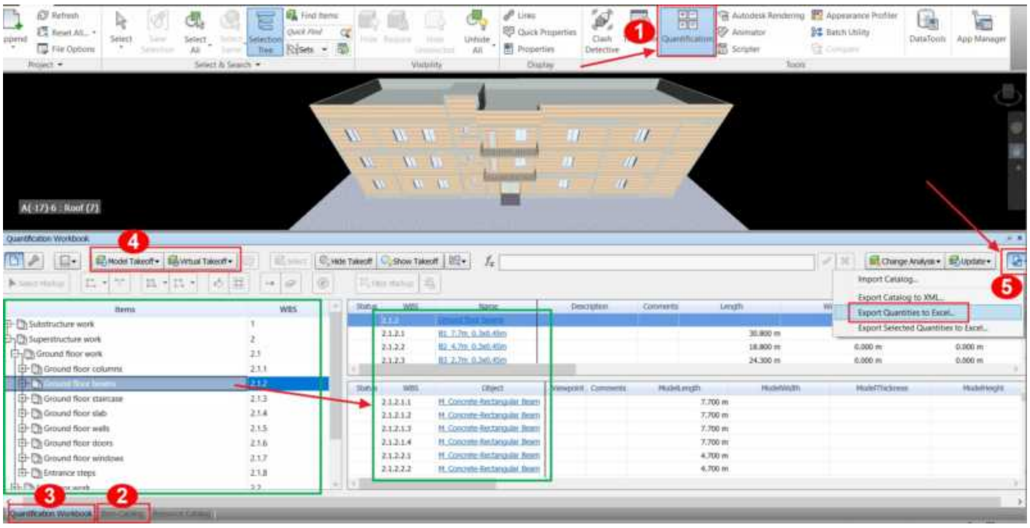


Figure 6.20: Model-based quantification in Navisworks Manage

Microsoft Excel and Microsoft Project were used alongside Navisworks for project schedule preparation, cost estimation and other general calculations required in the process of BIM model development. Even though Navisworks has certain schedule preparation functionalities, it is not feasible to be used for the size of building model adopted in this study. Therefore, both project schedule and costs for resources were prepared in Microsoft Project and later imported to Navisworks's '**TimeLiner**' tool. The main activities carried out in Microsoft Project with the support of Microsoft Excel include: definition of project tasks, determination of activity duration, scheduling of activities, determination of activity resources and pricing of resources. Fig.6.21 below depicts the scheduling and cost estimation process in Microsoft Project.

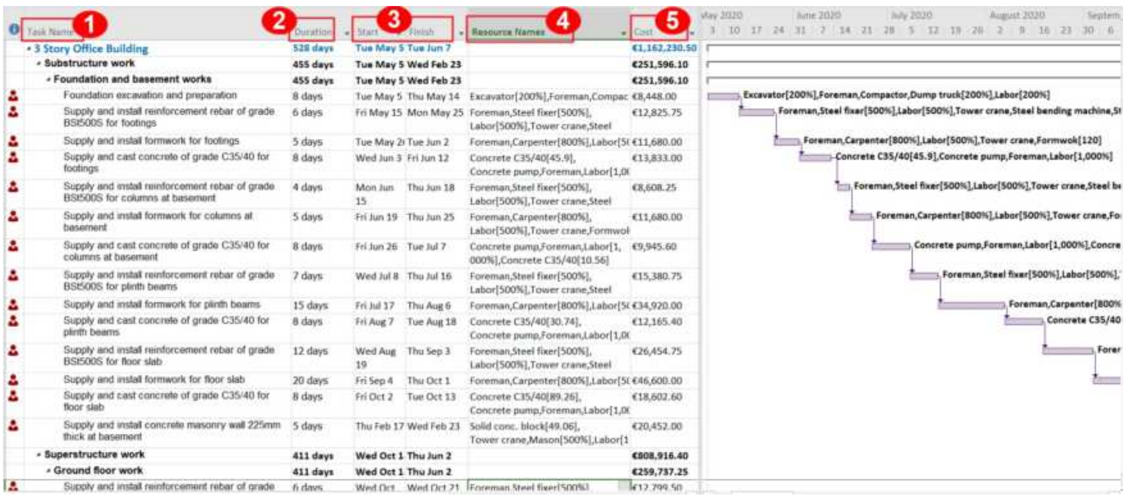


Figure 6.21: Project scheduling and resource estimation in Microsoft Project

The project schedule and cost from Microsoft Project was imported to Navisworks's TimeLiner in order to integrate the 4D (time) and 5D (cost) information to the composite 3D BIM model. The integration was achieved by manually linking each resourced-leaded and scheduled activity to the corresponding model element in the composite BIM model. This process is illustrated in fig.6.22 below. This step generated a schedule and cost integrated 5D BIM model.

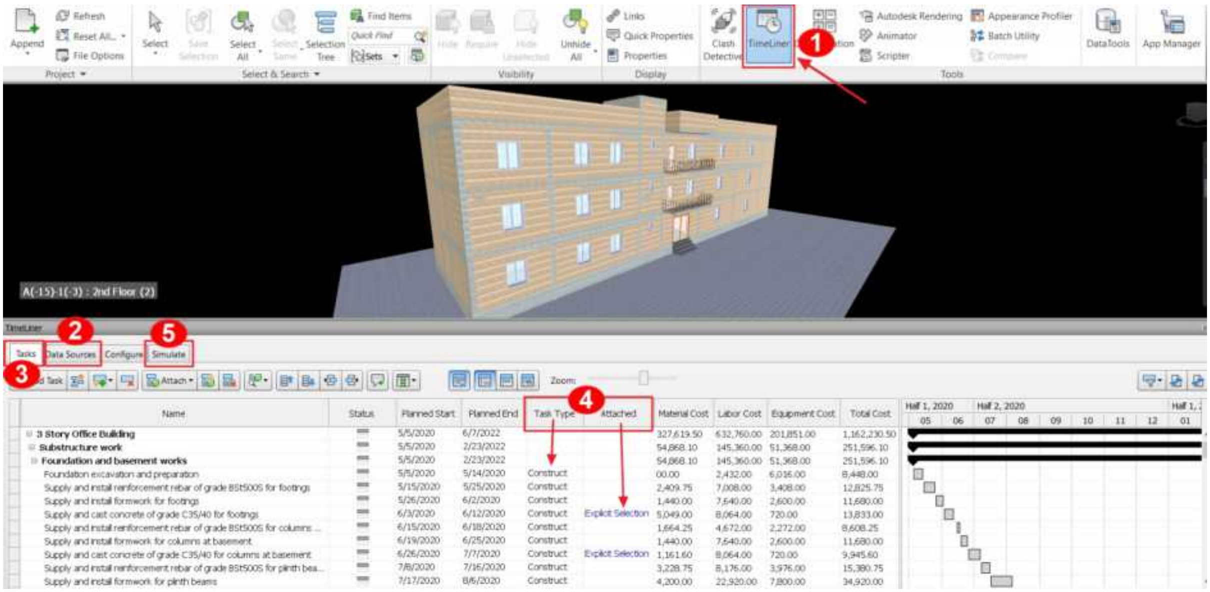
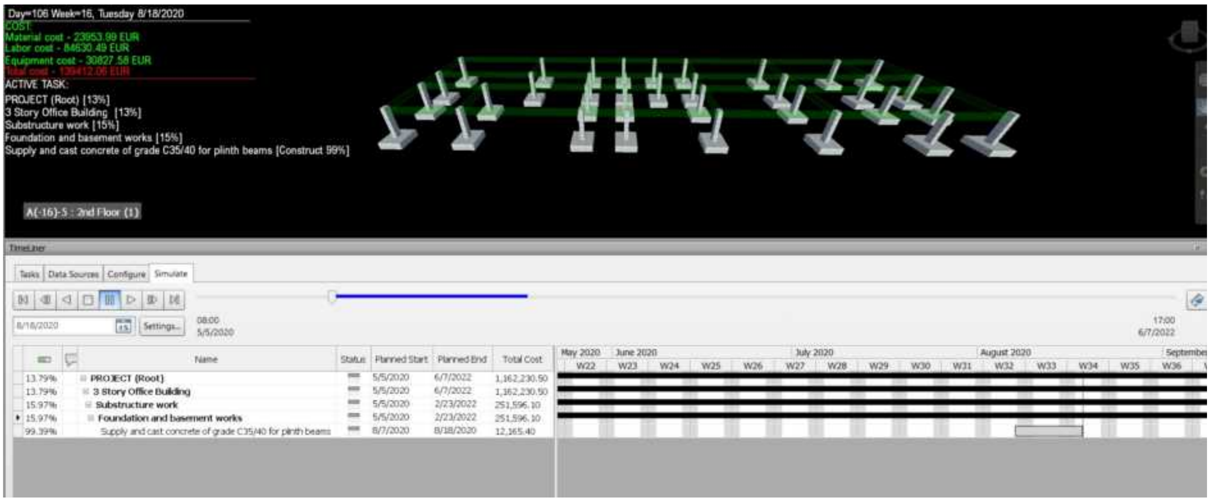
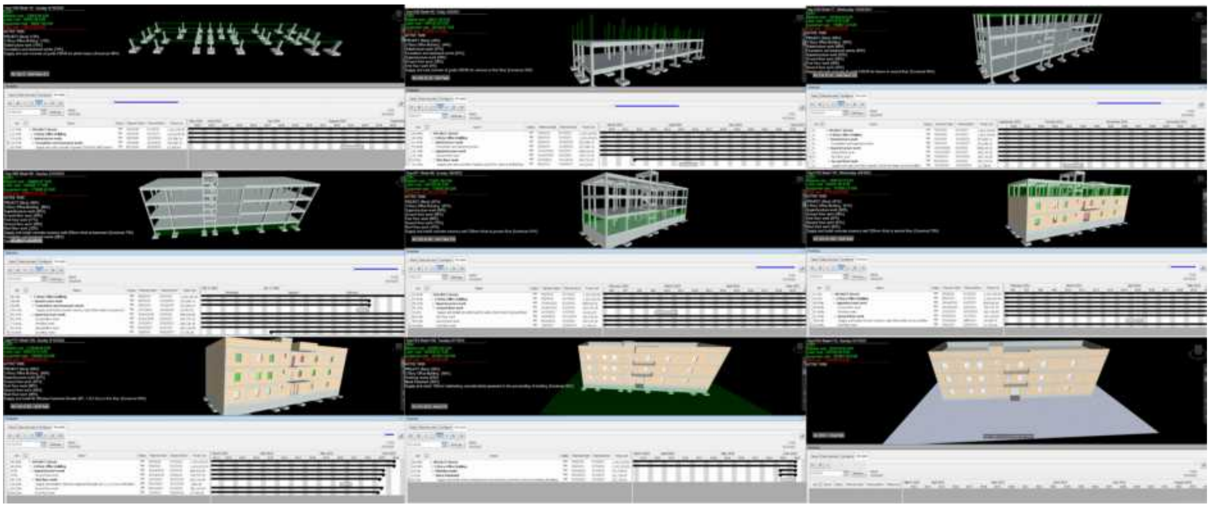


Figure 6.22: Integration of schedule and cost information to 3D model in Navisworks Manage

Finally, the model was visualized by performing 5D model simulation which presented a sequential construction of the project along with its schedule and cost statuses. The visualization is displayed in fig.6.23 below.



(a)



(b)

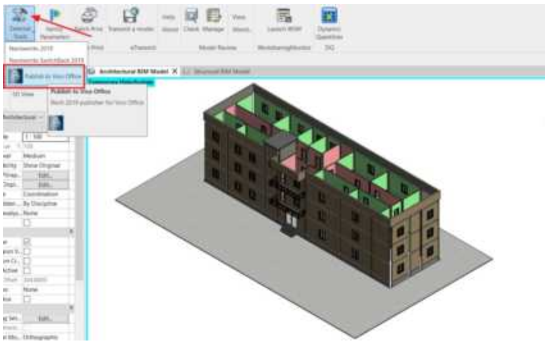
Figure 6.23: 5D model simulation in Navisworks Manage

6.3.3 Vico Office

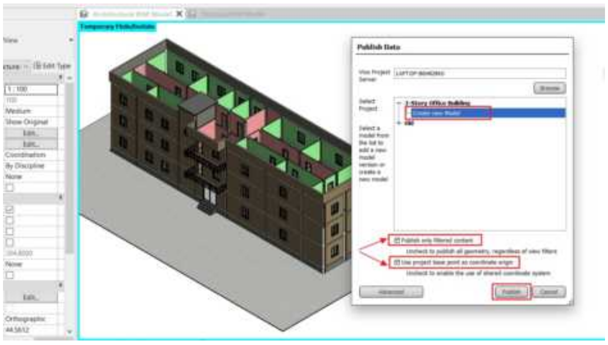
Importing of 3D BIM models to Vico Office

Importing 3D BIM models into Vico Office involves two steps: creating a project in Vico Office and then publishing models prepared in various BIM applications (Revit, Tekla, SketchUp, etc.) into the created project. There are two possible ways to publish models prepared in Revit into Vico Office. The first is using Revit model publisher tool for Vico Office, a plugin in Revit. This will directly publish the model into the the project created in Vico Office. The second method is to export the Revit file (.rvt) to an IFC file (.ifc) and then importing the model in Vico Office as an IFC fie. In this study, for the purpose of demonstrating both procedures, the architectural BIM model was published using the Revit model exporter tool and the structural BIM model was imported as an IFC file into Vico Office.

Similar to the Revit model exporting procedure for Navisworks Manage described in the previous section, model elements not wanted to be exported to Vico Office (i.e. structural members in the architectural model, landscaping, vehicles, etc.) were filtered out from the architectural Revit model prior to publishing to Vico Office. Also, the origin coordinates of the architectural and structural models were set to the same point so that the models would not scatter or become misaligned when imported to Vico Office. Fig.6.24 below shows the Revit model publishing procedure to Vico Office.



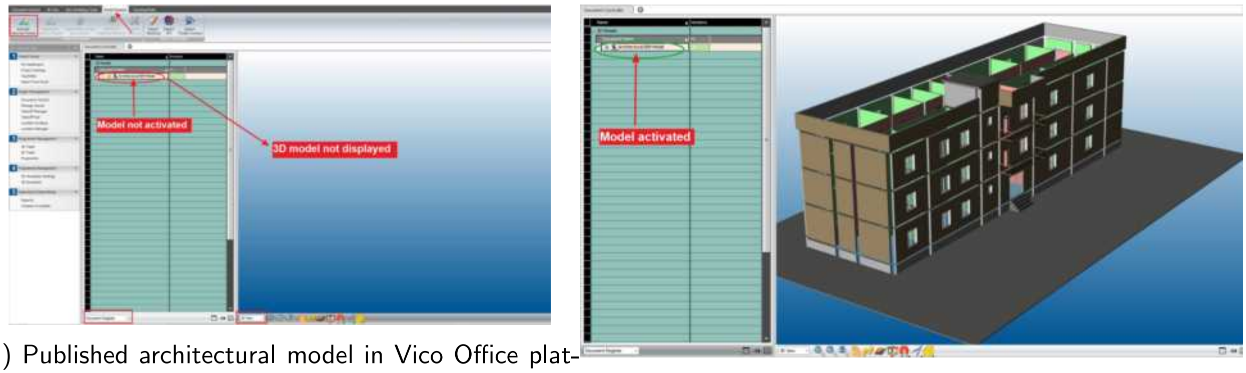
(a) Opening the Revit model exporter



(b) Setting options for model publishing

Figure 6.24: Publishing architectural BIM model to Vico Office using Revit model exporter to Vico Office

Once the architectural model is published from Revit to Vico Office, it needs to be activated in Vico Office environment without which the 3D model cannot be displayed and also the model cannot be used for further work. The model activation procedure is shown in fig.6.25 below.

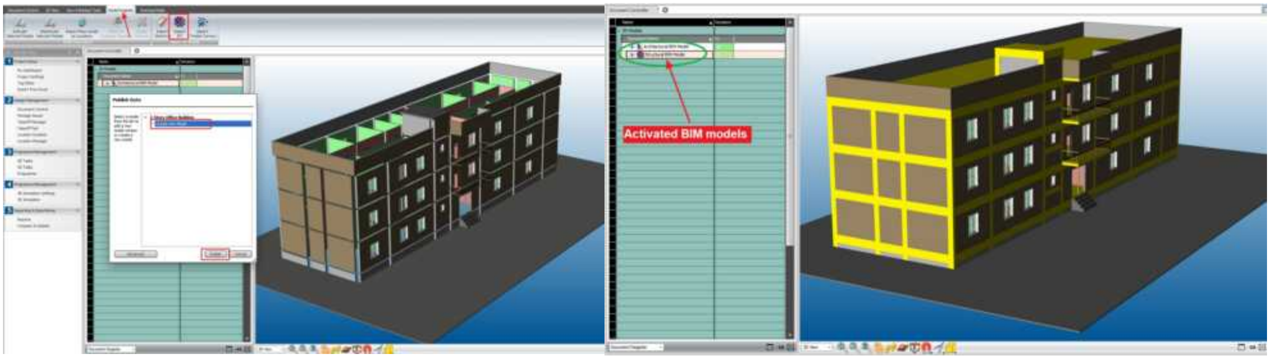


(a) Published architectural model in Vico Office platform before model activation

(b) Architectural 3D model after model activation

Figure 6.25: Publishing architectural BIM model to Vico Office using Revit Model Exporter to Vico Office

Finally, the structural BIM model was imported to Vico Office as IFC file through the file importing option available in Vico Office's toolbar. Once imported and model activation was carried out, a combined 3D BIM model was obtained. This step is depicted in the below fig.6.26.



(a) Importing structural model as IFC file in Vico Office

(b) Composite 3D BIM model

Figure 6.26: Importing structural BIM model to Vico Office as IFC file

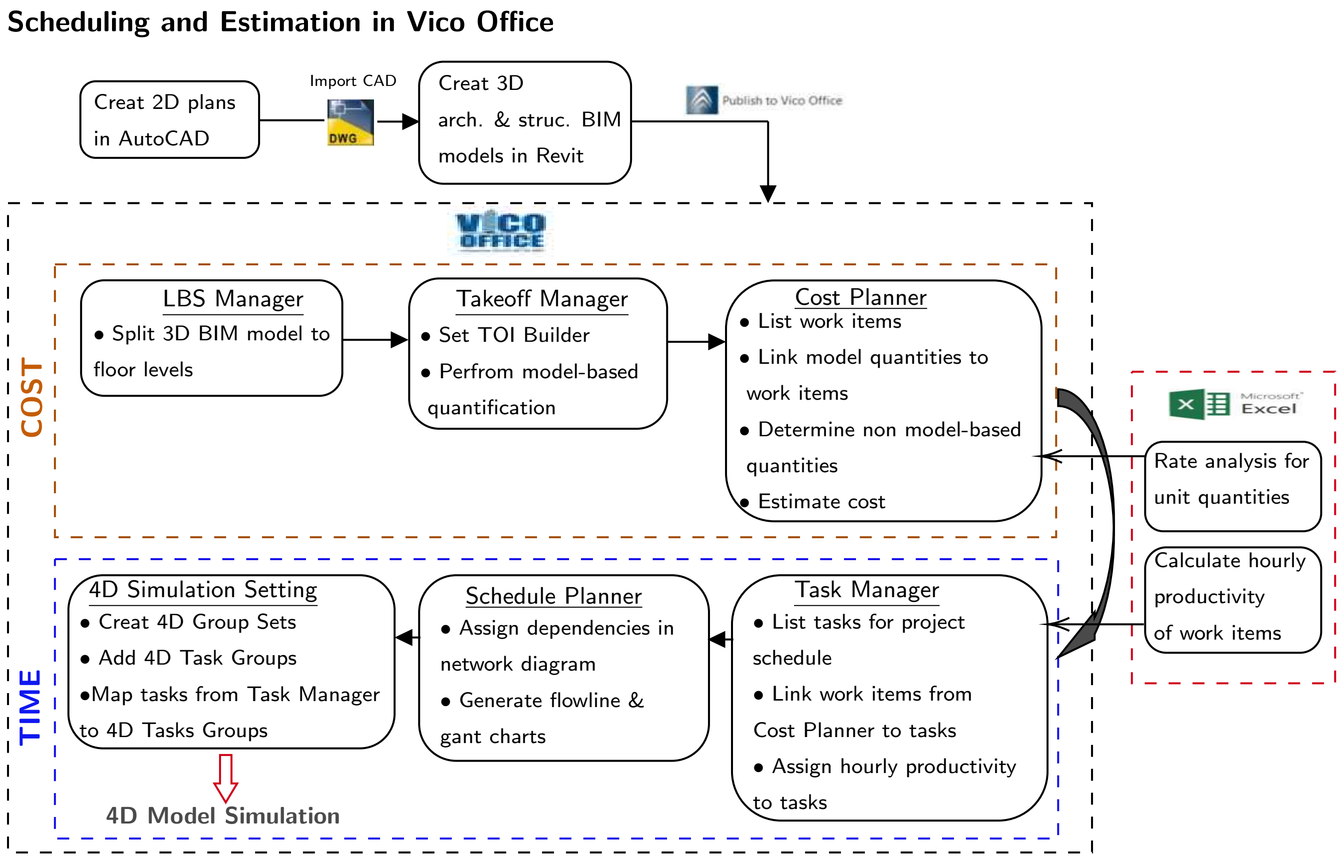
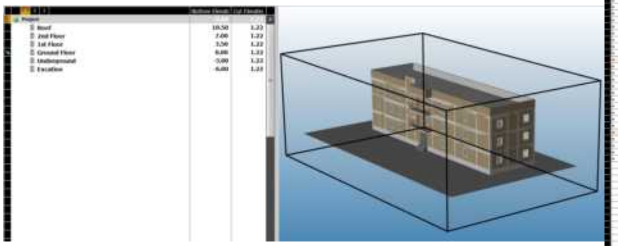


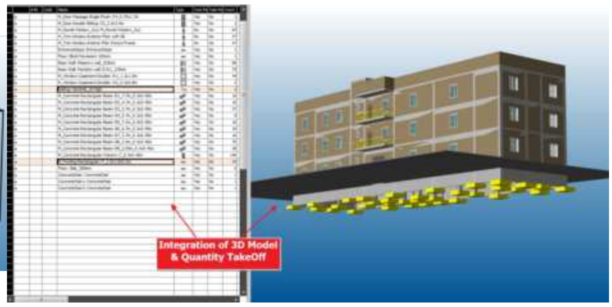
Figure 6.27: Procedure of 4D and 5D BIM model development in Vico Office

The adopted procedure for 4D and 5D BIM model preparation in Vico Office is shown in fig.6.27 above. First, the composite 3D model was split into floor levels within Vico Office's **Location Breakdown Structure (LBS)** module. This is because Vico Office does not recognize the floor levels in the Revit models imported to Vico Office. Once the 3D model was split into required floors (1 nr. underground, 3 nr. above ground and roof floors), model-based quantification was performed in the **Takeoff Manager** module which generates quantities of model elements split into different floors. Fig.6.28 in the next page depicts the location-based model quantification process in Vico Office environment.

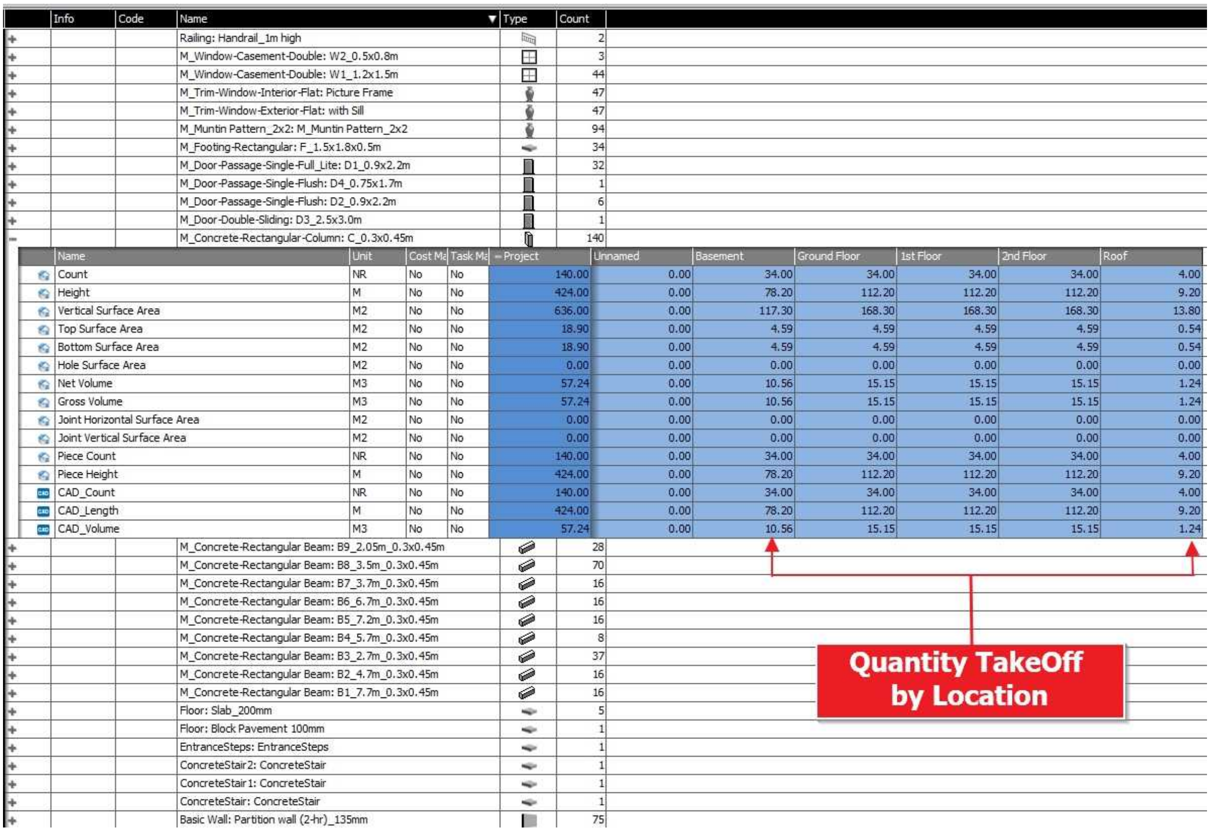
In Vico Office's **Cost Planner** module, project work items were prepared based on the Work Breakdown Structure (WBS) presented previously in section 6.3.1, and the model takeoff from the previous step was then linked to these work items in order to perform cost estimation. Since model quantities are linked to the cost estimate, a change to the 3D model (e.g. element dimension and number) will automatically update the cost estimate. Unit rates of work items were calculated in Microsoft Excel and imported to the Cost Planner. The estimated project cost in Vico Office is presented in fig.6.29 of the following page. A detailed cost report generated from Vico Office is provided in Appendix A.



(a) Splitting 3D model to floos in LBS module



(b) Integration of model quantities and 3D model



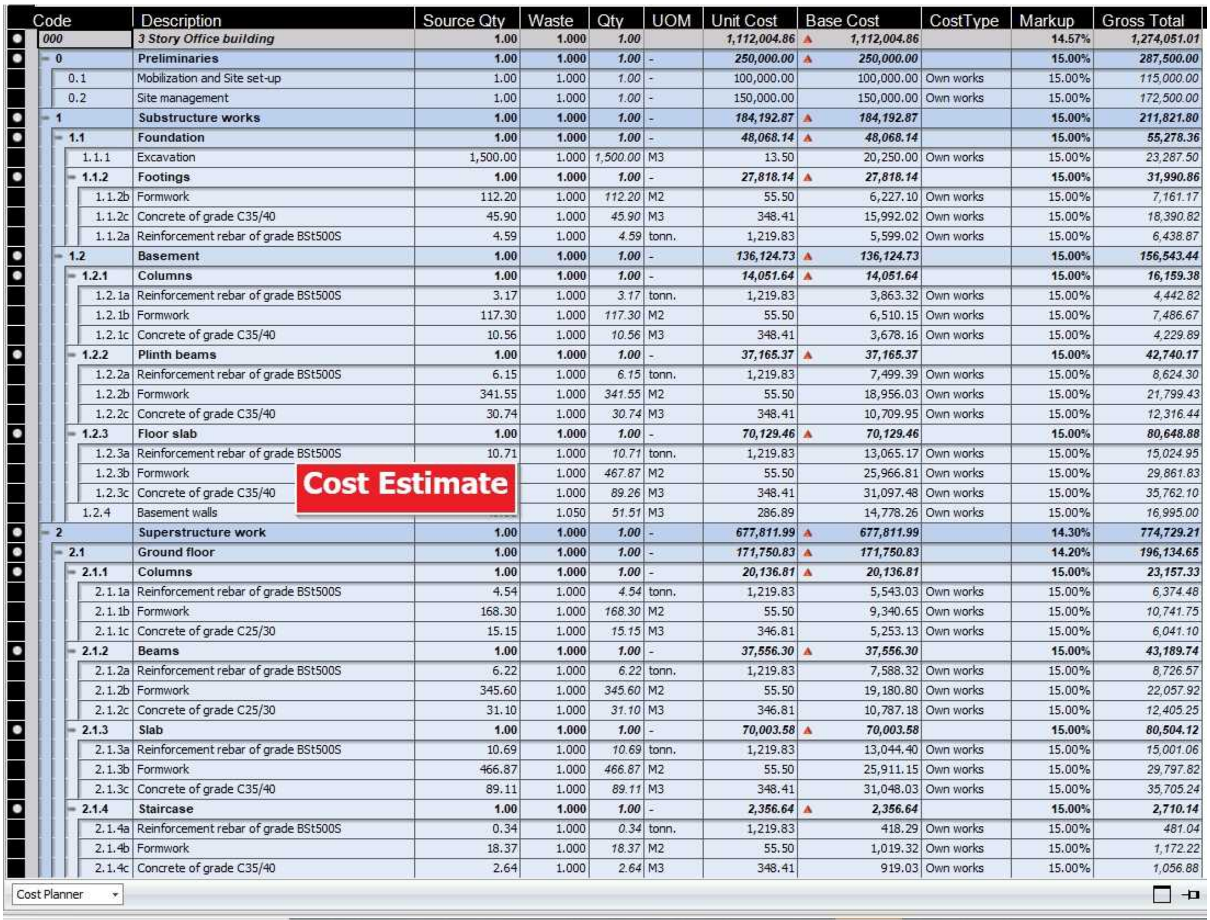
Info	Code	Name	Type	Count
		Railing: Handrail_1m high		2
		M_Window-Casement-Double: W2_0.5x0.8m		3
		M_Window-Casement-Double: W1_1.2x1.5m		44
		M_Trim-Window-Interior-Flat: Picture Frame		47
		M_Trim-Window-Exterior-Flat: with Sill		47
		M_Muntin Pattern_2x2: M_Muntin Pattern_2x2		94
		M_Footing-Rectangular: F_1.5x1.8x0.5m		34
		M_Door-Passage-Single-Full_Lite: D1_0.9x2.2m		32
		M_Door-Passage-Single-Flush: D4_0.75x1.7m		1
		M_Door-Passage-Single-Flush: D2_0.9x2.2m		6
		M_Door-Double-Sliding: D3_2.5x3.0m		1
		M_Concrete-Rectangular-Column: C_0.3x0.45m		140

Name	Unit	Cost Ma	Task Ma	Project	Unnamed	Basement	Ground Floor	1st Floor	2nd Floor	Roof
Count	NR	No	No	140.00	0.00	34.00	34.00	34.00	34.00	4.00
Height	M	No	No	424.00	0.00	78.20	112.20	112.20	112.20	9.20
Vertical Surface Area	M2	No	No	636.00	0.00	117.30	168.30	168.30	168.30	13.80
Top Surface Area	M2	No	No	18.90	0.00	4.59	4.59	4.59	4.59	0.54
Bottom Surface Area	M2	No	No	18.90	0.00	4.59	4.59	4.59	4.59	0.54
Hole Surface Area	M2	No	No	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Volume	M3	No	No	57.24	0.00	10.56	15.15	15.15	15.15	1.24
Gross Volume	M3	No	No	57.24	0.00	10.56	15.15	15.15	15.15	1.24
Joint Horizontal Surface Area	M2	No	No	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Joint Vertical Surface Area	M2	No	No	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piece Count	NR	No	No	140.00	0.00	34.00	34.00	34.00	34.00	4.00
Piece Height	M	No	No	424.00	0.00	78.20	112.20	112.20	112.20	9.20
CAD_Count	NR	No	No	140.00	0.00	34.00	34.00	34.00	34.00	4.00
CAD_Length	M	No	No	424.00	0.00	78.20	112.20	112.20	112.20	9.20
CAD_Volume	M3	No	No	57.24	0.00	10.56	15.15	15.15	15.15	1.24

Info	Code	Name	Type	Count
		M_Concrete-Rectangular Beam: B9_2.05m_0.3x0.45m		28
		M_Concrete-Rectangular Beam: B8_3.5m_0.3x0.45m		70
		M_Concrete-Rectangular Beam: B7_3.7m_0.3x0.45m		16
		M_Concrete-Rectangular Beam: B6_6.7m_0.3x0.45m		16
		M_Concrete-Rectangular Beam: B5_7.2m_0.3x0.45m		16
		M_Concrete-Rectangular Beam: B4_5.7m_0.3x0.45m		8
		M_Concrete-Rectangular Beam: B3_2.7m_0.3x0.45m		37
		M_Concrete-Rectangular Beam: B2_4.7m_0.3x0.45m		16
		M_Concrete-Rectangular Beam: B1_7.7m_0.3x0.45m		16
		Floor: Slab_200mm		5
		Floor: Block Pavement 100mm		1
		EntranceSteps: EntranceSteps		1
		ConcreteStair2: ConcreteStair		1
		ConcreteStair1: ConcreteStair		1
		ConcreteStair: ConcreteStair		1
		Basic Wall: Partition wall (2-hr)_135mm		75

(c) Model-based quantity takeoff based on locations (i.e. floors)

Figure 6.28: Splitting 3D model to floors and location and model-based quantity takeoff in Vico Office



Code	Description	Source Qty	Waste	Qty	UOM	Unit Cost	Base Cost	CostType	Markup	Gross Total
000	3 Story Office building	1.00	1.000	1.00		1,112,004.86	1,112,004.86		14.57%	1,274,051.01
0	Preliminaries	1.00	1.000	1.00	-	250,000.00	250,000.00		15.00%	287,500.00
0.1	Mobilization and Site set-up	1.00	1.000	1.00	-	100,000.00	100,000.00	Own works	15.00%	115,000.00
0.2	Site management	1.00	1.000	1.00	-	150,000.00	150,000.00	Own works	15.00%	172,500.00
1	Substructure works	1.00	1.000	1.00	-	184,192.87	184,192.87		15.00%	211,821.80
1.1	Foundation	1.00	1.000	1.00	-	48,068.14	48,068.14		15.00%	55,278.36
1.1.1	Excavation	1,500.00	1.000	1,500.00	M3	13.50	20,250.00	Own works	15.00%	23,287.50
1.1.2	Footings	1.00	1.000	1.00	-	27,818.14	27,818.14		15.00%	31,990.86
1.1.2b	Formwork	112.20	1.000	112.20	M2	55.50	6,227.10	Own works	15.00%	7,161.17
1.1.2c	Concrete of grade C35/40	45.90	1.000	45.90	M3	348.41	15,992.02	Own works	15.00%	18,390.82
1.1.2a	Reinforcement rebar of grade BSt500S	4.59	1.000	4.59	tonn.	1,219.83	5,599.02	Own works	15.00%	6,438.87
1.2	Basement	1.00	1.000	1.00	-	136,124.73	136,124.73		15.00%	156,543.44
1.2.1	Columns	1.00	1.000	1.00	-	14,051.64	14,051.64		15.00%	16,159.38
1.2.1a	Reinforcement rebar of grade BSt500S	3.17	1.000	3.17	tonn.	1,219.83	3,863.32	Own works	15.00%	4,442.82
1.2.1b	Formwork	117.30	1.000	117.30	M2	55.50	6,510.15	Own works	15.00%	7,486.67
1.2.1c	Concrete of grade C35/40	10.56	1.000	10.56	M3	348.41	3,678.16	Own works	15.00%	4,229.89
1.2.2	Plinth beams	1.00	1.000	1.00	-	37,165.37	37,165.37		15.00%	42,740.17
1.2.2a	Reinforcement rebar of grade BSt500S	6.15	1.000	6.15	tonn.	1,219.83	7,499.39	Own works	15.00%	8,624.30
1.2.2b	Formwork	341.55	1.000	341.55	M2	55.50	18,956.03	Own works	15.00%	21,799.43
1.2.2c	Concrete of grade C35/40	30.74	1.000	30.74	M3	348.41	10,709.95	Own works	15.00%	12,316.44
1.2.3	Floor slab	1.00	1.000	1.00	-	70,129.46	70,129.46		15.00%	80,648.88
1.2.3a	Reinforcement rebar of grade BSt500S	10.71	1.000	10.71	tonn.	1,219.83	13,065.17	Own works	15.00%	15,024.95
1.2.3b	Formwork	[illegible]	1.000	467.87	M2	55.50	25,966.81	Own works	15.00%	29,861.83
1.2.3c	Concrete of grade C35/40	[illegible]	1.000	89.26	M3	348.41	31,097.48	Own works	15.00%	35,762.10
1.2.4	Basement walls	[illegible]	1.050	51.51	M3	286.89	14,778.26	Own works	15.00%	16,995.00
2	Superstructure work	1.00	1.000	1.00	-	677,811.99	677,811.99		14.30%	774,729.21
2.1	Ground floor	1.00	1.000	1.00	-	171,750.83	171,750.83		14.20%	196,134.65
2.1.1	Columns	1.00	1.000	1.00	-	20,136.81	20,136.81		15.00%	23,157.33
2.1.1a	Reinforcement rebar of grade BSt500S	4.54	1.000	4.54	tonn.	1,219.83	5,543.03	Own works	15.00%	6,374.48
2.1.1b	Formwork	168.30	1.000	168.30	M2	55.50	9,340.65	Own works	15.00%	10,741.75
2.1.1c	Concrete of grade C25/30	15.15	1.000	15.15	M3	346.81	5,253.13	Own works	15.00%	6,041.10
2.1.2	Beams	1.00	1.000	1.00	-	37,556.30	37,556.30		15.00%	43,189.74
2.1.2a	Reinforcement rebar of grade BSt500S	6.22	1.000	6.22	tonn.	1,219.83	7,588.32	Own works	15.00%	8,726.57
2.1.2b	Formwork	345.60	1.000	345.60	M2	55.50	19,180.80	Own works	15.00%	22,057.92
2.1.2c	Concrete of grade C25/30	31.10	1.000	31.10	M3	346.81	10,787.18	Own works	15.00%	12,405.25
2.1.3	Slab	1.00	1.000	1.00	-	70,003.58	70,003.58		15.00%	80,504.12
2.1.3a	Reinforcement rebar of grade BSt500S	10.69	1.000	10.69	tonn.	1,219.83	13,044.40	Own works	15.00%	15,001.06
2.1.3b	Formwork	466.87	1.000	466.87	M2	55.50	25,911.15	Own works	15.00%	29,797.82
2.1.3c	Concrete of grade C35/40	89.11	1.000	89.11	M3	348.41	31,048.03	Own works	15.00%	35,705.24
2.1.4	Staircase	1.00	1.000	1.00	-	2,356.64	2,356.64		15.00%	2,710.14
2.1.4a	Reinforcement rebar of grade BSt500S	0.34	1.000	0.34	tonn.	1,219.83	418.29	Own works	15.00%	481.04
2.1.4b	Formwork	18.37	1.000	18.37	M2	55.50	1,019.32	Own works	15.00%	1,172.22
2.1.4c	Concrete of grade C35/40	2.64	1.000	2.64	M3	348.41	919.03	Own works	15.00%	1,056.88

(a) Estimated project cost in Cost Planner

(b) Integration of Cost Estimate with 3D model and quantity takeoff

Figure 6.29: Project cost estimation in Vico Office

After completion of the Cost Estimate, Project Schedule was developed. As a first step in the scheduling process, in **Task Manager** module, project tasks list was prepared according to the planned construction sequence presented before in section 6.3.1. The estimated project work items from the previous step in the Cost Planner were then linked to these tasks in the Task Manager. Due to this linking, a change in model quantities or costs will be automatically updated in the Task Manager and hence in the Project Schedule. Duration of tasks were then determined by assigning each task an hourly productivity rate prepared in Microsoft Excel. The procedure is depicted in the following fig.6.30.

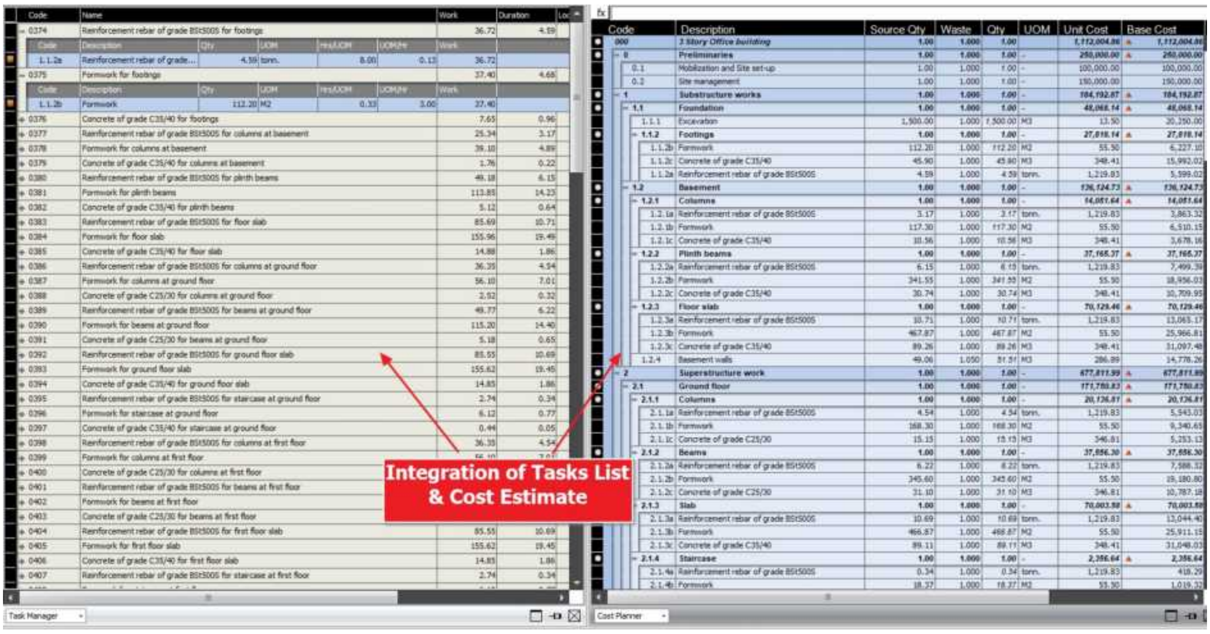
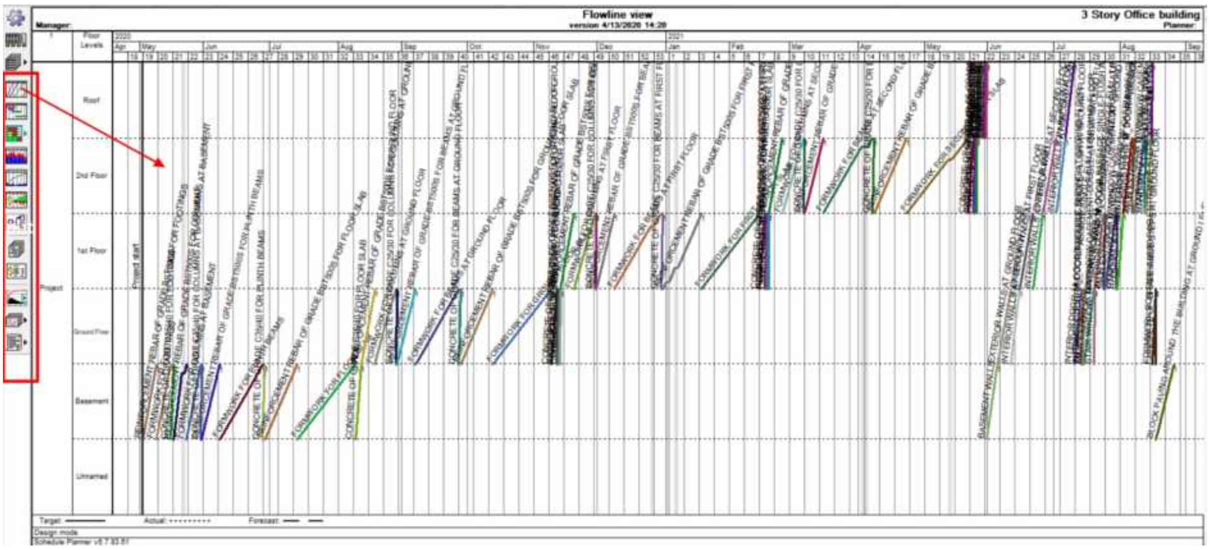


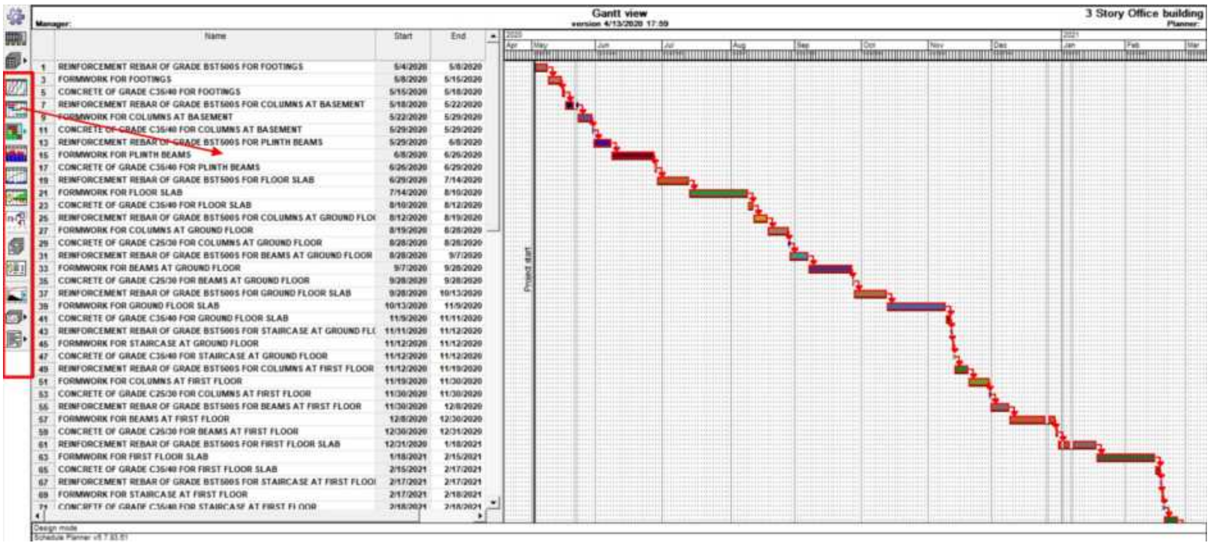
Figure 6.30: Preparation of tasks list in Task Manage

The project tasks created in the Task Manager were then scheduled in **Schedule Planner** module. The tasks were linked according to their dependencies. Upon completion, various charts were automatically generated including Gantt chart, Time-Location (Flowline) chart, Cashflow, Resource histogram, etc. The Time-Location (Flowline) chart is an improved way of showing project schedule compared to the traditional Gantt chart because, in addition to start and end date of an activity, it also shows the location of the activity (e.g. floor level, project sector, etc.). Fig.6.31 in the following page shows the Flowline and Gantt charts obtained in the Schedule Planner. The complete and larger view of the Gantt and Flowline charts are provided in Appendix B.

Finally, 4D model simulation was performed showing the step-by-step construction of the project and schedule status. Fig.6.32 in the next page displays the 4D model simulation of the building project in this study.



(a) Time-Location (Flowline) chart



(b) Gantt chart

Figure 6.31: Project scheduling in Vico Office

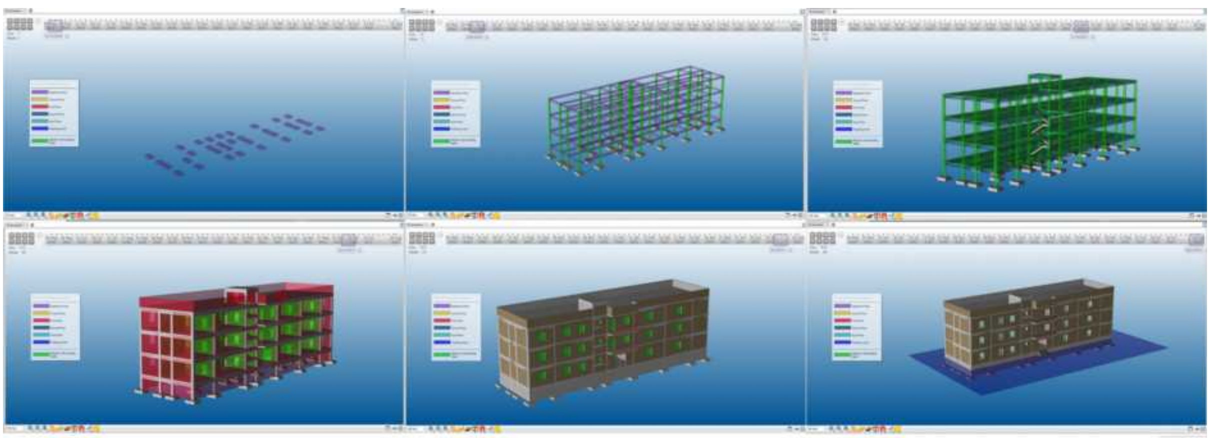


Figure 6.32: 4D model simulation in Vico Office

Chapter 7

Discussion and Analysis

7.1 Analysis of RIBA Plan of Work, HOAI 2013 and SIA 112 Standards

7.1.1 Mapping of Project Life-cycle Phases defined by the National Standards

In this section, the project life-cycle phases from the three national standards presented in sections 4.1, 4.2 and 4.3 are overlaid and mapped to one another for the purpose of showing an overview of the similarities and differences in the project stages set out in the respective national standards and guidelines.

An approximate mapping of project phases from the three standards is illustrated in fig.7.1 below. For easier identification of similar project phases or sub-phases in the three standards, color codes were used. As can observed, the flow of processes in the three standards are similar even though each standard utilizes different terminologies and task descriptions. Each standard begins with rough and preliminary studies and plannings; followed by a more detailed planning of the project; followed by execution of the project on-site; followed by project handover and finally operation and maintenance.

However, unlike HOAI and SIA 112 standards the RIBA Plan of Work does not have a numbered stage for tendering (procurement) activities; the tendering process in the RIBA Plan of Work is a flexible process that can be carried out in stage 2 (Concept Design) through stage 4 (Technical Design). Similarly, planning permission (application for permit from legal authorities) also does not have a specific stage in the current RIBA Plan of Work; it is a moveable process that can be carried out in stages 2, 3 and 4. However, since typically planning permission is made using the results of stage 3 (Developed Design) [Sinclair, 2013], it was included as part of stage 4 (Technical Design) in the mapping depicted in fig.7.1 below.

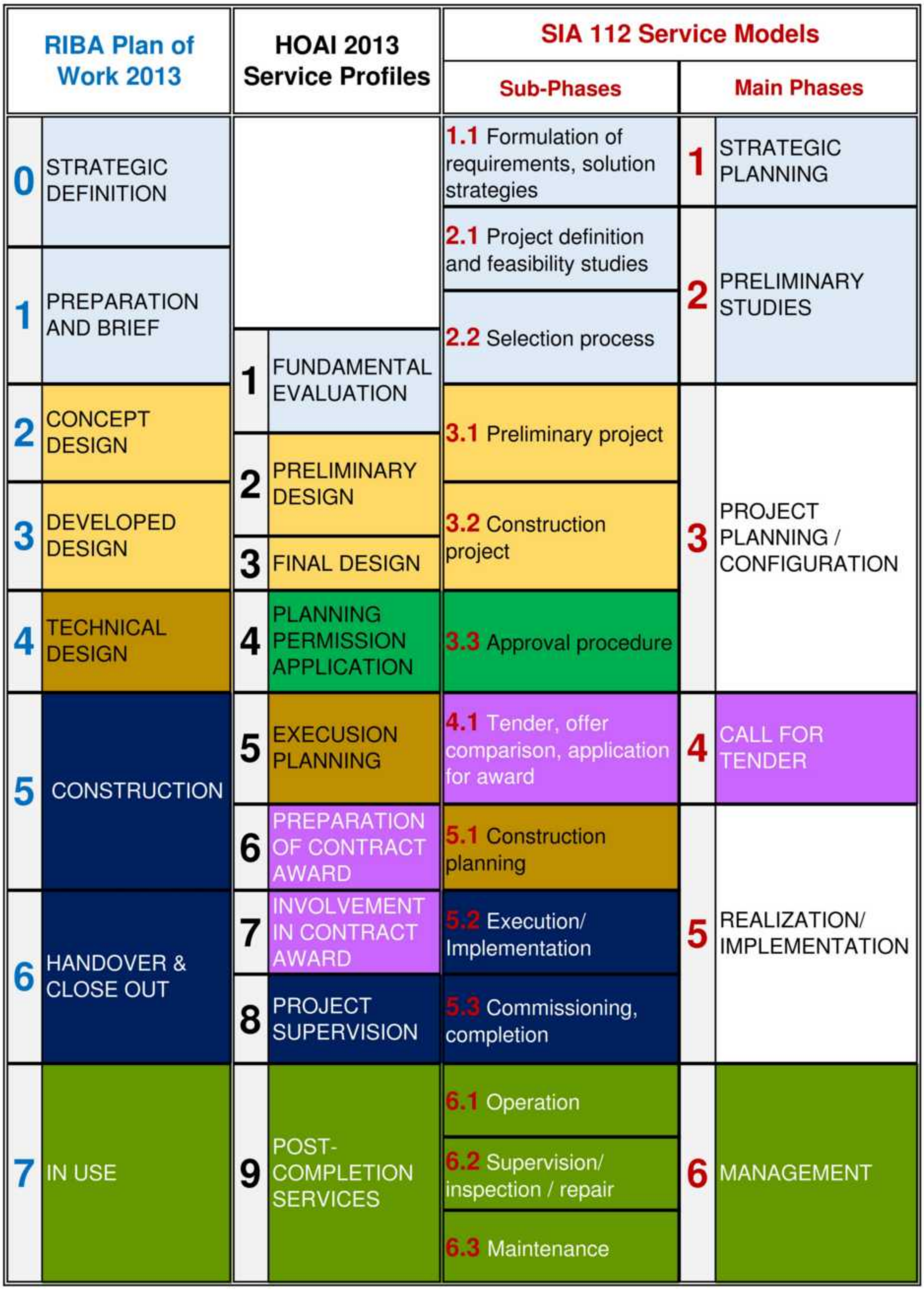


Figure 7.1: Project life-cycle stages mapping between RIBA Plan of Work, HOAI and SIA 112 standards

7.1.2 Identification of Project Stages Requiring 5D BIM Model Development

Detail information on the individual three standards considered in this study was presented already in chapter 4. The level of adoption of BIM in the standers was also discussed. All the three standards specify the various services to be provided at the project phases that they define. However, the stages to develop 3D, 4D and 5D BIM models is not specified in the standards. Exception to this is the HOAI standard where in the current version 3D or 4D model preparation was included as part of additional tasks in service phase 2 (Preliminary Design). Even though 3D and 4D models may be started in service phase 2, they do not stop there; a more detailed model is developed in later stages of the project life-cycle as more information about the project is obtained.

The development of 5D BIM model in the different stages of a construction project will depend on factors such as client requirement, the nature of the project (BIM-based or traditional), contract agreement, etc. It is possible that in a construction project 5D model is developed during the planning and design stage by the architect and engineer, but this 5D model is not maintained in the construction phase by the contractor. It is also possible that in a project 5D model is developed only during the construction stage as it is the longest and more complex stage which involves most of the project life-cycle cost. Nonetheless, as a general statement, based on the project phase tasks specified in the three national standards the possible stages at which 5D BIM model would be required are indicated in table 7.1 below.

Table 7.1: Possible project stages in the three national standards at which 5D BIM model would be required

RIBA Plan of Work 2013	**HOAI 2013 Service Profiles**	**SIA 112 Service Models**
Stage 2: Concept Design	Service Phase 2: Preliminary Design	Phase 3: Project Planning 31: Preliminary Project 32: Construction Project
Stage 3: Developed Design	Service Phase 3: Final Design (Integrated System Design)	Phase 5: Realization/ Implementation 52: Execution
Stage 4: Technical Design	Service Phase 8: Construction Supervision and Documentation	
Stage 5: Construction		

7.1.3 Level of Development (LOD) of 5D BIM model in Project Life-Cycle Stages

As it was discussed in section 2.2.2, BIM model development is not a single-stage task or process; rather it is an accumulative process which starts during conception of the project and continuous in the project life cycle. As such, each LOD includes the previous LOD; that means LOD 200 includes LOD 100, LOD 300 includes LOD 200, etc.

The five LOD definitions defined by AIA are mapped into a particular stage in the project life-cycle as follow:

LOD 100 ⟶ Conceptual design

LOD 200 ⟶ Schematic design

LOD 300 ⟶ Construction documents

LOD 400 ⟶ Fabrication/ Assembly

LOD 500 ⟶ As-built conditions for Facility Management

Project schedule and project cost are prepared and determined progressively in the life-cycle of the construction project. For example, during early stages of the project preliminary estimates are developed using minimal available information from the model in order to have an insight about the cost of the project based on a particular design alternative. As, more information is added to the BIM model with detailed design information, the cost is refined and a more detailed cost calculations are performed. Similarly, project schedule's accuracy depends on the available information in the BIM model which gets more clearer and detailed in the later phases of the project. Due to the progressive nature of project cost determination, the German HOAI regulation uses the terms '**Cost Estimation**' and '**Cost Calculation**' which are defined as follow:

Cost Estimation: a rough determination of project cost based on preliminary design which is determined based on:

- preliminary design results,
- quantitative estimates,
- explanatory information concerning the planning contexts, processes and conditions,
- information pertaining to the building plot and its connection to utilities.

Cost Calculation: determination of project cost based on the final design and is determined based on:

- detailed drawings,
- quantity calculations and
- explanations relevant for the calculation and evaluation of the costs.

The degree of detail and accuracy which Project Schedule and Project Cost Estimate can be developed depends on the LOD of the 3D BIM Model. For example, in the early stages of a building construction project, the architect develops a massing model of the building without modeling interior walls, Cost Estimate developed at this stage can be based on approximate floor area or volume. As more details are added to the BIM model, the LOD of the 3D BIM model increases from lower level to higher which in turn provides a more detailed information upon which Project Schedule and Cost Estimate can be prepared. The Project Schedule and Cost Estimate will be at lower LOD if they are developed based on a 3D BIM model which is at lower level, and their LOD will increase as the LOD of the 3D BIM model increases through the project life-cycle.

In this study, for the purpose of illustrating how the detail of information of a 5D BIM model progresses in construction project life-cycle, the project phases defined by RIBA Plan of Work were adopted. Thereafter, the LOD of 3D BIM model in the project phases and the corresponding Project Schedule (4D) and Project Cost (5D) preparation process were shown. This is depicted in fig.7.2 in the following page.

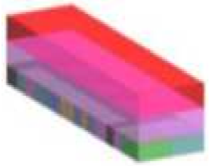
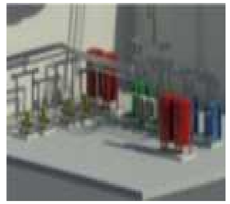
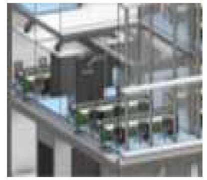
	Stage 0 Strategic Definition	Stage 1 Preparation and Brief	Stage 2 Concept Design	Stage 3 Developed Design	Stage 4 Technical Design	Stage 5 Construction	Stage 6 Handover and Close Out	Stage 7 In Use
3D BIM Model								
			LOD 100	**LOD 200**	**LOD 300**	**LOD 400**	**LOD 500**	
Project Schedule (4D)	Establishing project programme (Based on client requirement)	Review and comment on project program	Establishing total project construction program (based on analogous time estimating technique or expert judgement)	Preparing project program showing major project activities	Preparing project program with detailed activities and resources	Preparing detailed construction program for execution (also incorporating specialist subcontractor programs)		
Project Cost (5D)	Outlining cost plan to report on cost implications and affordability of the project	Preparation of project budget by consulting the client to check cost implications and affordability	Preparation of preliminary or conceptual cost information using analogous cost estimating techniques (e.g. price per square area),	Updating the preliminary cost estimate based on measurement of generic elements and cost information from suppliers and market testing	Updating the cost estimate based on measured specific assembly and price information from suppliers (*Costruction docs. available in this stage*)	Updating the cost information incorporating the actual supplied, fabricated and approved materials	Updating cost information incorporating all As-constructed information representing actual field installation (As-built cost)	Updating cost information incorporating repair & maintenance information

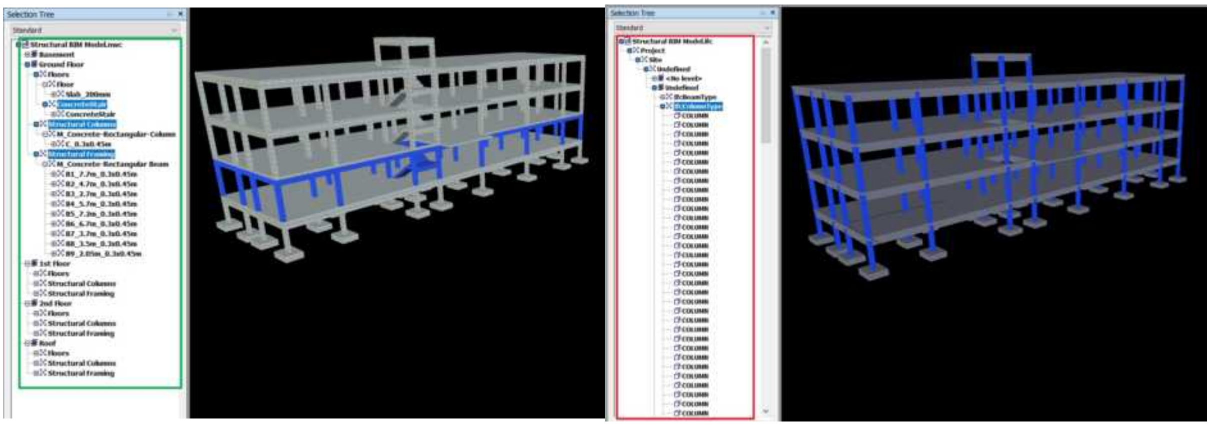
Figure 7.2: LOD of 5D BIM model in project life-cycle phases of RIBA Plan of Work

7.2 Analysis of the Case Study of 5D BIM Model Development

The focus here is to compare the quality of 5D BIM models that were developed in the previous chapter using Navisworks Manage and Vico Office. Also, to analyze the challenges and constraints encountered during the development of 5D BIM models.

Even though both Navisworks Manage and Vico Office had the capability for 5D BIM model development, there are certain differences in their capabilities and features they support that affects the quality of 4D and 5D BIM model development. The following paragraphs will discuss some points of comparison for the two BIM tools and the challenges encountered while developing 5D BIM models.

Importing 3D models: one of the constraints encountered in the process was in importing 3D models to Navisworks Manage. For this study, it was first planned to develop architectural BIM model in Revit and the structural in Tekla Structures so that by making use of the vendor-neutral format Industry Foundation Classes (IFC), the two models from different BIM tools and different companies would be exported to 4D and 5D BIM tools for further development. By doing so, the possibilities would be checked and any constraints encountered would be investigated. However, an issue was discovered in transferring the 3D BIM model from Tekla Structures to Navisworks Manage and Vico Office. In Navisworks Manage, the quantity takeoff process is facilitated if the various building elements (walls, doors, windows, columns, beams, etc.) are grouped according to respective floor levels. This makes selecting elements at each floor easier, otherwise it will be a tedious work specially for bigger structures like the one in this study which comprises a total of 140 columns, 220 beams, 41 windows, and other elements. This splitting of model elements as per floor levels was automatically achieved in the architectural BIM model imported from Revit to Navisworks; however, model elements of the structural BIM model imported from Tekla showed a scattered result even though the original 3D model in Tekla was split into different levels. Due to this problem, the structural 3D BIM model was prepared in Revit and used both for Navisworks and Vico Office. Fig.7.3 below shows the difference in structural model imported to Navisworks from Revit and Tekla.



(a) Model from Revit: elements grouped into floors (b) Model from Tekla: elements not grouped into floors

Figure 7.3: Problem in structural BIM model imported from Tekla to Navisworks Manage

Quantity Takeoff: The quantity takeoff process in Navisworks comprised of two steps: the creation of quantity items in **Item Catalog** and then attaching these items to respective elements in the 3D model to generate model-based quantity. This procedure, in addition to being tedious, it is prone to mistakes as the user might select the wrong element from the model or miss some elements while attaching the elements to quantity items in Navisworks' Quantification Workbook. However, this issue is not present in Vico Office as the quantification is achieved automatically. Moreover, some work items not included in the 3D model might be required to be included in quantity take off, for example: a floor finish item, carpet area, a foreseen door item not included in the model, etc. These items can still be measured using Navisworks' **Virtual Takeoff** tool and the corresponding cost can be taken into account in the Cost Estimate. However, Vico Office does not support this feature; the quantities generated are only those included in the model.

Cost Estimation and Project Scheduling: One of the major drawbacks of Navisworks Manage is the unavailability of Cost Estimation functionality. Also, developing a project schedule in Navisworks has some limitations, for example lack of activity dependency assignment feature which makes it hard for projects with many activities to be scheduled without defining dependencies. Due to this, in this study the quantity takeoff from Navisworks was exported to Microsoft Excel and Microsoft Project to carryout both cost estimation and scheduling and later imported to Navisworks' TimeLiner to integrate with the 3D model. The problem with this is that if a major change is introduced in the 3D model, the entire procedure will be repeated as the 3D model is not linked to the cost calculation and scheduling. Conversely, in Vico Office, interlinking exists between the 3D model, quantity takeoff, cost estimate and tasks list; so a change in the 3D model will also get updated in the rest of the modules. Fig. 7.4 below explains the integration of 3D model with other process in

Vico Office.

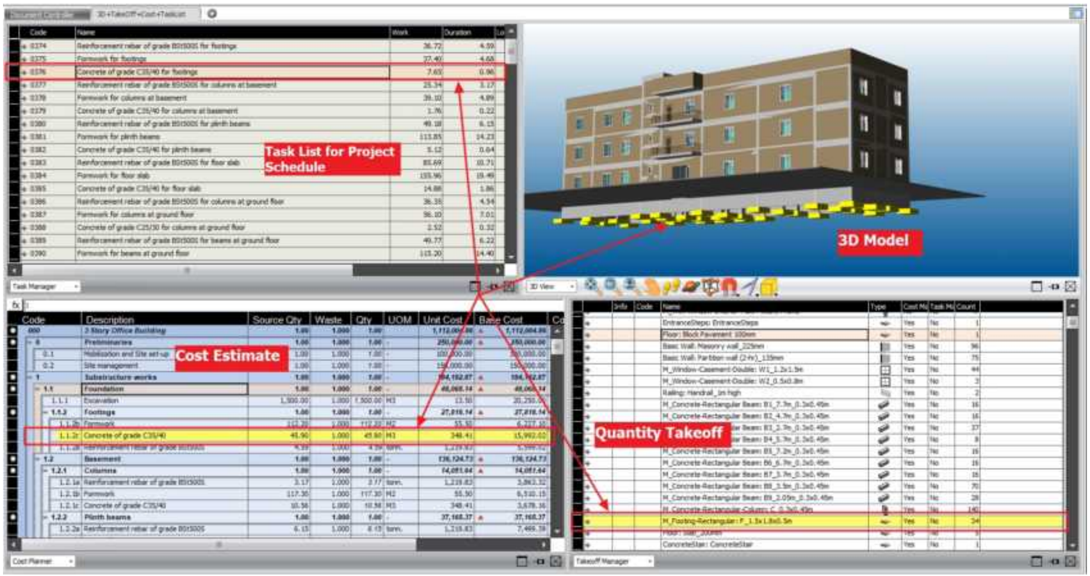


Figure 7.4: Integration of 3D model, quantity takeoff, cost estimate and project tasks list in Vico Office

5D model simulation: Visualization of 5D model is possible in Navisworks as shown in the previous chapter under section 6.3.2; whereas in Vico Office only 4D model simulation is possible. Nonetheless, as shown in fig.7.5 below, by making use of Vico Office's Viewsets functionality, 4D simulation can be displayed alongside Cost Estimate, model quantities or any other required view. However, the simulation is not linked to the cost estimate; hence, the cost status of the project cannot be visualized in the simulation.

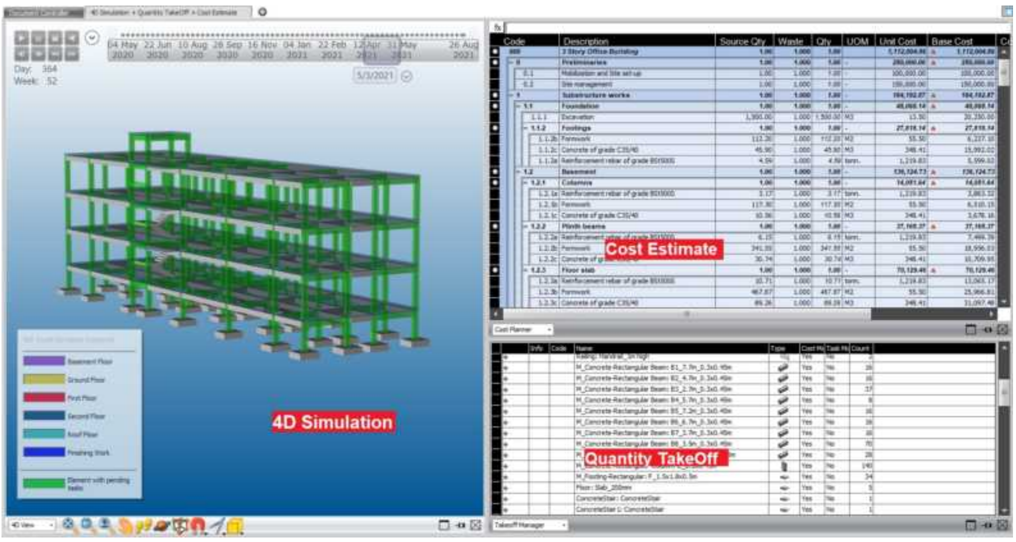


Figure 7.5: Visualizing 4D model simulation alongside cost estimate and quantity takeoff in Vico Office

Coordinate Transformation of imported models: Sometimes it might necessitate to transform the coordinates of 3D and 2D models imported to 4D and 5D BIM tools so that all imported models have the same origin and they fit together. In Vico Office, the imported models cannot be moved to another coordinate; therefore, all models (architectural, structural, electrical, mechanical, plumbing, etc) have to be created using same shared origin prior to importing to Vico Office. In Navisworks, however, if some of the imported models do not fit origin-to-origin with the rest of the models, coordinate transformation can be performed. Fig.7.6 illustrates the coordinate transformation process in Navisworks between an architectural model from Revit and a structural model from Tekla structures.

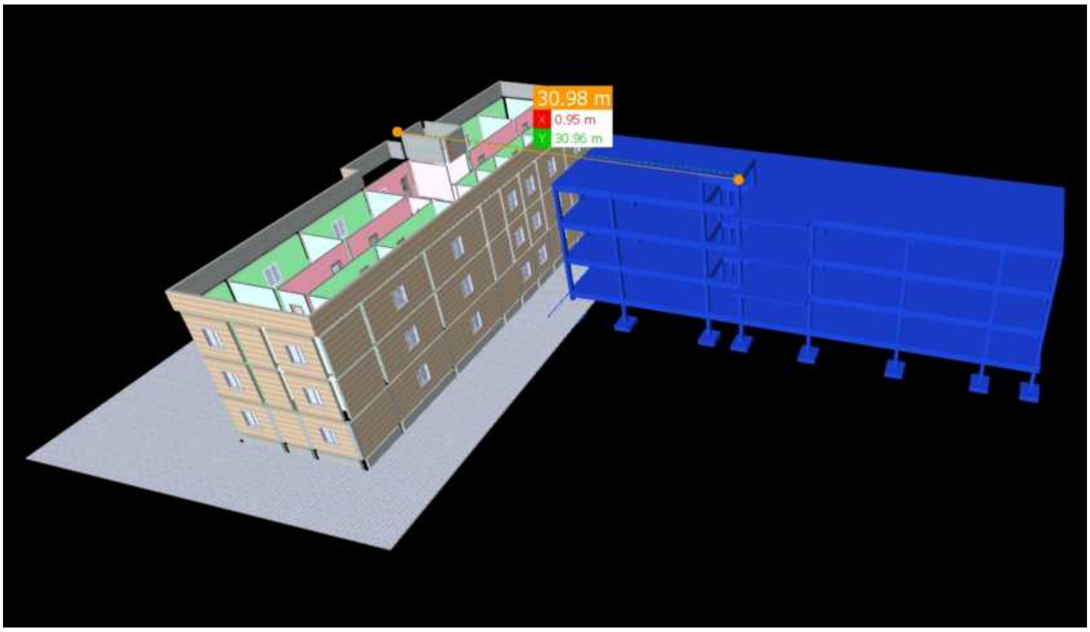


Figure 7.6: Coordinate transformation in Navisworks Manage

Retrieving deleted items: In the process of 5D BIM development, some activities or items might be deleted intentionally or unintentionally and later it might necessitate returning the deleted item. In this study also there were several times that undoing or redoing of tasks were needed. Unfortunately, redo and undo features are not supported in Vico Office; when an item is deleted in Vico Office, there will be a notification message asking for confirmation; once it is confirmed, the activity or item cannot be retrieved. Contrarily, undo and redo features are supported in Navisworks.

4D and 5D BIM model data Interoperability: This is concerned with sharing or exporting the completed 4D and 5D BIM model data prepared using Navisworks and Vico Office to either of the BIM tools through certain file formats. Unfortunately neither Navisworks nor Vico Office support such interoperability features. However, the BIM model from Vico Office can be uploaded to the cloud-based coordination tool **Trimble Connect** and the model can be made accessible to other stakeholders in the project. Similarly, BIM model from Navisworks can be published to the cloud-based BIM management and coordination tool **Autodesk BIM 360**.Fig.7.7 below depicts BIM coordination process in Trimble Connect.

Figure 7.7: BIM Coordination using Trimble Connect

Chapter 8

Conclusions and Recommendations

8.1 Conclusions

The current study analyzed the three widely used national standards in Germany, UK and Switzerland, namely HOAI regulation, RIBA Plan of Work and SIA 112 standards with respect to construction project life-cycle management. The mapping between the project phases in the three standards indicated that the project stages follow a similar pattern beginning from the initial strategic definition to the operations phase. Exception to this is the RIBA Plan of Work where it was found that in the current version it does not define a specific stage for planning permission application and procurement activities (tendering process and awarding of contract) but rather these activities can be performed between range of project stages as required. Such flexibility in the current RIBA Plan of Work makes it more suitable for application in BIM-based projects.

The study on the aforementioned standards also investigated the project stages at which 5D BIM model is required. It was found that the standards barely specify project stages for 5D BIM model development. However, development of 3D or 4D models as part of additional services in Preliminary Design stage were incorporated in the current version of the HOAI regulation. Nonetheless, based on the requirements of project phase tasks in the three national standards, possible stages requiring 5D BIM model development were identified. Four project stages were identified in RIBA Plan of Work, namely: Concept Design (Stage 2), Developed Design (Stage 3), Technical Design (Stage 4) and Construction (Stage 5). Whereas in HOAI regulation three phases were identified, namely: Preliminary Design (Service Phase 2), Final Design (Service Phase 3) and Construction Supervision (Service Phase 8). Similarly, three stages requiring 5D BIM model were identified in SIA 112 service model, these are: Preliminary Project (Sub-phase 31), Construction Project (Sub-phase 32) and Execution (Sub-phase 52).

The study also showed the challenges that the three national standards considered in the thesis have been having with adoption of BIM working methods and their suitability for implementation in BIM-based project. It was found that, in comparison, the project life-cycle phases and phase tasks as defined in the current RIBA Plan of Work are more suitable to be applied for BIM-based projects as the current version of RIBA Plan of Work was prepared taking into account the requirement of the UK government for a fully collaborative BIM for all public projects in the UK by 2016. However, the HOAI regulation and SIA 112 service models still require amendments to incorporate the BIM-working methods.

According to the analysis of 5D BIM models using Navisworks Manage and Vico Office, it was found that Navisworks Manage is equipped with a powerful 4D and 5D model simulation features enabling the visualization of cost and schedule integrated 3D model of construction projects and also has powerful clash detection functionalities. However, as its cost estimation and project scheduling features are weaker, Vico Office was found to be an ideal BIM tool for 5D model development. Vico Office was also found to be a more user friendly and enables to perform important tasks in a simpler way, for example model-based quantification and linking together the 3D model, the quantity takeoff, cost estimation and project schedule. Adding features such as cost estimation, linking model-based quantities with schedule and cost in TimeLiner, and task dependency assignment features in future updates of Navisworks Manage will make the BIM tool more efficient for 5D BIM model development.

The study also found that interoperability feature does not exist for 4D and 5D BIM models developed using Navisworks Manage and Vico Office. However, for sharing with other project participants, the BIM models from the two BIM tools can be shared through cloud-based BIM coordination tools that they support. For example, BIM model from Vico Office can be uploaded to Trimble Connect and BIM model from Navisworks Manage can be shared through Autodesk BIM 360.

In the study, various BIM tools from different companies were used in the process of producing 3D, 4D and 5D BIM models. The constraints identified in these BIM tools are summarized in table 8.1 below.

Table 8.1: Supported functionalities by BIM tools used in this study for developing BIM models

Item description	**AutoCAD**	**Revit**	**Tekla Structures**	**Solibri**	**Navisworks Manage**	**Vico Office**
2D modeling	Yes	Yes	Yes	No	No	No
3D BIM modeling	Yes (limited)	Yes	Yes	No	No	No
3D model import as IFC file	No	Yes	Yes	Yes	Yes	Yes
3D model export as IFC file	No	Yes	Yes	No	Yes	No
3D model export using file exporter/publisher plugin	No	Yes	Yes	No	No	No

continued ...

. . . continued

Item description	AutoCAD	Revit	Tekla Structures	Solibri	Navisworks Manage	Vico Office
Coordinate transformation of imported models	Yes	Yes	Yes	Yes	Yes	No
Clash detection	Yes	Yes	Yes	Yes	Yes	Yes
BIM validation	No	No	No	Yes	No	No
Model-based quantity take-off	No	Yes	Yes	Yes	Yes	Yes
Virtual quantity takeoff	No	No	No	No	Yes	No
Project scheduling	No	No	Yes	No	Yes	Yes
Cost estimation	No	Yes (limited)	Yes (limited)	No	Yes (limited)	Yes
Linking quantity takeoff with Cost Estimate and/or Project Schedule	N/A	Yes	Yes	N/A	No	Yes
4D model simulation	N/A	N/A	No	N/A	Yes	Yes
5D model simulation	N/A	N/A	No	N/A	Yes	No
Project progress monitoring and control	N/A	N/A	Yes	N/A	Yes	Yes
4D or 5D BIM model data Interoperability	N/A	No	No	N/A	No	No
Model version management	No	No	No	No	Yes (limited)	Yes
Retrieving deleted items	Yes	Yes	Yes	N/A	Yes (limited)	No

8.2 Recommendations

In this study Navisworks Manage and Vico Office were primarily used for developing 5D BIM models. There are also other BIM tools that are used in the AEC industry for similar purposes. Therefore, it is recommended to consider such BIM tools in future studies. Some of these BIM tools include Bexel Manager and RIB iTWO.

Moreover, it was indicated the possibility of sharing 4D and 5D BIM models generated from Navisworks Manage and Vico Office to cloud-based BIM coordination tools. Further investigation is required to see the level of 4D and 5D data that can be shared through these web-based BIM platforms and to study associated constraints.

In addition, reviews of literature indicated that various standards and guidelines for BIM have been developed and are also being developed in different European countries to enable planners, designers, contractors, facility managers, etc. to implement BIM working methods in construction projects. It is recommended to conduct studies on some of these publications in future works.

Literatures Cited

Borrmann, A.; König, M.; Koch, C.; Beetz, J. Building Information Modeling. *Technologische Grundlagen Und Industrielle Anwendungen: Vieweg+ Teubner Verlag* **2015**,

Arayici, Y.; Egbu, C.; Coates, P. Building information modelling (BIM) implementation and remote construction projects: Issues, Challenges and Critiques. *ITcon* **2012**, *17*, 75–92.

Bew, M.; Richards, M. BIM maturity model. Construct IT Autumn 2008 Members' Meeting. Brighton, UK. 2008.

AllenConsultingGroup, Productivity in the buildings network: assessing the impacts of building information models. 2010.

Sen, S. The Impact of BIM/VDC on ROI: Developing a Financial Model for Savings and ROI Calculation of Construction Projects. Master's Thesis, Royal Institute of Technology, Stockholm, Sweden, 2012.

BibLus, BIM dimensions - 3D, 4D, 5D, 6D, 7D BIM explained. From: http://biblus.accasoftware.com/en/bim-dimensions-3d-4d-5d-6d-7d-bim-explained/, n.d.; (Accessed on 11/28/2019).

Liu, S.; Xie, B.; Tivendal, L.; Liu, C. Critical barriers to BIM implementation in the AEC industry. *International Journal of Marketing Studies* **2015**, *7*, 162–171.

Succar, B. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in construction* **2009**, *18*, 357–375.

Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*; John Wiley & Sons, 2011.

Arayici, Y. *Building Information Modelling*; 2015.

Xu, X.; Ma, L.; Ding, L. A framework for BIM-enabled life-cycle information management of construction project. *International Journal of Advanced Robotic Systems* **2014**, *11*, 126.

McPhee, A. practical BIM: What is this thing called LOD. http://practicalbim.blogspot.com/2013/03/what-is-this-thing-called-lod.html?goback=.gmr_68075.gde_68075_member_218542623, 2013; (Accessed on 12/05/2019).

BMVI, Umsetzung des Stufenplans Digitales Planen und Bauen, Erster Fortschrittsbericht. **2017**,

Archigraphic, BIM vs. HOAI...? — Archigraphic.com. http://wordpress.archigraphic.de/en/2015/04/20/bim-vs-hoai/, n.d.; (Accessed on 11/25/2019).

Eschenbruch, K.; Malkwitz, A.; Grüner, J.; Poloczek, A.; Karl, C. K. Maßnahmenkatalog zur Nutzung von BIM in der öffentlichen Bauverwaltung unter Berücksichtigung der rechtlichen und ordnungspolitischen Rahmenbedingungen. *Gutachten zur BIM-Umsetzung, Forschungsprogramm des Bundesministeriums für Verkehr, Bau und Stadtentwicklung, Berlin* **2014**, buildingSMART, IFC4 Documentation. https://standards.buildingsmart.org/IFC/RELEASE/IFC4_1/FINAL/HTML/, n.d.; (Accessed on 12/08/2019).

BibLus, Construction Estimating. http://biblus.accasoftware.com/en/construction-estimating/, n.d.; (Accessed on 12/11/2019).

Gaudin, B. Impacts of Building Information Modelling (BIM) on Project Management in the French Construction Industry August 2013. **2013**,

Bedrick, J. Organizing the development of a building information model. *The American Institute of Architects* **2008**, *9*.

Sinclair, D. BIM overlay to the RIBA outline plan of work. *RIBA, London* **2012**,

Ilozor, B. D.; Kelly, D. J. Building information modeling and integrated project delivery in the commercial construction industry: A conceptual study. *Journal of Engineering, Project, and Production Management* **2012**, *2*, 23–36.

Lone, U.; Hassan, S.; Yaqoob, N. BIM adoption by UK project managers-challenges involved and way forward. *EXCEL International Journal of Multidisciplinary Management Studies* **2013**, *3*, 115–129.

Sediqi, M. 4D BIM Adoption: The Incentives for and Barriers to 4D BIM Adoption within Swedish Construction Companies. 2018.

Jayasena, H. S.; Weddikkara, C. Assessing the BIM maturity in a BIM infant industry. Proceedings of the Second World Construction Symposium 2013: Socio-Economic Sustainability in Construction. 2013; pp 14–15.

Deutsch, R. *BIM and integrated design: strategies for architectural practice*; John Wiley & Sons, 2011.

DeutscheBahn, BIM Strategy: Implementation of Building Information Modeling (BIM) in the Infrastructure Division of Deutsche Bahn AG. 2019.

BIMwiki, BIM maturity levels - Designing Buildings Wiki. https://www.designingbuildings.co.uk/wiki/BIM_maturity_levels, 2019; (Accessed on 11/27/2019).

Succar, B. *Handbook of research on building information modeling and construction informatics: Concepts and technologies*; IGI Global, 2010; pp 65–103.

Amaratunga, D.; Baldry, D. Moving from performance measurement to performance management. *Facilities* **2002**, *20*, 217–223.

BRE, BRE Group: About BIM. https://www.bre.co.uk/page.jsp?id=3445, n.d.; (Accessed on 11/27/2019).

BIMWiki, BIM dimensions - Designing Buildings Wiki. From: https://www.designingbuildings.co.uk/wiki/BIM_dimensions, 2019; (Accessed on 11/27/2019).

Smith, P. BIM & the 5D project cost manager. *Procedia-Social and Behavioral Sciences* **2014**, *119*, 475–484.

Ding, L.; Zhou, Y.; Akinci, B. Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD. *Automation in construction* **2014**, *46*, 82–93.

Bloomberg, M. R.; Burney, D. J.; Resnick, D. BIM Guidelines. Retrieved from: http://www.nyc.gov/html/ddc/downloads/pdf/DDC_BIM_Guidelines.pdf, 2012; (Accessed on 11/27/2019).

Smith, A. Will BIM go bang? from: https://www.theconstructionindex.co.uk/news/view/will-bim-go-bang, 2012; (Accessed on 11/27/2019).

Gerges, M.; Ahiakwo, O.; Jaeger, M.; Asaad, A. Building Information Modeling and its application in the state of Kuwait. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering* **2016**, *10*, 81–86.

Kiani, I.; Sadeghifam, A. N.; Ghomi, S. K.; Marsono, A. K. B. Barriers to implementation of building information modeling in scheduling and planning phase in Iran. *Australian Journal of Basic and Applied Sciences* **2015**, *9*, 91–97.

Thompson, D.; Miner, R. G. Building information modeling-BIM: Contractual risks are changing with technology. *WWW document] URL http://www. aepronet. org/ge/no35. html* **2006**,

Guo, H. L.; Li, H.; Skitmore, M. Life-cycle management of construction projects based on virtual prototyping technology. *Journal of Management in Engineering* **2009**, *26*, 41–47.

Hoeber, H.; Alsem, D. Life-cycle information management using open-standard BIM. *Engineering, Construction and Architectural Management* **2016**, *23*, 696–708.

Zhang, J.; Hu, Z. BIM-and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. Principles and methodologies. *Automation in construction* **2011**, *20*, 155–166.

Becerik-Gerber, B.; Jazizadeh, F.; Li, N.; Calis, G. Application areas and data requirements for BIM-enabled facilities management. *Journal of construction engineering and management* **2011**, *138*, 431–442.

Kovács, G.; Kopácsi, S.; Haidegger, G.; Michelini, R. Ambient intelligence in product life-cycle management. *Engineering Applications of Artificial Intelligence* **2006**, *19*, 953–965.

Ellis, M. Level of Detail or Development: LOD in BIM. https://rebim.io/level-of-detail-or-development-lod-in-bim/, 2019; (Accessed on 02/26/2020).

BIMForum, Level of Development (LOD) Specification Part I & Commentary. 2019.

AECOM, *Spon's Architects' and Builders' Price Book*, 140th ed.; CRC Press, 2015.

Langdon, D.; Everest, *Spon's European Construction Costs Handbook*, 3rd ed.; Taylor & Francis, 2000.

UKConstructionOnline, BIM Progress & Adoption in the UK. https://www.ukconstructionmedia.co.uk/features/bim-progress-adoption-uk/, 2018; (Accessed on 01/05/2020).

BIMWiki, Step-by-step guide to using BIM on projects. https://www.designingbuildings.co.uk/wiki/Step-by-step_guide_to_using_BIM_on_projects, 2019; (Accessed on 01/05/2020).

BIMWiki, RIBA plan of work. https://www.designingbuildings.co.uk/wiki/RIBA_plan_of_work, 2019; (Accessed on 01/05/2020).

RIBAPlanofWork2013Online, RIBA Plan of Work 2013 - Introduction. https://www.ribaplanofwork.com/About/Introduction.aspx, n.d.; (Accessed on 01/06/2020).

Borrmann, A.; Hochmuth, M.; König, M.; Liebich, T.; Singer, D. Germany's governmental BIM initiative–Assessing the performance of the BIM pilot projects. Proceeedings of the 16th International Conference on Computing in Civil and Building Engineering, Osaka, Japan. 2016; pp 871–878.

BMVI, Stufenplan Digitales Planen und Bauen, Einführung moderner, IT-gestützter Prozesse und Technologien bei Planung, Bau und Betrieb von Bauwerken. **2015**,

Vogel, I. W. Schwelmer Symposium 2019 - Building Information Modeling (BIM - Hintergrund und aktuelle Entwicklung). **2019**,

Beuth, Guideline series VDI 2552 - Building Information Modeling - Beuth.de. https://www.beuth.de/de/regelwerke/vdi/richtlinienreihe-vdi-2552?gclid=Cj0KCQiAmZDxBRDIARIsABnkbYQkgdCT3CreKLseFcLfNhOOEhpPcbwCKWC_AJBOMIe48P8-Mgdxw8AaAmlAEALw_wcB, 2020; (Accessed on 01/19/2020).

Romy, I.; Morf, C.; Dürig, B.; Brogini, R. Construction and projects in Switzerland: Overview. https://uk.practicallaw.thomsonreuters.com/1-620-1228?transitionType=Default&contextData=(sc.Default)&firstPage=true&bhcp=1, 2019; (Accessed on 12/02/2019).

BIMconnect, BIM in Switzerland. https://bimconnect.org/en/switzerland/in-the-last-18-months-bim-in-ch-has-developed-strongly/, 2018; (Accessed on 01/04/2020).

BIMCommunity, How is BIM in Switzerland? https://www.bimcommunity.com/news/load/942/how-is-bim-in-switzerland, 2018; (Accessed on 01/04/2020).

Turner, O. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)—Sixth Edition*; Project Management Institute, 2017.

Elbeltagi, E. Quantity Take-Off. http://www.deltauniv.edu.eg/new/engineering/wp-content/uploads/Cost-Ch2.pdf, n.d.; (Accessed on 12/10/2019).

Ramaji, I. J.; Richardson, N.; Mostavi, E.; Kermanshachi, S. Investigation of Leveraging BIM Information Exchange Standards for Conducting LOD-Based Cost Estimating. Construction Research Congress 2018. pp 480–490.

Bennett, F. L. *The Management of Construction: a Project Lifecycle Approach*; Butterworth-Heinemann, an imprint of Elsevier, 2003.

Jackson, B. J. *Construction Management JumpStart, 2nd Edition*; Wiley Publishing, Inc., 2010.

Chen, W.-F.; Liew, J. R. *The Civil Engineering Handbook, Second Edition*; CRC Press, 2002.

Flanagan, R.; Jewell, C. *New Code of Estimating Practice*; John Wiley and Sons, Ltd, 2018.

Sears, S.; Clough, R.; Sears, G. *Construction Project Management: A Practical Guide to Field Construction Management, Fifth Edition*; John Wiley and Sons, Inc., 2008.

Sinclair, D. RIBA Plan of Work 2013 overview. *London: Royal Institute of British Architects* **2013**,

Appendix A

Detailed Cost Report from Vico Office

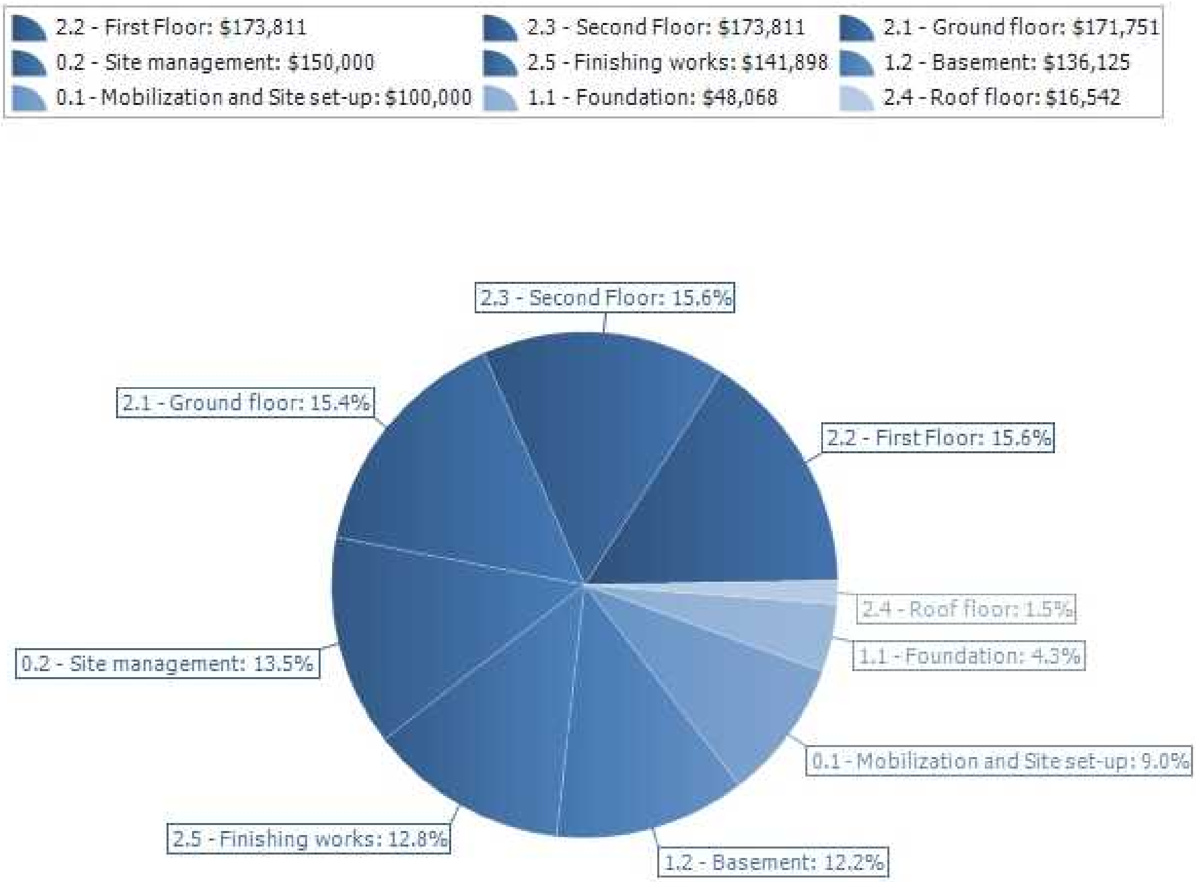
3 Story Office building

Detailed Costs by Project Totals

Cost Report

Code	-	Company	-
Name	**3 Story Office building**	Contact	-
Type	-	E-Mail	-
Address	-	Address	-

Cost Level 2 Summary



Code	Description	Quantity	Unit	Unit Cost	Base Cost
0	Preliminaries				$250,000
0.1	Mobilization and Site set-up				$100,000
0.2	Site management				$150,000
1	Substructure works				$184,193
1.1	Foundation				$48,068
1.1.1	Excavation	1,500.0	M3	$13.5	$20,250
1.1.2	Footings				$27,818
1.1.2a	Reinforcement rebar of grade BSt500S	4.6	tonn.	$1,219.8	$5,599
1.1.2b	Formwork	112.2	M2	$55.5	$6,227
1.1.2c	Concrete of grade C35/40	45.9	M3	$348.4	$15,992
1.2	Basement				$136,125
1.2.1	Columns				$14,052
1.2.1a	Reinforcement rebar of grade BSt500S	3.2	tonn.	$1,219.8	$3,863
1.2.1b	Formwork	117.3	M2	$55.5	$6,510
1.2.1c	Concrete of grade C35/40	10.6	M3	$348.4	$3,678
1.2.2	Plinth beams				$37,165
1.2.2a	Reinforcement rebar of grade BSt500S	6.1	tonn.	$1,219.8	$7,499
1.2.2b	Formwork	341.6	M2	$55.5	$18,956
1.2.2c	Concrete of grade C35/40	30.7	M3	$348.4	$10,710
1.2.3	Floor slab				$70,129
1.2.3a	Reinforcement rebar of grade BSt500S	10.7	tonn.	$1,219.8	$13,065
1.2.3b	Formwork	467.9	M2	$55.5	$25,967
1.2.3c	Concrete of grade C35/40	89.3	M3	$348.4	$31,097
1.2.4	Basement walls	51.5	M3	$286.9	$14,778
2	Superstructure work				$677,812
2.1	Ground floor				$171,751
2.1.1	Columns				$20,137
2.1.1a	Reinforcement rebar of grade BSt500S	4.5	tonn.	$1,219.8	$5,543
2.1.1b	Formwork	168.3	M2	$55.5	$9,341
2.1.1c	Concrete of grade C25/30	15.1	M3	$346.8	$5,253
2.1.2	Beams				$37,556
2.1.2a	Reinforcement rebar of grade BSt500S	6.2	tonn.	$1,219.8	$7,588
2.1.2b	Formwork	345.6	M2	$55.5	$19,181
2.1.2c	Concrete of grade C25/30	31.1	M3	$346.8	$10,787
2.1.3	Slab				$70,004
2.1.3a	Reinforcement rebar of grade BSt500S	10.7	tonn.	$1,219.8	$13,044
2.1.3b	Formwork	466.9	M2	$55.5	$25,911
2.1.3c	Concrete of grade C35/40	89.1	M3	$348.4	$31,048
2.1.4	Staircase				$2,357
2.1.4a	Reinforcement rebar of grade BSt500S	0.3	tonn.	$1,219.8	$418
2.1.4b	Formwork	18.4	M2	$55.5	$1,019
2.1.4c	Concrete of grade C35/40	2.6	M3	$348.4	$919

Code	Description	Quantity	Unit	Unit Cost	Base Cost
2.1.5	Exterior walls	66.4	M3	$237.5	$15,764
2.1.6	Interior walls	46.9	M3	$237.5	$11,136
2.1.7	Door entrance steps				$1,010
2.1.7a	Formwork	6.5	M2	$55.5	$361
2.1.7b	Concrete of grade C25/30	1.9	M3	$346.8	$649
2.1.8	Doors				$7,593
2.1.8a	Interior door: M_Door-Passage-Single-Full_Lite	10.0	NR	$542.3	$5,423
2.1.8b	Interior door: M_Door-Passage-Single-Flush	2.0	NR	$438.8	$878
2.1.8c	Entrance door: M_Door-Double-Sliding	1.0	NR	$1,291.7	$1,292
2.1.9	Windows				$6,195
2.1.9a	Main exterior window: M_Window-Casement-Double	14.0	NR	$421.6	$5,902
2.1.9b	Stair window: M_Window-Casement-Double	1.0	NR	$293.2	$293
2.2	First Floor				$173,811
2.2.1	Columns				$20,137
2.2.1a	Reinforcement rebar of grade BSt500S	4.5	tonn.	$1,219.8	$5,543
2.2.1b	Formwork	168.3	M2	$55.5	$9,341
2.2.1c	Concrete of grade C25/30	15.1	M3	$346.8	$5,253
2.2.2	Beams				$37,556
2.2.2a	Reinforcement rebar of grade BSt500S	6.2	tonn.	$1,219.8	$7,588
2.2.2b	Formwork	345.6	M2	$55.5	$19,181
2.2.2c	Concrete of grade C25/30	31.1	M3	$346.8	$10,787
2.2.3	Slab				$70,004
2.2.3a	Reinforcement rebar of grade BSt500S	10.7	tonn.	$1,219.8	$13,044
2.2.3b	Formwork	466.9	M2	$55.5	$25,911
2.2.3c	Concrete of grade C35/40	89.1	M3	$348.4	$31,048
2.2.4	Staircase				$2,357
2.2.4a	Reinforcement rebar of grade BSt500S	0.3	tonn.	$1,219.8	$418
2.2.4b	Formwork	18.4	M2	$55.5	$1,019
2.2.4c	Concrete of grade C35/40	2.6	M3	$348.4	$919
2.2.5	Exterior walls	66.9	M3	$237.5	$15,884
2.2.6	Interior walls	46.9	M3	$237.5	$11,136
2.2.7	Doors				$6,843
2.2.7a	Interior door: M_Door-Passage-Single-Full_Lite	11.0	NR	$542.3	$5,966
2.2.7b	Interior door: M_Door-Passage-Single-Flush	2.0	NR	$438.8	$878
2.2.8	Windows				$6,617
2.2.8a	Main exterior window: M_Window-Casement-Double	15.0	NR	$421.6	$6,324
2.2.8b	Stair window: M_Window-Casement-Double	1.0	NR	$293.2	$293
2.2.9	Handrail	8.8	M	$372.4	$3,277
2.3	Second Floor				$173,811
2.3.1	Columns				$20,137

Code	Description	Quantity	Unit	Unit Cost	Base Cost
2.3.1a	Reinforcement rebar of grade BSt500S	4.5	tonn.	$1,219.8	$5,543
2.3.1b	Formwork	168.3	M2	$55.5	$9,341
2.3.1c	Concrete of grade C25/30	15.1	M3	$346.8	$5,253
2.3.2	Beams				$37,556
2.3.2a	Reinforcement rebar of grade BSt500S	6.2	tonn.	$1,219.8	$7,588
2.3.2b	Formwork	345.6	M2	$55.5	$19,181
2.3.2c	Concrete of grade C25/30	31.1	M3	$346.8	$10,787
2.3.3	Slab				$70,004
2.3.3a	Reinforcement rebar of grade BSt500S	10.7	tonn.	$1,219.8	$13,044
2.3.3b	Formwork	466.9	M2	$55.5	$25,911
2.3.3c	Concrete of grade C35/40	89.1	M3	$348.4	$31,048
2.3.4	Staircase				$2,357
2.3.4a	Reinforcement rebar of grade BSt500S	0.3	tonn.	$1,219.8	$418
2.3.4b	Formwork	18.4	M2	$55.5	$1,019
2.3.4c	Concrete of grade C35/40	2.6	M3	$348.4	$919
2.3.5	Exterior walls	66.9	M3	$237.5	$15,884
2.3.6	Interior walls	46.9	M3	$237.5	$11,136
2.3.7	Doors				$6,843
2.3.7a	Interior door: M_Door-Passage-Single-Full_Lite	11.0	NR	$542.3	$5,966
2.3.7b	Interior door: M_Door-Passage-Single-Flush	2.0	NR	$438.8	$878
2.3.8	Windows				$6,617
2.3.8a	Main exterior window: M_Window-Casement-Double	15.0	NR	$421.6	$6,324
2.3.8b	Stair window: M_Window-Casement-Double	1.0	NR	$293.2	$293
2.3.9	Handrail	8.8	M	$372.4	$3,277
2.4	Roof floor				$16,542
2.4.1	Columns				$1,651
2.4.1a	Reinforcement rebar of grade BSt500S	0.4	tonn.	$1,219.8	$455
2.4.1b	Formwork	13.8	M2	$55.5	$766
2.4.1c	Concrete of grade C25/30	1.2	M3	$346.8	$431
2.4.2	Beams				$2,038
2.4.2a	Reinforcement rebar of grade BSt500S	0.3	tonn.	$1,219.8	$412
2.4.2b	Formwork	18.8	M2	$55.5	$1,041
2.4.2c	Concrete of grade C25/30	1.7	M3	$346.8	$585
2.4.3	Slab				$2,440
2.4.3a	Reinforcement rebar of grade BSt500S	0.4	tonn.	$1,219.8	$430
2.4.3b	Formwork	17.8	M2	$55.5	$987
2.4.3c	Concrete of grade C35/40	2.9	M3	$348.4	$1,023
2.4.4	Parapet wall & exterior wall	42.7	M3	$237.5	$10,129
2.4.6	Doors				$284
2.4.6a	Exterior door: M_Door-Passage-Single-Flush	1.0	NR	$283.6	$284
2.5	Finishing works				$141,898

Code	Description	Quantity	Unit	Unit Cost	Base Cost
2.5.1	**Block paving**	**1,186.1**	**M2**	**$119.6**	**$141,898**

ESTIMATE SUMMARY

	Description	Mark-up%	Net / Gross Costs
Breakdown by assigned cost categories			
	Own works		$1,064,459
	Subcontract		$47,546
BASE TOTAL COST			**$1,112,005**
	Own works	15.00%	$159,669
	Subcontract	5.00%	$2,377
GROSS TOTAL COST			**$1,274,051**

Appendix B

Project Schedule: Gantt and Time-Location Charts from Vico Office

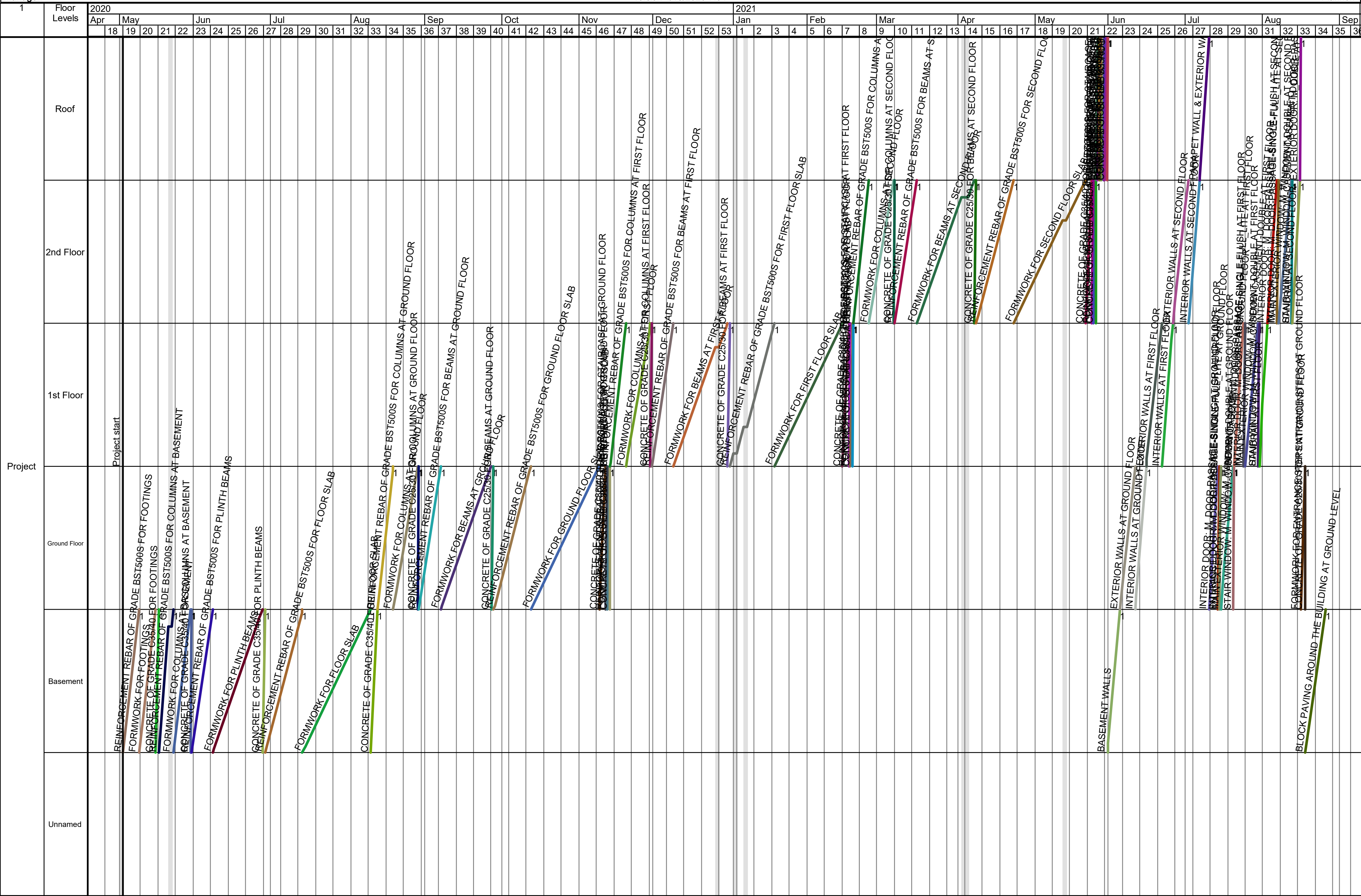
Manager:

Flowline view

version 4/13/2020 7:04

3 Story Office building

Planner:



Target:

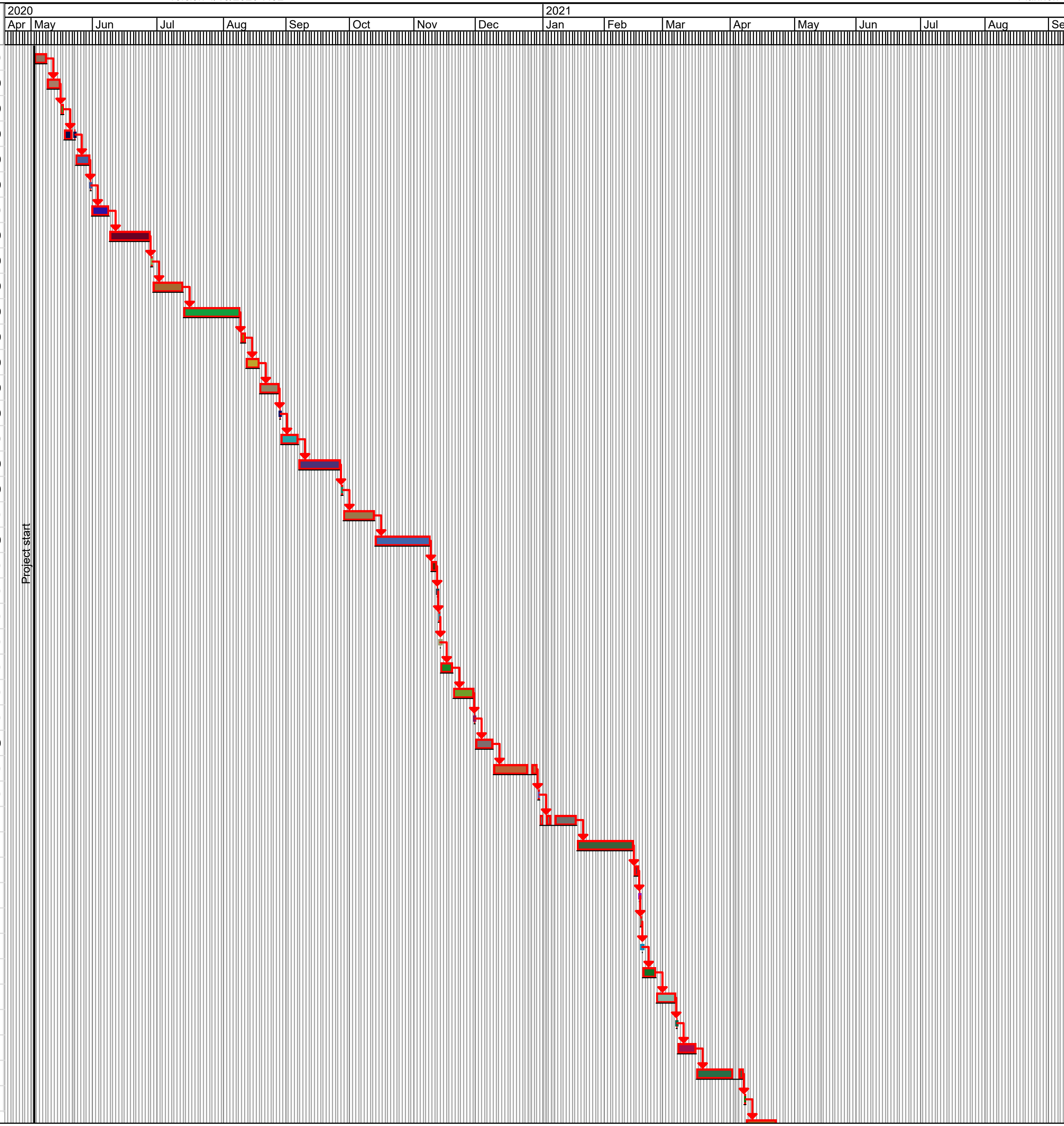
Actual:

Forecast:

Design mode

Schedule Planner v6.7.83.61

Name	Start	End
REINFORCEMENT REBAR OF GRADE BST500S FOR FOOTINGS	5/4/2020	5/8/2020
FORMWORK FOR FOOTINGS	5/8/2020	5/15/2020
CONCRETE OF GRADE C35/40 FOR FOOTINGS	5/15/2020	5/18/2020
REINFORCEMENT REBAR OF GRADE BST500S FOR COLUMNS AT BASEMENT	5/18/2020	5/22/2020
FORMWORK FOR COLUMNS AT BASEMENT	5/22/2020	5/29/2020
CONCRETE OF GRADE C35/40 FOR COLUMNS AT BASEMENT	5/29/2020	5/29/2020
REINFORCEMENT REBAR OF GRADE BST500S FOR PLINTH BEAMS	5/29/2020	6/8/2020
FORMWORK FOR PLINTH BEAMS	6/8/2020	6/26/2020
CONCRETE OF GRADE C35/40 FOR PLINTH BEAMS	6/26/2020	6/29/2020
REINFORCEMENT REBAR OF GRADE BST500S FOR FLOOR SLAB	6/29/2020	7/14/2020
FORMWORK FOR FLOOR SLAB	7/14/2020	8/10/2020
CONCRETE OF GRADE C35/40 FOR FLOOR SLAB	8/10/2020	8/12/2020
REINFORCEMENT REBAR OF GRADE BST500S FOR COLUMNS AT GROUND FLOOR	8/12/2020	8/19/2020
FORMWORK FOR COLUMNS AT GROUND FLOOR	8/19/2020	8/28/2020
CONCRETE OF GRADE C25/30 FOR COLUMNS AT GROUND FLOOR	8/28/2020	8/28/2020
REINFORCEMENT REBAR OF GRADE BST500S FOR BEAMS AT GROUND FLOOR	8/28/2020	9/7/2020
FORMWORK FOR BEAMS AT GROUND FLOOR	9/7/2020	9/28/2020
CONCRETE OF GRADE C25/30 FOR BEAMS AT GROUND FLOOR	9/28/2020	9/28/2020
REINFORCEMENT REBAR OF GRADE BST500S FOR GROUND FLOOR SLAB	9/28/2020	10/13/2020
FORMWORK FOR GROUND FLOOR SLAB	10/13/2020	11/9/2020
CONCRETE OF GRADE C35/40 FOR GROUND FLOOR SLAB	11/9/2020	11/11/2020
REINFORCEMENT REBAR OF GRADE BST500S FOR STAIRCASE AT GROUND FLOOR	11/11/2020	11/12/2020
FORMWORK FOR STAIRCASE AT GROUND FLOOR	11/12/2020	11/12/2020
CONCRETE OF GRADE C35/40 FOR STAIRCASE AT GROUND FLOOR	11/12/2020	11/12/2020
REINFORCEMENT REBAR OF GRADE BST500S FOR COLUMNS AT FIRST FLOOR	11/12/2020	11/19/2020
FORMWORK FOR COLUMNS AT FIRST FLOOR	11/19/2020	11/30/2020
CONCRETE OF GRADE C25/30 FOR COLUMNS AT FIRST FLOOR	11/30/2020	11/30/2020
REINFORCEMENT REBAR OF GRADE BST500S FOR BEAMS AT FIRST FLOOR	11/30/2020	12/8/2020
FORMWORK FOR BEAMS AT FIRST FLOOR	12/8/2020	12/30/2020
CONCRETE OF GRADE C25/30 FOR BEAMS AT FIRST FLOOR	12/30/2020	12/31/2020
REINFORCEMENT REBAR OF GRADE BST500S FOR FIRST FLOOR SLAB	12/31/2020	1/18/2021
FORMWORK FOR FIRST FLOOR SLAB	1/18/2021	2/15/2021
CONCRETE OF GRADE C35/40 FOR FIRST FLOOR SLAB	2/15/2021	2/17/2021
REINFORCEMENT REBAR OF GRADE BST500S FOR STAIRCASE AT FIRST FLOOR	2/17/2021	2/17/2021
FORMWORK FOR STAIRCASE AT FIRST FLOOR	2/17/2021	2/18/2021
CONCRETE OF GRADE C35/40 FOR STAIRCASE AT FIRST FLOOR	2/18/2021	2/18/2021
REINFORCEMENT REBAR OF GRADE BST500S FOR COLUMNS AT SECOND FLOOR	2/18/2021	2/24/2021
FORMWORK FOR COLUMNS AT SECOND FLOOR	2/24/2021	3/5/2021
CONCRETE OF GRADE C25/30 FOR COLUMNS AT SECOND FLOOR	3/5/2021	3/8/2021
REINFORCEMENT REBAR OF GRADE BST500S FOR BEAMS AT SECOND FLOOR	3/8/2021	3/16/2021
FORMWORK FOR BEAMS AT SECOND FLOOR	3/16/2021	4/7/2021
CONCRETE OF GRADE C25/30 FOR BEAMS AT SECOND FLOOR	4/7/2021	4/8/2021



Manager:

Gantt view

version 4/13/2020 7:32

3 Story Office building

Planner:

Name	Start	End
REINFORCEMENT REBAR OF GRADE BST500S FOR SECOND FLOOR SLAB	4/8/2021	4/23/2021
FORMWORK FOR SECOND FLOOR SLAB	4/23/2021	5/21/2021
CONCRETE OF GRADE C35/40 FOR SECOND FLOOR SLAB	5/21/2021	5/25/2021
REINFORCEMENT REBAR OF GRADE BST500S FOR STAIRCASE AT SECOND FLOOR	5/25/2021	5/25/2021
FORMWORK FOR STAIRCASE AT SECOND FLOOR	5/25/2021	5/26/2021
CONCRETE OF GRADE C35/40 FOR STAIRCASE AT SECOND FLOOR	5/26/2021	5/26/2021
REINFORCEMENT REBAR OF GRADE BST500S FOR COLUMNS AT ROOF FLOOR	5/26/2021	5/26/2021
FORMWORK FOR COLUMNS AT ROOF FLOOR FOR COLUMNS AT ROOF FLOOR	5/26/2021	5/27/2021
CONCRETE OF GRADE C25/30 FOR COLUMNS AT ROOF FLOOR	5/27/2021	5/27/2021
REINFORCEMENT REBAR OF GRADE BST500S FOR BEAMS AT ROOF FLOOR	5/27/2021	5/27/2021
FORMWORK FOR BEAMS AT ROOF FLOOR	5/27/2021	5/28/2021
CONCRETE OF GRADE C25/30 FOR BEAMS AT ROOF FLOOR	5/28/2021	5/28/2021
REINFORCEMENT REBAR OF GRADE BST500S FOR SLAB AT ROOF FLOOR	5/28/2021	5/28/2021
FORMWORK FOR SLAB AT ROOF FLOOR	5/28/2021	5/31/2021
CONCRETE OF GRADE C35/40 FOR SLAB AT ROOF FLOOR	5/31/2021	5/31/2021
BASEMENT WALLS	5/31/2021	6/4/2021
EXTERIOR WALLS AT GROUND FLOOR	6/4/2021	6/10/2021
INTERIOR WALLS AT GROUND FLOOR	6/10/2021	6/15/2021
EXTERIOR WALLS AT FIRST FLOOR	6/15/2021	6/22/2021
INTERIOR WALLS AT FIRST FLOOR	6/22/2021	6/25/2021
EXTERIOR WALLS AT SECOND FLOOR	6/25/2021	7/1/2021
INTERIOR WALLS AT SECOND FLOOR	7/1/2021	7/6/2021
PARAPET WALL & EXTERIOR WALL AT ROOF FLOOR	7/6/2021	7/9/2021
INTERIOR DOOR: M_DOOR-PASSAGE-SINGLE-FULL_LITE AT GROUND FLOOR	7/9/2021	7/14/2021
INTERIOR DOOR: M_DOOR-PASSAGE-SINGLE-FLUSH AT GROUND FLOOR	7/14/2021	7/14/2021
ENTRANCE DOOR: M_DOOR-DOUBLE-SLIDING AT GROUND FLOOR	7/14/2021	7/15/2021
MAIN EXTERIOR WINDOW: M_WINDOW-CASEMENT-DOUBLE AT GROUND FLOOR	7/15/2021	7/20/2021
STAIR WINDOW: M_WINDOW-CASEMENT-DOUBLE AT GROUND FLOOR	7/20/2021	7/20/2021
INTERIOR DOOR: M_DOOR-PASSAGE-SINGLE-FULL_LITE AT FIRST FLOOR	7/20/2021	7/23/2021
INTERIOR DOOR: M_DOOR-PASSAGE-SINGLE-FLUSH AT FIRST FLOOR	7/23/2021	7/26/2021
MAIN EXTERIOR WINDOW: M_WINDOW-CASEMENT-DOUBLE AT FIRST FLOOR	7/26/2021	7/29/2021
STAIR WINDOW: M_WINDOW-CASEMENT-DOUBLE AT FIRST FLOOR	7/29/2021	7/30/2021
HANDRAIL AT FIRST FLOOR	7/30/2021	8/3/2021
INTERIOR DOOR: M_DOOR-PASSAGE-SINGLE-FULL_LITE AT SECOND FLOOR	8/3/2021	8/5/2021
INTERIOR DOOR: M_DOOR-PASSAGE-SINGLE-FLUSH AT SECOND FLOOR	8/5/2021	8/6/2021
MAIN EXTERIOR WINDOW: M_WINDOW-CASEMENT-DOUBLE AT SECOND FLOOR	8/6/2021	8/12/2021
STAIR WINDOW: M_WINDOW-CASEMENT-DOUBLE AT SECOND FLOOR	8/12/2021	8/12/2021
HANDRAIL AT SECOND FLOOR	8/12/2021	8/16/2021
EXTERIOR DOOR: M_DOOR-PASSAGE-SINGLE-FLUSH AT ROOF FLOOR	8/16/2021	8/16/2021
FORMWORK FOR ENTRANCE STEPS AT GROUND FLOOR	8/16/2021	8/18/2021
CONCRETE OF GRADE C25/30 FOR ENTRANCE STEPS AT GROUND FLOOR	8/18/2021	8/18/2021
BLOCK PAVING AROUND THE BUILDING AT GROUND LEVEL	8/18/2021	8/25/2021

Design mode

Schedule Planner v6.7.83.61