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Master in

Building Information Modelling

BIM A+ European Master in Building Information Modelling

PROJECT VISUAL PLANNING

Structured and optimized processes to integrate 4D and 5D BIM to plan construction activities

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Alessandro Vacante is a postgraduate student of the first edition of the European Master in Building Information Modelling BIM A+. Alessandro attended BIM A+ after awarding a full consortium scholarship and he has been officially enrolled at the University of Minho (Portugal) and at the Polytechnic of Milan (Italy) for the academic year 2019/2020. Regarding his educational background, in 2014, Alessandro obtained his BSc degree in Civil and Construction Engineering from the University of Palermo (Italy) by awarding the first place in the decile ranking in his coursework. Later, in 2017, he earned, with honours *cum laude*, his MSc degree in Civil and Hydraulic Engineering from the Polytechnic School of the University of Palermo (Italy). Meanwhile, during the second year of the MSc, Alessandro spent 6 months at the University of Coimbra (Portugal), after awarding the Erasmus+ scholarship financed by the European Commission. Right after the Erasmus + experience, he awarded the 15th call of the NATO Internship Programme at NATO HQ based in Brussels (Belgium). Regarding his professional carrier, Alessandro have been working closely with Engineers, Architects, Project Managers and Military Officers coming from different countries over the world and in international projects and programs across the public, military and private sectors. He is addicted to innovation and digitisation across the value chain of the AEC industry with a special emphasis on the transition from fragmented project delivery methods towards an integrated approach. His technical interests include information technology for project management, building information modelling, collaboration and coordination technologies. Lastly, his mission is to help project teams in delivering best outcomes during each stage of the project life-cycle and businesses in closing the gap by increasing collaboration and productivity.

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To my truly passion, for giving me the opportunity to better myself.

To my great parents and brother, who are beyond supportive.

A.V.

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STATEMENT OF INTEGRITY

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

I further declare that I have fully acknowledged the Code of ethics and conduct of Polytechnic of Milan.

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ABSTRACT

Title: Project Visual Planning – Structured and optimized processes to integrate 4D and 5D BIM to plan construction activities

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The transition to digital technology is having a transformative impact on the building industry. Indeed, the implementation of the latest digital technologies and introduction of national BIM programs is advancing rapidly. However, in Europe, BIM adoption has not progressed concurrently across the nations. In fact, the pace, drivers and strategies of BIM adoption in different European countries vary greatly and may often reflect national industry tendencies. In Italy, for instance the BIM implementation strategy began with the approval and publication of the standard UNI 11337 and the decree DM 560/2017 – as per the article n. 23 of D.Lgs. 50/2016 concerning public procurement and contract – which states the roadmap for the mandatory use of BIM for public buildings and large-scale infrastructure projects. Progressive mandatory adoption of BIM started from the 1st January 2019 for projects exceeding 100 million EUR and full implementation is expected by 2025 for all public projects, even small construction works.

Among BIM tools' distinctive qualities is their ability to generate information that contain not only 3D geometrical features of a building but also structured data concerning its materials, components, structure, schedule, cost, etc. Therefore, the core of BIM is represented by an intelligent nD digital model of a building which is now further evolving into another concept known as "Digital Twin". Organizations started to pay attention to this new exciting tool and process. Nowadays, 3D modelling, clash detection, construction sequencing, cost estimation, and walk-throughs have become table stakes. Customers and owners are now asking about Big Data, Internet of Things (IoT), model to prefabrication, life-cycle energy modelling, project partnering approaches, and how BIM can mitigate other risk factors during construction. BIM behaves as a socio-technical system; it changes institutions, businesses, business models, education, workplaces and careers and is also changed by the environment in which it operates. The most important contribution of BIM is not that it is a tool of automation or integration but a tool of further specialization. Specialization is a key to the division of labour, which results in using more knowledge, in higher productivity and in greater creativity. In this light, both public and private sector actors within the domain of the AEC industry have started to align their business practices in adopting BIM in order to (i) enable efficiency in design through better collaboration and (ii) use the model for simulating all construction process prior to the start of the real construction which would, in turn, prevent errors during the construction phase for enabling a more agile, effective and efficient process.

In order to embrace the full potential of BIM and, consequently, boost productivity, organizations within the AEC industry are called to re-think their internal organizational business processes. For this reason, recently, organizations and Project Managers (PMs) have been attracted by the possibility to improve their BIM maturity level and thus competitiveness by using the latest technological advancements offered by the industry in the area of construction scheduling and cost estimation to plan, visualize and monitor the construction activities. Indeed, construction scheduling and cost estimation are the key-features that the client requires and asks to be identified at the early stages of a construction project. In this view, BIM has the power to integrate the information regarding time and cost into the 3D model – 4D and 5D BIM. Such as integration, if implemented by following procedures and highlighting the goals during each stage of the project, can improve the communication between the players, reduce the risk of cost and time overrunning, speed up delivery times, increase team-collaboration, cut waste and deliver assets that are right at the first place through predictive data that flow across the project life cycle. On the other hand, client and stakeholders can acquire a detailed overview of the entire process and stay on top of everything that happens or is going to happen on the project.

In Building Information Modelling (BIM) it is common talking about 4D and 5D BIM with reference to the integration of time and costs information onto the 3D models. According to the objectives and use of the models this integration can follow different approach and workflows. Furthermore, such integration involves the use of diverse specialised tools quite different from the simple BIM authoring tools. The management of 4D and 5D open the complex of interoperability requiring the definition of processes and rules that can guarantee the correct generation and use of the information.

Indeed, 4D and 5D BIM are two of the facets of the overall BIM technology, in which the 3D model is integrated to the time and cost. It allows the project team to visualize, analyse the various aspects at any given point of time throughout the project life cycle to discover any potential issues and bottlenecks before the construction phase. Based on the literature review, latest standards, state of the art and real case scenario, the master thesis proposed a workflow to integrate 4D and 5D BIM during the design stage of a building project. By using this proposed workflow, the project team and decision makers can quickly obtain a reliable project construction simulation with the information of the time and cost, so that they can have an efficient overview of the proposed project to make appropriate judgements and decisions during the design stage – this represent the added value to increase competitiveness.

The outcomes of this research work shall help enterprises, and, in particular A&E firms, to appreciate the advancement of the technology within the AEC industry. It should help them in taking action in their internal delivery processes by adopting specialized tools and new workflows.

Keywords: Project Visual Planning, Building Information Modelling, 4D BIM, 5D BIM, Project Management

SOMMARIO

Titolo: Progettazione Visiva – Processi strutturati e ottimizzati per integrare il 4D e 5D BIM per pianificare la fase costruttiva

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Il passaggio alla tecnologia digitale sta avendo un impatto trasformativo sull'industria edilizia. Infatti, l'implementazione delle più recenti tecnologie digitali e l'introduzione di programmi BIM nazionali sta avanzando rapidamente. Tuttavia, in Europa, l'adozione del BIM non è progredita simultaneamente in tutte le nazioni. Infatti, i tempi, i driver e le strategie di adozione del BIM nei diversi paesi europei variano notevolmente e spesso possono riflettere le tendenze dell'industria nazionale. In Italia, ad esempio, la strategia di attuazione del BIM è iniziata con l'approvazione e la pubblicazione della norma UNI 11337 e del decreto DM 560/2017 - ai sensi dell'articolo 23 del D.Lgs. n. 23. 50/2016 in materia di appalti pubblici e contratti - che stabilisce la tabella di marcia per l'utilizzo obbligatorio del BIM per gli edifici pubblici e le grandi opere infrastrutturali. L'adozione obbligatoria progressiva del BIM è iniziata il 1° gennaio 2019 per i progetti superiori a 100 milioni di euro e la piena attuazione è prevista entro il 2025 per tutti i progetti pubblici, anche per le piccole opere di costruzione.

Tra le qualità distintive degli strumenti BIM vi è la capacità di generare informazioni che contengono non solo le caratteristiche geometriche 3D di un edificio, ma anche dati strutturati riguardanti i materiali, i componenti, la struttura, i tempi, i costi, ecc. Pertanto, il nucleo del BIM è rappresentato da un modello digitale nD intelligente di un edificio che si sta ulteriormente evolvendo in un altro concetto noto come "Digital Twin". Le organizzazioni hanno iniziato a prestare attenzione a questo nuovo ed entusiasmante strumento e processo. Oggi, la modellazione 3D, clash detection, simulazione durante la costruzione, la stima dei costi e i walk-throughs sono diventati dei paletti da tavolo. I clienti e i proprietari chiedono ora informazioni su Big Data, Internet of Things (IoT), dal modello alla prefabbricazione, dalla modellazione del ciclo di vita dell'energia alla modellazione del ciclo di vita, agli approcci dei partner di progetto, e come il BIM può mitigare altri fattori di rischio durante la costruzione. Il BIM si comporta come un sistema socio-tecnico; cambia le istituzioni, le imprese, i modelli di business, l'istruzione, i luoghi di lavoro e le carriere ed è anche cambiato dall'ambiente in cui opera. Il contributo più importante del BIM non è che sia uno strumento di automazione o di integrazione, ma uno strumento di ulteriore specializzazione. La specializzazione è una chiave per la divisione del lavoro, che si traduce in un maggiore utilizzo delle conoscenze, in una maggiore produttività e in una maggiore creatività. In questa prospettiva, sia gli attori del settore pubblico che quelli del settore privato nell'ambito dell'industria AEC hanno iniziato ad allineare le loro pratiche commerciali nell'adozione del BIM al fine di (i) consentire l'efficienza nella progettazione attraverso una migliore collaborazione e (ii) utilizzare il modello per la simulazione di tutti i processi di costruzione prima dell'inizio della costruzione vera e propria che, a sua

volta, eviterebbe errori durante la fase di costruzione per consentire un processo più agile, efficace ed efficiente.

Al fine di abbracciare il pieno potenziale del BIM e, di conseguenza, aumentare la produttività, le organizzazioni all'interno dell'industria AEC sono chiamate a ripensare i loro processi organizzativi interni di business. Per questo motivo, recentemente, le organizzazioni e i Project Manager (PM) sono stati attratti dalla possibilità di migliorare il loro livello di maturità del BIM e quindi la competitività, utilizzando gli ultimi progressi tecnologici offerti dal settore nell'area della programmazione delle costruzioni e della stima dei costi per pianificare, visualizzare e monitorare le attività di costruzione. Infatti, la programmazione della fase di costruzione e la stima dei costi sono le caratteristiche chiave che il cliente richiede ed esige di essere identificato nelle prime fasi di un progetto. In questa visione, il BIM ha il potere di integrare le informazioni relative ai tempi e ai costi nel modello 3D - 4D e 5D BIM. L'integrazione, se implementata seguendo le procedure ed evidenziando gli obiettivi durante ogni fase del progetto, può migliorare la comunicazione tra gli attori, ridurre il rischio di superamento dei costi e dei tempi, accelerare i tempi di consegna, aumentare la collaborazione, tagliare gli sprechi e consegnare asset che sono corretti e funzionali fin dal momento della consegna. D'altra parte, il cliente e gli stakeholder possono acquisire una visione d'insieme dettagliata dell'intero processo e tenere sotto controllo tutto ciò che accade o sta per accadere sul progetto.

Nel BIM è comune parlare di 4D e 5D con riferimento all'integrazione delle informazioni sui tempi e sui costi nei modelli 3D. A seconda degli obiettivi e dell'uso dei modelli questa integrazione può seguire diversi approcci e flussi di lavoro. Inoltre, tale integrazione comporta l'uso di diversi strumenti specializzati molto diversi dai semplici strumenti di authoring BIM. La gestione di 4D e 5D apre il complesso di interoperabilità che richiede la definizione di processi e regole in grado di garantire la corretta generazione e l'utilizzo delle informazioni.

Infatti, il 4D e il 5D BIM sono due degli aspetti della tecnologia BIM complessiva, in cui il modello 3D è integrato al tempo e al costo. Esso consente al team di progetto di visualizzare, analizzare i vari aspetti in qualsiasi momento del ciclo di vita del progetto per scoprire eventuali problemi e colli di bottiglia prima della fase di costruzione. Sulla base della revisione della letteratura, degli ultimi standard, dello stato dell'arte e del caso reale, la tesi di master ha proposto un flusso di lavoro per integrare il BIM 4D e 5D durante la fase di progettazione di un progetto di costruzione. Utilizzando questo flusso di lavoro proposto, il team di progetto e i decisori possono ottenere rapidamente una simulazione affidabile della costruzione del progetto con le informazioni dei tempi e dei costi, in modo da avere una visione d'insieme efficiente del progetto proposto per formulare giudizi e decisioni appropriate durante la fase di progettazione - questo rappresenta il valore aggiunto per aumentare la competitività.

I risultati di questo lavoro di ricerca aiuteranno le imprese, e in particolare le imprese del settore A&E, ad apprezzare il progresso della tecnologia all'interno dell'industria AEC. Dovrebbe aiutarle ad agire nei loro processi interni di delivery adottando strumenti specializzati e nuovi flussi di lavoro.

Parole chiave: Progettazione Visiva, Building Information Modelling, 4D BIM, 5D BIM, Project Management

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1. INTRODUCTION

This first chapter of the present master thesis introduces the work with a general background, purpose and aim of the research. Right after, the research questions will be presented, followed by the applied methodology together with the organization of the present work and the expected contribution.

1.1. General background

Nowadays, the world is changing faster than ever before. According to the research *Shaping the Future of Construction: A Breakthrough in Mindset and Technology* [1] published by the *World Economic Forum®* and *The Boston Consulting Group®*, the population of the world's urban areas is increasing by 200,000 people per day, all of whom need affordable housing as well as social, transportation and utility infrastructures. This represents just one of the global megatrends that are currently shaking up the Architecture, Engineering and Construction industry (AEC). In front of such challenges the AEC industry is almost under a moral obligation to transform its fragmented value and supply chain (Oesterreich and Teuteberg, 2016). While most other industries from retail to manufacturing have undergone tremendous changes over the last few decades, and have reaped the benefits of digitization and innovation, the AEC industry has been hesitant about fully embracing the latest technological opportunities, and its growth has stagnated accordingly (World Economy Forum, 2016). This not only represents a lost opportunity inside the AEC industry's domain but costs for the economy of the world. Such as lost opportunity has been deeply analysed by *McKinsey Global Institute (MGI)* which represents the business and economics research arm of *McKinsey & Company®*. Their research report *Reinventing construction: a route to higher productivity* says: "*the construction sector is one of the largest in the world economy, with about $10 trillion spent on construction-related goods and services every year. However, the industry's productivity has trailed that of other sectors for decades, and there is a $1.6 trillion opportunity to close the gap"*.

Throughout history, the AEC industry has been truly recognised as the economic backbones of many countries (McKinsey Global Institute, 2017). A sustainable and competitive AEC industry brings many benefits to society and the worldwide economy: (i) buildings and infrastructure adapted to social changing and economic needs, (ii) meets global challenges[2] such as energy security and climate change, (iii) provide an attractive sector to work in, complete with excellent opportunities for career development, good pay, and improved health and safety (United Nations, 2015). The sector is affected by several other policies, such as environmental protection, energy efficiency, work safety, taxation and public procurement. The policymakers around the world have been calling for years to draft and promote a favourable framework to boost competitiveness and support sustainable growth in the sector. For

[1] The report is the first publication of the multi-year Future of Construction Project, guiding and supporting the AEC industry in its digital transformations. It presents an "industry transformation framework", which lists 30 measures that cover such aspects at the uptake of innovative technologies, enhancements in operations and processes, new adjustments to business and HR strategies, industry cooperation and optimization of public policy.

[2] Global challenges identified within the *2030 Agenda for Sustainability Development, 2016*.

instance, within the European Union (EU) borders, the policies and initiatives include the Strategy for the sustainable competitiveness of the construction sector and its enterprises (2012)[3], the EU BIM Task Group[4] and the EU Digital Construction platform (2019)[5]. The digitisation of the construction sector is also integrated in other policy areas such as the EU directive on Public Procurement (2014), which promotes the use of Building Information Modelling (BIM) in construction project; or the Digital Entrepreneurship Monitor[6] (European Commission, 2019). BIM represents one of the key to boost productivity in AEC industry. This technology is being adopted in many different countries, in a wide range of types of projects, and by public sector, private sector and several professionals from different background and disciplines[7]. The transition to digital technology is having a transformative impact on the building industry. Indeed, the implementation of the latest digital technologies and introduction of national BIM programs is advancing rapidly. Following several guides issued by several professional association from UK and USA, in December 2018, the International Organization for Standardization (ISO) published the ISO 19650, in its parts 1 (Concept and principles) and 2 (Delivery phase of assets), which through the mechanism of direct adoption stated on the Vienna Agreement have become an European (EN) and national standard for each member state during 2019[8] (UNI EN ISO, 2020). However, in Europe, BIM adoption has not progressed concurrently across the nations. In fact, the pace, drivers and strategies of BIM adoption in different European countries vary greatly and may often reflect national industry tendencies. In Italy, for instance the BIM implementation strategy began with the approval and publication of the standard UNI 11337 and the decree DM 560/2017 – as per the article n. 23 of D.Lgs. 50/2016 concerning public procurement and contract – which states the roadmap for the mandatory use of BIM for public buildings and large-scale infrastructure projects. Progressive mandatory adoption of BIM started from the 1st January 2019 for projects exceeding 100 million EUR and full implementation is expected by 2025 for all public projects, even small construction works (Italian Government, 2016, 2017; UNI, 2017).

Among BIM tools' distinctive qualities is their ability to generate information that contain not only 3D geometrical features of a building but also structured data concerning its materials, components, structure, schedule, cost, etc. Therefore, the core of BIM is represented by an intelligent nD digital model of a building which is now further evolving into another concept known as "Digital Twin"[9] (Glaessgen and Stargel, 2012; Grieves, 2014; Tao *et al.*, 2018). Organizations started to pay attention to this new

[3] EC (2012). Strategy for the sustainable competitiveness of the construction sector and its enterprises.
Source: https://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0433:FIN:EN:PDF

[4] Source: http://www.eubim.eu/.

[5] The European digital platform for construction is intended to serve the purpose of facing the main challenges related to the uptake of digital tools in support of the digital evolution of the sector. The EU digital platform is known with the name of DigiPLACE, which represents a framework with the purpose to have a common ecosystems of digital services that will support innovation, commerce, etc. It will define a Reference Architecture Framework for digital construction platform based on an EU-wide consensus involving a large community of stakeholders, resulting in a strategic roadmap for successful implementation of this architecture.
Source: https://www.digiplaceproject.eu/.

[6] Source: https://ec.europa.eu/easme/en/tender/36/digital-entrepreneurship-monitor.

[7] The estimated value for the European BIM market was 1.8 billion EUR in 2016, and it is expected to grow up to 2.1 billion EUR by 2023 (European Commission, 2019).

[8] Source: https://www.ingenio-web.it/26765-standard-bim-il-mondo-dopo-la-iso-19650.

[9] The concept of Digital Twin was firstly presented by Grieves at one of his presentation about PLM in 2003 at University of Michigan. A general definition of Digital Twin which has been recognized and used by most people till now was given by Glaessegen and Stargel in 2012: Digital Twin is an integrated multi-physics, multi-scale, probabilistic simulation of a complex product and uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin.

exciting tool and process. Nowadays, 3D modelling. clash detection, construction sequencing, cost estimation, and walk-throughs have become table stakes. Customers and owners are now asking about Big Data, Internet of Things (IoT), model to prefabrication, life-cycle energy modelling, project partnering approaches, and how BIM can mitigate other risk factors during construction (Hardin and McCool, 2015). BIM behaves as a socio-technical system; it changes institutions, businesses, business models, education, workplaces and careers and is also changed by the environment in which it operates. The most important contribution of BIM is not that it is a tool of automation or integration but a tool of further specialization. Specialization is a key to the division of labour, which results in using more knowledge, in higher productivity and in greater creativity (Turk, 2016). In this light, both public and private sector actors within the domain of the AEC industry have started to align their business practices in adopting BIM in order to (i) enable efficiency in design through better collaboration and (ii) use the model for simulating all construction process prior to the start of the real construction which would, in turn, prevent errors during the construction phase for enabling a more agile, effective and efficient process.

In order to embrace the full potential of BIM and, consequently, boost productivity, organizations within the AEC industry are called to re-think their internal organizational business processes, Information Technology (IT) and Information Communication Technology (ITC) by adopting digital technologies and new approaches. This procedure can be identified as the well-known Business Process Reengineering (BPR), which, shortly, represents the practice of rethinking and redesigning the way work is done to better support an organization's mission and reduce costs (Wikipedia, 2020). Several research studies examine how the relationship between IT, ITC and BPR is capable to make an organization more efficient and competitive. The motivation is usually the realization that there is a need to speed up the process, reduce needed resources, improve productivity and efficiency, and, consequently, increase competitiveness (Attaran, 2004). For this reason, recently, organizations and Project Managers (PMs) have been attracted by the possibility to improve their BIM maturity level and thus competitiveness by using the latest technological advancements offered by the industry in the area of construction scheduling and cost estimation to plan, visualize and monitor the construction activities. Indeed, construction scheduling and cost estimation are the key-features that the client requires and asks to be identified at the early stages of a construction project. In this view, BIM has the power to integrate the information regarding time and cost into the 3D model – 4D and 5D BIM. Such as integration, if implemented by following procedures and highlighting the goals during each stage of the project, can improve the communication between the players, reduce the risk of cost and time overrunning, speed up delivery times, increase team-collaboration, cut waste and deliver assets that are right at the first place through predictive data that flow across the project life cycle. On the other hand, client and stakeholders are able to acquire a detailed overview of the entire process and stay on top of everything that happens or is going to happen on the project.

1.2. Problem statement

Scheduling and cost estimation have been recognized as two challenging activities during the design and construction stage of a building project life cycle. First of all, they involve different features such as good knowledge of all the activities during the construction phase and the related risks, the estimation of the quantity of materials, collection of cost and data regarding the duration of the activities, as well

as the arrangement of resources for the construction activities – such as resources can be identified in labour, materials and machinery. The aforementioned activities are time-consuming and labour-intensive, especially for large construction projects. Secondly, they require the expertise and collaboration of three key-people within the project team: the Quantity Surveyor, the Cost Manager and the Planner. According to many studies, BIM aims at increasing the quality of construction scheduling and cost estimation by promoting digital working space that enable collaboration and sharing of the information between the members of the project team during the modelling activities as well as virtual simulations. In BIM, it is common talking about 4D and 5D BIM with reference to the integration of time and costs information onto the 3D digital models. According to the objectives and use of the 3D models during the design development stage, this integration can follow different approaches and workflows. Such integration involves, too, the use of different specialized tools available in the market that enable to connect people with data and resources. Since the interest in 4D and 5D BIM applications is growing, several software houses have started to provide dedicated tools supporting schedule and cost integration, such as Primus® (ACCA software), Vico® Software (Trimble), STR Vision CPM® (TeamSystem), Naviswork® (Autodesk), Synchro PRO® (Synchro Software) and Bexel Manager® (Bexel Consulting). In order to fully embrace the integration of the information regarding time and cost during the design stage, the tools must be used with the right processes in place, in order to create tremendous value for an organization. When new tools are combined with old processes, they can inhibit success as well as frustrate users. This is why it is so important to look at new tools as they become available for what they are and treat the investigation of the processes required to enable a new tool with the same rigor as that of the technology itself.

1.3. Objectives and research questions

Based on the literature review, latest standards, state of the art and real case scenario, this dissertation work aims at developing a structured and optimized workflow to integrate 4D and 5D BIM during the design stage of a building project. By using this proposed workflow, the project team and decision makers can quickly obtain a reliable project construction simulation with the information of the time and cost, so that they can have an efficient overview of the proposed project to make appropriate judgements and decisions during the design stage – this represent the added value to increase competitiveness.

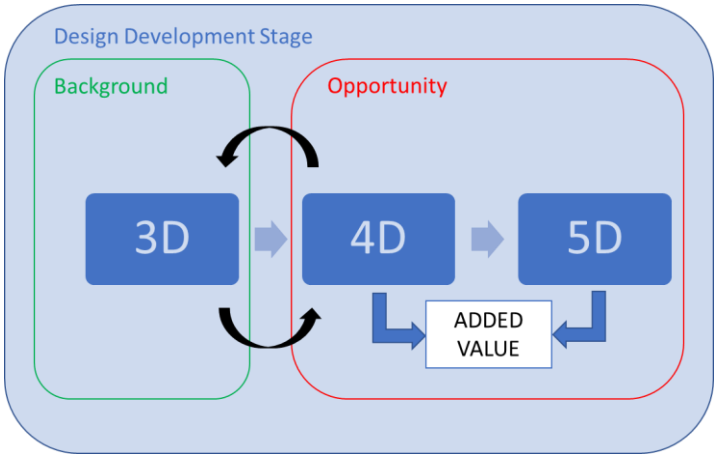

Figure 1: BIM dimensions schematic sequence during the Design Development Stage

This present research and proposed workflow are based on seven main questions:

1. How does BIM support the digitization of the construction scheduling?
2. How does BIM support the digitization of the cost estimation?
3. Which are the BIM tools that allow the 4D BIM and 5D BIM integration?
4. How can we use the nBIM models to enable better and faster decision making?
5. How the integration of 4D and 5D BIM during the design development help to increase competitiveness, mitigate risks and deliver projects on time?
6. Is it possible to put in place standard and automatic procedures for such integration?
7. What are the benefit of such integration during the design development?

1.4. Research methodology

The present work has been carried out by combining the theory and the practice through a real case study concerning a building project given by a player within the AEC industry – an Architectural and Engineering (A&E) design office. A deep understanding in several areas has been required: the project life cycle, international plan of work and its stages, the use of BIM to carry out building projects, international and national standard, professional literature regarding scheduling and cost estimation and a complete study of the specialized software tools to be used for the 4D and 5D BIM integration. Last but not least, a deep study of the project regarding the case study and the documents about the technical design.

The work took place through the following stages:

- Defining research-area;
- Research and study;
- Analysis and implementation of the proposed workflow;
- Evaluation through the case study; and
- Conclusions.

The overall stages are illustrated in detail by using the waterfall structure in Figure 2.

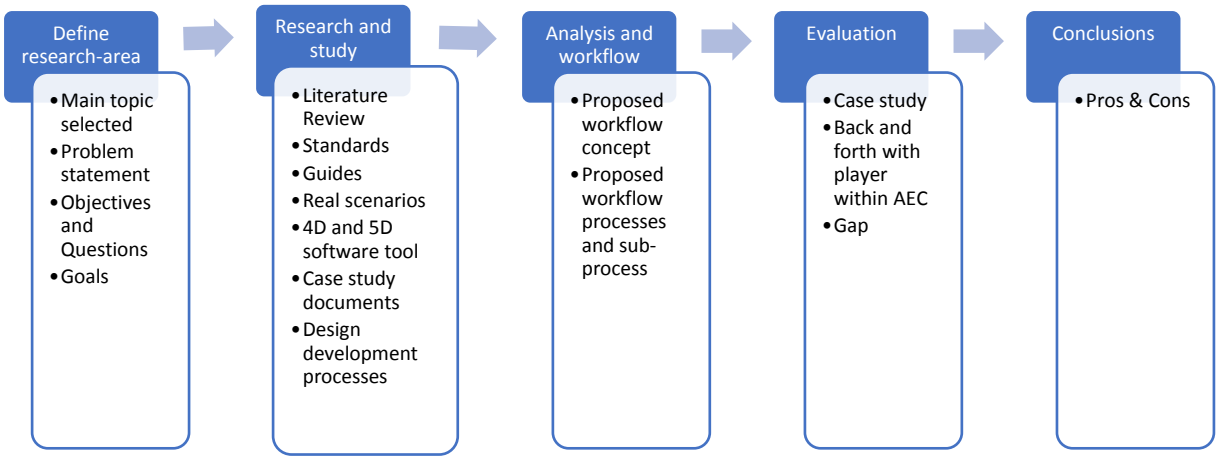

Figure 2: Overview of the development stages of the Master Thesis.

1.5. Thesis organization

The present master thesis is divided into five main chapters further described:

- **Chapter 1 – Introduction:** This chapter gives a general background of the objectives of the research work, methods and expected outlines;

- **Chapter 2 – Literature Review:** This chapter focuses on the review of literature related to the main topics discussed in this research, including national and international standard: BIM, design development, construction scheduling, cost estimation, 4D and 5D BIM. The literature provides the basic definitions, information about previous related studies and related methodologies in the construction scheduling and cost estimation areas.

- **Chapter 3 – Proposed Workflow:** This chapter describes in detail the workflow that should be adopted during the design development to integrate data onto the 3D model concerning time and cost.

- **Chapter 4 – Case Study:** This chapter gives a practical example through a real case study in which is applied the proposed workflow during the design development stage; and

- **Chapter 5 – Conclusion:** Lastly, this chapter provides an analysis of the work with the pros and cons of the applied workflow and gives a summary of future developments to expand the scope of the current workflow.

1.6. Expected contribution

First of all, considering the traditional methods applied for scheduling and cost estimation in building construction management, this research is meant to expand the knowledge and to improve the efficiency of using these methods by integrating the 3D model with data regarding cost and time. One of the goals of the work is to point out an optimized workflow for making scheduling and cost estimation during the design development of a building project. Indeed, 4D and 5D BIM are two of the facets of the overall BIM technology, in which the 3D model is integrated to the time and cost. It allows the project team to visualize, analyse the various aspects at any given point of time throughout the project life cycle to discover any potential issues and bottlenecks before the construction phase. The outcomes of this research work should help enterprises, and, in particular A&E firms, to appreciate the advancement of the technology within the AEC industry. It should help them in taking action in their internal delivery processes by adopting specialized tools and new workflows. Moreover, the outcomes will help clients and investors to define the requirements in their Project Delivery Plan (PDP) and Exchange Information Requirements (EIR).

The goal of the research is to analyse to help in order to change the technology and build a new framework and workflow in order to help the evolution to create the simulation focused on scheduling and cost estimation that could be used throughout the project life cycle and in tendering evaluation as well. The target of the work and thus the expected contribution is represented by the player involved during the construction.

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2. LITERATURE REVIEW

This chapter focuses on the review of some literature related to the main topics discussed in the following chapters. The review is meant to provide the basic definitions, information about previous related studies and related workflows that have been adopted during the design phase and within the domain of construction scheduling and cost estimation areas.

2.1. Introduction

For more than a decade, the AEC industry is facing enormous technological changes and challenges including the proliferation of information technology and appropriate application of sustainable practices. Project teams and PMs must be able to deal with a rapid pace of technological change, a highly interconnected world and complex problems that require multidisciplinary solutions (Becerik-Gerber and Kensek, 2010). BIM represents one of the technological advancements that each player within the AEC industry would like to implement and to improve in order to satisfy the market's requirements. What is the promise of BIM? The promise of BIM is to build a structure virtually prior to physically constructing it. This allows project teams to design the 3D model of buildings and analyse, sequence, and explore them through a digital environment where it is far less expensive to make changes than in the field during construction, where changes are exponentially more costly. Today, this promise has become reality. Several BIM software and mobile applications are delivering results that mitigate construction risk by integrating data in order to obtain a 4D and 5D BIM model. Although some tools are more advanced than others, we are rarely at an impasse where some function is simply "impossible" and not able to be achieved through technology.

2.2. Building Information Modelling (BIM)

The International Organization for Standardization (ISO) published the ISO 19650 in December 2018 as the standard for organising information about construction works. It "*sets out the concepts and principles for the business processes across the built environment sector in support of management and production of information during the lifecycle of built assets, referred to as 'information management' in the text, when using building information modelling"*(BS EN ISO 19650- 1:2018, 2018). There is no universally accepted definition of BIM. However, the standard gives the definition of BIM as *"shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions".* BIM is an intelligent 3D model-based process that gives AEC professionals the insight and tools to more efficiently plan, design, construct and manage building and infrastructure. At the heart of BIM is a smart building data model that incorporates not only 3D geometry but also all the relevant data relating to the building and its components. A holistic definition of BIM encompasses three interconnected aspects (Royal Institution of Chartered Surveyors (RICS), 2014):

- **The model itself** – a computable representation of the physical and functional characteristics of the project;
- **The process of developing the model** – the hardware and software used for developing the model, electronic data interchange and interoperability, collaborative workflows and definition

of roles and responsibilities of project team members in relation to BIM and a common data environment; and

- **The use of the model** – business models, collaborative practices, standards and semantics, producing real deliverables during the project life cycle.

BIM utilises data-rich 3D models through a collaborative working processes in order to eliminate waste and improve the quality of information provided during the design and construction phases. Moreover, BIM, when integrated with a proper information management system within a Common Data Environment (CDE), also provides the opportunity to deliver structured data for asset management which can be used throughout an agreed process to inform Facility Management (FM) systems – such as Building Management System (BMS). Shortly, BIM is a collaborative way of working with the right processes and support of the digital technologies. So, what are the benefits of BIM? Some of them are:

- Reduce errors and omissions;
- Reduce rework;
- Improve collaboration;
- Reduce waste;
- Whole live cycle management;
- Reduce life cycle time of specific workflows; and
- Better information for improved decision making.

The technology and the idea behind BIM enable behaviour in two different contexts: the specific project and the broader general industrial and society. In a project context, BIM pushes technological opportunities and changes business models, organizational patterns and information process in which the project is developed. It encourages centralized information management, reduces improvisation, and calls for better organization of processes. It should respond to varying levels of IT literacy of project partners and their achieved technological levels. On a general level, BIM encourages changes in legal processes and changes in procurement processes and is causing restructuring of the AEC industry as whole (Turk, 2016).

2.2.1. The BIM nDimensions

Indeed, BIM methodology can be described as a process where the asset is built twice, first virtually in the digital environment and later, physically at the site. A BIM model can be utilized for pre-defined specific purposes. It is important to define why using BIM in the first place. Over the years, several studies focused on identifying the use of the BIM model have been conducted. To help the AEC industry, various classification systems have been published. They provide a common language for the uses of BIM that can be leveraged to communicate the precise purpose and context of implementing BIM on a capital facility project. A BIM use is defined as a method of applying BIM during facility's lifecycle to achieve one or more specific objectives. Perhaps, BIM uses are a method of associating specific BIM benefits to steps in the design, build and operate workflow (Kreider and Messner, 2013; Rojas *et al.*, 2019). BIM has so many potential benefits for a building lifecycle that it is important to define the specific BIM uses per project. According to the project stage requirements and project complexity, specific parameters are added to the existing information contained in BIM. These additions of pre-defined BIM use can be also described as BIM dimensions as illustrated in Table 1. These dimensions

enhance the data associated with a model to share a greater level of understanding of a construction project. Nowadays, BIM technology has evolved from 3D dimension to more data-integrated dimensions such as 5D, 6D & 7D that are posed to change the future of AEC industry. Each dimension has its own purpose and is useful in finding out how much a project would cost, its timeline, when it would be completed and how sustainable it would be in the future.

Dimension	Application
3D Coordination	Visually interface checking with mechanical, electrical, and plumbing (MEP) integration reduce conflicts
Design and Constructability Reviews	Analyze design for practicality and identification of errors and omissions
4D Scheduling and Sequencing	Activities sequencing with visualization. Simulation for update time and resource schedule
5D Cost Estimation	Material quantities are extracted automatically and changed when any changes are entered in model. Micro and Macro Costing Models.
6D Procurement	Integration of subcontractor supplier and vendor data into isolated models.
Prefabrication	Optimization of prefabricated construction components. Integration with MEP components.
Structural Analysis	External analytical engine develop architecture design to structure and then analyzed for loading.
Lightening Analysis	Creation of effective, efficient, ambient and constructible lightening systems with enhancement in quality, cycle time and cost.
Mechanical (HVAC) Analysis	Clash, conflict and overlapping detection with computerized visualization.
Energy Analysis	Energy analysis, delighting, orientation analysis, solar analysis, building, massing analysis and site analysis with Virtual Environment (VE).
7D Operation and Maintenance	Facilities management for renovations, repairs, restorations, space planning, and operations maintenance. Security management and safety information such as emergency lighting, emergency power, egress, fire extinguishers, fire alarm, smoke detector and sprinkler systems. Radio Frequency Identification (RFID) application for gathering information from real world components into BIM.
GIS based Visualization	The model satisfies and enhanced visualized system by incorporating of as-built site photographs
8D Modeling with PTD	Risk assessment of design component of facility for prevention through design.

Table 1: The nDimension of BIM with application *Source:(Masood, Kharal and Nasir, 2014)*

2.2.2. Common Data Environment (CDE)

Before a project starts, it is extremely important setting up the requirements of the employer when ordering services. In BIM such a document is called Exchange Information Requirements (EIR). Without going deeper, the EIR concerns, among others, Level of Information Need (LOIN), requirements concerning training and competence, management systems and data exchange requirements. All the total amount of digital documents in BIM environment requires a shared repository to exchange information between the players of a building project in order to avoid duplications and respecting the ownership of data. Moreover, such a repository should have in place a proper information management system that enables to take actions, in accordance with roles and responsibility for each player, during the development of the project. The concept of CDE, illustrated in Figure 3, comes from

the British Standards (BS) BS1192:2007[10]; its definition is stated within the ISO 19650 as a "*single source of information for any given project or asset which is used to collect, manage and disseminate each element of the information model using a managed process"*(BS EN ISO 19650- 1:2018, 2018). This definition indicates the importance of CDE for collaboration in a working environment. Furthermore, such definition means that a single source of information is strictly necessary to manage all the input received from stakeholders. The CDE collects, manages and distributes relevant validated project documents for multidisciplinary teams at the specified access level – set up within the information management system.

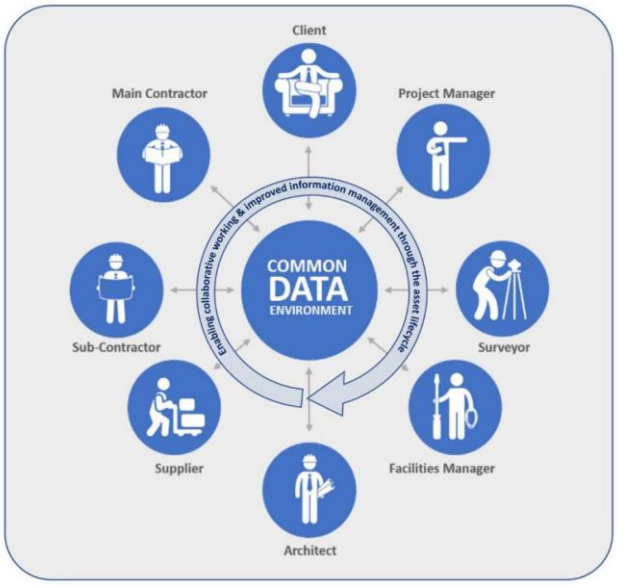


Figure 3: Schematic concept of Common Data Environment (CDE) *Source: Google Images*

Figure 4, taken from the standard ISO 19650, describes the workflow that should have a CDE.

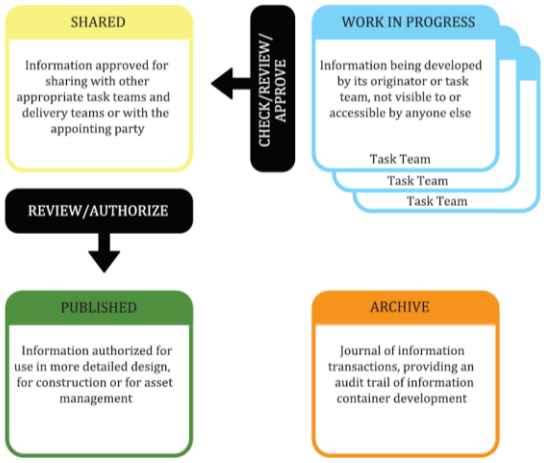


Figure 4: Common Data environment (CDE) workflow *Source: (BS EN ISO 19650- 1:2018, 2018)*

10 BS 1192:2007 Collaborative production of architectural, engineering and construction information – Code of practice (http://bim-level2.org/en/standards/).

The advantages of adopting such a CDE solution and workflow include:

- Responsibility for the information within each information container remains with the organization that produced it, and although it is shared and reused only that organization is allowed to change the contents;
- shared information containers reduce the time and cost in producing coordinated information; and
- a full audit trail of information production is available for use during and after each project delivery and asset management activity.

2.2.3. BIM Tools

Many of the performed tasks require appropriate soft skills as well as technical training and the ability to use specialized tools that should be stated within the Exchange Information Requirements (EIR). Without the tools and the expertise to manage them, it would be difficult, if not impossible to carry out projects in BIM. Over the last ten years, IT companies and software vendors have developed many different solutions to support the AEC industry to carry out projects in BIM environment. Commercially available software tools are equipped to manage the evolution of design, engineering and construction information. The situation has significantly changed regarding technology and software features. For instance, traditionally, design coordination has relied on drawing and other two-dimensional paper-based design information. With the use of BIM this process has been greatly enhanced. Software tools such as Solibri Model Checker®, SimpleBIM® and Autodesk® Navisworks® assist the design team in federating the disciplinary BIM and streamlining the coordination process. These tools greatly assist the project teams, construction contractors and clients during the design development stage, construction, hand-over and even further during the operation and maintenance of the assets. Figure 5 illustrated the main BIM software solution that could be used during the Project Life Cycle.

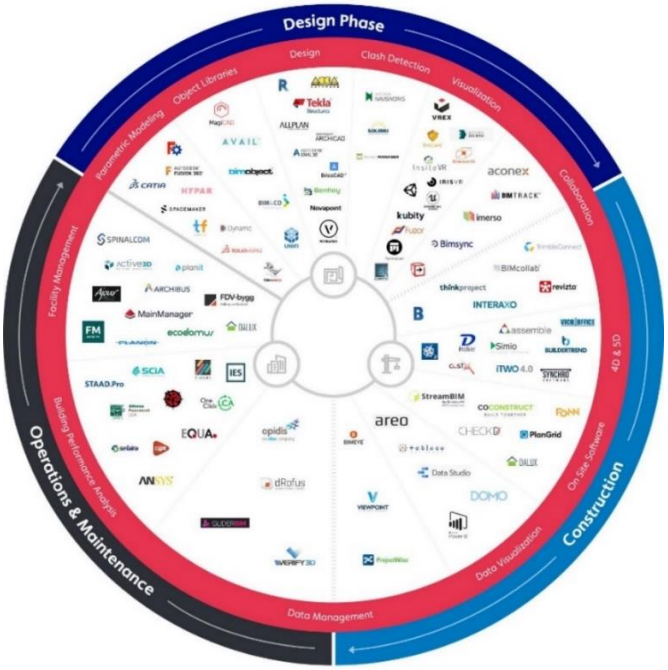


Figure 5: BIM software solution in Project Life Cycle *Source: Catenda.no*

As the Figure above shows, there are many tools available in the market. It is reasonable try to divide such tools into different categories in accordance with the purpose of the use:

- Communication;
- BIM Content Management;
- BIM Objects databases;
- BIM Authoring tool or BIM Modelling software;
- Generative Design software or Algorithmic BIM software;
- BIM Analysis software;
- BIM Collaboration software;
- BIM Validation or BIM Checking software;
- Preconstruction BIM 4D/5D software;
- Construction BIM software
- Facility Management BIM software; and
- Virtual Reality BIM software.

Nowadays, by using BIM tools and processes correctly, some companies are starting to gain a competitive advantage (McKinsey Global Institute, 2017). Others are starting to adopt innovative tools in their internal process. To accomplish this, the organisation will have to spend significant resources on hardware, software, training and developing an internal library of BIM objects (Royal Institution of Chartered Surveyors (RICS), 2014)

2.3. Delivery Methods

The delivery method is the way in which the owner contractually works together with the designer and the construction contractor. It is one of the first decisions that an owner makes when deciding to build a building. Before that the owners decide on the appropriate method of delivery, they must answer a number of questions about their project: What type of building is it? How risky is this job? When does this project need to be completed What is the budget? The answer to these questions will guide owners in deciding the appropriate delivery method. There are four major delivery methods mentioned by the Construction Management Association of America (CMAA): Design-Bid-Build (DBB), Construction Management at Risk (CMAR), Design-Build (DB), and Integrated Project Delivery (IPD). The most prevalent methods used by owner in construction projects is DBB, which is divided into three separate stages: the designer provides the design service; owner selects a contractor according to the bids received; the contractor constructs the building (Construction Management Association of America (CMAA), 2012). Unfortunately, there is any universal solution for the best delivery method, but the AEC industry started to understand the advantages and disadvantages of each delivery method to properly implement BIM.

2.3.1. Integrated Project Delivery (IPD)

Integrated Project Delivery (IPD) is a concept that has emerged to minimize project inefficiencies, waste as well as cost overruns. Many researches have been conducted to point out the benefits of IPD. The American Institute of Architects (AIA) published a guide in 2007 where defined IPD as *"a project*

delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimise project results, increase value to the owner, reduce waste, and maximise efficiency through all phases of design, fabrication, and construction" (Becerik-Gerber, DDes and Kent, 2010; American Institute of Architects (AIA), 2017). The IPD method is most likely the well-known Design-Build (DB)– adopted by the private owner and public procurement where the project is carried out by a General Contractor. However, the major contractually difference with the DB is the risk. As illustrated in Figure 6, in IPD, the risk is shared between the owner, the design firm and the contractor, but so the reward.

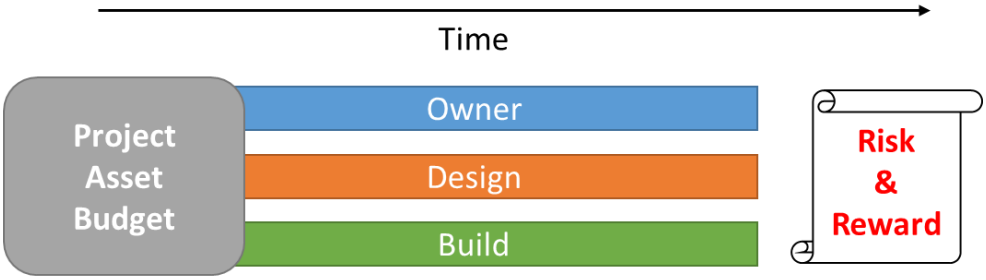


Figure 6: Integrated Project Delivery method

In this scenario the contract between the parties becomes a multiparty agreement. Technically, the IPD enables a great degree of communication and promotes intense collaboration among the project team, because it can result in additional profits for all members of the team. BIM in IPD presents the opportunity to fully leverage the technology by incentivizing collaboration. The benefit of this collaboration between owner, designers and builders can be appreciated during the design development. Indeed, as illustrated in the well-known MacLeamy Curve in Figure 7, the most beneficial time to solve problems is during the design phase, not during construction. If constructible models aren't produced and /or the personnel involved during design are not involved later to build the project, then the opportunity to proactively solve issues and save the owner money is missed.

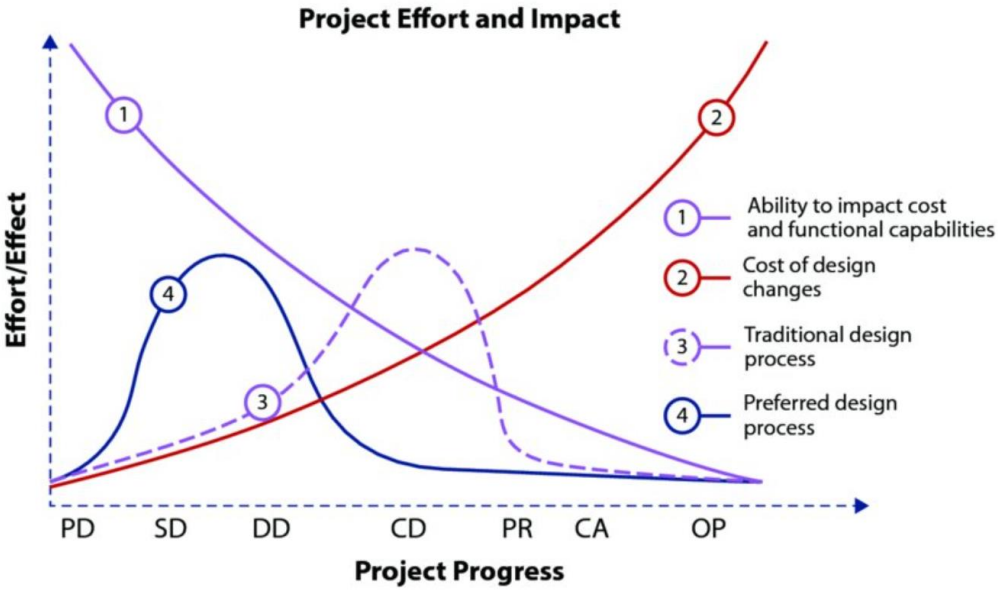


Figure 7: MacLeamy Curve *Source: (Hardin and McCool, 2015)*

2.4. BIM and Project Life Cycle (PLC)

Construction projects have three main lifecycle phases: design, construction and operations (Succar, 2009). The power of BIM technology should be applied during the whole PLC and not only in the early phase. Figure 8 illustrates the use of BIM across the entire life cycle of a building project. As a best practice, using BIM should begin at the conceptual design or planning stage of a project. Model developed at this stage should be converted into a full-blown building information model as the design and planning of the project evolves. Having a data-rich and computable 3D model then allows project teams to conduct a variety of analysis that enhance the value generation of the project through time, cost and sustainability-related efficiencies.

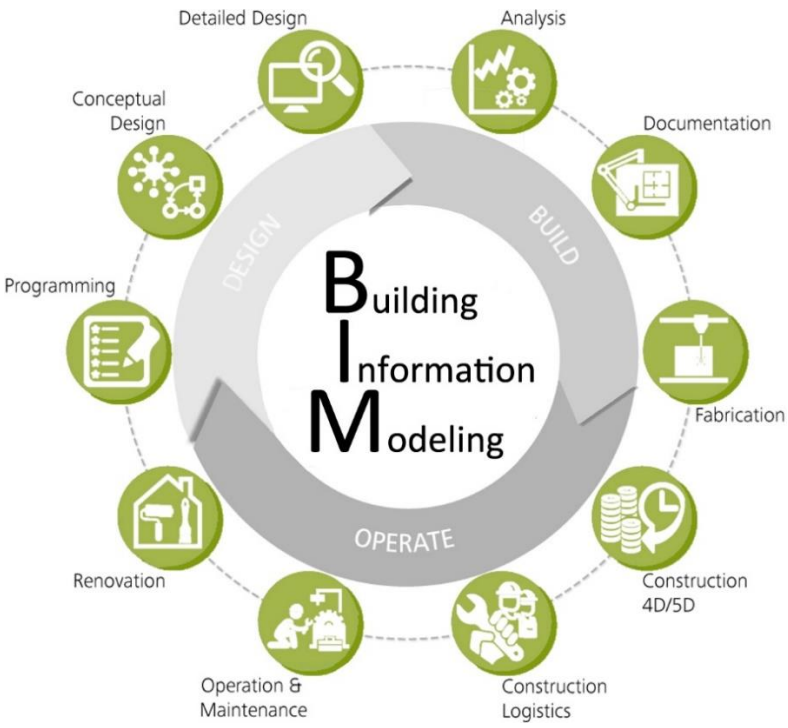


Figure 8: BIM in Project Life Cycle (PLC). *Source: Bexel Consulting*

Furthermore, the same model allows the project team to drive the documentation, procurement and pre-construction planning activities on the project. It should then drive the construction process, and after commissioning, the same model can assist in the operation and maintenance phase. Retrofit and demolition decisions can also be driven by the building information model. Perhaps, BIM technologies enable to increase the level of efficiency during a PLC if there is a plan to follow. It is crucial to understand that, over the life cycle of a project, the building information model becomes progressively data and information rich. In addition to the design, engineering and construction-related information, cost-related information also evolves as the project progresses. The utility of the BIM process can be enhanced if the project team ensures that design, engineering, construction and cost information is conjointly carried through effectively over the project life cycle.

In many countries there is no formal set process for designing a building. Often, the way to do it is unwritten and unrecorded, with informal process handed down from one generation of professionals to the next. When buildings are designed using repeatable, consistent and intuitive process, this informal

approach works. As the design process becomes more complex, influenced by many factors – such as new forms of procurement, modern methods of construction or new drivers, for example sustainability and maintainability – this approach becomes unsustainable. Without a process map, different members of the project team will have different versions of the right way to do it, making it inevitable that the project will be undertaken inefficiently. There are several design processes maps, or plans of work, used throughout the works to guide clients through briefing, design and construction, handover and beyond. In most countries, the process maps are set by the professional institutes or by sector bodies. Table 2 illustrates some of these.

	Pre-Design		Design				Construction	Handover	In Use	End of Life
RIBA (UK)	0	1	2		3	4	5	6	7	
	Strategic Definition	Preparation and Brief	Concept Design	NOT USED	Developed Design	Technical Design	Construction	Handover & Close Out	In Use	NOT USED
ACE (Europe)	0	1	2.1	2.2	2.3	2.4	3		4	5
	Initiative	Initiation	Concept Design	Preliminary Design	Developed Design	Detailed Design	Construction	NOT USED	Building Use	End of Life
AIA (USA)			–		–	–	–			
	NOT USED	NOT USED	Schematic Design	NOT USED	Design Development	Construction Documents	Construction	NOT USED	NOT USED	NOT USED
APM (Global)	0	1	2		3	4	5	6	7	
	Strategy	Outcome Definition	Feasibility	NOT USED	Concept Design	Detailed Design	Delivery	Project Close	Benefits Realisation	NOT USED
Spain			–			–	–	–		
	NOT USED	NOT USED	Proyecto Básico	NOT USED	NOT USED	Proyecto de Ejecución	Dirección de Obra	Final de Obra	NOT USED	NOT USED
NATSPEC (Aus)		–	–	–	–	–	–		–	
	NOT USED	Establishment	Concept Design	Schematic Design	Design Development	Contract Documentation	Construction	NOT USED	Facility Management	NOT USED
NZCIC (NZ)		–	–	–	–	–	–		–	
	NOT USED	Pre-Design	Concept Design	Preliminary Design	Developed Design	Detailed Design	Construct	NOT USED	Operate	NOT USED
Russia			–	–	–	–	–			
	NOT USED	NOT USED	AGR Stage	Stage P	Tender Stage	Construction Documents	Construction	NOT USED	NOT USED	NOT USED
South Africa		1	2	3	–	4	5			
	NOT USED	Inception	Concept and Viability	Design Development	NOT USED	Documentation	Construction	Close Out	NOT USED	NOT USED

Table 2: Comparison of some international plans of work. *Source: RIBA Plan of Work 2020*

For instance, as illustrated in Table 2, Royal Institute of British Architects (RIBA) divides the pre-construction phase into five stages: strategic definition, preparation and briefing, concept design, spatial coordination and technical design in *"Riba Plan of Work 2020"* (Royal Institute of British Architects (RIBA), 2020).

2.5. BIM during Technical Design phase

The primary goal of the technical design stage of a building project is to provide construction-level detailing in the model developed so far. The key BIM-related activities during this phase are:

- Detailed modelling, integration and analysis by discipline;
- Finalisation of the design stage model of all disciplines;
- Final coordination of the model;
- Pre-construction planning using BIM including safety planning, phasing and prototyping, procurement planning and supply chain management;
- Finalisation of specifications at the building element level based on the creation of production-level parametric objects for all major elements in the project;
- Code checking and export of data for building control analysis;
- Quantity Take-Off (QTO) and cost planning;
- Perform risk management activities associated with the project;
- Document production as per the procurement strategy;
- Final review and sign off of model; and
- Finalising and enabling access to model for constructors.

Figure 9 shows the workflow for the technical design stage of the project presented within the *BIM Implementation Guideline* published by RICS. The lead design consultant for the project, working closely with other design and engineering consultants, undertakes the finalisation of the models by using specific modelling elements and by enriching the model with specific technical information. These disciplinary models are coordinated with the main discipline model (i.e. the architectural model for a non-building project) with close interaction with the entire project team. In the process map in Figure 8 it is assumed that the Project Management Consultant (PMC) has been made responsible for conducting the coordination tasks and developing the federated model.

After numerous iterations the final technical design stage models are completed and approved by the client or the client's representative. After this, the PMC publishes a federated model that combines all disciplinary inputs: for instance, Structural, Architectural, Mechanical, Electrical etc. Additional analysis is carried out by using this federated model; for instance, code compliance checks by the lead design consultant, cost planning by the Quantity Surveyor (QS) or Cost Planner (CP) and 4D planning by the construction team. Thereafter the technical design-stage models are frozen, the client's approval is obtained and the project proceeds to the construction phase. During the technical design stage very specific information pertaining to the modelling elements in the model is provided. The model is essentially ready to be transferred as a construction-stage model. In this phase of the project specifications are added to the model using an open-definition and interoperable format. The objective is to establish a protocol for the identification of properties required to specify materials, products and equipment used in the model. The process of adding specifications to the modelling elements involves using a master specification file (e.g. UniFormat or Uniclass) or a customized standard provided by the company or even by the design consultant. After that, binding and mapping modelling elements in the building information model. For example, using the BIM-authoring tool and a plugin (e.g. e-SPECS) the modeller can add specifications to the modelling elements in the right property of the object.

Similarly, the process of quantity extraction and cost planning is also undertaken in the technical design stage of the project (National Institute of Standards and Technology (NIST), 1999).

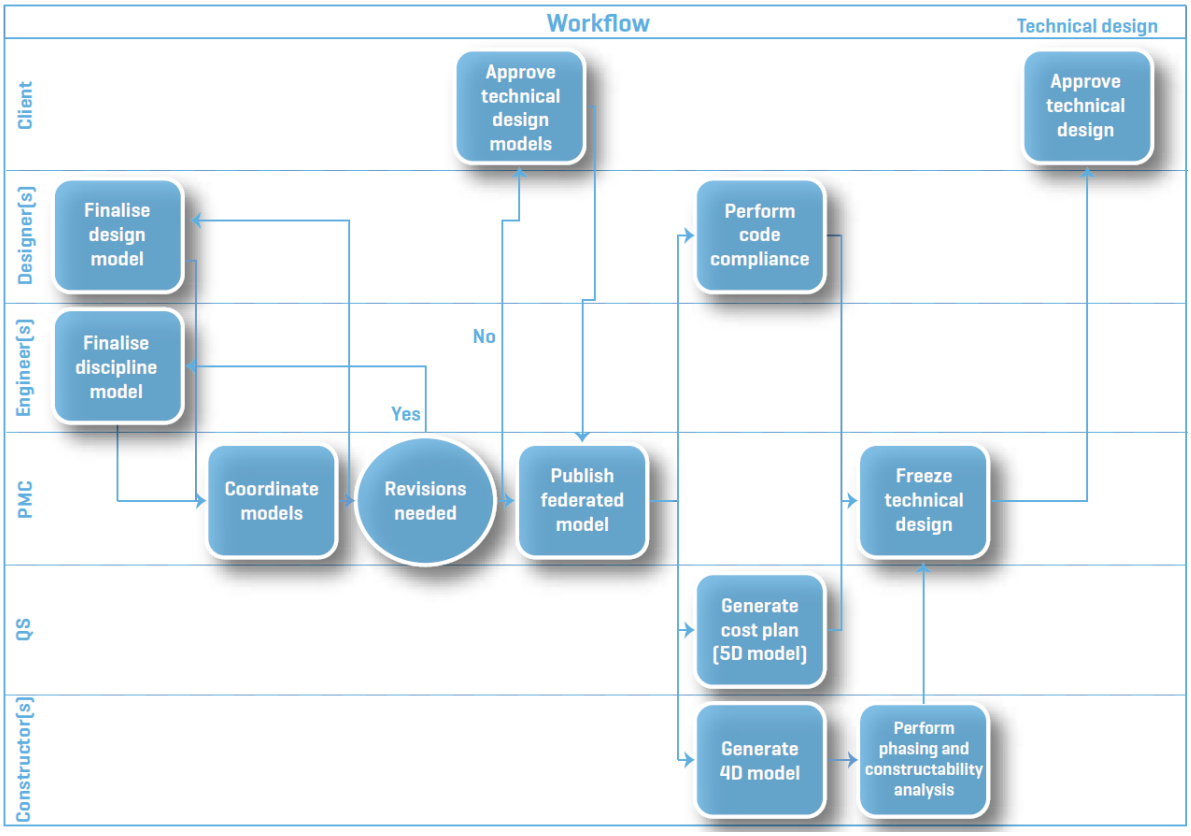


Figure 9: Process map for technical design stage *Source:* (Royal Institution of Chartered Surveyors (RICS), 2014)

2.5.1. 4D BIM - Construction Scheduling

Construction scheduling is one of the project delivery milestones to achieve during the technical design stage. Schedules in construction are intended to clearly identify how projects will be constructed with defined activities and sequencing logic that determine durations and directs the overall flow of progress on site. Schedules are traditionally created by one or more scheduling professionals or planners, whose role on a project is to take a deduction based on past performance and other available industry data to generate a project timeline. Figure 10 gives the order of magnitude regarding the complexity to take the right and correct deduction for some activities such as building foundation casting-in-place. Although this method of scheduling has long been considered the golden standard, it is by no means affective. The schedules are wrong 70 percent of the time. The industry is still using them because there simply is not another available solution. Yet, many contractors are now realizing the value of the integration of the model with schedule information. From this effort, firms are producing collaborative simulations with subcontractors to validate and ensure schedule accuracy as well as create efficiencies. The integration of schedules into BIM has been coined with the name 4D BIM. Model information for scheduling can be used by several ways. Due to the fact virtual elements or geometric components are visible in a model environment such as Naviswork®, Synchro PRO® and Bexel Manager®, they can be animated. By linking these assemblies to schedule data, a video of the project's construction can be simulated.

Additionally, these linked simulations can also detect incorrect schedule logic through sequenced clash detection.

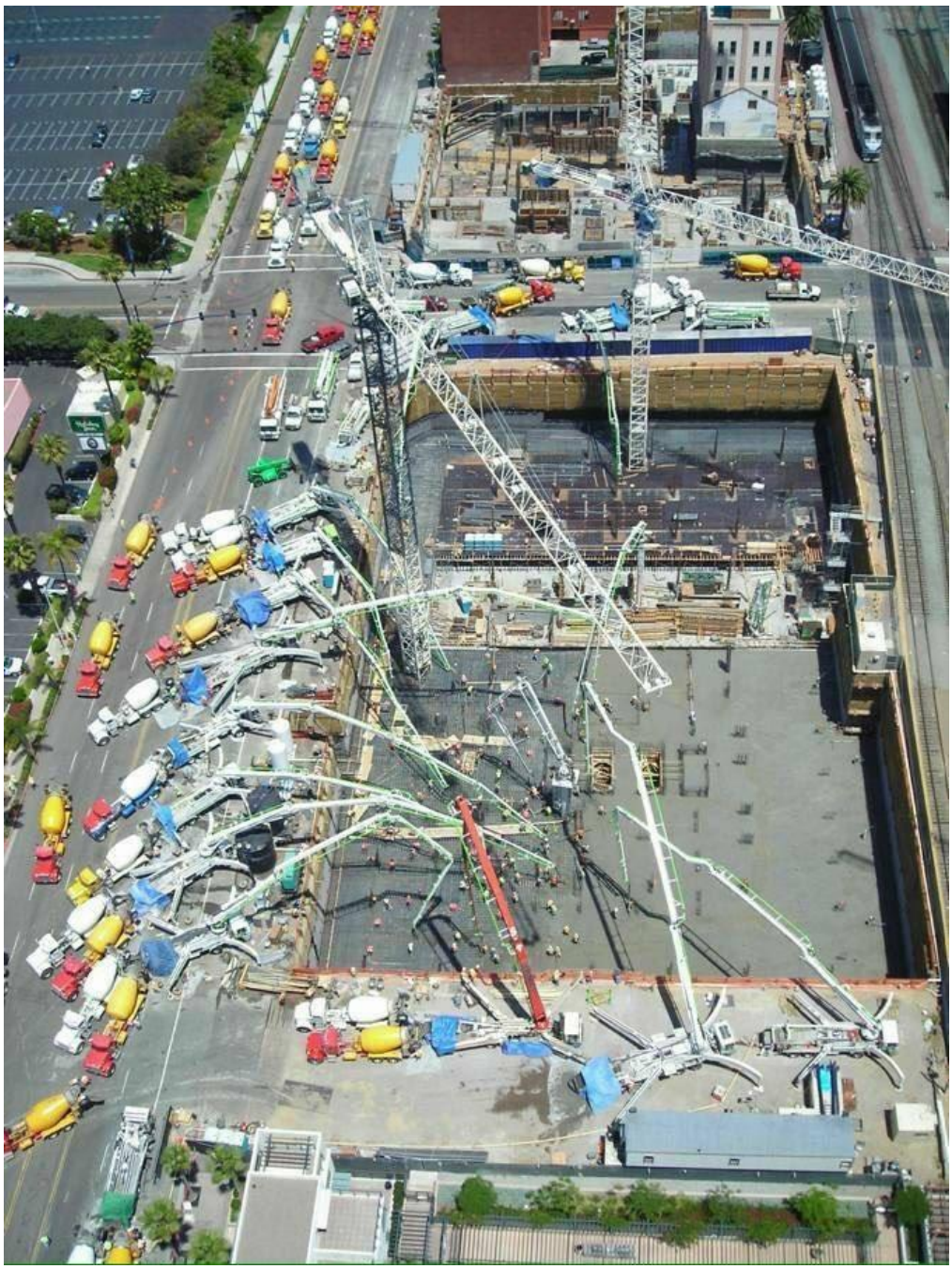


Figure 10: Concrete cast-in-place of a building foundation *Source: Google Images*

These simulations visually highlight issues such as equipment being set on raised pads prior to curing being completed, or beams appearing in thin air without supporting columns or superstructure. In Figure 11 the 4D planning process completed in the technical design stage is explained. The process involves linking the model with the project schedule. A variety of schedule formats can be used in this process.

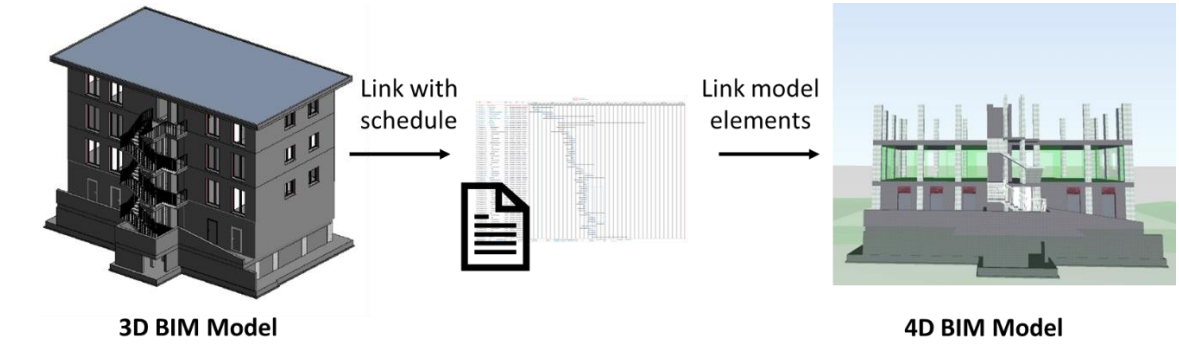


Figure 11: 4D BIM-base modelling process

BIM in scheduling continues to create a higher level of project clarity and has proven to be an effective means of communicating with a team visually for how a project is going to be put together. The tools are growing in sophistication, and many are starting to provide features such as the ability to slice models into phases and schedule task as they would be constructed for Location Based System (LBS) or Advanced Work Packaging System (AWPS) work, as well as introducing optimization features such as line-of balance schedule views (Hardin and McCool, 2015).

2.5.2. 5D BIM - Cost Estimation

As per construction scheduling explained in the previous section, cost estimation is one of the project delivery milestones to achieve during the technical design stage. The traditional way of doing estimating and cost trending is to get the PDFs or printed drawings off each deliverable in order to manually take off the work and link those to the price list. Estimating with BIM results in tremendous efficiencies for QS, Cost Manager (CM) and PMs. Often in the IPD, owners will require multiple estimates to be performed at different deliverables to ensure that the project is staying within the originally estimated budget (Hardin and McCool, 2015). The estimating activities should be performed by the QS. In Figure 9 the cost planning process map is shown.

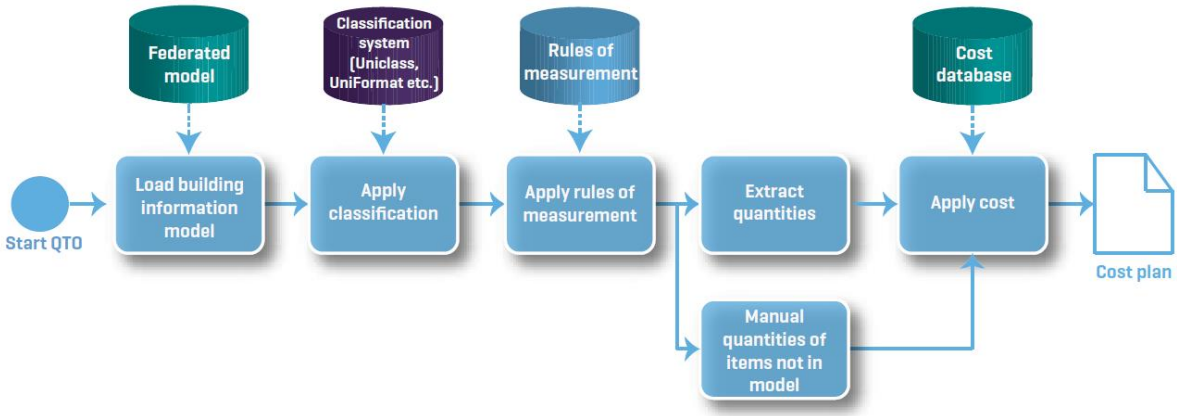


Figure 12: Cost planning process using BIM *Source:* (Royal Institution of Chartered Surveyors (RICS), 2014)

The QS utilises the model in BIM-authoring tools or special BIM-based cost planning tools. If not already set, the QS sets the classification system for the model so that the model elements can be

classified and quantified using an industry-accepted classification standard. Using the accepted rules of measurement, the QS then produces a schedule of quantities for various modelling elements. Objects that are not modelled or cannot be quantified using the models are separately calculated using manual procedures. This results in the production of a bill of quantities that can then be priced to produce a cost plan for the project. Sometimes, estimating from the model could be not accurate. If the model is not created accurately, then the quantities will not be accurate. In this case the "I" of BIM become very important. The QS must first understand how information is created in the authoring software in order to leverage it for estimating or any other analysis. The model is a database of information that can be manipulated in both a positive.

3. PROPOSED WORKFLOW

This chapter introduces the proposed workflow and the reason why should be adopted during the design phase to optimize the process of integrating 4D and 5D BIM to plan construction activities for a building project.

3.1. Introduction

As introduced in the previous chapter, 4D and 5D BIM are the dimensions whenever the use of the 3D model concerns construction scheduling and cost estimation. During the starting stages of the design phase, the architects and engineers (BIM Specialist or BIM Modeller) create, through the BIM authoring tool, objects defined by qualitative and quantitative features. These features are the primary data and, indeed, represent the information to be used for such integration. Theoretically, this information can be used to determinate the QTO and cost by linking the data to a cost database. Moreover, the BIM objects in the 3D model can be linked to the activities within a Gantt chart in order to obtain a virtual construction simulation and thus the 4D BIM model. In this way, the BIM technology allows project team and enterprise to use data to be produced during the overall design phase even for further purpose. The theory is clear. In practice, however, it is a matter of bringing together goals, processes, tools, roles and responsibilities, competences and skills. This requires a new way of thinking and a somewhat radical change in workflows and work practices.

3.2. Background

The proposed workflow has been implemented taking into account the following reasons:

1. Idea of the Author to create a workflow that might be transformed in Standard Operations Procedure (SOP) in future development to optimize the data and information flow between the project team for complex operation regarding the 4D and 5D BIM integration during the design phase;
2. Integrating new and modern tools to workflow already tested by the academia and by the AEC industry – for instance the workflow presented by RICS in the literature review chapter;
3. Meeting with players of the AEC industry which need to improve productivity and capability to achieve the clients' requirement; and
4. Market gap – few A&E design office have implemented this BIM maturity level for the 4D & 5D BIM integration.

3.3. Proposed workflow concept

In Building Information Modelling (BIM) it is common talking about 4D and 5D BIM with reference to the integration of time and costs information onto the 3D models. According to the objectives and use of the models this integration can follow different approach and workflows. Furthermore, such integration involves the use of diverse specialised tools quite different from the simple BIM authoring tools. The management of 4D and 5D open the complex of interoperability requiring the definition of processes and rules that can guarantee the correct generation and use of the information.

Indeed, 4D and 5D BIM are two of the facets of the overall BIM technology, in which the 3D model is integrated to the time and cost. It allows the project team to visualize, analyse the various aspects at any given point of time throughout the project life cycle to discover any potential issues and bottlenecks before the construction phase.

As discussed in the literary review and in the introduction of this chapter, construction scheduling and cost estimation are two project delivery milestones that every owner and client require during the technical design stage. Even during the development of the design itself, they can provide decision makers with added value information, especially when the project offers various alternatives. Improving the construction scheduling and cost estimation technology with new processes by using smart tool available in the market is the goals of this proposed workflow.

There are four main sections in the proposed workflow, including:

1. **3D Modelling Section;**
2. **Scheduling Section;**
3. **Cost Estimating Section; and**
4. **4D/5D BIM Simulation Section.**

The 3D modelling section gives to the modellers the process and input to calibrate the BIM model, in accordance with the BEP, to allow the 4D and 5D integration afterwards.

The schedule section explains the assembly process and duration estimate for the construction of a proposed project.

The cost estimation section illustrates how to extract the QTO from the 3D model and the resources needed for the construction of a building – resources are identified as materials, labour and equipment.

The 4D and 5D BIM simulation section refers to integrate the 3D model with cost estimation and construction schedule in order to simulate the construction assembly process and display the cost and duration of the corresponding construction stage.

All the sections are supported by the internal database or repository of the designers based on completed project that can be considered as lesson learned and so templates. In case of IPD such database/repository is integrated by the information from the General Contractor based on past projects. To allow the current project data sharing the CDE is implemented too. The sections create a workflow to obtain an integrated 4D and 5D BIM model during the design phase, which gives to the decision maker a new set of outputs regarding cost and duration of projects in a fast and efficient way.

The proposed workflow considers the collection of all necessary data and information in a database, which can be linked to BIM tools.

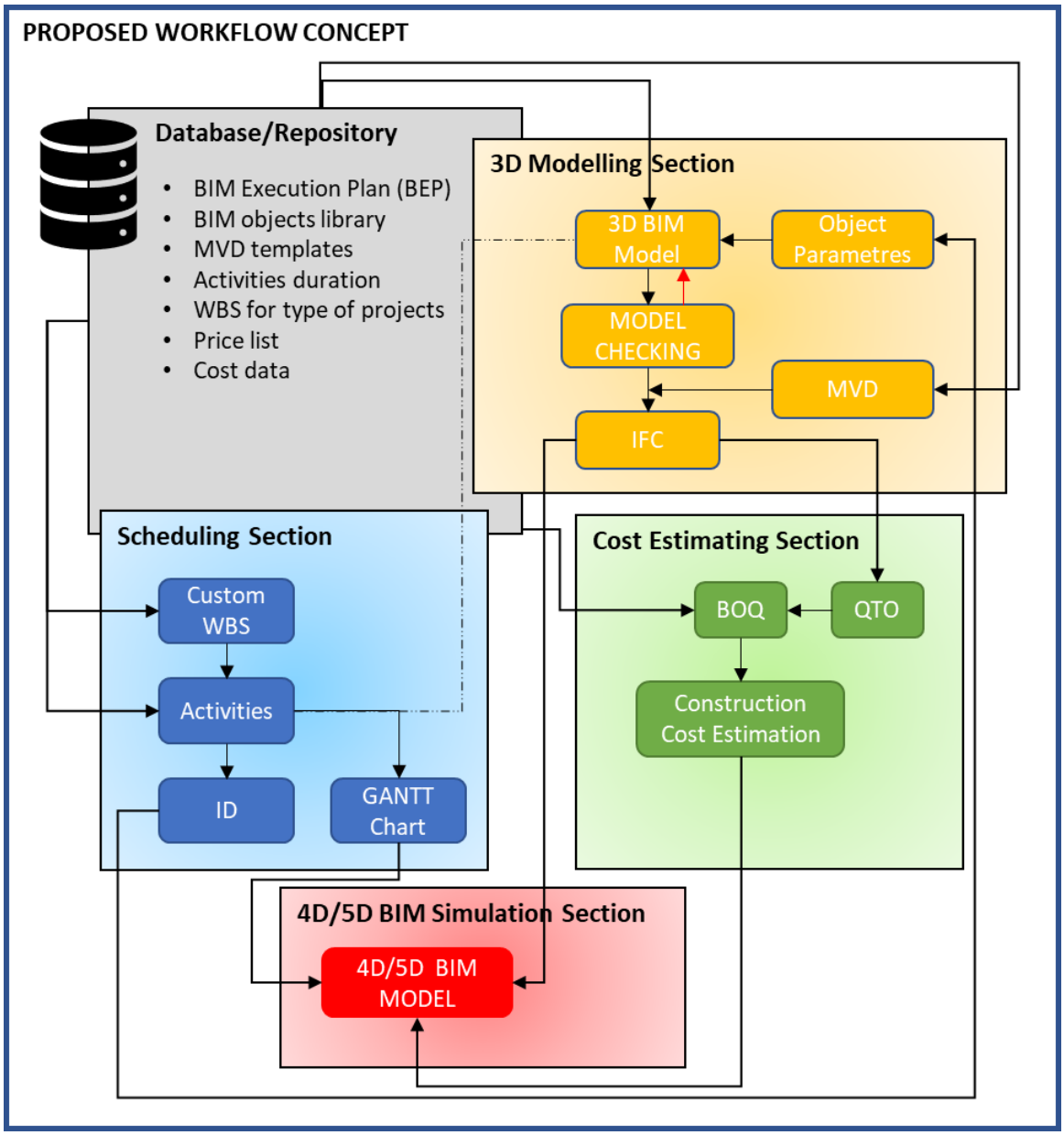


Figure 13: Proposed workflow concept

3.3.1. Data repository and gathered

The content of the database/repository is determined by the objectives and requirements of the proposed workflow, as follow:

- BEP agreed between the designers and the client;
- BIM objects library to be used for the development of the 3D model. The objects to be used in the model require corresponding properties, such as dimension, unit, materials, as well as 3D visual views for building development and construction simulation;
- Gathered information regarding the unit cost of each type of element and eventually price list to be indicated by the owners or client;
- Gathered WBS template for type of project;

- Gathered information about the activities duration during the construction phase – for IPD the General Contractor and subcontractors can provide reliable information;

3.3.2. IFC for exchanging BIM information

The Industry Foundation Classes (IFC) is an open format for the exchange of building data models used in building design and construction across different software. It is used to exchange information within a project team and between software applications used in design, construction, procurement, maintenance and operation. In an ideal scenario, the IFC file should be used for coordination purposes in an IFC viewer or as a reference within the editor software. In this proposed workflow the IFC file will be one of the requirement that the design team needs to share with the others member of the team to allow the 4D and 5D BIM integration.

3.3.3. MVD customized for the purpose of the 4D and 5D integration

In addition to the file format and versions, the Model View Definition (MVD) determines how to use an IFC file, because it enables a specific data exchange scenario. MVDs are used for the targeted exchange of specialized models, taking into account the graphic and content-related information that recipient needs. For instance, specialized IFC models require only the basic geometric information to be transferred to a QS for QTO purpose. In this proposed workflow the MVD should target only the information regarding the qualitative and quantitative properties of the object for 5D BIM integration as well as information regarding specific code regarding the object to enable the fast matching during the 4D BIM integration.

4. CASE STUDY

In the previous paragraph, the proposed workflow for the 4D and 5D BIM integration during the design development has been introduced. In this chapter, a building project will be utilised to illustrate the process in a real case scenario. In order to remain within the boundaries of the domain of the research purpose, some assumption have been stated.

4.1. Introduction

When it comes to communication and planning, the use of technology is critical in passing and sharing information. Moreover, such technology can be used to take decision and to minimize the risk during a PLC. The use of BIM on construction projects is a great enabler for better team engagement. Perhaps, BIM, when pushed to its maximum capability, not only allow to strength the team engagement but improve the client engagement. Client is always looking for satisfaction in order to strength the relationship with the service provider. Indeed, the 4D and 5D BIM integration can be the gold that each A&E firm is looking for and would like to implement in its internal standard as project delivery in order to meet the client satisfaction. Following this principle, in this case study, a 3D BIM model of a multi-story building will be utilised to illustrate the proposed workflow to integrate 4D and 5D BIM during the design development.

4.2. Project overview

The project is a six-story building categorized as a special-purpose building located in Turin, Italy. The building is one of the first module of the whole infrastructure that will host the Technology Transfer Centre of the Biotechnology Molecular Centre (MBC) of the University of Turin. The whole building will fill the gap between academia and industry by creating relationships with biotechnology companies. The centre provides laboratory spaces, scientific know-how and the knowledge for intellectual property, licencing and business start-up plan development and will also foster interactions with venture capitalists.

Today, the construction of the building is over, and its PLC has reached the hand-over phase to the owner. The skeleton of the building is in reinforced concrete and its vertical and horizontal layout is distributed, as following:

- Basement: parking and technical rooms;
- Ground floor: entrance, control and service rooms, animal housing;
- First floor: divided into two functional modules. A small portion linked to the ground floor. A large portion dedicated as technical space;
- Second floor: research area (labs, offices and functional spaces as support of the lab activities);
- Third floor: research area (labs, offices and functional spaces as support of the lab activities);and
- Fourth floor: technical space for the building's systems.

4.2.1. Documents gathered and analysed

The project just mentioned in the previous paragraph is used as reference for testing the proposed workflow. The 3D models and the documents have been kindly given by *AI Engineering and AI Studio®* (hereinafter *AI®*) which was appointed by the University of Turin (representing the public owner of the project) as main designers for the developed design stage and as work supervisor during the construction phase afterwards. The documents gathered and analysed are included in the project delivery of the technical design package developed by the GC that has been appointed to carry out the design and the construction under a DB contract. It is important to highlight that the technical design of the building has not been carried out in BIM but with the traditional 2D-based technology. However, *AI®*, having a certain high level of BIM maturity in its internal design development capability, created a 3D BIM model for the Architectural and Structural disciplines in Autodesk Revit®, as illustrated in Figure 14 and 15, for work supervision purpose, which has been very appreciated by the client. The following documents, in Italian, have been gathered and analysed with the respectively format:

- 3D BIM Architectural model – Autodesk Revit®;
- 3D BIM Structural model – Autodesk Revit®;
- Technical Structural drawings – PDFs;
- Technical Architectural drawings – PDFs;
- Cost analysis – PDFs;
- Price list – PDFs and Acca Primus®;
- BOQ – PDFs and Acca Primus®;
- Cost Estimation – PDFs, Microsoft Excel®;
- Construction scheduling, Gantt Chart – PDFs and Microsoft Project®;
- Technical Specifications – PDFs;
- General Report – PDFs; and
- Operation and Maintenance plan – PDFs;

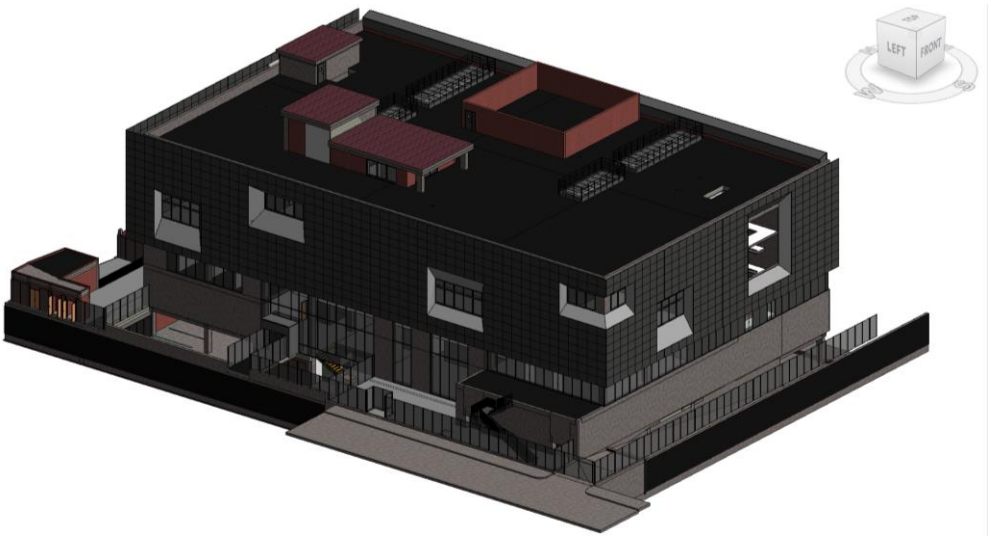


Figure 14: 3D view of the federated BIM model (ARC & STR) of the building, realisitc style, Autodesk Revit®

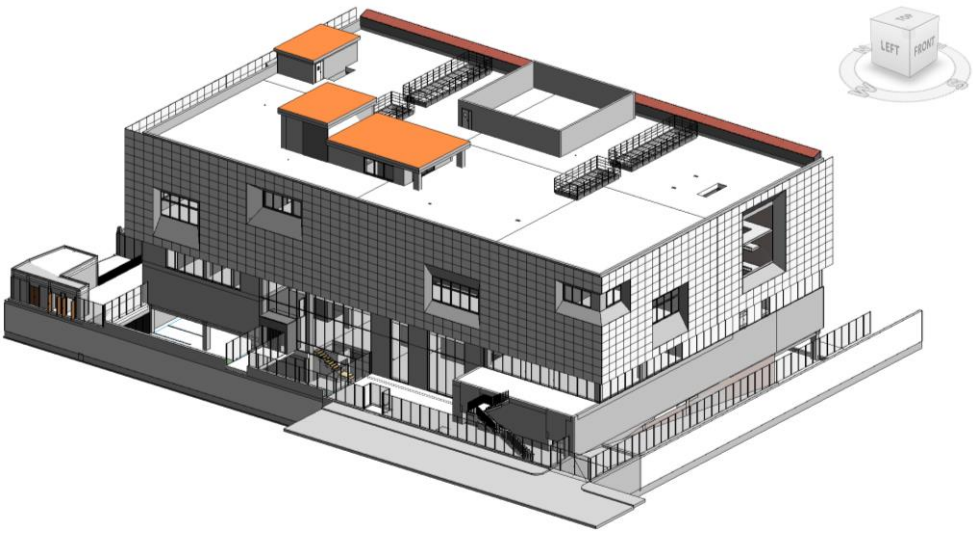


Figure 15: 3D view of the federated BIM model (ARC & STR) of the building, consistent colours style, Autodesk Revit®

4.2.2. Assumption for this case study

In order to remain within the boundaries of the domain of the research purpose, for the case study some assumption have been stated:

- The analysis considered only the 3D BIM Structural Model with the Level of Development (LOD) created for the work supervision purpose. The 3D model has been designed with LOD 200 for almost all the objects. Such LOD was accepted for the purpose of the research;
- The project team during the technical design development considered three main separated entities: the Structural (STR) Team, the Quantity Surveyor (QS) and the Planner. The author, during the implementation of the case study by following the proposed workflow, acted according to each role and responsibility. This assumption is meant to test the proposed workflow; it is clear that in a real environment the tasks for the three entities are implemented by people with different background, skills and responsibilities;
- Coordination, code checking and clash detection not taken into account;
- Cost data and price list according to the Italian environment. The price list has been integrated considered the public Piemonte Regional Price list of 2012 and a cost analysis in accordance with the construction market for some works;
- Excellent knowledge of the 4D and 5D software tool and the formula that the tools used for the QTO;

4.2.3. Specialized software tools

As stated in the previous paragraphs, the 4D and 5D BIM integration must be performed by using advanced specialized software available in the market. In this case study the following software tools are used:

- **Autodesk Revit 2020® -** Educational license provided by Autodesk®;

- **TeamSystem CPM Cloud®** (well-known as STR Vision CPM®) – Commercially License provided by TeamSystem®;
- **Bentley Synchro PRO® -** Educational License provided by TeamSystem® as Bentley® business partner;
- **Microsoft Project® -** Commercially License for student provided by Microsoft®;

4.2.4. Primary purpose

In regard of the 4D and 5D BIM integration, there are many workflows adopted by the AEC industry. These processes use different approach and several specialized software tools. One of the primary purposes of the proposed workflow and case study is to test the information flow and the way to create and share the data. Moreover, the case study would state who is the creator of the data and how such data is shared and integrated by the other people inside the project team. The scope is to optimize such a flow during the design development in order to obtain a 3D model that can be easily integrated with information regarding time and costs afterwards.

Such 4D and 5D BIM integration will be the asset to perform virtual simulation in order to adapt the design according to the building performance and the wish of the client and owners. The capability to deliver this type of outputs during the design development enables team to improve quality, safety, productivity and efficiency of the construction.

4.3. Proposed workflow implementation

4.3.1. 3D BIM Model

3D modelling is the critical part of the model because it is related to the reliability of construction scheduling and cost estimation. The keys of 3D modelling are the degree of accuracy, visualization ability, as well as easy editing and data transfer abilities. According to the technical design development, an internal plan with milestones and project deliveries has been drafted. This plan is shared to each member of the project team, which validate the part that is related with his or her role and responsibility. In accordance with such a plan, the STR team developed the STR BIM model by using the internal objectives library and by following the requirements stated within the BEP. Once the STR model has reached the milestone, the native file and the IFC of the BIM model, is ready to be shared by the ST for the model checking. In this case the IFC can be exported with the Coordination View MVD already set as default inside the BIM authoring tool.

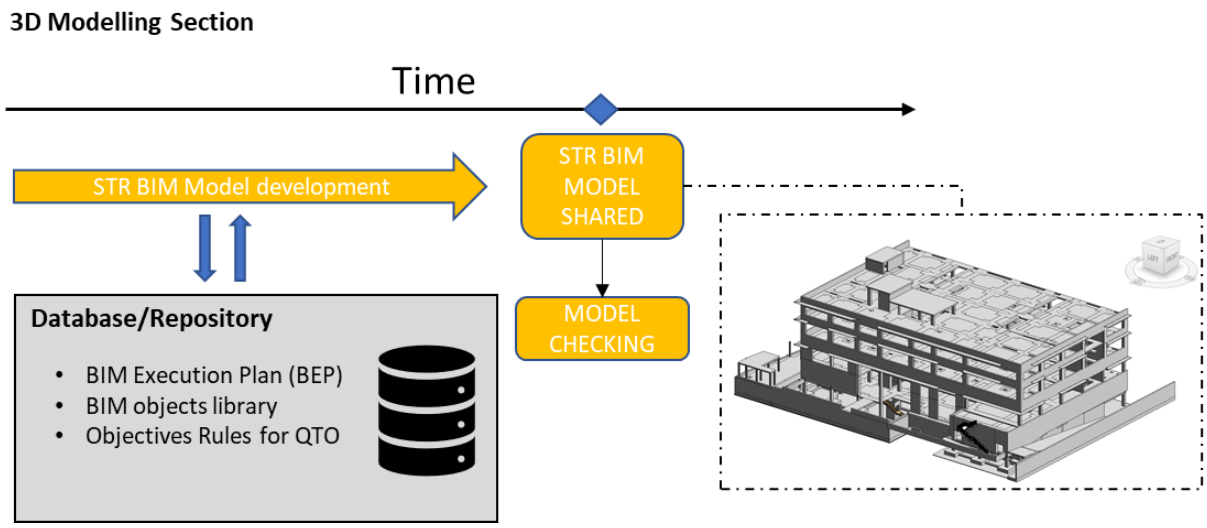


Figure 16: Sub-process for 3D BIM Model in the 3D Modelling section of the proposed workflow

4.3.2. Model checking

The model checking is performed by the QS inside both Autodesk Revit® and TeamSystem CPM Cloud®. The goal of this phase is to check the accuracy of the objects for QTO purpose prior proceeding to the next phase.

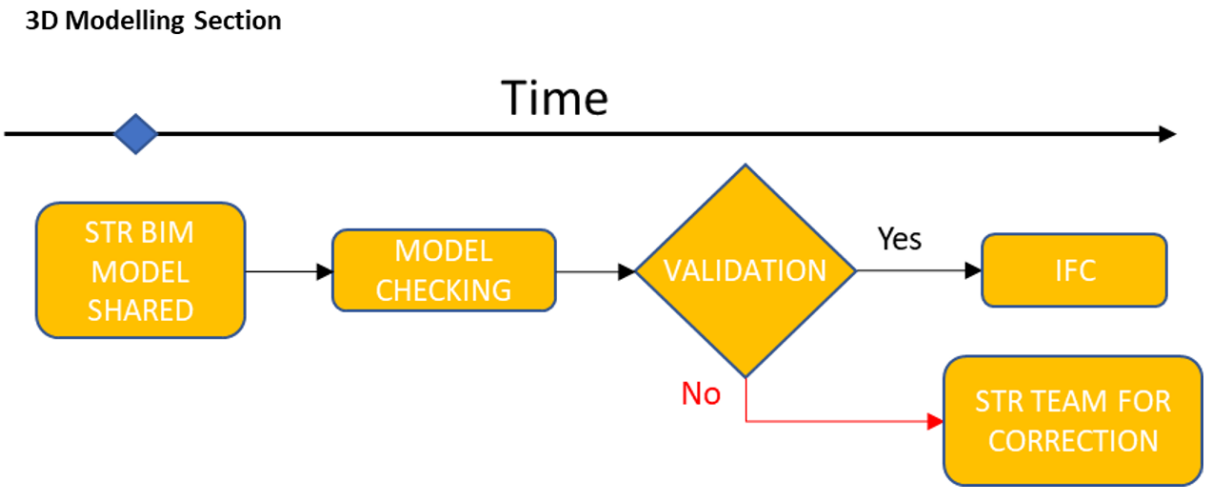


Figure 17: Sub-process for the model checking in the 3D Modelling section of the proposed workflow

The model checking performed for the STR BIM model inside TeamSystem CPM Cloud® highlighted an issue concerning some objects of the isolated foundation as illustrated in Figure 18. Some objects regarding the isolated foundation ("plinto" in Italian) have been modelled with the lean concrete below. This issue, if not corrected during the design development phase, will give an incorrect volume of the isolated foundation and an incorrect total volume of the lean concrete whenever the specialized tool run the QTO. In this case, the issue would be reported to the STR team which will put in place the proper

correction. Whenever the BIM model passes the model checking, the STR team will re-export the IFC file by following the requirements regarding the MVD to adopt for the final exportation.

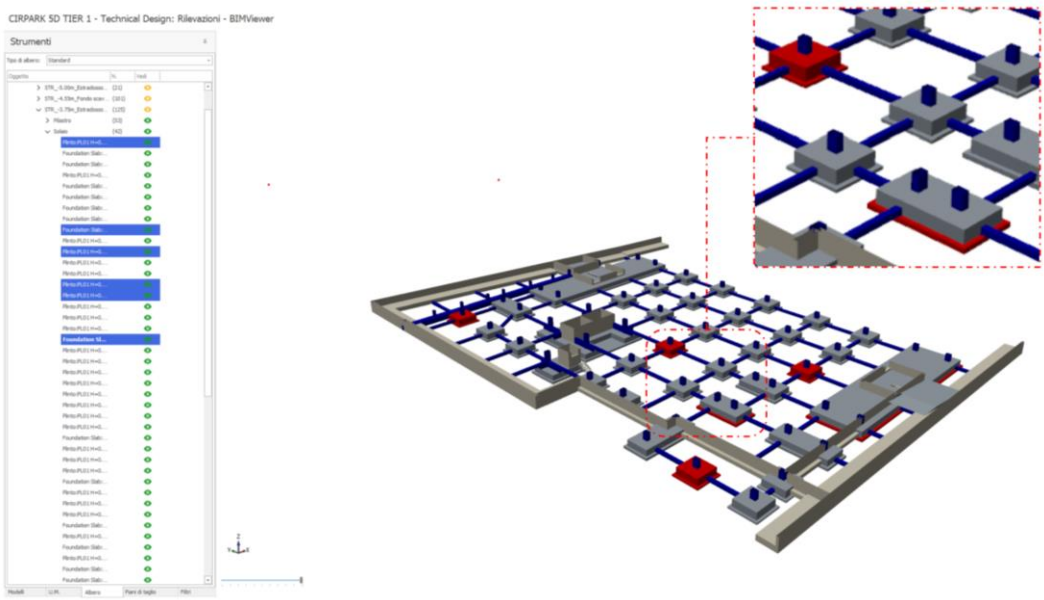


Figure 18: Issue regarding the isolated foundation and lean concrete, TeamSystem CPM Cloud®

4.3.3. Custom WBS and activities

During the modelling activities performed by the STR team, the Planner drafted the construction scheduling by using Microsoft Project® (MP®). The WBS for type of projects and the duration of the activities are available in the repository. The document is the background to start to assembly the construction scheduling and thus the Gantt chart. Moreover, the Planner created the customized ID Breakdown Structure (IDBS), as illustrated in Figure 19.

IDBS - 4D and 5D BIM Integration

L1	Project
P1	Main Building

L2	Discipline
SP	Site Preparation
EW	Earthworks
SW	Structural Works

L3	Building Levels
S0	Site
F1	Foundation 1
F0	Foundation 0
B1	Basement 1
L0	Level Groundfloor
L1	Level 1st
L2	Level 2nd
L3	Level 3th
R0	Roof 0
R1	Roof 1

L4	Building Systems
L	Lean
F	Footings
B	Beams
C	Columns
S	Slabs
H	Earthwalls
W	Stairwells (Wall)
E	Elevator (Wall)
T	Stairs (Stairwell)
N	Tank Wall
R	Ramp
P	Pulvini
G	Flooring Steel Grill
A	Precast Concrete Panel
D	Stairs (Entrance Panoramic)
K	Catwalk
X	External Wall
Y	External/Internal Steel Stairs

L5	Activities
FI	Formwork Installation
RB	Rebars
PC	Pouring Concrete
FR	Formwork Removal
II	Installation

Figure 19: Customized ID Breakdown Structure

Here, there is the core of the workflow that allows to generate data concerning to 4D BIM Scheduling Code that will be useful for the matching between objects and activities afterward. The code, always by the Planner, is implemented inside the MP® in accordance with each WBS level reported in column. The IDBS values of the columns are pre-set through the function *Custom Fields/Edit Lookup Table for Levels* in order to omit errors and the column of the *4D Scheduling Code* used a customized formula for the combination of the IDBS according to the WBS of the schedule, as illustrated in Figure 20 and 21.

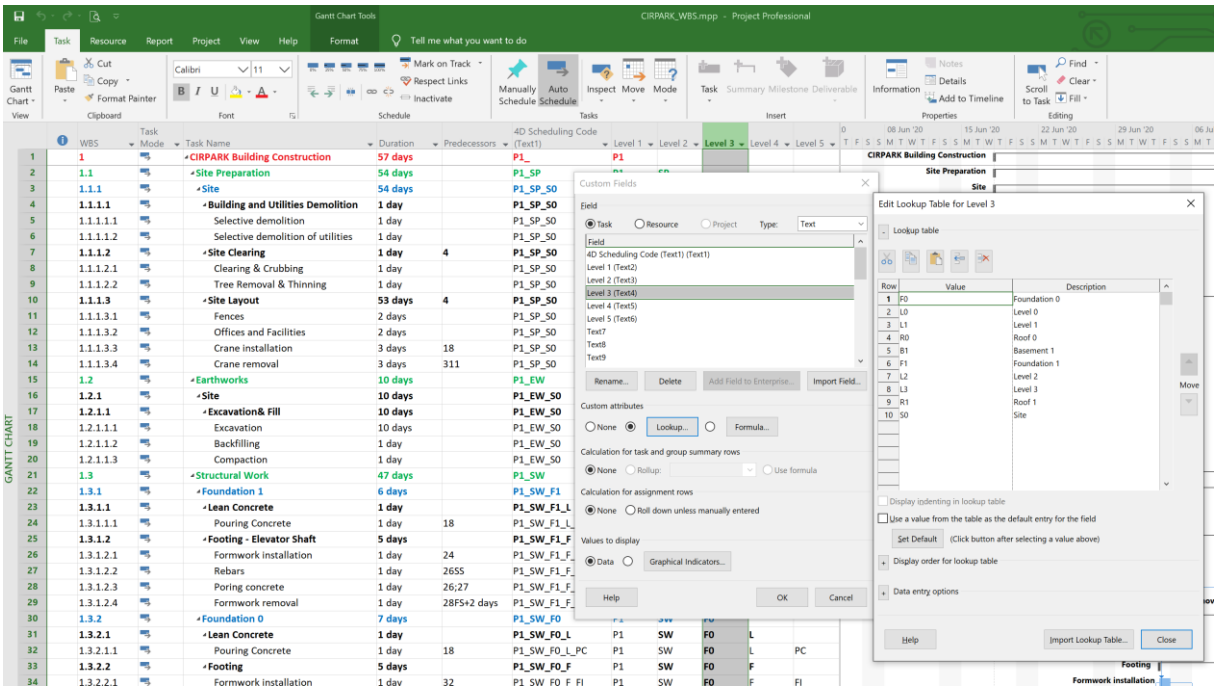


Figure 20: Gantt chart and activities, customized set-up for the IDBS level integration, MP®

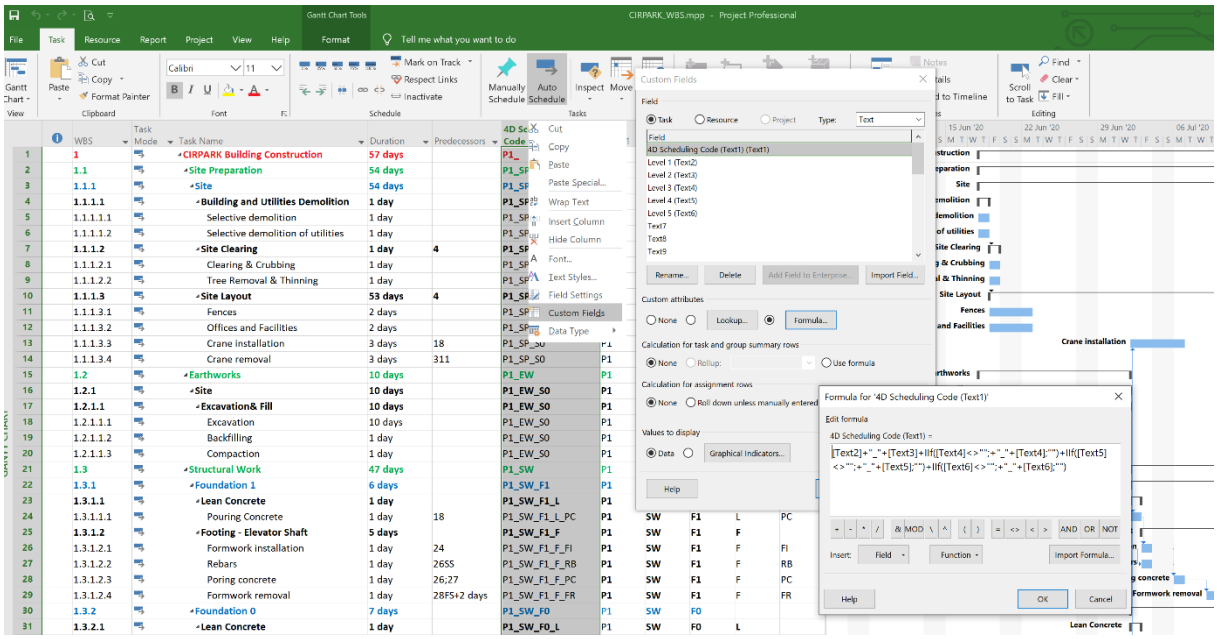


Figure 21: Gantt chart and activities, customized set-up for the 4D Scheduling Code creation, MP®

The Gantt chart is shared to the STR team following the sub-process in Figure 22.

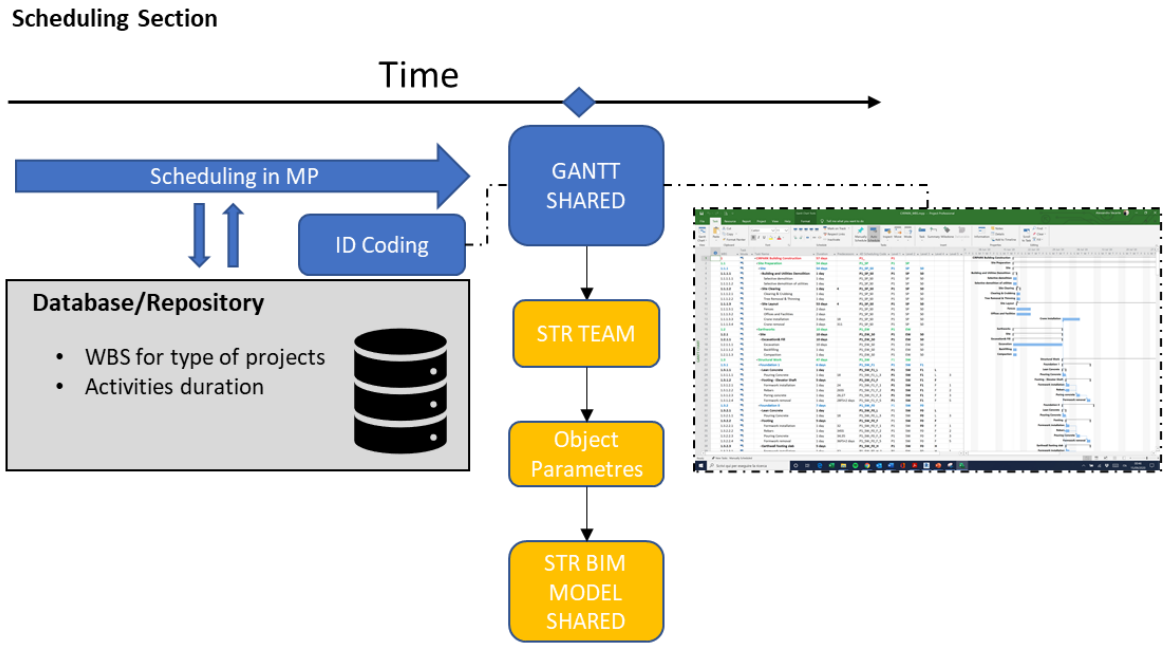


Figure 22: Sub-process for the Gantt creation and sharing in the Scheduling section of the proposed workflow

4.3.4. Assigning IDBS and 4D Scheduling Code to the object

The STR team developed the STR BIM Model by creating the shared parameters, illustrated in Figure 23, according to the indication received by the Planner concerning the IDBS and the 4D Scheduling Code. Note that the name of the parameter is related to the logic behind the WBS of the schedule.

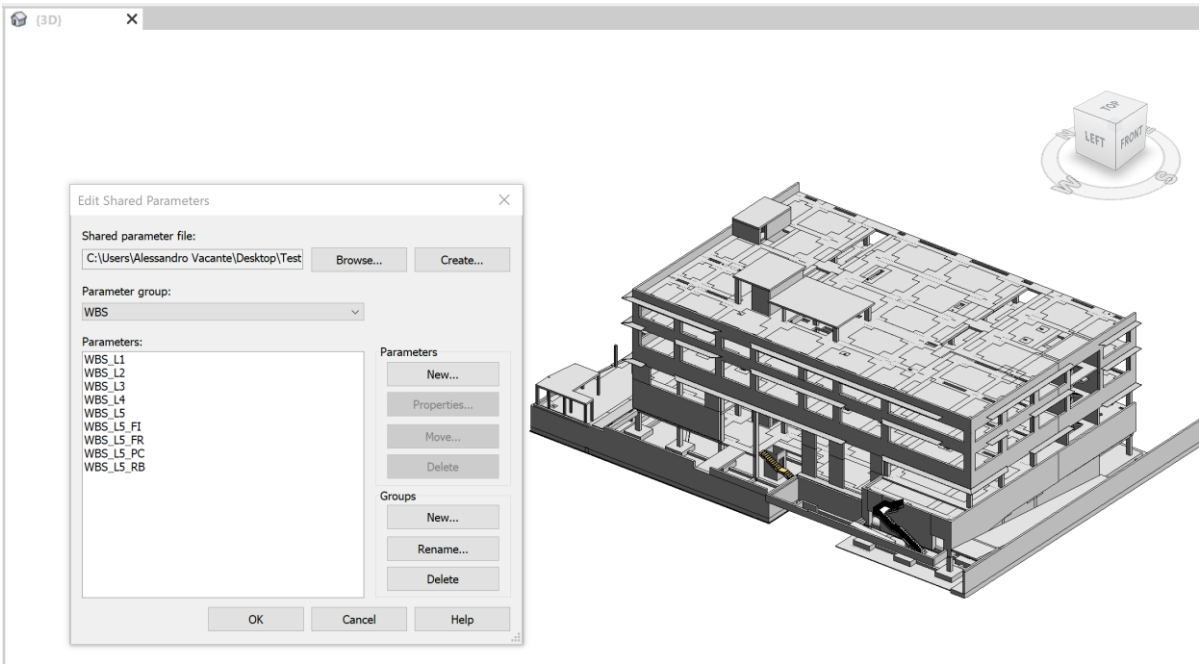


Figure 23: Shared parametres window and 3D view of the STR BIM model, Autodesk Revit®

The shared parameters are imported in the current project. The parameter property is created for each instance of the STR BIM model under the construction group parameters. The example of the WBS_L1 parameter is illustrated in Figure 24.

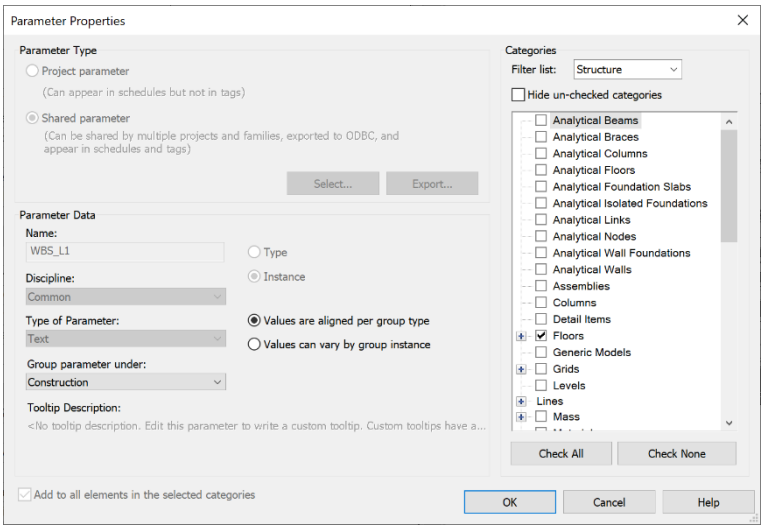


Figure 24: WBS_L1 parameter property, Autodesk Revit®

During the design, the modeller inserted the codes regarding the IDBS and 4D Scheduling for each object/instance within the STR BIM model. The example of the Basic Wall located in the basement is illustrated in Figure 25. In order to speed up the process the modeller can use some script in Dynamo or some free plug-in that allow to select the objects and modify the parameter of the properties according to some specific feature (Level, family, etc.).

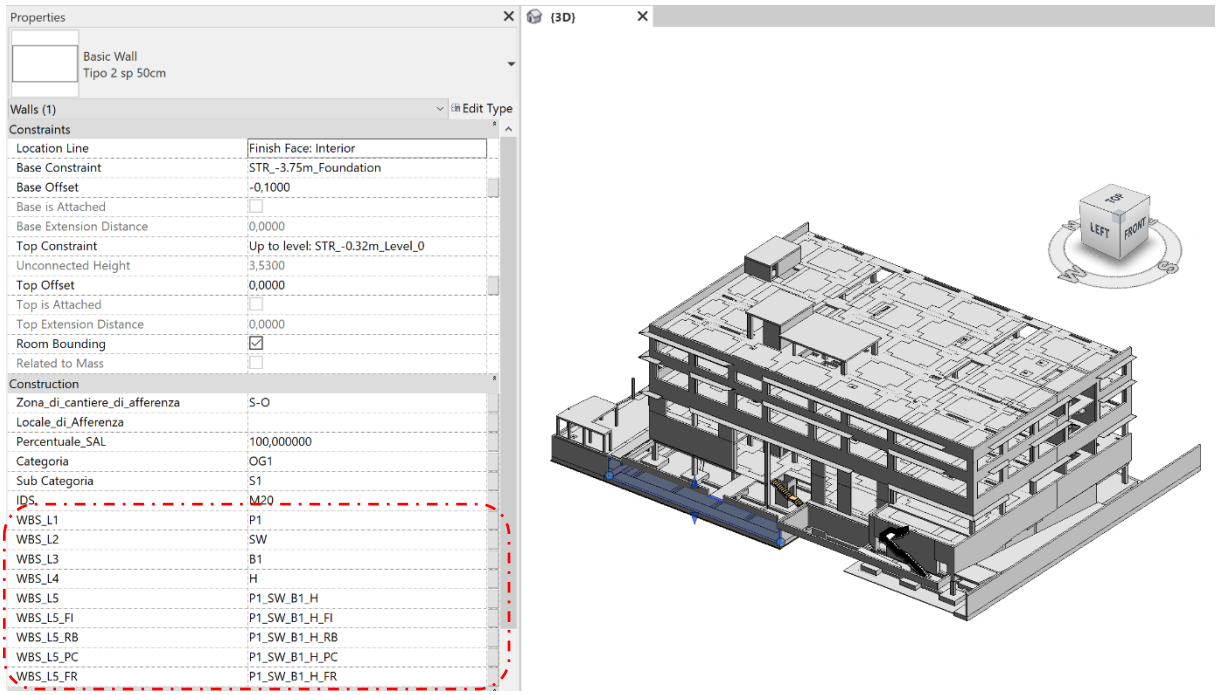


Figure 25: Selected Basic Wall properties and 3D view of the STR BIM model, Autodesk Revit®

4.3.5. IFC exporting with MVD

The STR team, once completed the STR BIM model with all the information regarding WBS, IDBS and 4D Scheduling Code, exported the model in IFC by using the *export user defined property sets* in Autodesk Revit®. It is another way of exporting specific selected properties that serve the purpose of the IFC file. Indeed, this IFC file will be used for 4D and 5D BIM integration purpose. Figure 26 illustrate the customized *AV Master Thesis* set up to be used for the IFC exporting from Autodesk Revit®

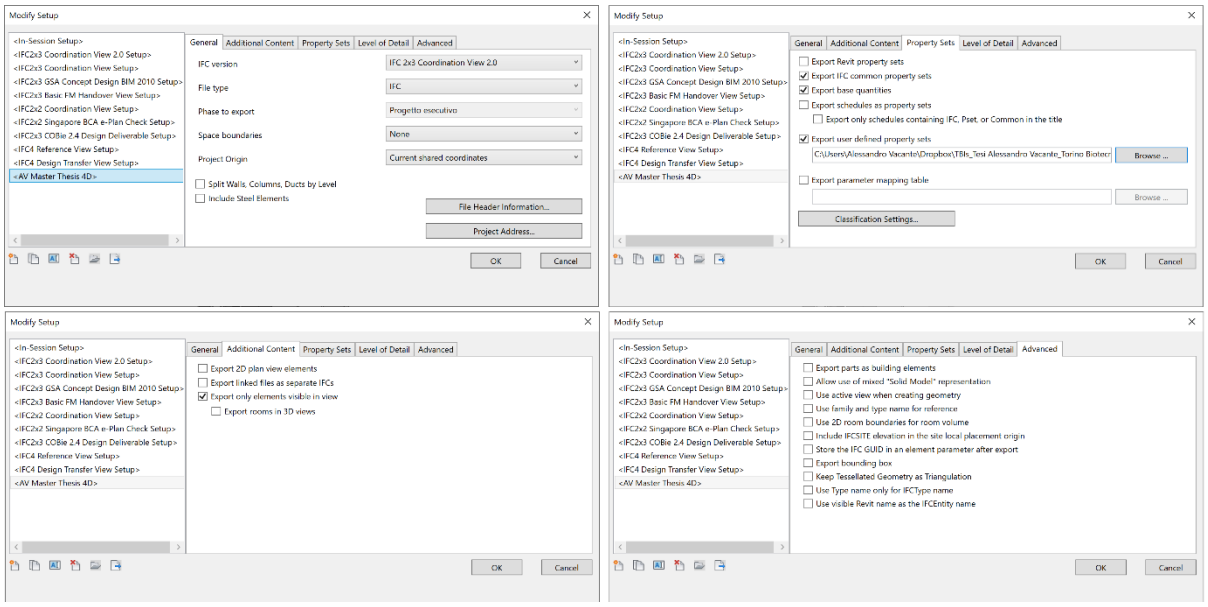
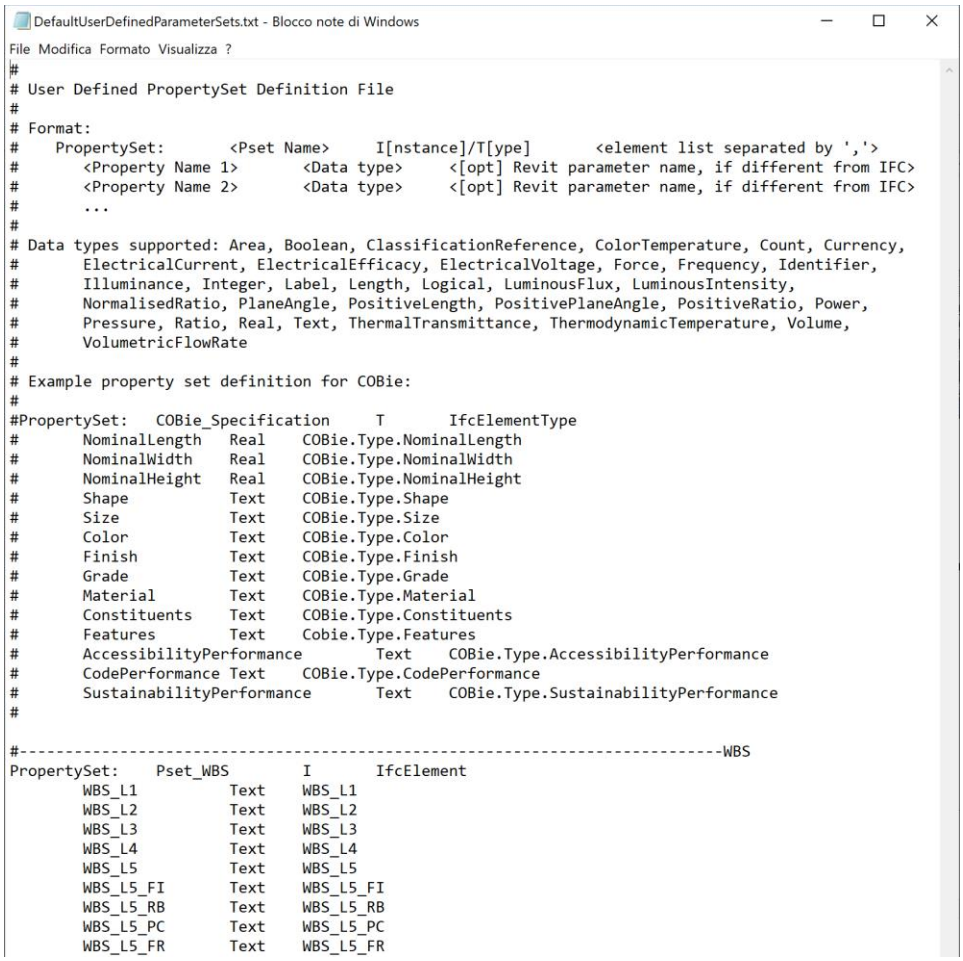


Figure 26: AV Master Thesis setup for the IFC exporting, Autodesk Revit®

By using the user defined property sets, the parameters to be exported are specified in a text file illustrated in Figure 27.



DefaultUserDefinedParameterSets.txt - Blocco note di Windows

File Modifica Formato Visualizza ?

```
#
# User Defined PropertySet Definition File
#
# Format:
#    PropertySet:       <Pset Name>     I[nstance]/T[ype]       <element list separated by ','>
#       <Property Name 1>       <Data type>     <[opt] Revit parameter name, if different from IFC>
#       <Property Name 2>       <Data type>     <[opt] Revit parameter name, if different from IFC>
#       ...
#
# Data types supported: Area, Boolean, ClassificationReference, ColorTemperature, Count, Currency,
#       ElectricalCurrent, ElectricalEfficacy, ElectricalVoltage, Force, Frequency, Identifier,
#       Illuminance, Integer, Label, Length, Logical, LuminousFlux, LuminousIntensity,
#       NormalisedRatio, PlaneAngle, PositiveLength, PositivePlaneAngle, PositiveRatio, Power,
#       Pressure, Ratio, Real, Text, ThermalTransmittance, ThermodynamicTemperature, Volume,
#       VolumetricFlowRate
#
# Example property set definition for COBie:
#
#PropertySet:   COBie_Specification     T       IfcElementType
#       NominalLength   Real    COBie.Type.NominalLength
#       NominalWidth    Real    COBie.Type.NominalWidth
#       NominalHeight   Real    COBie.Type.NominalHeight
#       Shape           Text    COBie.Type.Shape
#       Size            Text    COBie.Type.Size
#       Color           Text    COBie.Type.Color
#       Finish          Text    COBie.Type.Finish
#       Grade           Text    COBie.Type.Grade
#       Material        Text    COBie.Type.Material
#       Constituents    Text    COBie.Type.Constituents
#       Features        Text    Cobie.Type.Features
#       AccessibilityPerformance        Text    COBie.Type.AccessibilityPerformance
#       CodePerformance Text    COBie.Type.CodePerformance
#       SustainabilityPerformance       Text    COBie.Type.SustainabilityPerformance
#

#-------------------------------------------------------------------------------WBS
PropertySet:    Pset_WBS        I       IfcElement
        WBS_L1          Text    WBS_L1
        WBS_L2          Text    WBS_L2
        WBS_L3          Text    WBS_L3
        WBS_L4          Text    WBS_L4
        WBS_L5          Text    WBS_L5
        WBS_L5_FI       Text    WBS_L5_FI
        WBS_L5_RB       Text    WBS_L5_RB
        WBS_L5_PC       Text    WBS_L5_PC
        WBS_L5_FR       Text    WBS_L5_FR
```

Figure 27: MVD data set to be used for exporting the IFC

To summarize, Figure 28 shows the sub-process concerning the IFC exportation.

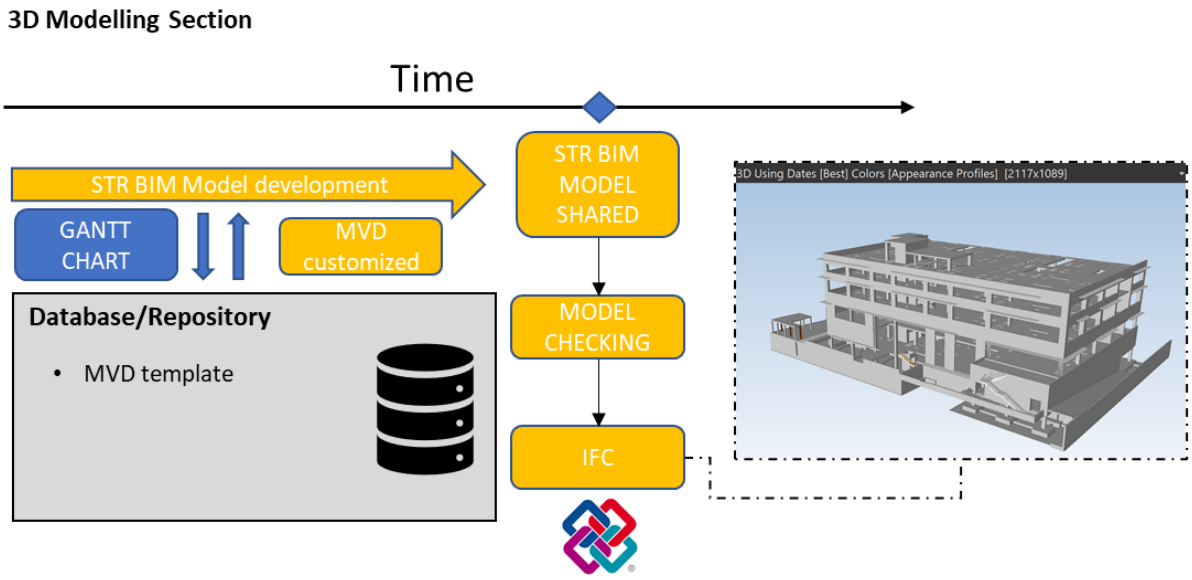


Figure 28: Sub-process for IFC exportation and IFC viewer in the 3D Modelling Section of the proposed workflow, Synchro PRO®

4.3.6. QTO, BOQ and Cost Estimation

Figure 29 illustrates the sub-process of the Cost Estimating Section. The QS imported the IFC file and the WBS of the Gantt chart within the TeamSystem CPM Cloud® (hereinafter TeamSystem CPM®) – unfortunately, the Gantt chart cannot be imported and so the code of the WBS with the description of the activities needed to be created manually.

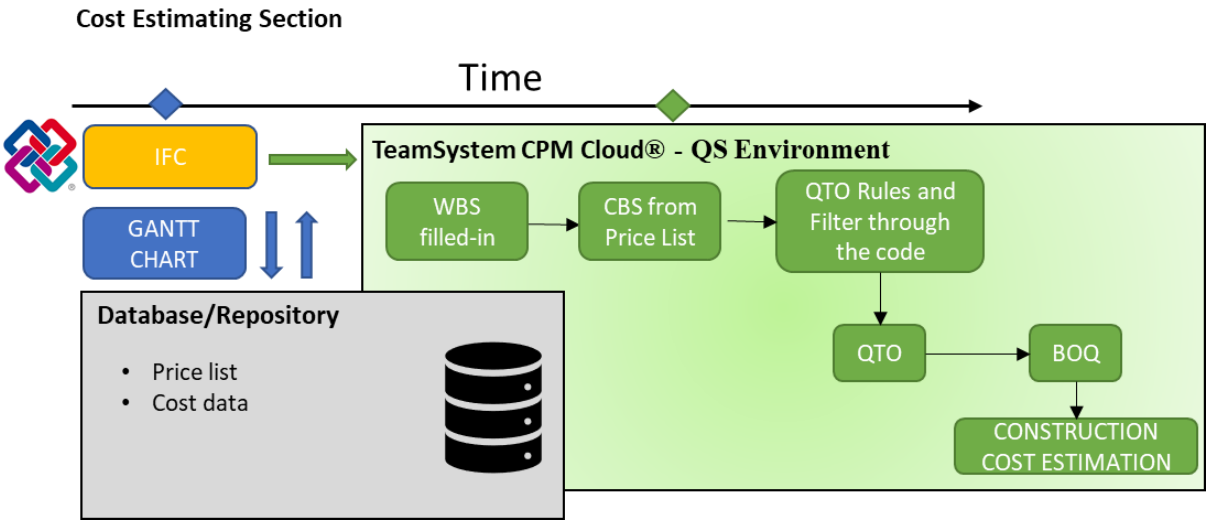


Figure 29: Sub-process for QTO, BOQ and Construction Cost Estimation of the Cost Estimating Section of the proposed workflow

The QS loaded the price list and the cost data, already inside the database of the software. The QS by using the IFC viewer started to create the QTO rules for calculating the measures from the IFC file and the filter in order to select the defined objects. An example is illustrated in Figure 30.

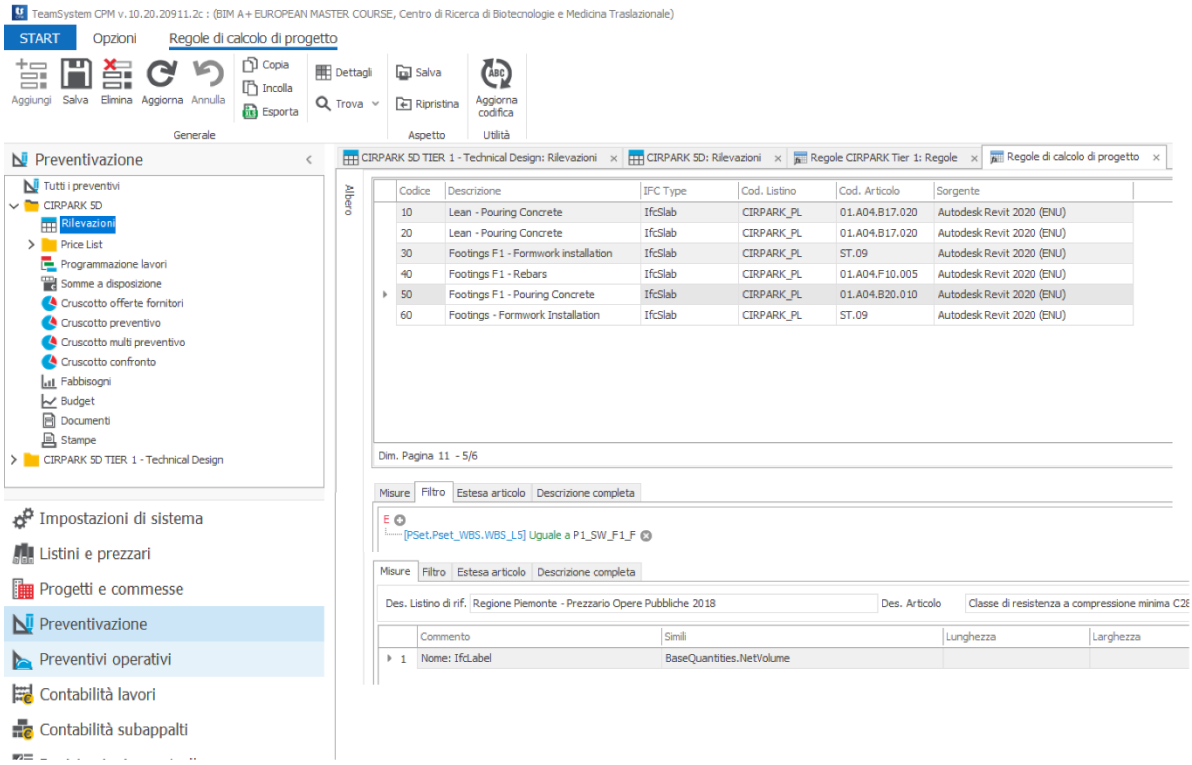


Figure 30: QTO module in TeamSystem CPM®

The BOQ is created by linking the QTO to be extracted by the IFC file with rules and filter saved inside our project to the code of the price list also loaded inside our project. This will allow the parametric generation of the BOQ. Whenever the QS needs to upload a new IFC file shared by the STR team, the BOQ will be updated with the new quantities. Moreover, with the selection tool the QS can verify if an object has been computed or not. Figure 31 illustrated a part of the BOQ. The BOQ followed the same structure of the WBS for the construction scheduling. This last thing is extremely important for the 4D and 5D BIM integration.

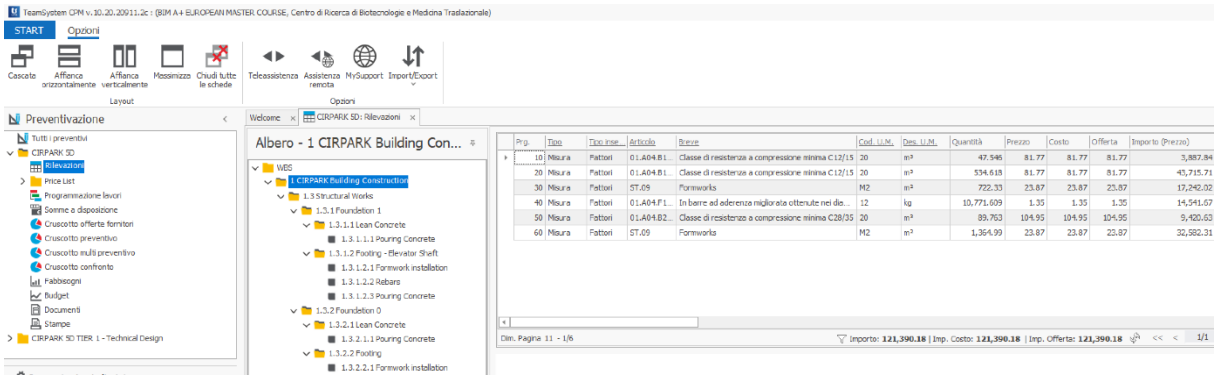


Figure 31: BOQ module in TeamSystem CPM®

4.3.7. 4D and 5D BIM Integration

The data were ready to be integrated in Syncro PRO® in order to achieve the initial purpose of the proposed workflow, as shown in Figure 32.

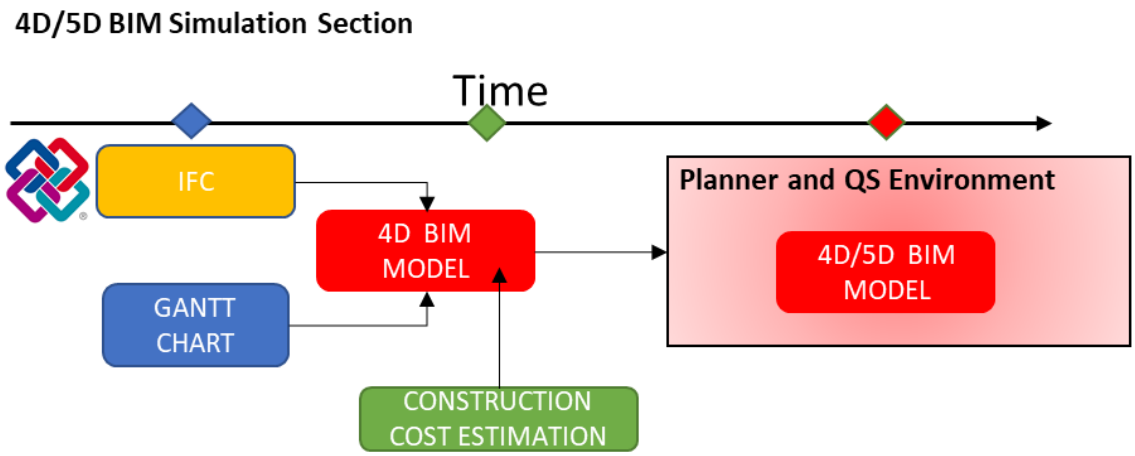


Figure 32: 4D/5D BIM Integration in the Simulation Section of the proposed workflow

The IFC file and the XML format of the Gantt chart in MP® were imported. Through the tool *Resources to Task*, the auto-matching has been performed as shows in Figure 33.

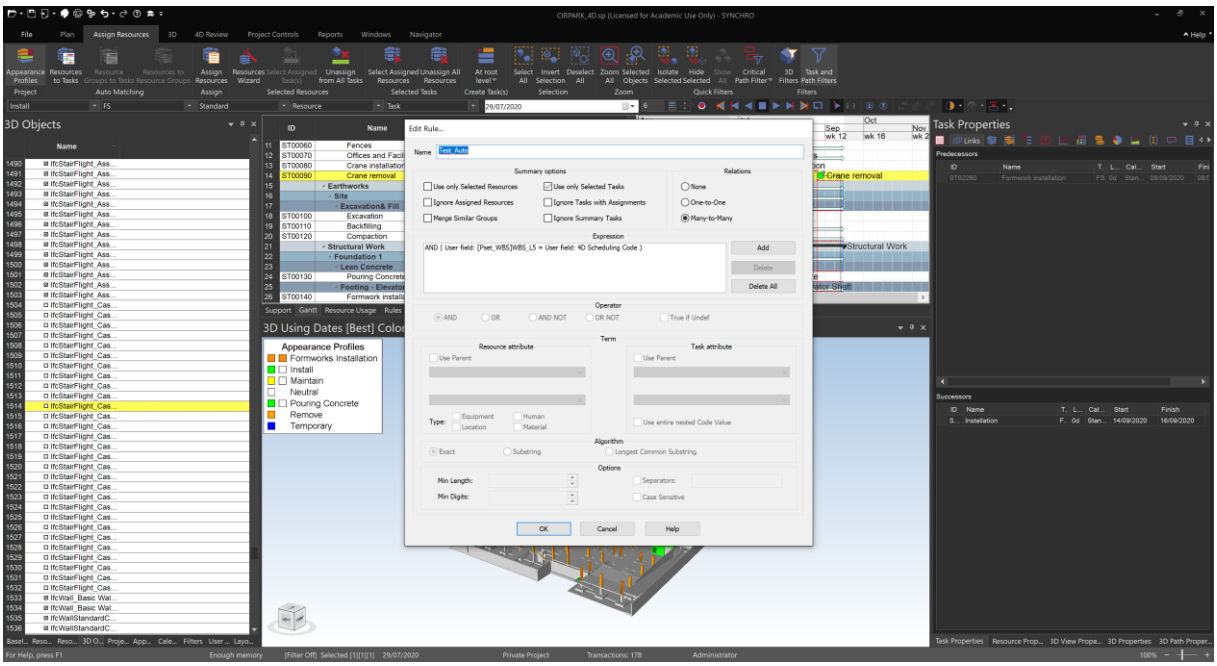


Figure 33: 4D BIM Integration with code matching between objects and activities, Syncro PRO®

The interoperability and the data exchange by using the cloud is one of the best features of these two software tools. Thanks to that, the construction cost for each activity were exported into Syncro PRO® from TeamSystem CPM®, as illustrated in Figure 34.

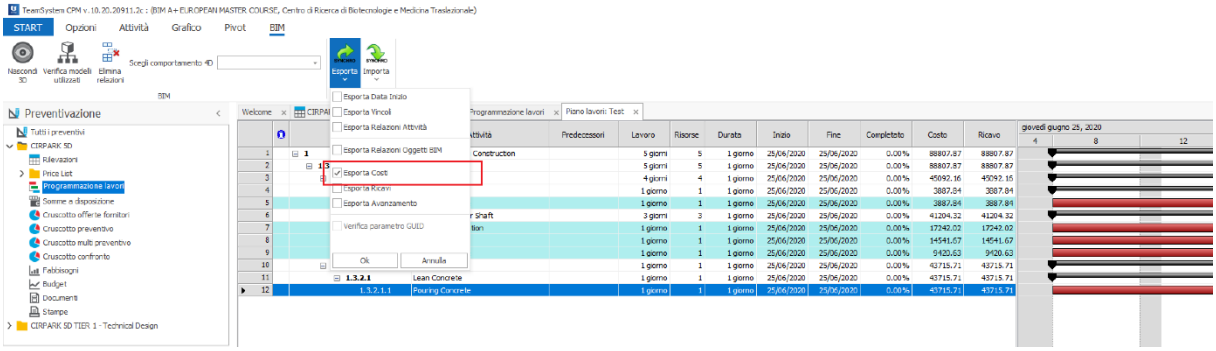


Figure 34: WBS structure for cost estimation and exporting tool to Syncro PRO tool, TeamSystem CPM®

Finally, the 4D/5D STR BIM model was ready for the further analysis during the technical design stage, as illustrated in Figure 35.

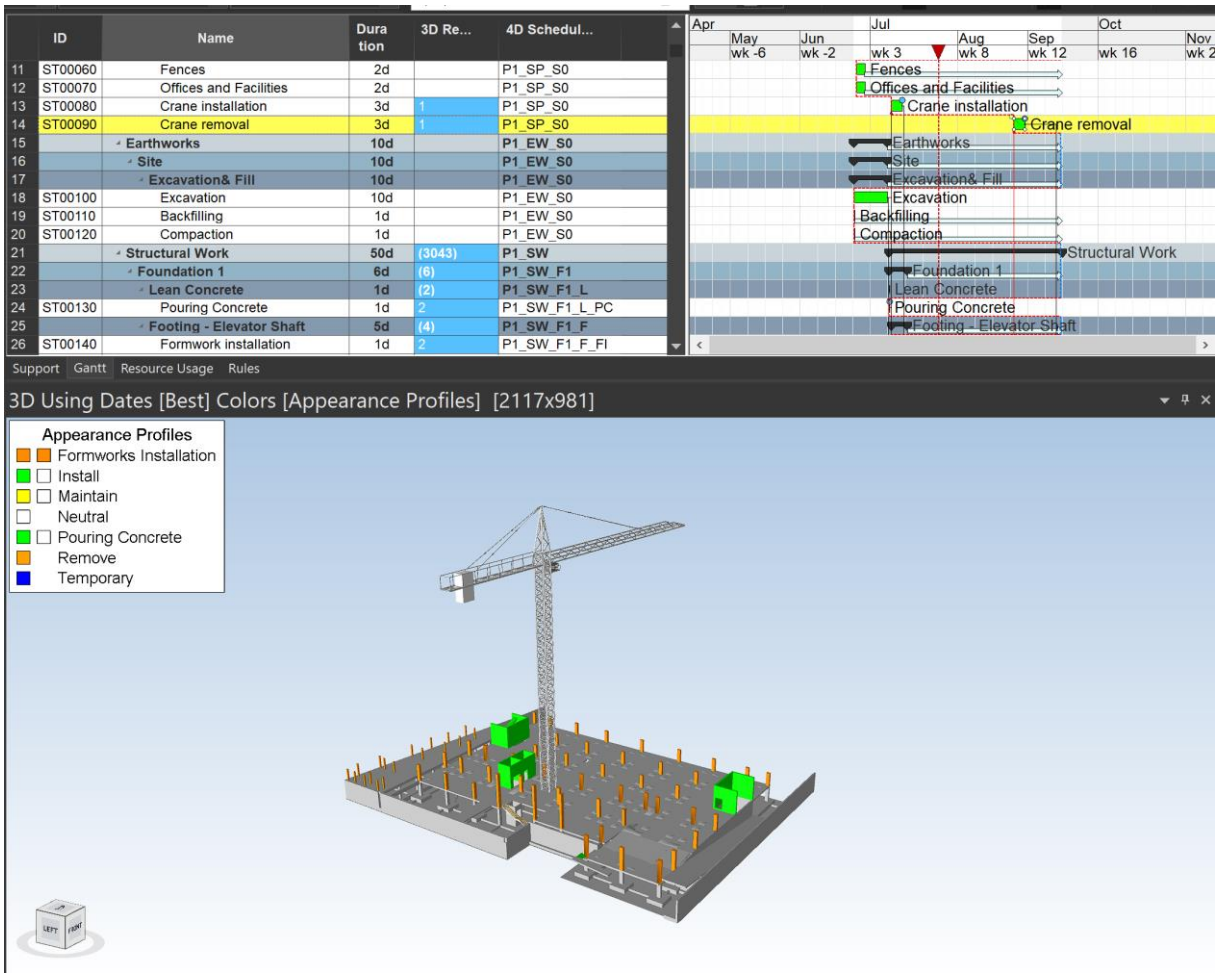


Figure 35: 4D/5D STR BIM Model, Synchro PRO®

5. CONCLUSION

Starting from the research questions presented in the introduction it is possible summarising the main results presented in this thesis.

5.1. Benefits of the 4D and 5D BIM integration during the design phase

BIM is an intelligent 3D model-based process that gives AEC professionals the insight and tools to more efficiently plan, design, construct and manage building and infrastructure. At the heart of BIM is a smart building data model that incorporates not only 3D geometry but also all the relevant data relating to the building and its components. As it is known by a fact that construction industry's productivity has remained flat in the last 60 years and in fact, it has started to decrease in the last two decades, despite numerous technological advancements and adoptions, while other industries have reaped the productivity improvements. Most of the projects face schedule & cost overruns the root cause for these could be attributed to silo working nature, lack of coordination & collaboration and inefficient planning and construction practices which leads to the generation of waste, rework and reduced productivity and resulting in delayed project delivery, cost overruns, reduced quality and an industry plagued with litigations.

To summarize, some of the benefit of the integration are describe further:

- **Visual Communication Tool:** With the 4D and 5D model, all the stakeholders not just construction professionals but even people with different background who can't understand the construction process can accurately visualize the project at any required time on the project life cycle and with cost information. By doing this, the collaborative platform would be established where all the stakeholders provide their valuable inputs and participate in decision making, which often results in reduced changes, increased productivity, open to share concerns and discuss to arrive at the feasible solution as it is easier to understand and everyone is on the same page;

- **Site planning:** Traditionally site layout including but not limited to selecting the laydown area, selection of equipment, defining site access and vehicle pathing, transportation routing for both material and workers is done with the help of static 2D drawings by marking up which lack the temporal dimension and does not specifically signify the accurate position of materials and equipment as they don't possess the 3rd dimension. Perhaps, with the help of 4D model, all the above aspects could be accurately visualized with respect to time as well as accurate position in all directions, since 4D model is Digital Twin of the facility and hence various alternatives can be considered such as fixing the location of tower crane by simulating throughout the project life cycle to see if it clashes with any other components during the construction phase. Also, as change is inevitable in the construction projects, at any point of time, accurate layouts & site maps can be extracted from 4D model automatically which accurately depicts the status of facility & site at that point in time as opposed to generating from 2D drawings via mark-ups which is error-prone as it requires to use up to date data and subject to human error;

- **Constructability Analysis:** Numerous constructability issues could be identified digitally in the virtual environment right before they surface at the site if the 4D model has been created at the appropriate Level of Development (LOD) both in terms of geometric and information detail in the 3D information model and in the schedule;
- **Project Monitoring and Control:** Project monitoring and control is one of the crucial phases of construction project management, so as to know how the project is performing and taking necessary action to keep the plan. With 4D and 5D BIM it is really easy to compare planned vs actual using the 3D object filters and colour profiles to highlight the components which require attention as opposed to comparing few hundreds of activities with planned start and finish and actual start & finish dates which are cumbersome and very difficult to gain insights into project performance, especially in complex and large projects;
- **Schedule Validation:** Sometimes plan might miss few of the design intent and other times it might exaggerate the project scope, usually it is difficult to identify all these bottlenecks in the early stages due to traditional nature of few hundreds of drawings and few thousands of activities in the schedule which are not integrated at all. On the other hand, with a federated 4D BIM model, it is easy to identify all the bottlenecks via simulation and take corrective action early in the process before construction begins rather than confronting the unforeseen issues at the construction site once the project is underway;
- **Dynamic Clash Detection:** BIM has gained most of the traction because of the ability to detect collisions between multi-disciplinary designs before the construction commences, but that doesn't end there, with 4D BIM temporal clashes could also be identified such as resource/ equipment clash if any has been planned to perform two activities at the same time;
- **Digital Rehearsals:** As 4D models act as a Digital Twin for the facility to be constructed, accurate trade sequencing and construction component installation can be simulated and subsequently conveyed to the construction workers who can get a deeper understanding of what to do, when and by whom, and how it should be progressed. Also, various alternative analysis could be generated, simulated, and compared to finalize the best feasible solution. For example, finalizing equipment travel paths, worker and material movement planning in order to avoid congestion and to incur minimum interference between different trade workers, etc.;
- **Detail Lookahead Planning:** The 4D model which represents the physical and temporal relationships for all the scope of works and with the incorporation of latest progress update into it can add a real value during the progress meetings and lookahead planning with great visualization, enhanced collaboration, and improved understanding. Project participants including last planners (those who execute the tasks) would be involved and can provide valuable suggestions into the lookahead planning as 4D BIM environment is collaborative, easy to visualize/imagine and hence decision making is better. Also, sophisticated 4D BIM tools allow to produce automated progress and lookahead reports accurately exploiting the use of 3D object filters, colour profiles, viewpoints, and simulations depicting what construction should take place in particular lookahead (both visual image and tasks), what are the resource requirements, material forecast and etc.;
- **Safety Planning:** Safety Planning is one of the key elements of successful construction project management and it is crucial for efficient project delivery. Traditionally, safety planning is based on the 2D drawings and observations at the site which makes it really difficult to envisage

ll the safety aspects because of the available information and changing nature of construction projects, and entire responsibility depends on safety manager who largely focuses on observing the site for safety concerns. With the computers and information models, most of the safety issues could be identified during the design stage as computers can detect various hazardous location based on some rule-based model checking and can notify/create safety measures and as the project progresses and changes get inevitable, BIM models will get updated to reflect the exact site conditions and hence informing about new measures to be taken resulting in enhanced safety. Also, with the integration of 4D models and AR and VR technologies, safety simulations, safety induction videos could be produced and shared to all the stakeholders and construction workers, which could be easily understandable and provides them guidance, knowledge, and confidence to work at construction workplace.

5.2. Outcomes and original contributions

Considering the traditional methods applied for scheduling and cost estimation in building construction management, this research is meant to expand the knowledge and to improve the efficiency of using these methods by integrating the 3D model with data regarding cost and time. Indeed, 4D and 5D BIM are two of the facets of the overall BIM technology, in which the 3D model is integrated to the time and cost. It allows the project team to visualize, analyse the various aspects at any given point of time throughout the project life cycle to discover any potential issues and bottlenecks before the construction phase. The outcomes of this research work should help enterprises, and, in particular A&E firms, to appreciate the advancement of the technology within the AEC industry. It should help them in taking action in their internal delivery processes by adopting specialized tools and new workflows. Moreover, the outcomes will help clients and investors to define the requirements in their Project Delivery Plan (PDP) and Exchange Information Requirements (EIR).

5.3. Recommendations for further research

An interesting future research would be to expand the proposed workflow to other disciplines and push the power of the tools by carrying out analysis as risk assessment, dynamic clash detection etc. Moreover it would be interesting to implement the workflow within a real design office with different teams and different construction projects in order to test the capability to achieve better result in less time and so cost.

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	Three-Dimensional
A&E	Architecture and Engineering
AEC	Architecture, Engineering and Construction
AIA	American Institute of Architects
AWPS	Advanced Work Packaging System
BIM	Building Information Modelling
BMS	Building Management System
BoQ	Bill of Quantities
BPR	Business Process Reengineering
BS	British Standards
CM	Cost Manager
CMAA	Construction Management Association of America
CMAR	Construction Management at Risk
CP	Cost Planner
CPM	Critical Path Method
DB	Design-Build
DBB	Design-Bid-Build
ECSO	European Construction Sector Observatory
EIR	Exchange Information Requirements
EN	European Norm
EU	European Union
EUR	EURO
FM	Facility Management
IFC	Industry Foundation Classes
IoT	Internet of Things
IPD	Integrated Project Delivery
IT	Information Technology
ITC	Information Communication Technology
ISO	International Organization for Standardization
LBS	Location Based System
LOD	Level of Development
LOIN	Level of Information Need
MVD	Model View Definition
Nd	numbers of Dimension
PDP	Project Delivery Plan
PLC	Project Life Cycle
PMC	Project Management Consultant
PMs	Project Managers
RIBA	Royal Institute of British Architects
SOP	Standard Operating Procedures
TD	Technical Design

QS	Quantity Surveyor
QTO	Quantity Take-Off
VDC	Virtual Design and Construction
WBS	Work Breakdown Structure