The BIM in Practice in the Real World

Anik Das

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Committee:

Carrie S. Dossick

Hyun Woo Lee

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Abstract

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Anik Das

Chair of Supervisory Committee:

Carrie Sturts Dossick

Department of Construction Management

The construction industry is undergoing rapid technological advancements with the introduction of Building Information Modeling (BIM) which has the potential to revolutionize building design, construction, and operation. Despite their potential, these technologies are not yet put into practice to the maximum potential by all the users around the world.

This research explores the current state of BIM in the construction industry and the different types of processes undertaken by BIM professionals to enhance the efficiency and productivity of a project.

The study revolves around some of the parameters such as accuracy, efficiency, quality, and time. This is done through several different case studies across different verticals of construction. The journey shows us a unique perspective that the BIM teams have adopted to take the project to a higher level.

It also depicts the need to usage of automation although there is a need to have a balance and there should be a clear understanding of when to rely on automation.

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I dedicate my thesis to my beloved parents. Firstly, to the memory of my late father. His unwavering inspiration and encouragement have been the foundation and the reason to pursue my higher studies. Although he is no longer with us, his influence continues to guide and influence me. My mother has been an instrumental force in supporting me in every small way. A part of my responsibilities has been taken by her in my pursuit of higher education. She has been the pillar of my life from the day I took my first flight to the US until today as I am writing this part of my thesis. Lastly, my partner Ananya who has been holding me, her love has been my guiding light, and her belief in me has been my greatest strength.

Dedicating my thesis to them is a small token of my appreciation for everything they have done for me.

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Chapter 1: Introduction

1.1 Background

The Digital boom started during the 1990s, and this has accelerated till today. It is impossible to think about a life without digital tools. There are things in today's life that are impossible to think of a decade from now such as smartphones, electric cars, and even the lifestyle of a normal human being. If I apply the same methodology, there are things shortly which will eventually happen such as flying cars, teleportation, interplanetary human travel, and even colonizing Mars. There will always be people who continually pursue digitalization to make work and life easier.

Let us talk a bit about the Dotcom Bubble. 1995 was the year when digitalization took off. Every small to large scale industry with a ".com" title to it gained huge response from investors during the IPOs but then there came a time when only one out of ten companies were making money. Hence during the year 2002, the market crashed with most of the technology stocks nosediving. But there is a twist in the story, a lot of the good companies did come back stronger and bounced back within months. For example, Amazon went all the way down from $100/ share to $7/share, and then again climbed back up to $600/share.

It was a fascinating human nature lesson but all I want to showcase here is that the wheel of technology kept on revolving despite such a catastrophic event. We are now two decades ahead of this occurrence, and this sector (new age digital companies) is still accelerating today in terms of internet, and digitalization.

1.2 Current Scenario:

A construction process is considered successful if it is completed on time, within the agreed budget and quality standards, and achieves a high level of customer satisfaction. Unfortunately, this is often not the case (Shirkavand et al., 2016). McKinsey reported that 98% of megaprojects experience cost overruns or delays, with average cost increases reaching 80% of the original budget and average delays extending to 20 months (McKinsey Global Institute, 2015). Key reasons for these issues include a lack of interdisciplinary collaboration and the accumulation of unresolved problems. A report by the Danish Construction Federation, in collaboration with Chalmers University in Gothenburg and the company BIMobject, found that the Danish private construction sector could save up to 10.5 billion DKK (approximately 1.41 billion Euros) by effectively using digital tools and enhancing communication during the design phase of a construction project (Malmgreen, 2020). They noted that significant economic benefits could be achieved during the transition from the design phase to the construction phase, where ambiguities often arise between consultants and contractors, leading to a knowledge gap.

My study is focused on the construction sector where how digital tools such as BIM (Building Information Management) are enhancing the ways the construction professionals build things. This would help other construction projects to know their potential, analyze the differences, and enable them to unlock new doors, by simple means to take a broader step towards creating value from BIM in the whole construction process.

1.3 Research Questions

RQ1: When and how has BIM improved our work process?

Building Information Modeling (BIM), have significantly improved our work processes by revolutionizing how the construction team plans, designs, constructs, and manages a built environment. BIM facilitates collaboration, and information sharing among project stakeholders, resulting in enhanced communication, coordination, and decision-making. I am going to elaborate in the thesis using practical examples from projects on how this is being implemented, what can be learned, and how this can be replicated in other projects.

RQ2: To what extent should BIM modeling be automated?

There is a trend in our industry that the team should automate the whole process of BIM instead of any manual application-based work. It is true we need to automate a lot of our work however, it's essential to strike a balance between automation, and manual intervention to ensure the accuracy, and quality of the BIM model. We will explore a case study on this, and illuminate more on this topic.

Chapter 2: Literature Review

2.1 Defining BIM

2.1.1 Digital Revolution

Digitization is the process of converting real objects into digital representations (Gupta, 2020). For example, a soft copy of a file rather than a hard printed copy (e.g., PDF). To put it another way, digitization is the process of transforming a non-digital object into a digital representation or artifact (Handan, 2022). Computerized systems can leverage this information for diverse objectives. On the contrary, the application of digital technologies that provide technical items such as hardware or software devices is known as digitization (Cenamor et al., 2019). Information, and communication technology (ICT) systems that standardize data to quickly describe, store, formalize, and transmit vast volumes of knowledge underpinning digital technologies (Pfister & Lehmann, 2021).

On the other hand, Digital Transformation is "The realignment of, or new investment in, technology, business models, and procedures to more successfully compete in an ever-changing digital market," according to Brian Solis of the Altimeter Group (Solis, n.d.). The definition itself explains the necessity of digital transformation in this era. The period of digital transformation is characterized by the transformation of entities, institutions, the public, and employees, as well as the emergence of new business models, and practices (Ulas, 2019).

2.1.2 Building Information Management (BIM)

BIM is an intelligent 3D model-based process that delivers relevant information to professionals at the right time and to the right individuals. Its goal is to facilitate the effective planning, design, construction, and management of facilities (Enegbuma, W. I., Dodo, Y. A., & Ali, 2014; Paneru et al., 2023).

Since its inception around the 1990s BIM has become the distinct technology that separates an ordinary project from a superior project which has completed strict timelines, prevented loss of information, and efficiency in productivity (Borrmann, König, Koch, & Beetz, 2018). It also provides a linear flow of information and helps with O&M phases throughout the lifecycle of a building (Lu, Xie, Parlikad, Schooling, & Konstantinou, 2020).

BIM software accelerates the drawing process by automating project documentation and enabling simultaneous design. It ensures that all changes are instantly reflected across all documents, enhancing workflow and minimizing errors. This efficiency saves time, thereby reducing the labor costs associated with project design and drawing. Additionally, at any stage of the project, the design options feature allows for the creation of design alternatives. BIM also serves as a multidisciplinary collaboration platform (Shing, Gu, & Wang, 2011).

BIM is a suitable method for the construction activity of humans rather than being a means tool that provides the opportunity to work by perceiving the design formally; underlines that BIM is an innovative approach in design and project (Eastman et al. 2008).

BIM software not only facilitates 3D modeling but also supports design, conducts cost analysis, coordinates project management, and assists in forming production details. Visualization, being one of the main features of BIM (Wu, Chen, Cai, Lu, Wang, & Yu, 2019), makes its use highly appealing for analyzing construction time, labor, and cost, in addition to providing 3D modeling.

The AEC industry does depend on the exchange of information, and the connection between each block of data (Das, Cheng, and Kumar, 2014; Alshammari, Beach, and Rezgui, 2021) which in turn is a result of higher collaboration.

2.1.3 BIM Maturity Levels

There are four levels of BIM adoption in the construction industry in a broad range.

Level 0: Constructing elements in 2D Computer-Aided Drawing (CAD) or possibly electronic paper) as a potential means of data collaboration (Ginzburg et al., 2016)

Level 1: Building information is managed in a 3D virtual environment using 2D CAD. The coordination method is based on the British Standard BS1192: 2007 (BSI, 2007), which provides a common data environment as well as some standard data practices, and format. Without any collaboration, trade data is controlled by independent stakeholders, and budgetary administrative products (Ginzburg et al., 2016).

Level 2: At this level, building information is maintained in a virtual 3D environment with linkages (e.g., parametric) to other restraint data sources such as Enterprise Resource Planning (ERP). At level 2, the idea of ‘properties’ or ‘interfaces,’ as signified by the label ‘iBIM,’ is used to integrate heterogeneous (i.e. building, and related) information (Ginzburg et al., 2016).

Level 3: In this level the BIM practices are all standardized, and a CDE (Common Data Environment) in taken into account for interoperability. An ecosystem is developed where there is flexible data exchange for all stakeholders in both ways. It also has the ability to use concurrent engineering methods (Ginzburg et al., 2016).

2.1.4 LOD – Level of Development

LOD can be defined in so many ways with one common idea in mind that enables practitioners in the AEC Industry to specify, and articulate with a high level of clarity the content, and reliability of BIMs at various stages in the design, and construction processes.

Research investigated the impacts of models with an undefined level of detail (LOD) (J. Basbagill, F. Flager, M. Lepech, 2015), indicating the granularity of information at a particular point in the project design stage (LOD100-conceptual, LOD200-approximate geometry, LOD300-precise geometry, LOD350-precise geometry with connections; LOD400-fabrication ready geometry, LOD500-as built.

The following table describes the expected model content at each LOD. These are simplified, indicative definitions that should be reviewed in conjunction with the US BIMFORUM 2019 Level of Development Specification.

LOD	Model Content
LOD 100	LOD 100 elements are not geometric representations. Information attached to other model elements or symbols showing the existence of a component but not its shape, size, or precise location. Any information derived from LOD100 elements must be considered approximate.

LOD 200	LOD 200 elements are generic placeholders. They may be recognizable as the components they represent, or they may be volumes for space reservations. Any information derived from LOD 200 elements must be considered approximate.
LOD 300	Model elements are modeled as specific assemblies accurate in terms of quantity, size, shape, location, and orientation.
LOD 400	Model elements are modeled as specific assemblies accurate in terms of quantity, size, shape, location, and orientation with complete fabrication, assembly fixing, hanging bracing, and detailing information.
LOD500	Model elements are modeled as constructed assemblies, actual, and accurate in terms of quantity, size, shape, location, and orientation with complete fabrication, assembly fixing, hanging bracing, and detailing information.

Table 0.1 "Level of Development (LOD) Specification." BIM Forum, bimforum.org/lod/. Accessed 28 Jan. 2024.

2.2 BIM Workflow Terminologies

2.2.1 Interoperability

It can be defined as the ability of the systems to interchange data. When we think of a digital transformation, we will need to create multiple sources of data nodes where there can be an inflow of various information. These must have the ability to interact, and exchange. Only then we can interpret them and derive values that can make a difference in the output product. The single biggest impact is on information substantiation, and validation, or the time engaged ensuring that the information accurately represents what is set in place." (Gallagher et al., 2004)

In our BIM industry, this is a major flag and a concern when different stakeholders use different technological software to plot their data in a digital platform. Now in most cases, we need to combine these data from different stakeholders to interpret, analyze, derive, and implement this in one federated model. This is where interoperability comes into action. In recent years big BIM software developers such as Autodesk, and Trimble have made this feasible however one needs to keep track of the possible software that is to be used in the whole project by all stakeholders at the start of the project during the BEP(BIM Execution Plan) created or defined at the start of the project.

2.2.2 BEP (BIM Execution Plan)

Building Information Modeling (BIM) Execution Plan is a comprehensive document that outlines the strategies, procedures, and protocols for implementing BIM on a construction project.

Effective BIM implementation in any project must be tailored to its unique requirements, fostering collaboration among stakeholders, and facilitating clear communication in the information exchange process to achieve success. Therefore, thorough research is essential due to the significant information, and collaboration demands involved in BIM execution (Gercek, B., Tokdemir, O. B., Ilal, M. E., & Gunaydin, H. M. 2017). This underscores the significance of the BEP as a pivotal element in the preparation phase for any construction project utilizing BIM (R. Sacks, 2016).

The Building Information Modeling (BIM) Execution Plan (BEP) outlines project vision, and implementation details, crucial for early development, and continuous refinement. It defines BIM scope, task flow, information exchange, and infrastructure needs. Continual monitoring ensures adaptation to changing requirements, fostering collaboration, efficiency, and successful implementation.

Developing a BEP ensures that the entire team benefits from heightened levels of planning, thereby minimizing uncertainties in the implementation process, and reducing overall risks for all stakeholders involved in the project.

2.2.3 TIDP

TIDP is the full form of Task Information Delivery Plan. There is very little thing that has been researched in the BIM community but here is some information that has been published by "ISO 19650 Guidance F: Information delivery planning, Edition 2".

According to clause 5.4.4 of ISO 19650-2, each task team is obligated to generate a delivery plan for the information pertaining to their specific tasks, known as the TIDP. This clause also outlines the factors that task teams must take into account while formulating their TIDP, including their allocated information requirements, specified responsibilities, and designated timelines.

The primary objective of the TIDP is to provide a clear definition of the deliverables, and timelines for each task team, and its members. It's essential to note that the TIDP will be integrated into the appointment agreement between the lead-appointed party, and the appointed party. Hence, it underscores the collaborative nature of planning information deliverables.

2.2.4 ISO 19650

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental, and non-governmental, in liaison with ISO, also take part in the work.

ISO 19650 is an international standard that provides guidelines for the organization, and management of information related to construction projects using Building Information Modeling (BIM) methodology. It aims to standardize the processes, and procedures for managing digital information throughout the project lifecycle (ISO, www.iso.org/obp/ui/en/. Accessed 28 May 2024).

2.3 Significance of BIM

2.3.1 Increase in BIM Adoption

The process of BIM adoption is driven by awareness, and persuasion, involving a shift in perception towards embracing a new approach to operations. BIM adoption occurs at three levels: Micro (within an organization), Meso (within a project), and Macro (market or countrywide). At the Micro level, BIM adoption pertains to organizational adoption, where top management prescribes the usage of BIM within the firm (Succar 2010; Papadonikolaki 2018). Substantial BIM adoption is observed during the design, and construction phases in several developed countries, such as the United States (US), United Kingdom (UK), Germany, and Scandinavian nations (Beaven 2012).

A study carried out by Azhar (2011) on four successful projects which recorded an average of 634% ROI on the cost of BIM is disclosing enormous benefits of BIM adoption. Moreover, 74% of frequent BIM users in Western Europe perceived positive return on their overall investment (McGraw & Hill 2010)

The increase in BIM implementation within the USA has been driven by the state government's mandates (Smith 2014). Contractors reported an important realization of the benefits of using BIM concept (Construction 2014). BIM was set as a requirement in all final concept approvals for all major projects in 2007. The 3D, 4D, and BIM technology deployment was encouraged in all GSA (U.S. General Services Administration) projects and supported by GSA BIM Guide Series. Two years after the release of BIM Guide Series (2009). BIM adoption almost doubled from the start-up (28%) in 2007. NIBS published many National Building Information Modelling Standards (NBIMS), and specifically on building energy performance (Edirisinghe, and London 2015).

The authors examine a construction project as a case study for BIM implementation, focusing on the construction of a high-rise building. They detail the application of BIM in project management, and enhancing communication among stakeholders. Through this case study, the advantages of BIM are demonstrated, including enhanced collaboration, error reduction, and better project results. Overall, the article offers valuable insights into BIM usage, and its integration within construction projects (Sinenko, S., Hanitsch, P., Aliev, S., &Volovik, M. 2020).

2.3.2 BIM Application in Various Stages of Project

In the Pre-Construction Phase, BIM holds considerable potential for enhancing the precision, and efficacy of design, and planning procedures. Below are several methods through which BIM can be applied during this phase. BIM software empowers architects, and designers to craft 3D models of buildings, aiding in project visualization, and design decision-making. BIM software identifies clashes or conflicts in designs across various systems, such as mechanical, electrical, and plumbing, preempting issues before construction, thereby saving time, and reducing rework costs. BIM models generate precise cost estimates for projects, enhancing cost control, and budget management. The software also offers insights into material quantities, labor expenses, and other project outlays.

BIM facilitates construction scheduling, pinpointing critical paths, and potential delays, thereby improving project planning, and management, and minimizing schedule overruns. BIM enhances construction efficiency, accuracy, and quality through benefits like clash detection, construction sequencing, quantity take-off, and 4D simulation. It coordinates the efforts of various trades, and subcontractors, fostering collaboration, and informed decision-making. BIM aids maintenance activities, enhancing efficiency, reducing downtime, and costs, and ensuring project longevity, and performance. BIM facilitates project closure, ensuring objectives are met, and information is effectively transferred to owners or operators for ongoing facility management (Arighnan G, and Sindhu Vaardini U. 2023).

2.4 BIM in Different Verticals of Construction

2.4.1 BIM in Design Process

During the design process, design reviews are conducted to identify omissions and defects, also known as issues. The design and construction of buildings is a complex process due to the uniqueness of each building and the varying partners involved in each project. In the design phase, current design and review processes are mainly communicated through media such as Building Information Models (BIM), while in the construction phase, design reviews are primarily communicated via 2D drawings and descriptions, with 3D models being used to a lesser extent (Haahr et al., 2019; Johansson and Roupé, 2019). According to space cognition theory (Golledge, 1991), which is based on visuospatial skills, processing, and working memory, the information delivery in current media is abstract (Figure 2.4.1). This abstraction places high demands on the individual's ability to encode and decode information, resulting in a higher cognitive workload for the actor (Johansson and Roupé, 2019; Kwiatek et al., 2019).

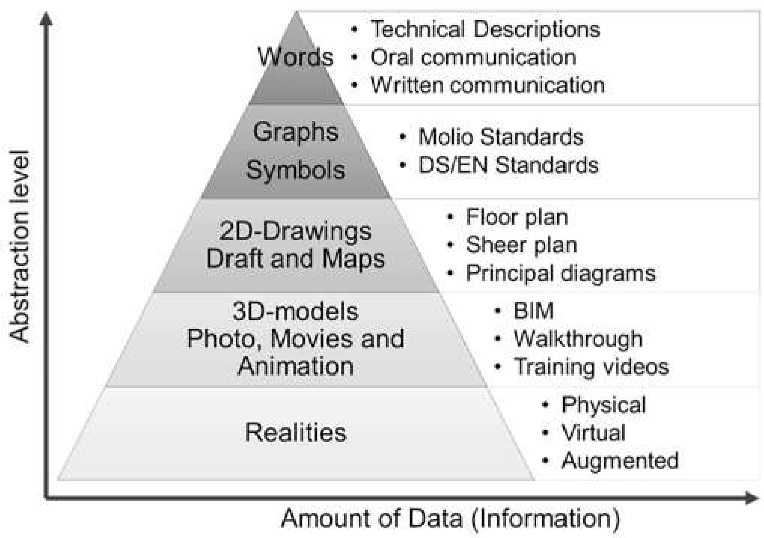

Figure 0.0 Abstraction pyramid – inspired by Kjems (2000).

BIM software serves a multifaceted role beyond 3D modeling, encompassing design support, cost analysis, project management coordination, and the formulation of production details. Visualization stands out as a key feature among the array of functionalities offered by BIM (Wu, Chen, Cai, Lu, Wang, & Yu, 2019).

BIM software accelerates the drawing process by automating project documentation, and offering concurrent design capabilities. The seamless reflection of changes across all documents enhances workflow efficiency, and reduces errors. Time savings translate into lower labor costs for project design, and drawing tasks. Additionally, the design options tab enables the exploration of alternative design scenarios at later project stages. BIM serves as a versatile platform for multidisciplinary collaboration (Singh, Gu, & Wang, 2011).

The simultaneous analysis of other disciplines like mechanical, electrical, and structural can be conducted alongside the BIM model during the design process, enhancing the accuracy, and quality of design while improving efficiency. The software retains all data, and grants access to project information for contractors, and groups involved in mechanical, electrical, and structural aspects during later project stages. By facilitating design reviews, and ensuring functional performance, BIM contributes to improved design outcomes (Gurevic, Sacks, & Shrestha, 2017).

2.4.2 BIM in Management

BIM software expedites the drawing process by automating project documentation, and enabling simultaneous design opportunities. Changes made reflect across all documents simultaneously, streamlining workflow, and reducing errors. Time saved during this process decreases labor costs associated with project design, and drawing procedures. In later project stages, the design options tab facilitates the exploration of alternative designs. BIM serves as a collaborative platform across multiple disciplines (Singh, Gu, & Wang, 2011). Integrating BIM into the curriculum as a response to demands in industry (Joannides, Olbina, & Issa, 2012) will enable students to experience BIM tools, and become ready for profession (Farnsworth, Beveridge, Miller, & Christofferson, 2015).

It is very important to conclude that BIM based design can be effectively implemented in the design practice by experienced designers. BIM allows for simplification of many tasks, and considerable savings both in terms of money, and time. However, the successful implementation of this technology requires skillful design team who acts exactly in accordance with BIM system procedures (Ireneusz Czmoch, Adam Pekala, 2014)

2.4.3 Constructability Review

Construction is an intricate process that necessitates a robust connection between its two main components: design, and construction. Unfortunately, it's not commonplace for designers and contractors to communicate before the construction phase begins.

The purpose of constructability reviews is to evaluate design options and identify areas where potential benefits can be realized. This practice, which involves addressing possible project oversights and minimizing construction issues, has been implemented by several state departments of transportation (DOTs) (Anderson and Fisher 1997). Constructability reviews allow for a systematic evaluation of projects at various stages of development, aiming to minimize future disputes and changes in project scope related to construction issues. This process typically relies on the expertise of construction engineers and their integrated knowledge of techniques, advancements, and experience to prevent future project oversights. Efforts to develop a systematic constructability review process have been discussed in the National Cooperative Highway Research Program (NCHRP) Report 390 (Anderson and Fisher 1997), which also identified preliminary benefits of the process.

(Jiang and Leicht 2014) developed a rule-based system for checking the constructability of formwork in cast-in-place concrete projects. (Ugwu et al. 2004) explored the use of ontologies to assess the constructability of steel frame structures. (Jarkas 2012) created a model to evaluate labor productivity for rebar installation in in situ reinforced concrete walls. (Soemardi 2000) employed a virtual reality-based system that allows designers to visualize the construction process of precast concrete elements. This system enables designers to gain a comprehensive understanding of both design and erection processes, thereby assessing the constructability of building construction methods.

2.4.4 Impact of BIM on project performance, and collaboration

The paper impact on BIM on project performance [Xinran Hu, and Yunfeng Chen, 2023] showcase how limited research has explored the effects of Building Information Modeling (BIM) on project performance based on business types, working experience, and project locations. A survey was undertaken, revealing that BIM positively contributed to early error detection in design, pre-construction RFIs, and an increase in repeat customers.

This study reveals three primary findings. First, and foremost, BIM demonstrates a favorable influence in identifying design errors, and pre-construction RFIs, and it contributes to attracting repeat customers when compared to projects that do not utilize BIM.

The second key finding highlights that among the stakeholders, contractors derive the most significant advantages from BIM in areas such as pre-construction design errors, pre-construction RFIs, and securing repeat customers. However, they also face the most challenges with in-construction RFIs, the cost of punch list items, and near misses. Conversely, software vendors, and architects experience benefits from BIM in the second set of indicators but encounter challenges in the first set. Lastly, the study indicates that the influence of BIM on project performance is not directly proportional to the level of BIM experience.

In another paper Erik A. Poirier, Daniel Forgues & Sheryl Staub-French (2017) Understanding the impact of BIM on collaboration: a Canadian case study, Building Research & Information, 45:6, 681-695, DOI: 10.1080/09613218.2017.1324724 was to formalize a comprehensive understanding of the impact of Building Information Modeling (BIM) on collaboration within the Architecture, Engineering, and Construction (AEC) industry. Motivated by the necessity to move beyond a predominantly positivistic viewpoint, the research sought a systemic, and dynamic understanding of BIM-enabled collaboration, with a particular focus on the individual level. To achieve this objective, the research involved characterizing collaboration in a manner conducive to systemic, and evolutionary investigation, addressing the need for a more nuanced, and holistic perspective on the subject.

The key findings of this research project revolve around the identification of five cognitive determinants that mediate individuals' actions, and interactions in the context of BIM-enabled collaboration. These determinants influence how agents frame core entities, and interactions within the collaboration system, consequently shaping event patterns, and outcomes. The argument is made that BIM's impact on collaboration lies in reshaping individuals' cognitive determinants, thereby altering the framing of event patterns, and their outcomes within the collaboration system. This impact is empirically observed in the redefinition of individuals' information landscapes—how information is generated, shared, and consumed within the collaboration system. The five cognitive determinants—requirements, expectations, intentions, incentives, and capabilities—were identified through an iterative coding process. These determinants act in combination to influence individuals' framing of event patterns, akin to the concept of appraisal domains in cognitive psychology. The development of frames is articulated across the four core entities of the collaboration system, such as structures, artifacts, processes, and events. For example, requirements as a cognitive determinant can shape the framing of structures, artifacts, processes, and events in the collaboration system. The empirical manifestation of this impact was evident in a specific BIM-related requirement identified in the request for proposal (RFP) for the studied project.

2.4.5 BIM application in precast elements

A modular building is a prefabricated building that consists of repeated sections called modules. (Lacey et al ,2018). Modularity involves constructing sections away from the building site and then delivering them to the intended site. Installation of the prefabricated sections is completed on site. Prefabricated sections are sometimes placed using a crane. The modules can be placed side-by-side, end-to-end, or stacked, allowing for a variety of configurations and styles. After placement, the modules are joined together using inter-module connections, also known as inter-connections. The interconnections tie the individual modules together to form the overall building structure.

The use of precast concrete elements, however, can suffer from system failures due to dimensional mismatches of precast products with other precast components, or the rest of the structure, during assembly. The Construction Industry Institute (CII) (Construction Industry Institute (CII), Making Zero Rework a Reality, Report 203-1, The Univ. of Texas, Austin, 2005) revealed that the average cost of rework caused by construction defects was 5% of the total construction costs.

It was reported that defect costs amounted to 4% of the contract value in new residential construction. Consequently, stringent dimensional quality assurance (DQA) measures are implemented for precast concrete elements before their shipment to construction sites (A. Mills, P. L. P. W. (n.d.) 2009.)

Recent research endeavors have investigated the potential of implementing a BIM-centric system to streamline the storage, and management of precast concrete element data, aiming for efficiency, and effectiveness. Many of these studies have concentrated on addressing challenges related to data exchange commonly encountered in construction projects, attributed to the diverse range of participants involved (Y.S. Jeong, C.M. Eastman, R. Sacks, I. Kaner 2009).

2.5 Conclusion from Literature Review

In this section, we have explored the evolution of Building Information Modeling (BIM) and the significant impact digitalization has had on advancing construction practices. While BIM is widely recognized for improving the success rates of construction projects across various countries, the critical question remains on how its implementation varies among different teams. The processes and methodologies adopted for BIM execution differ considerably, influenced by factors such as project scope, team expertise, and specific project objectives. Consequently, the value extracted from BIM's 3D models can vary, reflecting differences in how teams utilize the technology for design optimization, project visualization, and overall project management. In the following section, we will delve into case studies that address these research questions, providing concrete examples of how BIM is applied in diverse contexts and highlighting the outcomes achieved through different approaches. These case studies will illustrate the practical implications of BIM implementation and demonstrate how teams can maximize the benefits of this transformative technology in construction projects.

Chapter 3: Research

3.1 Research Method:

The research method will be a combination of interviews with industry experts, and highly experienced people involved in the field, and case studies on projects where BIM has been implemented in large-scale projects in a globally recognized company. These encompass a variety of approaches aimed at gathering qualitative data through direct conversations. These methods have served as invaluable tools for delving into complex topics and understanding diverse perspectives. The questions were semi-structured hence the interviews provided flexibility, employing key questions as guides to facilitate in-depth exploration.

There were a lot of narratives involved which focused on participants' part in the project, emphasizing the context of the projects defined in Table 1.1. Every interviewee was an expert in their field with a lot of experience and was involved with specialized knowledge in the field of BIM application. The interviews lasted more than an hour. A brief description of them has been listed in Table 1.2. As we can see from the table it includes a lot of personnel from the construction, and design field as well. The questions to the interviewees were majorly focused on the project as mentioned in Table 1.2 but they were also directed toward the parameters listed in Table: 1.3.

Below is the list of the types of interviewers that have been interviewed:

Interviewer	Client Type	Industry worked in	Experience (years)
Interviewee 1	BIM Manager	Specialty Concrete Contractor	20
Interviewee 2	Senior Project Manager	International Construction Firm	12
Interviewee 3	BIM Coordinator	International Design Firm	7
Interviewee 4	Senior BIM Modeler	Global BIM company	5
Interviewee 5	Design Manager	International Bridge Firm	14

Table: 1.1 lists the Description of the Interviewees

The projects that I have selected for describing the value addition in several forms with respect to BIM are mentioned below:

Project Type	BIM team	Field of Involvement of the BIM team
Airport Project	Airport BIM team	Worked for a construction company
Bus Depot Project	Bus Depot BIM team	Worked for a design company
Esplanade Project	Esplanade BIM team	Worked for a design company
Bridge Project	Bridge BIM team	Worked for a design company
University Compound Project	University Compound BIM team	Worked for a construction company

Table: 1.2 lists the project type, and the team that worked

(This table is a brief synopsis of the project. The reference of these teams is to be used in the later part of the thesis; I will elaborate more about these projects in the Findings section.)

3.2 Type of data:

Data has been collected for five projects based on the parameters mentioned in Table 1.3. The projects were chosen due to their proximity to being aligned with the BIM industry. All the projects have been a part of global companies that are at the helm of the construction industry. Every project has a different client base which encircles general contractors, owners, and sub-contractors that include trades such as architecture, concrete, steel, and MEFP. Interviews have been conducted with several key members of the project that have been mentioned in Table 1.1. I have been a part of several projects as a BIM Project Manager and as an engineer. Hence, I was very close to the inner happenings of them. I am going to elaborate on each of these projects to give a brief introduction to the type of project, location, and scope of work in terms of BIM in the section under Findings.

When we read through the research question one, we will find so many different variables that can be used to make the construction work more efficient. This ranges from prefabrication, lean construction, supply chain optimization, and so forth. In this thesis, I am going to talk about the things that the team has done better in terms of BIM. BIM can also be utilized by so many ways by different trades in construction. I am going to take some of the very critical parameters that pave the way for a more efficient process that improves our overall project. The parameters that are included have been listed in the table 1.3 below:

Parameters
Accuracy in design (Accuracy)
Managing the construction process (Efficiency)
Process of implementation of Design (Quality)
Implications of coordination (Reduced Rework)
Pace of construction/Impact on schedule (Time)

Table: 1.3 lists the project parameters used in the case study projects

	Esplanade Project	Bus Depot Project	Airport Project	University Compound Project	Bridge Project
Start date:	Jan 2019	Mar 2021	Oct 2019	Feb 2018	Mar 2022
End date:	Ongoing	Aug 2023	Apr 2024	Feb 2020	Ongoing
Design Team:	Global design team	Global design team	Global design team	Local Architects	Global design team
Country:	USA	Singapore	USA	USA	USA
Owner:	Government	Government	Government	University	Government
Estimated Construction Budget:	~$150 million	~$150 million	$950 million	~$77 million	~$550 million
Softwares:	AutoCAD, Revit	Revit, ProjectWise	Revit, Procore, BIM 360	Revit, BIM 360	Tekla, MicroStation, Python

Table 1.4 below showcases the contrasting differences between projects

3.3 Participant Observer and my professional connections

I am currently pursuing my master's at the University of Washington. I have completed my undergraduate degree in Civil Engineering. I have been working as a BIM Project Manager for the past seven years. I have been a part of companies like WSP, COWI, and Pinnacle Infotech Solutions which are global design and BIM companies. With my experience, I have tried to connect both fields with respect to my experiences in several different projects. Being a part of these companies helped me gather a lot of data. This is solidified with the interviews with several BIM experts all over the world.

With my working experience with several different projects, all I can say is that BIM is a differentiating factor and has completely reinvented the way a team thinks that they can build a project. The result has been, repeat orders from almost all the clients that have transformed from CAD to BIM. Once they are in this process, they can never even think of doing a construction project without a BIM team. I have been working in various firms dealing with multiple sectors of the construction industry such as Design, General Contractors, and sub-contractors, and every one of them has adopted BIM in various ways.

BIM is not only limited to a geometric modeling of a building or infrastructure: it has extensive usage in several other forms which include the following: concrete estimating model, concrete shop/lift drawing model, reinforcement model, logistics safety model, MEP coordination, Steel connection, and detailing for shops, presentation model, facility management. These are some of the uses. It is not only a growing trend but is now a necessity among all general contractors, designers, owners, and subcontractors as I have showcased in the Literature review section.

With my experiences in implementing BIM over the past seven years, I have discovered that the application of BIM is highly versatile, offering countless ways to enhance construction projects. The effectiveness of BIM largely depends on the styles and methodologies adopted by different BIM professionals, as well as their ability to extract value from the technology.

I want to share some of the industry trends on the future prospects that have evolved in this sector as well which is the application of Digital Twins. The budget constraints in the construction project are a big deal and generally, BIM is offered to 1%-4% of the total construction budget. Hence the application to make a higher LOD model in smaller projects is so near to impossible.

The concept of a Digital Twin extends beyond the mere use of dedicated software, contrary to common misconceptions in the literacy context. It is a gradual, evolving process that begins with a lower Level of Detail (LOD). Initially, the model may have basic details and functionalities. Over time, it progresses towards higher levels of parametric detail, bi-directional information management, and enhanced collaboration.

As the Digital Twin matures, its LOD increases, ultimately reaching advanced stages such as LOD 500 or higher. At this high maturity level, every element of the system is meticulously defined. More importantly, there is a dynamic flow of data and information between the physical entity and its virtual counterpart. This sophisticated interaction ensures that the Digital Twin accurately mirrors the real-world entity, allowing for comprehensive monitoring, analysis, and optimization. In essence, developing a Digital Twin is a meticulous, step-by-step process where the model evolves from basic to highly detailed, enabling robust data integration and real-time interaction with the actual system.

I have been an active or passive member in the projects that have been used as case studies. Also, I have had formerly worked with most of the interviewees that has been taken into account as a part of data collection. These have been kept anonymous for confidentiality, privacy and to encourage honest and open responses.

Chapter 4: Findings

4.1 Data collection:

This section outlines the data collected through interviews and active participation in the projects. The data collection process was designed to gather comprehensive insights into the projects and the parameters that are related to them as defined in Table 1.1. 1.2 & 1.3.

4.2 Projects used for case study:

A brief explanation of the projects and the BIM model that had been created in the process has been defined in this section.

4.2.1 Esplanade Project

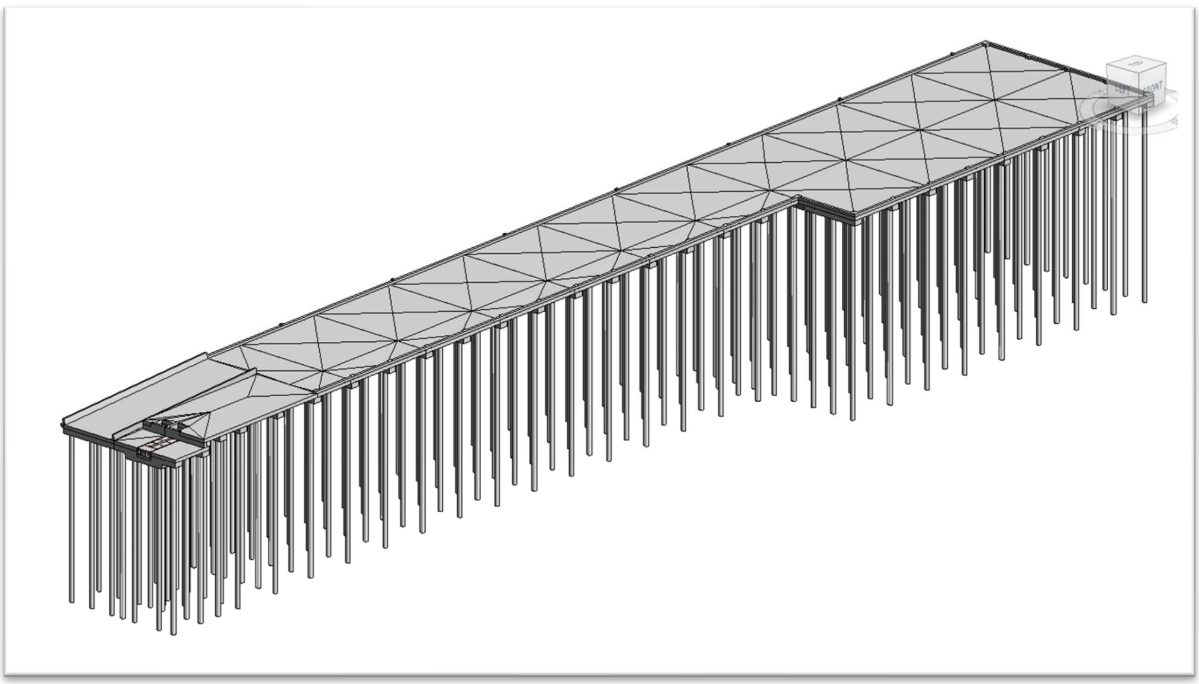

Fig. 0.1 showcases the BIM model for Esplanade Project generated on Revit software for the Esplanade project
(Picture provided by interviewee, (Typical for all figures, unless noted otherwise)

The project is based in the USA, and owned by the government, it was approved to start by the design team on January 1, 2019, with an ongoing duration. It involves a turnover of approximately $4,436.057 million and an estimated construction budget of around $47 million. The contract, executed in September 2018, spans four (4) years initially, with provisions for two one-year extensions. The project engaged a global design team, and AutoCAD in the initial, and eventually Revit as the primary BIM software.

The project is part of an overall plan for improving public access along a shoreline. It provides the missing link in the esplanade that connects the two terminals for a growing population in need of transportation alternatives. It also provides shoreline rehabilitation/hardening, resiliency, infrastructure, and connectivity needs while providing high-quality waterfront open space. Create nearly half a mile of pedestrian/bicycle pathways along the waterfront that connects another Island. It provides a permanent pier facility for DOT (Department of Transportation) and integrates safe esplanade access with existing water-dependent operations.

The scope of work for the Building Information Modeling (BIM) implementation includes several critical components necessary for the successful construction of the project. Firstly, it encompasses the construction of a pier spanning between 30,000 to 75,000 square feet, requiring meticulous planning, and coordination to ensure structural integrity and functionality. Utility work, essential for providing necessary services such as water, electricity, and drainage to the pier, is also part of the BIM scope. Additionally, in-water mitigation work aimed at minimizing environmental impact, and complying with regulatory requirements is included, emphasizing the project's commitment to sustainability, and responsible construction practices. Bulkhead work, involving the construction or reinforcement of retaining walls along the waterfront, is another crucial aspect addressed within the BIM framework. The scope further extends to the integration of precast elements, railings, and fendering systems, which are vital for enhancing the safety, accessibility, and durability of the pier structure.

By comprehensively addressing these elements within the BIM framework, the project aims to optimize construction processes, minimize risks, and deliver a high-quality, sustainable pier facility tailored to meet the needs of the stakeholders, and community.

4.2.2 Bus Depot Project

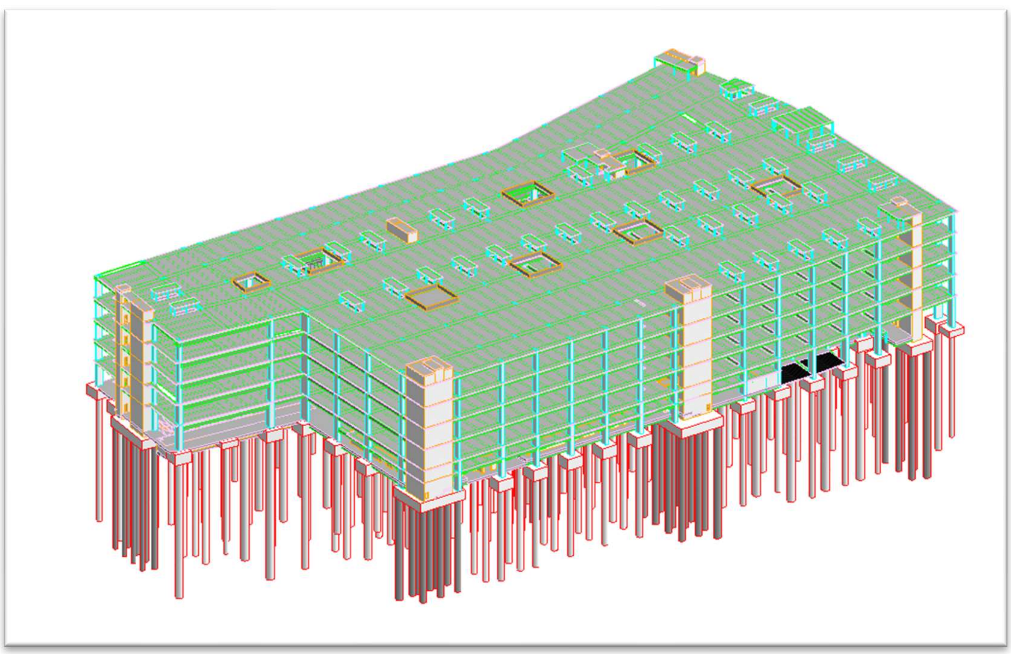

Fig. 0.2 showcases the BIM model for Bus Depot Project generated on Revit software

The project entails Bus Depots to cater for Diesel Bus, and Electric Bus (E-bus) electrification provisions. Existing Bus Depots are to be fully demolished, and the design team will provide designs based on empty land plot conditions to cater for Diesel Bus, and Electric Bus (E-bus).

The project is a significant endeavor spearheaded by the government authority. With an estimated construction budget of approximately $47 million, the project holds considerable importance in the nation's infrastructure development. Overseen by a global design team, the project leverages the expertise, and collaboration of professionals from various backgrounds to ensure comprehensive planning and execution. The contract, executed in September 2018, spans an initial term of four years, with provisions for two one-year extensions, demonstrating a long-term commitment to project success, and continuity. Central to the project's success is the utilization of Revit as the primary Building Information Modeling (BIM) software, enabling efficient design coordination, visualization, and project management. By harnessing the capabilities of BIM technology, and fostering international collaboration, the project aims to deliver a transformative transportation infrastructure solution that meets the evolving needs of Singapore's growing urban landscape.

The scope of work for Building Information Modeling (BIM) encompasses a comprehensive range of elements critical to the successful execution of the project. It includes the design, and coordination of foundations, ensuring stability and structural integrity to support the entire structure. The superstructure, comprising the framework, and load-bearing elements, is meticulously planned and coordinated within the BIM framework to optimize construction efficiency and safety. The façade, an essential component for both aesthetic appeal and functional performance, is carefully integrated into the BIM model to ensure seamless coordination with other building systems. Conveying systems, such as elevators, and escalators, are designed, and coordinated within the BIM environment to optimize space utilization and ensure smooth vertical transportation. Mechanical systems, particularly Air Conditioning, and Mechanical Ventilation (ACMV), are intricately integrated into the BIM model to optimize energy efficiency and occupant comfort. Electrical systems, including lighting, power distribution, and fire detection, are meticulously coordinated within the BIM environment to ensure safety, reliability, and compliance with regulatory standards. Access management systems, such as security, and surveillance, are designed and coordinated within the BIM framework to enhance building security and user access control. By comprehensively addressing these elements within the BIM scope of work, the project aims to optimize construction processes, minimize risks, and deliver a high-quality building that meets the needs of its occupants, and stakeholders.

4.2.3 Airport Project

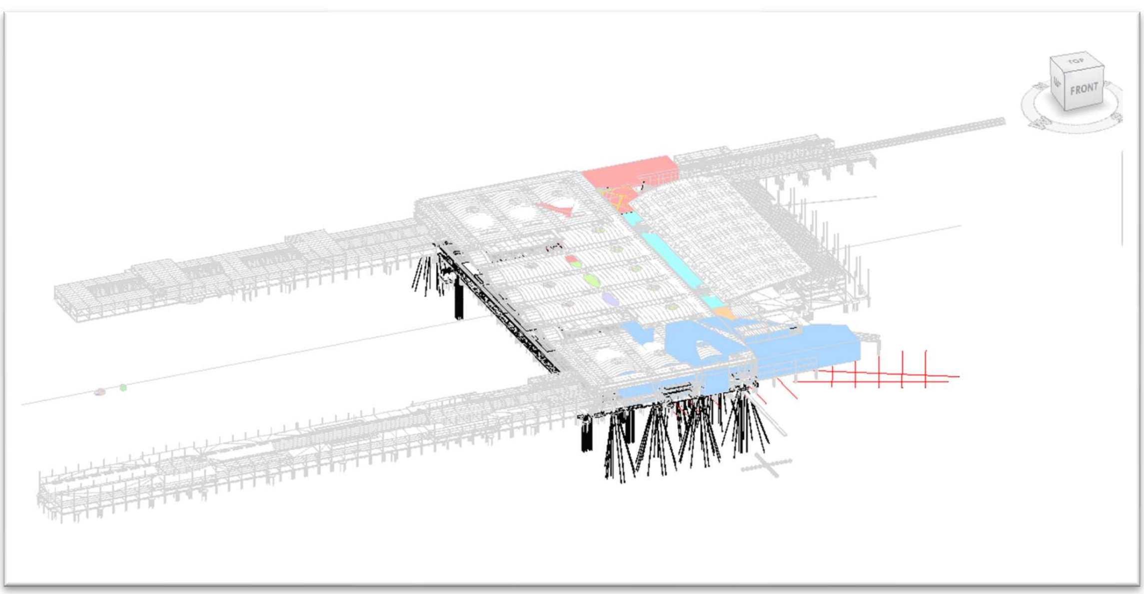

Fig. 0.3 showcases the BIM model for the Airport Project generated on Revit software

The current ongoing redevelopment project comprises five key construction projects which include a core terminal infrastructure redevelopment, Concourse E expansion, parking additions, and rental car facility, Concourse B redevelopment, and a quick turnaround facility. Concourse A was demolished due to aging infrastructure, and crowded hold rooms.

General Contractor (CM/GC) project delivery method allows an owner to engage a construction manager during the design process to provide constructability input. The Construction Manager is generally selected based on qualifications, past experience, or a best-value basis.

With Guaranteed Maximum Price contracts, the customer agrees to reimburse the contractor for materials, labor, and the contractor's fee that covers profit. The guaranteed maximum price is the highest amount customers would pay for the project.

The project, situated in the USA, and overseen by the government, is a substantial endeavor with a projected turnover of $950,000,000. Commencing in phases, with Phase 1 starting in 2023, and Phase 2 scheduled for 2025, the project spans an ongoing duration, reflecting its long-term significance. Led by a global design team, the project benefits from a diverse range of expertise, and perspectives to ensure comprehensive planning and execution. Contract execution took place in September 2022, signaling a firm commitment to project initiation, and progress. Notably, the project allocates an estimated BIM construction budget of approximately $0.85 million, underscoring the importance of utilizing Building Information Modeling (BIM) technology for efficient design coordination, and project management. Leveraging Revit as the primary BIM software, the project aims to optimize construction processes, enhance collaboration among stakeholders, and deliver a high-quality outcome that meets the needs of the community and aligns with governmental objectives.

4.2.4 University Compound Project

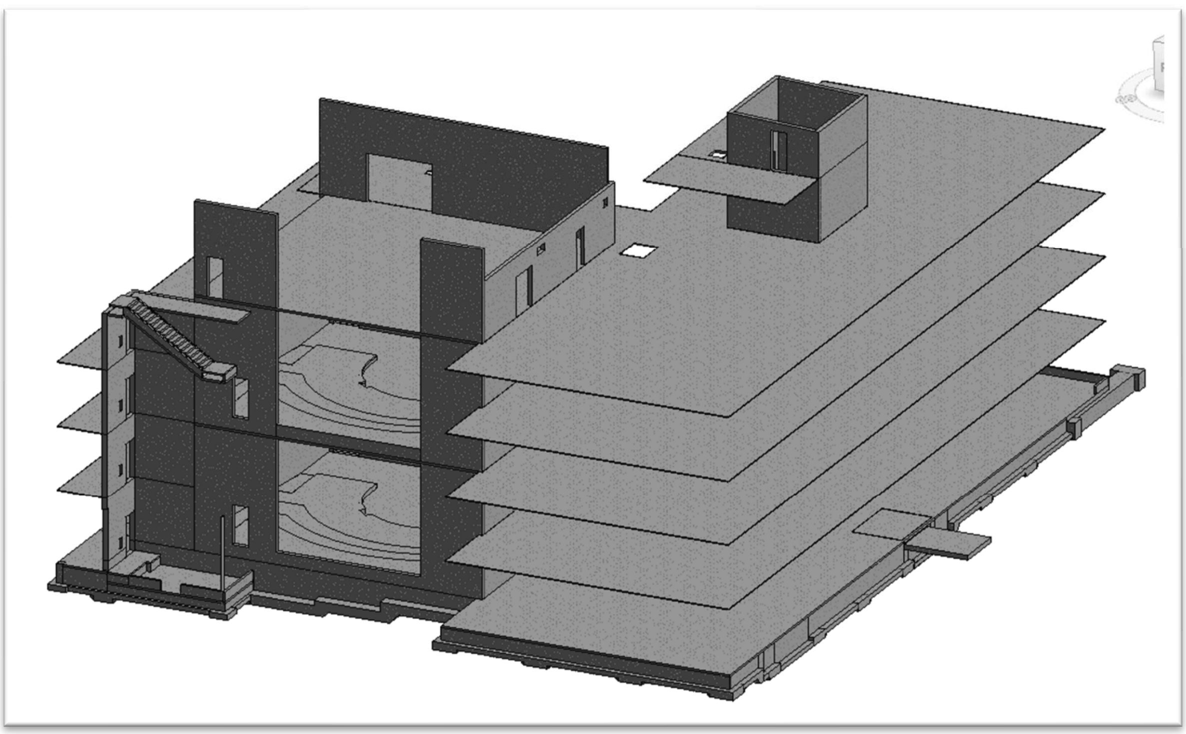

Fig. 0.4 showcases the BIM model for the University Project generated on Revit software

Integrated design-build team with the University, and renowned for expanding the Business school with an 85,500-square-foot building on the site of the existing Hall. The new building includes classrooms, program offices, research centers, career services offices, interaction spaces, event spaces, and amenity spaces to augment other Halls and support the School's vision, and goals.

The project continues the Business school's success in attracting the best faculty, students, and staff; creates space that is flexible, and adaptable to meet the evolving needs of the school, and celebrates, and enhances distinctive campus open space, and circulation patterns in this part of campus.

In 2022, a notable project was initiated with a contract type: Progressive Design-Build, a collaborative approach emphasizing innovation, and flexibility. Commissioned by a university client, the project aims for sustainable excellence, targeting LEED Gold certification to minimize environmental impact and promote resource efficiency. The architect brings local expertise, and a commitment to design excellence to the project. Leveraging Revit as the primary BIM software, the team embraces cutting-edge technology to enhance collaboration, streamline design processes, and ensure seamless project delivery. With sustainability, innovation, and collaboration at its core, this project represents a forward-looking endeavor poised to make a positive impact on the Seattle community, and beyond.

4.2.5 Bridge Project

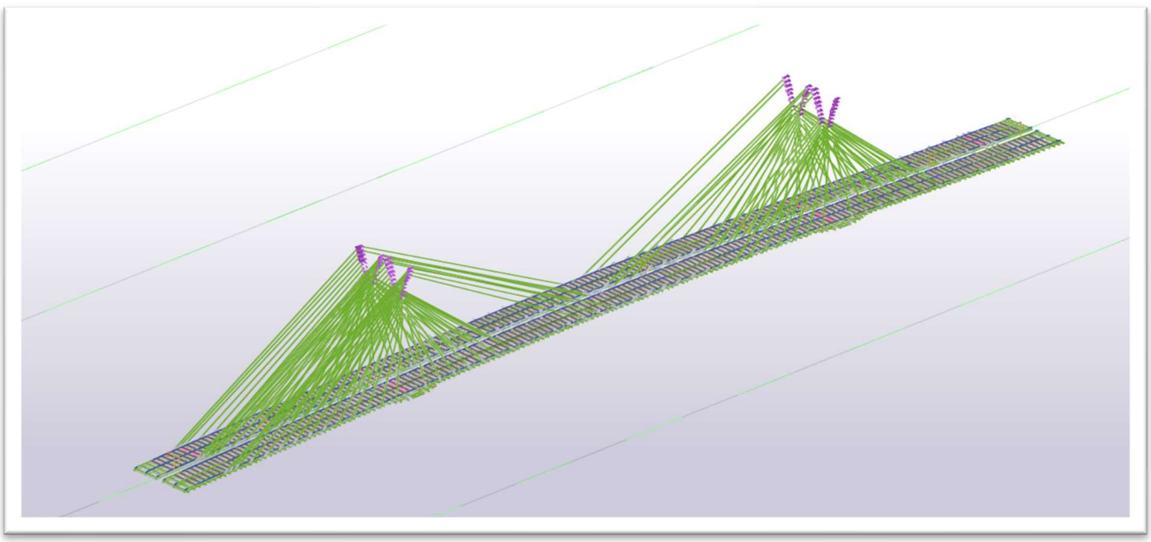

Fig. 0.5 showcases the BIM model generated for the Bridge Project on Tekla software

A monumental project is underway, overseen by the government, and boasting a turnover projected at an impressive $12.556 billion. Commencing on January 3, 2022, the project holds ongoing significance as it unfolds in phases. Guided by a global design team, the project leverages the expertise of professionals from around the world to ensure comprehensive planning and execution. Utilizing a suite of BIM software including Tekla, Revit, and MicroStation, the project embraces cutting-edge technology to enhance design coordination, visualization, and project management. The scope of BIM work encompasses critical elements such as foundations, piles, piers, pylons, steel girders, beams, cable rails, custom connections, and reinforcements. This comprehensive approach underscores the project's commitment to precision, efficiency, and quality, as it aims to deliver a transformative infrastructure solution for the Houston community, and beyond.

4.3 Defining the Parameters

4.3.1 Accuracy in Design (Accuracy)

In my observation, designing a construction project occurs in several segments. They can be generally categorized into concept, schematic, design development, and construction documents. In this whole process, a lot of the design progression is dependent on the accuracy of the design. The design accuracy is dependent on how the designers have considered all the parameters concerning the project. This mainly includes functional requirements, aesthetic considerations, structural integrity, building codes, and regulations. One thing that is common to all these major parameters is how well they visualize the ideas and replicate them into reality. This can be done with the help of BIM.

Now let me take you to our first project, which is an Esplanade Project. This pace of the project progression had an impact on the way the design was developed, and how the design could have been eased if there had been an early adoption of BIM. This project did not include BIM in its initial phase. The design developed in its initial schematic phase to a detailed design. This span extended to almost two years. Also, another point to note here is that the drawings were initially all done in AutoCAD after the finalization by the design team with the help of drafters. So, the final drawing set was a 2D set (which is what has been done for a very long time in the company).

The design was almost 80% when BIM review was introduced to this project. This was done since some of the BIM specialists had been working with other Project Managers in the same firm with a lot of success in drawing production.

As one of the interviewees said "*Initially it was very hard to convince the project team but essentially a significant enhancement was made to the project. This was in the form of an LOD 300 model where all the Architecture and Structural coordination was done in the initial phase, and then it was later built to a higher LOD (LOD 350). A complete constructability review was done for the project, and the biggest significance came in the form of how the design team could get the visual aesthetics and dynamics of critical areas of the project*"

There were a lot of interesting cases that evolved in the transition from AutoCAD to BIM, but I would like to highlight the important ones. Below are some of the issues that were resolved with the help of BIM in the project.

4.3.1.1 Precision in Fabrication

In my observation, and with my experience, I will provide an outline of the different phases of design in a construction project which will be later used to reference during presenting the case study. The initial phase of design entails understanding project requirements through comprehensive discussions with stakeholders, focusing on objectives, target audience, and specific features. Research is followed to gather ideas, and insights into design trends, industry standards, and user preferences, ensuring a balance between aesthetics, and functionality.

The ideation phase kicks off with sketching concepts, allowing designers to explore diverse ideas before progressing to detailed design work. Wireframing comes next, outlining the basic structure without delving into visual specifics. Prototyping follows, with low or high-fidelity models aiding in visualizing interactive elements, and identifying potential user experience issues.

Detailed design involves refining aspects like constructability, and value engineering based on stakeholder feedback, and usability testing. Development or implementation translates the design into a tangible entity, through multiple iterations in software design. Testing is crucial to ensure the design meets specified requirements, encompassing usability, and technical assessments.

The precision of these mentioned designs hinges on the thorough consideration of all project parameters, encompassing functional necessities, aesthetic elements, structural soundness, and adherence to building codes, and regulations. A common thread among these critical factors is the ability to effectively visualize concepts, and translate them into tangible outcomes. However, ensuring accuracy, and precision in translating design ideas into reality can be challenging, especially when dealing with complex projects, and multiple stakeholders. BIM serves as a valuable tool in achieving this goal, enabling designers to accurately depict ideas, and bring them to fruition. The are 200 pile foundations in this project, and the foundations or the pile group had a pile cap that connected them. Above these pile caps, there were pre-cast concrete decks that interjoined two or more pile caps. The below Fig. 1.1.1 shows a section cut of the configuration. This design was intended by the design team. Now these precast concrete decks were to be manufactured away from the site and then assembled which had a definite dimension associated to it as per the specification. Hence the dimensions had to be extremely precise. When this input schedule was reviewed, and the model was created, there was a discrepancy found in both. Originally the configuration should have looked like Fig. 1.1.1 but the precast U deck slab was taller than it actually should have been which has been shown in Fig.1.1.2 marked in blue. This prevented the upper deck slab from sitting on top of the U deck Slab.

A similar instance was discovered in another section as shown in Fig. 1.1.3, and Fig. 1.1.4, where the size of the Precast deck was much smaller than the actual size should have been. The drawings were already 80% design however it was found out that this happened due to the changes in the height of the elevator walls. It was a very small wall, and hence the designers and the drafting team could not capture this simultaneous change. However, when this was modeled in three-dimensional software, this was captured.

RFIs were created based on these findings, and through discussion, and further calculations, the BIM team received a response from the design team. The dimensions for the U-Slab were altered, and the schedule was revised in the next draft.

One of the interviewees who worked as a BIM coordinator in a global BIM company mentioned: “There are a lot of projects that I have been recently working on in the sector of pre-cast panels. This includes the construction of pre-cast panels, embeds, and their connections to steel elements. The work needs to be extremely precise in these projects, sometimes near to 1/32 of an inch.”

Findings: Under precision in fabrication, I have shown an example of how the pre-cast elements are required to be efficient in accuracy, consistency, and quality in the manufacturing process involved in producing these components.

If this issue that has been mentioned in section 1.1 was discovered in the field, it would have caused a lot of construction delays. The process would include sending the RFI from the construction team to the design team, and then back, and forth until the solution is determined. Even an easy solution would take a certain amount of day/time., and we know that time means money on the field. The construction team might hire a lot of equipment, and construction vehicles which costs money once the project schedule elongates. Construction is an overall process and every small process/change that we undergo impacts the big picture.

BIM can ensure that the precast elements are fabricated to meet the specified dimensions, tolerances, and design requirements with a high degree of accuracy. This includes precise molding, casting, and finishing techniques to achieve uniformity, and consistency across multiple elements. Precision in precast concrete elements is essential to ensure that they fit together seamlessly during assembly on-site, minimizing gaps, alignment issues, and structural deficiencies. It also contributes to the overall quality, durability, and performance of the finished structure.

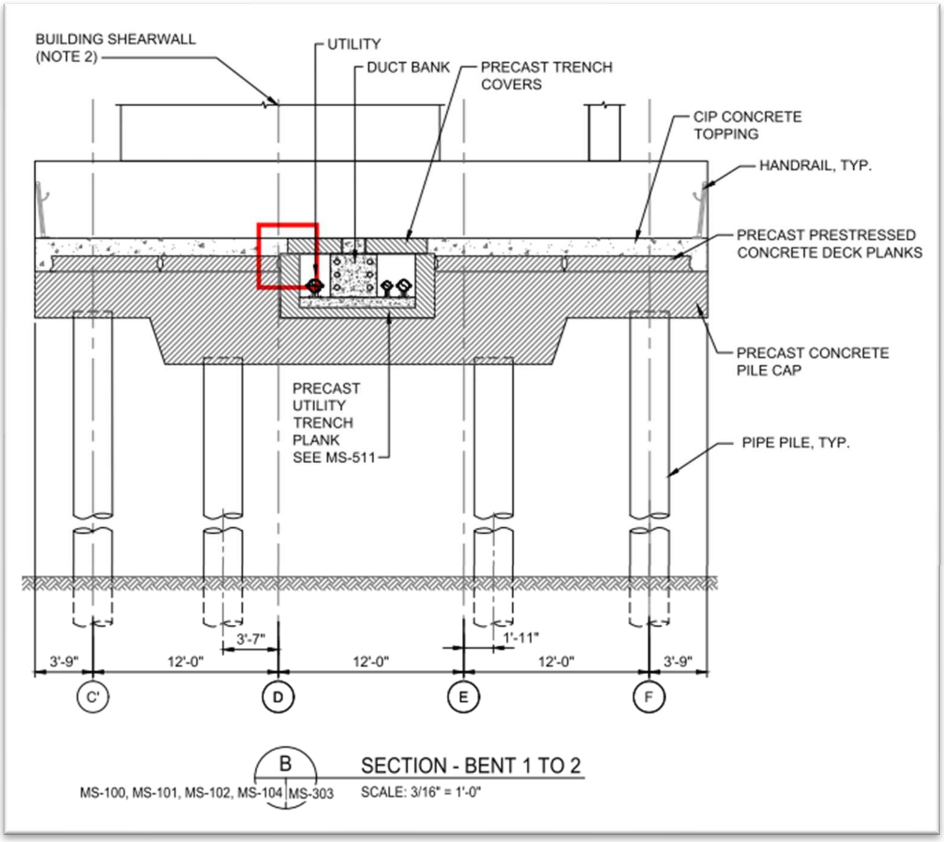

Fig.1.1.1 shows the precast pile cap, wall, and deck configuration

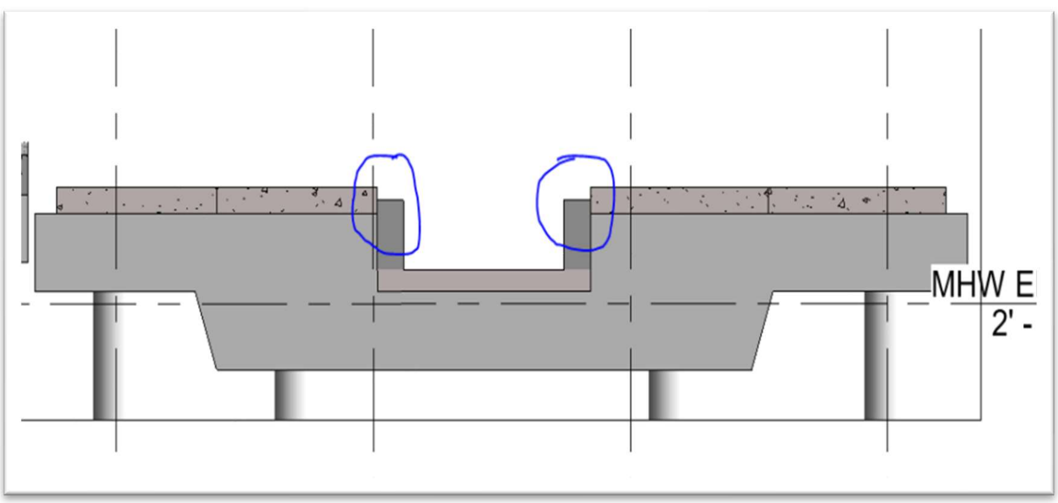

Fig.1.1.2 shows the mismatch in height of the precast walls

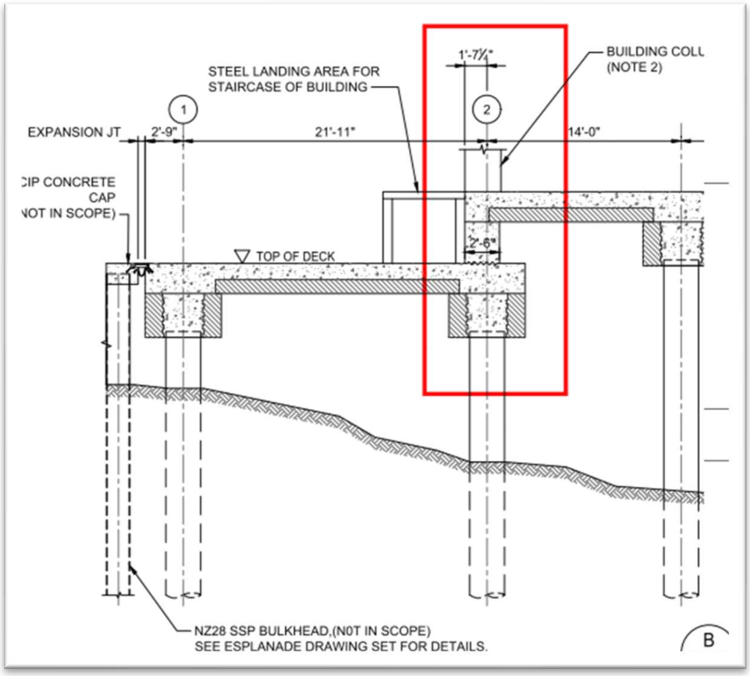

Fig.1.1.3 showcases the configuration of the precast deck intended by the designers

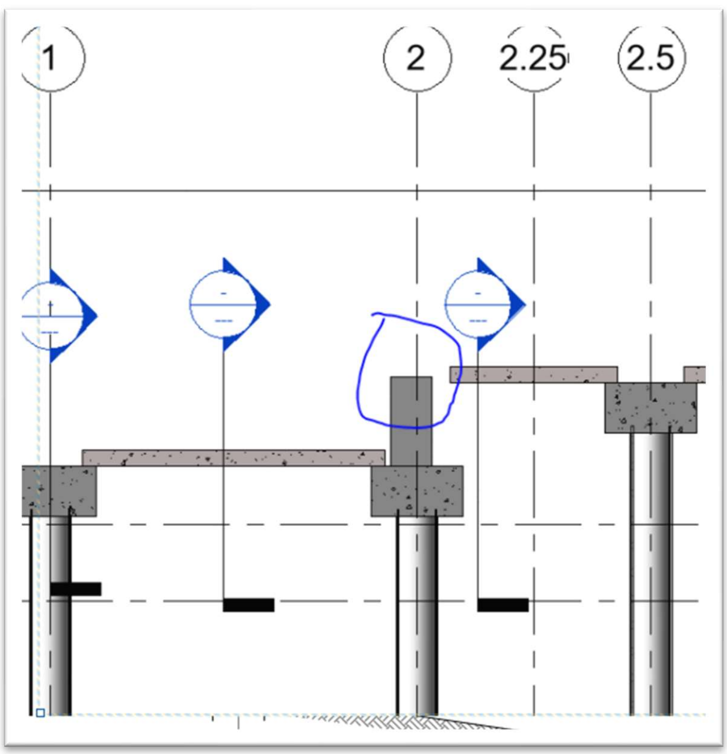

Fig.1.1.4 showcases the configuration of the precast deck in reality

4.3.1.2 Clarity in Construction

In my experience with BIM applications, construction professionals need to understand the extent to which a design can be successfully, and efficiently constructed in the real world. It involves evaluating the feasibility of implementing the design within the constraints of available resources, materials, labor, and construction techniques. A constructible design considers practical construction methods, sequencing, and logistics, minimizing potential conflicts, errors, and delays during the construction phase.

As one of the BIM Managers in the interview narrated, "*In BIM we need to understand the essence and ensure that the design can be built safely, cost-effectively, and within the specified timeframe while meeting the project's objectives, and quality standards.*"

Let us look at the case study example below which has been taken from the Esplanade project.

In the duct bank sump areas, the BIM team encountered a section [Fig. 1.2.1(Image also used in Fig.1.1.1)] that had been done by the design team in the two-dimensional drawing where the main slab on grade encroached on the duct bank on both sides. It was very vague how the slab was to be poured in the field. It seemed very unclear since there was an associated slope with both the adjacent slabs. However, the precast elements placed at the center of the duct bank were not on the slope. So, it was difficult to comprehend how the precast elements were to be placed in the field. The same situation has been shown in Fig. 1.2.2 where the precast slab sitting on the two walls that run throughout the span of the slab has a higher elevation than the two slabs on either side.

Initially, it was the notion that the dimension of the precast deck slab was not correct. However, on further investigation, it was found that the height of the duct walls that ran on either side of the trench needed to be in slope. This is due to the slab below it being in a constant elevation(slope). The duct bank carried several utilities, and hence it was necessary to include this slope in the slab.

To mitigate this problem, the walls were adjusted to match the exact slope of the slab, and a fine strip of concrete was added for the difference in elevation to match the constant slope on either side. Fig.1.2.3 represents how this was achieved by the team. This has been shown in this reference after the final changes were made in the model.

<u>Findings:</u> I have shown in the example how a simple design in the duct bank area had multiple constraints associated with it. Since initially this project was done in AutoCAD, it was hard for the design team to connect with all the dots associated with the duct bank. The project was running for two years, and the section in Fig. 1.2.1 was initially finalized. However, some associated changes occurred in the vicinity area concerning the slope of the adjacent slabs. However, AutoCAD is not a parametric software, these changes had not been captured. When the BIM team was introduced to the project this issue was highlighted, and the resolution as described in the section was provided.

This is an example of how BIM can lead to better design outcomes. Design iterations, while vital for refining, and enhancing project outcomes, can inadvertently contribute to construction delays if not managed meticulously. Each iteration cycle introduces adjustments, and improvements to the initial design concept, aiming to align with evolving project requirements and stakeholder feedback. However, these iterative processes often extend the design phase, delaying the finalization of construction drawings, and specifications.

Leveraging collaborative tools such as Building Information Modeling (BIM) can streamline design coordination, and enhance efficiency, ultimately minimizing the adverse impact of design iteration on construction schedules.

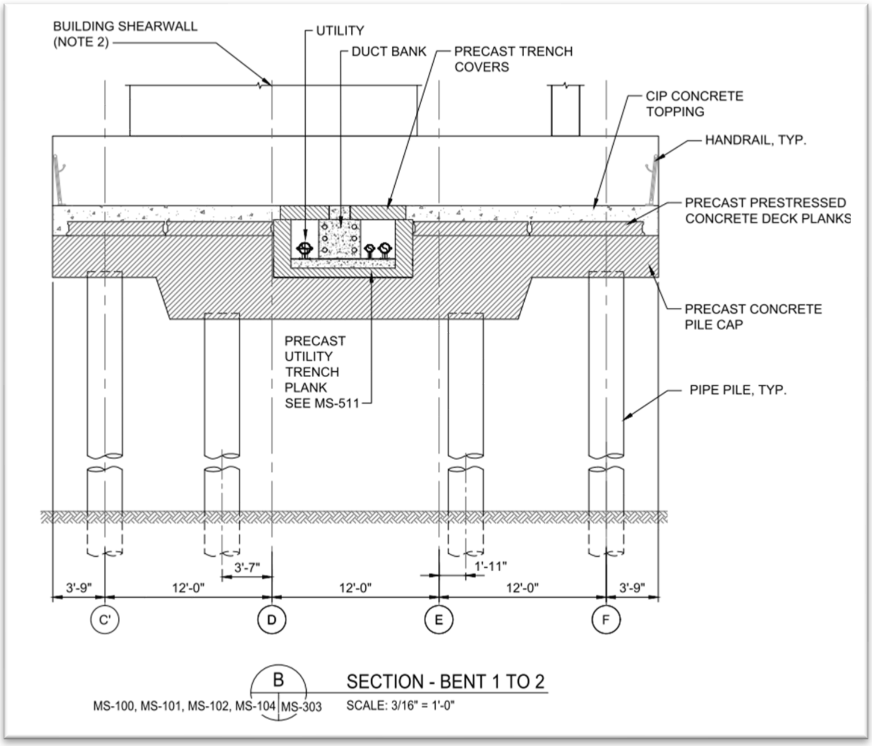

Fig.1.2.1 shows the configuration of the duct bank underneath the slab

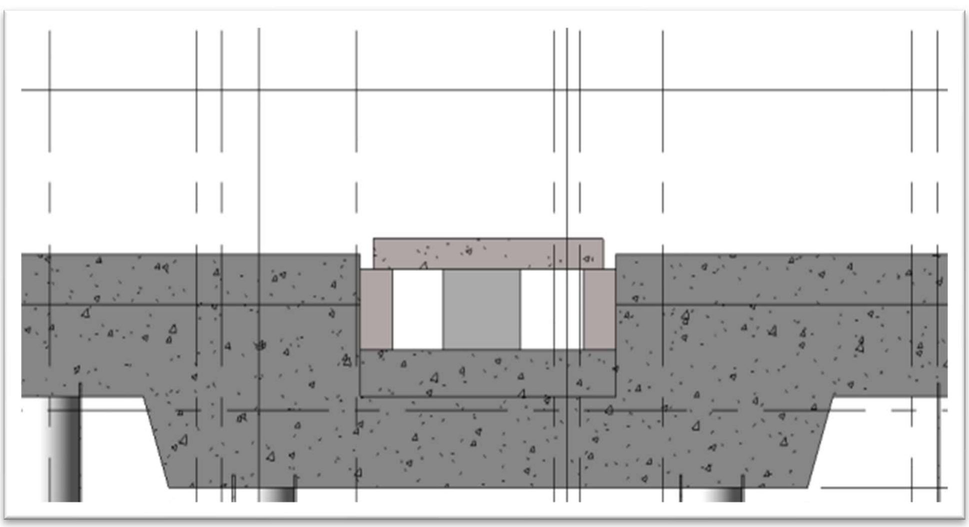

Fig.1.2.2 shows a precast slab sitting on the two walls that have a higher elevation than the two slabs on either side

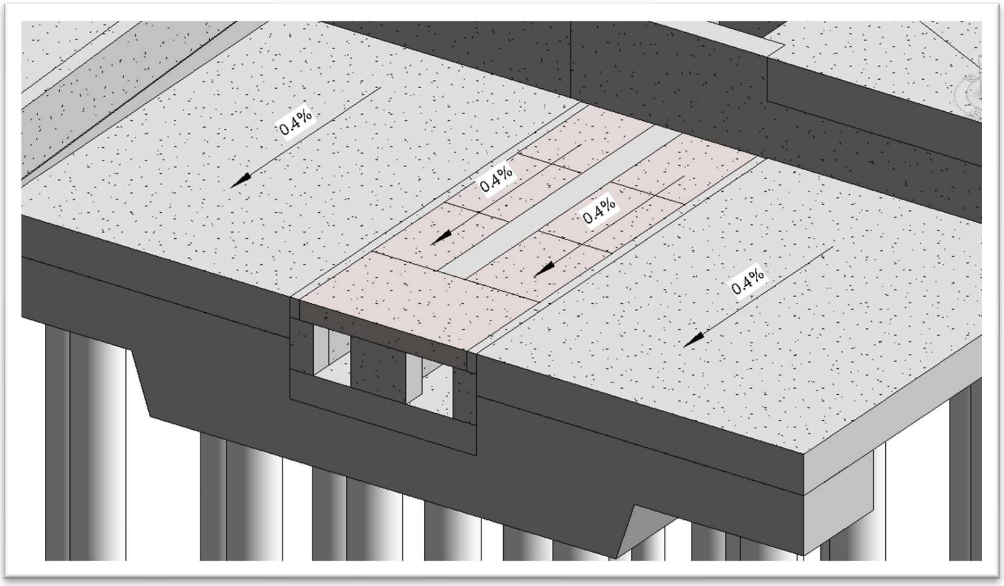

Fig.1.2.3 shows the final configuration of the duct bank achieved by the BIM team

4.3.1.3 Calculating exact quantities during design

One of the BIM Managers working for a concrete specialty contractor said “When we talk about quantities, this process in our construction industry starts after the design has been done, and the general contractor starts the construction bidding process, and the actual construction. It would be great to see the design team focus on this aspect as well. This would expedite the whole construction process.”

Case 1: The scope of the BIM was very limited concerning the budget of the project, and hence a constructability review was done based on LOD 350. There were not a lot of issues but some of the issues discovered had some serious implications on the site.

As I have talked about previously the Esplanade project had several precast elements. In Fig. 1.31 we can see a schedule that represents an underside slab, and a wall. The model had been developed as per this schedule but when all other elements were placed, and coordinated, there was a small gap of 4 ¾” that was discovered as shown in fig.1.32 where a plan of the location is shown. In fig.1.33 the actual representation of the gap can be seen. This is important to catch this sort of issue in the design stage as in a lot of situations when it is discovered in the field, it halts the construction. Moreover, the quantities calculation is altered. This is a major cause of schedule changes since the construction cannot go on until a response has been issued by the design team. In the field a delay in construction results in increased cost for construction.

This was coordinated and fixed at a later stage of the project.

PRECAST DECK PANEL SCHEDULE							
PANEL TYPE DESIGNATION	TOTAL	A	B	No. of Strands	Pjack (kips)	Pi (kips)	Peff (kips)
T1	175	312"	96"	17	561.8	526.7	421.4
T2	40	312"	132"	23	760.1	712.6	570.1
T3	12	252"	96"	17	561.8	526.7	421.4
T4	2	252"	132"	23	760.1	712.6	570.1
T5	2	217"	89.5"	16	528.8	495.7	396.6
T6	2	217"	99.5"	18	594.9	557.7	446.1
T7	6	312"	97"	17	561.8	526.7	421.4
T8	4	312"	103.5"	18	594.9	557.7	446.1
T9	4	217"	102.5"	18	594.9	557.7	446.1
T10	12	312"	102.5"	18	594.9	557.7	446.1
T11	1	120"	55"	10	330.5	309.8	247.9
T12	2	120"	99.5"	18	594.9	555.7	446.1
T13	2	144"	103.5"	18	594.9	557.7	446.1
T14	3	144"	97"	17	561.8	526.7	421.4
T15	1	52.5"	124"	22	727.1	681.6	545.3
T16	1	30"	120"	21	694.0	650.6	520.5
UT-1 (SEE NOTE 9)	1	215"	120"	21	694.0	650.6	520.5
UT-2	1	45"	120"	21	694.0	650.6	520.5

Fig.1.3.1 is a schedule for the precast deck panel

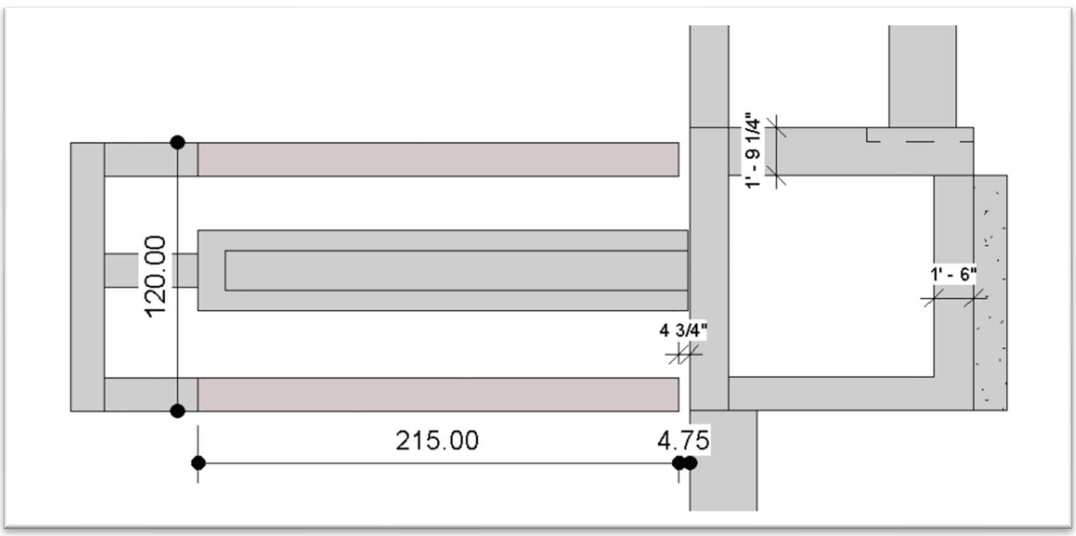

Fig.1.3.2 shows the 4 ¾" gap in plan

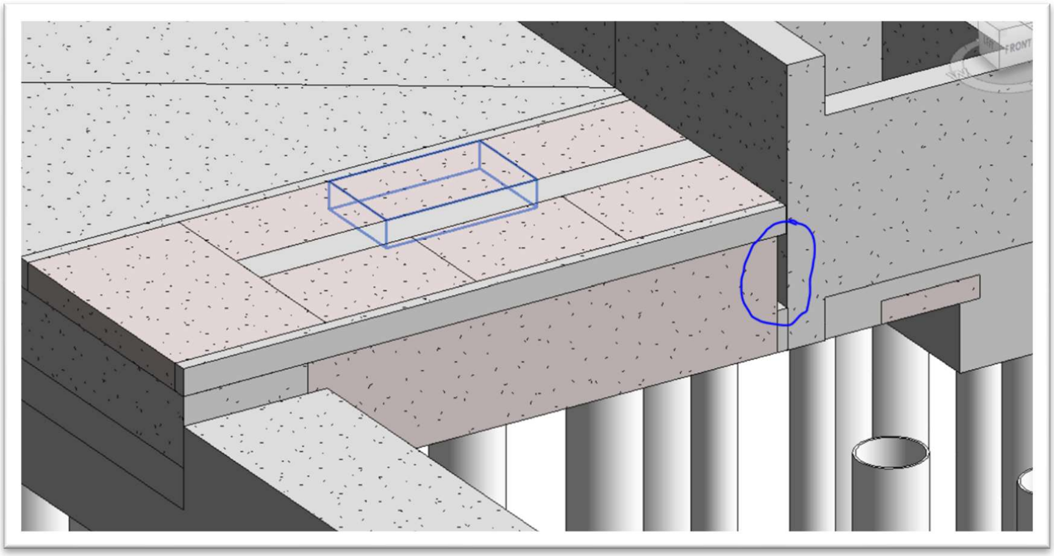

Fig.1.3.3 shows the 4 ¾” gap in three dimension

Case 2: In the second case, it was very it was evaluated by the BIM team that the slab on grade was not necessary to be placed everywhere above the pile caps. We see the different plans from Fig. 1.3.4, and Fig. 1.3.5. The first one represents the elevations of the top of the decks, and the second represents the precast deck plan. It was impossible to locate the slab extents and requirements that were being defined in the structural drawings. It seemed that the slab extended from section B as shown in Fig. 1.3.6, and also in Fig. 1.35 where the location of the section cut can be seen in the plan. The initial BIM model had the slab as shown in Fig. 1.3.7.

However, after the constructability review, it was analyzed that that slab didn't have to exist in the highlighted location in red, and hence it was later removed. This can be seen in Fig. 1.3.8.

The design manager on the Parking project quotes by saying “*It has been very informative on how BIM has helped the team to isolate and bring to notice anything related to design discrepancies. This has helped the whole team to prioritize work and make better design decisions*.”

From these three examples we can see that in numerous small ways, BIM workflow has helped the whole construction project to be better in terms of efficiency, and cost savings in quantities. It is very difficult, and unsafe to make instant decisions in the field by the Construction team on how to resolve issues as shown in Fig. 1.3.3.

Findings: Cases 1 and 2 both showcase the potential to halt construction if the issue was found on-site, leading to altered quantity calculations and schedule changes. Such delays result in increased construction costs. This issue was identified and resolved later in the project, highlighting the importance of addressing design discrepancies early to avoid costly on-site delays.

In the first case, we discovered that there was a small opening that had been discovered in the whole configuration after putting together the elements as per the dimensions. In the second case, it has been shown how the BIM team reviewed and helped the team save a lot of time, and money in cutting down the total volume of concrete poured that goes beyond the traditional quantity takeoff that can be taken out from the BIM model. This is a result of constant review of the BIM model as per the drawings, and this enabled the team to identify, and re-configure the location in the plan drawings. This was an extremely good time and money savior, and the design team appreciated the fact that the BIM team came across this at an early stage. The overall width and dimension of the quantity saved are 6’-3”, and 5’-7”. The depth of the slab was 2’- 0 ¾”. This equals to total volume of 864 cubic feet. If we consider the cost of pouring foundation as $15 per square foot (data taken from RS Means for an average cost for all US locations) for a foundation slab. This results in a total savings of $524 (Fig.1.3.9).

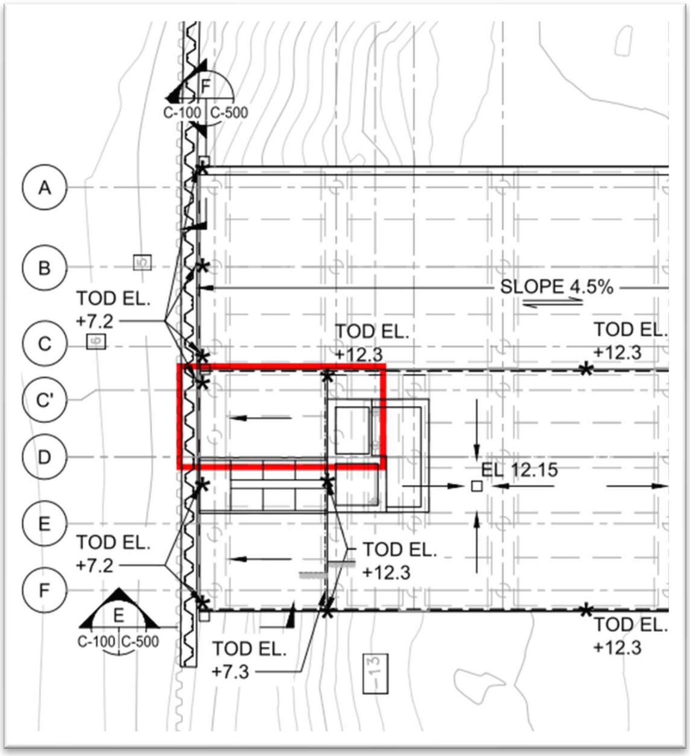

Fig.1.3.4 shows the plan of the layout of the slab mentioned in the section 4.3.1.3

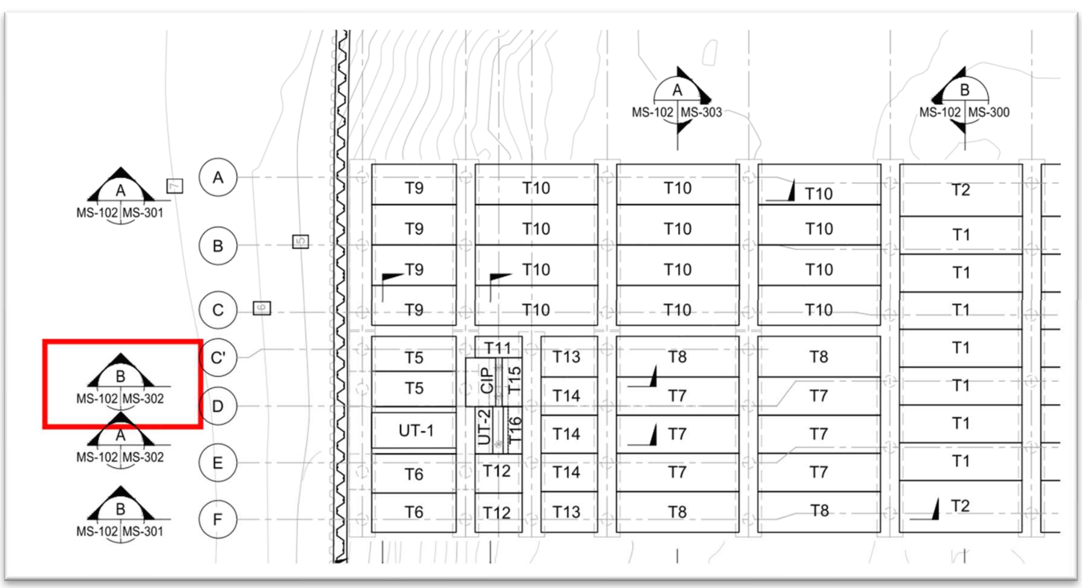

Fig.1.3.5 shows the plan for the layout of precast decks

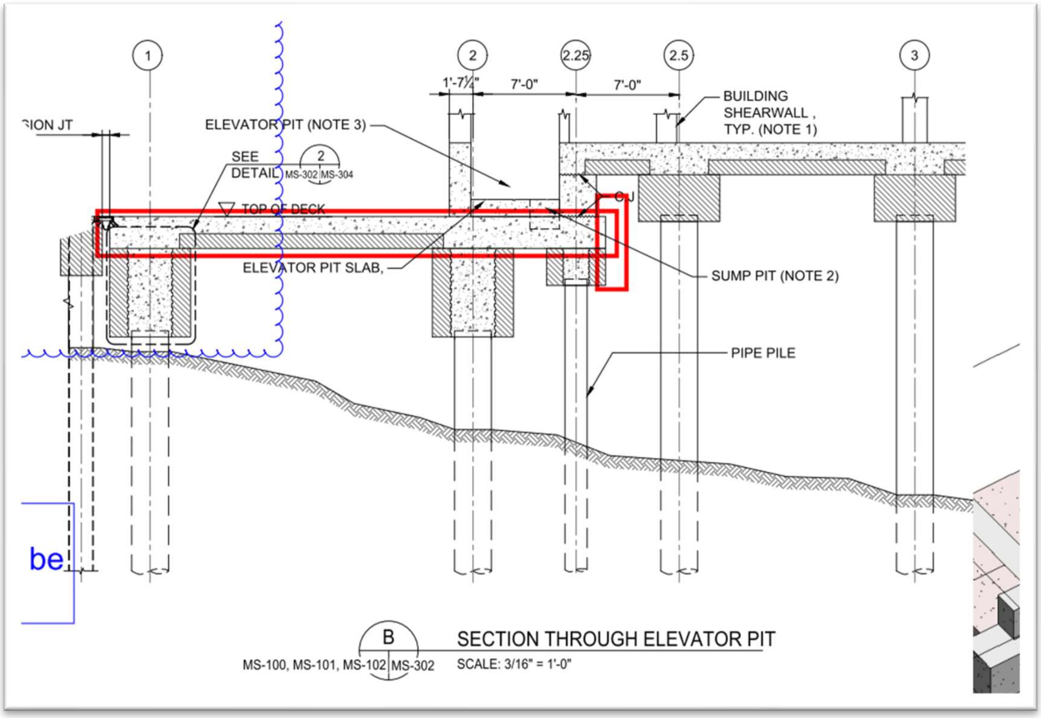

Fig.1.3.6 shows the overall layout of the slab in the section

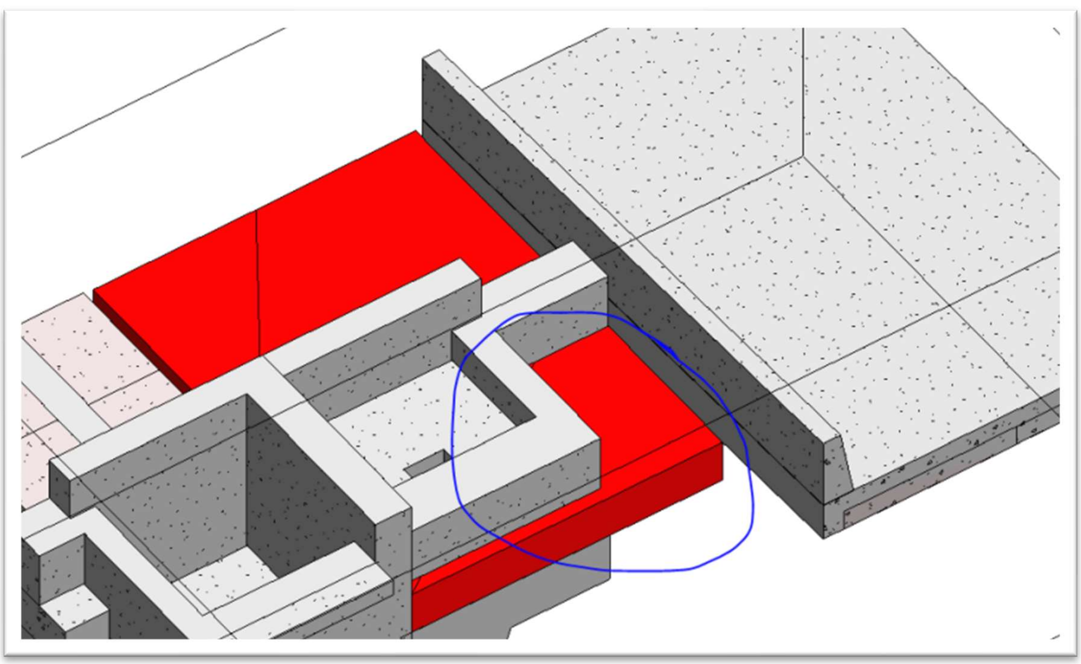

Fig.1.3.7 shows the area which is of no structural use

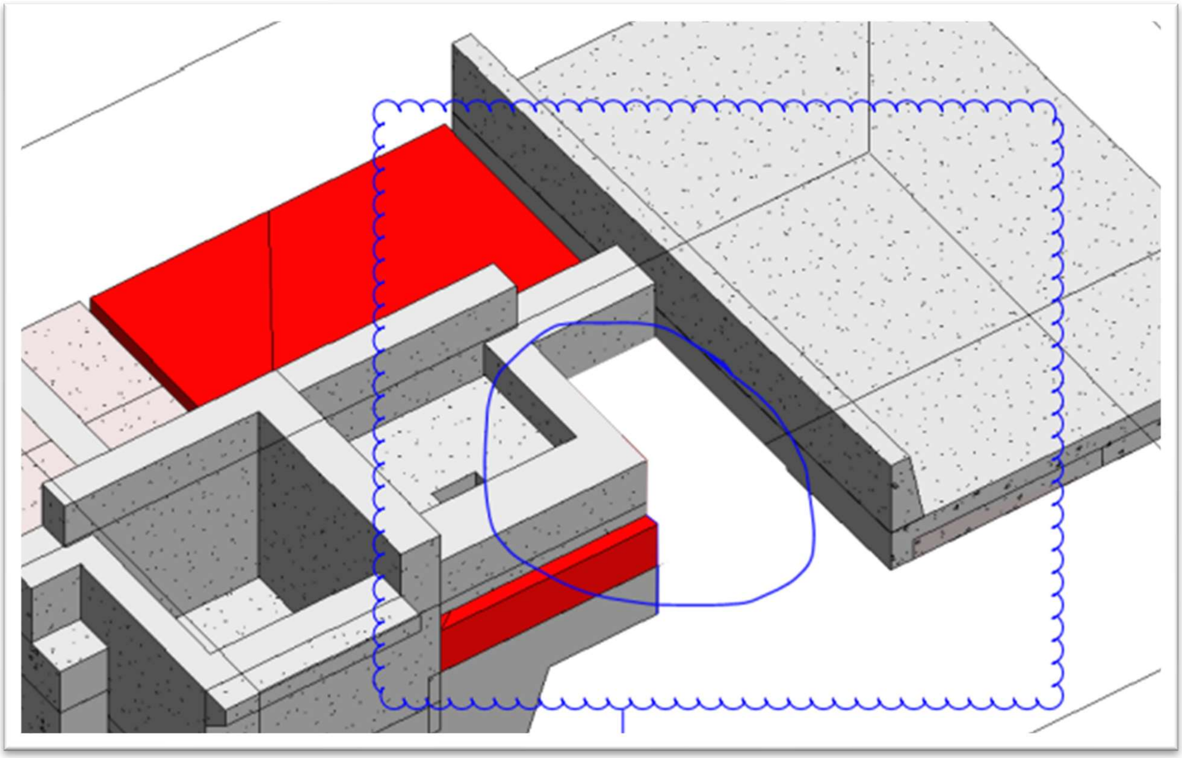

Fig.1.3.8 shows the final reconfiguration after the suggestion made by the BIM team

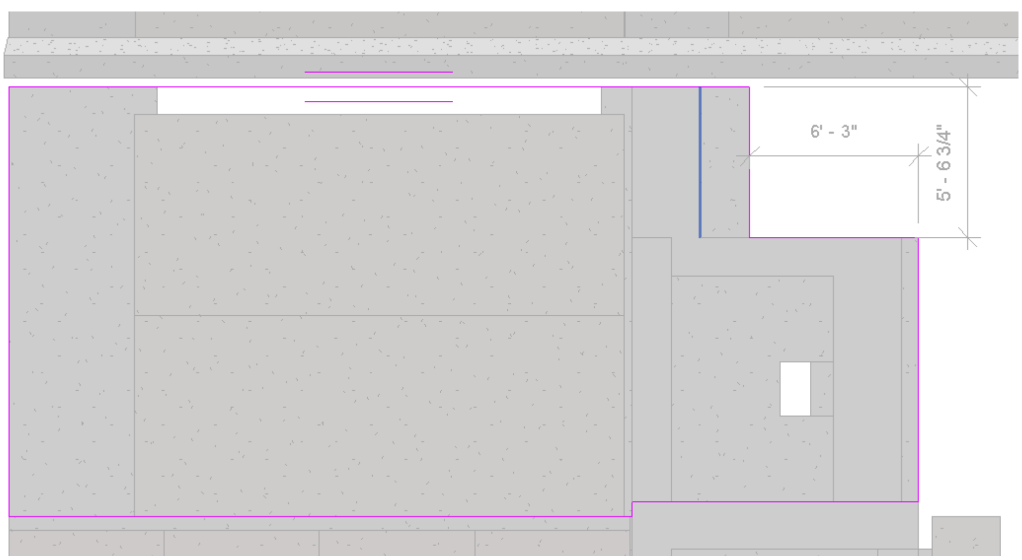

Fig.1.3.9 showcasing the dimensions of the area saved in concrete pour

4.3.2 Managing the Construction Process (Efficiency)

In my experience, project Collaboration facilitates real-time collaboration among project stakeholders, allowing architects, engineers, contractors, and owners to communicate effectively through markups, comments, and issue-tracking tools. Design Collaboration supports collaboration among project teams working on Building Information Modeling (BIM) projects, enabling multiple teams to work concurrently on a single BIM model to ensure coordination, and avoid clashes between disciplines.

The senior Project manager mentions that "*Field Management streamlines construction workflows in the field with tools for quality control, safety management, and progress tracking. It enables field teams to conduct inspections, create punch lists, and generate reports from mobile devices. Cost Management tracks project costs, budgets, and change orders in real time, providing insights into project finances, forecasts, and cash flow to help project managers make informed decisions, and mitigate risks. These are extremely essential in the whole construction workflow.*"

My interviews were focused on one of the BIM Managers who worked for specialty concrete contractors that typically used several BIM processes that made the construction workflow effortless. This would include creating shop drawings from all the coordinated drawings such as structural, architectural, civil, and site, and to a lot of extent MEPF drawings. This not only coordinated with the BIM team but also the construction, and the design team were included in the workflow to ensure all trades were included in the overall workflow.

Below are the things that the BIM manager used to work with:

a. OneNote - This is a product of Microsoft, and the company uses it as a book to maintain all the RFIs.
b. OneDrive – This is a cloud storage from Microsoft where the company stores all the logs to run a project smoothly. They usually put a two-week lookahead plan along with tracking logs, and some information about the previously completed projects.
c. Tracking log- This is an online log stored in OneDrive to have a look into the whole deliveries of shop drawings. This is a log to be handled, and maintained by the company itself, and they have given view-only access to the BIM team. The BIM team can have an idea about the construction dates, 1st draft submission dates, comment receives dates, and revised submission dates from this log.
d. Daily Status log - This is an online log that the BIM team maintains for submissions in the upcoming two weeks by maintaining some fixed color-coding conventions. The GC also investigates it and gives the BIM team their directives.
e. SOV (Schedule of Values) log - It is also a log stored in OneDrive to maintain invoices and change orders. This log is broken into multiple rows of parameters/levels which is the same for the subcontractor, and this is done at the time of estimation. At the end of each month, the BIM team puts the invoice amount for each level/task into a designated column, and the cumulative invoice can be automatically generated for the month. Also, an approximation budget and the expenditure can be gained from this log about the remaining, and total consumed invoices at any point in time.

4.3.2.1 Usage of PROCORE for all communication:

All the above-mentioned front-end software was taken out, of the process after the introduction of Procore. Procore combined all these parameters into one single platform, and hence it was made very easy for all stakeholders to participate, be aware, and communicate all activities in the whole construction project.

This is a global platform that connects all stakeholders. There are four main functional categories that Procore has divided the software into. This includes preconstruction, project management, resource management, and financial management. The data is stored in Maps views, financial summary, health, and risks for each job. These include Bidding, Budget, Change Orders, RFIs, Submittals, Drawings, Meetings, Reports, Drawings, Punch lists.

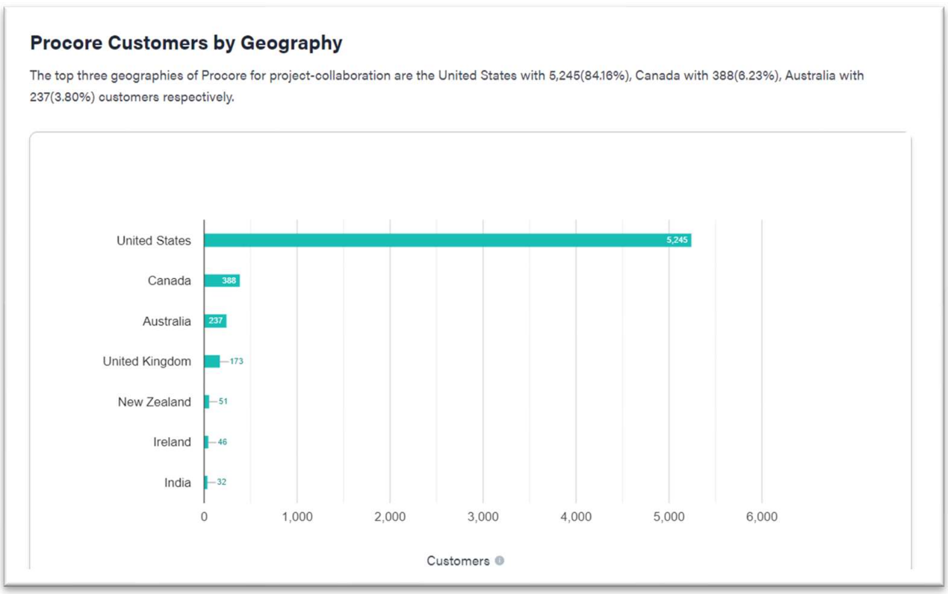

Fig 2.0 shows the extent of usage of Procore software in the United States
[6sense. (n.d.). *ProCore - Market share, competitor insights in project collaboration*. https://6sense.com/tech/project-collaboration/procore-market-share]

4.3.2.2 Server in Bluebeam

In addition to Procore other software are generally used. One of them is Bluebeam. It is a software company specializing in digital construction, and collaboration solutions for the architecture, engineering, and construction (AEC) industry. Their flagship product, Bluebeam Revu, is tailored for construction professionals, offering powerful features like PDF creation, editing, markup, and collaboration. With Bluebeam Revu, users can create, and edit PDF documents from various file formats, collaborate in real-time with markup tools, and manage documents efficiently with document organization, and indexing features. The software also includes tools for quantity takeoff, integrates seamlessly with other construction software platforms, and is compatible with desktop, and mobile devices. Bluebeam Revu's customization options allow users to tailor the software to their specific needs, making it an indispensable tool for professionals involved in construction projects of all sizes, and complexities.

This is a standard practice where all PDFs by any construction team is opened using Bluebeam, and while conducting my interviews, almost all the interviewers had been using this software.

4.3.2.3 Usage of BIM 360

BIM 360, developed by Autodesk, is a cloud-based platform designed to streamline construction project management, collaboration, and document management throughout the construction project lifecycle. It offers various modules and features tailored to different aspects of the construction process, enhancing efficiency, reducing errors, and improving project outcomes. The Document Management module centralizes project documentation, including drawings, models, specifications, and other project documents. It ensures version control, access controls, and document linking to provide team members with up-to-date information.

Several of the projects that had Revit as their basic platform used BIM 360 for collaboration. However, the projects that included Procore, did not include BIM 360 for communication.

4.3.2.4 Standard Book

The BIM manager said "*Although the team had been a BEP (BIM Execution plan), and a TIDP (Task Information Delivery Plan) the team has created a book that defines all the typical standards for drafting, and executing the model.*"

This would typically include detailing standards for annotation items such as gridlines, dimension style, section head/tails, level heads, text style, and size, revision cloud color, drawing, and sheet naming conventions, north arrow, sheet order, color legend, abbreviations, view scales, title block style, and the list goes on.

Different drawings such as plans, sections, elevations, and details have specific instructions, and the same standard is followed for all projects.

Below we can see the details in a tabular form (table 1.4) of how each of the projects compare to each other. We have learned from section 2 about managing the construction process, how things have evolved in terms of managing the overall BIM process. The project chosen in this case is the Airport project. This is because the Airport Project is the biggest in terms of the estimated cost. It had the biggest BIM scope which included BIM modeling to a LOD 350 spanning over 400,000 square feet, creating more than five thousand shop drawings coordinated with structural, architectural, civil, and site, and to a lot of extent MEPF drawings.

The shop drawings created were being used by the craftworkers in the field. The BIM Manager defines why these drawings are so important to have a consistent standard and are also required to be as simple as possible.

She explained: "*Craftworkers in the field are pivotal to the success, and profitability of construction projects. Detailed drawings play a crucial role in empowering these craftworkers by providing them with essential information upfront, minimizing downtime spent on research or seeking clarification. Clear instructions and specifications in detailed drawings help reduce errors, and rework, ensuring precise execution of tasks, and preserving project profits.*"

"*Moreover, detailed drawings optimize efficiency by eliminating guesswork, and streamlining construction processes. Craftworkers can plan their work effectively, sequence tasks efficiently, and coordinate with other trades seamlessly, ultimately enhancing project productivity and profitability.*"

In my observation, these drawings serve as a common reference point for all project stakeholders, facilitating clear communication, and collaboration among field teams, subcontractors, project managers, and designers. This alignment of information minimizes misunderstandings, and conflicts, thus safeguarding project timelines and profitability.

Furthermore, equipped with detailed drawings, craftworkers have the autonomy to make informed decisions and solve problems autonomously in the field. This empowerment not only boosts their confidence, and job satisfaction but also accelerates decision-making processes, ensuring that the project stays on track, and within budget.

Also, the standards are transferred from one project to another, and this minimizes creating the BIM standards every time a project is initiated cutting down a lot of initial setup time. There are several global BIM companies, and GCs that use several different BIM software for managing the process of construction. This differs in several ways. Global BIM companies have a wide spectrum of clients. This ranges from clients, general contractors, and sub-contractors such as specializing in mechanical (heating, and ventilation), electrical, plumbing, and fire protection.

Findings:

Hence, we can see how important it is to have a standard workflow to execute larger BIM projects.

The BIM team initially had a process, but they have always been evolving, and looking into strategies to streamline their workflow. Although the team already had been working with BEP and TIDP, the BIM manager couldn't include every small detail in these documents. However, they did this with the help of a standard booklet. They also had several smaller tools to execute the BIM communication with the field such as one note, OneDrive, tracking log, Daily Status log, and SOV to manage.

However, Procore, and BIM 360, created a seamless working, and execution process for all the BIM work in the project. We also see the overall project was being managed in Procore by the Project Managers, design team, and the owner to track all the project-related documents including finance, schedule, and estimates. Linking everything together in the same platform helped all stakeholders to be aware of every small thing happening on the project.

Thus, any BIM team before starting their work should have standard protocols., and this process should be consistent with the whole team. This can be in the form of any software or platform where all stakeholders can interact, and there is a transparent flow of data.

4.3.3 Process of Implementation of Design (Quality)

BIM has different segments where it can be implemented. A global BIM company has a different client base, and this includes owners, sub-contractors, architects, and engineers. When the BIM team works for a sub-contractor it deals with a 2D drawing set that has already navigated through the bigger part of the design phase. In such a case there is not much scope where the BIM team can provide their input in terms of design or value addition. But when a BIM team works for a design team creating the actual design set from the raw design files and ideas, there is a lot of scopes where design implementation can take place. Below are some of the examples from real-life projects where this was done by the BIM team.

4.3.3.1 Seismic Retrofit

Description: Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, and failure due to earthquakes.
Seismic retrofitting involves assessing existing structures for vulnerabilities, conducting risk analyses, and developing tailored strategies to strengthen key components. This includes reinforcing structural elements like columns, and beams, upgrading foundations, and retrofitting non-structural systems such as mechanical, and electrical components. Compliance with building codes is crucial throughout the process, ensuring safety, and resilience. Construction and monitoring ensure the effective implementation of retrofitting measures. Overall, seismic retrofitting is essential for reducing the risk of damage or collapse during earthquakes, thereby safeguarding lives, and property.

The same concept is implemented in one of the projects. It was a new scope that the BIM team encountered during the ongoing phase of the project. This was an additional scope that was included in the BIM contract. The design team also needed a lot of input from the field to provide a good amount of input.

Before starting the work, the BIM team was provided with input highlighting the areas where the work was to be done in the pour break drawings with no other details, and no explanation of how the job was to be performed. A rough estimate was put forward as a bid and was accepted by the design team. Below we can see the diagram of how the information was received by the team in Fig. 3.1.1. The details include a color-coded representation of the type of retrofitting in the beams.

The BIM team compared the latest input drawing with that of 1952's drawing document (as shown in Fig. 3.1.2) which consisted of the design parameters. When the current design was done the design team did not take into consideration all the previous old drawings since this was not in their scope of work. However, after this scope was added by the client, the design team along with the BIM team started comparing these documents as shown in Fig. 3.1.2. The team found several mismatches between the two drawings. There were just no details provided in the drawings but slowly the BIM team started creating RFIs, and with the help of the responses, drawings were developed by the design team. While reviewing the drawing, the BIM team encountered several doubts like how they would model the details, the diameter of diagonal bars, and its representation.

Several field engineers verified the details, and all the RFIs were resolved after several inspections of the site comparing the old design documents, and the current location as what could be seen. After receiving the confirmation from all corresponding stakeholders involved & answers from RFI, the team proceeded with the scope. The first draft was completed after this and submitted for design review for construction.

After submitting the sample shop- drawing, the BIM team received several markups as shown in Fig 3.1.3. Even the input provided to the BIM team had gone through many design changes due to this. Several new plates and rebars were introduced at the perimeter areas. Accordingly, the team has modified their shop-drawing and submitted the next revision. After several drafts, the final issued construction drawings were stamped. The team received the rebar calculation in Excel to cross-check with what was initially provided., and eventually, the outcome from this is attached below in Fig. 3.1.4.

Findings: We have seen through the case study how the design team developed a new scope with the help of BIM. The BIM was initially contracted for concrete contractor construction. However, the design team collaborated with the BIM team, and they found value in working with them. The Airport BIM team already had a model for the airport project where they had been working on several different segments of the building which included the creation of the model, and the shop drawings. Hence, it gave a platform for the design team to build their design on the new scope that was included. The combination of effectively coordinating with the field engineers, and the Airport BIM team helped initiate the development of the seismic retrofits.

The BIM team also fruitfully coordinated the layout of the old 1952 drawings and included the real picture in the field. This helped build the design from a 2D coordinated set which was derived from the federated model. Several different issues were addressed instantly during this phase since the actual general contractors were also involved.

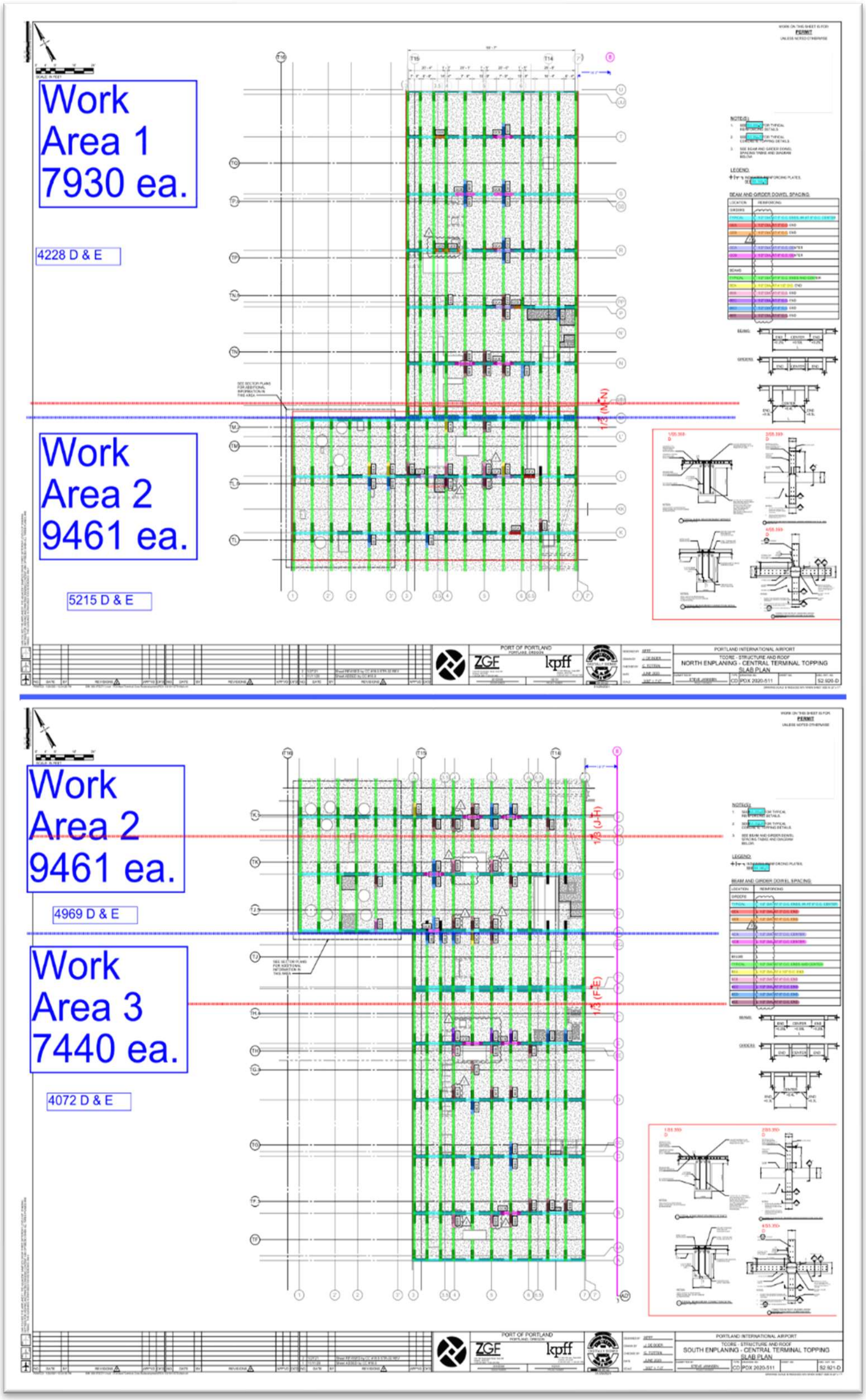

Fig. 3.1.1 shows the layout of the information received by the BIM team for the seismic retrofit

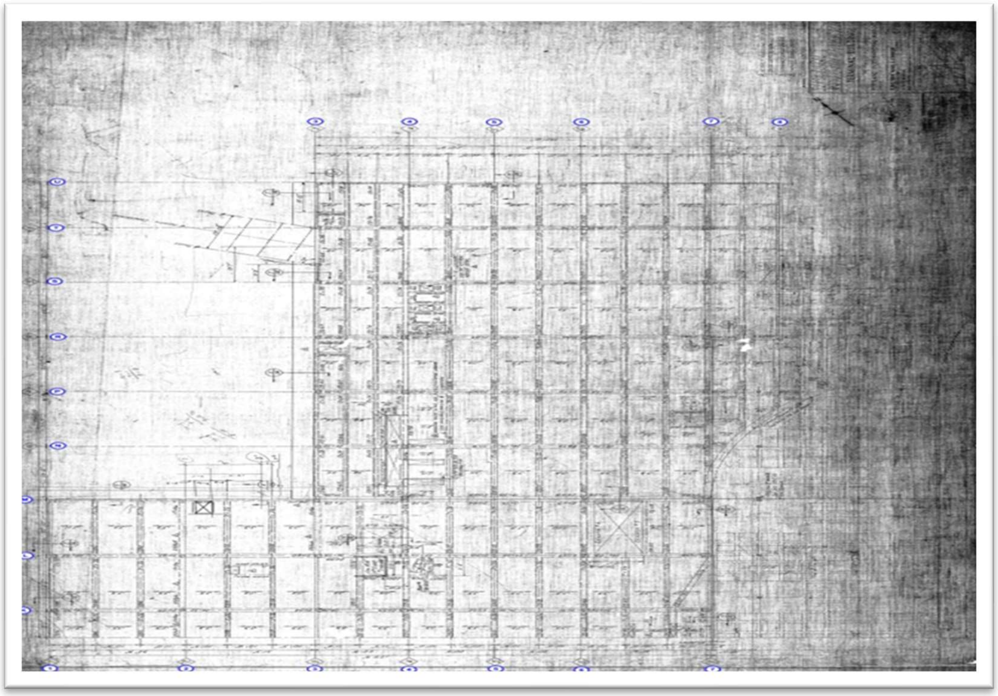

Fig. 3.1.2 shows the plan layout of the old drawings for seismic retrofits

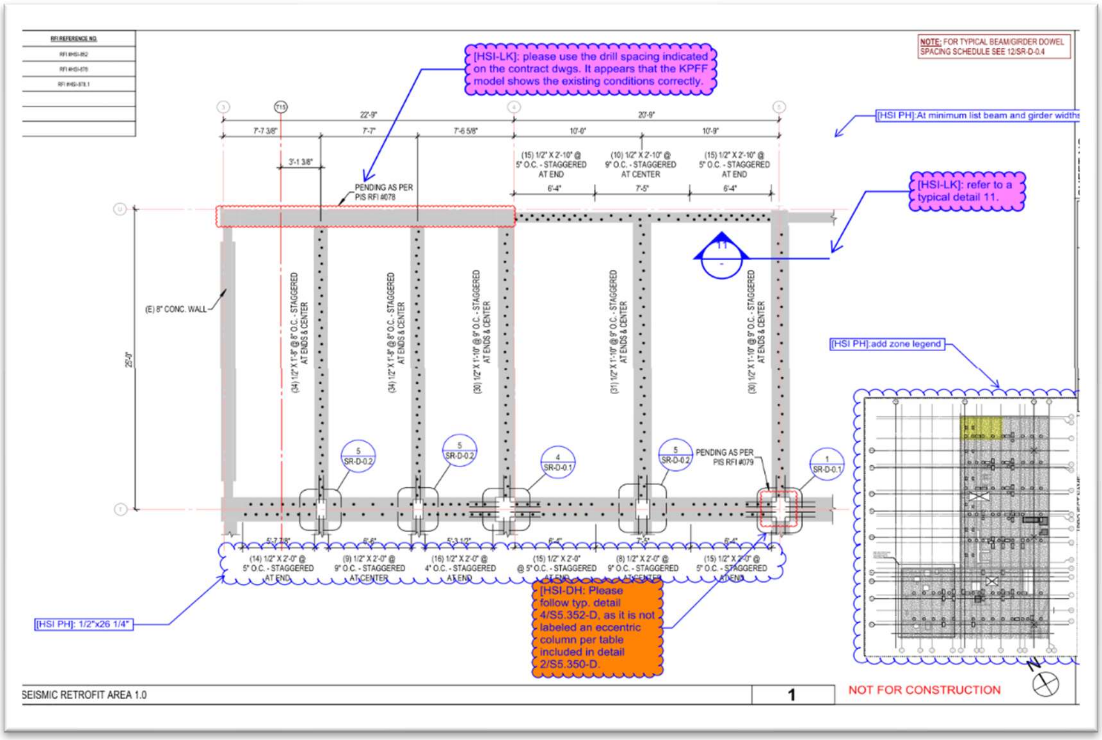

Fig. 3.1.3 shows the comments from the design team on the progression draft for seismic retrofits

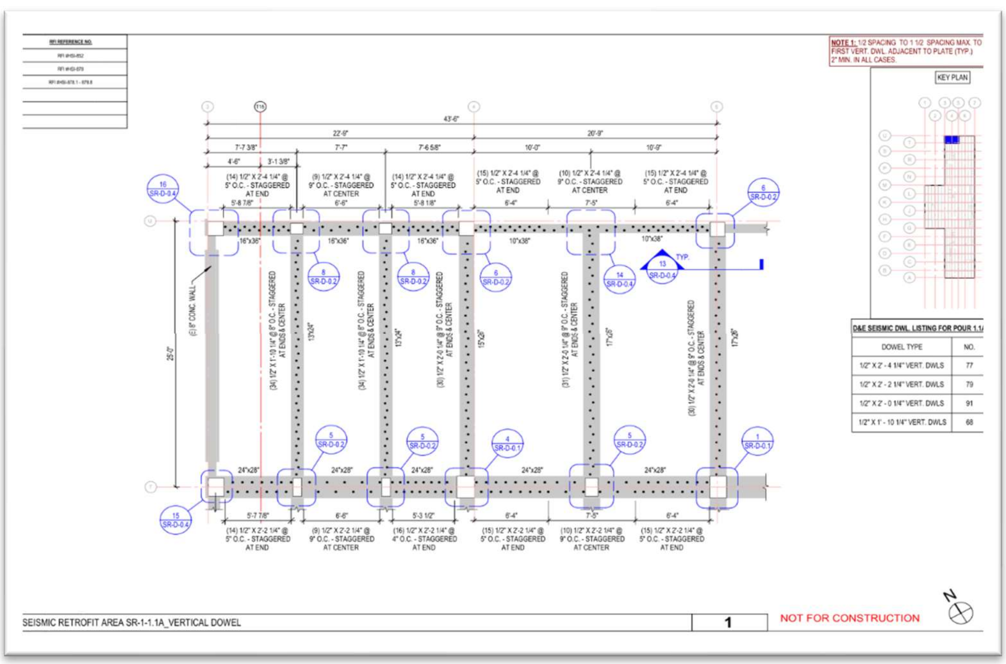

Fig. 3.1.4 shows the final draft for seismic retrofits

4.3.3.2 Crafting the Design

In this section, we will discuss the Bus Depot Project, and how the design is being developed at the Design Development stage. It involves the iterative refinement, and enhancement of project concepts, and plans to translate initial ideas into detailed, and actionable designs.

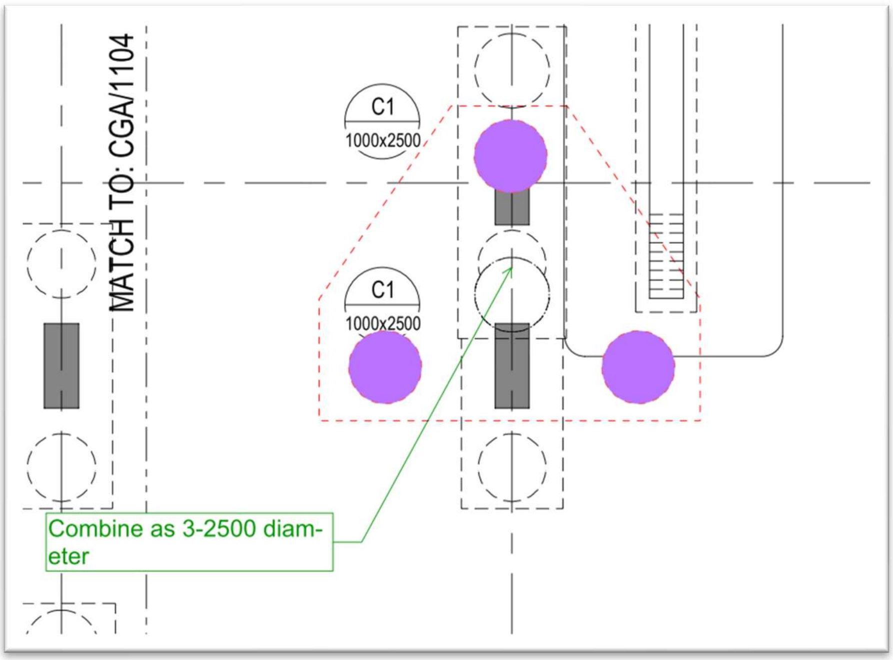

Fig. 3.2.1 shows the converted layout of pile cap

Case 1: In the above picture we see a partial layout of a pile cap plan. The two isolated footings have a very close distance between each other as per the concept design. This is a result of the initial load of the superstructure, the surrounding pile, and the pile cap configuration. However, after the design review, we see that both the footings have been combined to form a combination of three piles, and a single pile cap. The diameter of the piles is kept the same. The number of piles is reduced, and a better arrangement of the system is put together.

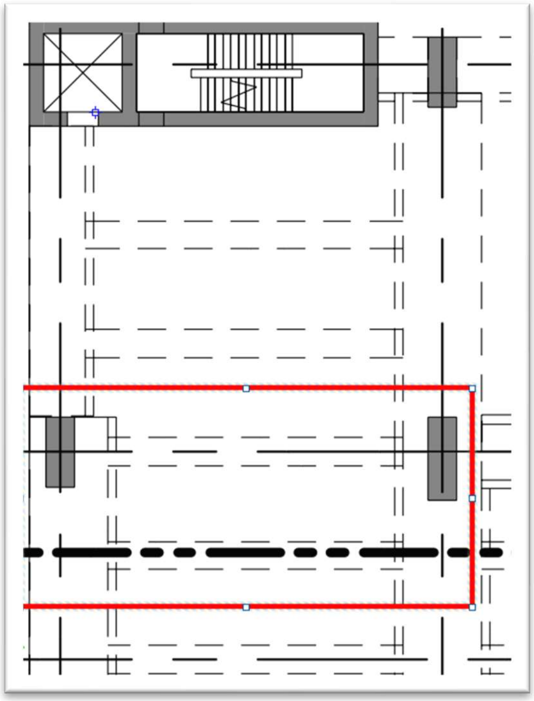

Fig. 3.2.1 shows the beam and column location in plan

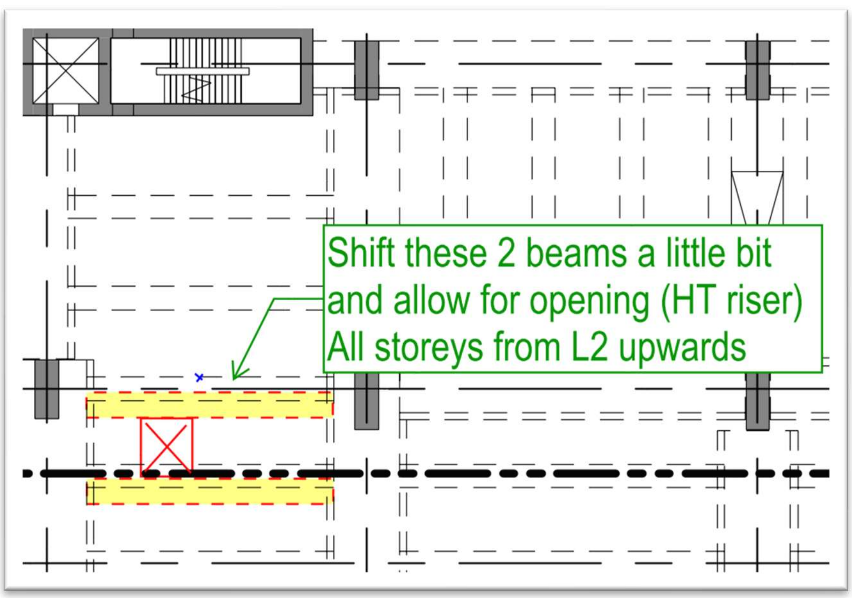

Fig. 3.2.2 shows the modified beam location in plan

Case 2: In the picture above, we see a layout of the level two floor. The shaded elements represent the columns, and the walls, and the dotted lines represent the framing. In the first snap Fig. 3.2.1 we see the marked location in red has a configuration where the beams are spaced equally and aligned to the centerline of the gridline as per the initial design.

In the next phase of drawing, the designer commented to align the beams for the presence of a riser (the water supply lines that move from one floor to another) that starts at the level two floors and goes to the top of the building. We see how the plumbing design is being implemented into the drawing set.

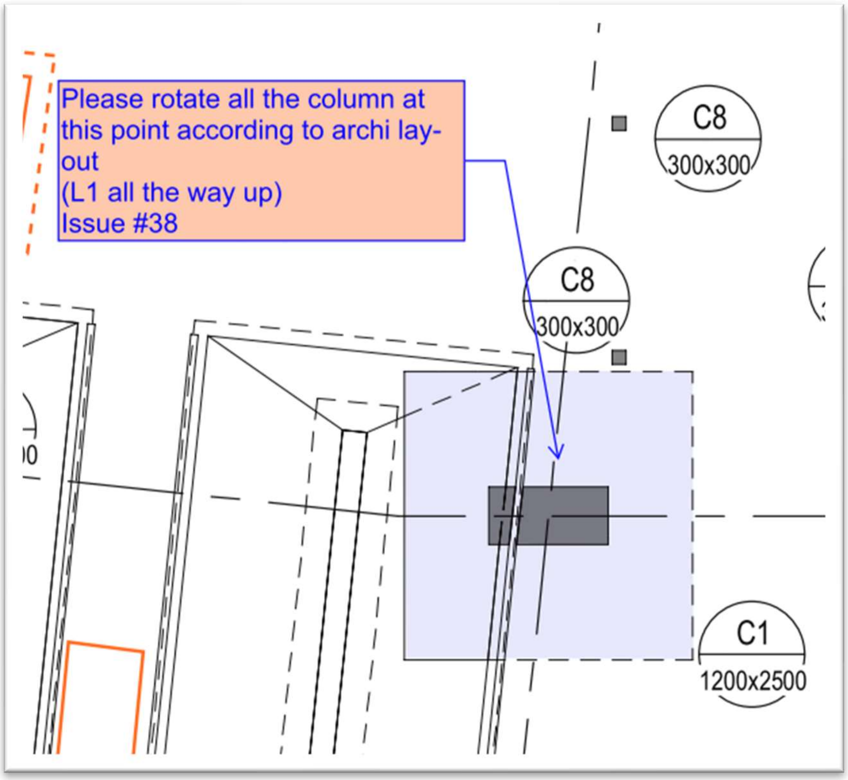

Fig. 3.2.3 shows the location of column clashing with pit

Case 3: In the above picture we see a layout of a level one plan. The column C1 shaded has a dimension of 1200x2500mm. Below it we have the pile cap that is in hidden lines. Left of the pile cap, and column, we have a layout of an automatic washing bay. These are designated zones for bus cleaning, and repair. They were introduced at a later stage in the design phase, and hence after the review, we see how the pile cap and column are coinciding with it. The pile cap is located below this level and hence does not cause any problem however we see that the column was clashing with the bay. After the review by the BIM team, this was highlighted in the meeting, and changes were made as per the comment we see which is to rotate all the columns at this location from this level to the top of the building.

Findings: The examples demonstrate how the design team utilizes the BIM model to review, and markup drawings during the design development stage. Often in the form of 2D markups, are extracted from BIM coordination, and design review meetings. From all the three examples, we see the value the BIM model is generating. This ranges from constructability review, coordination between different trades, and to a lot of extent value engineering. They serve as a means for the design team to mainly propel design development, communicate, and document changes.

4.3.4 Implications of BIM Coordination (Reduced Rework)

The beneficial effect of clash detection vs Building Information Modeling (BIM) has been revolutionizing coordination among stakeholders in construction projects for a very long period now. By acting as a centralized repository, BIM ensures that all project-related information, from 3D models to schedules, is easily accessible to every stakeholder, fostering clarity, and minimizing errors. Moreover, its capability for real-time collaboration breaks down geographical barriers, allowing diverse teams to work seamlessly together, enhancing efficiency, and innovation.

We have already learned how integration with project management tools streamlines workflows, ensuring that changes made in one aspect of the project are promptly reflected across all related areas, maintaining consistency, and coherence.

I want to highlight BIM's clash detection feature, which is particularly highlighted, as it enables early identification and resolution of potential conflicts among various building elements. This proactive approach significantly reduces rework, and delays during the construction phase, leading to considerable cost savings. Additionally, BIM's visualizations and annotations facilitate clearer communication, enabling stakeholders to understand design intent and provide feedback more effectively.

The BIM Manager that I interviewed narrated "*MEP(mechanical, electrical, and plumbing) has an advanced high level of BIM coordination when compared to structural or architectural. This is because MEP has a large potential in terms of designing the shortest, and most efficient routes to different building locations. Every stage of the building project is influenced by MEPF Design. Properly executed MEPF (Mechanical, Electrical, Plumbing, and Fire Protection) coordination systems in construction projects yield numerous benefits, foremost among them being substantial reductions in utility expenditures. Through meticulous coordination, these systems harmonize mechanical, electrical, plumbing, and fire protection elements, thereby streamlining their operation, and minimizing energy, and resource wastage. This optimization begins with the efficient design of system layouts, equipment sizing, and distribution networks, ensuring that energy consumption is minimized without compromising functionality.*"

Integrated MEPF systems incorporate cutting-edge technologies, and best practices to enhance energy efficiency across all domains. For instance, HVAC systems may integrate features like energy recovery ventilation, and variable speed drives, while electrical systems might leverage energy-efficient lighting and smart controls. By implementing such measures, coordinated MEPF systems reduce electricity usage while maintaining optimal comfort levels within the building environment.

Moreover, MEPF coordination emphasizes water conservation through the adoption of water-efficient plumbing fixtures, rainwater harvesting systems, and greywater recycling mechanisms. By addressing leaks, and inefficiencies, and optimizing water distribution networks, these systems significantly curtail water consumption, leading to tangible reductions in water bills, and the conservation of precious resources.

Another key aspect of MEPF coordination lies in the selection, and specification of equipment, and fixtures that adhere to high-efficiency standards. From energy-efficient HVAC equipment to water-saving plumbing fixtures, and low-energy lighting systems, careful consideration is given to every component to minimize utility expenditures over the building's lifecycle.

Furthermore, comprehensive commissioning processes and ongoing performance monitoring ensure that MEPF systems operate at peak efficiency levels. By fine-tuning system parameters, identifying inefficiencies, and providing regular maintenance, building operators can further optimize energy, and resource utilization, thereby lowering utility costs even more.

Lastly, MEPF coordination factors in lifecycle cost considerations, considering not just initial capital costs but also ongoing operating expenses, and maintenance costs. By optimizing system designs for long-term performance, and cost-effectiveness, coordinated MEPF systems deliver substantial savings in utility expenditures over the lifespan of the building.

In essence, properly executed MEPF coordination systems represent a holistic approach to reducing utility expenditures, encompassing efficient system design, energy efficiency measures, water conservation efforts, optimized equipment selection, rigorous commissioning, and monitoring, and lifecycle cost considerations. By leveraging these advanced strategies, building owners can bid adieu to high utility bills while simultaneously promoting sustainability and environmental responsibility.

In the words from interview 1, we got to hear that "*The MEPF department in BIM is way ahead when compared to architecture or structure. Since they have a way bigger scope in terms of design which can be so effortlessly done in a BIM software*."

Hence it is quite evident that the requirements in MEPF design are quite high in terms of BIM, and hence a bigger chunk of revenue is focused on the BIM contract for the MEPF. Let us look at some of the examples where this is being implemented.

4.3.4.1 MEPF services, and concrete space utilization:

MEPF (Mechanical, Electrical, Plumbing, and Fire Protection) services are integral to optimizing concrete space utilization within buildings. Effective spatial planning is crucial for allocating space to accommodate MEPF components while maximizing usable floor area. Architects and engineers collaborate to design layouts that minimize wasted space and facilitate efficient MEPF installation, and maintenance.

The BIM team in this case worked with the concrete subcontractors. There is always a fight between different trades for the empty spaces for the different services. However, the structural elements get their priority in this matter, and the MEPF has to redevelop their design in case of a coordination issue. The MEPF was involved in the early stages of the project, and the team needed to fill spaces with concrete so that no MEPF services could enter the region. These spaces would be a part of the slab edge sat a later part of the design. In this project majority of the beams connected with two pile caps center to center, and grade beams were aligned to the top of the pile caps (Fig. 4.1.2). However, in many cases the top of pile cap elevations were different. Thus, the beams were in slope.

Now to provide slab edges above the grade beams the BIM team had to create the slab edge with sweep blend (a Revit function to create geometry between two different profiles), and whenever the slope changed, the team had to repeat the process.

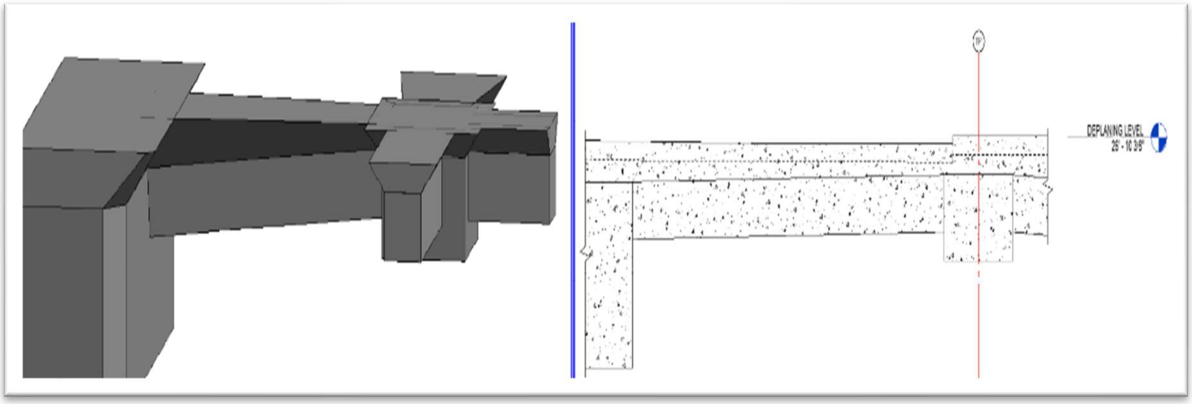

Fig. 4.1.1 shows the modeled slab edges between pile caps

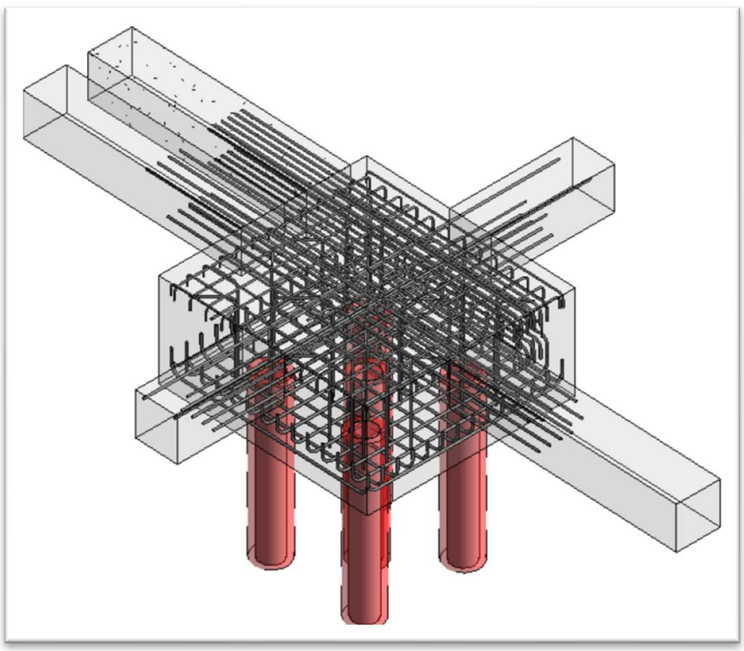

Fig. 4.1.2 shows the grade beams connections with pile caps

In many locations to support the respective slab rebars, the Airport BIM team had to widen the grade beams calculating where, and how much the beams were to be widened (Fig. 4.1.1). Therefore, in many cases, the beams are no longer connected to the center line of pile caps. Also, the team had to coordinate with the existing model to form the shape of grade beams.

Every project has different trades involved in different phases of the project, and hence it becomes very important to build a process where the trades execute their part, and are included in the overall design as a part of the whole construction. This is where BIM acts as a catalyst and facilitates the whole process.

Interviewer 1: Here are some of the live quotes from the interviewer regarding this example. The interviewer was a BIM Manager of a subcontracting firm which was a subsidiary of the general contractors. "*The design* *team(structural) did already have a model of their own which they used to build their drawing from. However, there were no slab edges that had been modeled, and this is a standard practice that is done in the industry. The minor concrete elements are generally represented with 2D elements. However, it is very important for coordination purposes as the MEPF designs need to be rerouted once they design in these open pockets however later they discover that concrete would be occupying these spaces. Our team included all the unique slab edge areas that connected multiple pile caps. After this was done, the team shared the model with other trades, and coordinated their model."*

<u>Findings:</u> BIM coordination is indeed a critical aspect of maximizing the value derived from a BIM model. In this case, we observe the BIM team going above, and beyond traditional coordination practices. They proactively filled the virtual concrete spaces within the model to prevent other trades from utilizing them. This strategic decision was driven by the recognition that allowing other trades to use these spaces later would necessitate rerouting, and redesign efforts, leading to potential delays, and inefficiencies in the project execution.

By taking preemptive action to occupy these spaces within the BIM model, the BIM team effectively safeguarded against future conflicts and disruptions. This proactive approach demonstrates a keen understanding of the project's requirements, and potential challenges, as well as a commitment to optimizing coordination efforts for the benefit of the overall project. It highlights the value of strategic thinking, and proactive problem-solving in BIM coordination, ultimately contributing to smoother project execution and improved outcomes.

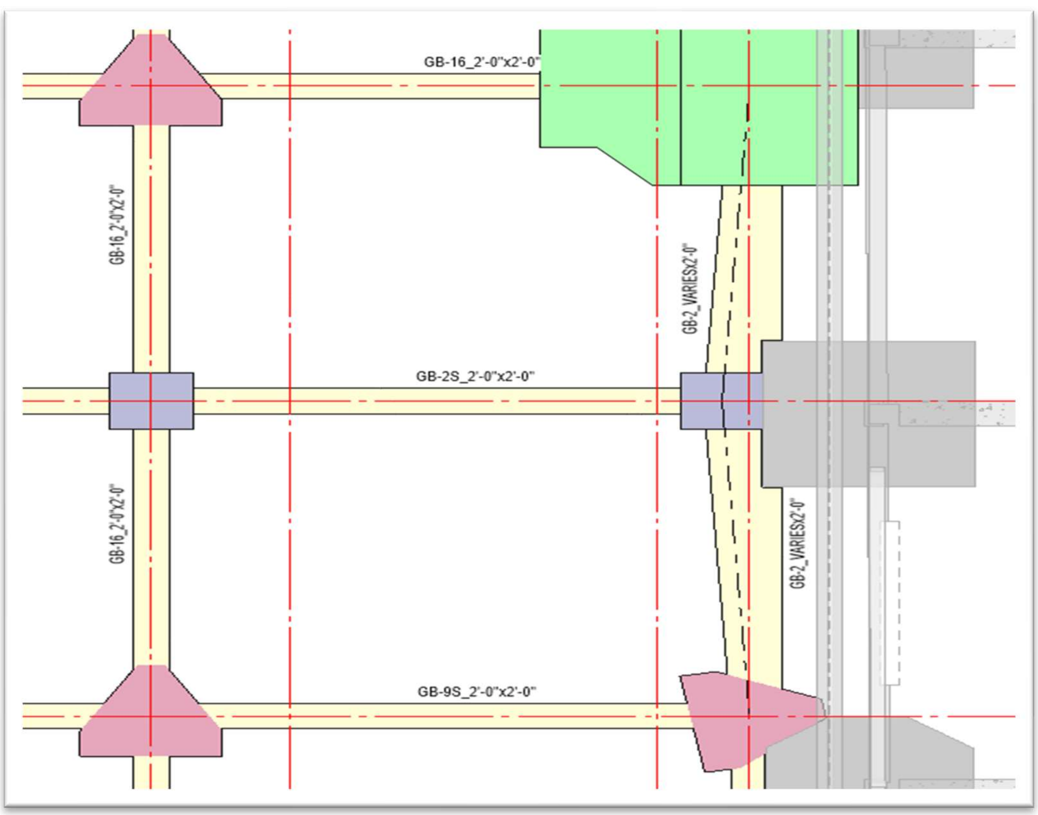

Fig.4.1.2 shows the interconnection of pile caps with grade beam

4.3.4.2 Constructability review:

As we have seen in Case 1, BIM coordination goes far, and beyond traditional clash detection. When a BIM team has a lot of experience then it is evident that the team will come up with different value propositions in terms of better design, and constructability. The term constructability review can be done in small ways in a project, but its impact is substantial. Let us see another example below:

Fig 4.2.1 shows the location of different pile caps connected. The Grade beam in purple is connected by two Pile caps which are named PC-2 with different elevations. The same grade beam is also connected to MC-21 which also has an elevation like the pile cap in the north. These elevations are provided by the design team after almost 100% design set. It is quite evident that the design has gone through a lot of iterations. However, when the elevations are modeled in BIM software, the yellow marked cloud points to the location where we see that the slope cannot be constructible in the field (can be seen in Fig. 4.2.2).

The design team reviewed the scenario and provided instructions to lower the grade beam to the same elevations as the other Pile caps. Other design measures were taken to connect and construct the three pile caps, and the connecting grade beam.

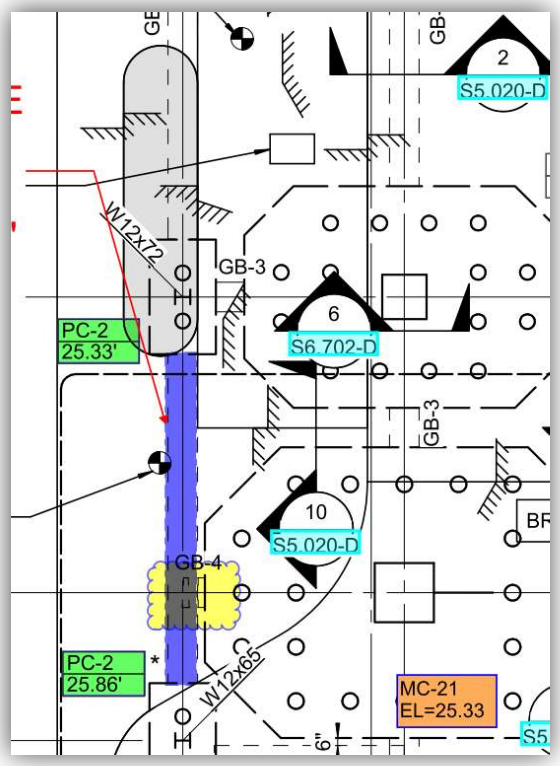

Fig 4.2.1 shows the location of edge in plan in yellow that cannot be constructible

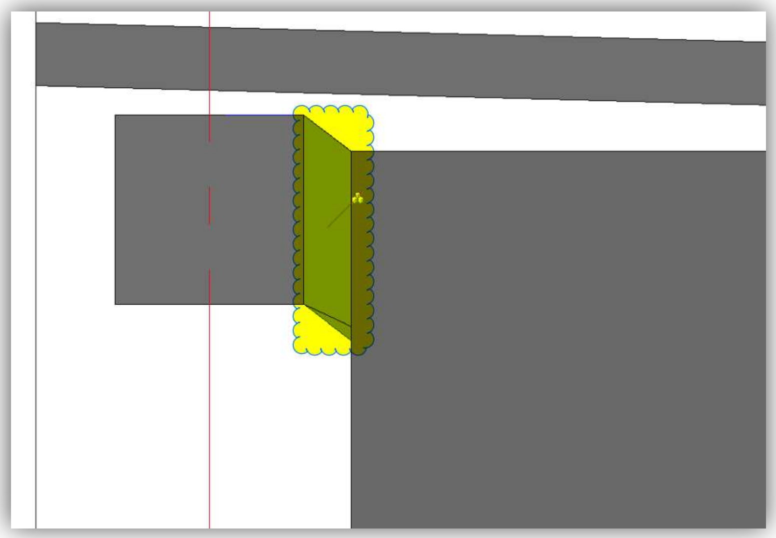

Fig 4.2.2 shows the edge in section view that cannot be constructible

4.3.5 The pace of construction/Impact on schedule (Time)

Completing a construction project on time is a crucial factor in determining its success. Several factors determine the timeliness of a construction project. Hence the project schedule There are a lot of studies that indicate that a vast majority of construction projects experience schedule delays. Timely completion ensures that the project meets its objectives, satisfies stakeholders, and minimizes costs. One of the signification problems is handling changes. Changes can be in the form of scope or design changes which adversely affect the schedule, and cause construction delays. We saw how BIM is helping different stakeholders in construction projects in terms of design changes in the previous parameters. We will elaborate on the things we talked about here in this section.

Case 1: It is a fallacy that BIM is to be implemented in big projects. Bigger projects often have bigger budgets, and hence it becomes an easier decision to allocate a small percentage of money to BIM which is often a percentage that ranges from 1-3% of the total project budget. Various scopes can be explored in bigger projects with higher money allocation however, there are a lot of benefits that BIM can offer even in smaller projects. Let us take the example of the case stated below:

In the very initial phase of the bridge project, the project had just been approved by the business development team, BIM was introduced. The design was in the concept phase, and the project had mandatory BIM requirements. Hence the BIM team was especially called into action for preconstruction work in the project. The team has been working for the first time with the design team. There were hardly any drawings that had been done at that point. Only hand-drawn drawings, and sketches were present with the team (see Fig. 5.1.1). The project included ground stabilization of a tunnel including the usage of a TBM (tunnel boring machine). The major elements included piles, sheet piling, pile connectors, and different columns that were to be drilled inside the deep ocean thousands of feet below MSL (Mean Sea Level).

Generally, the designers used hand sketches to finalize the concept drawings however this time everything was done in a CDE (common data environment). This enabled all stakeholders in the project to be involved with the design progress, and this included the design company, the construction company, and the owner who was a government authority of the state. There were several iterations in design which included the usage of several hot-rolled steel sheet piles that formed the coffer dam at the perimeter of the site. There were some standard sizes for the hot rolled steel piles, and there were a lot of special makeup pieces (Fig. 5.1.2) that were introduced throughout the different locations of the ground stabilization area.

<u>Findings:</u> Transparency in communication in the concept stage was the biggest advantage that the team derived as one of the owners mentioned after the preliminary submission of the drawings.
Introduction to a CDE (common data environment) provided a gateway for stakeholders to have real-time data. A lot of different problems and ideas were put forward by everyone concerning the different problems that the design could have faced. This generally happened very slowly as per the statement of one of the lead designers.

"All parameters cannot be defined in one single iteration of design. The client especially, and the different stakeholders eventually come up with different frameworks at certain stages of the project. It is a slow, and eventual process."

The concept drawings were converted to a drawing set at a turnover of two days. The model was created with the design input, and collaboration with the BIM, and the design team.
BIM enabled a foundation where this alteration of different design iterations could be facilitated, and a very quick turnaround was enabled for the published drawings. The project was a design-build project, and the schedule was extremely tight, and hence the BIM process enhanced the design, and the schedule in a very short, and efficient process.

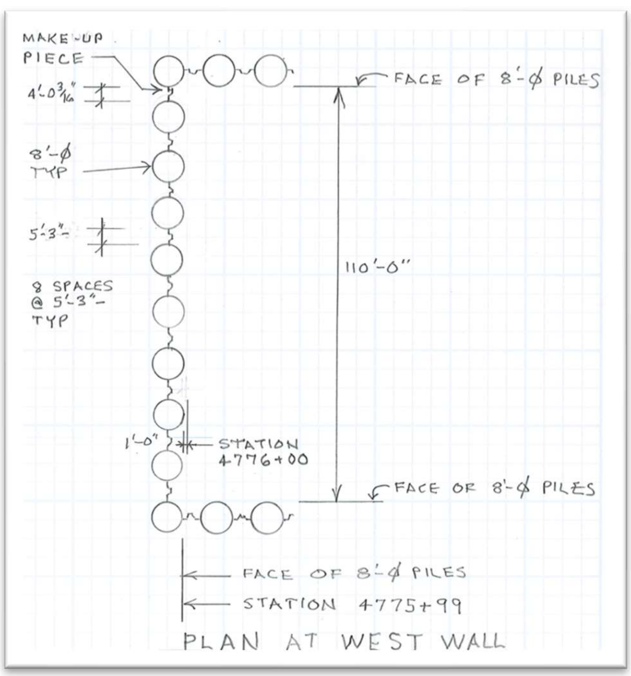

Fig. 5.1.1 shows the drawings sketched by hand in the initial stages of design

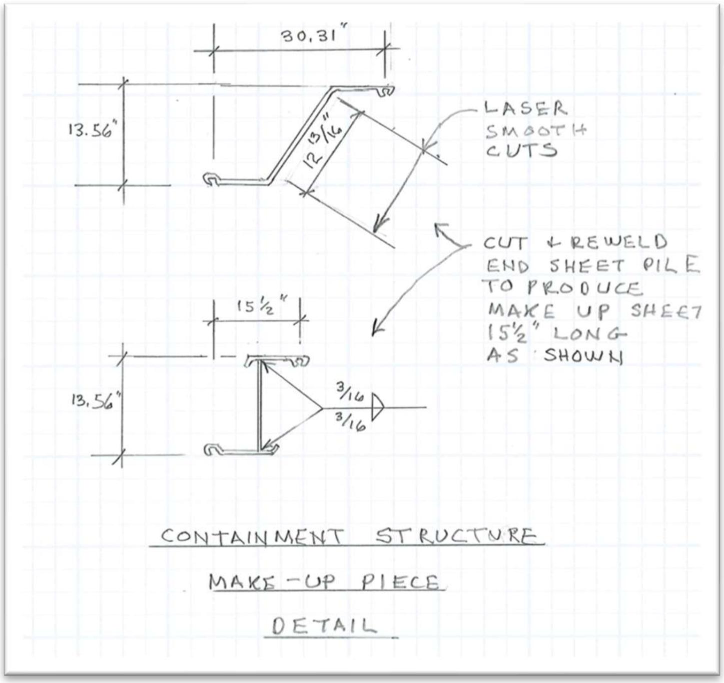

Fig. 5.1.2 shows the smaller pieces that form the sheet pile

4.3.6 To what extent should BIM modeling be automated?

Before I talk about the extent of automation in BIM let us talk a bit about the general terms on when, and why there should be a limit to automation. Determining the right level of digitalization, and automation for a company involves considering various factors. Firstly, understanding industry norms helps gauge the standard practices within the sector, which can vary widely. Secondly, identifying processes ripe for improvement through digitalization, and automation, such as repetitive or error-prone tasks, is crucial. Conducting a cost-benefit analysis helps weigh the expenses against potential benefits, including ROI. Meeting customer expectations for digital experiences, ensuring data security, and privacy, and considering the impact on the workforce is also key. Scalability, competitive advantage, and risk management are further aspects to evaluate. A balanced approach, blending technology, and human expertise, is essential for optimal outcomes. Ultimately, the chosen level of digitalization should align with the company's strategic objectives, and contribute to its long-term success, with regular reassessment to adapt to changing circumstances.

Visual programming in Building Information Modeling (BIM) has created a lot of hype recently. It is the same use of a programming language but in a visual form, and not in terms of the traditional coding form where lines of code are written for a task. It refers to the use of graphical interfaces, and node-based systems to create custom scripts and automate tasks within BIM software platforms like Autodesk Revit, Trimble Tekla Structures, or ARCHICAD.

Node-Based Interface: Visual programming environments in BIM software typically use a node-based interface, where users connect graphical nodes to create scripts. Each node represents a specific action, operation, or data input.

Automation: Visual programming allows users to automate various tasks, and workflows in BIM software. This includes tasks such as generating complex geometry, creating parametric designs, modifying building components, extracting, and manipulating data, and coordinating project information.

Customization: Users can create custom tools, workflows, and scripts tailored to their specific project requirements or design processes using visual programming. This flexibility enables users to adapt BIM software to their unique needs and streamline their workflows.

Efficiency: Visual programming in BIM enhances efficiency by reducing manual labor, minimizing errors, and speeding up repetitive tasks. It enables users to work more iteratively, explore design alternatives, and make informed decisions throughout the project lifecycle.

Integration: Visual programming environments are integrated seamlessly within BIM software, allowing users to execute scripts directly within the BIM environment. This tight integration ensures that changes made through visual programming are immediately reflected in the BIM model.

Collaboration: Visual programming promotes collaboration among project team members by providing a standardized platform for sharing custom tools, and scripts. It facilitates communication, knowledge exchange, and best practices across disciplines, and project phases.

Overall, visual programming in BIM enhances productivity, fosters innovation, and enables more efficient, and collaborative project delivery within the architecture, engineering, and construction (AEC) industry. However, it is very important how the BIM professionals limit themselves to this practice. Let us take the example of a Bridge project that we introduced.

There is an actual example of a project that experienced the application of extensive automation, and as a result, it had to go through a unique set of complications.

The project as we can see from the introductory projects was a complex bridge project with a lot of unique geometry. As we have learned BIM is used by several stakeholders of a construction project, and in this case, it was the design team that tried to leverage this benefit.

The design team had never worked with a BIM team or a BIM model. The former teams comprised drafters where the 2D elements were sketched. However, due to the complex geometry, and the iteration that was going to take place during the design, the design team decided that the work needed to be done in three-dimensional software. The team hired a group of coders who were experts in a programming language, and along with a couple of designers, this project was modeled.

Tekla Structures was used as the BIM software however the team used other visual programming software such as Grasshopper, and Rhino on top of Tekla Structures. Also, some of the codes were written in Python language. Since the team did not have any knowledge of Tekla structures hence almost the whole model was done with automation. The process was beautifully mechanized with a lot of effort to run the major design changes. Below I am sharing the general process of the BIM workflow:

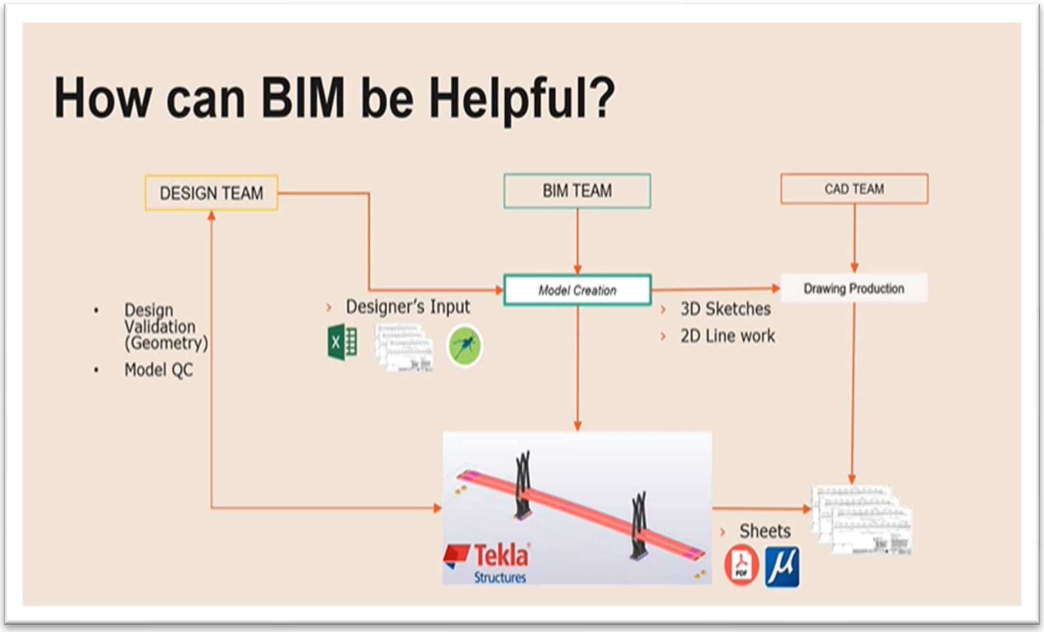

Fig. 6.1.1 shows the flowchart for implementation of automatio

The design input is further divided into several sections about where, and how the workflow was done. There were multiple personnel working on the project hence the work had been subdivided into several portions which is mentioned in Fig. 6.1.2. Some of them are floor beams, stiffeners, deck panels, and connection anchorages. Each of these grasshopper input data is binder together in a ".ghdata" extension file which is a Rhino extension file. This is done with the GUID (globally unique identifier) number. It's kind of using one script to determine the element properties in Tekla, retrieving a GUID, and sharing that with the other scripts.

Finally, this is collected in a .csv file(master spreadsheet), and this is pushed into Tekla Structures. Master spreadsheet inputs.xlsm is be a single source of numerical input for the GH script. The Excel spreadsheet exports .csv files which are directly read by the GH script.

The details of the scripts that are written in Grasshopper are very extensive, and hence a sample of it has been shown in Fig. 6.1.3.

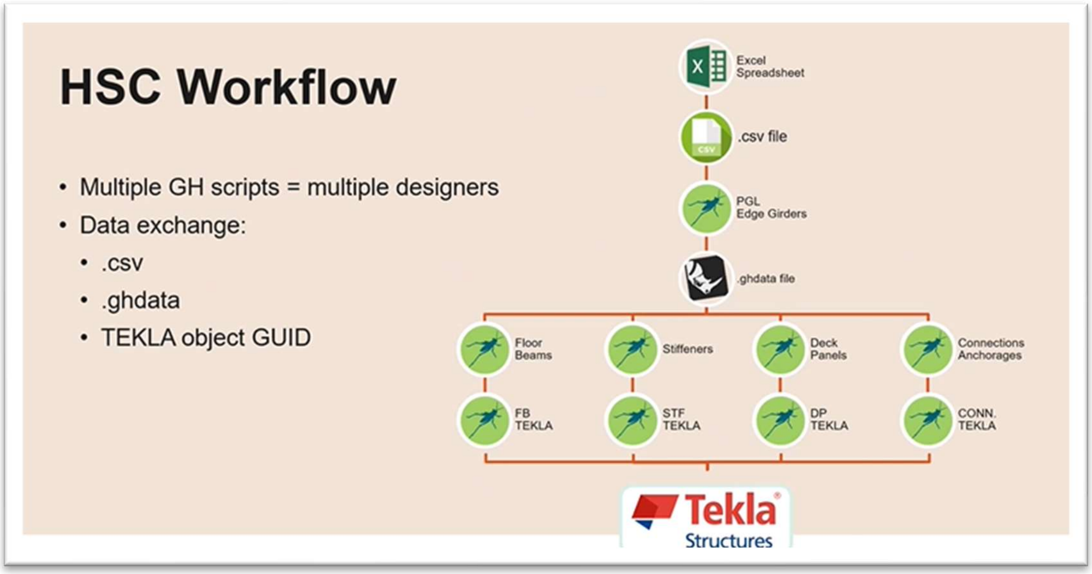

Fig. 6.1.2 shows the areas in which the automated process was divided

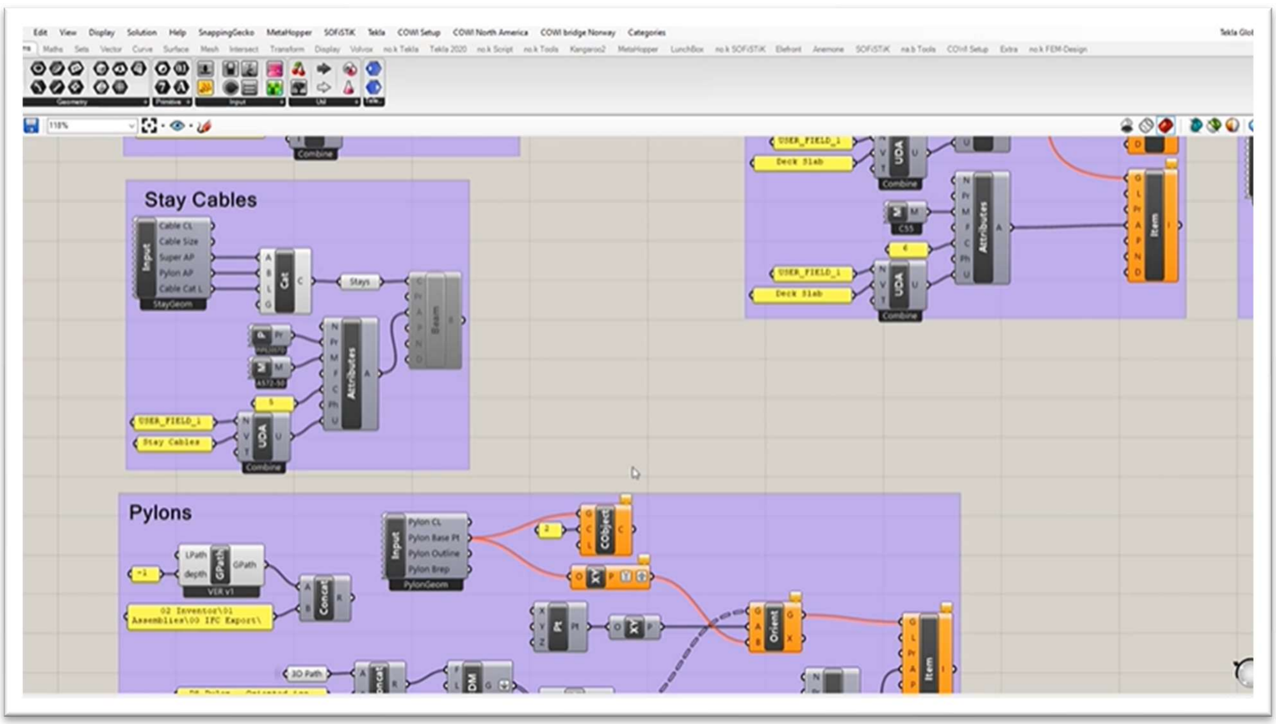

Fig. 6.1.3 shows an example of the grasshopper scripts used

While the completion of the project was deemed successful in terms of constructing the model, the journey was filled with numerous intriguing observations and insights that emerged throughout the process. These observations shed light on various aspects of the project, ranging from design intricacies to operational efficiencies.

There were several challenges that the team faced during the model progress which is why I have taken this example to learn how over-automation of BIM can affect production and the end product.

1. Complexity in the overall process

From the description, it has been described that there was no BIM team for the project, and hence the model was made by a group of engineers and programmers. To create this a very high level of knowledge is required in terms of programming skills. Although a very sophisticated flow chart was made, the process is extremely complex and requires an enhanced level of coding to be executed.

2. Creation of shop drawings

The model creation was the only part where the coding was used. There was the scope for creating the shops too but that could not be done due to several constraints that the software (Tekla Structures) had. The shop drawings were done in a different software where an extension called ".IFC" was exported and then imported into it. Another reason was the creation of the whole model every time the script ran so all the annotations that had been created would be off, and hence this was not possible to retrace this every time on what things changed for hundreds of sheets.

This also showcases that if the complete model is automated then it can cause serious problems during the creation of two-dimensional drawings.

3. Specific design changes

There was a lot of trouble that emerged when a small part of the model needed adjustment. The codes were written for similar items that occurred with different parameters in different locations. However, whenever there was a change that was required for a small specific location, it could not be done since the code was written for a group of elements, and not a single one. Let me explain this with a simple example:

The project was a cable-stayed bridge, and usually, this type of bridge has multiple cables coming out of the towers. The codes were written for all the cables at once. There was a hierarchy of parameters that were included in it such as length, orientation, angle of inclination, etc. However, all the cables would be changed if the script was activated. Several groups of cables would change. But it was not possible for a single cable to change. If this was required then codes would have to be written for every individual cable, however, this would rather take more time than to manually model individual cables in the BIM software.

This was a very typical problem that occurred in different segments of the model that the designers and the coders had to deal with.

4. Inability for users to change the attributes of custom components.

This was a problem that was found after the model was completed. There were hundreds of custom steel connections were created (can be seen in green in Fig. 6.2.1). These custom connections had been induced with several parameters that had been created keeping in mind multiple configurations based on length, width, height, number of bolts, bolt arrangement, bolt, and plate orientation, number of plate connections, etc. These codes were typically written by one of the coders, and a special GUID was created in the process. There was a process that was implemented where multiple people working on the project would have their GUIDs matched so that other codes could be induced into elements worked by a different user. However, this failed due to some technical problem that Tekla Structures had with respect to the GUIDs created for the custom connections only. The custom connections could not be manually edited in the software. This caused a lot of pain in the future where every time the code had to be altered whenever there was a change, and the model would be regenerated again.

The plan was to use these custom connections in the future for a similar project but this could not be achieved. Later BIM managers/coordinators were hired by the company to modify these custom connections in the model as per the design changes.

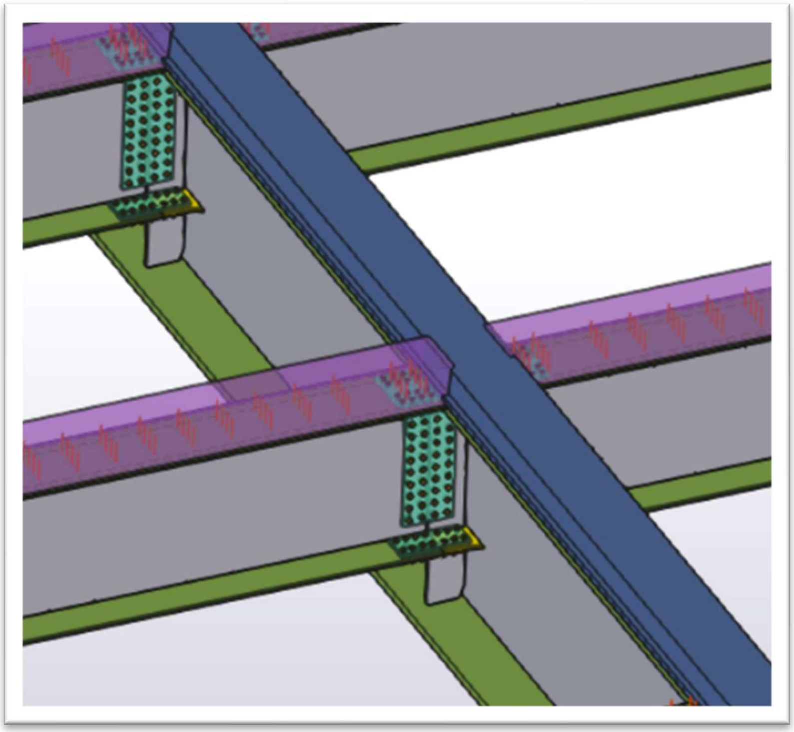

Fig. 6.2.1 shows the custom connections

5. Code constraints: Steel plate orientation, and edge dependency

There were several criteria for creating the custom connections as per the written code. Each of the BIM software is written in one or more languages, and these have a lot of constraints when used. That is why engineers need to learn the rules of software or take training sessions before using it. The codes that were written specifically for the elements used also had a lot of restrictions on how a team member needed to put them in order when we inserted or created these inside the software manually.

Let us take the example of steel plate orientation (see Fig. 6.2.2):

The connections are very dependent on what edges you're using in your element. So for example, one of the senior engineers directly tried to explain the issue: “If I have those two orange, C1, and C2 web plate connections. If I make a custom component for the C1 and connect it to Edge D, and side number one, I can't use the same component for the other side because it attaches to side three, and side B of the other. So you have to really remake the connection again for side three, and edge B or side B side three, and side B.

So that's unfortunately a consequence of just, you know, how Tekla, kind of understands what the edges are.”

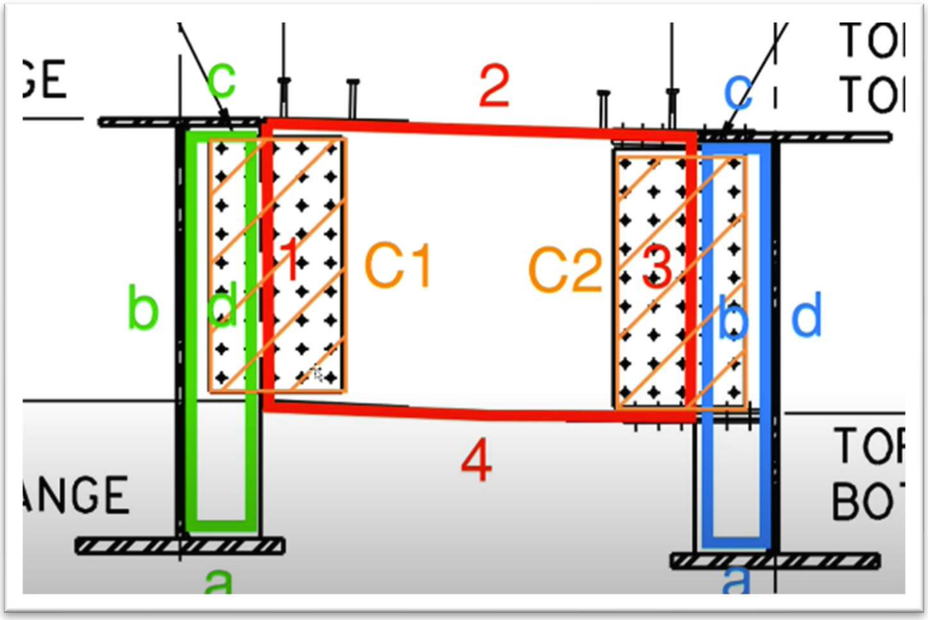

Fig. 6.2.2 shows the process of writing the code for the custom connections

Chapter 5: Discussion

We have studied the five different parameters and their examples. All parameters that we discussed are linked to each other in several ways. In this section, I will talk about how these have impacted the efficiency of the overall construction process. Also, in what ways the BIM professionals can learn, and how this can be useful in the application of other future projects that the BIM community would engage in?

5.1 Accuracy in design

It has been learned from the literature review how BIM software plays a crucial role beyond 3D modeling by supporting design, cost analysis, project management coordination, and production detail formulation. Now I am going to discuss the specific examples illustrated in the findings section.

Achieving accuracy in design is a multifaceted process that involves interconnected factors that form the big picture. There is a wider spectrum of how the design accuracy can be better in terms of sheer design parameters but here we looked at instances where BIM would help the design team to create more accurate designs. We saw this in the form of examples of the precision of fabrication provided through BIM work, how the transformation from AutoCAD to BIM impacted design validity, and lastly through value addition in terms of cost, and time-saving in the form of volume optimization. All these factors contribute to making an effective design. Let us take a wider look, and the things that I derived from the data I had.

The precision in the fabrication (mentioned in section 4.3.1.1) of precast elements is critical in ensuring quality design. BIM helped achieve accurate dimensions, and consistency in manufacturing, reducing the need for time-consuming RFIs between construction, and design teams. Precision ensured seamless assembly on-site, minimizing alignment issues, and enhancing the overall quality, and performance of the structure. This highlights the significant impact of small processes on the overall construction process, emphasizing the importance of precision in precast element fabrication, and making the overall design better.

The examples (section 4.3.1.2) illustrated how limitations in AutoCAD led to design challenges, and changes being overlooked, causing delays. BIM's parametric capabilities allowed for better coordination, and resolution of issues. Design iterations are crucial but can prolong the design phase, and delay construction. BIM mitigates this by streamlining coordination and improving efficiency. Overall, BIM minimizes the impact of design iteration on construction schedules, emphasizing its role in enhancing design outcomes, and project efficiency.

These examples (section 4.3.1.3) highlight how BIM workflows contribute to improved efficiency, and cost savings in construction projects. Instant decisions in the field can be challenging, and risky, as seen in Figure 1.3.3.

In the first case, a small opening was discovered in the configuration after assembly, emphasizing the importance of precise fabrication ensured by BIM.

In the second case, the BIM team's review led to significant time, and cost savings by optimizing the volume of concrete poured. This thorough review of the BIM model enabled early identification, and reconfiguration of plan drawings, benefiting the project's budget, and timeline that goes beyond traditional estimating of the quantities through the BIM.

Overall, these examples underscore how BIM enhances decision-making, efficiency, and cost-effectiveness in designing a construction project.

5.2 Managing the Construction Process

From the literature review, we have learned that BIM accelerates the drawing process through automated project documentation and simultaneous design capabilities. Changes made are instantly reflected across all documents, improving workflow efficiency, and minimizing errors. This leads to reduced labor costs for project design and drawing processes. The design options tab allows for exploring alternative designs in later project stages. BIM functions as a collaborative platform for various disciplines.

The importance of having a standardized workflow for managing larger BIM projects becomes evident. While the BIM team initially had a process in place, they continuously evolved and explored strategies to streamline their workflow. Despite utilizing BEP, and TIDP, it was challenging for the BIM manager to capture every detail in these documents. From the example stated in section 4.3.2.4 we learned, to address this, they adopted a standard booklet instead of deploying various smaller tools such as OneNote, OneDrive, tracking logs, daily status logs, and SOV, and opted for a single streamlined form of communication with the field in the form of Procore.

The integration of Procore, Bluebeam, and BIM 360 (cloud server for Autodesk) significantly improved the working, and execution process for all BIM-related tasks in the project. Moreover, Procore served as a central platform for managing the entire project, allowing project managers, the design team, and the owner to track project-related documents, finances, schedules, and estimates. This integration ensured that all stakeholders remained informed about project developments.

In conclusion, any BIM team needs to establish a standard protocol before commencing their work. This process should be consistent across the entire team, and preferably implemented through a software or platform that enables seamless interaction among stakeholders, and transparent data flow. This process will greatly improve the efficiency of the whole BIM process involved in the project which in turn will complement the productivity of the overall construction.

5.3 Process of Implementation of Design

From the literature review, we have learned that design development involves the creative, and systematic process of conceiving, planning, and experiences with the intent of achieving specific objectives. After looking at the case studies I can conclude that the BIM model acts as a platform for the design team to advance design development, facilitate effective communication, and document changes throughout the project.

The case study in section 4.3.3.1 illustrates how collaboration between the design team, and the BIM team led to the development of a new scope using BIM. Initially, the work was contracted with the concrete contractor, however, the design team recognized the value of working with the BIM team. Leveraging the existing airport project model, the design team built upon it to incorporate their new scope, including seismic retrofits. Effective coordination with field engineers and the BIM team facilitated this process. Additionally, the BIM team successfully integrated old 1952 drawings into the model, addressing various issues instantly with input from general contractors involved in the project.

The examples in section 4.3.3.2 illustrate the design team's use of the BIM model for reviewing and annotating drawings during the design development phase. Typically, these annotations take the form of 2D markups extracted from BIM coordination, and design review sessions.

In conclusion, across all three examples, I have observed significant value generated by the BIM model. This includes facilitating constructability reviews, coordinating between various trades, and largely enabling value engineering. The BIM model serves as a platform for the design team to drive design development, communicate effectively, and document changes throughout the process.

5.4 Implications of BIM Coordination

BIM coordination is crucial for maximizing the value of a BIM model. From the literature review we have learned that in the realm of design and construction, it is regrettably uncommon for designers and contractors to engage in communication before the commencement of the construction phase. The objective of coordination is to scrutinize design options and pinpoint areas where potential advantages can be realized. This practice is instrumental in addressing potential project oversights and mitigating construction issues, and it has been adopted by several state departments of transportation.

From section 4.3.4.2 we have seen that constructability reviews provided a systematic evaluation of the project at a developmental stage and reduced the future disputes and scope changes related to construction challenges. This methodology relied heavily on the expertise of the BIM team and their comprehensive knowledge of techniques, advancements, and experience to avert the problems that might arrive in the future.

In conclusion, we have learned from the case studies that the BIM team went beyond traditional practices by preemptively filling virtual concrete spaces in the model to prevent future conflicts. This strategic decision aimed to avoid rerouting and redesign efforts that could lead to delays. By proactively addressing potential issues, the team demonstrated a deep understanding of project requirements and a commitment to optimizing coordination. This proactive approach highlights the importance of strategic thinking in BIM coordination, leading to smoother project execution, and better outcomes.

5.5 The pace of construction/Impact on the schedule

We have learned from the literature review that there are multiple factors that are related to each other. I have talked about the parameters where an effective design, good management process, implementation techniques, and improved application can provide better value to the efficiency of a construction project where BIM acts as a platform. In all of these cases, it is also evident that these better processes will lead to better time schedules when a construction project is built.

In conclusion, from the examples shown it can be seen that another important factor that contributes to faster project execution is transparency in communication. During the conceptual stage, this was showcased to be a significant advantage, as acknowledged by one of the owners, following the initial submission of drawings. Introduction to a Common Data Environment (CDE) allowed stakeholders access to real-time data, facilitating the exchange of various ideas, and solutions. We have learned from the examples that the process of complex design is generally slow, as noted by one of the lead designers. However, as explained the drawings were produced in a short period of two days. The concept drawings were transformed into a drawing set through collaboration between the BIM team and the design team. BIM laid the foundation for facilitating different design iterations, leading to quick turnaround times for publishing drawings. Given the tight schedule of the design-build project, the BIM process efficiently enhanced both the design and schedule of the overall process.

5.6 To what extent should BIM modeling be automated?

The challenges highlighted underscore the critical need for a balanced approach to automation in BIM processes. While automation can streamline workflows, and improve efficiency, over-reliance on automated processes can lead to inefficiencies, and hinder project effectiveness. By integrating manual intervention where necessary, teams can address complex issues, make nuanced adjustments, and ensure the accuracy, and integrity of project deliverables.

Since the team was only comprised of engineers and coders the hiring of BIM managers/coordinators is a strategic response to mitigate the limitations of over-automation. These professionals possess the expertise to navigate complex BIM environments, troubleshoot technical issues, and optimize workflows. They play a crucial role in overseeing BIM implementation, coordinating collaboration between different project stakeholders, and ensuring that BIM processes align with project objectives and requirements.

Additionally, BIM managers/coordinators are instrumental in bridging the gap between automated tools, and human decision-making. They provide invaluable insights into when manual intervention is necessary, such as in cases of specific design changes or technical constraints. By leveraging their expertise, teams can strike a balance between automation, and manual intervention, effectively addressing challenges, and maximizing the benefits of BIM technology.

Chapter 6: Conclusion

The cases discussed above exemplify how Building Information Modeling (BIM) serves as a comprehensive solution to various challenges encountered in the construction process. BIM's multifaceted capabilities contribute to streamlining project workflows, enhancing collaboration, and improving overall project outcomes. This correlates to the Macleamy Curve where if we undertake the work with better planning and design in the initial stages then the final stages are more efficient, with fewer project delays, wastage, and lower costs.

Furthermore, BIM enhances the accuracy, and quality of construction drawings. By centralizing project data, and documentation within a BIM environment, teams can ensure consistency, and integrity across all project documentation. This reduces errors, and discrepancies in drawings, leading to improved construction quality, and reduced rework.

Moreover, BIM facilitates a faster pace of project execution by streamlining communication, and decision-making processes. Real-time collaboration features in BIM platforms enable instant sharing of information, and updates among project stakeholders, eliminating delays caused by communication barriers or data silos. Additionally, BIM's ability to automate repetitive tasks, and generate accurate quantities, and schedules accelerates project planning and execution.

Overall, BIM serves as a transformative technology that revolutionizes the construction industry by addressing various challenges, and inefficiencies. Each of the major parameters is interconnected and hence if one is done in a better way then the other parameters are also reciprocated. Also, we must draw a fine line in automation and AI in terms of managing the BIM model since the end result that is to be derived is important. Hence, we need to strike a balance between both the manual transformation and the computerization industrialization mechanization.

6.1 Limitations of the study and Future work

Limitations:

A broader range of factors, including company size, sector of operations, project budget, and the experience of BIM professionals. Professionals find it challenging to share drawbacks. Researching factors that reduce efficiency in a BIM project. Construction plays a more significant role than BIM; sometimes, a well-executed BIM project does not guarantee success

Future work:

Maximizing BIM implementation in terms of efficiency in construction might depend on other factors such as company size, sector of operations, project budget, and the experience of BIM professionals. Larger companies with ample resources often excel due to advanced technology and training opportunities. Different sectors have unique BIM requirements, impacting efficiency. Higher project budgets allow for comprehensive BIM adoption, while experienced professionals optimize its use. Addressing these factors enhances project outcomes, collaboration, and overall efficiency in construction processes.

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